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Buildings Interoperability Landscape

December 2015

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U.S. DEPARTMENT OF ENERGY

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

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Richland, Washington 99352

Executive Summary

Buildings are an integral part of our nation's energy economy. Advancements in information and communications technology (ICT) have revolutionized energy management in industrial facilities and large commercial buildings. As ICT costs decrease and capabilities increase, buildings automation and energy management features are transforming the small-medium commercial and residential buildings sectors. A vision is emerging of a connected world in which building equipment and systems coordinate with each other to efficiently meet their owners' and occupants' needs and buildings regularly transact business with other buildings and service providers (e.g., gas and electric service providers). However, while the technology to support this collaboration has been demonstrated at various degrees of maturity, the integration frameworks and ecosystems of products that support the ability to easily install, maintain, and evolve building systems and their equipment components are struggling to nurture the fledging business propositions of their proponents.

Through its Building Technologies Office (BTO), the United States Department of Energy's Office of Energy Efficiency and Renewable Energy (DOE-EERE) is sponsoring an effort to advance interoperability for the integration of intelligent buildings equipment and automation systems, understanding the importance of integration frameworks and product ecosystems to this cause. This is important to BTO's mission to enhance energy efficiency and save energy for economic and environmental purposes. For connected buildings ecosystems of products and services from various manufacturers to flourish, the ICT aspects of the equipment need to integrate and operate simply and reliably. Within the concepts of interoperability lie the specification, development, and certification of equipment with standards-based interfaces that connect and work. Beyond this, a healthy community of stakeholders that contribute to and use interoperability work products must be developed. On May 1, 2014, the DOE convened a technical meeting[1] to take stock of the current state of interoperability of connected equipment and systems in buildings. Several insights from that meeting helped facilitate a draft description of the landscape of interoperability for connected buildings, which focuses mainly on small and medium commercial buildings.

The draft document, released in February 2015, provided context for the Buildings Interoperability Vision technical meeting DOE held March 11 and 12, 2015. The discussions from that meeting reviewed the state of buildings interoperability and explored future integration scenarios and desired interoperability characteristics that would support visionary directions for connected buildings. Comments were also solicited from reviewers of the draft document. This document revises the February 2015 landscape document to address reviewer comments, incorporate important insights from the Buildings Interoperability Vision technical meeting, and capture thoughts from that meeting about the topics to be addressed in a buildings interoperability vision. In particular, greater attention is paid to the state of information modeling in buildings and the great potential for near-term benefits in this area from progress and community alignment.

To help describe this complicated landscape, a framework for buildings interoperability has been created (see Figure ES.1). This framework borrows from existing work from the GridWise Architecture Council; American Society of Heating, Refrigerating, and Air-Conditioning Engineers' automation model; and the National Institute of Standards and Technology's smart grid conceptual model. This framework adapts that material to emphasize a buildings-centric perspective. The scope of the landscape covers the interactions within buildings operations, between communities of buildings, with building service

[1] http://energy.gov/eere/buildings/downloads/technical-meeting-datacommunication-standards-and-interoperability-building

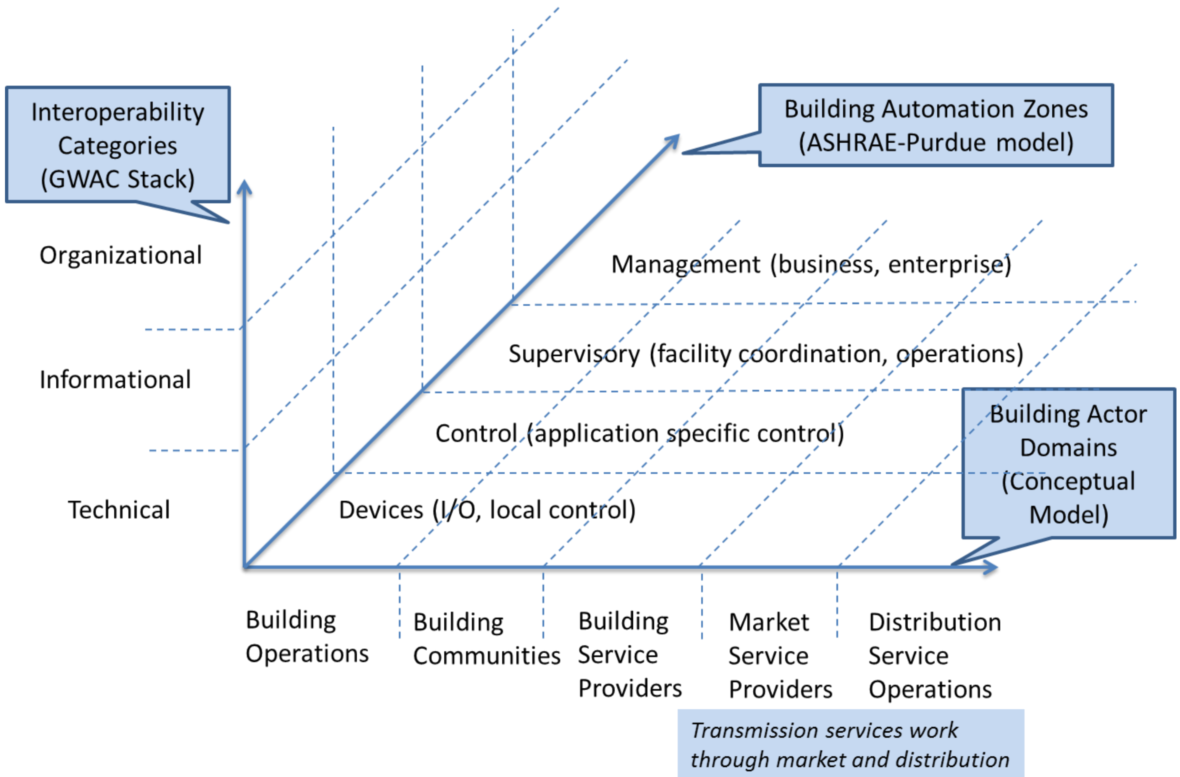

Figure ES.1. Buildings Interoperability Framework

providers, with market service providers (e.g., energy markets), and with energy distribution service operators. The framework is used to discuss (1) use case scenarios that describe these interactions; (2) existing standards used to advance interoperability to support the use case scenarios; and (3) the stakeholder community (organizations) influencing the advancement of interoperability standards, testing, and technology deployment.

While the landscape for connected buildings interoperability is indeed complex, the state of the art for integrating connected equipment is advancing quickly. Machine-to-Machine communication initiatives are developing new approaches for integration, Business-to-Business initiatives are offering progressive approaches to transact business once connected, and Internet-of-Things concepts are aligning people and companies toward ecosystems that support ease of system integration. These emerging ICT concepts and tools contribute to the imagination of new approaches for connected buildings interoperability. By capturing the attributes of interoperability desired to support the identified use cases, the connected buildings community can develop a set of requirements for interoperability as this marketplace matures. This landscape document attempts to set the stage with the current state of interoperability for connected buildings and outlines an initial list of requirements to be addressed going forward. In addition, it provides a summary of emerging ICT concepts that could advance interoperability for connected buildings and lays a foundation for developing a vision for buildings interoperability.

To encourage vibrant product ecosystems for connected buildings in the future, a series of meetings is proposed with the objective of developing a roadmap of activities that advance connected buildings interoperability. This landscape document is designed to provide context and provoke thinking for that discussion. Engaging attendees representing a variety of stakeholder perspectives should facilitate the discovery of the common characteristics that align the community on substantive directions toward the achievement of interoperability objectives.

Acknowledgments

This document reflects the valuable feedback and insights provided by buildings and connected equipment integration experts who attended a Buildings Interoperability Vision Technical Meeting in Seattle in March 2015 (DOE 2015b). The attendees represented a broad variety of individuals from technology and service suppliers, systems operators, academia, and government. The authors are grateful for the time and energy they contributed to articulate their perspectives. In addition, we are particularly appreciative of the comments from the reviews we received on the draft version of this document provided by James Mater, Bruce Nordman, and Allen Jones. Lastly, we wish to recognize Joe Hagerman, Rob Pratt, and Andrew Nichols for their guidance and encouragement.

Acronyms and Abbreviations

AEC	architecting, engineering, and constructing
AMI	automated metering infrastructure
ANSI	American National Standards Institute
API	application programming interface
AS	ancillary services
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BACS	building automation and control system
BCHP	building-cooling-heating-power
BIM	Buildings Information Model
BO	building owner
BPM	Business Process Modeling
BSP	building service provider
BTO	Building Technologies Office
C&I	commercial and industrial
CBIM	Connected Building Information Model
CE	configuration and evolution
CEA	Consumer Electronics Association
CEM	customer energy manager
CIM	Common Information Model
CSV	comma-separated values
DALI	Digital Addressable Lighting Interface
DER	distributed energy resource
DG	distributed generation
DLNA	Digital Living Network Alliance
DNS	Domain Name System
DOE	U.S. Department of Energy
DR	demand response
DS	distributed storage
DSO	distribution service operations
DSI	Digital Serial Interface
EEIM	Enterprise Energy Information Management
EESCC	Energy Efficiency Standards Coordination Collaborative
EHS	European Home Systems
EIA	Energy Information Administration
EIB	European Installation Bus
EIS	Energy Information Standards
EPC	Event-Driven Process Chains
ERP	Enterprise Resource Planning

ESI	energy services interface
ESPI	Energy Services Provider Interface
EV	electric vehicle
FDLIR	fault detection, location, isolation, and reconfiguration
FTP	File Transfer Protocol
GUID	globally unique identifier
GWAC	GridWise Architecture Council
HAN	Home Area Network
HVAC	heating, ventilation, and air conditioning
ICT	information and communications technology
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IFD	International Framework for Dictionaries
IMM	Interoperability Maturity Model
IoT	Internet-of-Things
IP	Internet protocols
JSON	JavaScript Object Notation
LOV	Linked Open Vocabularies
MVC	model view controller
NIST	National Institute of Standards and Technology
NZE	Net Zero Energy
O&M	operations and maintenance
OBIS	object identification system
OP	operation and performance
OPC-UA	Object Linking and Embedding for Process Control-Unified Architecture
OWL	Web Ontology Language
PEV	plug-in electric vehicle
PKI	public key infrastructure
PNNL	Pacific Northwest National Laboratory
RDF	Resource Description Framework
RPS	renewable portfolio standards
RTP	real-time price
SC	(DOE) Office of Science
SCADA	supervisory control and data acquisition
SCP	Secure Copy
SGAM	Smart Grid Architectural Model
SGIP	Smart Grid Interoperability Panel
SLP	Service Location Protocol
SPFF	STEP Physical File Format
SS	security and safety

T&D	transmission and distribution
TLS	transport level security
TOU	time-of-use
UML	Unified Modeling Language
UPnP	Universal Plug and Play
URI	Uniform Resource Identifier
UUID	universally unique identifier
VOAF	Vocabulary of a Friend
VSCP	Very Simple Control Protocol
XML	Extensible Markup Language
ZE	Zero Energy

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1.0 Introduction

Achieving national buildings energy efficiency goals requires the adoption and deployment of building energy management and automation systems at very large scale throughout the United States. Currently, only a small percentage of buildings have automation beyond simple control loops (e.g., thermostats). The Pacific Northwest National Laboratory (PNNL) report, *Small- and Medium-Sized Commercial Building Monitoring and Controls Needs: A Scoping Study* (Katipamula et al. 2012), indicated that "…over 90% of commercial buildings are either small or medium-sized (under 50,000 square feet) and most if not all lack the sensors and information and communications technology (ICT) systems needed to operate them at optimal efficiency…" That report targets energy efficiency of small- to medium-sized commercial buildings in the United States, but with a global perspective because many system vendors are international enterprises. Examples of small commercial buildings (i.e., under 5,000 sq. ft.) include retail stores, restaurants, dry-cleaners, offices, and convenience stores. These buildings constitute about ~55% of all commercial buildings. Examples of medium commercial buildings (i.e., typically greater than 5,000 sq. ft. but less than 50,000 sq. ft.) include chain retail stores, public assembly, religious worship, distribution warehouses, grocery stores, and multi-office buildings. This segment makes up another ~40% of all buildings.

Many of the challenges and issues that inhibit the rapid growth of building automation systems in these building categories revolve around the lack of sufficient connectivity and interoperability between devices within buildings, between buildings, and between buildings and service providers. The impact of improved interoperability on scalability is evident in other domains such as the Internet, where a set of core communication standards (i.e., HTML, HTTP, and TCP/IP) (Internet Engineering Task Force 2015; World Wide Web Consortium 2015) led to the exponential growth of web servers and browsers to quickly become the World Wide Web. Taken together, these standards created an open "communication stack" that could be implemented by different vendors and deployed independently while maintaining interoperability, which cultivated a fertile environment for growth.

This trend is becoming apparent with machine-to-machine communications and Internet-of-Things (IoT) technology, which are achieving a level of technical maturity and commercial viability that enables data and information to be exchanged uniformly and efficiently between small and inexpensive software-based devices and scalable cloud-based systems. The ubiquitous communications infrastructure allows these systems to easily connect at a very basic level using a standard set of widely supported protocols. Advances have ignited rapid growth in the numbers of connected devices. Gartner (2015) estimates that the overall number connected devices in cities will increase 145 percent from 1.1 billion in 2015 to 2.7 billion in 2017 and that connected devices in commercial buildings will increase from 206 to 648 million, representing a 214 percent increase in just 2 years. Connected devices will continue to increase in numbers and in capabilities.

Despite these predictions, buildings connectivity is complex. It requires common understanding and agreement between diverse stakeholders involved in a range of technical domains across a wide variety of buildings that support many different business purposes. This challenge is similar to that addressed by the GridWise Architecture Council (GWAC) Interoperability Framework (GWAC Stack) (GWAC 2008) (see Figure A.2) for improving smart grid interoperability. The GWAC Stack identifies the components of interoperability that need to be addressed with agreements between interacting parties that bring alignment to allow systems and devices to connect and interoperate. Buildings connectivity challenges can be characterized by leveraging this interoperability framework.

Buildings energy efficiency, connectivity, and automation are closely interrelated. Dynamic energy efficiency and energy optimization require a building to actively react to changes that impact consumption or generation of energy. Most automation systems today in small and medium commercial buildings are simple, standalone controls rather than integrated systems. Improving the value proposition for advanced building automation through enhanced building connectivity, which exposes opportunities for improved building efficiency and the provision of electric grid services, will help decrease lifecycle costs and increase application functionality.

Evaluating the existing standards landscape is an important initial step in identifying key challenges that impede buildings connectivity and impact the deployment of building automation systems. This document introduces the scope of buildings interoperability and develops a buildings interoperability conceptual model and framework based upon existing widely used architectural models. This model and framework provides a context for organizing key buildings use cases from related efforts. Relevant and nascent standards and key industry stakeholders are mapped onto the framework to provide a baseline for understanding the current buildings standards landscape. In addition, a set of preliminary challenges and gaps are identified through analyses and evaluations of the buildings standards relative to goals and objectives identified in the GridWise Architecture Council's Interoperability Maturity Model (IMM) (GWAC 2015).

This approach to improve buildings interoperability works to align relevant stakeholders through the development of an interoperability vision for connectivity in context with, but not constrained by, the existing standards landscape. When considering this long-term vision, near-term challenges can be set aside to allow focus on the ultimate characteristics that simplify the responsibilities of the integrators and users of buildings automation technology. From this unconstrained vantage point, the key gaps in standards and technology can be identified and the evolutionary paths defined to address specific challenges (e.g., the incorporation of legacy devices and systems requiring backward compatibility where needed).

To this end, this buildings interoperability framework introduces an interoperability vision scenario and briefly describes it as a basis for subsequent evaluation of standards requirements and technology. In addition to standards and technologies being applied within the domain of small to medium buildings, emerging communications standards gaining momentum in residential buildings, large commercial buildings, and areas outside the buildings industry are introduced. These standards provide capabilities that have the potential to be leveraged for enhancing building connectivity and contribute to a buildings interoperability vision extending beyond the small and medium buildings that are the focus of this framework.

2.0 Scope of Buildings Interoperability

Buildings differ greatly in their characteristics and in the scope of intelligent equipment connections they utilize. The diverse energy (e.g., electric and natural gas) equipment assets (i.e., loads, storage, and generation) within facilities can be characterized by energy capacity, operational characteristics, economic impact of building operations, operational flexibility of buildings, operational impact on the energy system, building system complexity, level of automation, building sustainability needs, and energy assurance needs (Hardin 2015). Many of these characteristics directly impact connectivity requirements and increase the complexity associated with selecting and applying communication standards.

The following sections discuss five major areas of interest that help define the scope of interactions being enabled by buildings interoperability: interactions between a building and its internal operations (Section 2.1), interactions among a community of buildings (Section 2.2), interactions with building service providers (Section 2.3), interactions with market service providers (e.g., energy markets) (Section 2.4), and interactions with energy distribution system operations (Section 2.5).

2.1 Buildings Operations

Buildings come in many shapes and sizes to serve a variety of purposes. The U.S. Energy Information Administration (EIA) Commercial Buildings Energy Consumption Survey (CBECS) [EIA 2012] classifies buildings based on the primary business or commercial activity, or function, carried on within the building: (1) education, (2) food sales, (3) food service, (4) health care (inpatient and outpatient), (5) lodging, (6) mercantile, (7) mercantile in enclosed and strip malls, , (8) office, (9) public assembly, (10) public order and safety, (11) religious worship, (12) service, (13) warehouse and storage, (14) vacant, and (15) other. These classes contain more detailed building types. For example, the mercantile type includes retail stores, studio/galleries and vehicle dealerships and the food sales type includes grocery stores and convenience stores along with gas stations with a convenience store.

From a size and electric energy perspective, homes and small commercial and industrial (C&I) facilities are smaller than 5,000 sq. ft., typically have less than 20 KW of electrical demand, and contain a relatively small number of low-power loads (FERC 2009). Multi-tenant residential and medium C&I facilities are less than 50,000 sq. ft. and typically have between 20 KW and 200 KW of electrical demand. In the commercial buildings sector, buildings 50,000 sq. ft. and smaller comprise nearly 95% of the nation's 5.557 million buildings (EIA 2012). Typically, large buildings are larger than 50,000 sq. ft. and have greater than 200 KW electrical demand. These large buildings contain significantly more diverse and specialized loads. In general, they contain a wider selection of connected devices and systems from a larger vendor community compared to smaller sized facilities, which have fewer connected devices and systems but typically greater constraints on operational resources (e.g., capital and manpower). Due to these constrained operational resources, a predominance of small- and medium-sized buildings in the United States would benefit from minimized manual interactions and maximized automated interactions.

Building classifications impact building operational priorities; however, buildings across classifications share many common interoperability requirements that can facilitate broad adoption and scalability. Interoperability standards and technologies primarily developed for a specific building class are often adapted for use in other classes. For example, residential standards and technologies tend toward low-cost and ease of use while large C&I interoperability standards tend toward system and device integration with higher reliability. Small to medium commercial buildings standards can potentially leverage and benefit from both.

Building operations can be impacted by contract-based relationships (e.g., leases) between building owners, operators, and tenants. Tenant-landlord relationships, which separate operational and financial responsibilities, can potentially result in a lack of central operations management and a distribution of financial incentives that inhibits investment in energy efficiency. For example, if tenants are responsible directly to energy providers for their individual energy expenses, then capital investments in overall building energy efficiency would require an agreement between the tenants.

Responsibilities associated with the successful operations of a building or campus of buildings include electrical energy management, gas/oil energy management, water management, building security, waste management, and asset management (e.g., keeping systems and equipment operating reliability and diagnosing and repairing systems and equipment when they fail). These systems utilize control and communications technology developed by stakeholders from different industries and with different requirements.

Currently, most residential and smaller commercial buildings have appliances and other loads but few have generation capabilities. Most facilities have heating, ventilation, air-conditioning, lighting, and general plug loads. In the future, more commercial facilities may have solar generation, fuel cells, or other backup generation. Large facilities and campuses may employ distributed generation, backup generation, and cogeneration. This generation equipment will evolve over time as innovation increases the economically viable distributed energy options available to building owners and operators (e.g., plug-in electric vehicles [PEVs] and renewables).

Building operations can vary in complexity. The primary goal of buildings systems is to provide comfort and quality service. Keeping these goals in mind, increased flexibility how building equipment operates can increase efficiencies and, in turn, reduce energy consumption and provide operational savings. In general, system complexity is minimal in residential buildings, greater in commercial facilities, and maximal within industrial facilities. At the low end is a simple residence with the operational flexibility of some appliances that can be cycled (e.g., air conditioner), load shifted (e.g., refrigerator defrost), or used for thermal storage (e.g., hot water heater). In the middle range are medium-sized commercial properties or small industrial facilities that have simple control systems and multiple subsystems (e.g., heating and cooling, lighting, and thermal storage). At the high end are large C&I campuses that operate many large, complex, interrelated energy and manufacturing distribution processes. These facilities must meet a wide range of business and safety priorities (e.g., subsystem performance, business objectives for process management, occupant comfort, energy cost management, and demand response).

Some large commercial and institutional owners and operators have energy management systems. These systems may utilize sophisticated distributed control systems that manage closed-loop controls for equipment but, in general, have constrained operational flexibility. In general, loads cannot simply be turned off without completely understanding the occupants' objectives and the interrelationship of their processes. Energy management involves not only electricity, but also gas, oil, chilled water, steam, air quality, and tradeoffs among these. This is particularly important if one considers remote operation by an external entity that does not understand the facility's complexity (as could happen in a demand-response scenario that benefits the electric grid).

The scope and capabilities of the automation systems that monitor and control building functions vary greatly. Automation systems represent significant capital investments and ongoing operational expense. They are typically implemented based on the automation system's ability to address operational and business challenges while providing a higher return-on-investment than manual operation. Typically, the benefits of automation increase as the complexity and costs of a task increase.

Levels of automation (up to ten levels) (Endsley 1999) describe different degrees of autonomy or decision-making capability between humans and machines. At the lowest levels, all decisions are made by humans and at the highest levels all decisions are made by machines. Simple control loops are the easiest and least expensive to automate. The costs and difficulty of automation increases as operational and system complexity and coupling between variables increases.

The level of automation within a facility will directly impact its ability to coordinate and optimize building energy usage both inside and outside the building's premises. This includes maximizing energy efficiency and dynamically responding to grid signals. Large C&I buildings and campuses typically have systems that integrate energy management into operations. These systems are often single-vendor, proprietary systems, but may also be solutions designed and installed by system integrators.

Medium commercial buildings typically have point-solutions that are cost-sensitive, energy-specific controls that require minimal integration. They are typically not designed for external connectivity due to high cost, low market demand, and lack of clear standards. Buildings that do have automation systems typically utilize single-vendor, proprietary systems or solutions assembled by system integrators using proprietary frameworks (e.g., Tridium Jace). Small commercial and residential buildings typically do not have control solutions but, if they do, they are packaged, standalone, very cost-sensitive energy-specific controls with plug and play integration requiring little or no engineering and minimal installation costs.

While the vast majority of buildings consume all their power from the electrical grid, a small set of facilities are only occasional energy consumers. To reduce the dependence upon traditional energy service providers, some investors (often with the help of policy encouragement) have decided to build Net Zero Energy (NZE) and Zero Energy (ZE) buildings. NZE buildings provide electricity to the grid when they produce more than they consume and draw power from the grid when there is a shortfall. To reduce their risk of an energy failure, ZE buildings interconnect to the electrical grid and draw power only during emergencies.

The social values of the building owner-occupants may have an effect on the electrical equipment and energy content required by a building. A building operator may choose between various energy efficiency decisions including onsite solar or may decide to consume only green (renewable) or low-emission power even if the cost of this energy is higher than traditional energy. This energy may be produced onsite or by an energy service provider.

2.2 Buildings Communities

Buildings communities differ from campuses in that they are a collection of buildings that do not share ownership. Interoperation in building communities requires that energy transactions occur between separate legal entities and that inter-building connectivity occurs between separate security and privacy trust zones.

Buildings communities and community microgrids are expected to increase over time as building operations personnel identify mutually beneficial opportunities and cost savings. Buildings with energy generation capability may be interested in trading energy with other buildings in a community that may derive financial, reliability, or other benefits from such transactions. This would be of particular importance during natural disaster events that interrupt the flow of grid power.

2.3 Buildings Service Providers

The field of buildings operations is difficult and demanding. The high complexity and cost of monitoring and automating buildings operations, diagnosing equipment and system faults, and optimizing energy use often requires resources not available to small and medium commercial buildings' owners and operators. While this is often an issue with large buildings as well, it is particularly problematic for smaller buildings, mainly because the owners or operators cannot afford to retain staff and have limited budgets for operations and maintenance services.

These functions can potentially be outsourced to organizations that specialize in providing buildings operations under contract to the building owner/operators. This is analogous in many ways to the standard industry practice of outsourcing information technology operations. Due to the wide variety of equipment and systems within buildings, several service providers may be involved. As in the ICT outsourcing model, standards are critical in providing flexibility and minimizing vendor lock-in.

2.4 Market Service Providers

Retail energy markets are slowly emerging in the United States as state and local regulation and policies are starting to recognize the benefits of retail competition and the success of wholesale energy markets. There is also an opportunity for third-party service providers, such as demand-response aggregators, to provide wholesale market transactive energy services for buildings (GWAC 2013; Somasundaram et al. 2014).

Buildings have the potential to participate in a wide variety of energy markets from forward and day-ahead markets down to ancillary service markets. However, this participation is contingent upon the building having the requisite sensing, automation, and decision-making capabilities.

2.5 Distribution System Operations

The electrical energy consumption of small commercial buildings and homes is relatively predictable in the aggregate as compared to medium and large C&I buildings. Energy consumption in C&I facilities tends to vary over time as large loads are activated and de-activated. This change in the demand for electricity can be unpredictable but needs to be balanced in real-time. C&I electricity bills reflect this variability in more complex tariffs that separate energy costs from demand costs. This increases the need for buildings automation and connectivity.

Energy bills vary based upon the electrical consumption, demand, number, and types of energy assets (i.e., loads, generation, and storage) and represent a portion of the overall costs of buildings operations. As the relative economic impact of energy increases, additional financial resources are applied to controlling costs based on return-on-investment. This is often reflected in increased expenditures for energy management and automation systems to help control energy costs.

Positive economics for large C&I buildings have led to the development of diverse and competitive control and automation industries. Historically, the use of small and medium commercial and home automation has been limited. However, adoption rates may increase over time as the relative economic impact of energy changes and the cost to buy and deploy automation technology decreases.

The capability for buildings to react to opportunities and challenges that occur in the energy system (i.e., dynamic pricing, demand-response events, and retail energy transactions) is highly dependent upon the occupants' flexibility given the constraints that are considered critical to buildings operations. Flexibility is directly influenced by the capability of building energy management systems to dynamically schedule and optimize the operation of energy assets.

Buildings can impact the reliability, quality, and stability of the electric system. C&I buildings often employ large inductive loads, which require regulation through volt/VAR ancillary services. Large inductive industrial loads can have a direct impact and smaller home loads can have a compounding impact as they become aggregated into larger systems (e.g., heavy use of residential air conditioners on hot days).

3.0 Buildings Interoperability Models

The buildings interoperability conceptual model and framework developed here provide a context and structure upon which building connectivity use cases, standards, and stakeholders (described in subsequent sections) can be organized and projected. They are buildings-centric models that leverage and build upon the National Institute of Standards and Technology (NIST) Smart Grid Conceptual Model (NIST 2014), the EU Smart Grid Architectural Model (SGAM) (CEN-CENELEC-ETSI 2014), the GWAC Stack (GWAC 2008), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) distributed control system model (ASHRAE 2014), the American National Standards Institute (ANSI) (ANSI 2015a) Energy Efficiency Standards Coordination Collaborative (EESCC) connectivity model and roadmap (EESCC 2014a), and the Purdue Enterprise Reference Model (PERA 2015) for large C&I facilities. These models each provide partial views into the system components and structure relating to buildings systems integration and connectivity and are detailed in Appendix A for reference.

3.1 Buildings Interoperability Conceptual Model

The buildings interoperability conceptual model (see Figure 1) provides a building-centric view into the connectivity of buildings systems from the perspective of buildings operations. Buildings operations are responsible for the ongoing operations and support of numerous energy consuming and producing systems necessary for the building or buildings to achieve its mission. These systems may interact with external actors (e.g., distribution service operations, market operations), other buildings in a community, or buildings service providers through an energy services interface (ESI). Internal actors include owners, operators, consumers, occupants, and tenants. Internal actors each have different financial and contractual relationships with a building and buildings operations that must be accounted for and resolved for interoperable interactions to exist.

The Smart Grid Interoperability Panel (SGIP) ESI white paper (Hardin 2015) states, "An ESI is a bi-directional, logical, abstract interface that supports the secure communication of information between internal entities (i.e., electrical loads, storage, and generation) and external entities. It comprises the devices and applications that provide secure interfaces between [Energy Service Providers] and customers for the purpose of facilitating machine-to-machine communications. ESIs meet the needs of today's grid interaction models (e.g., demand response, feed-in tariffs, renewable energy) and will meet those of tomorrow (e.g., retail market transactions)."

