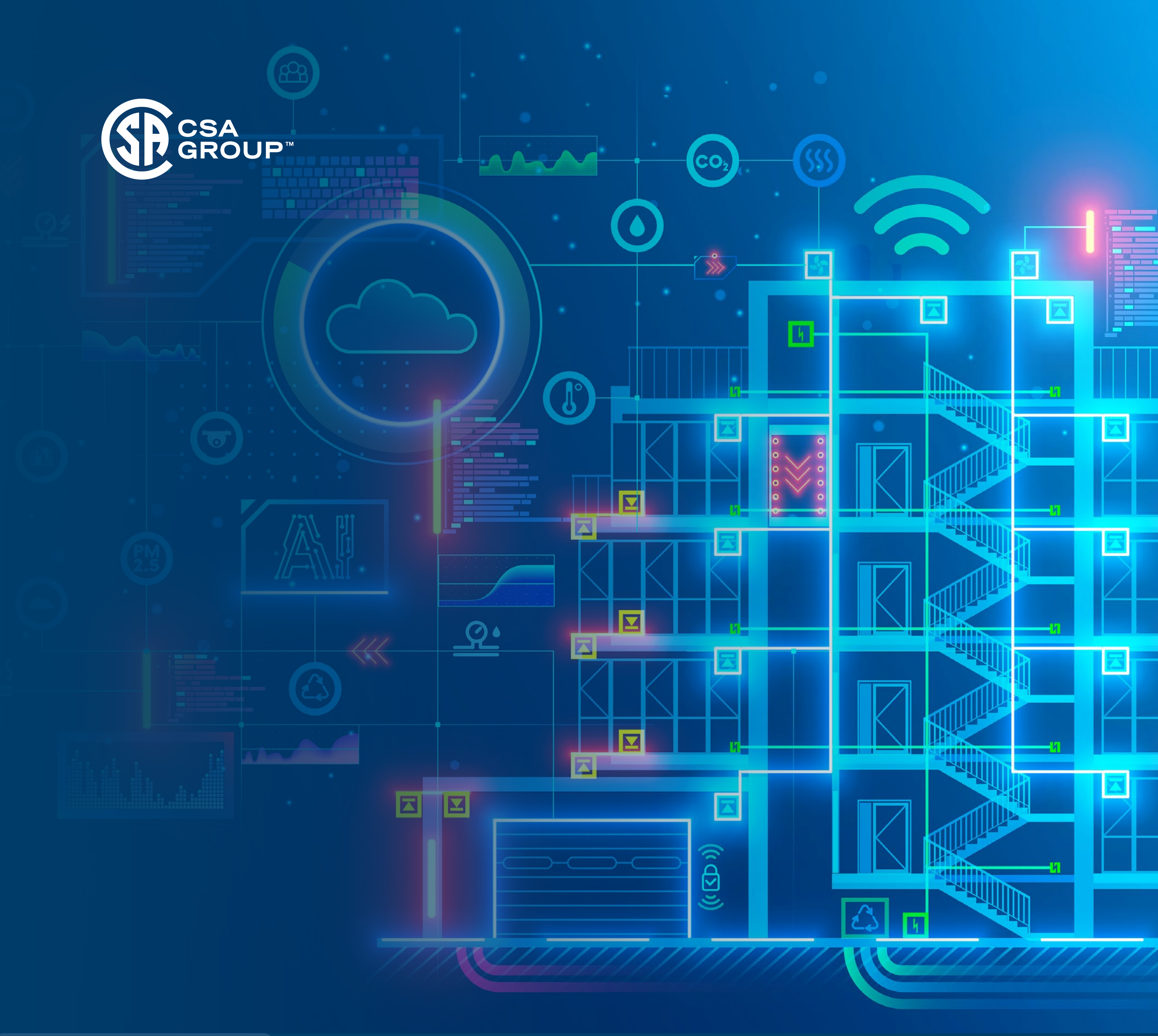

STANDARDS RESEARCH

Intelligent Buildings: Layout and Relevant Standards

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Executive Summary

Intelligent buildings continue evolving in concept and practice. This results from technological innovations generating new functionalities and changing priorities of building owners and operators that shape how these technologies are applied. For example, inexpensive sensors have made data collection more economical, and innovations in communication technologies have facilitated greater flows of data within buildings that can then be used to inform how buildings are operated.

Modern buildings are serviced by a wide variety of building subsystems (e.g., building management, lighting, fire safety, security, heating ventilation and air conditioning, etc.). These subsystems facilitate building operation and support occupant comfort and safety. Increasingly, intelligent buildings are associated with numerous characteristics, such as energy efficiency, automated operations, reduced environmental impacts, and responsiveness to both occupant needs and external variables typically resulting in greater occupant well-being.

Beyond the buildings themselves, innovations in the Smart Cities space, and within the energy and water sector, have increased the potential integration of buildings into these larger components of energy transition and fourth industrial revolution. However, while intelligent buildings have great potential, in practice there are still challenges to deploying them in ways that capture their full potential. Standards developed for intelligent buildings will help this sector progress towards its potential.

To understand the value and potential for intelligent building standards, this report reviews existing literature, conceptualizes the potential for intelligent buildings, analyzes the current standards landscape, surveys intelligent building stakeholders, and develops suggested next steps for pursuing intelligent building standards.

Through the literature review and standards landscape review, some key insights and gaps emerge. They include a lack of consistent definitions, interoperability challenges, cost implications, cybersecurity and privacy concerns, and lack of building-level focus. By exploring potential intelligent building system layouts, this report discusses how a whole building-level approach can help maximize intelligent building design benefits by reducing the application of redundant systems; creating consolidated communication networks offering greater functionality and fewer cybersecurity vulnerabilities; and supporting coordinated building management.

In addition, the project also sought the input of diverse intelligent building stakeholders. A survey was conducted to gauge stakeholder interest in intelligent building standards being developed and validate initial project findings. Overall, the stakeholders surveyed reinforced research findings. Interoperability was identified as the biggest intelligent building standards gap to be addressed. The most concerning barrier survey participants identified for deployment of intelligent buildings was cybersecurity risks. Participants indicated broad support for intelligent buildings standards being developed.

Based on the research conducted in this report, intelligent building standards development warrants further exploration. Some key initiatives for supporting intelligent buildings standards include: identifying concurrent intelligent building initiatives; developing consistent terminology; establishing stakeholder advisory committees and working groups to join actors across intelligent buildings layers and address key gaps; developing intelligent building case studies to understand current practices; and advancing the role of intelligent buildings technology considerations in the evolving smart cities landscape.

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1 Introduction

The design and operation of buildings are continuously responding to technological innovation and changing social priorities. Modern buildings are serviced by multiple subsystems, such as fire alarms, elevators, heating ventilation and air conditioning (HVAC), security, lighting, and telecommunication systems. To various degrees, these systems are becoming *smarter* and making use of automation, sensors, and data analytics to improve operations. Some service providers have developed tools to improve coordination across building subsystems, such as building management systems (BMSs) or energy management systems (EMSs). While the market is responding to increasingly complex building operation needs, few building-level standards have been established to facilitate integration of these subsystems.

Additionally, as energy technologies develop and concepts such as smart grids and smart cities become more prominent, there is a need to reconsider how buildings integrate into broader energy systems, such as the electricity grid, local microgrids, or district energy systems. Traditionally, buildings were seen as a source of demand. However, controlled and coordinated building energy systems can be a resource to broader energy systems. Buildings are increasingly being integrated with innovative energy resources, like generation technologies (e.g., solar photovoltaics (PV) or combined heat and power (CHP) systems), energy storage technologies, backup generation, and electric vehicle charging infrastructure. As technologies mature and become more economical, coordinated building energy systems and associated energy resources may be able to add greater value to broader energy infrastructure. These resources could support wholesale energy systems, local distribution system operation, or even microgrids.

While building technologies and energy systems have been evolving, social priorities for building design and operation have also been changing. Increasingly, the aim for buildings has been to improve operational and energy efficiency, reduce environmental impacts (e.g., greenhouse gas emission reductions, water conservation, stormwater management), and enhance building occupants' comfort and well-being. The evolution of technologies has created expectations that buildings will integrate more technologies and therefore become more complex. However, social priorities have shifted regarding intelligent buildings design and what they should offer their occupants and broader community.

Given the wide-ranging changes impacting building design and operation, this report is an effort to understand the standards and protocols that will enable the buildings of the future. This report complements recent publications on the intersection of buildings and innovation, including how standards could support the deployment of information and communication technology infrastructure (ICTi) in buildings [1] and DC microgrids [2]. This report presents suggested next steps for developing intelligent building standards and protocols that will help facilitate the buildings of the future.

1.1 Report Outline

The report is organized as follows:

- **Literature review –** Research on the conceptualization of intelligent buildings, how these concepts are applied in practice, energy system integration of intelligent buildings, and the challenges and barriers that may limit intelligent buildings in practice are presented.
- **Intelligent building conceptual layouts –** Two conceptual layouts of intelligent buildings are portrayed. The first offers a representative understanding of how intelligent buildings are currently implemented and the second presents how an intelligent building may be designed to capture their potential more fully.
- **Standards landscape –** Based on a review of standards associated with intelligent buildings, challenges, limitations, and gaps to the implementation of intelligent buildings are noted, as are standards that might inform the development of intelligent buildings standards.
- **Stakeholder survey –** A diverse range of potential stakeholders were surveyed to inform the gap analysis and inform the development of intelligent building standards and protocols. A summary of survey feedback is presented.
- **Conclusion –** This concluding section includes key gaps, an analysis of gaps, and recommendations regarding the development of intelligent buildings standards.

2 Methodology

2.1 Literature Review

A literature review was conducted to identify existing research regarding intelligent buildings and associated standards and protocols. The review included journal articles, white papers, and research reports. The following search description is representative of the initial literature review:

> ((Intelligent OR smart) AND building) AND ("Internet of things" OR IoT OR "big data" OR "artificial intelligence" OR AI OR cybersecurity OR privacy OR "smart sensors" OR automation OR interoperability OR "communication protocol" OR "fire system" OR "security system" OR "demand response" OR "grid integration" OR "Microgrid" OR "Smart Grid" OR "EV Charger" OR "distributed energy resources"

The primary search targeted articles no older than 2015. Some exceptions to this timeframe were made when few recent references were available for specific topics of interest or for highly referenced sources deemed relevant, particularly regarding the history of the intelligent building concept.

2.2 Standards Landscape

A review of existing standards, protocols and codes was undertaken to understand the standards landscape related to buildings and subsystems, as well as that related to grid integration. Though this study was not intended to review all standards related to intelligent buildings—an effort that would include all building systems, associated energy systems, and associated interoperability standards—it was meant to provide a thorough overview of existing standards as a reasonable representation of the existing landscape.

A first scan of existing standards was guided by keywords associated with the following categories and subcategories:

- **Safety:** Fire system / Security / Elevator / Electrical safety / Distributed energy resource or DER / EV chargers
- **Energy:** Energy performance / Electrical systems / Distributed energy resources or DER / Microgrid / EV chargers
- **Communication:** Internet of things or IoT / Network / Sensors / Data / Cybersecurity / Smart meter / Advanced metering infrastructure
- **Control systems:** Building automation / Building management system / Energy management system / Connected lighting system

Additional standards and protocols were pursued based particularly on literature review and consultation with peer experts regarding issues of electrical safety, grid integration, and microgrid design. Collected standards were scanned to identify relevant content. Those standards deemed most relevant were then reviewed in detail and included in the standards review.

2.3 Stakeholder Survey

A stakeholder survey was conducted in January and February of 2021 to enhance the findings of this report. Because intelligent buildings are assumed to integrate multiple technologies and interact with external energy systems, a diverse range of stakeholders were involved. Stakeholders were contacted by email (n=70) and invited to respond to an online survey. Participants were encouraged to share the survey with personal contacts whom they felt could contribute to the research. The survey was designed to inform the next steps for intelligent building standards and corroborate initial findings.

Participants were asked about potential intelligent building benefits; standards organizations that currently provide insight into application of intelligent building technologies; existing standards gaps that impact intelligent buildings; potential barriers and challenges to the development of intelligent building standards; and their assessment of the potential value for establishing intelligent building standards. Questions were designed primarily as multiple choices (see Appendix A for complete survey). Choices reflected findings from the literature review and standards landscape. However, participants also had the opportunity to add additional responses or thoughts. This way, the survey verifies findings from previous sections and the opportunity for participants to highlight new information not captured in previous sections.

3 Literature Review

3.1 Defining Intelligent Buildings

Intelligent buildings have been researched and theorized since the 1980's [3], [4]. However, the concept of an intelligent building is not static; numerous definitions for intelligent buildings exist and their exact parameters have changed with time [3], [5]. This change can be partly attributed to adaptation and use of emerging technologies, but can also be associated with changing social priorities.

The definition of intelligent buildings often overlaps with that of smart buildings, and while some academics clearly distinguish these terms, they are commonly used interchangeably [3], [5]. For the purposes of this report, the terminology of intelligent buildings is preferred; however, research using the terminology of smart buildings has also informed the report.

