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Pacific Northwest NATIONAL LABORATORY

Internet of Things (IoT) Products and Applications: Lighting

Manufacturer and End-User Perspectives

May 2019

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LJ Sandahl

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
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BATTELLE
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Executive Summary

Background

Lighting accounts for 15–20% of building electricity usage (EIA 2017). Significant energy savings have been achieved via the wide-scale introduction of light-emitting diode (LED) light fixtures and advanced lighting controls. These advanced lighting controls save energy via tuning, occupancy sensors, and/or daylight sensors that are often (but not always) incorporated into the light fixtures. The Internet of Things (IoT) will allow buildings to utilize new sensors, generate and record useful data, and influence building occupant behaviors and operational procedures for the next phase of energy savings.

The promise of IoT to revolutionize everyday life is clear, and there is significant excitement about its potential. For manufacturers, it can open up revenue streams through the sale of new products that are more capable and engaging. For end users, it potentially creates an environment that is more responsive to their needs (e.g., enhancing comfort). Significant growth is expected in IoT, with over $832 billion in investments from businesses in 2020, from a 2015 value of $215 billion (PWC 2017). Investments by end users have the potential to generate between $4 trillion and $11 trillion in economic value by 2025, with factory, city, human body, and retail segments among the most promising (Patel et al. 2017). Table ES.1 shows the different applications that were encountered as part of this study in several building sectors.

Table ES.1. General IoT Applications by Key Building Sectors

Healthcare	Office	Retail	Manufacturing/Industrial
Workflow optimization	Space utilization	Customer tracking and “targeting”	Inventory tracking/optimization
Medication adherence	Building operations	Wayfinding	Streamline operations
Continuous/remote monitoring	Energy savings	Security	Reduce maintenance costs
Asset tracking		Tracking inventory/supply chain	

This report summarizes research that was undertaken as part of a larger effort to understand the needs of the industry and the customer to support the adoption of IoT technologies that can increase the uptake of energy saving products (e.g., LED lighting, sensors and controls) through direct energy savings opportunities (e.g., plug loads and HVAC) or valued non-energy benefits (e.g., asset tracking). First, a review of the literature was conducted to better define the diversity of products and applications available, use cases, and common barriers to the adoption of IoT.

Approach

Representatives from seven manufacturers and eight end users were interviewed as part of this study in order to capture their views on IoT, especially as it relates to lighting, and the steps being taken to address/mitigate existing barriers. Manufacturers include light fixture manufacturers, lighting controls manufacturers, and IoT device and software application providers. End users include technology users, building owners, and consultants. Manufacturers were asked questions related to newer sensor types and other communication technologies being explored, energy benefits to other building systems, energy use of IoT devices, obsolescence, interoperability, standardization, skilled personnel requirements for commissioning advanced systems, cyber security, and what key concerns their customers may be voicing. End users were asked questions related to the types of IoT applications they have incorporated or explored, whether those IoT applications were considered for implementation in lighting, whether sufficient information was available to make an informed decision, the most promising benefits of IoT, communication means being used for any connected systems, and concerns they have about incorporating IoT in their buildings.

Key Findings

There is trepidation about IoT applications and benefits in lighting. Many of the manufacturers cited applications requested by the customer or that could be sold to customers, most commonly including (listed in order of frequency) wellness functions (anything that could enhance space quality for occupants), space utilization, and people counting. However, one manufacturer stated that their business model was first cost and code-compliant focused and thus, they probably will not enter the advanced sensor market until advanced sensors are required by codes. End users expressed a desire for information resources on IoT applications to support the decision-making process, with a high value placed on third-party verification of technologies and implementation in similar (i.e., peer) buildings presented as case studies. These should present best practices, benefits, and challenges of IoT technologies.

Cyber security is a nearly universal concern. Cyber security is one of the issues manufacturers frequently commented on as a barrier related to the adoption of IoT devices. Most end users also cited it as a concern because of the potential scale of the effect of failure to a business or to one's job or reputation. Cyber risks noted by end users included unauthorized access to customer data or patient records, and loss of control over equipment/operation, with one mentioning that a breach through BMS had been encountered and resulted in a heightened sensitivity within the organization. Many manufacturers stated that cyber security will never fully be addressed because it is a constantly changing issue; therefore, means of addressing it will evolve.

Cost is a barrier, but the value proposition of advanced features needs more data and consideration. Two things were evident in responses from end users; (1) the cost of IoT was deemed too high to result in an acceptable payback period for the investment and (2) the focus of IoT was on the potential for energy-saving opportunities in other building systems (e.g., HVAC and plug-loads). Although prices for IoT sensors are decreasing, some of the manufacturers interviewed acknowledged the lack of use of advanced sensors in current buildings and new projects. One manufacturer stated that their business model was first-cost-focused. A focus on first cost by the manufacturer or end user may overlook the fact that applications of IoT go well beyond energy-saving opportunities and can actually tap into greater value propositions. Using the 3-30-300 ratio, which represents rough approximations of utility, rent, and employee costs to a business, respectively, cost effectiveness might be easier to accomplish if the benefits to the use of a building (e.g., right-sizing office needs) or to people costs (e.g., in terms of efficiency or reduced labor costs) could be quantified and thus considered.

Conclusions and Future Research

IoT has the potential to revolutionize the lighting industry, but several factors must be addressed to encourage more broad adoption of IoT in luminaires and lighting systems. Among these, cyber security concerns, better understanding the value proposition of IoT, and addressing obsolescence concerns through standards are among the top items on the minds of those interviewed in this research. Future research efforts that would help support the uptake of IoT include the following:

- The development of IoT security best practices for devices in the built environment (e.g., references that improve end-user awareness of high-risk items and offer questions to ask manufacturers in order to adequately address IT department concerns)
  - Standardized information to help end-users choose products and evaluate cyber security risks
  - These best practices are probably best developed via NIST, industry, and other groups than the Department of Energy
- Field studies evaluating the performance and benefits of IoT solutions, with an emphasis placed on observing and quantifying benefits to more fully capture and characterize the cost effectiveness of IoT technology
  - By building type (office, retail, healthcare, education)
  - By technology type (tracking, occupancy, air quality, etc.)
- Cost analyses of IoT installation (savings from labor reductions) as well as long-term costs associated with subscription models.

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Acronyms and Abbreviations

BACnet	Building Automation and Control (BAC) networks
BMS	Building Management System
CAP	Cybersecurity Assurance Program
CBECS	Commercial Building Energy Consumption Survey
DDoS	distributed denial of service
EIA	U.S. Energy Information Agency
HVAC	heating, ventilation, air-conditioning
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IT	information technology
LED	light-emitting diode
LiFi	light fidelity
LTE	long-term evolution
NEMA	National Electrical Manufacturers Association
NIST	National Institute of Standards and Technology
OT	operational technology
PoE	Power over Ethernet
PIR	passive infrared
ToF	time-of-flight
USB	Universal Serial Bus
VLC	visible light communication

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1.0 Introduction

Energy savings are important to the U.S. government and to the commercial sector, and the Internet of Things (IoT) technology in that lighting provides ways to optimize energy savings. To assess the potential contribution of lighting to energy savings, the U.S. Energy Information Agency (EIA) conducts major energy use analysis, known as the Commercial Building Energy Consumption Survey (CBECS). Per the most recent report, CBECS 2012, commercial buildings in the United States consumed 6.9 quadrillion Btus (quads) of energy. Of this 6.9 quads of energy, 4.2 quads were in the form of electricity, 2.2 quads in the form of natural gas, and the remainder in other forms of energy.