The distribution service operations actor includes building to grid interactions for maintaining grid reliability and quality of service (e.g., typical demand response and dynamic pricing). Market service providers include interactions with external markets (e.g., retail energy markets and other transactive energy markets). Buildings service providers directly impact buildings operations by providing a range of monitoring, diagnostic, control, and analytical services for dedicated equipment up to and including outsourced whole buildings operations.

3.2 Buildings Interoperability Framework

The buildings interoperability framework (see Figure 2) provides a three-dimensional space that consists of (1) the three interoperability layers from the GWAC Interoperability Framework (GWAC 2008), (2) the ASHRAE distributed control system layers (ASHRAE 2014) that map into the SGAM Purdue model (CEN-CENELEC-ETSI 2014) zones, and (3) actor domains that represent important actors and roles relating to buildings connectivity derived from the NIST conceptual model (NIST 2014). Use cases, standards, and stakeholders are mapped or projected onto the framework. This provides a context for organizing the interoperability landscape.

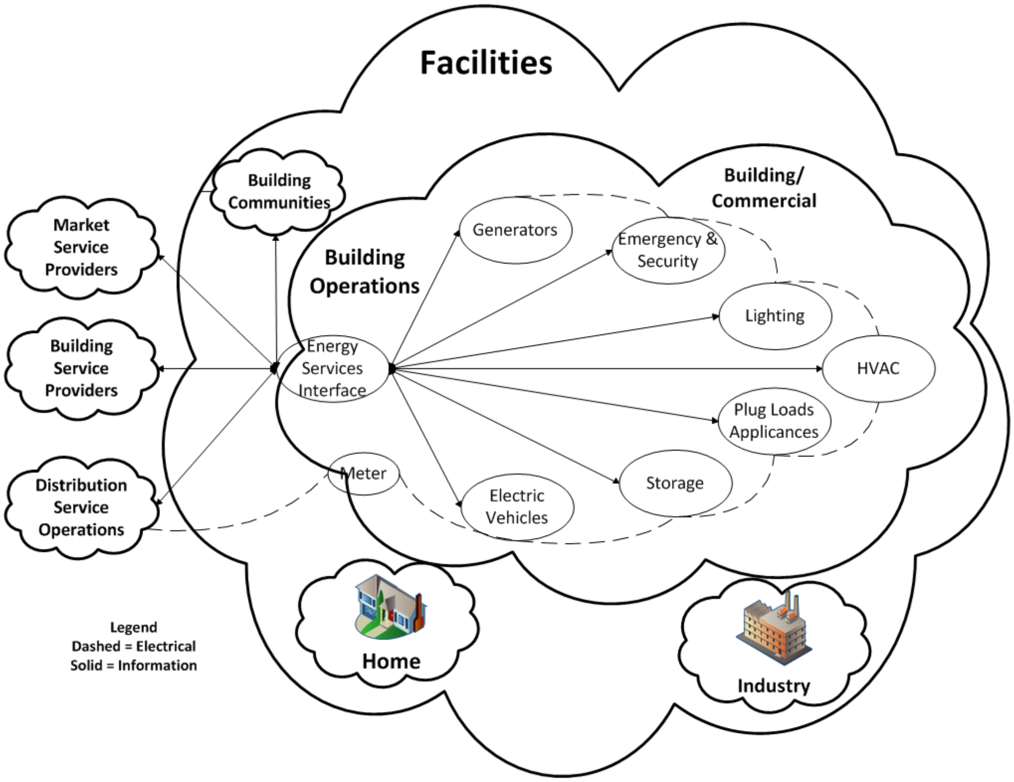

Figure 1. Buildings Interoperability Conceptual Model

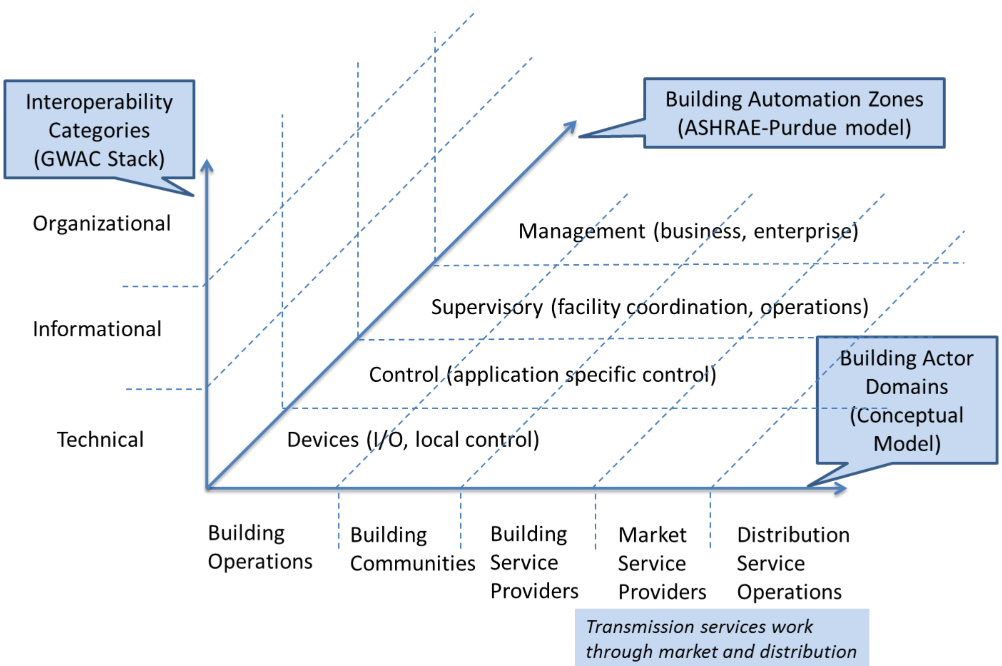

Figure 2. Buildings Interoperability Framework

3.2.1 Interoperability Categories

Building interoperability layers are defined in the GWAC Context-Setting Interoperability Framework (GWAC 2008).

The major aspects of interoperability fall into organizational, informational, and technical categories. The organizational categories emphasize the pragmatic aspects of interoperation and represent the policy and business drivers for interactions. The informational categories emphasize the semantic aspects of interoperation and focus on the information being exchanged and its meaning. The technical categories emphasize the syntax or format of the information and focus on how information is represented within a message exchange and on the communications medium. These categories are discussed further in the following sections.

Organizational Categories

Within the organizational categories, interoperability requires an agreement on the business process interaction expected to take place across an interface. Such an agreement would describe the service requests and responses that need to support the larger process picture shared by the collaborating parties. Business processes must be consistent with the tactical aspects of running the interacting businesses, the strategic aspects shared by the parties of the exchange, and the business environment embodied in economic and regulatory policy that governs the business interactions.

Devices and systems within the building also have business process interactions that take place across their interfaces. In this case, the organizational categories are just as valid, though the economic and policy issues may be more straightforward to resolve as they are within the domain of the building owner/operator.

Informational Categories

Informational interoperability focuses on the meaning or semantic understanding of the concepts contained in the message data structures and the relationships between the concepts represented in the message. Semantic models are often used to develop shared understanding by domain stakeholders.

Technical Categories

Technical interoperability encompasses the physical transmission of information including the protocols used and the syntax of the information payloads transported by the communications media.

3.2.2 Buildings Actor Domains

The buildings actor domains represent the categories of individuals and automation technology that interact with buildings. A description of each follows.

Buildings Operations

Buildings operations connectivity involves communication between devices and between devices and systems that reside within a building or facility. A facility can represent a collection of buildings that share owners/operators (e.g., a campus or a community) or a collection of buildings with a facility owner and occupants that manage separate business interactions (e.g., an apartment complex).

Buildings Communities

Buildings communities are collections of buildings that do not share owners or operators but have characteristics that enable them to work together to coordinate and optimize energy use under a variety of conditions. These communities have the potential to deploy distributed energy resources and operate as community microgrids. Rigorous consideration must be given to interoperability issues (e.g., business contracts, enhanced cybersecurity, and data privacy).

Buildings Service Providers

Buildings service providers provide a range of services to building owners and operators. Service domain connectivity involves the interconnection between devices and systems that reside within a building or facility and remotely located third-party service providers. These services supplement buildings operations by performing equipment and system monitoring, diagnostics, and troubleshooting along with software and information technology support. They also include local third-party energy providers (e.g., distributed generation and storage providers) or combined heat and power providers that contract their services with the building owner, but may also interact with market service providers.

Service providers are typically third parties that perform services for building owners or operators under contract relationships. IoT technology is rapidly impacting how service providers connect to sensors and actuators. The IoT is a high-growth area driving open architectures and new value propositions.

Market Service Providers

Market domain service provider connectivity involves the interconnection between devices and systems that reside within a building or facility and third-party market operations systems that are remotely located. Market service providers work with other electric power grid service actors (e.g., wholesale electricity markets and transmission system operations); however, these actors interact with distribution service operations and market service providers and not directly with the buildings communities and buildings operations actors. An example of a market service provider is an aggregator of buildings energy resources who coordinates controllable load from multiple facilities and contracts with wholesale electricity markets.

Distribution Service Operations

Distribution service operations domain connectivity involves the interconnection between devices and systems that reside within a building or facility and distribution system operators, such as utilities (e.g., electric, water, and gas). Market service providers may need to interact with distribution service operators to either offer services on behalf of the building to distribution system operations or to ensure that their service to the building addresses the reliable delivery requirements maintained by distribution system operations.

Other electric power grid service actors exist (e.g., wholesale electricity markets and transmission system operations); however, these actors interact with distribution service operations and market service providers and not directly with the buildings communities and buildings operations actors.

3.2.3 Buildings Automation Zones

Buildings automation zones are logical zones derived from the ASHRAE Distributed Control System Model (ASHRAE 2014) (Figure 3), which was inspired by the Purdue Enterprise Reference Model (PERA 2015) that defines five layers (i.e., physical process, intelligent devices, control systems, manufacturing operations systems, and business logistics systems). Data and information is distributed both vertically and horizontally in all buildings automation zones. Many cross-cutting issues are common to all zones (e.g., privacy and security).

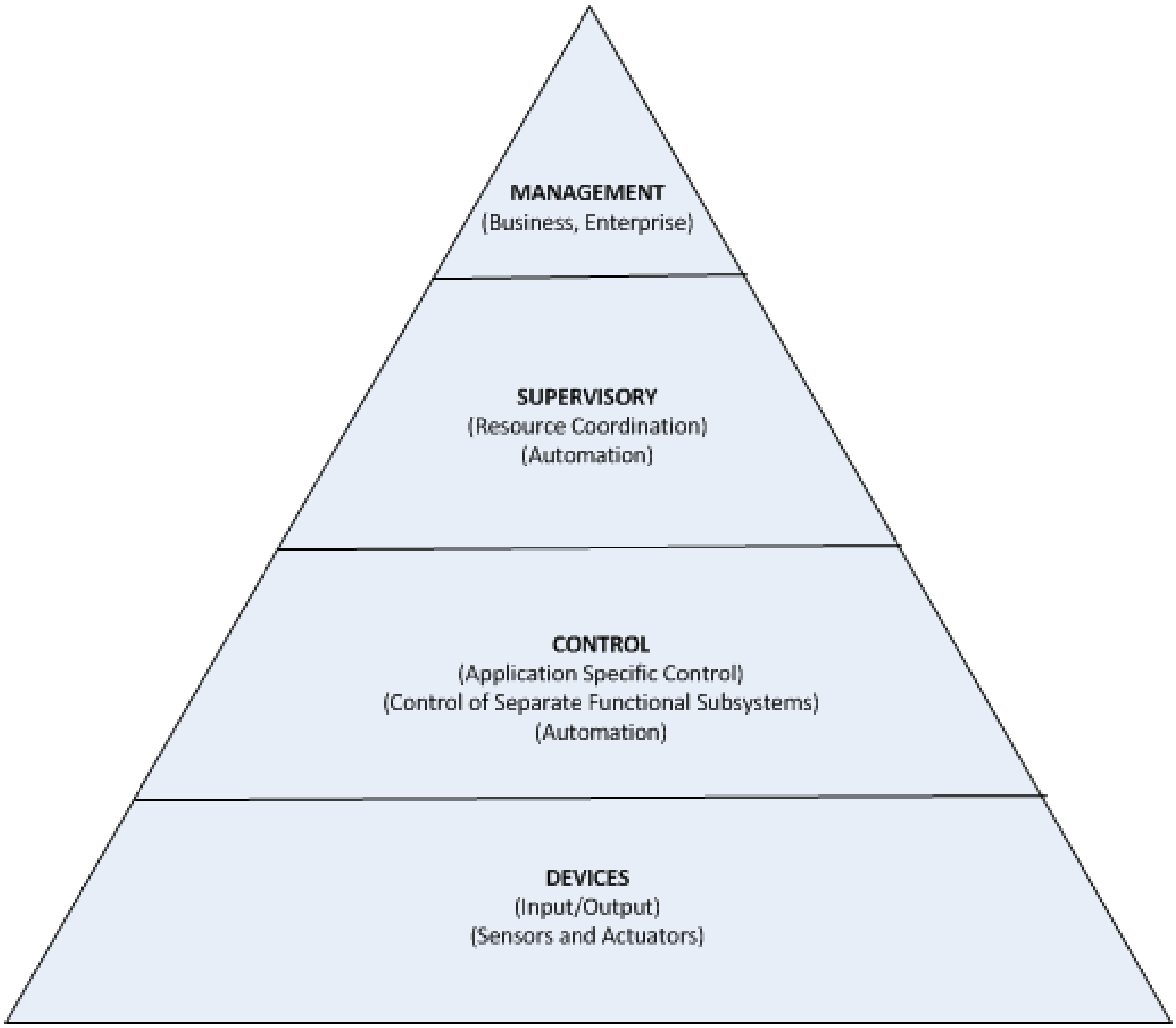

Figure 3. ASHRAE Distributed Control System Model

Management Zone

The management zone translates engineering metrics to economic and business metrics for the successful operation and functioning of the building. Examples include the integration of buildings information into enterprise systems, analytics and data mining, optimizers, and continual prediction and forecasting. As costs decrease and technology is adopted by building system integrators, management is starting to harness technology with origins in industrial facilities (e.g., more complex supervisory control systems).

Supervisory Zone

The supervisory zone is responsible for resource and asset coordination of clusters of control which includes sharing sensor data. Supervisory functions include open-loop and closed-loop multi-variable control as well as information management (e.g., data management, visualization, historical trending and data reduction, graphic user interfaces, alarming and notifications, reporting, and system configuration and management).

Automation examples include multi-variable cascade control and state machines, advanced model predictive controls, self-tuning and machine-learning adaptive controls, and transactive systems (Somasundaram et al. 2014; NIST 2014).

The integration of supervisory systems with business and enterprise management is undergoing rapid change due to the rise of (1) cloud-based applications and big data technologies (e.g., NOSQL MongoDB, and HADOOP/HBase), (2) web- and Internet-based technologies, and (3) open systems. In addition, the rapid growth of mobile technologies has led to a variety of mobile user interfaces.

Control Zone

The control zone consists of dedicated automation systems including single-variable controllers, application-specific controllers, custom application controllers, standalone subsystems, and packaged control systems.

Device Zone

The device zone consists of a variety of sensors and actuators located throughout a building's premises. These devices are connected both hierarchically and peer to peer.

4.0 Buildings Interoperability Use Case Landscape

A reasonable approach for evaluating the current buildings standards landscape is to evaluate connectivity standards within the context of use cases. Relevant use cases have been identified by PNNL, the Energy Information Standards (EIS) Alliance, International Electrotechnical Commission (IEC) TC 57, IEC PC118, and others (see Appendix B). Use cases provide a valuable context for analyzing current and nascent standards practice and evaluating challenges and gaps. Within this context, it is important to realize that use cases are not independent of each other.

For the purposes of discussing interoperability issues across all the sources of use cases listed in Appendix B, this document groups use cases into the following types: (1) onsite service, (2) offsite service, and (3) market service. Onsite service use cases describe energy interaction scenarios primarily within buildings. These scenarios may also involve third parties providing services on behalf of buildings operations. Offsite service use cases describe scenarios in which buildings interact with grid entities (e.g., distribution service operators or their proxy service providers). Market service use cases describe scenarios where buildings interact with retail markets directly or wholesale markets through service providers.

The use case landscape table (see Section B.5) identifies each use case and how it maps to the buildings connectivity framework actor domains and automation zones along with current standards practice for that use case and nascent standards that may impact that use case. Each use case maps to one or more actor domains and automation zones.

The use cases in Section B.5 are a mixture of interface-oriented and functionally oriented use cases. The PC118 use cases are interface-oriented and are abstracted from families of international functional use cases. These use cases focus on what information is exchanged at an interface and the requirements surrounding the information exchanged. Functional use cases describe application level scenarios and interactions between actors. Fully discerning the interface requirements from functional use cases requires that the use cases be considered in a system architectural context.

An example of a use case in Section B.5 is Efficiency Shared Savings, where a building owner (BO) contracts with a building service provider (BSP) that installs, operates, and maintains equipment at its expense. The building service provider then bills the building owner for the energy services provided to the building. In this example, the actors are the building service provider and building owner; buildings automation zone interaction in the use case is at the buildings supervisory level. Section B.5 identifies the actor domains involved and the automation zones. It also lists the touch points which are the associations between the actors involved in the use case. The touch points are identified by the nomenclature template ExternalDomain:BuildingOperations(Automation Zone). In this use case, the touch point is represented as BSP:BO. Use cases can involve multiple actors and include multiple touch points, each involving a pair of actors.

The table in Section B.5 also includes a column on the Current Standards Practice. This qualitatively indicates that standards are being broadly applied or not. It does not attempt to identify specific interoperability standards as the standards are defined on an individual interface basis and the use cases do not provide the detailed design, interaction and sequence information along with the functional and quality requirements necessary to specify specific interfaces. In general, standards that map into similar regions of the framework as a use case might potentially be used in implementing the use case.

5.0 Buildings Interoperability Standards Landscape

The standards landscape table (see Appendix C) identifies key buildings interoperability standards, the type of standard they represent, how they map into the buildings interoperability framework, the organization responsible for the standard, and a link to the specification, if available.

The interfaces are inter-domain buildings interfaces and are identified by the nomenclature format "ExternalDomain:BuildingOperations(Automation Zone)." These are the same as used in use case touch points. They represent typical application areas for the interface standard but are not intended to be comprehensive. A standard may satisfy some of the requirements of a use case touch point in the use case landscape but further decomposition and analysis of use case details is required to determine applicability.

A comprehensive energy efficiency standards inventory database is provided by the EESCC (EESCC 2014b). This database includes many standards directly relevant to systems interoperability and connectivity. These standards are included in the standards landscape table in Appendix C. The EESCC database also includes many standards that are important for achieving building energy efficiency but that do not directly impact connected buildings interoperability (e.g., building codes, regulations, and policies). These types of standards have been excluded from Appendix C.

The standards map in Figure 4 provides a broad overview of buildings standards and their approximate application across the automation zones and the actor domains. The mapping is not exact, but it is meant to show the general coverages of standards in these dimensions. Similarly, Figure 5 presents a broad overview of the standards mapped into the automation zones and interoperability categories. This picture suggests that many standards cover the technical interoperability categories, but may only touch upon information models. These figures illustrate some of the complexity involved to understand the variety of scope and overlap in the standards being used in deployments today.

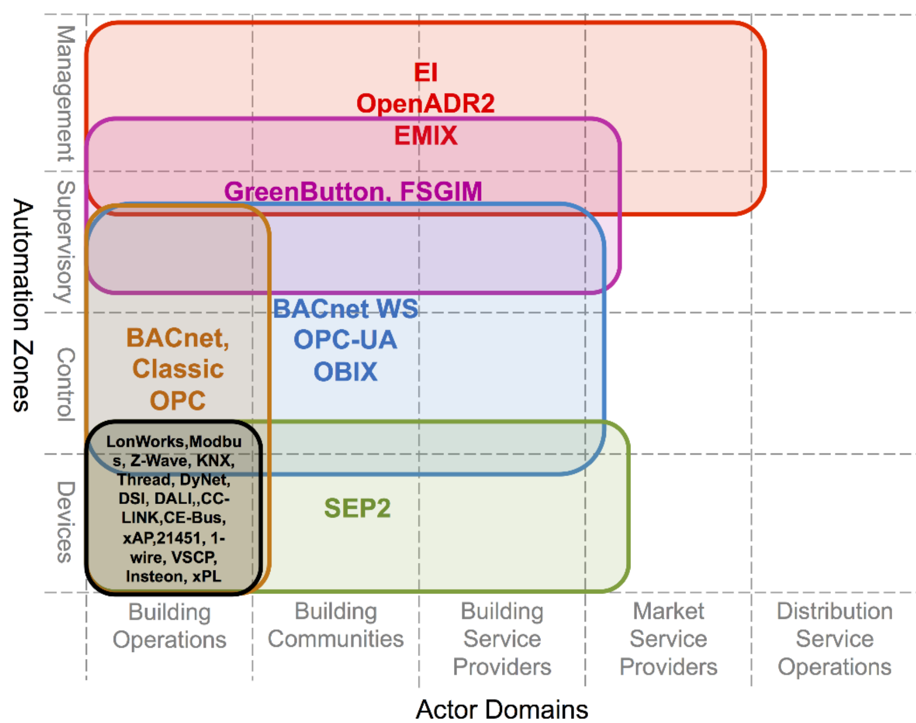

Figure 4. Automation Zones and Actor Domains Standards Map

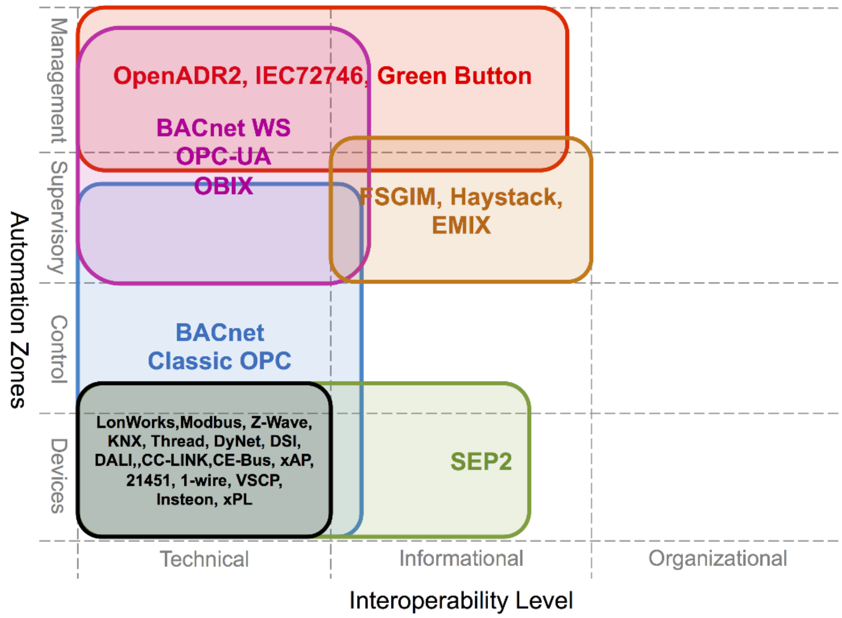

Figure 5. Automation Zones and Interoperability Level Standards Map

Interoperability categories (see Section 3.2.1) include: 1) technical, 2) information, and 3) organizational interoperability. Each category represents a different aspect; however, all three categories must be addressed to achieve interoperability.

5.1 Technical Interoperability

Technical interoperability includes; 1) basic connectivity, 2) network connectivity, and 3) syntactic interoperability (GWAC 2008). Basic connectivity refers to the communications protocols (e.g., Ethernet and WiFi) that enable establishment of both physical and logical connections between systems through the establishment of reliable communication paths for the exchange of digital data between two systems. Network interoperability expands basic connectivity to include communications across multiple communication networks (e.g., IPv4/IPv6). The data exchanged consists of low-level digital (e.g., character/byte array) data encoding. Syntactic interoperability adds agreed-upon message content structure (e.g., XML and HTML) and messaging patterns to the low-level data that is being exchanged so that both ends of a connection understand how to exchange, encode, and parse the data.

The components of technical interoperability should be independent (i.e., not comingled) as this enables them to be layered and easily upgraded. As an example, IPv4/IPv6 can be used to exchange a wide range of syntactically encoded messages with simple to complex content over a range of communication media and hardware.

Cybersecurity is a critical component of technical interoperability due to the potential adverse impact on buildings. Communications sent between building automation systems and building service providers represent an attack surface that has the potential to disrupt building operations and lead to unsafe and costly attacks. Invalid signals sent to customers' systems can interrupt and compromise commercial building operations and can result in harm to equipment and personnel. Invalid signals sent from buildings to service providers can cause misinformation and result in potentially harmful actions.

The five areas of cybersecurity that need to be addressed by building communication protocols are: authentication, authorization, confidentiality, integrity, and non-repudiation (see Section 7.2.3). Newer protocols (e.g., OpenADR2b) explicitly address these areas and embed efficient security technology (e.g., transport level security); however, most legacy building protocols do not implement rigorous security measures and instead rely on undocumented proprietary features often referred to as “security through obscurity.”

Advanced security technologies (e.g., X.509 digital certificates) need to be controlled and managed efficiently within a diverse buildings environment with limited technical resources. Secure protocols often implement security as an option which is subsequently disabled in many installations due to complexity or the impact of security on performance. The proliferation of wireless protocols further increases the buildings’ cyber-attack surface area.

Communications technology has been undergoing exponential growth (see Moore’s Law [1] and Metcalf’s Law[2]). This growth is reflected in the number of technologies and technical standards that have been developed and are currently used in the buildings domain (see Figures 4 and 5). These standards are typically created within the context of organizational ecosystems that share common business interests driven by the need to reduce costs and/or expand specific markets.

The evolution of buildings automation ecosystems and standards is heavily clustered around buildings devices and device networks as shown in Figure 5. These networked device ecosystems are buildings platforms that have been purpose-built to support vendor products and system applications. In general, they are characterized by the high cost and effort associated with the integration of physical device data. They typically specify full communication stacks and interfaces that address specific device interaction use cases with specific communication protocols and platform-specific information models. The technical levels of interoperability encompassing communications networking and information transport protocols are addressed in a variety of different standards that often do not support a clean separation of the information modeling aspects in an interface definition. Interoperability between these tightly coupled ecosystem device platforms that compete against each other in the market is often limited by design. This leads to a proliferation of fragmented platforms within buildings, as building owners and operators select devices and products based on best-of-breed functionality or other selection criteria. The integration of devices using different communications protocol platforms requires adapters and integration tools, which may not be appreciated as a priority during the technology selection process. This integration issue becomes far more important as buildings systems evolve to integrate new and legacy equipment.

The vertical integration of device capabilities (see Figure 5) with control, supervisory, and management information systems for the purpose of improving buildings operations has become a higher priority within large industrial and commercial facilities. This priority has risen due to the need to manage and optimize buildings operations and improve energy efficiency. Small and medium commercial buildings that lack an automation infrastructure select vendor and product ecosystem solutions that are cost-effective and address specific issues and opportunities.

Those buildings devices and networks shown in Figure 5 that support security often address different aspects of security. For example, LonWorks supports authentication, Z-Wave supports encryption, and KNXnet/IP supports authentication and encryption. Legacy protocols (e.g., Modbus) are widely deployed but lack security. Legacy standards and protocols in the control, supervisory, and management zones typically have evolved to incorporate several aspects of cybersecurity—as have newer communication protocols.

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[1] http://www.mooreslaw.org

[2] https://en.wikipedia.org/wiki/Metcalfe%27s_law

5.2 Informational Interoperability

Informational interoperability includes; 1) semantic understanding and 2) business context. (GWAC 2008) Semantics focuses on understanding the concepts contained within the message data structures and business context relates to the relevant business knowledge that applies the semantics to a business process workflow.

Many different information models are used during building operations for "real-time" information and metadata exchange between sensors, devices, and other buildings systems. Standards-based information models for building operations have not matured due to the general lack of automation and manually intensive nature of buildings operations and maintenance.

The information exchanged between buildings devices and systems typically consists of simple generic data structures identified by name, often called a point name or tag name, with associated parameter or attribute data. Parameters often consist of analog/digital values, status or quality flags, time stamps, engineering units, metadata, etc. This generic data can be used to refer to most real-time data in devices and systems enabling the simplification of systems needed to store and process large volumes of point data.

As a result of this approach, the meaning of the data, including building operational context and relationships between data, is generally separated from the data itself and embedded in associated applications, reports and user interfaces which are "hard-coded" with the point data. Devices and systems are not explicitly modeled and the data context and relationships are distributed throughout a system. Therefore, discovering data relationships and data context requires a deep human understanding of the system. Developing and maintaining these systems is a manually intensive and costly process throughout a systems lifecycle. After commissioning, these systems are unable to readily adapt as building operational requirements change, causing data configuration and quality errors.

Project conventions for naming points are often developed on a local basis to aid system configuration during initial installation, but subsequent integration with other systems requires that points be identified and carefully mapped between systems so as to align data semantics and avoid data corruption and quality issues. A number of buildings device ecosystems have developed conventions and standards for the identifiers, parameters and data types in an effort to embed meaning into the generic data and make the data easier to understand, but the issue of point mapping between systems from different ecosystems remains. An example of a state-of-the-art naming convention is Project Haystack, which has developed an open set of tags for naming key building energy components.