In the earliest stages, the idea of intelligent buildings reflected the integration of building management systems (BMSs) that allowed automation of various building operations, such as lighting, HVAC, security, and more. The development of BMSs created a new opportunity to maximize technical performance and reduce operational costs of buildings [5], [6]. Since then, various forms of automation have become common, and therefore, the concept of intelligent buildings has taken on new meanings. Rather than focusing primarily on operational efficiency, intelligent buildings are also increasingly expected to respond to occupant comfort via temperature, humidity, and lighting adjustment. Intelligent buildings are therefore expected to improve occupants' experience within the space, but rather than happening at the expense of operational efficiency, intelligent buildings aim to align these objectives [3], [4]. Recently, intelligent buildings have been increasingly associated with concepts of sustainable design like energy-efficiency, improved thermal comfort, and indoor air quality through integration of advanced sensors to facilitate self-adjusting systems and operational optimization [5].

Beyond traditional building subsystems, a range of emerging energy technologies—solar PV generation, electric vehicle EV charging, and energy storage technologies—are reshaping building energy profiles [7]. These technologies are creating new opportunities for buildings to coordinate with and integrate external energy systems [8]. Intelligent buildings are a key component of broader smart grids and smart cities [3]. Therefore, intelligent buildings are also associated with external responsiveness and interaction. These emerging concepts of intelligent buildings reflect technological advances related to availability of sensors and big data, advances in artificial intelligence systems, much increased computational capacities, and energy sector innovation. However, these emerging concepts also reflect greater social awareness of environmental issues and sustainability more broadly.

3.2 Intelligent Buildings in Practice

As technology improves and evolves, the concept of intelligent buildings can be expected to change. In practice, there are wide ranging implications for integrating more sensors, data analytics, and more sophisticated BMSs in buildings, as well as for evolving and rebalancing building operation goals (e.g., economic efficiency, reduced environmental impact, occupant comfort and well-being). Intelligent buildings have been implemented in diverse ways, yielding many related but secondary research papers and case studies. Rather than exploring how their implementation has impacted each building subsystem, the following sections will explore the literature on a few select components of intelligent buildings and their evolution in the context of intelligent buildings.

3.2.1 Building Management Systems

Automation of buildings systems operations has been a key part of intelligent buildings since their earliest conceptualizations. BMSs are computerized systems that monitor and control building environment and operation of building systems: a user interface communicates, either through wired or wireless channels, with sensors and actuators throughout the physical space of the building [9]. As computer systems and sensor technologies have improved and become more economical, intelligent buildings have benefited from greater BMS functionality and expanded potential applications for these systems.

This report primarily refers to building management systems (BMSs). However, across the intelligent building literature, a wide array of terms describe centralized systems that communicate with, automate, and control diverse systems within buildings: Building Automation Systems (BASs), Building Automation and Control Systems (BACSs), Building Energy Management Systems (BEMSs), Energy Management and Control Systems (EMCSs) [9]. Automating building operations has wide ranging implications and, when properly commissioned and maintained, potential benefits such as reduced operational costs, improved energy and water efficiency, improved space functionality, and increased user comfort and well-being.

3.2.2 Lighting

Similar to BMSs, lighting systems and their controls have a history of innovation that can be traced back to theatrical lighting controls in the 1920s and the introduction of commercial solid-state dimmers, which offered an alternative to the on/off wall switch in the 1960s [10]. In the 1980s, as early intelligent building concepts were being conceived, one of the first generation of software defined lighting control protocols was introduced—Digitally Addressable Lighting Interface (DALI). This interface provided a standardized communication network across lighting systems, allowing a new level of control and automation. These systems relied on the installation of additional communication networks throughout building lighting systems for greater lighting control (Network Lighting Control). Early development in this space had limitations, but network lighting controls continued to evolve, increasing functionality. Further developments in lighting controls have been pushed forward by policy choices. For example, policies requiring lighting systems to have demand response functionality (see Section 3.3.2) significantly pushed building developers to use networked lighting control systems, and, in turn, lighting control vendors introduced more advanced and cost-effective solutions.

More recently, advanced two-way communication (referred to as connected lighting systems) has been introduced [11]. Rather than installing a communication network that only facilitates sending out lighting controls, these more advanced networks can support data flow from sensors back to a BMS. Since lighting equipment is installed throughout occupied areas of buildings, two-way communication channels used in connected lighting systems have become a cornerstone of intelligent building designs and a platform for non-lighting related sensor data.

Connected lighting systems can be deployed as wired or wireless communications networks. Wireless connected lighting systems reduce the need for physical infrastructure, but have greater limitation on bandwidth, and are therefore more appropriate when there is less need for data exchange. Alternatively, wired connected lighting systems, such as power over ethernet (PoE) lighting, facilitate high bandwidth communication networks throughout buildings. Data exchange and building operation responsiveness are key to intelligent building functionality. For example, real-time responsiveness of building operations to occupant activity, be it lighting levels or other operations, requires continuous data flow. And the more data available the more potential to develop intelligent buildings applications. As such, PoE lighting and the underlying PoE network architecture can provide the core infrastructure for intelligent buildings.

3.2.3 Heating, Ventilation, and Air Conditioning

Heating, ventilation, and air conditioning (HVAC) systems control building temperature and air circulation. For typical buildings, HVAC systems can account for half of the buildings' overall energy consumption (approximately 20% of the global energy demand) [8]. In this context, it is not surprising that these were some of the earliest systems to be automated when BMSs were first implemented [4]. Improving the efficiency of HVAC systems offers operational and economic benefits and the management and automation of HVAC systems remains a key priority for intelligent building design [12]–[15].

Beyond their implications for overall building energy consumption, HVAC systems are critical for ensuring occupant comfort and healthy indoor air quality [8]. An important component of intelligent building design is to balance and maximize multiple goals. Climate control is a key function of modern buildings. It is critical to creating an indoor environment that maintains healthy conditions, supports occupant well-being, and is connected to greater productivity [3], [4], [12]. In intelligent buildings, automated HVAC operations allow for dynamic indoor environmental control that responds to occupant activity while still maintaining a level of energy efficiency. However, occupancy comfort is a subjective experience, and some intelligent building research is examining the optimum level of indoor environmental adaptability that can be provided to meet specific occupant preferences [12].

3.2.4 Internet of Things

Current intelligent buildings rely on the integration of sensors to improve data capturing building operations and increase controllability of various building systems to improve operations. Beyond traditional building systems, such as lighting and HVAC systems integrated with BMSs, a broad range of devices have been equipped with electronics that send and receive information and connect to the internet—a trend expected to continue [16], [17]. Collectively, these connected devices are called the internet of things (IoT). The IoT can generate significant data presenting new analytical and operational benefits from the perspective of intelligent buildings. For example, with increased sensors availability, it may be possible for the operation of the air conditioning system to respond to users opening or closing windows [18]. By providing greater operational awareness and enhanced analytics, device connectivity throughout buildings can also improve building managers' understanding of equipment repair needs or improve maintenance schedules [18]. As more equipment and appliances within a building are integrated into the IoT, there is increased potential to coordinate and automate how those devices are used. The growth of the IoT has implications for all building subsystems.

For example, the IoT is also implicated in improved understanding of building occupancy and occupant behaviour. This can result from sensors that track occupant activities within the building, or occupancy sensors or video cameras that identify occupancy or movement more directly [17]. This type of data can improve space use and conditioning efficiency, thereby reducing building operational costs. Additionally, the IoT also extends to wearable devices that can provide additional – even biophysical – information about specific occupants [18], [19]. Some wearable devices with established markets include smart watches or fitness trackers; but, this segment also includes smart glasses, smart jewelry, and smart clothing [20]. Beyond operational benefits associated with greater knowledge of building occupancy, these devices can facilitate occupant-based preferences, such as thermal comfort and lighting-levels [17], [18]. New sensor technology expands the potential for intelligent buildings and their operations.

In addition to providing sensors that collect data, the IoT then shares that data. Thus, communication networks that facilitate data sharing are a second technical IoT component. This has been described as the network layer of IoT [18]. The IoT relies on a variety of communication and information technologies infrastructure (ICTi) [1]. While some IoT devices will rely on wired network layers, many IoT incorporate wireless communication technologies. Some prominent wireless communications technologies that facilitate the IoT in buildings include: Wi-Fi, Zigbee, Long-term Evolution (LTE), Z-Wave, Wireless USB, and IrDA [18].

3.3 Intelligent Buildings and Energy Transitions

The electricity sector is currently in the process of a wide-ranging transition and has seen the rapid deployment of technologies reshaping how these systems operate [21], [22]. This energy transition is being driven by climate change mitigation efforts, energy sector innovation, and economics. These changes affect the building sector and how intelligent buildings are integrated within electricity systems. Renewable energy technologies are producing an increasing portion of electricity in many jurisdictions. Unlike many traditional sources of electricity generation, renewable generation – notably wind and solar– can vary significantly based on environmental conditions. Because electricity system operators need to continuously balance electricity supply and demand, there is increased value in aligning electricity demand and load profiles with those of the utility grid, as this creates a more responsive and interactive relationship between buildings and grid. A dynamic, responsive relationship of supply and demand is where intelligent buildings can offer great value [8], [23].

3.3.1 Advanced Metering Infrastructure

Advanced metering infrastructure (AMI), commonly known as smart meters, provide a means for improved communication between building energy demands and electricity system operators [8]. Smart meters can be considered an IoT example [18]. Traditional electricity metering technology did not provide real-time information to electricity operators. As advanced metering technologies have been deployed, both customers and electricity system operators have gained greater information regarding electricity usage [24]. By using smart meters, utilities can examine the regional and local peak load patterns and identify customers well-suited for conservation and demand management efforts. These technologies also improve electricity system operation by improving outage detection and increasing customer usage information [24]. Advanced metering technology also allows for more flexible electricity cost structures. With this flexibility, electricity rates can be developed that incentivize electricity usage away from system peaks and can help align user incentives with those of system operators.

To understand intelligent buildings, AMI facilitate communication between the building-level usage and electricity system operations. This communication offers usage information for traditional electricity system operation; however, these capabilities have additional implications when considering intelligent buildings integrated into smart grids or microgrids.

3.3.2 Demand Response

Buildings are increasingly viewed as an important unit in large conceptions of smart grids or smart cities [3], [23]. Demand response describes electricity loads adjusted to support grid-level needs. AMI can help facilitate effective demand response because two-way communication between customers and electricity system operators can offer real-time (or near real-time) understanding of facility demand. Creating greater flexibility in electricity demand is especially useful as more renewable generation is added to electricity systems. Renewable energy sources depend on environmental conditions. So, intelligent buildings with flexible demand can help support integration of more renewable energy.

A related functionality of intelligent buildings could involve peak shifting, such as pre-cooling or pre-heating of buildings [25]. Weather is a key driver of this functionality. Researchers are therefore exploring ways to create BEMSs that respond to weather patterns and minimize energy usage [15]. To be successful, these types of systems must be installed in buildings with high levels of insulation to avoid heat loss or gain that would impact the ability of the systems alone to regulate comfort conditions. Shifting cooling or heating load may not alone fully reduce peak energy demand in some building types; but, they can play a significant role in a more holistic approach to peak demand management. Depending on climatic conditions, these

"Demand response is expected to be an important resource in future grid operation; yet, at this stage, optimal functionality is not widely established."

approaches may result in energy penalty because pre-cooling or pre-heating requires additional energy when carried out solely by active systems (versus passive night ventilation) [25]. Implementing these approaches at scale will require an alignment of incentives for building operators and grid operators.

Demand response is expected to be an important resource in future grid operation; yet, at this stage, optimal functionality is not widely established. In fact, most demand response resources currently in operation are not automated [26]. Despite a promise of smart technologies within intelligent buildings operating in integrated fashion with the grid, few main IoT standards offer demand response functionality that supports intelligent building interaction with device level utility grids [23]. Currently, typical demand response enabled devices rely on internet connection to communicate load control instructions [26]. These demand response capabilities are not often integrated across IoT. Although some platforms can control numerous devices, no established standards exist to ensure response coordination.

In addition, demand response programs require building operators to commit to powering down a pre-determined percentage of peak loads. In buildings with high process loads (e.g., industrial facility or data centre), this may significantly impact building operations. Thus, both demand response standardization and attention to specific criteria of different building typologies are needed.

3.3.3 Associated Energy Resources

Increasingly intelligent buildings are also associated with a variety of energy technologies, collectively referred to as distributed energy resources (DERs) [8]. These include small renewable energy generation installations (e.g. solar photovoltaics), energy storage technologies, electric vehicles and their charging infrastructure, and controlled demand (such as demand response) [7]. These technologies have various capabilities and applications that could create new opportunities for interactions between energy generation systems, intelligent building systems, and the broader electricity system, be it a utility grid or a more localized microgrid [8], [9]. As described above, there is an increased communication and interaction trend between buildings and electricity system. As the DER deployment trend increases, intelligent buildings will potentially integrate more technologies and be expected to interact with utility grids and microgrids in more dynamic ways. DERs are fundamental to many municipalities and corporations in achieving their goal of transitioning to a clean energy infrastructure. Thus, the deployment of DERs elevates the role of intelligent buildings in the future of energy infrastructure.