Lighting accounts for 15–20% of building electricity usage (EIA 2017). Significant energy savings have been achieved via the wide-scale introduction of light-emitting diode (LED) light fixtures and advanced lighting controls. These advanced lighting controls save energy via tuning, occupancy sensors, or daylight sensors that are often (but not always) incorporated into the light fixtures. IoT will allow buildings to utilize new sensors, generate and record useful data, and influence building occupant behaviors and operational procedures for the next phase of energy savings.

IoT is a term that, in general, refers to a network of devices that are capable of being connected to the internet to enhance usability and functionality, or provide other benefits. Through the data available or collected from this network of devices, users are able to make assessments and decisions, or algorithms can automatically change settings, on a host of issues (e.g., adjust device operating parameters, inform others about equipment status, assess occupancy and security of a building). It is forecast that the IoT market will experience significant growth in the coming years, with many expecting compound annual growth rates generally in the mid-20% range (Forbes 2017). One study estimates that IoT sensor growth worldwide will increase from 71 million to 1.3 billion sensors between 2015 and 2020 (Kejriwal et al. 2016). For lighting manufacturers, this is a tremendous opportunity to revolutionize their products as well as bring new capabilities and services to their customers through luminaires (i.e., light fixtures) and other lighting system components.

This report summarizes research that was undertaken as part of a larger effort to understand the needs of the industry and the customer to support the adoption of IoT technologies that can increase the uptake of energy saving products (e.g., LED lighting, sensors and controls) through energy savings opportunities (e.g., plug loads and HVAC) or valued non-energy benefits (e.g., asset tracking). First, a review of the literature was conducted to better define the diversity of products and applications available, use cases, and common barriers to the adoption of IoT.

A small group of product manufacturers and end users were interviewed as part of this study in order to capture their views on IoT, especially as it relates to lighting, and the steps being taken to address/mitigate existing barriers. This report identifies manufacturer (supply-side) focus areas and challenges that manufacturers are encountering with roll-outs of IoT technologies. It also provides input from the end user (demand-side) on the prevalence of IoT in commercial spaces, the uses of IoT technologies, areas of interest, and barriers/challenges encountered or anticipated.

The primary audience for this document is building owners and operators who are interested in learning about functionality and applications of IoT, and may be interested in piloting projects. It also may be of interest to product manufacturers who seek to gain a better understanding of the barriers to IoT adoption faced by their customers. Utility and energy efficiency program stakeholders who are interested in testing or demonstrating emerging IoT technologies for incentive programs may also find it useful, as will government decision makers seeking to understand these technologies for purposes of research and/or promotion.

2.0 About IoT

Section 2.0 provides an overview of relevant information on IoT based on a review of the literature, including how IoT is defined (Section 2.1), an overview of the potential applications and benefits of IoT (Section 2.2), IoT in lighting (Section 2.3), and prominent IoT companies (Section 2.4).

2.1 What is IoT?

A consensus definition of IoT has been elusive, though some commonalities are found throughout the definitions, including the common phrase "a sensor that connects to the internet." The Institute of Electrical and Electronics Engineers (IEEE) maintains a webpage that encourages users to "contribute to the ever-changing definition of IoT," as well as a document that captures various definitions of IoT encountered in the literature (IEEE 2015). In this study, the definition of IoT is as follows: "the interconnection of machines and devices through the internet, enabling the creation of data that can yield analytical insights and support new operations" (Forbes Insights 2017).

For understanding IoT in commercial building applications, it is important to distinguish between information technology (IT) and operational technology (OT). Within the built environment, IT supports payroll, database, sales, news, and virtually every function of an organization. In contrast, OT involves hardware and software that detects or causes changes via monitoring and/or control of physical devices, processes, and events within the building or enterprise. IT and OT use similar devices and technologies (e.g., internet, gateways, applications, etc.); however, OT operates differently within the building to effect change to improve operations or efficiency within the building. In contrast, IT within a building includes web browsing, news sites, financial services, games, and virtually everything most consider when thinking about the internet. IoT devices enable the OT functions in a building.

2.2 Potential Benefits of IoT Applications for Commercial Buildings

The promise of IoT to revolutionize everyday life is clear, and there is significant excitement about its potential. For manufacturers, it can open up revenue streams through the sale of new products that are more capable and engaging. For end users, it potentially creates an environment that is more responsive to their needs (e.g., enhancing comfort). Significant growth is expected in IoT, with over $832 billion in investments from businesses in 2020, from a 2015 value of $215 billion (PWC 2017). Investments by end users have the potential to generate between $4 trillion and $11 trillion in economic value by 2025, with factory, city, human body, and retail segments among the most promising (Patel et al. 2017).[1] Table 1 shows the different applications that encountered as part of this study in several building sectors, with benefits discussed in subsequent paragraphs. Many of these are general IoT applications not specific, or dependent, on lighting. IoT applications particular to lighting are covered in Section 2.3.

[1] The human body segment refers to use cases where devices are worn (e.g., on skin or clothing) or ingested (e.g., swallowed or injected) for a variety of potential applications such as monitoring health, disease management, and activity tracking.

Table 1. General IoT Applications by Key Building Sectors

Healthcare	Office	Retail	Manufacturing/Industrial
Workflow optimization	Space utilization	Customer tracking and "targeting"	Inventory tracking/optimization
Medication adherence	Building operations	Wayfinding	Streamline operations
Continuous/remote monitoring	Energy savings	Security	Reduce maintenance costs
Asset tracking		Tracking inventory/supply chain	

In healthcare applications, quality of care benefits of IoT might include patient monitoring and data analysis using various types of sensors or wearable technologies in both a healthcare setting and at home. Some have extolled improvements in the efficiency of healthcare staff through more connected systems. Staff, for example, might more easily locate needed equipment or track a patient's location as they are relocated or transported for diagnostic procedures. Also, managing critical or expensive assets in healthcare can lead to improved staff efficiency and reduced operating costs (e.g., from excessive equipment purchases or loss due to theft).[1]

The office environment has garnered a tremendous amount of interest from manufacturers developing IoT solutions, and many building owners have already adopted solutions, via lighting systems and stand-alone products, that help them save money beyond the traditional energy savings afforded by legacy lighting sensors and controls. In a closed-loop system, where the luminaire and sensor interact but do not transmit sensor information elsewhere, energy savings beyond the luminaire and other potential uses of that sensor data are not possible. With IoT, data are now able to be transmitted outside the luminaire and can be leveraged to enable energy savings and other benefits. One such example includes using sensors to understand occupancy, ambient light, temperature, and other factors to inform other building systems and obtain other energy or non-energy benefits. For example, a room that has been unoccupied for some time might be temperature-adjusted to reduce heating/cooling of that space, or, conversely, a space's ventilation and heating/cooling might be increased to help maintain comfortable conditions when a meeting room is fully occupied.

Another example for an office environment is optimizing and managing utilization of a space. Sensor data analytics of an organization's use of a space—historical or real-time—can result in more efficient use of a building, track occupancy trends to identify other saving opportunities, and help manage shared spaces, such as conference rooms, by identifying spaces that are unoccupied.

Lastly for the office environment, Light Fidelity (LiFi or Li-Fi),[2] which encompasses visible light communication (VLC), is being touted as a secure and high-speed alternative to traditional Wi-Fi for transmitting data to devices by modulating the light source at a frequency that is imperceptible by the human eye. LiFi can transmit data faster and more data than WiFi. Because LiFi utilizes light to transfer

[1] For more examples of possible efficiency improvements in healthcare, see https://www.asmag.com/showpost/22473.aspx and https://ij-healthgeographics.biomedcentral.com/articles/10.1186/1476-072X-11-25.