Understanding buildings information semantics is critical for interoperable information exchange between systems throughout the building's lifecycle from planning, design and architecture, engineering, construction, commissioning, maintenance, and operations. Buildings Information Models (BIMs) have been developed and standardized to address specific interoperability challenges during the early design and engineering lifecycle phases of architecting, engineering, and constructing (AEC) buildings. Thus, building lifecycle phases can be summarized as; 1) design and engineering and 2) operations and maintenance (See Figure 6).

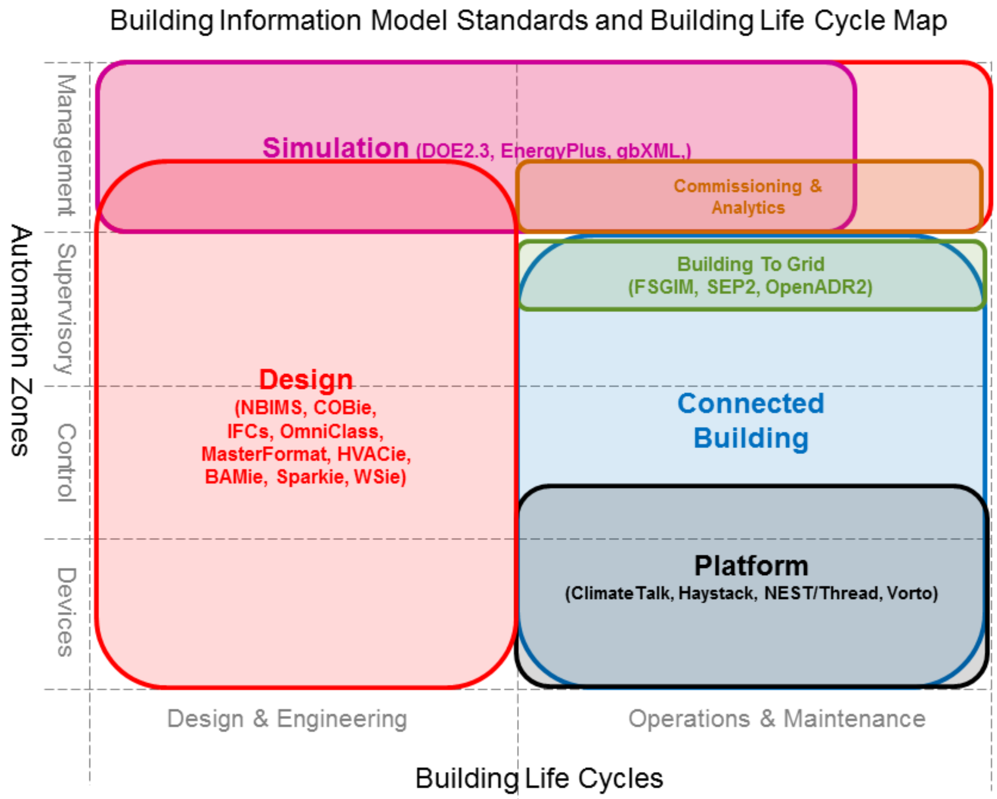

Figure 6. Buildings Information Model Standards and Buildings Lifecycle Map

Modern buildings are typically designed and engineered using modern computer-aided engineering tools (e.g., computer-aided design and buildings engineering and simulation software). These tools exchange domain-specific information in the form of non-time-critical bulk data exports and imports. Models focused on AEC phases have matured over the past decade and can be classified as "design" models. Data exchange standards (e.g., gbXML) can be used to transfer buildings data to and from engineering tools and simulation tools. After construction, buildings are occupied, commissioned, and enter the day-to-day management of operations and maintenance.

The information contained in design models is typically archived as a reference and not actively used in the operational phases. The overlap between simulation, design, and operations (see Figure 6) suggests an opportunity for leveraging mature and robust design models to enhance simulation and operational models. Design models provide valuable device and system context information and relationships that could be shared with simulation and operationally oriented systems to enable enhanced capabilities (e.g., auto-configuration). Simulations that provide design support could be adapted to provide ongoing operational support. Design models have the potential to provide the standard contextual foundation needed to enable automatic discovery of building data semantics and minimize the need for manual, time-consuming, error prone, point-mapping between systems.

Integration standards (e.g., BACnet and OPC-UA) support vertical data interoperability on top of the communication layers; however, they default to simple data exchange information models. In addition, some protocols (e.g., OPC-UA) have the ability to integrate and expose data within domain-specific information models, if such models exist.

5.3 Organizational Interoperability

Organizational interoperability includes; 1) business procedures, 2) business objectives, and 3) economic and regulatory policy. (GWAC 2008) Alignment is needed between operational business processes and procedures and strategic and tactical objectives need to be shared between business entities. In addition, political and economic objectives need to be aligned.

Business processes in large industrial and commercial organizations are often explicit, well-defined, and managed. Even so, the interfaces between devices and systems can be improved with advancement in business process modeling. Processes in small and medium commercial organizations, however, are often not defined explicitly but rather are embedded within the building's application and automation software. Buildings automation software typically communicates to devices by reading and writing named point parameters (See Section 5.2) through generic communication protocols. These command and control interfaces typically do not implement dynamic service-oriented negotiation patterns between devices or between devices and automation software and rely upon statically configured, predefined behavior.

Transaction-based approaches (Somasundaram 2014) include a wide range of use cases that involve new energy markets and interactions that extend beyond generic technical communications and will require integration with a variety of domain actor processes and procedures. Standards, policies, and regulations that enable broad, flexible, and adaptable organizational integration are needed to promote sustainable connected buildings solutions at scale. This will require that interfaces expose negotiable behavior. OpenADR2.0B is an example of an interface designed with the ability to adapt to a range of building demand-response program requirements by exposing key negotiable capabilities. Although some capabilities are either out-of-band or pre-configured, OpenADR2.0B represents an important step toward expressive service-oriented interfaces.

Standards, policies, and regulation that promote inter-organizational buildings interoperability are immature, but will become increasingly important as technical and information standards and solutions enable connected buildings and buildings communities to interoperate with other domain actors (e.g., distribution service operations, market service providers, and building service providers). There exists a lack of consistent and comprehensive security and privacy policies that adapt to the buildings domain and extend security beyond on-the-wire communication technologies into buildings information technology and operational processes and procedures. Securing data on-the-wire is required, but insufficient, to ensure end-to-end data security and privacy.

6.0 Buildings Interoperability Stakeholders Landscape

In establishing perspectives for smart grid interoperability, SGIP identified a spectrum of buildings interoperability stakeholder categories. These categories were considered in the development of stakeholder taxonomy suitable for buildings interoperability. Because buildings interoperability focuses on the customer domain and its interactions with other domains in the SGIP conceptual model, the SGIP stakeholder categories related to devices and systems in buildings were further refined and those related to the customer domain were simplified or omitted. A total of 17 stakeholder categories are shown in Table 1:

Table 1. Buildings Interoperability Stakeholder Categories

Stakeholder Name	Abbreviation
Building Automation Suppliers	BldgAutomat
Building Equipment Manufacturers	BldgEquip
Building Information Technology Products and Services	BldgIT
Communication Infrastructure and Service Providers	Comm
Industry Consortia and Trade Associations	Consortia
Consumer Products	ConsumProd
Distributed Energy Resource Manufacturers	DERMan
Distributed Energy Resource Service Providers & Aggregators	DERServ
Energy Service Companies	ESCO
Electric Vehicle Charging Companies	EVCharge
Facility Managers and Owners	FacilityMgr
Government Agencies	Gov
Meter and Sensor Manufacturers	MeterMan
R&D Organizations and Academia	R&D
Standards Development Organizations	SDO
Testing & Certification Organizations	Test
Utility	Utility

Appendix D describes and provides supplementary information regarding these stakeholder categories.

Figure 7 shows the overlapping landscape of the various stakeholder organizations against the framework of actor domains and automation zones. While the boundaries of these organizations are not necessarily clear cut, the ability to see the main actor domains and automation zones that are the focus of these organizations helps to show some of their differences. Many organizations cover the plane of concerns, as indicated by the BldgIT, Consortia, R&D, Gov, SDO, and Test categories. However, within these categories, many individual organizations focus on more targeted areas of the landscape. This is indicated in Figure 8, which shows several of the individual trade associations and consortia that occupy only portions of the landscape.

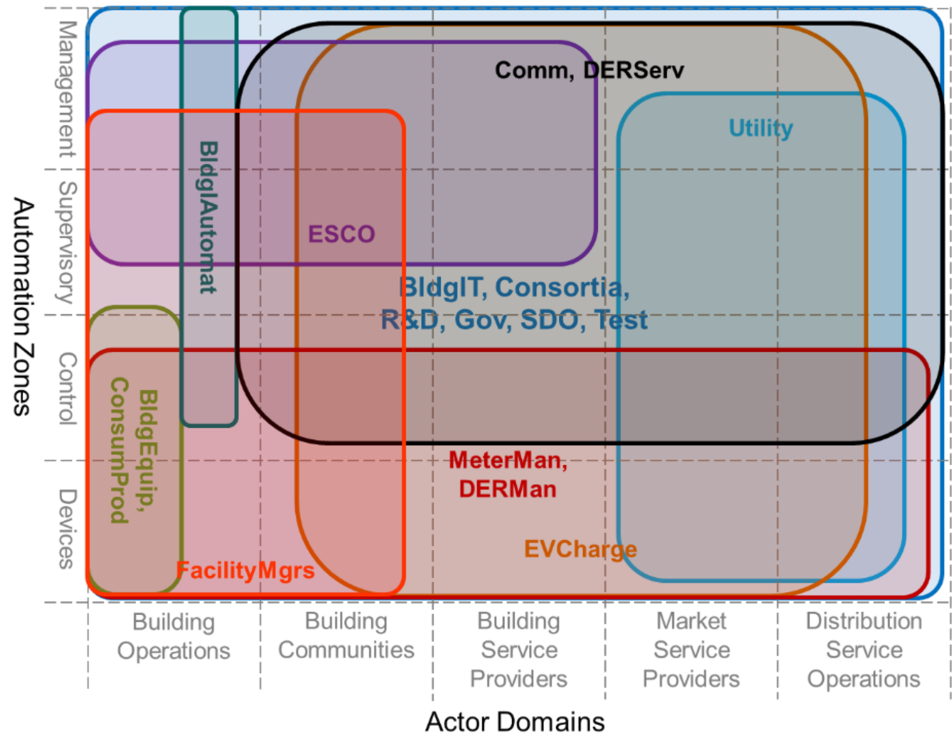

Figure 7. Stakeholder Landscape

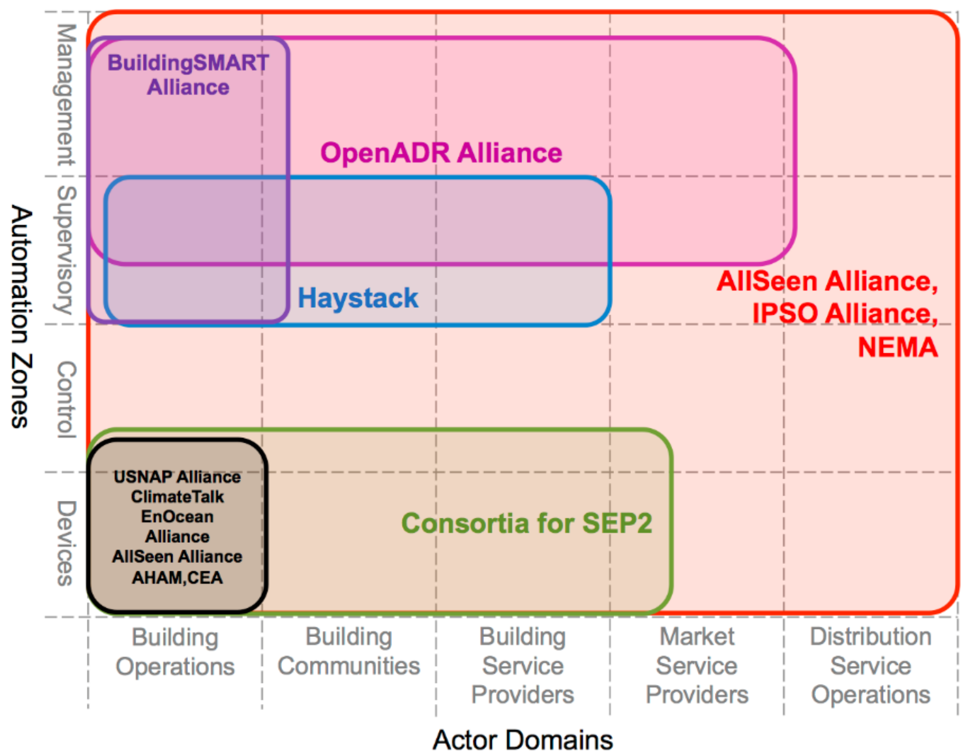

Figure 8. Consortia and Trade Association Stakeholders Map

7.0 Interoperability Goals and Objectives

Although interoperability goals and objectives are highly dependent upon the requirements of specific connectivity interfaces, general characteristics or indicators of highly interoperable connectivity have been identified by the GWAC's IMM (GWAC 2013). These are organized into general interoperability goals and cross-cutting issue goals derived from the interoperability categories and cross-cutting issues of the Interoperability Context-Setting Framework (Appendix A.2). These goals provide a baseline context for identifying interoperability desired characteristics from which progress, challenges, and gaps may be evaluated. In addition, the IMM outlines a set of characteristics to evaluate when considering the maturity level of the interfaces. A summary of these goals and characteristics follows.

General Interoperability Category Goals

- Organizational goals
  - *O1: Economic and regulatory interoperability policies are defined for the community.*
  - *O2: Regulatory alignment exists across the community.*
  - *O3: Policy provides incentives and removes impediments to enable interoperability.*
  - *O4: Policy is current and maintained.*
  - *O5: Business objectives of community participants are complementary and compatible.*
  - *O6: Compatible business processes and procedures exist across interface boundaries.*
  - *O7: Business interfaces are consistent with the business objectives.*
- Informational goals
  - *I1: There is an information model relevant to the business context.*
  - *I2: The information model that supports the business context is derived from one or more general information models relevant to the functional (application) domain.*
- Technical goals
  - *T1: Structure and format of information exchange are defined.*
  - *T2: Information transported on a communication network is independent from the network protocols.*
  - *T3: Management of a network between interacting parties is aligned.*
  - *T4: Transport protocols used in specific exchanges are consistent.*
  - *T5: A communications path exists for transparent and reliable exchange between interacting parties.*

General Cross-cutting Issue Goals

- Configuration and evolution (CE) goals
  - *CE1: Information models (vocabularies, concepts, and definitions) are agreed to by all parties.*
  - *CE2: Where multiple-source information models exist, there are bridges between them.*

  - *CE3: Semantics (information model) are captured independently of the technical interoperability categories.*
  - *CE4: Resources can be unambiguously identified by all interacting parties.*
  - *CE5: Resource identification management is defined.*
  - *CE6: Discovery methods exist for interacting parties.*
  - *CE7: Configuration methods exist to negotiate options or modes of operation.*
  - *CE8: Parties can enter or leave without disrupting overall system operation and quality of service.*
  - *CE9: Interface contracts between parties allow freedom of implementation.*
  - *CE10: A migration path from older to newer versions exists.*
  - *CE11: Capability to scale over time without disrupting overall system operation.*
- Operation and performance (OP) goals
  - *OP1: Common understanding of quality of service, time, and scheduling exists.*
  - *OP2: Time order dependency and sequencing are defined.*
  - *OP3: Time synchronization requirements are defined.*
  - *OP4: Transactions and state-management capability (atomicity, consistency, integrity, and durability) are defined.*
  - *OP5: Performance and reliability expectations are defined.*
- Security and safety (SS) goals
  - *SS1: Security policies (e.g., confidentiality, integrity, availability, and accountability) are defined, maintained, and aligned among parties.*
  - *SS2: Privacy policies are defined, maintained, and aligned among parties.*
  - *SS3: Risk is assessed and managed.*
  - *SS4: Logging and auditing processes are defined among parties.*
  - *SS5: Failures (loss of functionality) fail safe (health of system above individual components).*

Interoperability Maturity Characteristics

The five maturity levels defined by CMMI (CMMI 2011) can be applied to interoperability metrics to define levels of progress in terms of maturity. These levels include: 1) Initial, 2) Managed, 3) Defined, 4) Quantitatively Managed, and 5) Optimizing. The following maturity characteristics provide criteria for evaluating progress through these maturity levels toward improved interoperability:

- Community and governance
- Documentation
- Integration
- Test and certification.

7.1 Interoperability Category Goals

7.1.1 Organizational Goals

Improving business value propositions for buildings interoperability stakeholders requires that connected solutions scale to large numbers of buildings and be applied across regions. For small and medium buildings, the high degree of buildings diversity requires automated, adaptive connectivity solutions that minimize deployment and lifecycle maintenance costs by self-conforming to specific buildings systems and topologies. To make this work requires economic and regulatory policies in the buildings automation community that encourage interoperability.

Business and regulation alignment is required when multiple interacting use cases are being implemented. An illustrative example is energy efficiency and traditional demand response. The value of traditional event-based demand response is proportional to the load reduction from baseline achieved during curtailment. Improving energy efficiency tends to decrease the baseline and therefore decrease the value of load reduction. Offsetting interactions need to be accounted for in business models and policies.

Buildings community business value propositions, objectives, processes, and procedures across the interface between transacting parties must be aligned for interoperability. Misalignment impedes the growth of standards-based connected solutions. An illustrative example is a distribution system operator who desires to reduce costs by implementing demand response in a competitive, multi-demand-response provider environment. However, if every third-party demand-response provider's interface has a unique, proprietary business interaction then the misalignment causes increased integration and maintenance costs. Business and economic policies can encourage alignment by conforming to a common set of definitions and practices for transacting business that simplify integration, but allow for stakeholder innovation that increases business value.

The IMM indicates that for improvement of interoperability to higher levels of maturity, integration should be repeatable with predictable effort, integration metrics must be defined, reference implementations should exist, and integration metric measurements should be collected. It also specifies that appropriate and ongoing standards development and testing processes be in place for continually improving and evolving the integration experience. Creating the forums and processes to accomplish these things are community alignment activities that help achieve the organization goals of the IMM.

7.1.2 Information Goals

The deployment of connected adaptive buildings devices and systems at scale in a multi-solution provider ecosystem requires that the information exchanged be unambiguously understandable by the transacting parties. Because this information is not static and will evolve over time flexible, adaptive, and dynamic technologies and standards are required.

Information models (i.e., vocabularies, concepts, and definition) relevant to buildings operation use cases are agreed to by all parties and are used to exchange information. These semantic models differ from existing low-level data models where measurements are identified only by "tag name" or "point name." Instead, information models describe real-world buildings devices and systems along with their attributes and the relationships that exist between them. These information models should provide the "metadata" (i.e., data about data) necessary for interacting parties to understand the contents of the messages they exchange.

Easy-to-integrate buildings applications require clear definitions of terms, consistency, and uniformity. Therefore, BIMs must abstract buildings information while permitting access to the information needed to satisfy the application use case.

Where multiple BIMs exist, semantic bridges (adapters or translators) should be used to ensure that information is not lost. In addition, information models should be defined independent of technical interoperability so that the information content in a message transaction is independent of the communication network protocol used.

7.1.3 Technical Goals

The transport-independent structure and format (syntax) of buildings information exchange should be defined and understood by the transacting parties. The performance requirements for a use case interaction (e.g., transport speed and security requirements) drive the selection of the appropriate technical standards and solutions. Technical connectivity solutions that enable information exchange using multiple transport mechanisms (such as wired and wireless communication networks) can better adapt to varying application quality requirements.

Communication transport protocols used in integrating connected equipment need to be appropriate for security, reliability and robustness in the presence of errors and faults including application state management and recovery.

The communication network management may have requirements for rapid location-independent fault detection, diagnostics, isolation, and recovery. Standards that enable network and system management should be understood and aligned by the transacting parties.

7.2 Cross-cutting Issues Goals

7.2.1 Configuration and Evolution Goals

Scaling up connected buildings systems requires that the level of effort to deploy, commission, and support connected systems is minimized. System configuration is an important component of commissioning, but is often a time-consuming and error-prone manual process. Buildings systems and interfaces typically require that numerous system parameters be adjusted correctly for the system to function properly. Systems and interfaces should become more adaptive and self-configuring through interfaces that support transacting party discovery and negotiation processes. Once resources are discovered, mechanisms must exist for automated negotiation of modes of operation and other options. This requires that resource identification management is clearly defined.

Interoperability maturity efforts need to accommodate the ability of a buildings automation system to adapt as components undergo change while maintaining system operation. Connected parties must be able to enter or leave without disrupting overall system operation and quality of service and interface contracts between parties must allow freedom of internal implementation. Well-designed interface standards enable a variety of products to securely work together by defining interfaces that allow each transacting party to evolve independently while maintaining their shared connectivity agreement. This is especially needed to support legacy equipment together with new equipment capable of using the latest standard version. A clear migration path from older to newer interface versions should exist.

7.2.2 Operation and Performance Goals

Connected buildings applications range from real-time, mission-critical systems to management information and decision support systems. The interface OP requirements include a common understanding by the transacting parties of (1) quality of service, time, and scheduling; (2) time order dependency and sequencing; and (3) time synchronization. Transactions and state-management capabilities (i.e., atomicity, consistency, integrity, and durability) must be consistent and well-defined and performance and reliability expectations must also be explicitly and clearly understood and defined.

These goals are interrelated and directly coincide with specific use cases and the preconditions and assumptions that surround an interaction through a defined interface. Tradeoffs and assumptions must be clearly understood and accepted by all parties.

An illustrative example of a tradeoff relating to state management is that between stateful (i.e., has the ability to retain information about the state of a transaction) and stateless interfaces and the need for scalability and resilience. Stateless interfaces do not assume that application state is preserved and therefore send state information in each message resulting in larger messages, longer latency, and more bandwidth consumption. The W3C REST architectural style of interaction with webpages is an example of a stateless interface as the appropriate webpage content is sent without presuming the state in each interaction. Stateful interfaces assume that state is preserved and therefore require smaller messages, less latency, and less bandwidth, but increase the resources and complexity needed to maintain the state over time, especially under fault recovery conditions.

7.2.3 Security Privacy and Safety Goals

Security, privacy, and safety are critical aspects of connected buildings systems. Increased connectivity directly increases the cyber-attack surface area of systems. Communication standards must clearly and explicitly address security and privacy policies (e.g., confidentiality, integrity, availability, and accountability) to ensure that they are well-defined, maintained, and aligned among parties. This includes enabling and managing risk assessment and logging and auditing processes. NISTIR 7628, “Guidelines for Smart Grid Cyber Security” provides a comprehensive security reference (CSWG 2010).

Each automation zone presents a different attack surface and, therefore, is associated with a different security risk. Mitigation strategies at each automation zone—and likely each device—will be a function of that automation zone’s relationship to the overall health and operation of the systems to which it is connected. In some cases, a device may lack the ability or resources to be upgraded to deal with evolving cybersecurity threats, requiring strategies to be employed in connected systems to mitigate that device’s limitations.

Cyber security and privacy are critical components of end-to-end connectivity standards due to the potential for adverse impact on the building, the grid, building owner/operators, and occupants. At scale, large numbers of interaction messages will be sent between buildings automation equipment and systems, and outside parties. This represents an attack surface that has the potential to disrupt buildings and other systems, such as the power grid. Invalid signals sent to buildings systems can interrupt and compromise commercial operations and result in harm to equipment and personnel. Invalid signals sent from buildings to service providers can cause misinformation and result in potentially harmful actions or disruption of intended economic and social benefits.

The five areas of security that must be addressed by the interoperable equipment and systems are authentication, authorization, confidentiality, integrity, and non-repudiation. Authentication refers to validating the identity of a user or code. Authorization refers to validating the authority of a user or node to perform actions. Confidentiality is the ability to encrypt data to prevent its access. Integrity is the ability to detect data tampering. Non-repudiation is the ability to ensure that messages are sent and received by those that claim to have sent and received the messages.

Some examples of digital techniques used to mitigate these security issues are:

1. Authentication: digital certificates (e.g., X.509 [Housley et al. 1999]), username/password.
2. Authorization: digital certificates (e.g., X.509), username/password, usually handled internally and rejected by the application.
3. Confidentiality: message encryption using transport level security (TLS) with digital certificates.
4. Integrity: message signing using TLS with digital certificates.
5. Non-repudiation: validation using a combination of the above including message signing using digital signatures, time stamps, and encryption.

The use of X.509 digital certificates requires that the certificates themselves be managed securely and efficiently. As such, community interoperability policies need to ensure the secure and efficient management of digital certificates.

In addition, system-wide security integrity needs to be maintained. This means that the above security principles and techniques must be applied in such a way that if the security of a single component or interaction is compromised it does not affect the security of other components or interactions.

Safety is also a priority of buildings operations. As systems become more interconnected, maintaining safe operations becomes more demanding. System and equipment failures must fail safely and maintain the health of the system above the health of the individual components. Interfaces must be designed so that data written to buildings automation systems can be verified prior to impacting buildings operations.

7.3 Interoperability Maturity Characteristics

7.3.1 Community and Governance

Community and governance processes must be in place to provide effective management of interoperability solutions. The maturity of these processes range from project-level management to highly organized community management and improvement processes.

- Initial: Management is ad hoc
- Managed: Managed by project agreement
- Defined: Managed by community agreement
- Quantitatively Managed: Processes ensure currency and interoperation
- Optimizing: Managed by a community quality improvement process

7.3.2 Documentation

Documentation provides a record of functionality which supports interoperability. Documentation maturity ranges from project-level specifications to open community standards.

- Initial: Documentation is ad hoc
- Managed: Documented in a project specification
- Defined: References community standard with some customization
- Quantitatively Managed: References a community standard without customization
- Optimizing: Adopts an open community standard

7.3.3 Integration

Integration relates to the level of predictability and repeatability for achieving interoperable solutions. Integration maturity may range from unpredictable custom-only solutions to solutions based on standards and are predictable and repeatable while being further refined over time.

- Initial: Integration is a unique experience
- Managed: Integration is repeatable with customization expected
- Defined: Integration is repeatable with predictable effort
- Quantitatively Managed: Integration metrics are defined and measurements collected, and reference implementations exist
- Optimizing: Integration metrics used for improvement of the standard

7.3.4 Test and Certification

Testing and certification advances interoperability through formal compliance with standards and protocols. The maturity level of testing may range from project-level testing to community compliance and certification testing. Compliance testing may range from certification-only testing to testing that actually demonstrates interoperability and conformance of multiple products to relevant standards. The IMM currently does not cover testing and certification maturity, although the following definitions are proposed.

- Initial: Testing is ad hoc
- Managed: Tested to plan with results captured
- Defined: Tests exist for community with certification and members claim compliance with standard
- Quantitatively Managed: Community test processes demonstrate interoperability, and members claim interoperable conformance
- Optimizing: Test processes are regularly reviewed and improved

8.0 Interoperability Challenges and Gaps

Achieving adoption and deployment of buildings energy management and automation systems at very large scale throughout the United States requires standards that can successfully address the many advanced facets of interoperability. Where connectivity standards exist, they often fall short in one or more areas of functionality. This was reinforced at the May 2014 U.S. Department of Energy (DOE) Building Technologies Office (BTO) buildings connectivity technical meeting, where a number of interoperability issues were raised by buildings stakeholders (DOE 2014). In addition, solicited public comments to a DOE-BTO public meeting, "Physical Characterization of Grid-Connected Commercial and Residential Buildings End-Use Equipment and Appliances," held in July 2014 (DOE 2015a) reiterated the importance of specifying interoperability aspects when characterizing such equipment. Lastly, attendees of the BTO Buildings Interoperability Vision technical meeting held in March 2015 (DOE 2015b) reviewed the interoperability challenges and gaps indicated in the initial draft of this document (Hardin et al. 2015) and offered new insights. This section summarizes interoperability challenges and gaps for connected buildings as context for developing a vision for buildings interoperability.

Standards may lack the ability to model information, discover services, or provide sufficient security and privacy assurances. Evaluating existing connectivity standards against baseline interoperability goals and objectives helps identify the gaps between where standards-based technology deployments based are today and where they should be for achieving a high level of interoperability.

Some general observations can be drawn from the use case and standards landscapes:

1. Interoperability standards are not widely deployed, or do not exist, for most identified use case scenarios. This is not surprising because many of the use cases are forward looking; however, the observation applies to both current and future scenarios.
2. Standards concentration is highest in buildings device connectivity. This reflects the diversity and competition in onsite buildings systems. The impact of having many overlapping device standards significantly increases the integration and maintenance costs and complexity of sensor data acquisition and actuator control.
3. Most existing device standards expose simple data semantics and do not expose structured data in the context of a buildings information model. While communications technology is now allowing things to connect reliably, the integration challenges are beginning to focus on identifying data with specific equipment, consistently describing and interpreting the data, mapping data between deployment platforms, and accommodating the information dynamics associated with the evolution of the connected building over time.
4. As buildings interoperability standards struggle at the information level, there is a distinct lack of progress on standard buildings interaction processes, common business objectives for interactions, and supportive business or governmental policy with which to align technology decisions.