3.4 Intelligent Building Challenges and Barriers

3.4.1 Interoperability of Systems

In the literature, several gaps and challenges have been identified that limit the potential for intelligent buildings in practice. A commonly noted challenge in the literature relates to interoperability of systems to facilitate intelligent buildings. Numerous established firms and startups have moved into the intelligent building sector, which has driven innovation and new technologies; however, these products and systems have generally been developed primarily to respond to specific building occupant needs and building operations [23]. There has been relatively little effort to ensure that new products and systems are well integrated with other building systems. Instead, many have been developed as proprietary solutions that then limit the potential for integration with other building systems. Additionally, the effectiveness of certain intelligent building functions, such as integrating artificial intelligence for operation optimization, will depend on the availability of consistent and high-quality data [27]. If the available building data is of poor quality, non-uniform, or incomplete across various sensors or building systems, intelligent building designs and operations will be limited.

A lack of consistent descriptions and conceptualizations of intelligent building-related services and technologies is another noted challenge in the literature. This may partly be attributed to the lack of consistent, industry-accepted definitions of intelligent building, and associated technologies. Specifically, there is an identifiable need to define and implement interoperability standards associated with the IoT and sensors to support intelligent buildings [28]. A key component for developing standards related to smart grid technologies involved definitions, as well as standards for technology and infrastructure. This methodology can be a reference for developing future intelligent building standards [23].

3.4.2 Cost Barriers

A promise of intelligent buildings is that integrating diverse technologies will improve operations and reduce operating costs. However, there are also concerns that capital costs of equipment, installation, commissioning, and training may limit the application of intelligent building technologies [4]. For older building stock not equipped with BMSs, upgrades can be cost prohibitive, which encourages building operators to pursue siloed system- or component-level controls, rather than integrated building-level systems [8]. Upgrading our existing building stock is increasingly seen as a critical aspect of meeting municipalities' goals related to carbon emissions of the built environment. Related to interoperability concerns discussed above, there have been some efforts to create open automation standards for IoT that would help facilitate greater functionality of intelligent buildings. However, where open automation standards exist, financial constraints on manufacturers such as fees imposed on use of software, annual certification costs, or per device fees, may be a barrier to uptake and thus limit the potential technological benefits of applying the standards [23].

3.4.3 User Privacy

In the intelligent building literature, potential privacy issues are prominently identified. A tension between intelligent buildings and IoT collection of data is inherent to technology when intelligent buildings are designed to respond to occupants, and public expectation for privacy [29], [30]. Smart building data could be used to identify what people do, who they are with, health status, etc. Privacy concerns can occur during numerous intelligent building operations: data transfer, storage, and processing [29]. Ensuring intelligent buildings can maintain occupant privacy requires that data be protected and anonymized throughout building operations.

When it comes to implementing intelligent buildings and handling data, there is a wide range of occupant privacy expectations. Also, occupants in IoT environments or intelligent buildings may not recognize they are interacting with technologies collecting their data, not to mention understanding or consenting to how that data is used [30]. One approach would be to establish baseline privacy and data management standards. But, this could limit the functionality of intelligent buildings, especially as tools such as artificial intelligence (AI) become more prominent [27]. While there are a variety of potential approaches to implementing AI in building operations, recent advances in AI have relied on large quantities of data to optimize functionality [28].

There is a need to respond to this tension and balance user privacy preferences while maintaining the functionality of the systems. But this is a challenge, since integrating sensors to collect data is at the core of intelligent building operations [30]. Occupant data allows intelligent buildings to improve operational efficiency, comfort, safety, and more. IoT creates value by leveraging big data to create new knowledge [28]. With the data generated from these devices, analytics can offer insights to improve user experience, well-being (such as improving air quality and thermal comfort), and intelligent building operation [28]. Ultimately, some components of intelligent building operations, such as creating occupant responsive environments, require a certain amount of tradeoff with privacy. Therefore, the challenge is to identify where privacy concerns can be limited and aligned with occupant expectations.

Some technical solutions to address privacy issues have been presented in the literature. For example, privacy aware intelligent buildings could be designed to adapt their data collection parameters based on occupant preferences [30]. These intelligent buildings would have privacy registries that notify occupant of data gathering policies and offer some configuration of building settings in response to occupant requests. This approach, while possible, would require broad occupant buy-in to be effective.

3.4.4 Cybersecurity

In addition to privacy concerns, cybersecurity is another prominent issue identified in intelligent building literature. The integration and interconnection of systems across intelligent buildings increases potential cybersecurity concerns, which will impact building operators, occupants, and owners [29]. Integrating cloud computing, big data, software defined networks, and network functions virtualization with IoT can create cybersecurity risks, many of which overlap with potential privacy concerns [29].

For example, security and data privacy is a challenge associated with cloud computing [31], which “is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.” [32, p. 6]. To the degree that cloud computing is used to manage data and facilitate intelligent building operations, there will be an associated risk. There is a significant volume of literature associated with improving cloud computing security and privacy [33], [34]. These cloud computing vulnerabilities are likely to extend to intelligent buildings relying on these services. Other authors have suggested that intelligent buildings should employ edge computing rather than centralized cloud computing models to minimize potential privacy and security risks [28]. “Edge computing is a new paradigm in which the resources of an edge server are placed at the edge of the Internet, in close proximity to mobile devices, sensors, end users, and the emerging IoT.” [35, p. 1475]. By embracing innovative solutions, some cybersecurity issues may be improved; nevertheless, additional risks are likely to develop, as well.

Beyond cloud computing, from a cybersecurity perspective, communication networks, necessary to the intelligent building concept, create vulnerabilities susceptible to hacks [28]. Malicious attackers are increasingly using IoT networks as platforms for cyberattacks [29]. In the literature, there are calls to implement standards for IoT infrastructure to reduce the introduction of privacy risks, and threats and vulnerabilities to the systems [28]. Despite widespread acknowledgement of the risks, certain IoTs do not have anti-virus or anti-malware solutions available [29]. Thus, there is significant need for improvement.

As intelligent building solutions are developed, vulnerabilities in single subsystems or IoT components could have significant implications not only for the security of an entire building but also for the broader energy systems. Venticinque and Amato [28] offered the following illustrative example for understanding security of intelligent buildings:

> “The smart home provides a particularly resonant example of the risks involved when multiple brands, devices, and stakeholders aggregate and analyze multiple data sets and are knit together to form an ecosystem. For example, the garage door opener provides access to not just the garage, but also the primary home. In some configurations, opening the garage door deactivates the home alarm. This, however, means that the entire alarm system is deactivated if only the garage door opener is compromised.” [28, p. 133].

With relation to connect lighting systems, there are few standards dictating cybersecurity requirements. As a result, products on the market have found varying levels of authentication vulnerabilities [36]. Given different risk tolerance, some organizations will pursue higher levels of protection than others. Some organizations choose to install connected lighting systems but require that the system not be integrated with other corporate networks because of the potential cybersecurity risks. In practice, the lack of cybersecurity requirements across the sector means the responsibility to consider these risks is transferred to individual organizations installing these systems.

3.5 Summary of Findings

The literature review offered some important findings regarding intelligent buildings. On a conceptual-level, intelligent buildings are not static. As technological capabilities advance and social goals evolve, so does the concept of intelligent buildings.

Some key components of intelligent buildings currently include energy efficiency, systems automation, improved indoor environmental quality, and occupant engagement. While automation of building operations through BMSs began with a few high energy subsystems, the increasing availability of inexpensive sensors, connected through communication networks (wired and wireless), improved performance, and reduced cost computation are creating greater opportunities for intelligent building design and functionality.

Increasingly, buildings are being integrated with various DERs, and, additionally, intelligent buildings with flexible energy demand and responsive to the grid are being seen as energy assets themselves. Not only do BMSs coordinate the building subsystems operation, but also communicate and respond to external energy system requests. The concept and application of intelligent buildings should be expected to continue to evolve at the same time as the technologies they rely on.

While intelligent buildings offer numerous potential benefits, there are barriers to their implementation. As multiple actors have entered the sector, intelligent building solutions have developed independently, which has led to interoperability challenges, proprietary systems, and even inconsistent terminology and definitions. There were also concerns regarding costs associated with modernizing existing buildings to have intelligent building functionality, as well as costs associated with integrating technologies. A variety of privacy and cybersecurity concerns were also prevalent in the literature.

4 Intelligent Building Conceptual Layouts

As discussed in the literature review, there is a wide array of intelligent building technologies. Building developers, operators, and owners have applied these technologies in many configurations and building contexts, with varying outcomes. Intelligent building technologies have been incorporated into new builds and retrofitted into existing building stock. And over the past few decades, these technologies – and their functionality – have continued to evolve. In many cases, what might have previously been considered intelligent building technologies have been superseded by newer versions. The previously installed systems may require updating and reconfiguration to meet evolving technological compatibility with newer systems.

Given all this diversity, there is not a single representative example of an intelligent building, either in its current technological context or projected into the near future. Recognizing these limitations, two conceptual layouts for intelligent buildings are presented in the following section. The first conceptualizes a current intelligent building, reflecting current challenges and barriers identified in the literature review. The second conceptual layout offers a representation of a future intelligent building, one that leverages the inherent potential in current technological and operational innovations.

4.1 Representative Intelligent Building Systems Current Layout

Figure 1 is representative of the current paradigm of intelligent buildings, including but not limited to the following features:

- **Sensors –** Each building subsystem is contingent on specified sensors that provide data to inform the operation of that single subsystem. Depending on the subsystem characteristics, these sensors may provide input on diverse building conditions, such as carbon dioxide level, humidity, or daylighting, building occupancy, or system operation. In many cases, a single system will require numerous sensors installed throughout a building. The result of this approach is the installation of numerous specialized sensors unable to coordinate or communicate with other building systems.

- **Devices –** Each building subsystem will also have associated devices located throughout the building. Devices perform a physical system control function that can be automated. For example, a light switch is a device: it turns the light on and off. If a motion sensor light switch is installed, the sensor (motion detector) detects environmental conditions in the building and the switch (device) physically controls the lighting system. For each building subsystem with physically controlled operations throughout a building, there will be numerous associated devices.
- **Communication networks and IoT gateways –** The networks and gateways are the interface between the device and the cloud – all data moving between the sensors and devices, and the cloud, passes through the gateway first and can be stored or processed. Without a holistic design approach, multiple communications networks are used to support various building subsystems. This results in redundant IoT gateways being installed to support multiple communication protocols (e.g., Zigbee, Zwave, Bluetooth, LoRaWAN, WiFi, etc.). This redundancy can be mitigated by designing a converged physical infrastructure to support the multiple IoT communication protocols.
- **BMS –** In existing intelligent buildings, it is common for a BMS to only communicate with some building subsystems, and not holistically across all subsystems. Additionally, there may be multiple BMSs installed in a single building due to the proprietary nature of both BMS and the subsystem components they control. As a result, multiple BMSs are required to automate intelligent building operations.
- **Cloud storage –** Each subsystem making use of cloud storage may connect and communicate with independent cloud services. While cloud services can reduce the need for data processing and storage on site, they present a potential risk from a cybersecurity perspective and can limit operational independence in the event of communication loss.