[2] LiFi is networked and mobile communication of data using light. Some LiFi products exist that are bi-directional; whereas, other products are unidirectional. VLC utilizes the visible light spectrum (380–760 nm); in contrast, LiFi may use other parts of light spectrum (e.g., ultraviolet to infrared). For this analysis, the umbrella term, LiFi will be used and may include VLC. More information about VLC and LiFi may be found at https://news.rpi.edu/content/2016/11/03/communicating-light.

the data, it is more secure than wireless systems because to access the signal, a potential cyber threat must be physically within or adjacent (10 meters) to the space.

Among the technologies being implemented in a retail environment, indoor positioning systems appear to be gaining in popularity and creating opportunities that improve the customer experience and increase sales. Integrating IoT sensors for indoor positioning systems into lighting has some advantages. The light fixtures are overhead, placed in a regular array, have suitable surface for mounting sensors, and have power to readily operate the sensors. Indoor positioning in a retail environment can allow customers in a store to use a phone application to more quickly navigate the aisles, find the item they are looking for, and be informed of open check-out registers. A dense grid of luminaires in a retail environment enables indoor positioning systems that can be accurate to within a few feet using, for example, Bluetooth or VLC. Also, understanding traffic patterns and activity within a store can provide retailers with valuable information to improve the layout of the store, positioning of merchandise, and staffing needs. The same app might be used to understand a shopper's history, identify items that are on sale (or provide a coupon), and suggest additional items the shopper might wish to purchase during the visit. While gaining business intelligence is important, privacy is also an issue that will need to be addressed by the industry and end users.

In a manufacturing or industrial environment, even minor improvements to a process or to the efficiency of employees can result in significant cost savings to a business. Production-related savings might manifest themselves as increased throughput, higher yields, or reduced spoilage. IoT sensors, for example, may be installed on manufacturing equipment to identify problems before they arise, thereby performing preventive maintenance prior to a failure and thus reducing down-time. Labor-related savings might manifest themselves as increased task efficiency or reduced error rates. Using smart tags, IoT devices are capable of real-time tracking of items (e.g., within a warehouse), allowing for more efficient operations.

2.3 IoT in Lighting

As highlighted with the previous Table 1 discussion, lighting products and systems today, some of which are connected to a building management system (BMS) and to the internet, can be an important part of the IoT. It is worth noting, however, that a BMS, at least in the traditional sense, is not a necessity for the IoT. In fact, trends suggest that, in a not too distant future, IoT sensors and devices will be capable of connecting directly to the cloud via cellular networks, and that the cloud will serve the purpose of data processing and equipment control. This could be a benefit to small- and medium-sized buildings that may not have a BMS.

Common information that can be communicated today from connected lighting products may include occupancy, ambient light levels, and light output (i.e., dimming level) settings. Furthermore, these devices are capable of responding to data received from the internet, such as demand-response requests. More advanced functionality starting to be explored in today's lighting systems includes sending data to other devices through modulation of the light output of the device (i.e., LiFi), tracking people or objects leveraging a network of sensors or imaging devices, locating items through embedded sensors on equipment and using triangulation techniques. Although some of this functionality does not necessitate a luminaire to incorporate into buildings, the ubiquity of lighting systems, availability of power, and their dense positioning and location (think "eyes in the sky") make them an appealing vehicle for the incorporation of IoT devices, or at least as a platform for an IoT receptacle into which IoT devices can be installed.

Table 2 lists common characteristics of IoT technology encountered in lighting systems, including estimated cost of each component, typical installation methods, and some common features. Traditional lighting system components, such as luminaires, sensors, and switches, can interface through connectivity modules to enable IoT capabilities. One example is Samsung's Smart Lighting Module, which enables IoT for lighting through embedded lighting control and Bluetooth capability at the luminaire level.[1] Another is Acuity's ECLYPSE A1000, a module capable of interfacing with a BMS, energy meters, and software or cloud applications while performing other functions with connected lighting such as grouping, controlling, and scheduling.[2]

Table 2. Common IoT Technology Encountered in Lighting Products

Technology	Estimated Cost[(a)]	Installation	Features
Sensor	\$20–100 per sensor	Fixture/wall/ceiling; integral or post install via standard 0.5" trade knockout or 0.875" hole	Motion sensing, photosensing, detecting range, wireless protocol/range, encryption
Fixture Adapter	\$50–200 per fixture	In fixture; enables wireless connectivity (upgrade) of fixture	Dimming (e.g., 0–10 V, DALI), ballast/driver control, wireless protocol/range, sensor support
Controller / Gateway	\$300–1000 per gateway	Remote utility room or central location, NEMA enclosure, DIN rail	Connectivity (e.g., Building Automation and Control Network [BACnet]), maximum number of sensors/devices/BACnet points, demand response
Energy Management and Information System	Cloud-based: Initial: <\$0.01–0.40 /ft^2 Monthly: <\$0.01–0.10 /ft^2	Control/monitoring may be on-site or via web browser	Devices supported may include computer, tablet, and/or smartphone via software, browser, or application

(a) Estimated costs based on ACEEE report: Perry. 2017. *Smart Buildings: A Deeper Dive into Market Segments*. Washington, DC: ACEEE. http://aceee.org/research-report/a1703.

2.4 IoT Companies

As shown in Figure 1, the major companies in IoT, including Intel, Microsoft, Cisco, Google, and IBM, are not lighting manufacturers.[3] Nevertheless, the lighting industry has many players that have been very active in IoT, and efforts such as Zhaga Consortium's Book 20 demonstrate the value this industry places on IoT as part of its future.[4] Also, technologies such as Bluetooth® mesh have been touted as being ideal technologies for converting lighting into a connected grid that can enable new functionalities within buildings (Molony 2018). These are just two examples of efforts driving the lighting industry toward standardization, and it is uncertain whether they will prevail, or if multiple standards or proprietary

[1] For more information about the Smart Lighting Module, visit https://www.samsung.com/led/lighting/smart-lighting-platform/smart-device/slm/

[2] For more information about the ECLYPSE A1000, visit https://www.acuitybrands.com/products/detail/768184/nLight/ECLYPSE-A1000/IP-Building-Management-Interface-for-Atrius-Navigator

[3] The basis for the IoT Analytics rankings include the number of Google searches, Tweets, news items, and IoT employees (based on LinkedIn data).

[4] For more information about Zhaga Consortium's Book 20, which defines a smart interface between a luminaire and a sensor/communication node, visit https://www.zhagastandard.org/books/book20/.

solutions will remain the norm in the lighting industry. However, considering the other IoT players' ability to innovate (e.g., Amazon's Alexa, Google's Home and Nest products, etc.) without the burden of legacy products and systems, the lighting industry needs to move rapidly to adapt to the growing world of IoT.