Connected buildings must be flexible to accommodate independent changes in equipment components and ICT technology. Existing integration approaches are challenged to support the flexibility required for connected equipment and systems to evolve independently through time. Data access in many of today's buildings connectivity standard interfaces allows a party to inspect and read whatever data the device may want to expose in an implied agreement. Challenges arise when a device stops supporting a data field or perhaps changes the measurement units causing the party's process that is using the data to break. When a device is unaware who is using its data or for what purpose, it cannot notify the users of changes that may occur.

While today's data-oriented integration approaches establish data-level agreements, intelligence is moving down into the equipment at the control and device zone levels of the connected building. These distributed, multi-agent systems more naturally support interfaces that hide unnecessary internal device or subsystem details. They can do this by responding to system events or supporting service-oriented agreements that emphasize collaboration and delegation. This abstraction away from direct data sharing helps to reduce the amount of information exchanged and the effort to manage internal device data and process changes over time. Further, it clarifies the roles of each party so that each may evolve independently while continuing to support the same interface agreement. Systems incorporating such standard interfaces would require less time, effort, and costs to participate in supervisory distributed control strategies.

The use cases indicate that connected buildings will require initial and ongoing automated operations support to 1) commission and verify energy and system performance; 2) monitor and diagnose system faults; 3) improve energy performance through simulation, analysis, and machine learning; 4) provide advanced automation; and 5) respond to grid events and transactions. Providing these services is currently cost-prohibitive for many small and medium commercial buildings. Through improved interoperability, these specialized buildings device platforms can work together to enable advanced buildings energy management creating connected communities of systems and things or a buildings ICT platform of connected platforms.

The interoperability areas of the GWAC Interoperability Context-setting Framework are used below to structure a discussion on interoperability challenges and gaps.

8.1 Organizational Issues

In general, the state of standards making has not encompassed business processes or aligned business objectives. Deploying buildings connectivity solutions that satisfy one or more use cases at scale requires that policies and regulation be consistent and aligned across state and regional boundaries. Achieving alignment is a challenge due to the wide variation in regulatory structures and policies which include state-regulated, federal-regulated, and non-regulated energy providers.

Policies and incentives need to encourage interoperability stakeholders to work together while permitting them to achieve internal business objectives.

SDOs often compete by developing overlapping standards, which increase market uncertainty and delay standards adoption. Coordination and communication is needed to minimize the impact of this competition or to support the co-existence of equipment using similar, but competing, standards approaches in the same building where necessary.

Technology and service supplier organizations often perceive interoperability as a threat to business models as it can result in commoditization. In many cases this is not the result. An effort is needed to promote the business value of interoperability and its positive impact on expanding market growth.

Organizations involved in demand response and demand management often perceive energy efficiency as a threat to business models (Riker et al. 2014). An effort is needed to promote the business synergies and opportunities that span both facility-centric energy efficiency and energy interactions with actor domains that drive optimization of energy use and mitigate environmental impacts systemically.

Business transactions need to be encouraged through the development of machine-readable tariffs and contracts for interactions that permit building owners and operators to engage in automated business relationships. Today's standards presume a style of interaction when interfacing with equipment and systems, but do not explicitly specify the business process steps in a machine-readable form or in structured business process modeling tools, as exists in languages such as the Business Process Execution Language. This can lead to misunderstanding or misinterpretation in the configuring and integration of connected equipment. Also, as equipment and systems evolve, the lack of formal business process modeling can more easily lead to failures in connectivity or situations where the building owner and system operator may be unaware that the interaction is no longer operating as expected.

Reducing the costs of buildings connectivity for small- and medium-sized businesses is a particular challenge due to limited resources and the need for ongoing support and maintenance of automation and connectivity software solutions. Cybersecurity threats and associated risk assessments are likely to pose an even greater challenge in this cost-constrained environment.

8.2 Informational Issues

While the technical areas of connectivity and networking have made considerable progress regarding interoperability, addressing informational interoperability concerns arguably represents the next major challenge for connected buildings. As mentioned earlier, the information models widely used in connected buildings today model generic measurement and control points. Configuring connected equipment for coordination in a buildings management system is challenged by the lack of richness in the information models. The generic characteristics of the information models impacts the ability to enforce valid associations based on the type equipment and its particular attributes. Referencing the right data is error prone and usually relies on naming conventions that makes automated discovery and configuration more difficult. In addition, as interoperability advances to support service-oriented business process models, the content of the messages exchanged between interacting equipment and systems will benefit from a common model of information. An informational challenge is to establish a shared knowledge about the information being exchanged.

An important characteristic of connected equipment using emerging information models is that, after achieving basic connectivity at the technical level, they communicate with each other using a wide variety of platform languages, each with specific language semantics and information encoding. This permits them to interoperate only with other devices that speak the same platform language. A widely recognized connected buildings information model based on modern object-oriented concepts that could service a wide variety of use cases and embrace open-world assumptions would help ease the translation between different platforms and their associated languages, and therefore, advance interoperability within the buildings domain. While this remains a challenge for connected buildings, examples of progress exist in other domains. Two examples include 1) the Common Information Model (CIM) (IEC 2006) in the electric power industry and 2) the Federal Health Information Model, which supports electronic healthcare records in the medical area. In both cases, having a widely recognized semantic model provides a foundation that helps map between different platform languages. In addition, such a common information model provides a direction for new platforms to adopt commonly recognized names, descriptions, and relationships for their data of interest. For instance, as platforms are emerging in the residential buildings area (e.g., Google's NEST and Apple's iHome) with their own information models, integration between these platforms will become a challenge that a common buildings information model can help address over time.

There are many standards efforts to investigate when considering the information modeling issues associated with connected buildings operation. Several efforts have arisen in response to buildings to electric grid integration efforts. The ASHRAE Facility Smart Grid Information Model (BSR/ASHRAE/NEMA 2012) supports a representation of real-time energy information related to controllable loads in buildings so that building operation systems can understand the electric energy flexibility potential of shifting load and respond to calls for grid services from power system operations. OASIS eMIX and IEC PC118 represent standards efforts for engaging connected buildings in energy trading scenarios. The wide adoption of these models should help building to grid interoperability. However, these developments represent an incremental improvement to overall buildings interoperability and will need to evolve with the trends in information technology being driven by forces such as the Internet and ubiquitous connectivity visions.

The need for a common connected buildings information model for improving system integration and systems communications has been identified by the ANSI EESCC and included as recommendations in the Standardization Roadmap (ANSI 2015a). Information model recommendations in Section 2.3 of that document include:

- *Common information models and taxonomies:* Standards are needed around common information models and taxonomies using common protocols to transmit data between the building and the smart grid, so that smart grid service providers can utilize data in a consistent way.
- *Methodology and identification of energy data formats and attributes:* Standards are needed that provide for the development of the methodology and identification of commonly exchanged device, asset, process, and system integration parameters and specifications (data formats and attributes) related to significant energy uses or objectives of an energy management system.
- *Methodology for energy information sharing:* Standards are needed that provide a methodology for energy information sharing within a building, facility, or group of facilities, as well as with the grid.
- *Standards to provide for a buildings energy information model*: Standards are needed that provide for a buildings energy information model, consisting of a series of use cases, to shape future standards related to buildings energy performance and management. The content of those standards should be tested to ensure the content provides all of the information needed to optimize the energy performance of the building.

The commercial buildings domain will continue to consist of a diverse population of new and existing buildings that contain a wide range of equipment and interactions. A number of comprehensive BIMs are in use for architecting, engineering, simulating, analyzing, and constructing new buildings; however, these models are targeted at automating the early lifecycle phases of buildings and do not support the operational requirements of connected buildings. Instead, they address a wide range of buildings design and construction data exchange needs including both electronic and non-electronic exchanges. BIMs include buildings asset and component data as well as scheduling and process data used (e.g., in developing bills of materials, cost estimates, and construction schedules). These models have evolved over the past several decades and have been standardized by the industry. While they are not operational models, the equipment and systems represented in these models become operational once constructed. Moving equipment information from design tools to operational information models could greatly speed up and lower the costs associated with buildings systems integration.

National BIM Standard (NBIMS) and BuildingSmart are initiatives under the National Institute of Building Sciences and BuildingSmart, respectively, that have defined a set of related BIM standards that, together, address a common data dictionary of terms (i.e., International Framework for Dictionaries), common process definitions (i.e., Information Delivery Manual), and a comprehensive buildings data model (i.e., Industry Foundation Classes and Model View Definitions) (see Appendix C).

Connected device information models evolving from IoT are typically being developed to satisfy specific platform or product use cases and lack standard buildings context semantics needed for interoperability. BIM models such as the Industry Foundation Classes, COBie, OmniClass, and Green Building XML contain information models that describe buildings systems and many of their components. These models (see Appendix C) could potentially be leveraged for use within a connected buildings environment; however, challenges, including the following, remain:

- The National BIM Standard and BuildingSmart are attempting to target a complete lifecycle data model for a building, extending beyond the design and construction phases to buildings operations and maintenance. This is reflected in the COBie and COBie-specific models. The information in these models is designed to aid manual information transfer from design to operations, but not to be integrated into modern operational buildings ICT systems.
- BIMS such as NBIMS IFC utilize EXPRESS as the modeling language. EXPRESS is a standard information modeling language for product data and is formalized in the ISO STandard for the Exchange of Product model (STEP) (ISO 10303), and standardized as ISO 10303-11. The software industry however has standardized on the Unified Modeling Language (UML) which has resulted in a large and growing number of software development lifecycle tools from design and architecture to code generation. Software applications and systems targeted to connected buildings communications are best served by UML-based models.
- OmniClass classification is strictly hierarchical, and as a result is more difficult to extend in a consistent way that is discoverable by others. Classification lacks explicit rules for implementation, so that systems and users can implement it in different ways. Reliance on matching the name or numbers can be problematic if any errors are introduced through input or by differences in use.
- Several legacy classification systems are in use such as; 1) MasterFormat, which organizes specifications based on work results and is related to OmniClass; 2) UniClass; and 3) Uniformat.
- Green Building XML includes equipment metadata (e.g., buildings context and equipment design data) and an abstract “meter” element that could potentially be used to hold operational data. It was not designed for efficient real-time communications; however, the buildings contextual information could be of significant value for advanced buildings automation strategies and for providing the semantic context for connected buildings interoperability.
- Green Building XML is XML-schema centric and does not have an associated and supported UML model.

During building design, simulation is often used as a tool to reduce or optimize a building’s future use of energy. Energy simulation tools rely on physics-based models of the interactions of energy flows within a building (e.g., heating, cooling, ventilation, and lighting) and those external to the building (e.g., air and ground temperatures, wind, and solar radiation). Many simulation tools are available and each of them requires detailed inputs about the building’s configuration, systems, projected operations, and external environment. To represent these complex physics-based interactions, different energy-simulation tools rely on different assumptions and varying degrees of simplification, and as a result often lack common information requirements.

A canonical information model for buildings operation could also help support buildings services that provide construction and retrofit commissioning of buildings energy systems as well as ongoing energy analytics, forecasting, and guidance for operations. However, efficiently bridging the gap between the designed energy performance of a building (represented in the design model) and its actual performance (represented in the operations model) will be challenging. The ability to correlate designed performance versus actual performance creates a baseline for a modeling feedback loop that leverages quantitative measurements and metrics for effective management of buildings operational performance.

BIMs used for commissioning and analytics are still in the nascent phase and primarily vendor-specific. Cloud-based service providers rely upon proprietary technology and information models to transfer and map data from buildings automation systems to remote repositories and energy analytics software. Correlating buildings data currently requires mapping building-specific “tag names” and other metadata to proprietary databases. The challenge is that this approach does not scale well to large numbers of buildings as it is time-consuming and costly to implement and support.

8.3 Technical Issues

A wide variety of communication standards are used in buildings controls and devices. This makes device data access and device integration very expensive and time-consuming. If a smaller set of control and device standards were widely used that permitted auto-discovery and consistent semantic information exchange, data access would be greatly simplified and costs reduced while enabling innovation, competition, and market growth.

The Internet and Internet protocols (IP) have become the dominant ubiquitous networking technology; however, the open communication protocols that depend upon the IP stack are undergoing significant change driven by mobile technology and the need to access data from anywhere at any time. Several terms are used to describe this effort but one term in wide use is IoT (Internet of Things).

Stakeholders driving the requirements and standards in SDOs are very diverse and it is important that requirements fed into the standards development process are aligned with buildings connectivity requirements. One challenge facing automation technology use cases is the desire to use the public Internet with assurances of security, performance, and reliability. The concept of “net neutrality” represents a social policy to keep the Internet’s resources at an equal quality-of-service level and priority available to all users. While this has worked well for things such as e-mail, other things such as video streaming can cause bandwidth capacity problems, impacting other time-critical applications of the public Internet (e.g., buildings automation).

Real-time access to energy metering data is a basic requirement for buildings management and energy efficiency. While existing protocols (e.g., Modbus) are commonly used for this purpose, only two standards (i.e., SEP1 and SEP2) are targeted at providing this real-time energy metering data from utility revenue meters within a building. SEP1 has limited deployment and has been replaced by SEP2; however, SEP2 is not yet widely deployed and will require a significant amount of time involving large numbers of deployments to become established.

8.4 Configuration and Evolution

Resource search and discovery protocols are important for finding and interconnecting systems. Searching for resources from a collaborating, connected equipment perspective involves querying a specific inventory to find resources where the specific name or its full description is unknown. Resource discovery refers to the act of finding particular resources that may not initially be of interest or even known to exist. These functions assist in configuring devices and can be automated to support steps toward self-configuration. Many buildings standards do not support search or discovery, but instead rely upon manual configuration to specify network endpoints and connected devices. Smart adaptive automation systems require the ability to securely find and install devices in a manner—similar to how USB devices are discovered. Some of the discovery protocols currently in use with potential for buildings systems include: Universal Plug and Play (UPnP), Salutation, Jini, Service Location Protocol (SLP), Extended MulRcast Domain Name System (xmDNS) and DNS Service Discovery (Dns-sd).

Equipment and their data also need to be uniquely identified in the scope of the building, the owner’s portfolio of properties, or for related purposes (e.g., warrantees) across all buildings. Unique identification schemes present a challenge, particularly when their scope must transcend individual buildings, owners, and technology suppliers. Establishing a unique identification scheme for connected buildings is an interoperability challenge for alignment within the buildings community that, if resolved, could offer significant benefits.

Buildings systems are designed, installed, and configured. Typically, buildings design information needs to be manually configured into online automation systems. Standards such as COBie, a specification for the lifecycle capture and delivery of information needed by facility managers, and MasterFormat, a standard for organizing nonresidential construction specifications, may be extensible and utilized to decrease data entry errors and reduce the time and effort required to configure and commission buildings systems.

Some connectivity standards specify only functional interfaces and relegate interface configuration, such as security, to out-of-band vendor-specific protocols and processes. In addition, lifecycle system management functions for ongoing support and maintenance of the interface are typically out-of-band processes. Standards need to implement these ancillary functions or specify how they are to be handled to ensure correct and consistent application.

8.5 Operation and Performance

Connectivity standards and interoperable automation frameworks are needed that enable third-party buildings service providers to develop and deploy cost-effective, secure, scalable, and interoperable solutions across large geographical regions.

Some connectivity standards do not separate transport from payload and semantic content. As communications technology changes, options for matching cost with communications performance needs (e.g., bandwidth and interference robustness) are limited if the transport layer is not separated from the message content.

The Internet continues to be leveraged by buildings and market service providers as the primary network for the delivery of buildings services. It is important that the operational performance of the Internet be maintained even as general Internet content (i.e., video streaming) increases and absorbs bandwidth. This issue is related to “net neutrality.”

A primary advantage of Internet-based communications approaches is the ability of the network to scale. Approaches to equipment integration also need to consider the ability to scale to a great number of devices or interactions with other parties (buildings and service providers). As an example, centralized optimizers that need to model the characteristics of all the connected equipment can require a large amount of information to be communicated to support these models. That impacts the integration effort to configure and maintain the models as well as the performance of the system if the optimizer malfunctions. This is a significant challenge. A distributed multi-agent system design that pushes more decision making to the equipment itself is an example of an approach being proposed to reduce communication dependencies and address scaling issues.

Some connectivity standards are re-purposed for applications that have different quality requirements (e.g., message latency, throughput, and scalability). As an example, a notification standard that relies upon an HTTP polling (i.e., “PULL”) interaction in local area networks may not satisfy the network efficiency and latency requirements for notification in wide-area networks. Another example is state management. An interface standard that relies upon maintaining tight state and time synchronization in a local area network may not function properly over a wide-area network with variable latencies and wider time deviations. These issues, and others, are not always clearly described and specified in the standards.

8.6 Security, Privacy, and Safety

Building owners and operators do not want to surrender asset information and control to outside parties due to perceived risk, mission-critically, sensitivity of data, and protection of intellectual property. These concerns need to be addressed through the application of security and privacy technology, controls, and policy that can be implemented, verified and maintained by building owners/operators without requiring information technology expertise. Current security technologies, such as public key infrastructure (PKI) using X.509 certificates, have been designed and successfully deployed within the context of large corporations with trained and trusted personnel. X.509 certificates are issued by trusted certificate authorities and contain metadata such as algorithms and strong public key encryption for securing communications, but they need to be properly managed over time to provide a high level of trust. As an example, invalidated certificates must be revoked. X509 certificate deployment within an unstructured, distributed, small-commercial-buildings-automation environment represents a challenge that needs to be addressed.

Approaches are needed that minimize the interface definition through information hiding and delegation of responsibilities that encourage cooperation rather than direct control. In addition, standards are needed that enhance trust through security and privacy controls—including security certificate management—that are robust, yet easy to understand and maintain in the field. This includes the ability of buildings operations to easily apply security and privacy controls at a fine granularity. The secure exchange of buildings data with standardized semantics by building owners and operators will enable buildings service providers and buildings operations to lower costs and provide a wider range of buildings services.

Security for smaller, cost-sensitive embedded devices within a building requires tradeoffs between encryption strength and runtime processing time. In addition, the use of encryption and authentication needs to be cost-effectively scalable to large numbers of long-lived devices and designed for two-way connectivity without violating firewall integrity, such as requiring in-bound TCP/IP ports.

Safety requirements are assumed, but are often not addressed until problems arise. Just as security threats and risks need to be identified and planned for, interoperability efforts need to ensure that safety risks and related concerns are recognized and mitigated. This includes addressing local safety issues and systemic safety concerns, such as a collective response from individual buildings that could bring down the electric distribution system or blackout a region. Potential failure scenarios need to be assessed so that equipment can move to safe modes of operation under degraded situations.

Security configuration and deployment needs to be well-planned and executed to minimize the introduction of security faults. This requires that standards clearly specify how security is configured and maintained over the lifecycle of the interface. The long-lived nature of the devices and the variety of software versions that will likely need to be supported are looming challenges. These challenges are compounded by the consideration that small, cost-sensitive devices may require more software and hardware resources to handle upgrades than to accomplish their intended function.

9.0 ICT Foundations to Advance Interoperability

While there are a substantial number of standards used across industry today, there are still critical interoperability barriers facing industry including machine-to-machine interoperability honoring advertised capabilities, and the inability to simply and adequately exchange, federate, and integrate information. Fortunately from a visionary perspective, a number of standards bodies' initiatives are currently active and have the potential of advancing many aspects of how devices, services, and data interoperate in the future. While it is unknown which standards will ultimately be widely embraced and impact industry, current activities and industry trends offer the means of overcoming traditional barriers that buildings interoperability faces today. Some of the standards bodies are active in the buildings industry, while others offer approaches that are very synergistic with meeting current buildings energy needs, but can be applied to an even wider array of applications and industries.

This section discusses the emerging industry interoperability standards that may enable the future directions for interoperability of connected equipment, and in what areas they are advancing interoperability.

Throughout this section the terms information and data are used when describing interoperability. While there are different interpretations of data and information, for the purposes of this section data is defined as discrete values (e.g., measurement value) represented in syntactic data structures. Knowledge gives semantic meaning to the data (e.g., engineering units), and information is the embodiment of data and knowledge. Unlike data, information may be both structured and unstructured.

Interoperability relates to the way devices and systems (1) define and represent semantically meaningful information, (2) communicate and exchange the syntactically structured information accurately to produce useful results as defined by the end-users of both systems, and (3) coordinate activities (see Figure 9). Interoperability in the building energy domain is similar to other domains and is motivated by the need to provide common approaches to the way information is represented, exchanged, accessed, and interpreted. As such, interoperability standards and initiatives from other domains have the potential to be applied to the buildings domain.

ICT ecosystem stakeholders develop interoperability standards representing a wide range of general connectivity needs and interests as well as the needs and interests of specific industry sectors. Many of these standards have the potential to be adopted by the buildings sector. Ideally, to have the greatest impact, emerging interoperability standards would provide solutions for enabling new innovations in energy efficiency; support backward compatibility to existing deployed standards; and, when possible, bridge barriers that current buildings ecosystems face with existing legacy infrastructure.

This section addresses various classes of ICT standards that are gaining popularity and their interactions in an ecosystem of interoperable products. Appendix E contains more details about many of the standards.

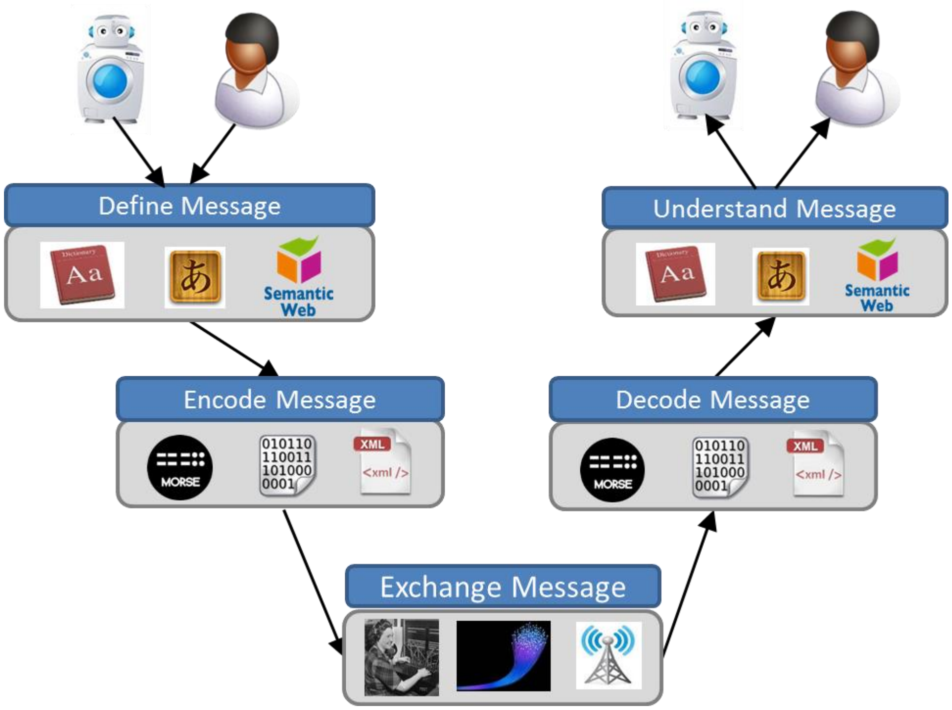

Figure 9. Interoperability Components

9.1 Defining and Understanding Meaningful Information

Interoperability begins with representing well-defined, semantically meaningful information that is both easily understood and can be reused. A number of different open data initiatives and SDOs, community vocabularies and ontologies, and technical achievements (e.g., the modeling standards bodies) are beginning to converge on the development of common approaches to organizing data, structuring data, organizing the surrounding body of knowledge that contextually describes the data, and modeling the systems responsible for exchanging and storing data.

9.1.1 Open Data Initiatives and Standards

"Open data" initiatives support standard representation of data so that information that can be freely used, modified, and shared by anyone for any purpose. This has the potential to make anonymous buildings data easy to find, access, and use for many purposes ranging from the development of advanced buildings analytics to the inspection of information for system interoperability testing. While operational interfaces to buildings automation equipment and systems should be designed to support only the narrow, connectivity agreement and hide internal device complexity, the fact that the data is transmitted in open data formats enhances the ease of interpretation and integration. In addition, open data standards are valuable in supporting diagnostics and performance logs, which tend to be more data intensive.

Data interoperability standards are important to enabling "open data" as they provide common approaches for more general software systems to read and exchange information. Best practices are guidance given to data producers who implement standards. By using best practices, data standards can be implemented in a way that ultimately provides the greatest benefit to the data consumer. The use of best practices also enhances interoperability, because interface definitions and resource identification strategies that use standards in common ways incorporate concepts and methods that make interaction with associated product offerings easier to interpret and less ambiguous. In addition, while not crucial for buildings systems integrators, the environment for software development toolsets is enhanced because the agreement on open data standards and implementation best practices encourages a variety of toolset suppliers to offer innovative user experiences based upon the same underlying data representation.

9.1.2 Community Vocabularies and Ontologies

Achieving the buildings interoperability vision will require that interfaces between automation equipment and systems participating in the ecosystems share a common understanding of the information being transferred through the interfaces. This is especially important for interfaces used within an ecosystem, but it is also important for semantic alignment (or at least semantic mapping) between ecosystems because all ecosystems interface to common physical systems within buildings. As an example, an heating, ventilation, and air-conditioning (HVAC) system provider would be best served were their system compatible with, or adaptable to, equipment and systems from multiple ecosystems. If common semantics are used at the interface, adaptation to specific technical protocols becomes significantly less challenging. In addition, common interface semantics decrease the challenges for a participant of one ecosystem to adapt products and services to another.

Ontologies are formal, expressive, descriptive information models that express real-world concepts and behaviors as organized and interrelated data structures using modeling languages such as Web Ontology Language (OWL). Technologies such as the Web of Things, Linked Data, and Linked Services leverage the web and Internet to integrate devices and connect related data and services that were not previously linked or that were linked using other methods. Applying these technologies to buildings energy would make it easier to link data from different ontologies and could support mechanisms to revise the ontology over time without breaking legacy connections. Lastly, these ontologies could enable the creation of new associations between buildings energy data that lead to new insights and knowledge for improving buildings energy analytics and modeling.

IEC CIM and the ASHRAE Facility Smart Grid Information Model are examples of community ontologies.

9.1.3 Modeling Language Standards

Modeling languages (e.g., UML and Resource Description Format [RDF]) are used to construct information models that express real-world concepts as interrelated data structures. These models can be used for defining the content of messages used in buildings equipment and system interfaces.

Modeling languages can be powerful interoperability tools because they are technology agnostic and can be used as a specification to generate data structures and software for interfaces. An information model of a device, system, or other abstract concept can be shared between organizations, allowing each organization to support the same standardized interface definition but implemented using software that is fully integrated within their current infrastructure.

IEC CIM and the ASHRAE Facility Smart Grid Information Model are examples of ontologies that use modeling languages such as UML and RDF for concisely describing information elements and relationships.

9.1.4 Resource Identification

Identifiers are simple labels that, by convention and software design, allow us to distinguish what is being identified from anything else: only one entity may have a given identifier, and an identifier always identifies the same entity. Identifiers are used extensively in every information system, making it possible to refer to any particular element and to establish relationships between entities. Depending upon the application, there are different options available for identification. Traditionally, many applications have used local identifiers (i.e., filenames or database keys); however, these are problematic in systems that will integrate data from multiple sources, preserve it for the long term, and make it available to a distributed community. Of primary importance is the need for identifiers to be globally unique and for the link between the identified entity and the identifier to be maintained in perpetuity. Another useful property is for identifiers to be 'actionable,' in the sense that simply knowing the identifier is enough to allow you to find out more about it. Web URLs are actionable and can be used to retrieve the identified web page, although they may not be persistent.

A number of identifier schemes provide these properties. They differ in the specifics of their technologies and socio-economic models (i.e., who can create identifiers, who is responsible for preserving them, and who makes them actionable). A Uniform Resource Identifier (URI) is used to indicate where such identifiers could appear in the data model. The definition of URI is broad enough to encompass identifiers such as raw digital object identifiers (DOIs), as well as actionable identifiers (e.g., a DOI Resolver web address + DOI combination). (Common http:// or https:// web addresses are a type of Uniform Resource Locator [URL] which is a type of URI.) While decisions as to which scheme(s) will be employed are still to be made, it is anticipated that any choice would be representable as a URI and further, that any scheme(s) chosen will need to be capable of mapping to an http(s):// URL to enable easy retrieval of more information. Other identification strategies include GUID (globally unique identifier) or (universally unique identifier [UUID]), indicating uniqueness of an identifier across all things. GUID and UUID are machine-readable and carry no semantic interpretation.

The DOI scheme, which is popular in the scientific community for identifying papers and datasets, creates identifiers of the form 10.1103/PhysRevD.89.032002, whose uniqueness and persistence are managed by a registration agency (the International DOI Foundation). While a DOI itself is not directly actionable, the DOI Foundation maintains a web 'resolver' at http://dx.doi.org/ and prepending this resolver address on any DOI will allow you to use your browser to retrieve more information about the identified entity. As a second example, ORCID, a non-profit operating http://orcid.org/ creates unique persistent identifiers for researchers that can be resolved (by prepending http://orcid.org/ to the actual identifier) to retrieve a page describing the person (i.e., their name, e-mail address, affiliations, and scholarly works).