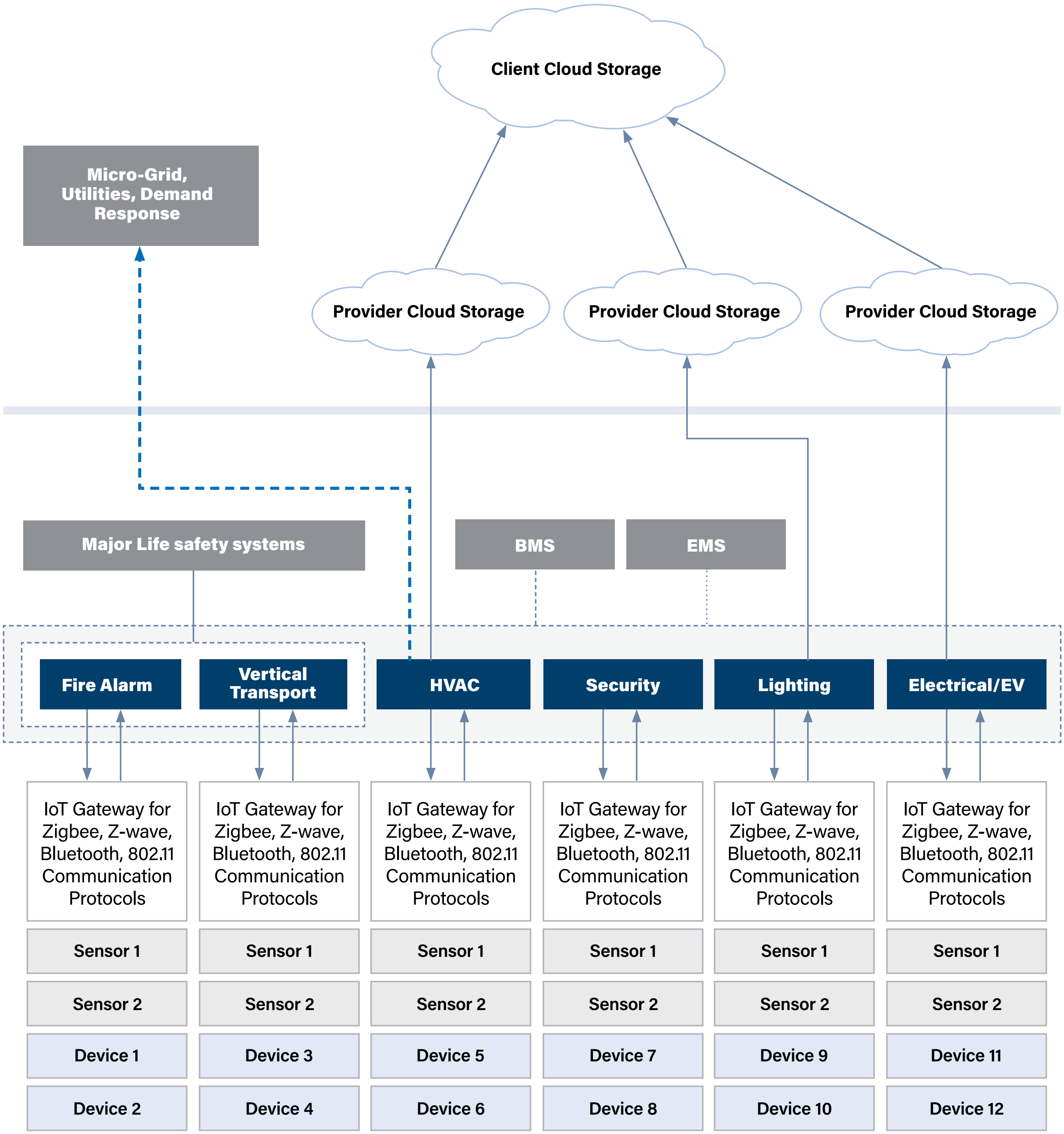
  Additionally, the current business models often require building owners to pay to host the data in the system providers' cloud storage and may be required to pay a transaction fee to import their data from cloud storage system if they want to use that data for other purposes.
- **Utility demand response –** Currently some building subsystems may be equipped with demand response capabilities, providing a degree of responsiveness to demand signals from utility providers. For example, a smart thermostat that allows for utilities to strategically reduce HVAC operations (as agreed with building owner) may be installed; yet, this is typically coordinated through cloud service. Rather than being organized at the BMS level, subsystems equipped with this functionality are controlled independently. Additionally, despite building-level demand response offering a useful potential resource, not all utilities offer demand response programs. Therefore, in many jurisdictions, building developers and owners have little reason to plan for or implement systems with these capabilities.

The current state of intelligent buildings is largely independently designed individual systems without clear standards for integration and interoperability, resulting in siloed systems. In practice, the redundant infrastructure and sensors required to operate siloed systems increase costs and limit functionality. While intelligent buildings in their current paradigm offer specific benefits regarding building automation and operation, they do not generally meet the full potential for the technologies if they were deployed in an integrated fashion.

4.2 Potential Intelligent Building Systems Future Layout

In the second conceptual layout (Figure 2), an intelligent building that has efficiently and effectively integrated intelligent building technologies to reduce the overall infrastructure required, the associated costs, and the complexity of deployment is presented. Rather than identifying redundant, siloed subsystems, the building is characterized by three functional layers (perception, application, and external). It prioritizes interoperability across subsystems, provides efficient building-level coordination, and offers controlled and secured data sharing with external actors.

Figure 1: Representative intelligent building systems current layout



4.2.1 Perception Layer

Intelligent building technologies in the perception layer gather information by interacting with the environment, and then communicate that data to the rest of building systems. This layer consists of all sensors, devices, and communication protocols for all building systems. Sensors gather the information about the environment; devices take that data to perform actions to enhance environment experience; communication protocols allow all sensors and devices to communicate, and freely share data with one another.

In the diagram are three different possible configurations for the perception layer. These configurations are based on different network topologies that depend on latency and bandwidth. Latency refers to the time it takes for data to travel from one point to another. Bandwidth is the amount of data transmitted over a connected medium. The three configurations are:

1. **Low Latency and Low Bandwidth –** Sensors communicate directly with devices in each subsystem. There will be a low level of data processing in this layer and relatively low data flow. Under these conditions intelligent building applications will be limited.
2. **Low Latency and High Bandwidth –** Communication networks facilitate unrestricted data flow. Sensor data is transmitted directly to the BMS. Data processing takes place in application layer.
3. **High Latency and Low Bandwidth –** Communication networks facilitate limited data flow. Rather than relying on BMSs for data processing, the perception layer supports data processing with edge computing capacity in sensors and devices.

4.2.2 Application Layer

The application layer is responsible for building level data processing, and coordination of external data exchanges and across subsystems. This layer is largely characterized by the BMS and subsystem data processing. Depending on the latency and bandwidth available at perception layer, data processing at the application layer may vary. Additionally, as cloud computing becomes more used, some data processing is also happening at the external layer. Still, there is a need for some autonomy and redundancy of data processing at the application layer. A BMS must be able to operate independently in case of communication interruptions with the external layer.

In this potential intelligent building layout, data processing and control at the application layer is done by a single BMS configured to optimize the operation of all the building subsystems holistically. The BMS would also act as a single point of communication for coordinating external data exchange rather than having multiple external data exchanges associated with individual subsystems. For example, cloud-based applications and controls might communicate with the BMS at preset intervals, while still allowing the BMS to operate independently.

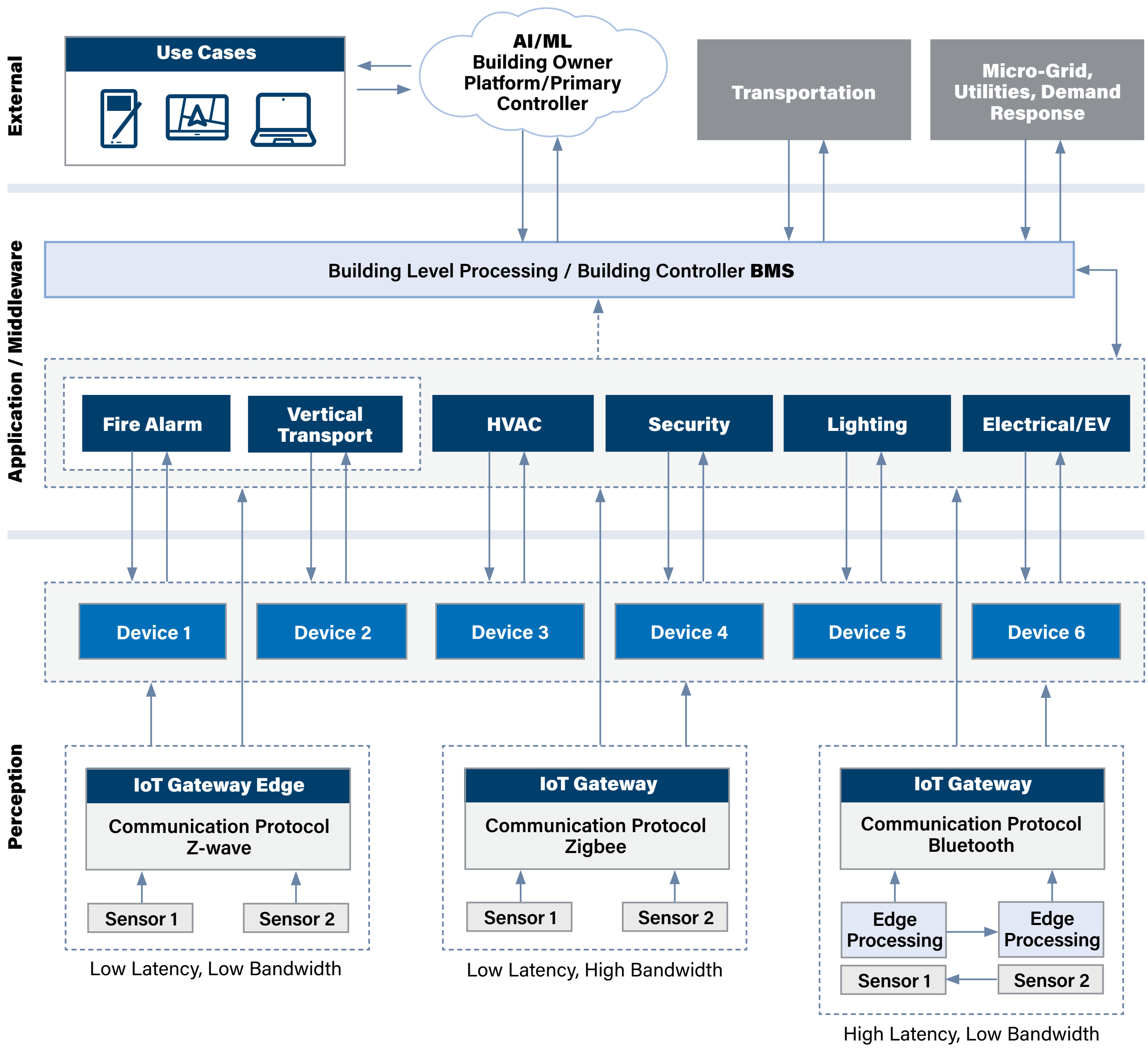
4.2.3 External Layer

The external layer refers to data exchanged with services or entities outside the physical buildings structure. Some connections to the external layer allow for more efficient intelligent building design while other connections to the external layer allow for intelligent buildings to be more responsive external smart grid and smart city signals such as electricity demand response signals from the utility or emergency management directions from a municipality.

Understanding data flow to and from the external layer can help maximize benefits and improve both the operational efficiency and return on investment of intelligent building systems. In both intelligent building layouts presented, cloud computing offers efficiencies by reducing the physical need for data storage and data processing capabilities within the building. However, in this layout, these services are streamlined and secure to enable easily accessible management and storage of businesses data. By collecting all building data in one location and aggregating data from multiple buildings, more potential applications are available. For example, with greater access to data, machine learning and artificial intelligence can be leveraged for holistic solutions.

Intelligent buildings are also expected to be responsive to external smart city or smart grid needs. The external layer allows for data exchange that facilitates this responsiveness. When considering the electricity grid, the BMS would be optimizing building energy use based on the building needs and the operational use case, as well as adjusting these operations based on external system needs such as time -of-use pricing or other demand response signals from the utility. More broadly, smart cities may also interact with intelligent buildings to coordinate the operation of other services, such as smart mobility and transportation services, as highlighted in Figure 2. As the ecosystems of smart city technologies are rapidly evolving, maximizing the design and integration of intelligent buildings with the external layer may require incorporating data sources not considered in current design practice.

Figure 2: Representative potential intelligent building systems future layout



5 Standards Landscape

To this point, standards have not typically been developed to operationalize the concept of intelligent buildings. Rather, a broad range of standards applying to various components, subsystems, and associated technologies have been developed, and these have influenced the design and deployment of intelligent buildings. Through the literature review and the conceptualizations of layouts for current and potential future intelligent buildings, several barriers and expectations for intelligent buildings were defined. With these items in mind, a review of the standards landscape was conducted.

In both the literature review and the standards landscape, challenges, limitations, and gaps to the implementation of intelligent buildings were noted. The landscape analysis included standards associated with specific subsystems, energy efficiency, building automation, IoT, DER, communication protocols, and codes and standards related to building life safety systems, and grid integration. A sample of the standards reviewed can be found in Appendix B. The following section provides insights that might inform intelligent building standards in these categories: communication and interoperability, cybersecurity, regulatory challenges, life safety and building codes, and building-level approach.

5.1 Communication and Interoperability

Interoperability challenges were identified across several subsystems, DER, and grid integration. Data communication is central to the concept of intelligent buildings. To mobilize intelligent buildings that respond—either to occupant and operational needs or to the external layer—will require data exchange. Interoperability challenges limit communication potential across all intelligent building layers and potentially among subsystems within a single layer.

Many standards associated with connected lighting systems highlight interoperability challenges. These systems rely on communications protocols and connectivity to function, and various applicable standards inform connected lighting system design. For example, there are standards to inform PoE lighting systems (IEEE 802.3af, IEEE 802.3at, IEEE 802.3bt), proprietary ethernet lighting systems (IEEE 802.3), and lighting systems with proprietary radio frequency (IEEE 802.15.4). While these standards define physical communication network characteristics—signal frequency, signal strength, cabling configuration, power and data transmission characteristic—these characteristics do not ensure interoperability. This is because connected lighting systems are often software defined. Although standards facilitate physical interoperability, no standards ensure the software is interoperable across vendors. From the vendors' perspective, developing and using proprietary software allows for greater innovation and incentivizes customers retention. Therefore, there are challenges associated with developing interoperability standards for software systems.

To address interoperability challenges, software defined control systems require the use of common protocols. There are several communications protocols that could help facilitate interoperability. Yet, even these protocols, intended to support greater interoperability, require broad deployment to be successful. The capacity for intelligent buildings to facilitate communication across and within layers relies on deploying protocols that can function collectively and integrate with a BMS. From the vendors' perspective, there is limited benefit to pursuing interoperable software. Additionally, redesigning products to operate based on interoperable communication protocols would be a major undertaking. This challenge extends beyond connected lighting systems. Interoperability challenges resulting from proprietary software could impact intelligent buildings more broadly, since many intelligent subsystems and BMSs are software defined, too.