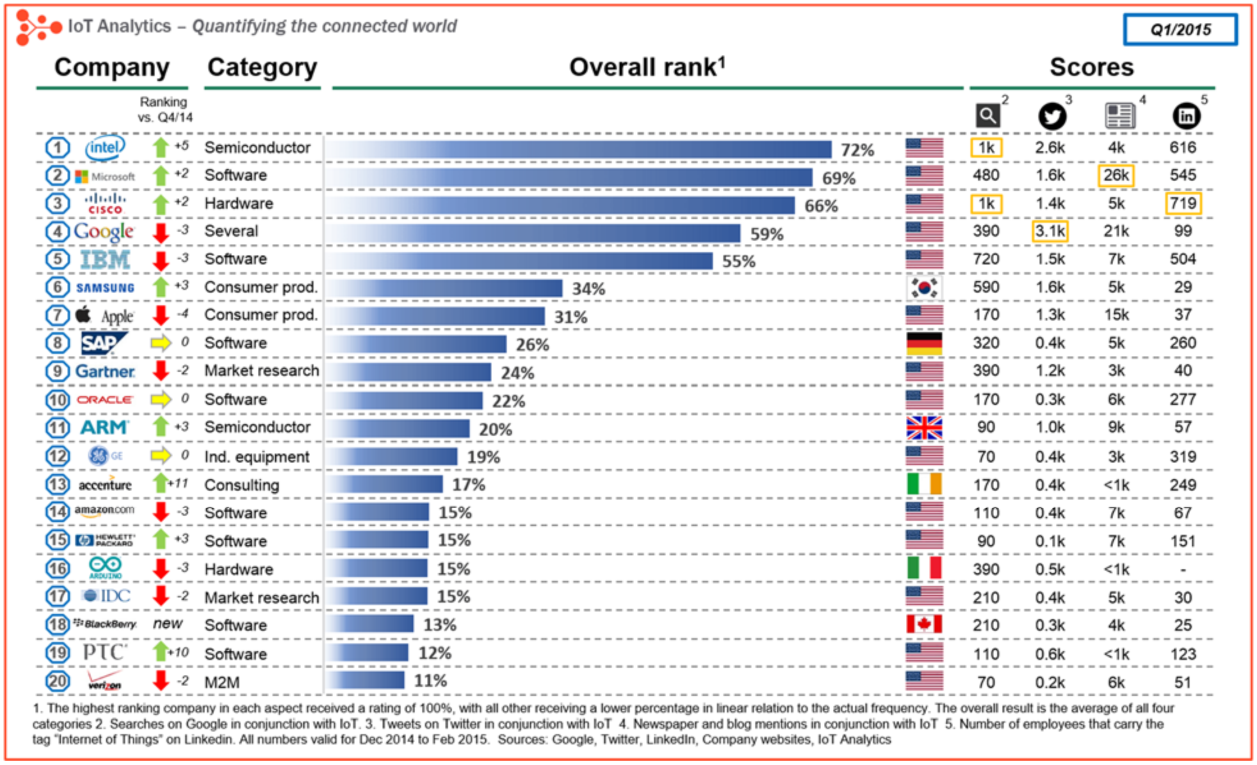

Figure 1. Internet of Things Company Rankings Based on Social Media and Web Presence (IoT Analytics 2015)

3.0 Industry and Customer Key Findings

As stated in Section 1.0, this research was undertaken to better understand IoT technologies, particularly how they are being used in lighting products, and how these are enabling direct energy saving opportunities (e.g., through interactions with a building's HVAC system or plug loads) or other valued non-energy benefits (e.g., asset tracking). As part of this effort, representatives of seven manufacturers and eight end users were interviewed to understand the future of IoT, especially as it relates to lighting, the steps being taken to address/mitigate existing barriers, and the existing experience from both manufacturers and end users of IoT technology. Manufacturers include light fixture manufacturers, lighting controls manufacturers, and IoT device and software application providers. End users include technology users, building owners, and consultants.

3.1 There is Trepidation about IoT Applications and Benefits in Lighting

Manufacturers were asked whether they were incorporating newer types of sensors and other communication technologies into their lighting fixture offerings, and what they were hearing from their customers regarding opportunities and challenges of integrating IoT into their buildings and, in particular, into lighting. End users were asked what IoT applications they were currently using or considering in their buildings, whether these applications were integrated with, or reliant on, lighting, and what they see as the most promising benefits of IoT.

Manufacturers stated that there is often a mismatch between what the customers want or say they want, and what is available in IoT lighting products. For example, one manufacturer indicated that customers say they want integrated systems, yet they had seen only one installation where the occupancy sensors were actually integrated with the HVAC system, and that was a special case where the customer was actively involved in smart buildings. Another manufacturer responded that the features that IoT lighting offers, like marketing analytics in retail, are outside the budget of most organizations or departments paying for lighting. Many of the manufacturers cited applications requested by the customer or that could be sold to customers, most commonly including (listed in order of frequency) wellness functions (anything that could enhance space quality for occupants), space utilization, and people counting. However, one manufacturer stated that their business model was first cost and code-compliant focused and thus, they probably will not enter the advanced sensor market until advanced sensors are a part of codes.

End users expressed a desire for information resources on IoT applications to support the decision-making process, with a high value placed on third-party verification of technologies and implementation in similar (i.e., peer) buildings presented as case studies. These should present best practices, benefits, and challenges of IoT technologies. Case studies about successful IoT implementations are helpful in communicating the potential of IoT by describing the specific solutions and the value they bring to a particular building type. Peer buildings would thus have information that might be used to evaluate and justify an investment in IoT. Some end users did express that manufacturers were able to provide adequate information for making a decision, while others felt they had to develop their own understanding of the benefits by undertaking IoT projects on a limited basis before scaling up to cover a whole building or organization.

3.2 Cyber Security is a Nearly Universal Concern

Manufacturers were asked how the need for ongoing cyber security support for IoT lighting is being addressed. End users were asked if any concerns existed about incorporating IoT into their building and what concerns were most important to overcome. This section provides an overview of their responses, as well as pertinent background information related to voluntary certifications and codes.

Certification and Code Approaches to Cyber Security

Although cyber security is a constant threat, testing products is one common industry practice to mitigate cyber threats. Circa 2015, non-manufacturer entities started addressing cyber security related to IoT and OT technologies. UL, leveraging their role already testing devices for safety and other metrics, developed *UL 2900-1 Standard for Software Cybersecurity for Network-Connectable Products, Part 1: General Requirements*[1] and runs the UL Cybersecurity Assurance Program (CAP),[2] which evaluates product and system compliance with Common Criteria, FIPS 140-2, and ANSI/UL 2900. Testing/certification is voluntary, and successful products earn a certificate indicating compliance with the standard, and includes testing for fuzz testing; known vulnerabilities; penetration testing; code and binary analysis; access

[1] https://standardscatalog.ul.com/standards/en/standard_2900-1_1
[2] https://industries.ul.com/cybersecurity/ul-cybersecurity-assurance-program

control and authentication; cryptography; remote communications; and software update. Figure 2 depicts UL's CAP process.

Figure 2. The UL Cybersecurity Assurance Program Tests and Certifies Product and System Security Utilizing the UL 2900 Standard

Beyond voluntary programs like UL's CAP, cyber security elements are being incorporated into codes and laws. As of publication of this report, Federal laws related to cyber security and specifically IoT technology are piecemeal and currently no major legistlation exists. In autumn 2018, California passed a law, Senate Bill No. 327, that requires any manufacturer of a device that connects directly or indirectly to the internet to equip the device with reasonable security features, designed to prevent unauthorized access, modification or disclosure of information.[1]

In addition to security testing programs, one manufacturer interviewed stated that another method for addressing cyber security is via system design, and went on to say that manufacturers are also limiting the number of attack surfaces (e.g., limit the number of devices in the system that communicate outside of the building). Early IoT lighting devices were infected with viruses and used as botnets, or robot networks, in DDoS (distributed denial of service) attacks. In newer IoT lighting systems, rather than every device connecting to the internet, devices communicate with each other within the building; when necessary, information that needs to connect to the internent can leave the building via a single, controllable, point.

Cyber Security Findings

Cyber security is one of the issues manufacturers frequently commented on as a barrier related to the adoption of IoT devices. Most end users also cited it as a concern because of the potential scale of the effect of failure to a business or to one's job or reputation. Cyber risks noted by end users included unauthorized access to customer data or patient records, and loss of control over equipment/operation, with one mentioning that a breach through BMS had been encountered and resulted in a heightened sensitivity within the organization. Many manufacturers stated that cyber security will never fully be addressed because it is a constantly changing issue; therefore, means of addressing it will evolve.