9.2 Encoding, Exchanging and Decoding Structured Information

Machine-to-machine communications require access mechanisms for easily communicating well-defined information representations. A number of SDOs have developed protocols and transport mechanisms to support information exchange. Open data encoding protocols refer to methods for encoding messages (e.g., JavaScript Object Notation and Extensible Markup Language) that are community developed and supported and openly available for use.

Information exchanged through buildings equipment or system interfaces needs to be encoded into a data stream and decoded from that data stream. Using widely used and supported data encoding standards decreases the level of effort and time required for ecosystem participants to implement interfaces.

9.2.1 Secure and Open Messaging

Buildings equipment and system interfaces require that encoded messages containing semantically understood information be exchanged through a messaging mechanism. Open messaging refers to community-developed protocols and standards used by software platforms for exchanging messages on networks that are openly available from multiple sources. Open messaging provides the means for distributed software systems (e.g., web services) to interoperate despite the fact that they were written in different software languages and run on different operating systems. Open messaging also provides the means to automatically generate client (user) interfaces to interact with the service (provider). Examples of open messaging include Representational State Transfer (REST), RESTful HTTP, Internet Engineering Task Force (IETF) XMPP, OASIS MQTT, and AMQP.

Information exposed to cybersecurity threats, or privacy policy violations, needs to be transferred using a secure messaging mechanism (e.g., Secure Hypertext Transfer Protocol). Standards pertaining to cybersecurity issues and interoperability are discussed in Section 9.4.

9.3 Business-to-Business Interoperability

Within ecosystems, business partnerships often form when relationships are beneficial to all parties involved. These symbiotic relationships evolve over time and require interoperable interfaces that integrate business processes, procedures, and workflows across business boundaries.

Building to building and building to grid interactions require contractual business relationships. These are normally manual transactions that require time and effort. They also involve an agreed-upon process for interaction that specifies not only the messages and their content, but their sequence and expected actions under degraded or failure situations. Interoperability technologies are being used in other domains such as financial markets to enable secure contractual agreements and processes between businesses and between people and businesses. These technologies could potentially be applied to contractual relationships between buildings and other buildings actor domains.

Business Process Modeling (BPM) refers to representing and modeling processes and interactions of an enterprise as they are important for defining interoperable interfaces both internally and externally. Modeling languages used for BPM include (1) Business Process Model and Notation (OMG BPMN), (2) SAP Business Process Library, and (3) ERIS Event-Driven Process Chains (EPC).

9.4 Cybersecurity and Privacy Standards for Interoperability

Cybersecurity is a critical aspect that must be preserved for buildings ecosystems to thrive and evolve. Cybersecurity includes the protection of personal and business sensitive information from potential miss-use, consistent with end-user privacy demands. One of the key aspects that differentiate buildings devices and systems from typical smartphones, tablets, and personal computers is the fact that they interface with and control physical buildings equipment. This capability amplifies the negative impact of cybersecurity violations on a building. Malicious access not only impacts data but can negatively impact occupant safety and comfort as well as buildings operations, reliability, and costs.

As a buildings ecosystem grows and its interoperable products and capabilities expand, so does the system attack surface (i.e., more opportunities exist for latent cybersecurity vulnerabilities to be identified and exploited). As a buildings ecosystem expands in market size and the quantity of buildings increases, cyberattacks can target common vulnerabilities, resulting in widespread negative impact. Connected buildings ecosystems built on open standards face an even greater challenge than proprietary ecosystems because of the wider availability and knowledge of their cybersecurity specifications and technology. Ecosystems using open cybersecurity standards cannot rely upon cybersecurity through obscurity and must explicitly address all aspects of cybersecurity.

Rigorous ecosystem conformance and cybersecurity testing can significantly reduce cybersecurity vulnerabilities but cannot eliminate them. Interoperability of ecosystem products and services needs to include support for secure installation and updating of software applications as well as associated services such as virus detection and elimination. As vulnerabilities are discovered, tested, and proven, updates need to be expeditiously dispatched to the ecosystem buildings platforms and software applications.

Cybersecurity technology has typically been developed and deployed within controlled ICT environments with corporate governance. Buildings ecosystem cybersecurity must be targeted at a wide variety of buildings operations environments that do not have specialized knowledge of cybersecurity. Cybersecurity needs to be embedded within products and services and easily configured and maintained by buildings operations. The latter consideration is particularly important as buildings systems and equipment typically have lifespans measured in decades, necessitating a greater degree of backward compatibility than is typical, for example, in consumer electronic devices. This also requires that ecosystem cybersecurity be supported by a wide range of hardware and software environments including both real-time and non-real-time systems. For example, digital certificates (e.g., X.509) have proven effective for authentication and encryption if they are deployed securely and their lifecycle is managed properly (i.e., revocation lists). Adapting digital certificates to build automation and controls at scale remains a challenge.

Related cybersecurity standards efforts that will impact connected buildings include activities in industrial controls, IoT, and smart grid communities. Industrial controls cybersecurity gained high visibility when the Stuxnet virus was discovered. Several industrial interoperability standards (e.g., OPC-UA) have incorporated advanced cybersecurity techniques and communication protocols for connected equipment that embed cybersecurity technology. Smart grid standards relating to buildings and facilities (e.g., SEP2 and OpenADR 2.0b) also incorporate modern cybersecurity techniques.

Specific cybersecurity techniques used by different buildings ecosystems could vary but it is important that all ecosystems provide sufficient cybersecurity measures to gain and maintain the confidence of buildings operations. Ecosystems can benefit from the collaborative development of best practice guidelines and standards for connected buildings. Though the threat target may be larger and better understood in a large ecosystem of products and services, the defensive measures (technology and processes) can also be more widely communicated, educated, and adopted. In addition, the pooled investments in an ecosystem to counter threats and vulnerabilities (e.g., cybersecurity-related tools and threat information sharing) are considerable and exceed the efforts that individual companies can afford to fund.

10.0 Future Directions for Buildings Interoperability

Given the changing nature and advances of ICT development and integration methods and tools as reported in the previous section, this section considers future directions for a growing population of intelligent equipment and their associated ICT platforms that can improve their integration into connected buildings.

10.1 A Buildings Interoperability Visionary Scenario

To appreciate how more general information and communication technology hardware and software trends may affect buildings, this section begins with a visionary scenario of a connected, small, commercial building.

The following story provides a first person view of applying automation technology to a small commercial building through the eyes of its owner. It focuses on technology deployment functionality, without providing a solution, but draws from interaction paradigms that the reader may find familiar and easy to extend.

I own and operate a decent-sized food restaurant. Some other building owners in the area have "buildings equipment management systems" and I'm thinking about buying one. They rave about how easy they are to install and use, and the comfort, security and savings they get. The prices have been coming down and I think I'm ready to try one out. I already have a bunch of appliances, why not add one more?

There are two that seem very popular. One, the "iBuilding," has the reputation of being very easy to use and has a bunch of cool features. Most new kitchen appliances, security systems, and heating and lighting systems are compatible with it. I saw one the other day and it looked like a little work of art that you could put anywhere.

The other, the "LightSaver", is very much like the iBuilding and seems to have the same features and functions. The one thing I did notice is that it is available from several companies and has support for a bunch of older appliances and HVAC systems. This is important to me because my building is 20 years old and has older kitchen appliances and HVAC system. I can buy these little boxes called "Black Boxes" that plug into the freezer, fridge, and HVAC that let them work with the LightSaver.

I don't really want to spend money upgrading the building equipment yet so I decided to go with the LightSaver. I also feel better because if the company goes belly up, I can replace it quickly with one from another company. I've done this with my phone already.

I ordered the LightSaver from a company called Orion Systems and all I had to do was plug it in and download an app called "The Agent" into my phone. The Agent quickly detected the LightSaver and walked me through the process of discovering my building after I got past the security and privacy screens. It found the electric and gas meters and the security and fire alarm system. Seems that the security system I installed last year is compatible and that the electric company had already installed compatible smart meters. That's good! Everything communicates wirelessly so I don't have to worry about running wires. I can see my energy usage and my security cameras from anywhere, at any time from my phone, tablet, or PC! It's a start!

I ordered and plugged in Black Boxes for my HVAC and appliances. Bingo! My Agent found them and now I can see and change the temperature as well as check out how the appliances are operating. When I *leave for the evening, I know everything is in good shape. I can even change the temperature setting on my freezer and fridge if I want to.*

So far so good but I'm not saving any money yet. In fact, I've spent money. What's next?

I go to the online Agent store and start looking around. There are all kinds of apps available to download into my LightSaver. One that folks have been raving about is a free app called "The Breeze." After walking through some screens where I tell it what my needs are, it responds by letting me know what information and resources it needs access to. It doesn't ask for everything, but for each capability, it lets me know what's needed to perform the job and asks for and obtains my permission before my LightSaver will allow it access. The access policies are established under pro forma language agreed to by the Connected Buildings Better Business Society, which works with state and federal legal groups on consumer rights and privacy issues.

Once the initial set up is complete, it monitors the energy usage of my building and my appliances for a week, and then shows me where I'm spending my money and how much I could save if I made some changes. It's important that my kitchen is fully functional during breakfast, lunch, and dinner, but I have flexibility between these times. I also don't mind if my lighting dims but it needs to be above a certain level during dinner. It keeps monitoring things and gets better and better. Almost like it was learning!

There's another app that can save even more by monitoring my three HVAC zones and automatically adjusting and balancing the units for top efficiency. This can really save dollars during the summer heat so it's worth paying $10 for the app. I don't like magic, but I've got confidence in it because it's an app from the same company that made my HVAC.

I just saw an ad from my energy company about a new app called "Help!" It listens to signals from my local "smart grid" and when a problem arises that my building can help with, it springs into action and I get paid without even noticing anything happened! I do have to install a Black Box on my water heater but I already have one on my big freezer. It's pretty smart. It knows about my equipment and makes sure that nothing bad happens to it. The ad says something about pre-cooling and ancillary-something but I'm happy if it works and I save money. They are also offering me a $300 rebate on a new water heater that is Help! enabled. It even monitors small flows of hot water that may indicate water pipe or valve leaks and sends LightSaver a message. They'll remove my old equipment and install the new one as part of the deal, but I need to decide in the next three months.

Well, so far I've saved more than I've spent and I love the added convenience of knowing what's going on at all times. If anything goes wrong, I get text and e-mail messages with links to a website that provides more information on the problem and summarizes my building's operation. This saved me a bunch of money last winter when a water pipe started to leak and I received a text while on vacation. I phoned home in time to prevent real damage!

I like the way the LightSaver is sensitive to the privacy aspects of my business, but I've been reading about major banks and businesses getting hacked. It seems like a never ending onslaught. I started looking into this more deeply and found that LightSaver has a host of cybersecurity features that helps allay my concerns. The system is equipped with an intrusion detection agent that allows me to configure my potential risk exposure while letting me know the tradeoffs in performance and functionality of the apps I've deployed. I regularly get notices for security upgrades and occasionally an event occurs when an immediate patch is recommended. It also has the capability to move into degraded modes of operation changing its behavior like a stop light moving from go to caution to emergency operation. Part of the operating agreement with each app is that they supply the fail-safe aspects of each buildings component so that devices can go to a default safe place while not necessarily shutting off.

I'm still reading reviews and looking at more apps. I'm thinking about adding solar panels and just found an app for that!

10.2 Characteristics of a Vision for Buildings Interoperability

The scenario above, along with several others representing interoperability scenarios from the perspective of various stakeholders, was presented at a technical meeting held in Seattle, Washington on March 11 and 12, 2015. Figure 10 provides a conceptual diagram of the types of interaction scenarios to be supported in a future vision for buildings interoperability. While some visions may consider a single integration platform within a building, the likely future scenario is that there will be multiple platforms associated with different equipment and these may change over time. Certainly the interactions among buildings and outside entities, such as other buildings and services providers, will involve integrating information exchange among different platforms. Therefore, enabling platform-to-platform interoperability is anticipated to be an important requirement in a future vision. The immediate beneficiary of interoperable interfaces is the system integrator. When the integrator's job is easier, compounding benefits fall to all actors.

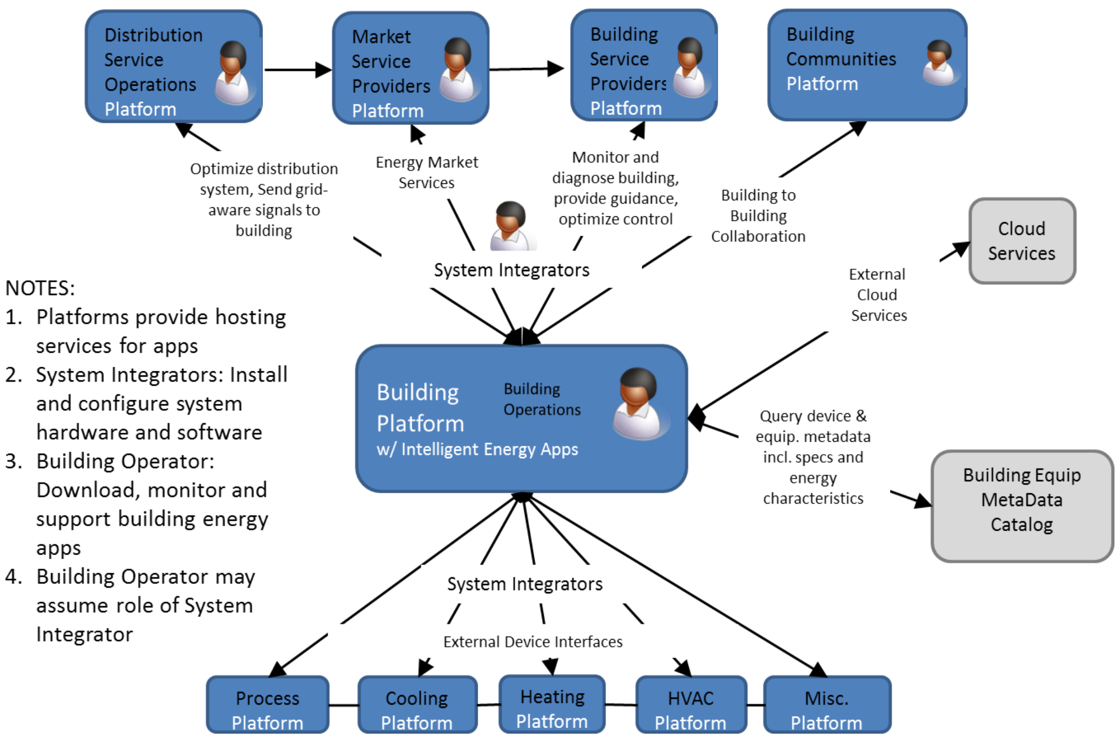

Figure 10. Concept Diagram for Buildings Integration Vision Scenarios

Through feedback captured during discussions and working sessions at the meeting, a draft outline was proposed for a buildings interoperability strategic vision document to support the development of a national roadmap for buildings interoperability. Key contributions of the future document are summarized below. Meeting proceedings, including the content ideas for a draft vision document outline are available from the EERE website (DOE 2015b).

- *Provide Background and Context:* Explain why a national strategy addressing buildings interoperability is needed, and how articulating a shared vision for interoperability relevant to buildings supports the development of such a strategy and acts as a first step to creating an interoperability roadmap. Describe basic interoperability principles and concepts important for industry, government, and decision makers critical to advancing buildings interoperability. Define the audience for such a document.

- *Define Value Proposition:* Describe the benefits of interoperability to the future of connected buildings, their equipment and the services interoperability enables, and how these translate into measureable impacts to various stakeholders.
- *Define the Objectives and Desired Outcomes:* Provide a vision statement for buildings interoperability, the objectives for a national buildings interoperability strategy, the metrics by which success is measured, and specific goals to be achieved over short, medium, and long terms.
- *Identify Challenges:* Describe the difficulties and barriers to advancing buildings interoperability beyond the current state and across a comprehensive spectrum of areas encompassing technical, policy, security, and social concerns. Proactively address potential criticisms that may arise.
- *Provide Formal Use Cases:* Describe integration scenarios, stakeholder interactions, and dependencies, processes, systems, and workflows necessary to support building interoperability.
- *Define Interoperability Requirements:* Describe expected characteristics of interoperability necessary to inform and establish standardized interfaces, information models, services, network protocols, and certification and testing procedures. Offer metrics to measure progress on technology achieving interoperability requirements. Ensure that safety, cybersecurity, and privacy issues are covered in these requirements and associated metrics.
- *Identify Topics Addressed in an Interoperability Roadmap:* Given a strategic vision, the next step will be to initiate a roadmap development process. Anticipating such an effort, describe the topics covered in a roadmap. This includes roles and responsibilities for the U.S. Government and industry, stakeholder engagement, education and marketing outreach, and reference implementations or example deployments for demonstrating visionary interoperability characteristics.

10.3 Realizing a Buildings Interoperability Vision

The buildings interoperability vision story described in Section 10.1 focuses on how typical building owners, operators, and technology integrators might interact with a connected building in the future. It outlines a usage scenario wherein a small commercial building owner connects with his/her buildings automation systems using a smartphone-inspired interaction paradigm. This is just one of many potential outcomes but it helps to illustrate some key interoperability concepts and enabling components needed to realize a future buildings vision.

The simplicity of these interactions masks the internal complexity and interoperability agreements required to achieve this vision. Smartphones are closed systems with fixed inputs and outputs such as accelerometers, cameras, and audio. These sensors and actuators have similar characteristics for any specific model of phone, thus making interoperability with the smartphone platform environment relatively straightforward. Extending this paradigm into the buildings domain, where the diversity of devices, systems, and ICT platforms and their variety of configurations increases by orders of magnitude, requires that devices and systems from many organizations integrate easily with each other.

An important concept leveraged by the smartphone industry and other technology sectors is that of multi-vendor ecosystems wherein many companies contribute products and services that interoperate with one another in a number of different ways. Ecosystems are important because they leverage the capabilities and resources of many organizations and can therefore identify and cost-effectively address a wider range of opportunities. Competition between ecosystems is beneficial as it helps drive innovation, market growth, and customer value.

Successful ecosystems must satisfy the business needs of their product and service providers as well as the product consumers. This requires achieving a mutually beneficial balance between the value propositions as seen by both providers and customer.

Ecosystems are typically formed around a core set of technology components which are then embraced and extended by ecosystem participants. The specific set of core technology components can vary and may be composed of both proprietary and open technologies. The level of effort needed for products to integrate with and enhance core ecosystem technologies can vary from very simple data transfers to high-level interactions and negotiations of service-oriented capabilities. Ecosystems can also form around software or hardware components or both. Examples of hardware ecosystems include Microsoft Windows personal computers with compatible devices and Android smartphones and tablets.

Important trends for buildings interoperability include the ICT ecosystems that develop products and services for more than one industry sector ecosystem. The physical appliances and mechanical systems in buildings have a long lifetime and are costly to replace. If these mechanical systems can cost-effectively interoperate with more than one ICT ecosystem, then buildings customers will have a broader selection of ICT ecosystem solutions to choose from.

An example of an ecosystem based upon proprietary information technology is Apple's iOS smartphone. Apple's core technology includes the hardware, operating system (i.e., iOS), system management, and application deployment services. Ecosystem participants develop software applications that must meet Apple's guidelines before being made available to customers through Apple's App Store. The hardware and operating system environment is kept under tight control for consistency and upgradeability, permitting Apple to achieve the intuitive user interface that has made the iPhone a globally successful smartphone. Within this technology platform, ecosystem software developers create innovative applications for customers and end-users while achieving fewer interoperability issues between select devices, but at the expense of ecosystem diversity and broader interoperability with third-party devices.

An important example of an open ICT ecosystem is Google Android, a successful open mobile phone platform. The Android operating system is based on Linux, an open operating system and Java, an open programming language. The operating system provides the execution environment for applications which are installed and updated from a central application market place, Google Play. The application execution environment provides common application programming interfaces (APIs) and Java libraries for interacting with the sensors and actuators contained in the mobile device. Software requires change management and the Google market platform provides a common mechanism for automatically or manually updating applications and adding new ones. The Android platform is open sourced by Google and hardware manufacturers can extend or change the operating system to adapt to different or new hardware functionality. This allows mobile device manufacturers to compete against each other while maintaining consistency for the application software developer who desires to build an application that can be installed and run in all conforming mobile devices. As a result, the Google Android ICT ecosystem has the most diverse hardware of all mobile platforms with the widest range of functionality and features. Buildings systems also contain diverse hardware and could leverage this form of open application execution platform to integrate buildings devices and form a buildings community of hardware and software developers that together could compete against each other while providing new and advanced buildings operations and energy management applications. ICT ecosystems can also compete with other ecosystems as evidenced by Google's Android competing head to head against Apple's iOS.

Another industry sector ecosystem example involves digital music recording and the technology platforms that have lowered the costs of music production to a commodity level where musicians can themselves integrate the sound processing components, called plugins, and produce quality recordings at in-home studios using personal computers. The ability to easily integrate advanced components into competing shrink-wrapped recording platforms (e.g., Avid ProTools and Steinberg Cubase) has led to a rapid growth of high-quality music available on the web from a large and growing number of musicians. The traditional barriers to entry have effectively been removed and any interested individual can now participate in the industry. This has opened the music market to greater diversity and immediacy of content, putting competitive pressure on professional sound studios to change business models and focus on satisfying the special needs of professional musicians.

As a final example, the Digital Living Network Alliance (DLNA) is a consumer electronics industry sector ecosystem that focuses on networking home media devices. DLNA devices (e.g., TVs, cameras, computers, mobile devices, and game consoles) discover, connect, and communicate with each other over a home network enhancing the user's access to a range of media from different sources.

Evolving and maintaining an industry sector technology ecosystem is difficult. Ecosystems are composed of many stakeholders with different, and potentially competing, business models and drivers. Ecosystems evolve when stakeholders can identify business value and when a consumer marketplace associated with the ecosystem is sufficient to balance internally focused business models. Two examples of ever-changing ICT ecosystems are the PC and smartphone. The PC platforms are evolving down toward tablets, while smartphone platforms are evolving up toward tablets and PCs. The market opportunities between ecosystems continues to drive innovation in both.

Some elements that enable the growth of connected buildings ecosystems by decreasing obstacles and increasing the business value proposition for consumers include the following:

- Value – Technology costs need to be aligned with the perceived customer value.
- Security and Privacy – Technology components need to protect security and privacy using techniques that enable customers to trust and verify the state and operation of security and privacy components.
- Ease of Installation and Commissioning – Technology components need to be designed for easy installation and commissioning by competitive system integrators or customers. This includes backward compatibility and the ability to retrofit existing equipment with interoperable components from different buildings technology ecosystem suppliers due to the long lifetime (typically many years) and costs of buildings appliances and equipment.
- Ease of Use – Technology components should be easily understood and usable by a wide range of customers without specialized, costly, or time-consuming training. Human interaction needs to be simple and self-explanatory for non-technical building owners and operators. Integration and interoperability with other connected buildings systems (e.g., security, operations and entertainment systems) increases the visibility and awareness of energy management functions.
- Ease of Ongoing Support – Technology components should be easily and cost-effectively supportable, maintainable, and upgradeable throughout their lifecycle.

Some elements that enable the growth of connected buildings ecosystems by decreasing obstacles and increasing the business value proposition for technology solution providers include the following:

- Value – Technology costs need to be aligned with the perceived provider value.
- Security and Privacy – Technology components need to protect security and privacy using techniques that enable providers to trust and verify the state and operation of security and privacy components.

This includes supporting mechanisms that will allow for upgrades to address security and privacy threats as they arise.

- Customization and Flexibility – Ecosystems that embrace flexible and customizable technology components can better adapt to new and different ecosystem needs. Flexibility enables a wider the range of applications and solution choices.
- Adaptation to Customer Capabilities – A large and growing portion of the global population is familiar with downloading and executing applications from a market. Leveraging this familiarity lowers the end-user learning curve. The success of online software application markets requires that devices and systems are capable of securely finding, purchasing, and downloading applications (e.g., buildings energy management applications).

  Adaptation includes interoperable ways to discover buildings automation components, their behaviors, how they are structured and networked together, and how to intelligently communicate with them in real-time. Application configuration is often a manual process requiring knowledge, time, and effort. The ability of an application to discover, access, and learn about the execution environment and associated system behaviors is needed to reduce the level of effort required to commission buildings applications and help ensure accurate buildings data quality and reliable performance.

  Also important are interoperable ways to discover access and model the physical and energy characteristics and behaviors of buildings systems. Buildings energy applications require knowledge relating to the physical and energy characteristics and behaviors of building and buildings system components. This knowledge needs to be accessed, discovered, and modeled with minimal level of effort and cost.

  In addition to interoperability within buildings premises, buildings system components also need to securely discover and interoperate with external actors and systems that impact buildings energy such as buildings communities, markets, service providers, and distribution system operators.
- Market Growth – Many stakeholders compete in static, zero-sum markets where market share becomes critical. Ecosystem-based markets can potentially achieve higher growth rates through leveraging a wider range of resources, thus, benefiting all participants.
- Open Technology Standards (see Appendix E) – The information and communication technology industry has driven, and is continuing to drive, the development of open technology standards. These standards are creating open technology communities and ecosystems which can be leveraged by the buildings community to enable buildings ecosystems by helping participants reduce the costs, time, and resources required to develop interoperable products.
- Ease of Installation, Commissioning, and Support – These are cornerstones for interoperable products and services. Ecosystem technology providers and associated technology components need to interoperate with each other as they compete with each other and other technology platforms. This includes mechanisms for products and services to be tested and certified not only to comply with relevant interoperability standards but that any ambiguities are resolved between product suppliers for interoperability before going to market. This decreases the effort, time, and costs associated with integrating products and services from multiple, diverse ecosystem stakeholders.

  Interoperable ecosystem platforms and applications need to be installed, commissioned, updated and managed throughout their lifetime. This requires standard mechanisms for platform and application installation, configuration, updates and ongoing maintenance and troubleshooting support (e.g., health monitoring, fault/failure diagnostics, and upgrades to address cybersecurity and privacy threats). Such upgrades may be challenging as a building's set of equipment evolves over time with the potential for having to support many different vintages of devices with various software versions over relatively long durations. Creative solutions will be necessary, but as the base of interoperable equipment in an ecosystem becomes larger, the incentives for manufacturers or third parties to provide such solutions increases.

10.3.1 Platform to Platform Integration

Buildings will increasingly require the support of service provider ICT platforms for providing advanced information and control technology along with monitoring and diagnostics services. These service providers require a consistent standard information view into the diverse buildings landscape in order to minimize the need for customized solutions. At the same time, new buildings platforms (and their ecosystems) are emerging through IoT and M2M technologies to provide a range of energy services. A convergence on any one ICT platform that equipment and system providers will use is unlikely. This implies that interoperability in connected buildings will need to address platform to platform integration scenarios.

The growth of platforms is being driven by buildings system manufacturers and service providers as innovation and competition drives faster time-to-market and product development cycles within the business context of limited resources. Platform ecosystems emerge as they enable organizations to leverage expertise, resources, and products from other business-aligned organizations. This trend is expected to continue.

As ecosystems grow and evolve, future connected buildings systems will be modeled as a "network of interoperating platforms" or a "platform of connected platforms." This will require the development and wide adoption of cross-ecosystem technology and information standards that support platform to platform integration.

10.3.2 Informational Directions

An important topic for alignment that can facilitate a network of interoperating platforms and is a logical focus area to advance interoperability is a Connected Building Information Model (CBIM) that provides canonical buildings semantics for communicating real-time buildings information in context with buildings systems and equipment for enabling advanced buildings commissioning, maintenance, operations and energy management. This could borrow from the BIMs used for buildings design (see Section 8.2) and harmonize with information models from a variety of M2M and IoT device-level platforms.

Effective interoperability between platforms requires that they share message content derived from an understanding of the buildings information semantics for important elements and concepts that are included in BIMs used for buildings design. These shared concepts provide a common understanding of buildings and equipment context that can be applied in information exchange between the real-time control and device domains as well as the non-real-time management information domain.

The concept of a CBIM is to provide an open standards-based semantic view of connected buildings equipment. Alignment on such a view would improve buildings interoperability and enable future building interactions. One example of such a concept is shown in Figure 11. The contents of a CBIM would be inspired by the existing buildings information models coming from the planning aspects of buildings reflected in design and simulation tools and the operations aspects of buildings reflected in existing operations platforms. A core set of CBIM semantics could be useful for representing the information content in most all interactions. However, to address specific application areas and better manage modeling changes over time, targeted extensions could be developed.