While establishing interoperability across intelligent buildings can be challenging, there are standards that recommend solutions for this issue to varying degrees. For example, IEEE 2030.2.1 guides the design, operation and maintenance of battery energy storage systems. It presents guidelines for battery energy storage system monitoring, controls, and information exchange between the battery system and the grid level supervisory control and data acquisition (SCADA) system. SCADA systems are commonly used by electricity systems operators to monitor various components in the electricity system.

"While establishing interoperability across intelligent buildings can be challenging, there are standards that recommend solutions for this issue to varying degrees."

Communications protocols outlined in this standard allow battery systems to be easily integrated with existing SCADA systems. A high priority for this standard appears to be ensuring the capacity to communicate with existing systems, and this provides an example of how intelligent building standards may pursue interoperability. However, in contrast to electrical system standards where SCADA communication standards are already well defined, there have not been comparable standards published to readily define the existing communication network within an intelligent building.

While IEEE 2030.2.1 integrates battery energy storage systems to existing SCADA systems, this can be costly and is not feasible for the diverse range of IoT being deployed now and in the future [37]. For the purposes of considering intelligent building standards, IEEE 2030.5 offers an important example of how standards can be designed to support interoperability across intelligent building layers. IEEE 2030.5 was developed to use the internet as a communications channel, and helps electricity systems operators manage energy on smart devices. There is a broad range of smart devices addressed by this standard, such as thermostats, water heaters, smart appliances, EV charging infrastructure, and EMSs, among many others. These devices are numerous and widely deployed, therefore, the standard was easily implemented with minimal investment. IEEE 2030.5 relies on internet services, now widely available, as a communication network to facilitate responsiveness of various connected devices.

IEEE 2030.5 is written to allow for flexibility of functions across devices. Overall, it provides electricity grid level operators with greater access to information about devices and their application in their territory, and provides capacity to control these devices within pre-agreed parameters. Thus, IEEE 2030.5 advances interoperability by establishing some basic protocols for data communication across a broad range of devices. Because it relies on the internet as a communication network, it avoids challenges associated with proprietary communications protocols and costly integration required to connect to SCADA systems. Compared to the potential intelligent building systems layout, IEEE 2030.5 allows electricity system operators to connect directly with smart devices within buildings and potentially with BMSs, as well. Enhancing the potential for BMSs in the application layer to be a coordinating intermediary between the external layer electricity system operators and the connected devices within the perception layer would offer a compelling path forward for intelligent building standards.

The ISO-IEC 21823 series offers an alternative approach to enhancing interoperability of multiple devices and systems. This standards series targets IoT applications. As described in Section 3.2.4, IoT holds a diverse range of devices and would include many smart devices addressed in IEEE 2030.5. The IoT continues to increase as electronics that send and receive data are more broadly deployed. Standards in this space must recognize the broad potential application of these technologies. ISO-IEC 21823 proposes a framework for achieving interoperability in the IoT space based on multiple factors (transport, syntactic, semantic, behavioral, and policy) that if addressed will enable interoperability. Depending on context and application, this standard acknowledges different approaches to achieving interoperability across these factors will be required. Rather than prescribing a specific approach to achieve interoperability across IoT, the series presents a high-level framework to support those aiming to deploy interoperable IoT. Given the diverse potential configurations and applications of intelligent buildings, a high-level framework approach, comparable to ISO-IEC 21823, may offer useful lessons developing intelligent building standards.

5.2 Cybersecurity

While data exchange is a key component to establishing intelligent buildings, accessible data and high connectivity across intelligent building layers, including the external layer, creates the potential for cybersecurity risks. Different levels of engagement with cybersecurity issues were identified across the standards reviewed.

When considering connected lighting systems, a number of frameworks, guidelines, and tests have been established for evaluating cybersecurity vulnerability. These can be used to assess the vulnerability of a connected lighting system in part or holistically; however, cybersecurity testing or certification is not mandatory and has not been widely addressed in the existing standards. Given standards have not been established, connected lighting systems on the market have varying levels of vulnerabilities. While there are few current standards in place, cybersecurity is an area of interest for many standards development organizations. It is expected that greater emphasis will be directed at addressing cybersecurity in coming years.

IEEE 2030.5, discussed under Section 5.1, allows electricity system operators to use smart devices as DER to support electricity systems operation. As critical infrastructure, power systems must meet high security requirements. Integrating large numbers of distributed devices creates a wide range of potential vulnerabilities that could impact operation of this critical infrastructure. Therefore, cybersecurity is a major component of IEEE 2030.5 and an important area of work related to DER deployment more generally. The standard relies on common internet communication protocols and defines baseline cybersecurity requirements. Additionally, under IEEE 2030.5, smart devices must meet encryption, authentication, and key management specifications to reduce cybersecurity risks. As far as intelligent buildings will respond to electricity system operators in the external layer, they will interact with critical infrastructure. As such, cybersecurity requirements will need to be emphasized in intelligent building standards development.

5.3 Regulatory Challenges

The conceptualization of potential intelligent buildings presented in this report includes a range of elements: subsystems, systems, associated technologies, and design concepts. When considering intelligent building standards development, regulatory requirements for these various components can vary greatly.

The potential impact of jurisdictional discrepancies on intelligent buildings regulatory requirements was identified as a potential challenge while reviewing energy efficiency standards. Multiple standards outline energy efficiency, as it relates to building design; ASHRAE is a prominent standards development organization related to energy efficiency. Various ASHRAE standards define energy requirements, simulation protocols, and overall goals to achieve an energy efficient building. However, energy efficiency regulations vary across provincial and municipal jurisdictions as authorities have based their energy efficiency requirements on governing regional standards. As a result, many energy efficiency standards suggest best practices but indicate local authorities should be consulted to ensure appropriate requirements are met. For example, ANSI/ASHRAE/IES Standard 90.2-2018, which covers how to develop energy efficient low-rise residential buildings, highlights a design approach but indicates design teams should contact the “Authority Having Jurisdiction” to verify the energy efficiency requirements for a building in the project location.

"Since data exchange is core to intelligent buildings, varying regulations could impact the application of intelligent buildings technologies in different jurisdictions."

Similar variations in jurisdictional requirements can be identified when reviewing DERs interconnections, such as solar generation, EV chargers, or battery systems, which might be incorporated into intelligent building designs. Connecting a building to the electricity system relies on the utility operating in that location. When DER systems are included within a building envelope, specific requirements from the utility for the grid connection may be imposed. Depending on the jurisdiction, utilities may impose varying requirements for DER connection, metering, and operation in their territory. Typically, requirements will depend on the DERs electricity capacity. These thresholds that determine utility requirements may also vary across jurisdictions. Beyond the utility that connects the DER to its distribution system, there may be additional jurisdictional considerations related to the transmission system operator and the provincial electrical system operator, which may be impacted by DER deployment. Generally, requirements from transmission system operators or provincial electricity system operators will only apply to large capacity DERs. However, no defined set of requirements available exists across Canada.

Provincial energy regulators combined with electrical system operators also have requirements for the sale should the DER be exporting to the grid. While a single intelligent building with a DER sized to accommodate the building load may not have any additional requirements, a larger DER designed to service a complex of intelligent buildings, each with its own utility connection, may see many barriers to energy flow between buildings. These barriers relate to ownership, registration requirements, operational control, and monetary transactions for energy flow across the complex of intelligent buildings. Energy regulators have recognized that jurisdictional variation in interconnection requirements currently represents a barrier to DER deployment.

Similarly, there may be jurisdictional implications related to data privacy and data security. Since data exchange is core to intelligent buildings, varying regulations could impact the application of intelligent buildings technologies in different jurisdictions. When exploring the development of intelligent building standards, it is likely these jurisdictional challenges will limit specificity of certain standards components.

5.4 Life Safety and Building Codes

Life safety systems have more explicit codes and standards given their potential safety implications. The existing codes and standards pertaining to the electrical safety for wiring systems within a building are generally covered in the present CSA standards and the Canadian Electrical Code. Additionally, building and fire codes also play an important part in defining the life safety requirements for buildings. Typically, the national and provincial building and fire codes define specific electrical installation requirements and equipment certifications for life safety systems. While these could also be perceived as a potential jurisdictional conflict, no immediate reason suggests they would impact intelligent building standards development.

It is worth considering the extent to which the potential intelligent buildings conceptualization would influence life safety systems. When reviewing the current codes and standards applicable to elevator systems, these focus primarily on ensuring safe, reliable function. Aside from fire alarm systems, which must include a physical interlock to any building elevators, codes and standards associated with elevator systems do not detail communications protocols or specific compatibility protocols for sensors. For sensible reasons, existing life safety systems standards do not prioritize connectivity to the BMS that would facilitate their integration into an intelligent building system. Instead, the focus of these standards is maximizing safety in emergency situations. Standards and codes dictate specific cable types and fire resistance rating for networked fire alarm systems. These requirements are intended to maintain functional systems in a fire event when they are critical.

A comparable approach might also be applied when considering cybersecurity of life safety systems in intelligent buildings. Clearly, cybersecurity will be core to intelligent buildings more broadly, but there is greater importance in ensuring the proper function of these subsystems than other buildings subsystems. Given their importance, higher cybersecurity or system design standards that can ensure proper function of life safety systems in case of a cybersecurity breach should be pursued. When considering future intelligent building standards, there may be some building design priorities, such as occupant safety during emergencies, which should supersede the aim of establishing an intelligent building with full connectivity and responsiveness. While life safety systems offer clear reason for favouring connectivity and responsiveness limits, competing priorities will need to be considered and balanced across the conceptualization of intelligent buildings.

5.5 Building-level Approach

Buildings are complex and have multiple stakeholders in their design, construction, and commissioning. These stakeholders have significant depth of knowledge within their individual areas of expertise. Yet, over the last decade, building design and building subsystem design has become more technologically complex. To the extent that building subsystems are interconnected, building designers must understand interactions across subsystems and at a holistic building-level. Deploying intelligent buildings that meet their potential will require an overall shift in building design philosophies: away from a focus on singular subsystems and towards a holistic, or a system of systems, intelligent building approach.

Based on the existing standards review, the lack of holistic intelligent building standards can be identified in several occurrences. First, definitions and language are inconsistent across standards. Many standards organizations and individual standards use differing terms to describe similar buildings components or subsystems. The variety of terms used to describe various forms of BMSs illustrates this point: CSA/ISO, 50004 refers to EMSs, ISO 16484-1 to building automation and control systems, ISO/IEC 18598 to automated infrastructure management, and ISO-22510:2019 to home and building electronic systems. In practice, some distinctions and overlaps may exist regarding how these systems are defined. However, clarifying definitions could be a first step towards establishing a holistic building-level approach to intelligent building standards.

Second, across a broad range of standards, there was a lack of comment or guidance on communication protocols and connectivity to BMSs. As discussed in Section 5.1, standards for improved interoperability often limit interoperability to a subset of the intelligent building concept. When considering standards associated with DER, such as IEEE 2030.5 and IEEE 2030.2.1 (discussed in Section 5.1), standards priority is ensuring electricity system operator communication, but attention to BMS interoperability is lacking.

A similar pattern was observed in relation to standards associated with EV charging infrastructure (IEEE 2030.1.1). While there are well defined communication protocols between EV chargers and EVs (CAN2.B Active), this standard does not define comparable protocols for EV charger communication with a BMS system. EV chargers rely on vendor software for smart charging and control. The current standards landscape is not well aligned to integrate EV charging within intelligent building energy management and coordination.

It does not appear that standards are being developed to empower BMSs as a core component of intelligent buildings. As conceptualized in Section 4.2, BMSs are expected to be central in coordinating between the application and external layers, and facilitates intelligent buildings as an organization unit. This is because the BMS can balance priorities and responsiveness across intelligent building layers. To some extent, interoperability improvements would address this issue; but, more broadly, these findings indicate a lack of attention to building-scale standards development.

6 Stakeholder Survey

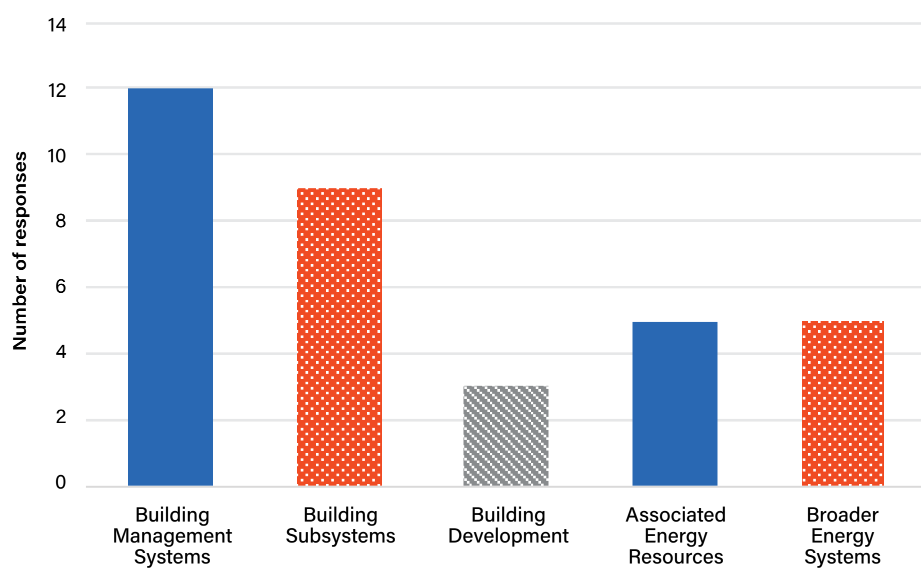
A stakeholder survey was conducted to bolster findings from literature review and standards landscape assessment and provide insights from the perspective of practitioners who develop and apply intelligent building technologies. The online survey was developed to corroborate findings and identify potential areas of further examination.