Certifications, requirements, and good system design are all important, but good cyber security often starts and ends with operational processes on site. If a certified product is not configured properly, a gap in the cyber security might exist. The manufacturers interviewed as part of this study often stressed the need for strong cyber security practices that include isolating the IT and OT networks with only necessary

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[1] The full text of this bill is available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB327.

and very limited communication between the networks. Manufacturers can stress this in their literature and set-up information, but ultimately it is the responsibility of the site to implement.

Manufacturers also stated that after isolating IoT building devices on an OT network, the devices might need periodic updates as security issues are identified and addressed. Ongoing firmware support is a necessary cyber security task. One manufacturer stated that, thus far, their company has not encountered a threat that could not be addressed via a firmware update. Firmware updates must be made available by the manufacturer, but then installed on site. One manufacturer stated that firmware updates do not always occur with the frequency the manufacturer believes that they should occur and are often treated as an afterthought by some sites.

Some end users mentioned either new alternatives (e.g., using a cellular network like Long-Term Evolution [LTE] or using physical connections rather than Wi-Fi) or good coordination with IT departments to address cyber security. Given that one of the main areas of concern is the risk that IoT devices pose to an IT network or a building's infrastructure (i.e., most systems today require a connection to a building's IT network), one end user's experience with a system that connects directly to the internet via a cellular network shows that this evolution might take the form of IoT devices that bypass local connections and go directly to the internet through LTE. Fifth-generation LTE, for example, addresses some of the barriers of current LTE connections such as high end-to-end latency and low data rates that are important in certain IoT applications.[1]

Other end users partially addressed cyber security via technologies they outright exclude. Even though Bluetooth provides several modes and levels covering authentication and security procedures and Wi-Fi is used extensively in the workplace and trusted for transmitting sensitive information of all sorts on a daily basis, some end users interviewed identified these technologies as non-starters, stating that anyone with a cell phone might gain access.

In the case of end users, bad experiences and perceptions of technology can have a lasting effect. In today's "rush-to-market" mentality, many manufacturers are rushing products out the door and counting on software/firmware updates to mitigate risks identified along the way.[2] However, it only takes one cautionary tale of significant impact (e.g., the hacking of a retailer in 2013 that is still mentioned by, and resonates with, end users interviewed) to create a more challenging environment for manufacturers to sell more advanced and secure products. Manufacturers likely have to balance security and complexity in their systems, and sometimes the trade-offs made could result in a vulnerability that can be exploited. Privacy, sometimes noted among concerns of IoT technology, was only peripherally mentioned by one end user and only in the context of noting it is not in their corporate culture to track people. However, there is some level of risk a business accepts whenever privacy concerns can surface. In one recent example, Google felt compelled to explain the existence of a microphone in one of their products that the technical specifications did not identify until after a public backlash.[3] With the employee or client data being gathered by businesses through IoT, a breach of data or privacy is a risk. There is a fourth value in the 3-30-300 ratio, which is introduced in Section 3.3, and that is a factor of 3000 representing the expected revenue generated per square foot by a business.[4] Although business intelligence enabled by IoT may help increase revenue, a data or privacy breach can have an adverse effect on this factor and thus result in a cost, or a loss or revenue, far exceeding the energy, space, or human capital costs represented in the 3-30-300 ratio.

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[1] A white paper from Ericsson regarding Fifth-generation LTE and its significance to IoT is available at https://www.ericsson.com/assets/local/networks/documents/gsma-5g-mobile-iot.pdf

[2] https://www.aberdeen.com/techpro-essentials/iot-device-security-seriously-neglected/

[3] https://www.popularmechanics.com/technology/security/a26448907/google-nest-hidden-microphone/

[4] https://lightingcontrolsassociation.org/2019/03/20/lighting-control-for-lighting-quality/

3.3 Cost is a Barrier, but Value Proposition of Advanced Features Needs More Data and Consideration

End users were asked what concerns existed regarding the incorporation of IoT, in general, in their buildings, and manufacturers were similarly asked about concerns they were hearing from their customers, with an emphasis being on IoT integrated into lighting. This section provides an overview of their responses, as well as pertinent background information.

An IoT solution—including sensors, associated hardware, and sometimes ongoing cloud service and data analysis costs—can be an expensive proposition for any business, but it might be justified by the value it adds. For example, using IoT devices to increase sales, optimize operations, or improve occupants' comfort and productivity might result in sufficient gains or efficiencies to make IoT lighting systems cost effective. However, typically, limited data exist to support the claims being made by manufacturers, making it difficult to quantify the value of a system to justify an investment in IoT. Many businesses today, in particular large businesses, run pilot programs in a limited number of stores to evaluate the technology and develop their own data and thus mitigate risk.

Two things were evident in responses from end users: (1) the cost of IoT was deemed too high to result in an acceptable payback period for the investment and (2) the focus of IoT was on the potential for energy-saving opportunities in other building systems (e.g., HVAC and plug-loads). It is not surprising that IoT sensors, and the infrastructure required to support them, are currently expensive. This is often the case with new or emerging technology. Prices for IoT sensors, however, have been decreasing, as may be observed in Figure 3, and lower prices are deemed an important driver in the adoption of IoT (Greenough 2014).

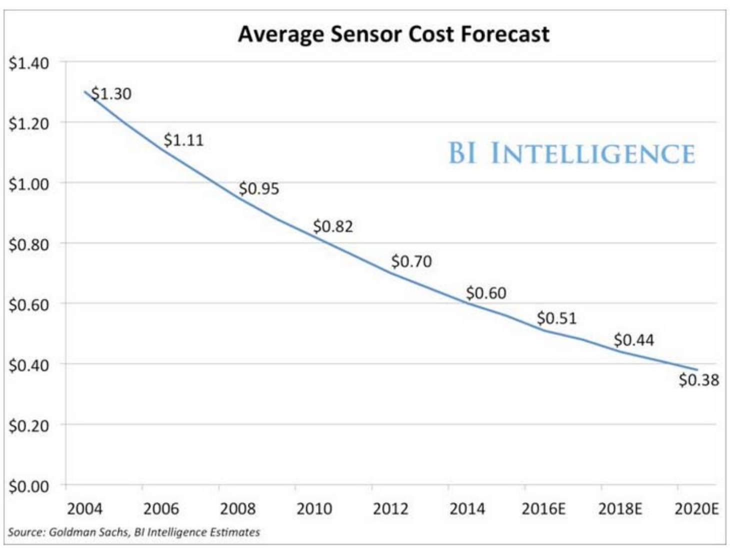

Figure 3. Historical and Projected Average Cost of IoT Sensors (Greenough 2014)

Although prices are decreasing, some of the manufacturers interviewed acknowledged the lack of use of advanced sensors in current buildings and new projects. One manufacturer stated that their business model was first-cost-focused. A focus on first cost by the manufacturer or end user may overlook the fact that applications of IoT go well beyond energy-saving opportunities and can actually tap into greater value propositions. Using the 3-30-300 ratio, which represents rough approximations of utility, rent, and employee costs to a business, respectively, cost effectiveness might be easier to accomplish if the benefits to the use of a building (e.g., right-sizing office needs) or to people costs (e.g., in terms of efficiency or reduced labor costs) could be quantified and thus considered. Figure 4 shows the effects of a 10% variation on a typical business' operating costs (WGBC 2014). Calculations performed by businesses in determining if an investment is worthwhile are known to include assumptions about potential energy savings. However, end users have limited information to rely on when it comes to other potential benefits or savings of IoT, resulting in the full value proposition of IoT not being well understood for this emerging technology.