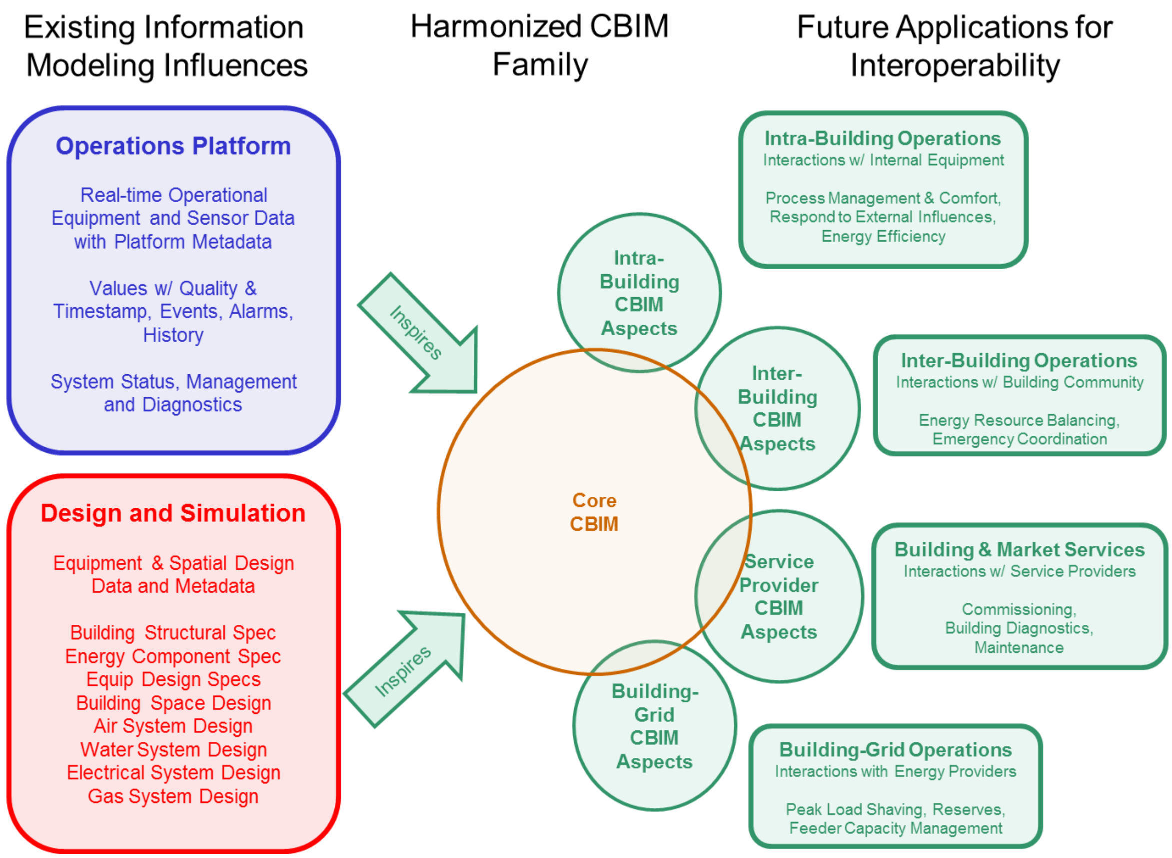

Figure 11. Connected Buildings Information Model Concept

Scenarios where a CBIM enables buildings interoperability in the future include the various use cases introduced in Section 4.0 and listed in Appendix B. Examples follow:

- Intra-Building Operations Connected Equipment Integration: Common semantics supported by equipment suppliers to understand the information being exchanged when interacting with the equipment will enhance interoperability. Self-describing message content referencing a CBIM would reduce interpretation errors. Business process interactions using the CBIM vocabulary would be easier to configure and adapt.
- Inter-Building Operations Integration: Common semantics supported by connected buildings automation systems suppliers could be used in messages exchanges for coordinating buildings operations in a community. These could be for local balancing of energy under locally constrained operation, for local economic incentives, or coordination of operations under emergency conditions.
- Building and Market Services Integration: Information models can support commissioning services that review design versus actual buildings performance. The correlation of design metrics with actual buildings measurements and data is a manually intensive effort involving mapping specific measurement identifiers (e.g., tag names) and time-series reductions to specific performance metrics. Buildings components and equipment could support messaging interfaces with sufficient standard semantics from a CBIM to enable automated equipment discovery and correlation with design models by service providers. Similarly, CBIM semantics could support buildings operational model exchange for remote energy analytics, diagnostics, and forecasting.
- Building-Grid Operations Integration: The interaction of connected buildings with energy providers' systems (e.g., a distribution service operation), is described in several of the use cases. Information

modeling is reflected in a few existing building-grid standards. Harmonizing the semantics in these models so that they are consistent with a core CBIM would help integration with legacy deployments and provide a manageable path for extensions that support future applications.

Many of the BIM standards currently in use already incorporate key modeling concepts and metadata important for providing buildings data context and can help support many potential uses of a CBIM. Examples of modeling concepts in current standards include the following:

- Bridging the design BIM with buildings maintenance and operations
  - Campus containing buildings (gbXML)
  - Relationships between facilities, floors, spaces and zones and the systems and components they spatially contain (IFC, COBie)
  - Data required for energy analysis including: physical building, energy design, construction, control, cost, size, daily schedule, and weather and space/zone data. (gbXML)
  - Energy system descriptions for air and water loops and lighting systems (gbXML, HVACie/WSie/Sparkie)
  - Extending the design model to include the structure of buildings air, water and electrical energy systems in addition to the equipment and components (COBie, HVACie/WSie/Sparkie)
  - Connections between components with upstream and downstream ports to specify flows and flow direction (COBie, HVACie/WSie/Sparkie)
  - Specific classes of operational energy equipment such as heat pumps, furnaces, air handlers, and air conditioners (SEP2, ClimateTalk)
  - Interior and exterior equipment with design energy performance attributes (gbXML)
  - Abstracted control functions (SEP2, ClimateTalk)
  - Common dictionary and meaning for terms related to buildings (gbXML, Project Haystack)
  - Mapping buildings design to specific buildings automation systems to support measurements about the performance of specific services (COBie, BAMie)
- Common object model consisting of classes with attributes and relationships
  - Device classes inheriting from a root class, IdentifiedObject (SEP2, FSGIM)
  - Globally unique identification and instances of objects (IFC, COBie)
  - Linking to existing information models (SEP2, FSGIM, OpenADR2)
  - Common equipment classification (IFC, COBie)
  - Name and type identification authorities (FSGIM)
  - Multiple views, or profiles, which define the subset of data used within a specific exchange (IFC, COBie)
  - Common dictionary of terms (IFC, COBie)
  - Abstracted device information (SEP2, FSGIM)

– Mapping an information model to a widely used open encoding syntax and communication protocol. (SEP2, OpenADR2)

– Mapping specific models to a canonical model for legacy integration (Eclipse Vorto)

Information models for connected buildings will continue to evolve down from design models and up from connected platform models as the need for advanced buildings lifecycle support, systems integration, and IoT technology gain industry visibility and support. This is evidenced by related international initiatives such as ISO TC 242, ISO AWI 17798, and ISO TC205 WG3. ISO TC 242 focuses on energy management and has published ISO 50006:2014, which provides guidance for measuring energy performance using energy baselines and energy performance indicators. ISO AWI 17798 is investigating how buildings automation and control systems can utilize design and engineering information models for processes such as systems configuration. TC 205 WG3 is proposing an initiative to integrate the ASHRAE Facility Smart Grid Information Model with design models. A CBIM needs to evolve as a timely, consistent, and coordinated industry effort so as to decrease the proliferation of fragmented and disconnected models. A widely deployed CBIM designed to provide standard buildings context and metadata semantics could bridge the gap between buildings design and buildings operations enabling 1) the rapid growth and expansion of scalable energy performance monitoring, 2) remote buildings system support through diagnostics and analytics and 3) the participation of buildings as active components in the nation's energy system.

10.3.3 Developing a Roadmap

The Buildings Interoperability Vision technical meeting confirmed, and further informed those in attendance on, the state of buildings interoperability. While the communications protocols at the technical level will continue to change, they are already relatively mature from an interoperability point of view as they decouple information and BPM from their transport mechanisms. The informational levels of interoperability represent obvious areas for attention with directions for activity being considered as described in the previous section; however, no overarching roadmap in the connected buildings community exists to prioritize actions, in the context of sequencing activities that advance buildings interoperability to achieve the spirit of a strategic vision. Developing a roadmap would require the engagement of all stakeholders and careful facilitation skills that respect perspectives and valuable contributions from participants, while continually driving for consensus.

Why develop a roadmap for buildings interoperability? Building asset owners, operators, solution providers, and policymakers have survived without one thus far. Industry and the nation will surely advance in technology deployment as time progresses. The value proposition for such a roadmap comes down to the speed, efficiency, and effective performance of new capability deployments. Each of these properties are valued differently from the various stakeholders. From a few narrow viewpoints, some of these properties may even be considered detrimental to business plans that stand to lose from changing the status quo. But forward-leaning stakeholders strive to address today's issues with new capabilities. New solutions to real problems drive expanding markets and these markets offer opportunities for consumers and suppliers. A roadmap that advances interoperability lowers the cost of entry and increases business volume. Besides having an incentive to support the economy, energy service providers and government agencies are looking for cleaner, more efficient ways to address new constraints on operations that challenge robust and reliable energy delivery. The faster connected buildings can interact with each other, the grid, and the energy marketplace, the quicker these challenges can be resolved or mitigated.

Despite the stated benefits of developing a roadmap, significant levels of stakeholder participation can be difficult to achieve, particularly if the value from participation is uncertain or is perceived to be realized too far into the future. Because stakeholder participation is necessary for adoption of a roadmap, stakeholder incentives for participation in its development need consideration. Incentives for participation would likely need to be tailored to stakeholder interests. For example, an incentive could be the emergence of must-have applications that drive market interest where cooperation is clearly in the interest of growing the market. Another example incentive mechanism could be large volume buyer procurement contracts that specify interoperability performance language or perhaps a grading mechanism that scores performance to interoperability goals. In any roadmap effort, effective publicity and outreach that appeals to the interests of stakeholders will be important.

A challenge with outreach for developing a roadmap is that the abstract qualities of interoperability concepts and their benefits can be hard to grasp and quantify. Describing a strategic vision for buildings interoperability can help offer a view of tangible capabilities that could be enabled by interoperability. To complement the vision material, example implementations can demonstrate how interoperable products and services might interact if commonly held agreements, guidelines, and standards were adopted by the buildings community. Such example implementations may emphasize only a subset of characteristics, (e.g., equipment discovery or information interpretation enabled through, for example, a CBIM); however, these can be powerful for ensuring that stakeholders share an understanding of concepts and specific considerations necessary for roadmap development.

Lastly, a roadmap would need to be a living document to remain effective. While the initial draft of a roadmap would help in amassing resources to address the highest priority tasks, the connected buildings landscape, stakeholder organizations, and supporting ICT would continue to evolve. That evolution would need to be considered in a re-energized vision, implementation of new strategies, and roadmap revisions.

11.0 Summary

The landscape for connected buildings interoperability is complex. It involves many stakeholders with a great variety of perspectives and objectives. This document attempts to capture a snapshot of the breadth of applications (use cases) related to connecting buildings automation equipment and systems, the state of ICT-related standards that are being used in the buildings automation community, and the diversity of players involved in specifying, developing, integrating, using, and servicing the technology associated with this field. To assist in presenting this information in a consistent fashion, this landscape report uses a framework composed of interoperability categories, automation zones, and connected buildings actor domains.

While progress is being made, particularly at the technical layers of interoperability, the integration of buildings automation equipment and systems is, for the most part, too complex, time-consuming, and unpredictable, resulting in expenses that compromise achieving the value propositions for deployments. This is particularly true for the small and medium commercial and residential buildings communities. However, progress is being made in several areas where ICT solutions are growing. This includes open linked data, semantic technologies, and system integration approaches being implemented in business-to-business, machine-to-machine, and IoT initiatives.

By developing a shared understanding of where the buildings automation community is today and imagining a vision for the desired characteristics of integration and maintenance of connected equipment in the future, we can identify requirements for interoperability that need to be addressed through multiple solution approaches. In some sense, the goals for perfect interoperability, cybersecurity, and privacy may always be just out of reach as new applications, features, and threats emerge; however, aligning a shared vision to a collective set of directions may allow buildings automation ecosystems to form and flourish.

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Appendix A

Interoperability Model Inspirations

Appendix A

Interoperability Model Inspirations

The following sections reference the models used to develop the interoperability framework presented in the narrative of this report.

A.1 NIST Smart Grid Conceptual Model

The National Institute of Standards and Technology (NIST) Smart Grid Conceptual Model describes buildings from the view point of the electricity system as a subdomain of the customer domain. Multi-dwellings are included within the customer domain with the distinction that multi-dwellings may differ in owner/tenet relationships. The buildings subdomain interconnects with other smart grid domains through the concept of a logical energy services interface (ESI) (NIST 2014) which improves connectivity, resilience, and robustness.

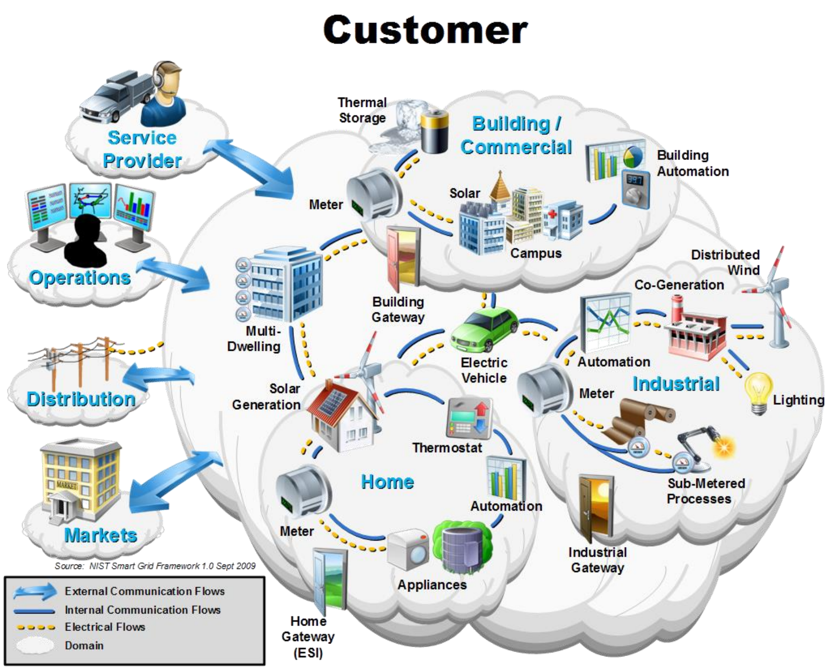

Figure A.1. NIST Smart Grid Conceptual Model

A.2 GridWise Architecture Council Interoperability Framework

The GridWise Architecture Council (GWAC) interoperability context-setting framework identifies eight interoperability categories relevant to the mission of systems integration and interoperation in the electrical end-use, generation, transmission, and distribution industries. The major aspects for discussing interoperability fall into the following categories: technical, informational, and organizational. The organizational categories emphasize the pragmatic aspects of interoperation. They represent the policy and business drivers for interactions. The informational categories emphasize the semantic aspects of interoperation. They focus on what information is being exchanged and its meaning. The technical categories emphasize the syntax or format of the information. They focus on how information is represented within a message exchange and on the communications medium.

http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf

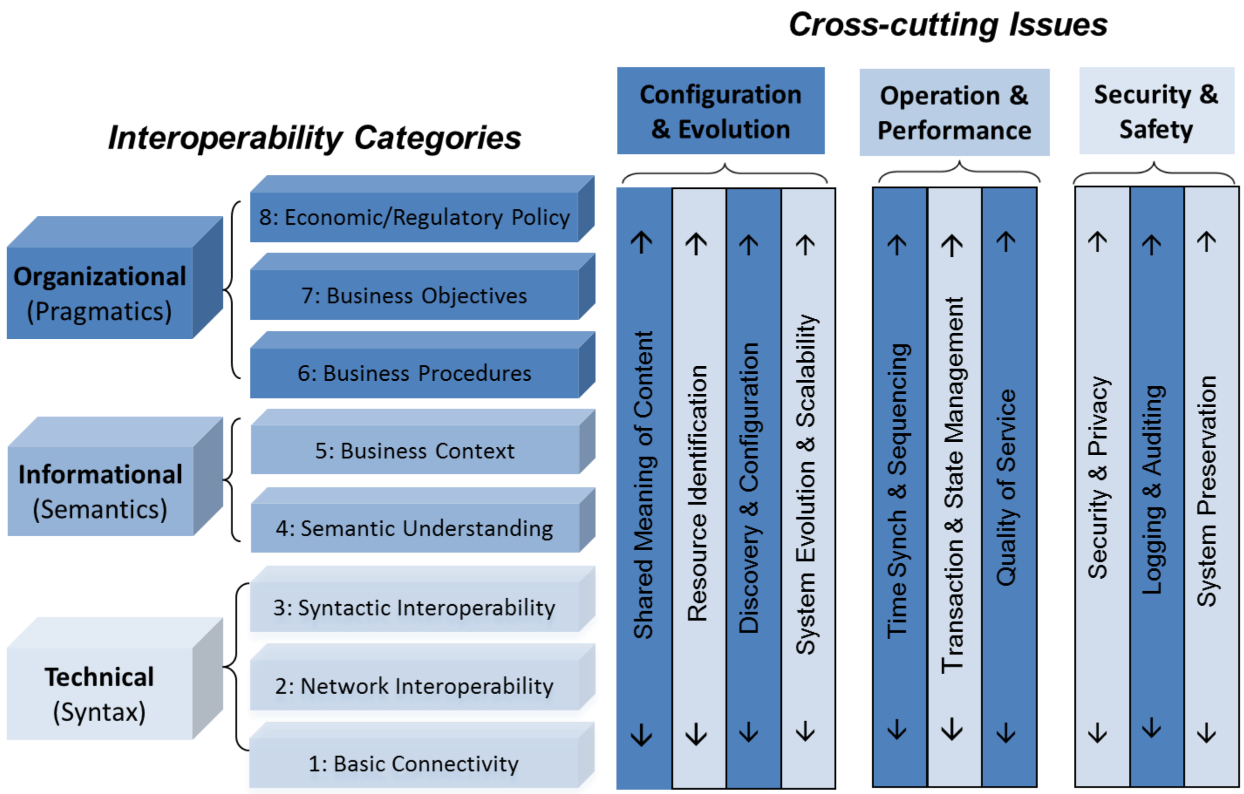

Figure A.2. GWAC Interoperability Framework

A.3 Purdue Enterprise Reference Model

The Purdue Enterprise Reference Model provides a model for enterprise control, which end-users, integrators, and vendors can share in integrating applications at key layers in the enterprise:

1. Level 0 – The physical process (defines the actual physical processes).
2. Level 1 – Intelligent devices (sensing and manipulating the physical processes, process sensors, analyzers, actuators, and related instrumentation).
3. Level 2 – Control systems (supervising, monitoring and controlling the physical processes, real-time controls and software, human-machine interface, and supervisory and data acquisition (SCADA) software).
4. Level 3 – Manufacturing operations systems (managing production work flow to produce the desired products, batch management, manufacturing execution/operations management systems, maintenance and plant performance management systems, data historians, and related middleware).
5. Level 4 – Business logistics systems (managing the business-related activities of the manufacturing operation). Enterprise Resource Planning (ERP) is the primary system that establishes the basic plant production schedule, material use, shipping, and inventory levels.

http://www.pera.net/

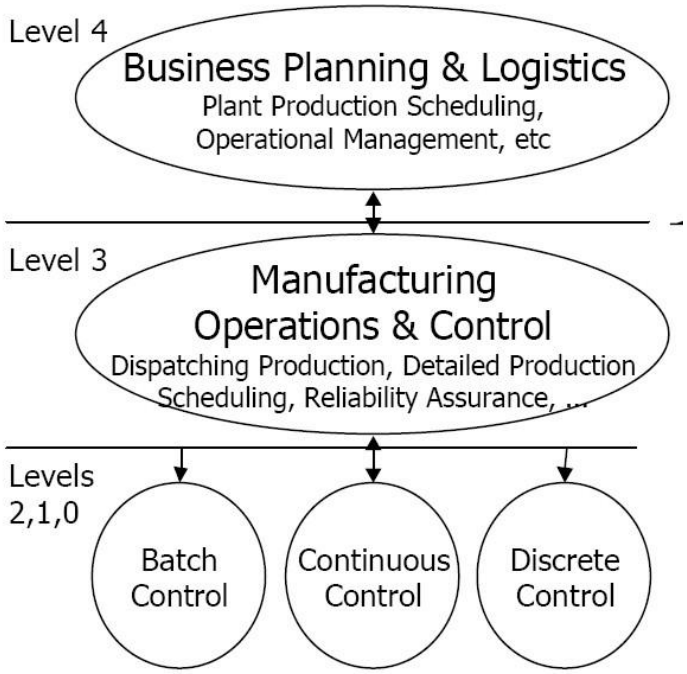

Figure A.3. Purdue Enterprise Reference Model

A.4 European Union Smart Grid Architectural Model

The EU Smart Grid Architectural Model supports the design of smart grid use cases with an architectural approach allowing for a representation of interoperability viewpoints in a technology neutral manner, both for current implementation of the electrical grid and future implementations of the smart grid. It is a three-dimensional model that incorporates the dimension of five interoperability layers (i.e., business, function, information, communication, and component) with the two dimensions of the Smart Grid Plane, i.e., zones (representing the hierarchical levels of power system management: Process, Field, Station, Operation, Enterprise, and Market) and domains (covering the complete electrical energy conversion chain: Bulk Generation, Transmission, Distribution, Distributed Energy Resources, and Customers Premises).

http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/xpert_group1_reference_architecture.pdf

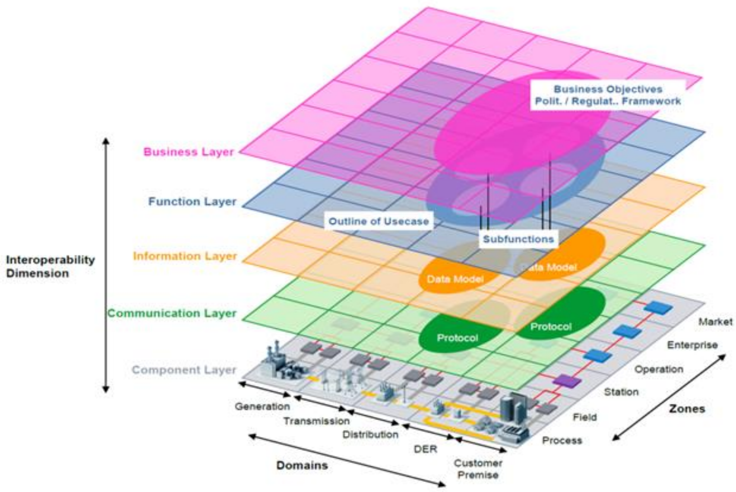

Figure A.4. EU Smart Grid Architecture Model

A.5 ASHRAE Distributed Control System Model

ASHRAE Guideline 13-2000 "Specifying Direct Digital Control Systems" was developed in 2000 as an aid for specifying buildings control systems. It actually describes a distributed control system model consisting of (1) a building controller, (2) custom application controllers, (3) application-specific controllers, (4) other communication devices, (5) operator interfaces, and (6) input/output devices. The building controller normally functions as a supervisory system. Custom application and application-specific controllers normally provide regulatory control functions.

https://www.ashrae.org/File%20Library/docLib/Public/20070709_gdl13_2000_bdlmnpq.pdf

A.6 ANSI Energy Efficiency Standards Coordination Collaborative

The American National Standards Institute (ANSI) Energy Efficiency Standards Coordination Collaborative (EESCC) describes a distributed buildings system as being made up of a number of different subsystems (e.g., HVAC, lighting, electric power, or cybersecurity). Each subsystem has a defined function, importance, and a set of energy performance indicators. A "systems approach" to a building considers how the subsystems influence each other within the buildings system as a whole, and can determine whether an improvement in one area may adversely affect another area of the buildings system. Figure A.5 provides a model of a commercial building with a buildings automation system. This model illustrates the interaction among buildings system components and the interaction between the building and Smart Grid. The terms and interactions described in relation to this model can also be applied to smaller commercial buildings that do not have buildings automation systems.

http://www.ansi.org/standards_activities/standards_boards_panels/eescc/overview.aspx?menuid=3

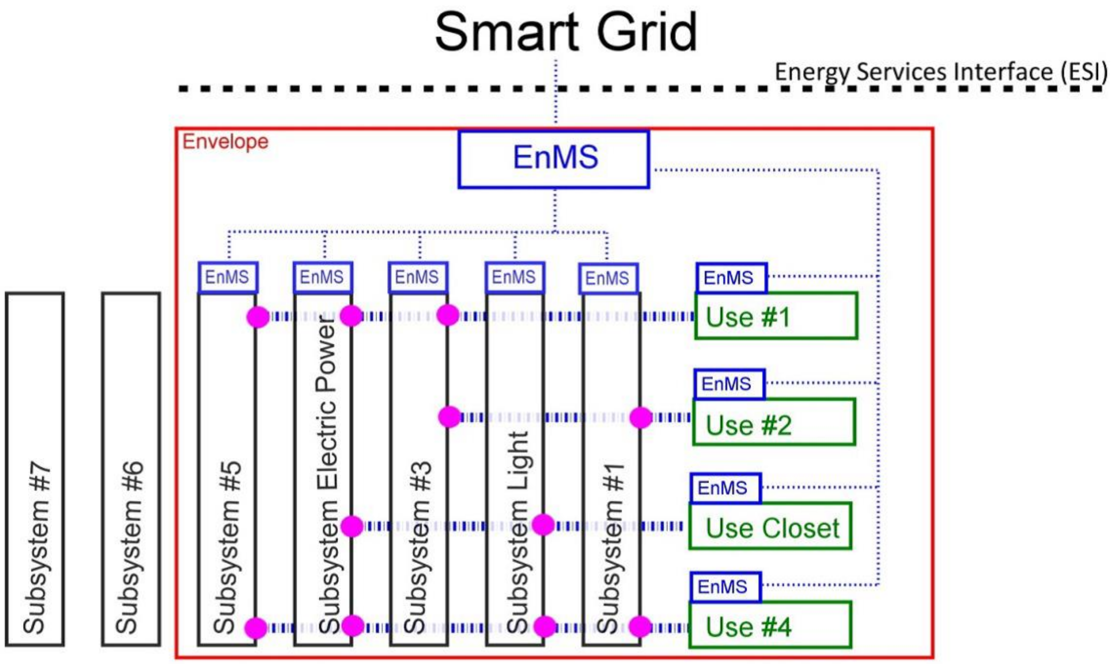

Figure A.5. EESCC Buildings Automation Systems Physical Architecture

Appendix B

Use Cases

Appendix B

Use Cases

This appendix provides a broad range of use cases involving buildings interoperability. The use cases were identified by the Pacific Northwest National Laboratory (PNNL) (Somasundaram et al. 2014), the Energy Information Standards (EIS) Alliance (Hardin 2015), International Electrotechnical Commission (IEC) Technical Committee (TC) 57, IEC PC118 (IEC 2013) and IEC TC57 WG21 (IEC 2014). Section B.5 summarizes the use case landscape, itemizing the use case type and location within the buildings interoperability framework. Sections B.1 through B.4 provide descriptions of the use cases according the sources where they were developed.

B.1 PNNL Use Cases

B.1.1 End-User Services

Use Case	Use Case Description
Third-Party Energy Provider	Customer (typically a commercial building owner) contracts with a vendor that installs, operates, and maintains equipment at its expense, such as a building-cooling-heating-power (BCHP) system, thermal or battery storage system, or a conventional generator. The vendor then bills the customer for the energy services provided to the building and/or shares in the proceeds from value provided to the electric power grid (e.g., net reduction in demand, ancillary services, etc.).
Efficiency Shared Savings	Customer (typically a commercial building owner) signs up with an energy service company (ESCO), which provides energy efficiency retrofits and services in exchange for a shared savings contract.
Tenant Contracts with Building Owner for Energy	Building or facility owner or operator (1) passes through energy costs (including dynamic rates), peak demand charges, etc. to tenants of or business divisions occupying the building, or (2) gives them a monthly allowance for energy consumption that is covered in the tenant's monthly rent. In case (2), if the monthly allowance is exceeded by the tenant/division, the tenant incurs a penalty, or they may receive a rebate to the extent the monthly allowance is not exceeded. Tenants or business divisions are also allowed to trade surplus allowances with other tenants/divisions who have a need for an additional allowance. This engages tenants and business divisions in conserving energy, managing peaks loads, and responding to dynamic rates by co-optimizing comfort or quality of service for the costs of their provision.
Transactive Control for Large Commercial Building HVAC Systems	Customer or building operator uses transactive concepts in a hierarchical control system for a multi-zone commercial building with a complex, built-up HVAC system comprising chillers, cooling towers, air-handling units, etc.
Diagnostic and Automated Commissioning Services	Customer (typically a commercial building operator or owner) signs up with a service provider for remote diagnostic services and/or automated commissioning services.
Data Centers Trade Computation Jobs	A data center (server farm or high-performance computing center) shifts computing jobs to another such service provider where electricity costs are cheaper.
Microgrid Coordinating Demand Response,	Consumers sign up to participate in a transactive energy market within a microgrid to balance its resources and loads when operating in islanded mode to ensure reliable electricity services. In example presented here, all resources are independently

Use Case	Use Case Description
Distributed Generation and Storage	owned by building owners, including distributed generation (DG) and distributed storage (DS). The microgrid use case is built upon use case Transactive Retail Energy Market (see Section B.1.3).
Trading Positions in an Electric Vehicle Charging Queue	A limited number of electric vehicle (EV) charging stations are available at a parking lot. Re-charging is available on a first-come, first-served basis. A vehicle changes positions in the charging queue with another owner for a negotiated price.