6.1 Survey Results

The survey was shared with a diverse range of 70 stakeholders across North America in January and February 2021. The survey received a 24% response rate, suggesting a keen interest to engage with this topic from the stakeholders contacted. Participants were asked to indicate which components of intelligent buildings they worked with. Most participants (59%) indicated they worked with multiple components associated with intelligent buildings. Participants were most engaged with building management systems, then building subsystems; however, collectively, participants did offer a broad range of experience across intelligent building components (See Figure 3).

Survey participants perceived a wide range of benefits to intelligent buildings. Environmental and productive/efficiency benefits were the most identified (94%), followed closely by financial benefits (88%). Social benefits were also well-represented, with 59% of participants identification. Responses indicate participants felt there were many benefits associated with intelligent buildings. One participant noted that while many benefits are possible, realizing them depends on implementation and design. Another participant noted there might be different benefits for occupants and building owners. There were also comments noting the high potential for intelligent buildings to stimulate productivity gains, but that these might be more difficult to quantify.

Figure 3: Participants Work Experience



Survey participants consulted standards from a diverse array of standards development organizations; however, ASHRAE was the most noted organization, followed by CSA, and IEEE (See Figure 4).

Based on the previous research in this study, several gaps regarding intelligent buildings were identified. Participants were asked to select the top three gaps they felt needed to be addressed. Integration and interoperability was the most selected (76%) gap. Cybersecurity and siloed systems were the next most selected gaps. However, aside from life safety system integration, all the other identified gaps received between 29% and 41% selections (See Table 1).

Regarding barriers to developing intelligent building standards, participants were asked to select all that applied and provide any additional insight they might have. Cybersecurity was the most identified barrier (76%). Proprietary systems and services, technical barriers, and data ownership were all also identified between 47% - 53%, suggesting these are also barriers of concern for many practitioners. In additional comments about barriers, participants noted potential barriers because systems are becoming more complex and identified tensions that exist "The industry is asking for 'open' but they are also asking for 'secure.' This is a tall ask." The growing complexity of these systems was not a barrier previously identified in the project research. As intelligent building standards are pursued, it will be necessary to consider potential tension between objectives and increasingly complex system integration.

Another shared perspective in the comments about barriers related to using and enhancing awareness of existing standards. One participant felt existing standards simply needed to be adopted more widely, and another participant noted that education was necessary to increase awareness of standards (See Figure 5).

Figure 4: Standards Referenced by Participants Grouped by Standards Development Organization

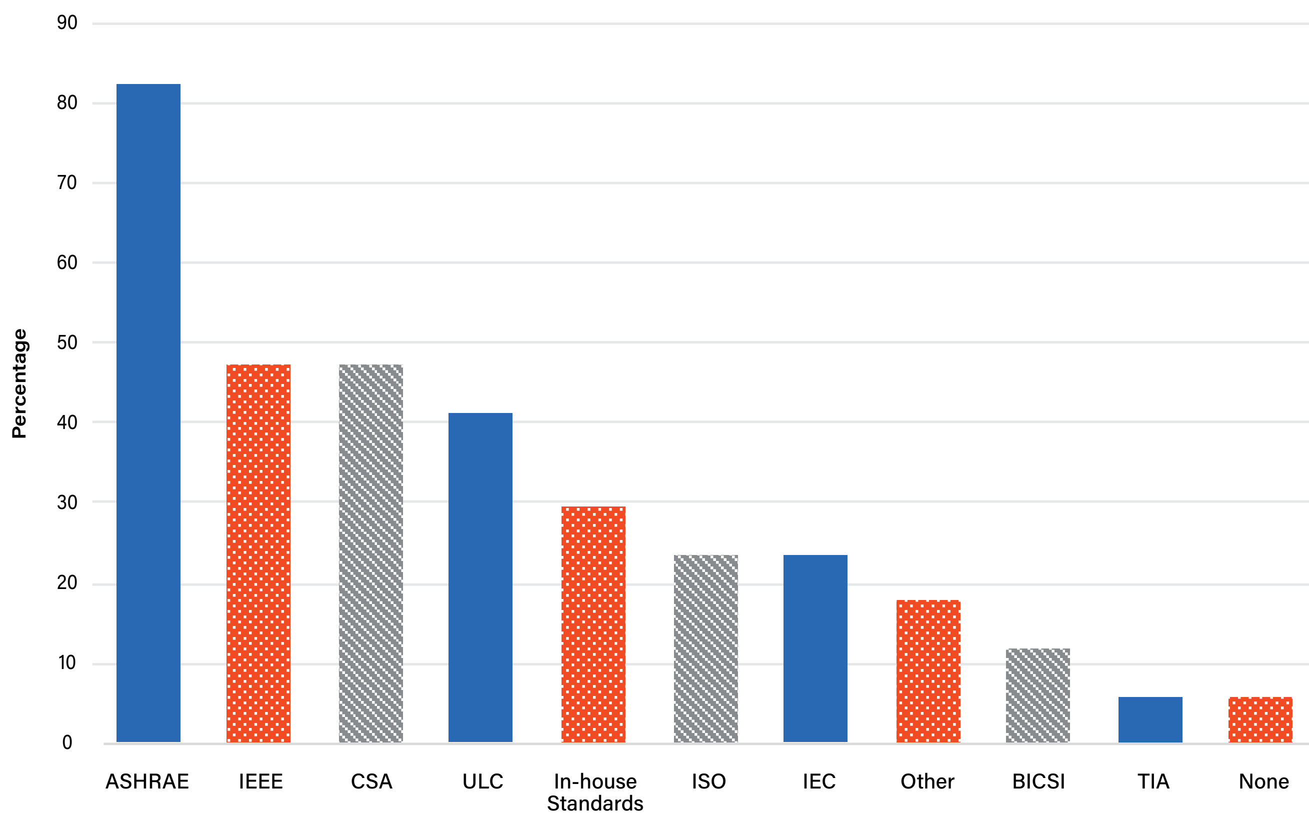
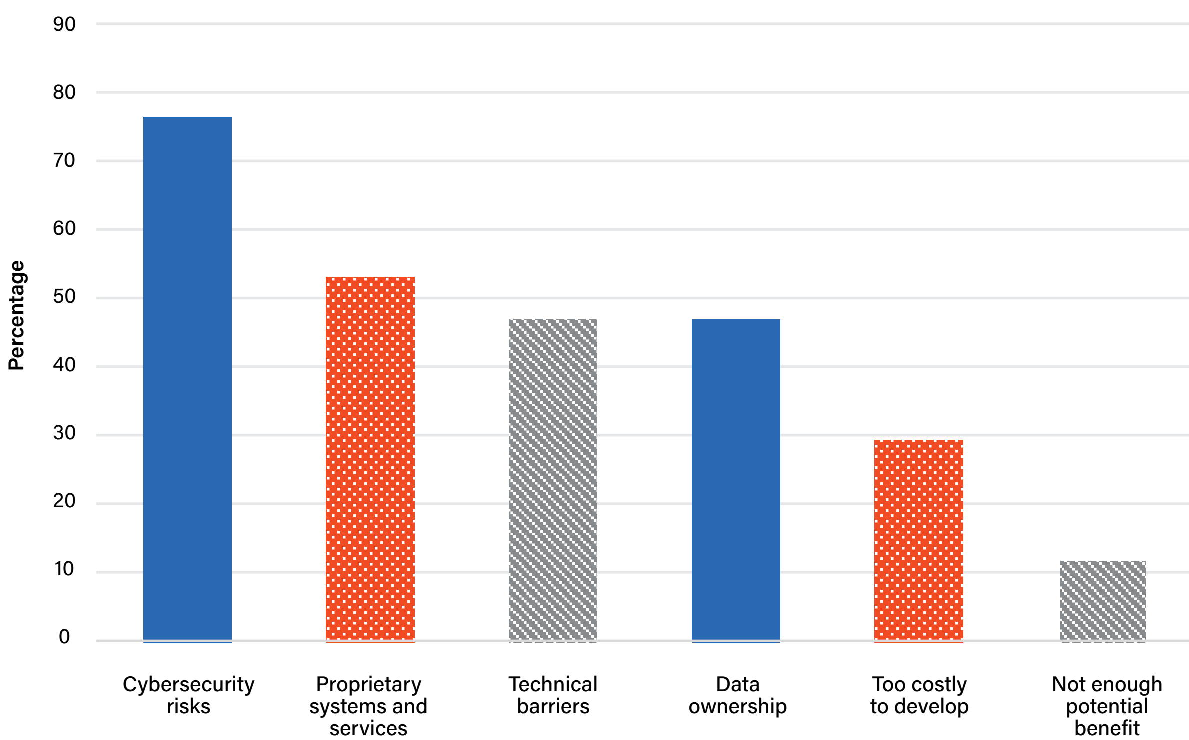


Table 1: Ranked Identified Gaps

Gaps	Ranking	Number of Responses
Integration and Interoperability	1	13
Siloed Systems	2	7
Cybersecurity	2	7
Privacy Protection	3	6
Holistic Intelligent Building Approach	3	6
Legacy/Proprietary Systems	4	5
Distributed Energy Resource Integration	4	5
Life Safety System Integration	5	1

Figure 5: Identified Major Barriers to Intelligent Building Standards Development



Finally, participants were asked about their assessment of developing intelligent building protocols and standards. Overall, 76% of participants were somewhat positive or very positive in their assessment of intelligent building protocols and standards. The remaining 24% were neutral, and no participants noted a negative impression for the project. In their additional comments, participants did make clear that to be successful, this project would depend on the standards eventually developed. Standards were incited to allow creativity and not see all proprietary systems as a negative. One participant noted that intelligent buildings standards might follow standards development in various building subsystems, meaning that building owners continue to have options when considering vendors.

"Any progress towards the development of intelligent buildings standards should incorporate a particular focus on addressing cybersecurity."

7 Findings

7.1 Key Gaps in Standardization

Based on this report's assessment as well as the stakeholder survey feedback, some key gaps regarding intelligent building standards include:

- **Interoperability challenges:** The most commonly identified intelligent buildings standards gap in the stakeholder survey was integration and interoperability. The development and deployment of intelligent buildings has typically been driven by development at the subsystem-level. As various vendors have developed intelligent building technologies, they have created proprietary systems, relying on their own software, and intellectual property, which limits integration across vendor solutions. When multiple subsystem solutions are combined, this can result in redundant systems and lack of interoperability. Without the potential to share of data with and across building layers, the impact of intelligent buildings will be significantly diminished.

Gaps identified in this report offer an initial assessment of the standards needed to support intelligent buildings deployment. Many existing standards reviewed in this report offer potential approaches or insights for addressing these gaps. While interoperability is a major challenge, IEEE 2030.5 and ISO-IEC 21823 offer constructive examples for how standards may respond to this challenge. Building on IEEE 2030.5 to emphasize the role of BMSs to balance external layer and perception layer responsiveness of intelligent buildings seems promising. ISO-IEC 21823 offers an alternative approach; perhaps intelligent buildings standards are better championed through a high-level approach flexible in diverse application contexts.

- **Cybersecurity and privacy concerns:** Intelligent buildings require data collection and sharing about building operations and occupant behaviour. There is a tension between the need to collect and share significant volumes of data to facilitate intelligent building operations and the inherent risk to occupant privacy and creating cybersecurity vulnerabilities. Given it was the most commonly stated barrier to intelligent buildings in the stakeholder survey, cybersecurity should be given particular attention in future standards development processes.

Data generation and sharing are central components of intelligent buildings. Data create the potential for subsystems and buildings to be operated intelligently; however, data generation and sharing also create the potential for cybersecurity and data privacy issues. Cybersecurity has been addressed to varying degrees across existing standards, but there are noted efforts underway by numerous standards committees to engage cybersecurity. Any progress towards the development of intelligent buildings standards should incorporate a particular focus on addressing cybersecurity. Data privacy is a similar yet distinct challenge. The standards landscape review in this report did not identify data privacy related findings. This is an issue for further consideration.