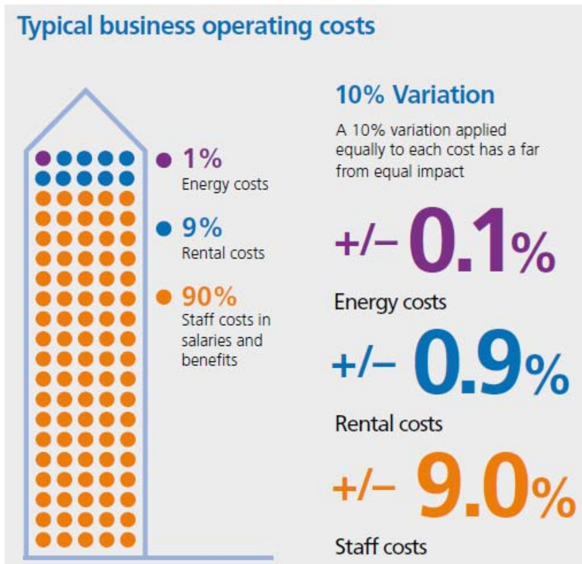

Figure 4. Typical Business Operating Costs (WGBC 2014)

3.4 Interchangeability, Interoperability, and Open Standards are Desired to Address Obsolescence Concerns

Manufacturers were asked about the pain points for designing-in multiple sensors and components and whether interoperability and standardization were necessary for success. End users were asked generally what concerns existed and whether interoperability was among them. This section provides an overview of their responses, as well as pertinent background information.

The National Institute of Standards and Technology (NIST) defines interoperability as "the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information—securely, effectively, and with little or no inconvenience to the user." NIST also defines interchangeability as "An extreme degree of interoperability characterized by a similarity sometimes termed "plug and play." Interchangeable components can be freely substituted without loss of function and requiring minimum to no additional configuration." [1]

Devices must also be interoperable (i.e., able to communicate and work with each other). Historically, many lighting control manufacturers opted for proprietary control interfaces and protocols, thereby

[1] An overview of the subtleties between interoperability and interchangeability may be found at https://www.nist.gov/sites/default/files/documents/public_affairs/releases/smartgrid_interoperability_final.pdf.

limiting interoperability between manufacturers. However, interoperability is an important consideration for end users in selecting IoT solutions.[1]

Interoperability and the use of open standards are seen as ways to simplify the process of integration into a building and allay concerns about product obsolescence. Standardization, in particular for IoT-enabled lighting, has not kept up with the rapid rate of adoption of IoT technologies. While other industries are able to build IoT solutions from the ground up using existing standards for power and connectivity, lighting companies need to build those IoT solutions on legacy systems. As a result, there might be resistance, or a cautious approach, to change and standardization.

Other than electrical and mechanical interfaces, many aspects of lighting products are not standardized. With the arrangement and ubiquity of lighting within buildings, new mesh capability to interconnect luminaires allows lighting manufacturers to begin to integrate connected lighting and sensing into their product offerings. Furthermore, the ability of lighting systems and sensors to connect to other building systems is beneficial to improved building operation. As lighting systems attempt to become platforms for various types of devices, interoperability will be an important factor.

Although interoperability is generally desired by end users, all manufacturers asked to identify "pain points" for the inclusion of multiple sensors and other components in IoT lighting installations noted interoperability as one pain point. However, the nature of the interoperability challenge and the approach to dealing with it varied significantly. Interoperability in regard to the ability to mix products from multiple manufacturers in IoT lighting systems was discussed by some manufacturers. Some manufacturers also mentioned that decision-makers involved in the purchase do not currently have the expertise to effectively evaluate and make decisions in IoT lighting, both in the lighting industry channels and at the customer level. If decision makers for IoT decisions are IT or human operations focused, they may not be aware of the interoperability challenges between the different technologies and systems.

Some manufacturers stated that interoperability at the individual device level is neither necessary nor cost effective, and that interoperability at the gateway or hub level is sufficient. Others mentioned standards as potentially helping reduce interoperability issues, although the enthusiasm for standards in general was somewhat muted. Indeed, one of the manufacturers suggested that interoperability is not necessarily good for manufacturers, even if it does help with overall adoption. Interoperability can be a challenge for manufacturers because it could apply between different product lines of the lighting manufacturer, between lighting manufacturers, between lighting and other building systems (e.g., lighting and HVAC, lighting and BMS), as well as lighting devices communicating to other equipment via the internet. Proprietary solutions have been selected by lighting manufacturers in the past partially to protect business, partially for cost reasons, and particularly to manage operational issues.

Another manufacturer raised the concern related to troubleshooting problems in the field and interoperability. Some manufacturers noted that if multiple parts of the system are nominally interoperable with each other and a problem arises, it may not be clear which technology "owns" the problem. According to manufacturers, the end user could struggle to address the problem because there is no clear manufacturer to hold accountable.

In contrast, end users noted the need for interoperability and standards, with some concerned that manufacturers might go in different directions with their own proprietary/unique solutions. End users feel that the use of proprietary solutions might impact more than the ability of devices to work together with

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[1] The U.S. Department of Energy published a report on connected lighting system interoperability where the interfaces in several connected lighting systems were studied and the extent of interoperability they provide was evaluated (DOE 2017).

other/future products, and they noted that standards are also prudent for how data are captured or logged so that the data can be analyzed in the future.

Obsolescence can be a real concern for some early adopters of technology. Manufacturers identified multiple characteristics that affect their preferences among existing standards. Several of the manufacturers indicated that the anticipated useful longevity of protocols was a factor in determining their connectivity choices. Other characteristics mentioned were whether a given standard is open or closed and how well the standard supports encryption and other security measures. There was mixed opinion as to the costs and benefits of older standards. Some standards that have been around for a while have broad adoption and might make the addition of new sensors and technologies easier, but those older standards can also have limited or no security or encryption features.

Most of the manufacturers interviewed acknowledged that concerns about these changes in connectivity technology and their potential obsolescence in installed connected lighting are significant for IoT lighting. The means for addressing these concerns varied among the interviewed manufacturers. Some manufacturers stated their intention to support protocol updates and extensions through firmware updates over time. Some also said that they concentrate their IoT lighting system connectivity in devices or interfaces that could be changed out if necessary without replacing lighting fixtures.

Industry efforts are underway to help address this, as well as to provide confidence to customers that they would be able to take advantage of upcoming technologies without the need to replace a significant portion of their investment.

In the exterior lighting market, the National Electrical Manufacturers Association (NEMA) formed a working group and developed the "NEMA 7-pin receptacle." As existing street and area light fixtures were being converted to LED fixtures, manufacturers and end users wanted to provide a means for future devices to connect to these light fixtures. Labor costs often equal or exceed the costs of equipment. At the time of installation, some IoT and non-IoT devices in exterior applications were not ready. The 7-pin receptacle allows for a standardized connection through which adding devices is facilitated in the future.

The Zhaga Consortium—a global association of lighting companies—also recently published Zhaga Book 18, which defines a standardized interface between an outdoor LED luminaire and a sensing/communication module that sits on the outside of the luminaire.[1] It has also initiated development of Zhaga Book 20, which "will define a standardized interface between an indoor luminaire and a sensing/communication module that can be mounted on the surface of the luminaire."[2] In April 2019, Zhaga and the IoT-Ready Alliance™, which was established to develop an industry standard for sensor and connectivity module installation in LED fixtures, aligned efforts and the IoT-Ready Alliance™ has since dissolved.[3] This consolidation of what may have been competing approaches for upgrading interior luminaires is a positive step toward standardization.