B.1.2 Energy Market Services

Use Case	Use Case Description
Dynamic Rate	Customer signs up with retail utility or a retail service provider for a dynamic (time-varying) rate program such as (1) a time-of-use (TOU), (2) a critical-peak price, or (3) a real-time price (RTP).
Optimize EV Charging for Dynamic Rate	Customer signs up with retail utility or a retail service provider for a dynamic (time-varying) rate program to charge EV.
End-Use Differentiated Dynamic Rates	Customer signs up with retail utility or a retail service provider for different dynamic (time-varying) rate programs for different end uses: e.g., (1) a TOU rate for process end uses like dishwashing and clothes washing and drying that are driven by occupant usage patterns and (2) an RTP for end uses like space conditioning and water heating where automated controls can be employed to respond to short-term changes in price. The essential driver for splitting the loads into two rate classes is that loads driven by behavior are best shifted by the occupants' awareness of consistent pricing patterns, whereas loads that operate more continuously and have thermostatic controls can be programmed to respond automatically to rates that vary more dynamically. Such a "split rate" approach may be both more equitable and more effective for encouraging load shifting at appropriate times.
Transactive Energy Market Exchange	Customer purchases electric energy and delivery services from generation and transmission and distribution (T&D) suppliers in an asynchronous, bilateral, stock market-like transaction. Separate forward contracts can be purchased at various time scales. Customer can re-sell contracts for unneeded energy and delivery back into the market.
Trading Efficiency to Relieve Congestion	The utility or aggregator sets up an "eBay-like" marketplace to obtain efficiency that specifically targets an area served by a congested, capacity-limited element of a distribution or transmission system.
Differentiated Reliability Service	Customer signs up for premium reliability service, paying a surcharge for being more likely to have service quickly restored after a distribution-level outage. The distribution utility uses the additional revenue to help it invest in deployment of fault detection, location, isolation, and reconfiguration (FDLIR) technology, making the system more reliable for all customers, without burdening customers without need for improved reliability with higher overall rates. This assumes that the distribution system has the ability to "back feed" power from adjacent feeders, or has some distributed energy resources (DERs) it can use to provide power to premium customers in some circumstances. It further assumes that automated metering infrastructure (AMI) with remote disconnect capability is deployed. When a distribution outage occurs, the utility uses the FDLIR technology to quickly isolate the faulted section, to determine how many customers can be supported with the available capacity from adjacent feeders and DERs. If all customers cannot be supported given the current time-of-day, day-of-week, and weather, then it uses the remote disconnect feature of the AMI system to reduce the load that must be served. First priority goes to the premium customers.

B.1.3 Grid Services

Use Case	Use Case Description
Interruptible Service or Direct Load Control	Customer signs up with retail utility/load serving entity or a demand-response aggregator for (1) interruptible service or (2) direct load control program, in exchange for a reduced rate or a credit on their electric bill.
Transactive Retail Energy Market	Customer signs up with retail utility or a retail service provider for a transactive control and coordination program, involving an RTP determined by customer bids for electricity demand from a short-term (~5-minute) retail price-discovery process (e.g., a market).
Trading Allocated Capacity Rights	Existing customer rate plans explicitly include (1) payment for the right to utilize a specified amount of system capacity (kW) or (2) customers are allocated their share of the system capacity by their service provider. An allocation may be based on a utility's standard "rules-of-thumb" (e.g., regarding diversified peak loads for a customer class). Customers are encouraged to trade their short-term capacity rights with each other in near real time, so the capacity right need only reflect a customer's diversified share of peak load, rather than their absolute peak load. The customer is required to manage their average load over short time intervals (e.g., a 5-minute interval) to not exceed their current capacity limit. In this fashion, peak demand at any constrained point in the grid can be managed. The governing constraint may be in overall generation capacity or at a point of delivery in the transmission or distribution systems. In the case of (2) a forward market is also set up to allow customers to trade for long-term capacity rights.
Ancillary Services via Aggregator	Customer signs up with a demand-response aggregator or utility to provide ancillary services in the form of (1) regulation or (2) spinning reserve. Today, these are provided by central generation capacity that is not otherwise engaged in producing electricity. These services can also be provided to customers by allowing them to participate in one of three load control programs: interruptible service, direct load control, or dynamic rate, with additional incentives and rebates. The utility reserves capacity based on the willingness of customers to participate, then loads are dispatched by the utility when necessary based on a 4-second resolution regulation signal.
Transactive Acquisition of Ancillary Services	Customer signs up with a utility, retail service provider, or demand-response aggregator to provide ancillary services via transactive control in the form of (1) regulation or (2) spinning reserve. Today, these are almost exclusively provided by central generation capacity that is not otherwise engaged in producing electricity.
Rate Dependent Priority for Cold Load Pickup	The distribution utility leverages demand-response programs at its disposal to mitigate very large loads that result after an outage because of pent-up demand for electricity by thermostatically controlled loads (cold load pickup).

B.1.4 Societal Services

Use Case	Use Case Description
Emergency Power Rationing	This transaction provides an emergency power-rationing system to limit power consumption to the available supply in case of a government-declared emergency or disaster, providing a more equitable and flexible approach than the key alternative–rolling blackouts. When customers sign up for electric service, they are assigned to a default customer class by the load serving entity (utility). Each class has an assigned set of power consumption limits corresponding to levels of emergency declared by a state or federal government representative (not the utility). These limits are communicated to customers' smart (AMI) meters via the emergency broadcasting system. In addition, the emergency level is communicated at the time

Use Case	Use Case Description
	of an emergency to enable smart meters and home/buildings energy management systems to enforce the corresponding limits via a “virtual circuit breaker” function. Customers may apply for higher limits by claiming and justifying special needs. If normal communications channels are still operational, customers can trade their capacity rations in with each other to better allocate power supply to society’s needs.
Efficiency Incentive Payment	Customer signs up with a utility that provides an incentive payment for efficiency achieved, and the utility uses the resulting savings to either meet its regulatory obligations, trade in a secondary market for generation-produced carbon, or meet its renewable portfolio standards (RPS).
Air Shed Management	An air shed management authority created to improve air quality in a “smog basin” receives the authority to manage pollution levels in its district on declared “smog alert” days via an air quality surcharge on electricity and natural gas rates. These variable real-time surcharges may be zero or near zero under normal circumstances, but rise during such events, to reflect discharges from (1) generation used to power electric end uses and (2) gas and oil end uses, to encourage the following: • load curtailments, particularly for customer segments and end uses that have high contributions of local pollutants • shifting of electricity generation to cleaner and extra-regional sources, including curtailment of DG and combined cooling-heating-power systems in the air shed district. The surcharges are applied to existing utility rates, whether flat or time-varying dynamic rates, via the utility billing infrastructure.

B.2 IEC PC118 Technical Report Use Case Classes

Use Case Category	Use Case Description
Market Interactions	Market transactions and interactions
Convey Price Information	Price information
Convey Ancillary Services (AS) Signals	AS including faster response change-in-use (e.g., phase control); sometimes these functions are implemented using so-called “fast demand response (DR)” a service is provided by curtailment and increase.
Convey DR and DER Signals	DR or DER events
Convey Indications of Impending Power Failure or Exceptional Event	Notification that a power failure and/or natural disaster is imminent.
Convey Directed Interaction Requests (includes direct load control [DLC])	Use cases suggest direct interaction with a device through service or control-centric means to address specific device response or behavior.
Convey Energy Usage Data (Meter Data)	Historical, present, and projected information. For example, projected demand, historical usage, and response to a curtailment event.
Convey Monitoring Information	Monitoring and verification of the state of energy management and use, e.g., with respect to response to a curtailment, generation, or storage draw request.

B.3 EIS Alliance Use Case Categories

Use Case	Use Case Description
DR	Load shed and shift, to minimize cost and to meet contractual obligations.
Energy Management of Complex Facilities With Storage and Generation	This expands the DR and dynamic pricing use cases to include more detailed monitoring and planning of energy use, production and storage to balance energy costs with operational and production energy needs.
Demand Forecasts Provided to the Energy Service Provider	Conveys expected power usage, after the customer has examined energy price forecasts and local energy needs.
Balancing and Trading Power	An energy manager can choose to buy power from one or more energy suppliers, or to store or generate onsite. One may also trade off between onsite fuel sources for heating or electricity generation needs. The energy manager can choose to generate onsite for sale in energy markets if the prices are advantageous.
Measurement, Validation, and Display	Sub-metering (or metering on individual devices) allows for better tracking of energy consumption, allocating energy costs, display of equipment power usage and costs, calculation of emissions, energy benchmarking, monitoring of power quality, and validation against energy supplier energy usage data. This may include the monitoring of facility emissions for benchmarking, market trading, or reporting purposes and enabling the monitoring of grid emissions for facility reporting purposes.
Exchange of Grid and DG Status	Enables the facility to learn about upcoming grid outages for planning purposes and to inform the energy service provider about the status of DG.
DLC	Interrupting a customer load, typically residential air conditioning or hot water heaters, by direct control from the energy service provider system operator.
Monitoring and Management of System Health by Service Providers	Allows for business models such as: (1) leasing of DG, storage, and other DERs; (2) the proactive remote analysis and management of energy assets such as appliances and equipment; (3) the capability to interface to building/home energy management systems for the purpose of detecting operational efficiencies and anomalies; and (4) the ability to monitor facility energy producing equipment that may affect the safety of grid maintenance personnel.

B.4 IEC TC57 WG21 Preliminary Use Cases

Use Case	Use Case Description
Flex Start Washing Machine	The user wants to get the laundry done by 8:00 p.m., customer energy manager (CEM) optimizes facility operations plan.
Flex Start EV Charging	The user wants to have his EV charged by 8:00 a.m. CEM optimizes facility operations plan.
Severe Grid Stability Issues	The grid recognizes (severe) stability issues. CEM optimizes facility operations plan.
Power Limitation PV	The user wants to limit his consumption to his own local production (e.g., PV)
CEM Manages Simple Devices	Switch on/off simple devices, dim simple devices
Customer Sells Flexibility	The customer wants to sell his flexibility to the grid. CEM optimizes facility operations plan.
Customer Sells Decentralized Energy	The customer wants to sell own decentralized energy (e.g., PV) to smart grid. CEM optimizes facility operations plan.

Use Case	Use Case Description
Grid-Related Emergency Situations	Grid-related emergency situations (blackout prevention). CEM optimizes facility operations plan.
Customer Connects New Smart Device	The customer wants to connect a new smart device to the CEM
Energy Consumption Information	The consumer wants to be informed on their historic and forecasted energy use. CEM may build a short-term energy forecast and informs the user.
Unexpected Disconnect	A smart device disconnects unexpectedly (failure). CEM responds.
Expected Yearly Costs Of Smart Device	The consumer wants to know an estimate of the yearly energy cost of a smart device. CEM responds.
Energy Storage And Feed-In Based On Tariff	The consumer wants a storage device to feed energy to the grid once the tariff reaches a certain threshold. CEM responds.
Energy Consumption Management From External	Manage energy consumption of smart devices by smart grid energy services provider or buildings services provider.
Manage In-Premises Battery System	Manage in-premises battery system. CEM optimizes facility operations plan.
Manage DER	Manage DER. CEM optimizes facility operations plan.
Peak Shift Contribution By Battery Aggregation	Peak shift contribution by battery aggregation. CEM optimizes facility operations plan.
Control Appliances Based On Price Information	Control of smart home appliances based on price information by time slot. CEM optimizes facility operations plan.
Control Appliances Based On Energy Savings Signal	Control of smart home appliances in response to power saving request from electric power supplier. CEM optimizes facility operations plan.
Control Appliances Before Power Cut	Control of smart home appliance before power cut. CEM optimizes facility operations plan.
Control Appliances In Case Of Natural Disaster	Control of smart home appliances in case of natural disaster. CEM optimizes facility operations plan.
Bilateral DR-Negawatt	Bilateral DR (Negawatt Transaction = Japanese-related requirement). An energy supplier asks for a demand responsive load from consumer on the day when tightness of electricity supply and demand is expected.
User Story Lighting	Reduce lighting load and other loads in a building during a DR event (e.g., tariff information too high or forecast of renewable energy too low) or a demand side management event (e.g., stability issue in the grid with the request to reduce energy consumption). CEM optimizes facility operations plan.
Energy Market Flexibility Management Long-Term Demand Planning	A building owner/operator wants to use the energy flexibility of its building(s) to optimize its energy procurement by adapting the consumption according to flexible energy tariffs and/or to achieve additional revenue at the ancillary service energy markets. The process with the retailer business to procure a certain amount of energy needed by his customers based on long-term contracts (1 week up to multiple years).
Energy Market Flexibility Management Energy Trade Through Day-Ahead Market"	The process of procuring the remaining amount of energy which is needed on top of the already procured energy by long-term contracts.
Energy Market Flexibility Management Energy Trade Through Intra-Day Market"	The process when a major deviation from the planned buildings energy scheduled is detected.
Energy Market Flexibility Management Providing Secondary/Tertiary	The participation of smart buildings at the secondary/tertiary reserve energy markets.

Use Case	Use Case Description
Reserves At The Control Reserve Market"	
Energy Market Flexibility Management Reaction On Grid Congestions"	The reaction of buildings on grid congestion events initiated by the distribution grid operator.
Demand-Supply Adjustment With Cooperation Between Supplier And Customer (Model 1) Japan	Customers and suppliers cooperate in determining the final pricing information from the supplier.
Energy Saving, Demand-Supply Control For Individual Buildings (Model 2) Japan	Optimizing the power consumption and generation, the CEM provides functionality in coordinating loads and resources for an individual building.
Energy Saving, Demand-Supply Adjustment For The District (Model 3) Japan	Customer and district service provider coordinate operations plans.
Self-Sustaining Community (Model 4) Japan	Community cooperation and coordination in managing renewables
Adjustment Of Energy Production & Consumption In Normal Conditions	Customer action in case of a shortage of supply of electricity and in case of an excess of supply of electricity.
Energy Accommodation In Disaster Conditions	CEM coordinates with the district to optimize operations plan during disaster conditions.

B.5 Use Case Landscape

The buildings interoperability use case landscape is presented in the following table. Each row contains a use case identified by its type, title, the source of the information, the actor domains, and automation zones. The types of use cases indicate whether the scenario is primarily related to a market service (e.g., buying a commodity from a marketplace, such as electricity), an offsite service (e.g., making a deal with a neighboring building or purchasing a diagnostics service), or an onsite service (e.g., the coordination of something within the building, such as a tenant contracting for energy from the building). Abbreviations are used for the actor domains (BO = Buildings Operations, BC = Buildings Communities, BSP = Buildings Service Providers, MSP = Market Service Providers, and DSO = Distribution Service Operations). Similarly, the automation zones are indicated by the first letter of their name (D = Devices, C = Control, S = Supervisory, and M = Management).

To indicate the primary points of interface connectivity, a touch points column is included. It indicates which actors are primarily connected and the automation zone involved for each actor. Information is also provided about the status of standards that support the use case and if standards are emerging.

Use Case Type	Use Case	Source	Actor Domains	Automation Zones	Touch Points	Current Standards Practice	Nascent Buildings Standards (Released)
Market Service	Dynamic Rate	PNNL	BO, DSO, MSP	M, S	MSP:BO(M/S), DSO:BO(M/S)	Standards not widely deployed	SEP2, OpenADR2
Market Service	Optimize EV Charging for Dynamic Rate	PNNL	BO, DSO, MSP	M, S	MSP:BO(M/S), DSO:BO(M/S)	Standards not widely deployed	SEP2, OpenADR2, SAE
Market Service	End-Use Differentiated Dynamic Rates	PNNL	BO, DSO, MSP	M, S	MSP:BO(M/S), DSO:BO(M/S)	Standards not widely deployed	SEP2, OpenADR2
Market Service	Differentiated Reliability Service	PNNL	BO, DSO, MSP	M	MSP:BO(M/S), DSO:BO(M/S)	Standards not widely deployed	
Market Service	Transactive Acquisition of Ancillary Services	PNNL	BO, DSO, MSP	C	MSP:BO(M/S), DSO:BO(M/S)	Standards not widely deployed	OpenADR2
Market Service	Third-Party Energy Provider	PNNL	BO, BSP, DSO	S, C	DSO:BO(C), BSP:BO(S/C)	Standards not widely deployed	
Market Service	Efficiency Shared Savings	PNNL	BO, BSP	S	BSP:BO(S)	Standards not widely deployed	
Market Service	Efficiency Incentive Payment	PNNL	BO, DSO, MSP	M	DSO:BO(S), MSP:BO(S)	Standards not widely deployed	
Market Service	Transactive Energy Market Exchange	PNNL	BO, DSO, MSP	M, S	DSO:BO(M), MSP:BO(M)	Standards not widely deployed	OpenADR2, EMIX
Market Service	Trading Efficiency to Relieve Congestion	PNNL	MSP, BO, DSO, BSP	M, S	DSO:BO(S), BSP:BO(S), MSP:BO(M)	Standards not widely deployed	
Market Service	Transactive Retail Energy Market	PNNL	MSP, BO, DSO	M, S	DSO:BO(S), MSP:BO(M)	Standards not widely deployed	OpenADR2, EMIX
Market Service	Trading Allocated Capacity Rights	PNNL	BO, DSO, BSP, MSP	M, S	DSO:BO(S), BC:BO(S), MSP:BO(M)	Standards not widely deployed	OpenADR2, EMIX
Market Service	Balancing and trading power	EIS Alliance	BO, DSO, BSP, MSP	M, S	DSO:BO(S), BSP:BO(S), MSP:BO(M)	Standards not widely deployed	OpenADR2, EMIX
Market Service	Convey Price Information	IEC PC118	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	OpenADR2
Market Service	Market Interactions	IEC PC118	BO, MSP	M	MSP:BO(M)	Standards not widely deployed	OpenADR2, EMIX
Market Service	Customer Sells Flexibility	IEC TC57 WG21	BO, DSO, MSP	M, S	DSO:BO(S), MSP:BO(M)	Standards not widely deployed	OpenADR2, EMIX
Market Service	Customer Sells Decentralized Energy	IEC TC57 WG21	BO, DSO, MSP	M, S	DSO:BO(S), MSP:BO(M)	Standards not widely deployed	OpenADR2, EMIX
Market Service	Energy Storage And Feed-In Based On Tariff	IEC TC57 WG21	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	SEP2, OpenADR2

Use Case Type	Use Case	Source	Actor Domains	Automation Zones	Touch Points	Current Standards Practice	Nascent Buildings Standards (Released)
Market Service	Energy Market Flexibility Management Long-term demand planning	IEC TC57 WG21	BO, DSO, MSP	M	DSO:BO(M), MSP:BO(M)	Standards not widely deployed	
Market Service	Energy Market Flexibility Management Energy trade through day-ahead market	IEC TC57 WG21	BO, DSO, MSP	M, S	DSO:BO(S), MSP:BO(M),	Standards not widely deployed	OpenADR2, EMIX
Market Service	Energy Market Flexibility Management Energy trade through intra-day market	IEC TC57 WG21	BO, DSO, MSP	M, S	DSO:BO(S), MSP:BO(M),	Standards not widely deployed	OpenADR2, EMIX
Market Service	Energy Market Flexibility Management Providing secondary/tertiary reserves at the control reserve market	IEC TC57 WG21	BO, DSO, MSP	M, S	DSO:BO(S), MSP:BO(M),	Standards not widely deployed	OpenADR2, EMIX
Market Service	Energy Market Flexibility Management Reaction on grid congestions	IEC TC57 WG21	BO, DSO	M, S	DSO:BO(S), MSP:BO(M),	Standards not widely deployed	
Offsite Service	Interruptible Service or Direct Load Control	PNNL	BO, BSP	C, D	BSP:BO(C/D)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Rate Dependent Priority for Cold Load Pickup	PNNL	BO, DSO	C, D	DSO:BO(C/D)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Emergency Power Rationing	PNNL	BO, DSO,BSP	S	DSO:BO(S), BSP:BO(S)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Air Shed Management	PNNL	BO, DSO, BSP	M, S	DSO:BO(M), BSP:BO(S)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Ancillary Services via Aggregator	PNNL	BO, BSP	C	BSP:BO(C)	Standards not widely deployed	OpenADR2
Offsite Service	Monitoring and management of system health by service providers	EIS Alliance	BO, BSP	S, C	BSP:BO(S/C)	Standards not widely deployed	OPC-UA
Offsite Service	3rd Party Energy management of complex facilities with storage and generation	EIS Alliance	BO, BSP	S, C	BSP:BO(S/C)	BACnet, OPC, Modbus and other fieldbuses. Numerous industrial and commercial standards and proprietary protocols are being applied by systems integrators.	OPC-UA
Offsite Service	Demand forecasts provided to the energy service provider	EIS Alliance	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	OpenADR2
Offsite Service	Demand response	EIS Alliance	BO, BSP, DSO	M, S, C	BSP:BO(S/C), DSO:BO(M,S)	Standards not widely deployed	OpenADR2

Use Case Type	Use Case	Source	Actor Domains	Automation Zones	Touch Points	Current Standards Practice	Nascent Buildings Standards (Released)
Offsite Service	Direct load control	EIS Alliance	BO, BSP, DSO	D	DSO:BO(D), BSP:BO(D)	Standards not widely deployed	
Offsite Service	Exchange of grid and distributed generation (DG) status	EIS Alliance	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	OpenADR2
Offsite Service	Convey Energy Usage Data (Meter Data)	IEC PC118	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	SEP2, OpenADR2, ESPI
Offsite Service	Convey DR and DER Signals	IEC PC118	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Convey Ancillary Services (AS) Signals	IEC PC118	BO, DSO	S, C	DSO:BO(S/C)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Convey Indications of Event	IEC PC118	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Convey Directed Interaction Requests (includes DLC)	IEC PC118	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Convey Monitoring Information	IEC PC118	BO, DSO, BSP	S	DSO:BO(S), BSP:BO(S)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Severe Grid Stability Issues	IEC TC57 WG21	BO, DSO	S, C	DSO:BO(S/C)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Grid-Related Emergency Situations	IEC TC57 WG21	BO, DSO	S, C	DSO:BO(S/C)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	EnergyConsumptionManagement FromExternal	IEC TC57 WG21	BO,DSO	S	DSO:BO(S)	Standards not widely deployed	
Offsite Service	Bilateral DR-Negawatt	IEC TC57 WG21	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	SEP2, OpenADR2
Offsite Service	Demand-supply Adjustment with Cooperation between Supplier and Customer (Model1) Japan	IEC TC57 WG21	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	
Offsite Service	Energy saving, Demand-supply adjustment for the district (Model 3) Japan	IEC TC57 WG21	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	
Offsite Service	Self-Sustaining Community (Model 4) Japan	IEC TC57 WG21	BO, DSO, BC	S	DSO:BO(S), BC:BO(S)	Standards not widely deployed	
Onsite Service	Tenant Contracts with Building Owner for Energy	PNNL	BO, DSO, MSP	M, D	DSO:BO(D), MSP:BO(M)	Standards not widely deployed	
Onsite Service	Transactive Control for Large Commercial Building HVAC Systems	PNNL	BO, DSO	S, C	DSO:BO(S)	Standards not widely deployed	

Use Case Type	Use Case	Source	Actor Domains	Automation Zones	Touch Points	Current Standards Practice	Nascent Buildings Standards (Released)
Onsite Service	Trading Positions in an Electric Vehicle Charging Queue	PNNL	BO, BSP	M, S	BSP:BO(M/S)	Standards not widely deployed	
Onsite Service	Microgrid Coordinating Demand Response, Distributed Generation and Storage	PNNL	BO, BC, BSP	M, S	BC:BO(M/S), BSP:BO(M/S)	BACnet, OPC, Modbus and other fieldbuses. Numerous industrial and commercial standards and proprietary protocols are being applied by systems integrators.	OPC-UA
Onsite Service	Data Centers Trade Computation Jobs	PNNL	BO, BSP	S, C	BO(S/C), BSP:BO(S/C)	Standards not widely deployed	
Onsite Service	Diagnostic and Automated Commissioning Services	PNNL	BO,BSP	S, C	BSP:BO(S/C)	Standards not widely deployed	OPC-UA
Onsite Service	Measurement, validation and display	EIS Alliance	BO	S	BO(S/C)	SEP1, numerous industrial and commercial standards and proprietary protocols are being applied by systems integrators.	SEP2
Onsite Service	Energy management of complex facilities with storage, EVs and generation	EIS Alliance	BO, BSP	M, S	BSP:BO(M/S)	BACnet, OPC, Modbus and other fieldbuses. Numerous industrial and commercial standards and proprietary protocols are being applied by systems integrators.	OPC-UA
Onsite Service	Flex Start Washing Machine	IEC TC57 WG21	BO, DSO	C	DSO:BO(C)	Standards not widely deployed	SEP2, OpenADR2
Onsite Service	Flex Start EV charging	IEC TC57 WG21	BO, DSO	C	DSO:BO(C)	Standards not widely deployed	SEP2, OpenADR2
Onsite Service	Power Limitation PV	IEC TC57 WG21	BO, DSO	S, C	DSO:BO(S/C)	Standards not widely deployed	
Onsite Service	CEM manages Simple Devices	IEC TC57 WG21	BO	S, C	BO(S/C)	Standards not widely deployed	
Onsite Service	Customer Connects New Smart Device	IEC TC57 WG21	BO	S, C	BO(S/C)	Standards not widely deployed	
Onsite Service	Energy Consumption Information	IEC TC57 WG21	BO	S	BO(S)	Standards not widely deployed	SEP2
Onsite Service	Unexpected Disconnect	IEC TC57 WG21	BO	S	BO(S)	Standards not widely deployed	
Onsite Service	ExpectedYearlyCostsOfSmartDevice	IEC TC57 WG21	BO	S	BO(S)	Standards not widely deployed	SEP2, OpenADR2

Use Case Type	Use Case	Source	Actor Domains	Automation Zones	Touch Points	Current Standards Practice	Nascent Buildings Standards (Released)
Onsite Service	ExpectedYearlyCostsOfSmartDevice	IEC TC57 WG21	BO	S	BO(S)	Standards not widely deployed	SEP2, OpenADR2
Onsite Service	Manage In-Premises Battery System	IEC TC57 WG21	BO	S, C	BO(S/C)	Standards not widely deployed	
Onsite Service	Manage DER	IEC TC57 WG21	BO	S	BO(S), BSP:BO(S)	BACnet, OPC, Modbus and other fieldbuses. Numerous industrial and commercial standards and proprietary protocols are being applied by systems integrators.	
Onsite Service	Peak Shift Contribution by Battery Aggregation	IEC TC57 WG21	BO	S	BO(S)	Standards not widely deployed	
Onsite Service	Control Appliances Based On Price Information	IEC TC57 WG21	BO, DSO	S	DSO:BO(S)	Standards not widely deployed	SEP2, OpenADR2

Appendix C

Buildings Interoperability Standards

Appendix C

Buildings Interoperability Standards

The following table lists relevant standards that exist today that influence buildings interoperability. The "Std Type" indicates whether the entry is directed to (1) enabling market interactions, (2) connections with offsite entities (e.g., other buildings or third-party service providers), or (3) onsite integration of equipment within the building.

The table includes standards that are relevant to both the operations/maintenance and design lifecycle phases of buildings. The design phase includes buildings architecture, engineering and construction and the operations and maintenance (O&M) phase refers to operations and maintenance. The "LifeCycle Phase" column indicates the area in the lifecycle of buildings where the standard applies: O&M or Design.

The "Type" indicates whether the standard exists as created by a standards body, whether it is in-process, or whether it is a de-facto standard (i.e., the standard is widely adopted but may have come from a private organization and did not go through an open standards development process). "In-Process" standards are in the development process and considered important but have not been released.

The areas of the buildings interoperability framework that apply to the standard are also shown along with the targeted interfaces between actor domains. The interfaces are inter-domain buildings interfaces and are identified by the nomenclature format "ExternalDomain:BuildingOperations(Automation Zone)" using abbreviations for the actors (BO = Buildings Operations, BC = Buildings Communities, BSP = Buildings Service Providers, MSP = Market Service Providers, and DSO = Distribution Service Operations) and automation zones (D = Devices, C = Control, S = Supervisory, and M = Management). Lastly, a link to the standard specification is also provided (where available).