Table 2: Mapping of the Identified Gaps

Gaps identified in intelligent building systems current layout	Layers of potential intelligent building systems future layout	Steps to transition from current to potential intelligent building systems future layout
Interoperability	**Application (Middleware) Layer** The BMS would also act as a single point of communication for coordinating external data exchange rather than having multiple external data exchanges associated with individual subsystems.	Ensuring the capacity to communicate with existing systems. This provides an example of how intelligent buildings standards may pursue interoperability.
Cybersecurity	**External Layer** These (building) services are streamlined and secure to enable easily accessible management and storage of businesses data. By collecting all building data in one location and aggregating data from multiple buildings, more potential applications are available. For example, with greater access to data, machine learning and artificial intelligence can be leveraged for holistic solutions.	The smart devices must meet encryption, authentication, and key management specifications to reduce cybersecurity risks. To the extent that intelligent buildings will be responsive to electricity system operators in the external layer, they will interact with critical infrastructure. As such, cybersecurity requirements will need to be emphasized in intelligent building standards development.
Building-level Approach ▪ EMSs ▪ EV Charging	**Application (Middleware) Layer** BMSs are expected to play a central role of coordinating between the application and external layers, and it facilitates intelligent buildings as a unit of organization. This is because the BMS can balance priorities and responsiveness across intelligent building layers. To some extent, interoperability improvements would address this issue; however, more broadly, these findings indicate a lack of attention to building-scale standards development.	Deploying intelligent buildings that meet their potential will require an overall shift in building design philosophies: away from a focus on singular subsystems and towards a holistic, intelligent building approach, or a system or systems.
Regulatory Challenges	**Application (Middleware) Layer** and **External Layer**	There may be jurisdictional implications related to data privacy and security. Since data exchange is core to intelligent buildings, varying regulations could impact the application of intelligent buildings technologies in different jurisdictions. When exploring the development of intelligent building standards, the jurisdictional challenges should be accommodated while developing the intelligent building systems standard.
Life Safety and Building Codes ▪ Canadian Electrical Code ▪ Fire codes (national and provincial) ▪ Elevators Code	**Application (Middleware) Layer**	When considering future intelligent building standards, there may be some building design priorities, such as occupant safety during emergencies, that should supersede the aim of establishing an intelligent building with full connectivity and responsiveness. While life safety systems offer clear justification for favoring limits to connectivity and responsiveness, considering and balancing competing priorities across the conceptualization of intelligent buildings will be necessary.

- **Lack of building-level focus:** Intelligent buildings are premised on building-level coordination and responsiveness. Most standards currently in-place do not position the building as the unit of focus. Historically, standards have been created to support the application of specific subsystems or associated technologies. As a result, there has been little attention to establishing cross building interactions. Technological innovation has created opportunities to deploy formally unassociated subsystems and associated technologies in new ways. If intelligent buildings are to become an important technology, there needs to be a reorientation in standards that prioritize buildings as an important scale of design.

In the literature review, it was identified that early activities to establish shared definitions encouraged the development of smart grid standards, and this could provide a useful example to guide the process in the intelligent building space. Shared definitions might improve the capacity for stakeholder collaboration and enhance the potential for a building-level focus to emerge.

- **Lack of consistent definitions:** The intelligent buildings sector continues to evolve. As new technologies and social expectations progress, the definition of intelligent buildings changes. From a practical standpoint, this means that various stakeholders hold differing definitions and expectations for what intelligent buildings are and how they should operate. Intelligent buildings require communication among various stakeholders and the development of shared definitions offers a means to advance collaboration to this end.

7.2 Mapping of the Identified Gaps to Current and Future States

Based on the combined findings of this research, Table 2 maps the layers and connections between the current and potential intelligent building systems layouts presented in Figures 1 and 2.

The table summarizes the overall gaps in the intelligent buildings based on findings from the literature and validated by the stakeholder survey. It also positions these challenges to the specific layers of potential intelligent building systems and identifies suggested steps to transition from current state of intelligent buildings to future or potential intelligent building systems. Hence, the table provides a holistic view of the findings from the research.

8 Conclusion and Recommendations

The research first identified the current ecosystem of intelligent buildings and, based on the literature review, conceptual layout of the current state and potential future state of intelligent buildings were developed. It was followed by a standards landscape review to identify gaps in standardization, and a stakeholder survey was conducted to validate findings.

Finally, the potential layout of intelligent buildings was used as a starting point to address research findings by mapping current layout gaps (Figure 1) to the future layout (Figure 2) and to provide the suggested steps to transition from current to future state.

The following standards development activities are recommended to help support the deployment of intelligent buildings:

1. **Identifying concurrent intelligent building initiatives:** There may be international standards committees currently developing intelligent building standards. Leveraging standards efforts from other organizations or supporting work in-progress could add value. It will remain important to advance intelligent building standards that reflect the Canadian context, but international efforts may be able to inform this process.
2. **Develop consistent intelligent building terminology standard:** There is currently a wide range of terminology for describing various components, subsystems, and related technology associated with intelligent buildings. Across this terminology, there is some overlap as well as conflict. Establishing common language and definitions for intelligent building components would be a helpful project. Intelligent buildings will require collaboration to deploy, and facilitating effective communication across stakeholders seems a valuable endeavor towards that end.

3. **Establish stakeholder advisory committees and working groups:** Assuming adoption of the multi-layer conceptualization of intelligent buildings presented in this report, developing intelligent building standards will require working groups spanning multiple areas of expertise and diverse stakeholder groups. Besides working across building subsystems, it will be necessary to remain engaged with stakeholders representing the various layers of intelligent buildings. A few key challenges have been identified in this report: interoperability of intelligent buildings, cybersecurity, and data privacy. Given the different characteristics of these challenges and the potentially varied impact distinct stakeholders, it may be useful to engage with these challenges in distinct working groups.

4. **Develop intelligent building case studies:** Intelligent building technologies are already being deployed to varying degrees. As explored in this study, the definition of intelligent buildings continues to evolve. A case studies series might offer useful knowledge regarding the state of practice in Canada. A range of case studies exploring different applications of intelligent building technologies could highlight the drivers for owners and developers of intelligent buildings and offer some insights into how this sector is developing.

5. **Advance the role of intelligent buildings in smart cities:** Smart cities involve data and information sharing across numerous systems to improve livability for residents. Intelligent buildings are an important unit in smart cities. Developing intelligent buildings able to integrate with the external layer is important to improving outcomes for smart cities. As policy and standards develop in the smart city space, there should be engagement to understand the role of buildings and how they can support larger scale objectives. This may involve requirements to support integration with energy technologies, such as microgrids, demand response, and EV charging. But, it could also extend to data sharing to broader systems that make up smart cities: enhanced transportation systems, water systems, and information systems. The degree and extent to which intelligent buildings will interact and share data with the external layer remains to be seen and will likely take different paths in different geographic contexts.

References

[1] A. Pride, "Information and communication technology infrastructure (ICTi) in buildings," Canadian Standards Association, Toronto, ON, 2020. [Online]. Available: https://www.csagroup.org/article/research/information-and-communication-technology-infrastructure-icti-in-buildings/

[2] A. Pride, "DC microgrids in buildings: Planning today for tomorrow's needs," Canadian Standards Association, Toronto, ON, 2020. [Online]. Available: https://www.csagroup.org/article/research/dc-microgrids-in-buildings-planning-today-for-tomorrows-needs/

[3] A. H. Buckman, M. Mayfield, and S. B. M. Beck, "What is a smart building?," *Autom. Constr.,* vol. 3, no. 2, pp. 92–109, 2014, https://doi.org/10.1108/SASBE-01-2014-0003.

[4] K. W. J. Wong, H. Li, and S. W. Wang, "Intelligent building research: A review," *Autom. Con,* vol. 14, no. 1, pp. 143–159, 2005, https://doi.org/10.1016/j.autcon.2004.06.001.

[5] A. Ghaffarianhoseini, U. Berardi, H. Alwaer, E. Halawa, A. Ghaffarianhoseini, and D. Clements-croome, "What is an intelligent building? Analysis of recent interpretations from an international perspective," *Archit. Sci. Rev.,* vol. 59, no. 5, pp. 338–357, 2016, https://doi.org/10.1080/00038628.2015.1079164.

[6] J. A. Powell, "Intelligent design teams design intelligent buildings," *Habitat Int.,* vol. 14, no. 2/3, pp. 83–94, 1990, https://doi.org/10.1016/0197-3975(90)90038-3.

[7] SEPA, "Beyond the meter: Distributed energy resources capabilities guide," 2016. [Online] Available: https://sepapower.org/resource/distributed-energy-resources-capabilities-guide/

[8] T. M. Lawrence et al., "Ten questions concerning integrating smart buildings into the smart grid," *Build. Environ.,* vol. 108, pp. 273–283, 2016, https://doi.org/10.1016/j.buildenv.2016.08.022.

[9] J. Al Dakheel, C. Del Pero, N. Aste, and F. Leonforte, "Smart buildings features and key performance indicators: A review," *Sustain. Cities Soc.*, vol. 61, no. June, p. 102328, 2020, https://doi.org/10.1016/j.scs.2020.102328.

[10] Smithsonian Institute, "Lutron electronics donates company history to National Museum of American History," 2010. [Online]. Available: https://americanhistory.si.edu/press/releases/lutron-electronics-donates-company-history-national-museum-american-history

[11] Pacific Northwest National Laboratory, "Let there be (connected) light," *PNNL News & Media Relations,* 2017. [Online]. Available: https://www.pnnl.gov/news/release.aspx?id=4461. [Accessed: Nov. 8, 2021].

[12] S. Lee and P. Karava, "Towards smart buildings with self-tuned indoor thermal environments – A critical review," *Energy Build.,* vol. 224, p. 110172, 2020, https://doi.org/10.1016/j.enbuild.2020.110172.

[13] R. Z. Homod, "Analysis and optimization of HVAC control systems based on energy and performance considerations for smart buildings," *Renew. Energy, vol.* 126, pp. 49–64, 2018, https://doi.org/10.1016/j.renene.2018.03.022.

[14] M. Gholamzadehmir, C. Del, S. Buffa, R. Fedrizzi, and N. Aste, "Adaptive-predictive control strategy for HVAC systems in smart buildings – A review," *Sustain. Cities Soc.*, vol. 63, no. November 2019, p. 102480, 2020, https://doi.org/10.1016/j.scs.2020.102480.

[15] M. M. Mazar and A. Rezaeizadeh, "Adaptive model predictive climate control of multi-unit buildings using weather forecast data," *J. Build. Eng.,* vol. 32, pp. 1–9, 2020, https://doi.org/10.1016/j.jobe.2020.101449.

[16] J. Horn, A. Koohang, and J. Paliszkiewicz, "The Internet of Things: Review and theoretical framework," *Expert Syst. Appl.,* vol. 133, pp. 97–108, 2019, https://doi.org/10.1016/j.eswa.2019.05.014.

[17] F. Zafari, I. Papapanagiotou, and K. Christidis, "Microlocation for Internet-of-Things-Equipped Smart Buildings," *IEEE Internet of Things Journal,* vol. 3, no. 1, pp. 96–112, 2016, https://doi.org/10.1109/JIOT.2015.2442956.

[18] M. Jia, A. Komeily, Y. Wang, and R. S. Srinivasan, "Adopting Internet of Things for the development of smart buildings : A review of enabling technologies and applications," *Autom. Constr.,* vol. 101, no. July 2018, pp. 111–126, 2019, https://doi.org/10.1016/j.autcon.2019.01.023.

[19] A. Verma, S. Prakash, V. Srivastava, A. Kumar, S. Member, and S. C. Mukhopadhyay, "Sensing , controlling , and IoT infrastructure in smart building: A Review," *IEEE Sensors Journal,* vol. 19, no. 20, pp. 9036–9046, 2019, https://doi.org/10.1109/JSEN.2019.2922409.

[20] S. Seneviratne et al., "A survey of wearable devices and challenges," *IEEE Communications Surveys and Tutorials,* vol. 19, no. 4, pp. 2573–2620, 2017, https://doi.org/10.1109/COMST.2017.2731979.

[21] IEA, "Energy transitions indicators," *IEA,* 2019. [Online]. Available: https://www.iea.org/articles/energy-transitions-indicators [Accessed: Nov. 8, 2021].

[22] IRENA, "Global energy transformation: A roadmap to 2050," *IRENA,* 2018. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf [Accessed: Nov. 8, 2021].

[23] G. Lilis, G. Conus, N. Asadi, and M. Kayal, "Towards the next generation of intelligent building: An assessment study of current automation and future IoT based systems with a proposal for transitional design," *Sustain. Cities Soc.,* vol. 28, pp. 473–481, 2017, https://doi.org/10.1016/j.scs.2016.08.019.

[24] G. R. Barai, S. Krishnan, and B. Venkatesh, "Smart metering and functionalities of smart meters in smart grid," In Proc. 2015 IEEE Electrical Power and Energy Conference (EPEC), pp. 138–145.

[25] W. J. N. Turner, I. S. Walker, and J. Roux, "Peak load reductions: Electric load shifting with mechanical pre-cooling of residential buildings with low thermal mass," *Energy,* vol. 82, pp. 1057–1067, 2015, https://doi.org/10.1016/j.energy.2015.02.011.

[26] P. Stluka, "Automated demand response for smart buildings and microgrids: The state of the practice and research challenges," *Proceedings of the IEEE,* vol. 104, no. 4, pp. 1–19, 2016, https://doi.org/10.1109/JPROC.2016.2520639.

[27] Y. Zhao et al., "Artificial intelligence-based fault detection and diagnosis methods for building energy systems: Advantages, challenges and the future," *Renew. Sustain. Energy Rev.,* vol. 109, no. November 2018, pp. 85–101, 2019, https://doi.org/10.1016/j.rser.2019.04.021.