Also, the Illuminating Engineering Society recently established the IoT Connected Lighting Systems Committee to research and develop best practices and standards encompassing connectivity through the implementation of lighting products and lighting equipment.[4]

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1 https://www.zhagastandard.org/features/277/zhaga-publishes-specification-allowing-mechanical-iot-upgradability
2 https://www.zhagastandard.org/books/book20/
3 https://www.zhagastandard.org/data/downloadables/1/1/4/3/pr-zhaga-and-iot-ready-alliance-20190402.pdf
4 https://www.ies.org/standards/technical-committees/internet-of-things-connected-lighting-systems-committee/

4.0 Manufacturer Specific Findings

This section includes supplementary findings from analysis of the interview responses provided by manufacturers. Manufacturers were asked about availability or plans for newer sensor types or communication nodes that may be used in lighting, the use of energy by sensors and controls, and of skilled personnel to install and maintain more advanced lighting and IoT systems.

4.1 Newer Sensor Types

Manufacturers were asked about new sensor technologies and communication technologies beyond the already typically used passive-infrared (PIR), ultrasonic, and daylight sensors utilized in lighting controls. An initial survey of existing IoT lighting technologies completed as part of this study indicated that current products available still utilized these conventional sensing technologies, and that very few manufacturers had incorporated advanced sensors or communication systems.

In terms of advanced communication and beacons, two manufacturers acknowledged developing LiFi products. Bluetooth Low Energy beacons were mentioned by many of the manufacturers; however, there has been minimal adoption of beacons to date.

4.2 IoT Device Energy Use and Energy Savings

Because the addition of IoT functionality to lighting adds hardware that consumes energy, manufacturers were asked whether energy losses are a factor in deciding which connectivity technology to use. Many of the manufacturers mentioned the energy efficiency features of their luminaires and other devices. Introducing a sensor or communication device that significantly increases the energy consumption would merit concern. Manufacturers had mixed reactions to this issue. If the IoT device being introduced was not energy efficiency focused, but rather focused on providing additional functionality, then the power draw (or energy use) of the device or connectivity was described by some manufacturers as less of a concern (i.e., since it is providing a utility).

Yet one manufacturer cited Power over Ethernet (PoE) as a technology with higher energy costs that negated the improvements in both form factor and ease of installation. This manufacturer stated that this was one of the reasons the manufacturer had not introduced PoE products.

Two manufacturers stated that power draw and energy use of each IoT component was a consideration. For these manufacturers, power draw was the starting point in the decision-making process. However, these were company choices and their customers were not driving this request. Manufacturers have started including this information on data sheets to educate consumers. One of the manufacturers did note some of the ongoing work in California related to low-power and standby loads.[1] This manufacturer stated they were following the California efforts and that this is affecting decisions they make.

In contrast, one manufacturer stated that the current cost of electricity was low. Therefore, the company was not overly concerned about device power draw compared to the value provided by the device.

Beyond energy use of IoT devices, energy savings from IoT devices was also discussed with manufacturers. Some manufacturers stated that lighting energy savings via IoT is limited, but identified a possible path of increased energy efficiency from IoT lighting in greater granularity related to loads and

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[1] California Energy Commission Docket 17-AAER-12

maximizing lighting benefits by going beyond just the sensor and incorporating advanced logic into the systems.

Beyond energy savings from lighting, many manufacturers also considered additional energy benefits at the building level by looking beyond the existing control methodology or sources (moving from lighting to other building systems). They identified integration with the HVAC system, primarily via the BACnet protocol, as a possible path. HVAC systems often cool or recirculate air in spaces regardless of whether they are occupied. With sensors in many more light fixtures, there is greater granularity in sensor coverage, enabling integration of HVAC and lighting systems for additional benefits.

4.3 Skilled Personnel

The inclusion of IoT functionality in lighting adds an additional level of complexity to both the commissioning and the maintenance of both the hardware and software components of installed systems beyond that involved in traditional lighting. The skills involved in this commissioning and maintenance differ from traditional lighting related skills.

Manufacturers were asked who performs IoT lighting commissioning for the systems they offer. Most manufacturers stated that specially trained professionals were necessary for commissioning, with the manufacturer or third-party suppliers performing that function for customers. The connectivity portion of commissioning sometimes involves the customer IT personnel because of security concerns.

The level of expertise required for maintenance of IoT lighting systems, as reported by manufacturers, varied more than that for commissioning. Some manufacturers indicated that customers are able to perform some or all of the normal maintenance, especially with larger customers. However, even in those cases, larger maintenance tasks might still be handled by third parties. Two manufacturers reported that customers often prefer to have maintenance performed by other parties through a service/support contract.

5.0 End-User Specific Findings

Included here are supplementary findings from analysis of the interview responses provided by end users. Because the interviews were conducted individually and end-user experience with IoT was at times limited, discussion or consensus around these topic areas was not possible and the responses varied. As a result, this section presents the findings from these interviews in a list format.

5.1 IoT Applications

End users were asked what IoT applications they were currently considering or using in their buildings. It was determined early in the process that a focus on IoT in lighting alone would have been too restrictive and provided little information about IoT. As a result, respondents were encouraged to share any application of IoT throughout the interview. Lighting was only mentioned occasionally or tangentially in responses, and the common responses revolved around the energy savings potential of IoT on other building systems (e.g., HVAC). Respondents mentioned the following IoT applications being used or considered:

- The use of an under-desk sensor for understanding satellite office space utilization
- A sub-metering IoT sensor for energy use which was used for capital project justification and fault detection

- A lighting system to track lighting energy use and operation through the cloud
- A system to track assets and people within buildings (which was ultimately incorporated as a stand-alone system, although a system incorporated in lighting was also considered)
- A system to monitor environmental factors (e.g., temperature, humidity, air quality, light levels) to improve occupant comfort.

5.2 Role of Lighting in IoT

End users were asked whether any of the IoT technologies they have currently installed were integrated with or reliant upon lighting solutions (e.g., luminaires, a lighting system). As most responses to this question were negative, follow-up questions focused on what if any IoT solutions in lighting had been proposed or explored, and why they were not considered for implementation if that was the case. Three of the eight end users interviewed stated that they had IoT-enabled lighting, or had considered it.

The following are benefits of systems described by respondents (with explanations in the last example for why they are not being implemented):

- Remote monitoring of lighting system operating mode/state (i.e., on/off/level) and energy use tracking, which in one case is providing the ability to demonstrate the realized savings from the system
- Demand response, which is being explored in upcoming updates to current lighting/IoT system
- Occupancy analytics for providing insights to designers for space use and space planning, which one respondent stated provided the benefit of having smaller conference rooms.
- Asset and people tracking through lighting, which is being explored but has not been implemented because:
  - IoT sensor cost was too high, energy savings were insufficient to justify cost, user had prior experience with "aggressive" models for lighting energy savings that proved inaccurate
  - "Lighting does make sense [for integrating IoT in a building], but it is just in a holding pattern [for us]"
- Security was also mentioned. Audio sensors for gun shot or other early warning signs, integrating cameras into the sensors, or other means of security integration.

5.3 Most Promising Benefits

End users were asked what they perceived as the most promising benefits of IoT for their organization. Some responses noted during the interviews include the following:

- Space utilization and comfort
  - Satellite office space utilization, which allows for proper determination of actual space needs, reducing costs to business
  - Building occupancy and operation, facilitating proactive identification and resolution of issues; this can be a benefit in a tenant-landlord situation specifically
  - Environmental control and improved comfort, through the use of electrochromic technology on glass windows to dynamically tint and set the mood, sensors to monitor and help improve air quality, and to allow for the possibility of color tuning and circadian lighting

- Building system integration
  - Occupancy sensor data to BMS/HVAC to explore savings in other building systems
  - Central monitoring to identify and/or create energy saving opportunities
- Fault detection and diagnostics
  - Sensor/equipment information to determine when equipment is down and needs maintenance (e.g., lamp/luminaire out)
  - Vibration and temperature sensors for tracking equipment operation/condition, enabling predictive maintenance (e.g., if temperatures in data closets are uneven, the system can trigger an alarm and send a notice).

5.4 Key Concerns

End users were asked whether any concerns existed prior to installing an IoT technology, or still exist today, and what are the most important concerns that need to be overcome. Section 3.0 discusses many of these concerns and included here are some additional findings. Despite the benefits cited by end users, in some cases they started to explore IoT but sometimes elected not to proceed with its implementation or expansion, or changed their expectations (e.g., for return on investment as a result of lessons they learned). Reasons cited include the following:

- Poor implementations of technology can leave a bad impression:
  - Explored HVAC/lighting/plug load control via lighting, but not all office occupants like the technology. The combination of systems could not be integrated into all of the cubicles. In some conference rooms, sensors could not accommodate three-way switches.
- Adequate coverage of large spaces is a challenge:
  - Large spaces can cause hardware costs to increase and solutions with better coverage (e.g., requiring only one hub to cover entire space) may be deemed more cost effective.
- Return on investment was too low:
  - A power strip using the Zigbee communication protocol was evaluated but not deemed economical.
  - Service/subscription models are not seen as economical. One end user noted that by the end of the service agreement, its cost would have paid for a full replacement of the system.
  - Some collaborations between manufacturer and end users were halted due to funding, with end users opting for solutions that integrate into the current platform.
  - Aggressive calculations/models of energy savings might help make the initial sale, but limit future investment by the customer. Most end users count on the savings from an investment to justify its cost and even fund future projects. In one case, an end user noted management's expectation went from a required 5-year payback to 2.5 years (i.e., making the justification for future purchases more difficult) as a result of experiences with energy savings calculations that missed the mark.
- Must understand customer needs when proposing IoT solutions:
  - Predictive maintenance/failure might not add much value if significant redundancy is built-in.
  - Corporate cultures and sensitivities to technologies differ (e.g., some companies might be sensitive to privacy issues and have concerns about tracking their employees or customers).

6.0 Conclusions and Future Research

6.1 Conclusions

IoT has the potential to revolutionize the lighting industry, but several factors must be addressed to encourage more broad adoption of IoT in lighting systems. Among these, cyber security concerns, better understanding and communicating the value proposition of IoT, and addressing obsolescence concerns through standards are among the top issues on the minds of those interviewed in this research.

There is a need for better connection and communication between IoT lighting manufacturers and end users with regard to cyber security. End users frequently expressed concern about security and mentioned avoiding certain connection technologies as a means to address the security risk. For instance, Wi-Fi and Bluetooth were both specifically mentioned by some end users as technologies that might be better avoided because of security concerns. However, there are existing published best practices to minimize the security risks involving these and other connectivity technologies that manufacturers can follow and use in communication with customers.[1] In addition, both Wi-Fi and Bluetooth have been increasing their security features with new revisions, and manufacturers might address some customer concerns by adopting and highlighting their adoption of these enhanced security capabilities in their IoT lighting products.[2,3]

End users, used to justifying the additional expense of sensors and controls in lighting systems through energy savings of the lighting system which can be readily quantified, noted that limited data exists to be able to do the same for more advanced applications of IoT. However, the potential for these applications to create higher value propositions to a business than what is possible through energy savings alone (e.g., through more efficient use of a space, optimizing staffing needs, or increasing productivity or yield) may not be evident, and even less so quantifiable, unless a concerted effort to better document these real-world benefits is undertaken. Although some marketing literature is available touting these benefits, end users expressed that objective third-party evaluations are needed on similar buildings to their own.

Lastly, in commercial and industrial environments luminaires are typically expected to last over 10 years, with some, such as troffers, not being replaced for more than 20 years after installation. With such a long life-expectancy, luminaires installed today, including their associated sensors and controls, would be expected to adequately provide the same utility over its life. The lighting (then building and finally utility) industry needs to drive toward standardization and interoperability to provide end users with the confidence that their investment will not become obsolete and that it will be easy to maintain, or upgrade, within a few years of installation.

6.2 Future Research Opportunities to Meet Needs

Based on the findings in this research, future research efforts that would help support the uptake of IoT technologies in lighting products include the following:

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[1] To access two examples of best practice guides, visit https://www.nist.gov/news-events/news/2011/10/nist-releases-two-wireless-security-guides-requests-comment.

[2] A Bluetooth mesh security overview is at https://blog.bluetooth.com/bluetooth-mesh-security-overview.

[3] For an example of introducing a new security capability, visit https://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-introduces-wi-fi-certified-wpa3-security.

- The development of IoT security best practices for devices in the built environment (e.g., references that improve end user awareness of high-risk items and offer questions to ask manufacturers in order to adequately address IT department concerns)
  - Standardized information to help end users choose products and evaluate cyber security risks
  - These best practices are probably best developed via NIST, industry, and groups other than the U.S. Department of Energy
- Field studies/reports evaluating the performance and benefits of IoT solutions, with an emphasis placed on observing and quantifying benefits to more fully capture and characterize the cost effectiveness of IoT technology
  - By building type (office, retail, healthcare, education)
  - By technology type (tracking, occupancy, air quality, etc.)
- Cost analyses of IoT installation (savings from labor reductions) as well as long-term costs associated with subscription models.

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Appendix A

Manufacturer Questions

Appendix A

Manufacturer Questions

- Are you incorporating newer sensor types (e.g., video, audio, ToF) and other communication technologies (like LiFi and beacons) into your fixtures?
- What additional energy benefits (e.g., HVAC, plug loads, energy savings due to reduced space usage) do you expect your customers to achieve through sensing technologies associated with IoT lighting?
- The addition of IoT functionality to lighting adds hardware that consumes energy. Are energy losses a factor in deciding which connectivity technology to use?
- How do you think concerns over IoT connectivity technology obsolescence (e.g., firmware, connectivity, or device lifetime) during the long lifetimes of LED lighting might affect development or adoption of IoT solutions in lighting?
- What are your pain points for designing in multiple sensors and components? Is interoperability/standardization necessary for success?
- Who provides the skilled personnel to commission IoT lighting systems you offer, and can your customers maintain installed IoT lighting without specially trained personnel or outside support services?
- How is the need for ongoing cyber security support for IoT lighting being addressed by lighting manufacturers and the industry?
- What are you hearing from your customers about the opportunities and challenges they see in integrating IoT into their buildings and, in particular, into lighting?

Appendix B

End-User Questions

Appendix B

End-User Questions

- What IoT applications are you currently considering/using in your buildings?
  - Are any of these IoT applications integrated or reliant on lighting solutions (e.g., luminaires, sensors)?
  - Is/Was sufficient information available to make an informed decision regarding IoT in your building? If so, what was the primary source of information? If not, what information would be most helpful in the decision-making process?
- For your organization, what are the most promising benefits of IoT?
- If any concerns existed, or still exist, about incorporating IoT into your building(s), what were/are the most important to overcome? For example, commonly cited concerns are high cost, security, and interoperability.
- What communication protocols are currently used in your building(s) to wirelessly communicate with IoT solutions, if any (e.g., Bluetooth, Wi-Fi, ZigBee)? How well are they working?

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