[28] S. Venticinque and A. Amato, *Smart Sensor and Big Data Security and Resilience,* 1st ed., no. 2015. Elsevier Inc., 2017.

[29] R. Khatoun and S. Zeadally, "Cybersecurity and privacy solutions in smart cities," *IEEE Commun. Mag.,* vol. 55, no. 3, pp. 51–59, 2017, https://doi.org/10.1109/MCOM.2017.1600297CM. [Abstract].

[30] P. Pappachan et al., "Towards privacy-aware smart buildings: Capturing, communicating, and enforcing privacy policies and preferences," Proc. – *IEEE 37th Int. Conf. Distrib. Comput. Syst. Work. ICDCSW 2017,* pp. 193–198, 2017, https://doi.org/10.1109/ICDCSW.2017.52.

[31] K. El Makkaoui, A. Ezzati, A. Beni-Hssane, and C. Motamed, "Cloud security and privacy model for providing secure cloud services," *Proc. 2016 Int. Conf. Cloud Comput. Technol. Appl. CloudTech 2016,* pp. 81–86, 2017, https://doi.org/10.1109/CloudTech.2016.7847682.

[32] L. CLoud Strategy Partners, "Cloud computing definition, reference architecture, and general use cases," IEEE, 2014.

[33] C. Dyess, "Maintaining a balance between agility and security in the cloud," *Netw. Secur.,* vol. 2020, no. 3, pp. 14–17, 2020, https://doi.org/10.1016/S1353-4858(20)30031-3.

[34] P. Sun, "Security and privacy protection in cloud computing: Discussions and challenges," *J. Netw. Comput. Appl.,* vol. 160, no. March, p. 102642, 2020, https://doi.org/10.1016/j.jnca.2020.102642.

[35] W. Shi, G. Pallis, and Z. Xu, "Edge Computing," *Proc. IEEE,* vol. 107, no. 8, pp. 1474–1481, 2019, https://doi.org/10.1109/JPROC.2019.2928287.

[36] M. Poplawski, A. St. Lawrence, and H. Ngo, "An authentication vulnerability assessment of connected lighting systems," *Pacific Northwest National Laboratory,* 2020, https://doi.org/10.2172/1618038

[37] F. Wauquiez, "IEEE 2030.5 – Connect to the wide world of distributed energy resources," *Energy Source & Distribution,* 2020. [Online]. Available: https://esdnews.com.au/ieee-2030-5-connect-to-the-wide-world-of-distributed-energy-resources/ [Accessed Mar. 25, 2021].

Appendix A – Stakeholder Survey Questionnaire

1. Briefly list your title and area of work?

2. Which intelligent building component(s) do you work with? Select all that apply

- **i.** Building subsystems – Develop or install subsystem or hardware for building subsystems, like fire, elevator, security, lighting, electricity systems for building
- **ii.** Building development – Design and development of whole buildings, such as architect, or building developer
- **iii.** Building management systems – Develop or install building or energy management systems
- **iv.** Associated energy resources – Develop or install energy resources, such as solar PV, CHP, energy storage, EV charging
- **v.** Broader energy system – Utility representative, electricity system operator, microgrid developer
- **vi.** Other – Please describe: ____

3. In your experience, what (if any) are the biggest benefits seen from implementing intelligent building technologies? (Mark all that apply)

- **i.** None
- **ii.** Financial
- **iii.** Social
- **iv.** Environmental
- **v.** Productivity/Efficiency
- **vi.** Other

Please feel free to share any additional thoughts:

4. Which standard organization do you reference when implementing intelligent building technologies? (Mark all that apply)

- **i.** None
- **ii.** ASHRAE
- **iii.** BICSI
- **iv.** CSA
- **v.** IEC
- **vi.** IEEE

vii. ISO

viii. TIA

ix. ULC

x. In-house developed standards

xi. Other

If Other, which standard organization do you reference?

Follow up: Which specific standards do you rely on?

5. Of the identified smart building standardization gaps described below, which do you consider the most important to address? (select up to 3)

   i. Siloed systems – Building subsystems and energy resources are currently designed and operated individually.

   ii. Integration and interoperability – Subsystems are not designed to communicate and share data or coordinate across intelligent buildings.

   iii. Legacy/proprietary systems – Certain subsystems rely on legacy or proprietary communications protocols that limit their potential integration into intelligent building systems.

   iv. Cybersecurity – There are few established cybersecurity standards that are tailored to intelligent buildings. Each manufacturer is responsible for their own product. Therefore, security across the intelligent building is dependent on the variety of components included.

   v. Privacy protection – Intelligent buildings will generate significant amounts of potentially sensitive data; there are no consistent privacy standards.

   vi. Holistic intelligent building approach – Multiple standards apply to various components within intelligent buildings, but there are no standards that deal with intelligent buildings in their entirety.

   vii. Life Safety System Integration – There is a lack of intercommunication standards between life safety systems (e.g., fire alarm, elevator, door safety).

   viii. Distributed energy resource integration – There is a lack of standards for energy management system and building management systems to integrate associated distributed energy resources (e.g., solar PV, EV charging).

   Based on your experience, are there other gaps that should be considered?

   - Yes
   - No
   - Unsure
   - Please share any additional thoughts: ____

6. What potential barriers or challenges do you see regarding developing Intelligent Building standards and protocols? (select all that you believe are important to consider)

i. Too costly to develop

ii. Not enough potential benefit

iii. Proprietary systems and services

iv. Cybersecurity risks

v. Technical barriers

vi. Data ownership

Please share any additional thoughts: ____

7. Rate your assessment of developing Intelligent Building protocols and standards?

- Very negative – Intelligent Building protocols and standards are not needed or would be problematic
- Somewhat negative – Intelligent Building protocols and standards are unlikely to be beneficial
- Neutral – It would depend on the Intelligent Building protocols and standards developed
- Somewhat positive – Intelligent Building protocols and standards would likely be a net benefit
- Very positive – Intelligent Building protocols and standards are highly needed and would be beneficial
- Unsure/no response – I don't feel I have enough information, or I don't have an opinion

Please share any additional thoughts: ____

8. Are there any additional points regarding Intelligent Building protocols and standards that you would like to share? ____

Appendix B – List of Standards

Table 3: List of Standards

Category	Organization	Standard #	Year	Title/Description
BMS	ISO	16484-1	2010	Building automation and control systems (BACS) — Part 1: project specification and implementation
	ISO	16484-2	2004	Building automation and control systems (BACS) — Part 2: Hardware
	ISO	16484-3	2005	Building automation and control systems (BACS) — Part 3: Functions
	ISO	16484-5	2017	Building automation and control systems (BACS) — Part 5: Data communication protocol
	AVIXA	TR-111	2019	Unified automation for buildings
Cybersecurity	CSA	EXP200	2019	Evaluation of software development and cybersecurity programs
Energy/ Communication	IEEE	1547	2018	Standard for distributed energy resources with electrical power systems
	IEEE	2030.1	2015	Guide for design, operation and maintenance of battery energy storage systems, both stationary and mobile and applications integrated with electric power systems
	IEEE	2030.5	2018	Standard for smart energy profile application protocol
	CSA/ISO	50004	2014	Energy management system
	IEEE	2030.2.1	2019	Guide for design, operation and maintenance of battery energy storage systems, both stationary and mobile and applications integrated with electric power systems
	IEC	62351-3	2020	Power systems management and associated information exchange – Data and communications security
Energy/ Electrical	CSA	22.2	2018	Industrial control equipment
	CSA	22.3	2020	Interconnection of distributed energy resources and electricity supply systems
	ASHRAE	90.1	2019	Energy standard for building (except low-rise residential building)
	ASHRAE	90.2	2018	Energy efficiency design of low-rise residential building
	ASHRAE	189.1	2019	Standard of the design high performance green building (except low-rise building)
	ASHRAE	201	2016	Facility smart grid information model
	ASHRAE	209	2019	New energy modeling framework for building design
	CSA	381.2	2017	Energy performance of battery-charging systems and uninterruptible power supplies
	CSA	812	2016	Energy performance of large battery charger systems
	IEEE	937	2020	Recommended practice for installation and maintenance of lead-acid batteries for photovoltaic (PV) systems
	IEEE	1377	2012	Standard for utility industry metering

Category	Organization	Standard #	Year	Title/Description
Energy/ Electrical	IEEE	1547.2	2009	Application guide for IEEE Std 1547™, IEEE standard for interconnecting distributed resources with electric power systems
	IEEE	1679	2020	Recommended practice for the characterization and evaluation of energy storage technologies in stationary applications
	ISO/TS	50008	2018	Energy management and energy savings — Building energy data management for energy performance — Guidance for a systemic data exchange approach
	IEC	61557	2019	Electrical safety in low voltage distribution systems up to 1000 V AC and 1500 V DC
	IEC	61724	2017	Photovoltaic system performance: Monitoring
	IEC	61730	2016	Photovoltaic (PV) module safety qualification
	IEEE	2030.1.1	2016	Standard technical specifications of a DC quick charger for use with electric vehicles
Fire Alarm	CSA/ULC	S524	2019	Installation of fire alarm
	CSA/ ULC	S527	2019	Standard for control units of fire alarm systems
	CSA/ULC	S573	2018	Standard for ancillary devices of fire alarm
Fire System	CAN/ULC	524 (Ed. 7)	2019	Installation of fire systems
	CAN/ULC	525 (Ed. 4)	2016	Audible signal devices for fire alarm systems, including accessories
	CAN/ULC	526 (Ed. 4)	2016	Visible devices for fire alarm systems, including accessories
	CAN/ULC	529 (Ed. 4)	2016	Smoke detectors for fire alarm systems
	CAN/ULC	533 (Ed. 4)	2015	Egress door securing & releasing devices
	CAN/ULC	536 (Ed. 6)	2019	Inspection & testing of fire alarm systems
	CAN/ULC	561 (Ed. 3)	2020	Installation and services for fire signal receiving center and systems
HVAC System	ASHRAE	55	2017	Thermal comfort
	ASHRAE	62.1	2019	Ventilation and air quality
IOT/ Communication	ASHRAE	135	2019	BACNET — A data communication protocol for building automation and control networks
	IEEE	1775	2011	Standard for power line communication
	IEEE	1815	2012	Standard for electric power systems communications — Distributed Network Protocol (DNP3)
	IEEE	1855	2016	Fuzzy markup language
	IEEE	1888	2014	Addressing ubiquitous green community control networks
	IEEE	2011	2010	Broadband over powerline networks
	CAN/ULC	2525	2020	Two-way Emergency communications systems for rescue assistance

Category	Organization	Standard #	Year	Title/Description
IOT/ Communication	IEEE	12207	2017	IT– software life-cycle processes
	ISO/IEC	14762	2009	Information technology — Functional safety requirements for Home and Building Electronic Systems (HBES)
	ISO/IEC	18598	2016	Information technology — Automated infrastructure management (AIM) systems — Requirements, data exchange and applications
	ISO	22510	2019	Open data communication in building automation, controls and building management — Home and building electronic systems — KNXnet/IP communication
	IEC	61757	2018	Fiber optic sensors
	IEC	62481	2017	Digital Living Network Alliance (DLNA) home networked device interoperability guidelines
	ANSI/BICSI	007	2020	Information communication technology design and implementation practices for intelligent buildings and premises
	ISO/IEC	21823-1	2019	Internet of things (IoT) — Interoperability for IoT systems — Part 1: Framework
	ISO/IEC	21823-2	2020	Internet of things (IoT) — Interoperability for IoT systems — Part 2: Transport interoperability
	ISO/IEC	24775-1	2014	Information technology — Storage management
	IEEE	802.15.3	2017	High data rate wireless multi-media networks
	IEEE	802.15.4	2019	Low-Rate wireless network
	IEEE	P1451-99	2016	Harmonization and security of IoT
	IEEE	P2413	2016	Architectural framework:
	IEEE	P2510	2017	Defines quality measures, controls, parameters, and definitions for sensor data related to Internet of Things (IoT) implementations.
	ISO/IEC	TR 14543-4	2002	Information technology — Home Electronic System (HES) architecture — Part 4: Home and building automation in a mixed-use building
Lighting System	IEC	62384	2020	AC or DC supplied electronic control gear for LED modules – Performance requirements
	IEC	62386	2018	Digital addressable lighting interface
Safety/ Communication	CAN/ULC	576 (Ed. 2)	2019	Mass notification systems

Category	Organization	Standard #	Year	Title/Description
Security System	IEC	60839	2016	Alarm and electronic security systems
	CAN/	2030.1	2015	Guide for design, operation and maintenance of battery energy storage systems, both stationary and mobile and applications integrated with electric power systems
	CAN/CSA-IEC	62443-4-1	2018	Security for industrial automation and control systems – secure development lifecycle requirements
	CAN/CSA-IEC	62443-4-2	2019	Security for industrial automation and control systems – IACS components security specifications
Vertical Transportation	ASME	A17.1	2019	Safety code for elevators and escalators
	CSA/ASME	B44:1:19/A17.5	2019	Electrical equipment details of elevator
	CSA/ ASME	B44:19/A17.1	2019	Structural and mechanical safety details of elevator

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

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