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
Market	O&M	EMIX	Energy Market Information Exchange	Std	EMIX is a standard information model and XML schema for communicating energy price and product definition. This standard is a component of Energy Interoperations.	OASIS	I	S	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=emix
Offsite	O&M	ASHRAE 201	Facility Smart Grid Information Model	Std	The purpose of this standard is to define an abstract, object-oriented information model to enable appliances and control systems as organized by homes, buildings, and industrial facilities to manage electrical loads and generation sources in response to communication with a “smart” electrical grid and to communicate information about those electrical loads to utility and other electrical service providers. The ASHRAE SPC 201 Facility Smart Grid Information Model was developed to specifically abstract building energy systems within the context of building to grid interactions, the OASIS Energy Interoperations service model, OpenADR 2.0b, and the energy services provider.	ASHRAE	I	S,C	BO, DSO, BSP	DSO:BO(S/C), BSP:BO(S/C)	Available thru ASHRAE
Offsite	O&M	BACWS	BACnet Web Services	Std	BACnet Web Services is an emerging high-level interface for BACnet systems.	ASHRAE	I,T	S	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	Not available
Offsite	O&M	EI	Energy Inter-operations	Std	OASIS Energy Interoperations is an information model that defines messages to communicate price, reliability, and emergency conditions over communications interfaces. Energy Interoperation is agnostic as to the technology that a communications interface may use to carry these messages and therefore requires the definition of a full communications stack including message transport mechanism and security in order to achieve interoperability.	OASIS	I	S	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.html#_Toc388603962
Offsite	O&M	GBC	Green Button Connect	Std	Green button is a protocol based on the Energy Services Provider Interface that provides customers with secure and private, non-realtime, validated energy data from utility backhaul data collection systems over public IP networks.	NAESB, NIST	I,T	S	BO,DSO, BSP	DSO:BO(S), BSP:BO(S)	http://greenbuttondata.org/
Offsite	O&M	IEC 62056	IEC 62056-6-1 ed1.0 (2013-02)	Std	Electricity metering data exchange – The DLMS/COSEM suite – Part 6-1: Object identification system (OBIS).	IEC	I	D	BO, DSO, BSP	DSO:BO(D), BSP:BO(D)	Available from IEC

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
Offsite	O&M	IEC 72746	IEC 72746	In-process Std	Systems interface between customer energy management system and the power management system.	IEC	I	S,C	BO,DSO, BSP	DSO:BO(S/C), BSP:BO(S/C)	Not available
Offsite	O&M	IEC CIM	IEC Common Information Model	Std	Energy management system application program interface	IEC	I	M	BO	n/a	https://webstore.iec.ch/publication/6208
Offsite	O&M	IEC62541	OPC Unified Architecture	Std	OPC UA is a high-level standard for a wide range of commercial and industrial facilities. It includes integrated security and information modeling capability.	IEC	I,T	S	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	Available thru OPC Foundation/IEC
Offsite	O&M	IEEE 21451	IEEE IoT P21451	Std	Smart Transducer Interface for sensors and actuators.	IEEE	I,T	S,C,D	BO, DSO, BSP	DSO:BO(S/C/D),BSP:BO(S/C/D)	Available thru IEEE
Offsite	O&M	OADR2B	OpenADR2.0B	Std	OpenADR 2.0 is a demand response (DR) service interface to support the delivery of DR events and energy pricing over IP networks. It is based on a profile (or subset) of the OASIS Energy Interoperations.	OpenADR Alliance	I,T	S,C	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	http://www.openadr.org/specification
Offsite	O&M	oBIX	Open Building Information Exchange	Std	oBIX is a web services standard to facilitate the exchange of information between intelligent buildings and enable enterprise application integration	OASIS	I,T	S	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	http://www.oasis-open.org/committees/download.php/21462/obix-1.0-cs-01.zip
Offsite	O&M	WSC	WS-Calendar	Std	WS-Calendar is a standard information model and XML schema for communicating time and time interval. This standard is a component of Energy Interoperations.	OASIS	I	S	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=ws-calendar
Onsite	O&M	1-Wire	1-Wire	Defacto	1-Wire is a device communications bus system designed by Dallas Semiconductor Corp. that provides low-speed data, signaling, and power over a single signal. 1-Wire is similar in concept to I^2C, but with lower data rates and longer range. It is typically used to communicate with small inexpensive devices such as digital thermometers and weather instruments. A network of 1-Wire devices with an associated master device is called a *MicroLan*.	1-Wire	T	C,D	BO	BO(C/D)	http://www.ibutton.com/ibuttons/standard.pdf
Onsite	O&M	ANSI/CEA 2045	ANSI/CEA 2045	Std	Modular Communications Interface for Energy Management.	IEEE	T	C,D	BO	BO(C/D)	Available thru ANSI

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
Onsite	O&M	ANSI/TIA-862	ANSI/TIA-862-A	Std	Building Automation Systems Cabling Standard.	ANSI	T	D	BO	BO(D)	Available from ANSI
Onsite	O&M	ASHRAE Gdl 13-2007	ASHRAE Gdl 13-2007	Guide	Specifying Building Automation Systems.	ANSI	I	S,C,D	BO	BO(S/C/D)	Available from ASHRAE
Onsite	O&M	BACnet	ASHRAE Std 135-2010	Std	BACnet is the ASHRAE standard for interconnecting building automation components.	ASHRAE	I,T	S,C	BO	BO(S/C)	Available thru ASHRAE
Onsite	O&M	CC-LINK	CC-LINK	Defacto	Open industrial network that enables devices from numerous manufacturers to communicate. It is predominantly used in machine, cell or process control applications in manufacturing and production industries.	CC-LINK Partner Assoc, Supported by Mitsubishi Electric	T	C,D	BO	BO(C/D)	http://www.cclinkamerica.org/cc-link/Specifications.html
Onsite	O&M	CE-Bus	CE-Bus	Std	A communications protocol for home and building automation.	Electronic Industries Alliance (EIA)	T	C,D	BO	BO(C/D)	Available thru EIA
Onsite	O&M	ClimateTalk	ClimateTalk	Defacto	ClimateTalk is a common information model developed for the exchange of information between disparate systems and devices. The ClimateTalk Alliance supports the ClimateTalk specification which defines both an energy model and protocol for interconnecting HVAC and hot water equipment from different vendors. It uses a byte-oriented protocol suitable for very resource constrained devices and a service-oriented approach for controlling, operating and monitoring HVAC in multiple zones.	ClimateTalk Alliance	I	C,D	BO	BO(C/D)	http://www.climatetalkalliance.org/ClimateTalkTechnology/DownloadSpecification.aspx
Onsite	O&M	DALI	Digital Addressable Lighting Interface	Defacto	IEC 60929 and IEC 62386 are technical standards for network-based systems that control lighting in building automation. They were established as a successor for 0-10 V lighting control systems, and as an open standard alternative to Digital Signal Interface (DSI), on which it is based. IEC 60929 is the first version of the standard and will be withdrawn by 23 June 2014. Members of the AG DALI are allowed to use the DALI trademark on devices that are compliant with the current standard.	DALI	T	C,D	BO	BO(C/D)	http://www.dali-ag.org/discover-dali/dali-standard.html

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
Onsite	O&M	DLNA	DLNA	Defacto	A DLNA Certified device connects with any other DLNA Certified device to share media such as music, pictures and videos – regardless of manufacturer.	DLNA Alliance	I, T	C,D	BO	BO(C/D)	http://www.dlna.org/
Onsite	O&M	DSI	Digital Serial Interface	Defacto	Digital Serial Interface (DSI) is a protocol for the controlling of lighting in buildings (initially electrical ballasts). DSI was the first use of digital communication in lighting control, and was the precursor to DALI.	Tridonic	T	C,D	BO	BO(C/D)	http://mipi.org/specifications/display-interface
Onsite	O&M	Dynet	Dynet	Defacto	Dynalite components communicate using DyNet. The physical layer consists of a modified RS-485 TIA/EIA-485-A serial bus running along CAT5 cable.	Dynet	T	C,D	BO	BO(C/D)	Available thru Dynet
Onsite	O&M	EEIM-CRD	EEIM-CRD	Std	The Enterprise Energy Information Management (EEIM)-CRD documents 127 standard data elements needed to manage facility energy information across the Department of Defense. These requirements were developed through a business process. Capability Requirements Document, Deputy Under Secretary of Defense for Installations and Environment, Business Enterprise Integration Directorate.	DOD	I	S	BO	BO(S)	Available from DOD
Onsite	O&M	EnOcean	EnOcean	Defacto	The EnOcean technology is a wireless energy-harvesting technology used primarily in building automation systems.	EnOcean Alliance	T	C,D	BO	BO(C/D)	https://www.enocean-alliance.org/en/home/
Onsite	O&M	Haystack	Haystack	Defacto	Project Haystack is an open source initiative to develop naming conventions and taxonomies for building equipment and operational data. It supports a dictionary of terms associated with building energy along with an HTTP/JSON encoding	Haystack	I	S,C	BO, DSO, BSP	DSO:BO(S), BSP:BO(S)	http://project-haystack.org/download
Onsite	O&M	IEC 60338	IEC 60338 ed1.0	Std	Withdrawn corrigendum. Telemetering for consumption and demand.	IEC	T	D	BO,DSO, BSP	DSO:BO(D), BSP:BO(D)	Available from IEC
Onsite	O&M	IEC 61158	IEC 61158	Std	Industrial communication networks – Fieldbus specifications.	IEC	T	D	BO	BO(D)	Available thru IEC
Onsite	O&M	IEC 61499	IEC 61499	Std	Function blocks for industrial-process measurement and control systems.	IEC	I	C	BO	BO©	Available thru IEC
Onsite	O&M	IEC/TR 62051	IEC/TR 62051	Std	Electricity metering.	IEC	T	D	BO,DSO, BSP	DSO:BO(D), BSP:BO(D)	Available from IEC

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
Onsite	O&M	IEEE 1547	IEEE 1547	Std	Standard for Interconnecting Distributed Resources with Electric Power System.	IEEE	T	C,D	BO, DSO, BSP	DSO:BO(C/D), BSP:BO(C/D)	Available thru IEEE
Onsite	O&M	IEEE P2030.X	IEEE 2030.X	Std	Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure.	IEEE	I	C,D	BO, DSO, BSP	DSO:BO(C/D), BSP:BO(C/D)	Available thru IEEE
Onsite	O&M	Insteon	Insteon	Defacto/ Closed	Proprietary wireless home-control networking technology.	N/A	T	C,D	BO	BO(C/D)	Proprietary
Onsite	O&M	ISO 16484	ISO 16484-1:2010	Std	This International Standard specifies guiding principles for project design and implementation and for the integration of other systems into the building automation and control systems (BACS).	ISO	I	C	BO	BO(C)	Available from ISO
Onsite	O&M	ISO 50006	ISO 50006:2014	Std	Provides guidance to organizations on how to establish, use and maintain energy performance indicators and energy baselines (EnBs) as part of the process of measuring energy performance.	ISO	I	M	BO	n/a	http://www.iso.org/iso/catalogue_detail?csnumber=51869
Onsite	O&M	KNX	KNX	Defacto	KNX is a standardized (EN 50090, ISO/IEC 14543), OSI-based network communications protocol for intelligent buildings. KNX is the successor to, and convergence of, three previous standards: the European Home Systems Protocol, BatiBUS, and the European Installation Bus (EIB or Instabus).	KNX Association	T	C,D	BO	BO(C/D)	http://www.knx.org/knx-en/news/2014/entries/2014-01-10_KNX-Specifications.php
Onsite	O&M	Lon-Works	LonWorks	Std	LonWorks is a building control networking platform.	LonMark	T	C,D	BO	BO(C/D)	Available thru LonMark
Onsite	O&M	Master-Format	Master-Format	Std	MasterFormat is a standard for organizing specifications and other written information for commercial and institutional building projects in the United States and Canada to organize information about a facility's construction requirements and associated activities.	Construction Specifications Institute (CSI)	I	C,D	BO	BO(C/D)	Available thru CSI
Onsite	O&M	Modbus	Modbus	Std	Modbus is a low-level legacy protocol for exchanging simple datatypes between devices.	Modbus Org	T	C,D	BO	BO(C/D)	http://www.modbus.org/specs.php
Onsite	O&M	NestAPI	NestAPI	Defacto	The Google NEST API is an HTTP/JSON protocol for NEST thermostats and is the basis for interoperability within the "Works With NEST" ecosystem. It uses a simple linear information model based on text tagnames and data structures. Google has announced future support for an expanded API called Weave.	Google	T	C,D	BO	BO(C/D)	https://developer.nest.com/

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
Onsite	O&M	OASIS EEIM	OASIS Energy Efficiency Information Model	Std	EEIM serves as a domain model to define, detect, isolate, facilitate, intercept, arbitrate, trigger and execute Energy Efficiency events EEIM will automate and scale energy efficiency.	OASIS	I	S	BO	BO(S)	Available thru OASIS
Onsite	O&M	oneM2M	oneM2M	Std	Technical specifications for a common M2M Service Layer	oneM2M	I,T	D	BO, DSO, BSP	Generic	http://www.onem2m.org/
Onsite	O&M	OPC	Classic OPC	Std	Widely used standard for communicating between Microsoft systems and devices.	OPC Foundation	T	S,C	BO	BO(S/C)	Available thru OPC Foundation
Onsite	O&M	SEP1	Smart Energy Profile 1	Std	Smart meter protocol. Precursor to SEP2	ZigBee Alliance	I,T	C,D	BO, DSO, BSP	DSO:BO(C/D), BSP:BO(C/D)	http://www.zigbee.org
Onsite	O&M	SEP2	IEEE 2030.5	Std	SEP2.0 was developed as a smart meter protocol to enable secure customer meter data access to a range of data including the ability to deliver energy pricing through the AMI network from energy service provider to customers. SEP2 was designed to interact with devices within a home or building as it incorporates a device model and ZigBee networking.	IEEE	I,T	C,D	BO, DSO, BSP	DSO:BO(C/D), BSP:BO(C/D)	http://www.zigbee.org/Standards/ZigBeeSmartEnergy/SmartEnergyProfile2.aspx
Onsite	O&M	Thread	Thread	Defacto	Low-power mesh network designed to securely and reliably connect hundreds of products around the home. Robust self-healing mesh network Interoperable by design using proven, open standards and IPv6 technology with 6LoWPAN.	Thread Group	T	D	BO	BO(D)	Available from The Thread Group
Onsite	O&M	TIA 4940	ANSI/TIA-4940.022	Std	Smart Device Communications; Protocol Aspects; Deploying and Securing Applications.	TIA	T	D	BO	BO(D)	Available thru ANSI
OnSite	O&M	Vorto	Vorto	Defacto	Vorto is an open source Eclipse project, based upon the Eclipse Modeling Framework, which provides a meta-modeling framework based on Eclipse EMF and set of eclipse tools focused on improving IoT interoperability. Specific protocols are mapped to a repository-resident user-defined abstract information model. Code-generation tools enable software integration.	Eclipse	I	D	BO	BO(C/D)	https://projects.eclipse.org/proposals/vorto
Onsite	O&M	VSCP	Very Simple Control Protocol	Defacto	An open and free framework/protocol for IoT/m2m automation tasks with Uniform device discovery, identification and device configuration. Autonomous/distributed device functionality. Update/maintain device firmware. VSCP is an application level protocol.	VSCP	I,T	C,D	BO	BO(C/D)	http://vscp.org/vscpspec/vscp_spec_latest.xhtml

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
Onsite	O&M	X10	X10	Defacto/ Closed	A classic powerline carrier device protocol used in-home automation.	X10	T	C,D	BO	BO(C/D)	
Onsite	O&M	xAP	xAP Home Automation Protocol	Defacto	Open protocol intended to support the integration of telemetry and control devices primarily within the home.	XAP Automation	T	C,D	BO	BO(C/D)	http://www.xapautomation.org/index.php?title=Protocol_definition
Onsite	O&M	xPL	xPL	Defacto	xPL is an open protocol intended to permit the control and monitoring of home automation devices.	XPL	T	C,D	BO	BO(C/D)	http://xplproject.org.uk/wiki/index.php?title=XPL_Specification_Document
Onsite	O&M	ZigBee	ZigBee Wireless	Std	Low-power IPv6 networking.	ZigBee Alliance	T	D	BO	BO(D)	http://www.zigbee.org/Specifications.aspx
Onsite	O&M	Z-Wave	Z-Wave	Defacto	Z-Wave is a wireless communications protocol designed for home automation, specifically for remote control applications in residential and light commercial environments. The technology uses a low-power radio frequency radio embedded or retrofitted into electronic devices and systems, such as lighting, access controls, entertainment systems and household appliances.	Z-Wave Alliance	T	C,D	BO	BO(C/D)	Available thru Z-Wave Alliance
Onsite	Design	BAMie	Building Automation Information Exchange	Std	The Building Automation Management Information Exchange (BAMie) models sensor systems and measurements related to the performance of services. It specifies an IFC representation for addressing using BACnet and oBIX.	Building Smart Alliance	I	M	BO	n/a	http://docs.buildingsmartalliance.org/MVD_BAMIE/
Onsite	Design	BPie	Building Programming Exchange	Std	The Building Programming Information Exchange (BPie) models building resource requirements including the expected minimum requirements for the finished facility, activities taking place within facility, room data sheets, and space types.	Building Smart Alliance	I	M	BO	n/a	http://www.nibs.org/?page=bsa_bpie
Onsite	Design	COBie	Construction Operations Building information exchange (COBie)	Std	COBie is an information exchange specification for the lifecycle capture and delivery of information needed by facility managers. COBie is the "trade name" for a NBIMS-US that defines a minimum set of construction handover information. COBie includes the subset of managed and maintained assets during the life of a building project. It uses a common definition of assets such as facilities,	National Institute of Building Sciences/Building Smart Alliance	I	M	BO	n/a	http://www.nibs.org/?page=bsa_commonbimfiles

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
					floors, and equipment as well as individual components. It includes spatial containment only, not geometry such as piping, air flow, or water flow. Asset names must be unique and in addition to GUIDs. COBie uses the IFC STEP Physical File Format to exchange data but can also use ifcXML, the COBieLite schema and SpreadsheetML.						
Onsite	Design	gbXML	Green Building XML	Std	gbXML is an export/import XML schema developed to enable integrated interoperability between building design and engineering analysis tools such as energy simulations. gbXML has achieved significant market adoption due to the wide range of building information supported including physical building data, energy design data, construction data, control data, cost data, size data, daily schedule data, weather data, and space/zone data. The gbXML schema includes a dictionary with definitions for campus and building energy-related terms and equipment including three key energy flow systems: (1) air loop, (2) hydronic loop, and (3) lighting. Elements are defined for building type, identification, location, geometries, equipment design loads, performance and efficiencies, environmental and design parameters, and control types.	Green Building XML	I	M	BO	n/a	http://www.gbxml.org/
Onsite	Design	HVACie	HVAC Information Exchange	Std	HVAC Information Exchange (HVACie) specifies components, assemblies, systems and connections that support requirements. Ports are defined for all equipment, valves, ductwork, and piping including connections between components using upstream and downstream ports and port property sets which define port details.	Building Smart Alliance	I	M	BO	n/a	http://docs.buildingsmartalliance.org/MVD_HVACIE/
Onsite	Design	ISO 10303	ISO 10303 - Industrial automation systems and integration	Std	The ISO STandard for the Exchange of Product model data (STEP) describes how digital product information is represented and exchanged.	ISO	I	M	BO	n/a	http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=56424
Onsite	Design	ISO 12006-2	OmniClass	Std	OmniClass is a comprehensive construction classification system containing 15 tables that classify the built environment and the processes	Building Smart Alliance	I	M	BO	n/a	http://www.buildingsmart-tech.org/

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
					used to create it. These tables include: construction entities by function, construction entities by form, spaces by function, spaces by form, elements, work results, products, phases, services, disciplines, organizational roles, tools, information, materials, and properties. OmniClass is the recommended classification system for use in identifying information types in exchanges standardized in NBIMS. The International Framework for Dictionaries (IFD) Library complements OmniClass by providing definitions and relationships for the items classified and a mechanism to make them explicit and persistent through the application of a GUID for all terms.						
Onsite	Design	ISO 12006-3	International Framework of Dictionaries	Std	The IFD is a library standard for a terminology database. This framework includes concepts such as GUIDs, classes or types of objects, data dictionaries, classes with relationships, subjects/terms with characteristics/properties, subjects with a name and properties, behavior, environmental influence, function, measure, property, and unit. It also specifies a technology mapping to EXPRESS (ISO STEP 10303-11) and web services.	ISO/Building Smart	I	M	BO	n/a	http://www.buildingsmart-tech.org/
Onsite	Design	ISO 16739	Industry Foundation Classes	Std	IFC is an ISO standard format through which any BIM information may be exchanged. They include a full set of asset classes with class attributes.	ISO/Building Smart	I	M	BO	n/a	http://www.iso.org/iso/catalogue_detail.htm?csnumber=51622
Onsite	Design	ISO 17798	ISO/AWI 17798	In-process Std	The building information model (BIM) includes applications for building automation and control systems	ISO	I	M	BO	n/a	http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=60570
Onsite	Design	MVD	Model View Definitions	Std	MVDs specify the required IFC subset for specific purposes. E.g., an MVD is used to communicate BIM project standards as part of the United States National BIM Standard (NBIMS-US). They specify a subset of these classes used within an exchange. MVDs include a list of included objects, the required level of detail, and the business rules that	ISO/Building Smart	I	M	BO	n/a	http://www.buildingsmart-tech.org/specifications/ifc-view-definition

Std Type	Life Cycle Phase	Std ID	Name	Type	Standard Description	Organization	Interop Layers	Auto Zones	Actor Domains	Interface	Spec Link
					align the class characteristics with the business case. This level of detail, however, is insufficient for interoperability because it lacks standard semantics and encoding. These are provided by other standards such as mvdXML, which supports COBie.						
Onsite	Design	NBIMS-US	National BIM Standard-United States	Defacto	Provides consensus-based standards through referencing existing standards, documenting information exchanges, and delivering best business practices for the entire built environment.	National Institute of Building Sciences/Building Smart Alliance	I	M	BO	n/a	https://www.nationalbimstandard.org/
Onsite	Design	Sparkie	Electrical System Information Exchange	Std	The Electrical System Information Exchange (Sparkie) specifies electrical systems to the same level of detail as HVACie	Building Smart Alliance	I	M	BO	n/a	http://docs.buildingsmartalliance.org/MVD_SPARKIE/
Onsite	Design	Uniclass		Std	A classification system for structuring information freely available for all participants throughout the lifecycle of a project and beyond	Construction Project Information Committee	I	M	BO	n/a	http://www.cpic.org.uk/uniclass/
Onsite	Design	UniFormat	UniFormat	Std	A method of arranging construction information based on functional elements, or parts of a facility characterized by their functions, without regard to the materials and methods used to accomplish them	Construction Specifications Institute	I	M	BO	n/a	http://www.csinet.org/uniformat
Onsite	Design	WSie	Water System Information Exchange	Std	The Water System Information Exchange (WSie) specifies water systems to the same level of detail as HVACie.	Building Smart Alliance	I	M	BO	n/a	http://docs.buildingsmartalliance.org/MVD_WSIE/

Appendix D

Buildings Interoperability Stakeholders

Appendix D

Buildings Interoperability Stakeholders

The following table lists related stakeholder categories to buildings interoperability with example organizations. The relevant actor domains and automation zones are also indicated for each stakeholder category. The notes section contains web links for more information on some of the main organizations in a specific category. A description of the type of information contained in the columns of the table follows.

- The description column provides a brief explanation of each stakeholder category.
- The example organization column provides several organizations representative of each stakeholder category. It is not uncommon for an organization to be in more than one stakeholder category. Note that special attention was given to the Industry Consortia and Trade Associations category, which presents a relatively complete list of relevant industry alliances and user groups. These industry groups are expected to play important roles in buildings interoperability standards development and applications.
- The actor domains column maps the actor domains from Section 3.3.2 to each stakeholder category (see Figure 7) using an abbreviation (BldgOps = Buildings Operations, BldgCommun = Buildings Communities, BldgServProv = Buildings Service Providers, MrktServProv = Market Service Providers, and DistrSysOps = Distribution Service Operations)
- The automation zones column indicates which buildings automation zones from Section 3.3.3 are of major interest to the stakeholders in each category (see Figure 7)..

A couple other points are worth noting.

- Building occupants are important stakeholders for realizing buildings interoperability. Their perspectives are expected to be represented by Facility Managers-Owners-Operators-Occupants groups (e.g., the Building Owners and Managers Association and the International Facility Management Association) under the stakeholder category of professional associations.
- Stakeholder categories may overlap (e.g., many professional associations and trade associations are also SDOs).

Stakeholder Name	Abbreviation	Description	Sample Organizations	Actor Domains	Automation Zones	Notes
Building Automation Suppliers	BldgAutomat	Manufacturers and integrators of hardware and software for commercial building automation systems covering HVAC, lighting, and access control.	Alerton, Honeywell, Johnson Controls, Lutron, Leviton, Schneider, Siemens, Echelon, Pacific Controls, Rockwell, Tridium	BldgOps	Control, Supervisory, Management	More manufactures can be found from http://en.wikipedia.org/wiki/Building_automation#Manufacturers
Building Equipment Manufacturers	BldgEquip	Manufacturers of building systems equipment (e.g., HVAC chillers, boilers, pumps, fans, compressors, elevators, and escalators).	Carrier, Danfoss, Daikin, Lochinvar, Trane, Hitachi, Otis, Schneider	BldgOps	Devices, Control	More companies can be found from http://www.ari.org/site/661/About-Us/AHRI-Members. Some stakeholders in this category may also offer building automation and control systems.
Building Information Technology Products and Services	BldgIT	Companies that develop software, platforms, and tools to support building information modeling, computing services, and IoT	Autodesk, Amazon, Google, Microsoft, Cisco, IBM	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	
Communication Infrastructure and Service Providers	Comm	Companies that provide wide-area network communication services over wired cables or wireless.	AT&T, T-mobile, Verizon	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Management	

Stakeholder Name	Abbreviation	Description	Sample Organizations	Actor Domains	Automation Zones	Notes
Consumer Products	ConsumProd	Manufacturers of consumer appliances and electronics (e.g., clothes washers, dryers, dishwashers, refrigerators, ranges, home automation networks, thermostats, and video equipment).	Electrolux, GE, LG, Samsung, Whirlpool, Control4, Crestron Electronics, ELAN Home Systems, Honeywell, Sony	BldgOps	Devices, Control	A full list of appliance categories can be found at http://www.aham.org/ht/d/sp/i/1667/pid/1667. Consumer electronic categories can be found at https://www.ce.org/Membership/Divisions-and-Councils.aspx
Distributed Energy Resource Manufacturers	DERMan	Manufacturers of equipment for distributed generation, energy storage, and flexible load.	AES, CALMAC, Caterpillar, Cummins, Xantrex,	BldgOps, BldgCommun, DistrSysOps	Devices, Control	
Distributed Energy Resource Service Providers & Aggregators	DERServ	Companies that facilitate onsite generation or demand flexibility of electricity and thermal energy and can aggregate services for utilities or markets.	First Solar, Solar City, Comverge, EnerNOC	BldgOps, BldgCommun, MrktServProv, DistrSysOps	Control, Supervisory, Management	
Energy Service Companies	ESCO	Companies that provide energy auditing, retro-commissioning, energy efficiency retrofits and energy analytics solutions that manages and utilizes building automation data continuously for operational efficiency improvement.	Accenture, AMERESCO, Cimetrics, SkyFoundry	BldgCommun, BldgServProv	Supervisory, Management	
Electric Vehicle Charging Companies	EVCharge	Companies that build charge stations and provide electric vehicle charging systems.	ChargePoint, GridPoint, Ford, GM, Toyota	BldgOps, BldgCommun, BldgServProv	Devices, Control, Supervisory, Management	More companies can be found from http://www.electricdrive.org/index.php?ht=d/sp/i/28786/pid/28786

Stakeholder Name	Abbreviation	Description	Sample Organizations	Actor Domains	Automation Zones	Notes
Facility Managers and Owners	FaciltyMgr	Companies or units that own building properties and provide building operation and maintenance services.	McKinstry, ABM, MacDonald-Miller, facility management departments in universities hospitals and chain-stores	BldgOps, BldgCommun	Devices, Control, Supervisory, Management	Overlaps exist between facility managers and building energy service companies. Represents building occupants.
Government Agencies	Gov	Agencies of the United States federal and state governments that may place requirements on building connectivity or be affected by applications of building interoperability.	DOE, LBNL, NIST, PNNL, CA Building Standards Commission, California Energy Commission, NY Div. of Building Standards and Codes	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	
Meter and Sensor Manufacturers	MeterMan	Manufacturers of smart meters, sensors, and actuators.	Elster, Itron	BldgOps, MrktServProv, DistrSysOps	Devices, Control	
R&D Organizations and Academia	R&D	Organizations whose interest in building interoperability is primarily for research, teaching, or other types of technology transfer.	Carnegie Mellon University, Stanford University	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	

Stakeholder Name	Abbreviation	Description	Sample Organizations	Actor Domains	Automation Zones	Notes
Standards Development Organizations	SDO	Organizations that create national or international standards specifications through an open, public process.	ASHRAE, International Electrotechnical Commission (IEC), ANSI, IEEE, Internet Engineering Task Force (IETF), International Society of Automation (ISA), ISO, OASIS, World Wide Web Consortium (W3C)	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	
Testing & Certification Organizations	Test	Organizations that develop interoperability test tools and offer testing and certification services for ecosystems of products that conform to the associated standards.	UL, Intertek, QualityLogic	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	
Utility	Utility	Public or private regulated utility companies that supply electricity and gas to consumers.	Con Edison, Munis, PG&E, PUDs, Rural Electric, Southern California Edison	MrktServProv, DistrSysOps	Devices, Controls, Supervisory, Management	All different electricity providers are combined as a whole because the focus is on the interface between buildings and the grid
Industry Consortia and Trade Associations	Consortia	Organizations consisting of companies for the development and promotion of an industry segment or the adoption of a specific technology for building interoperability.	Air-Conditioning Heating and Refrigeration Institute (AHRI)	BldgOps, BldgServProv	Devices, Control, Supervisory	

Stakeholder Name	Abbreviation	Description	Sample Organizations	Actor Domains	Automation Zones	Notes
			AllSeen Alliance	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	To advance the Internet of Things based on AllJoyn. (https://allseenalliance.org/about/why-allseen)
			Association of Home Appliance Manufacturers	BldgOps, BldgServProv	Devices, Control	
			buildingSMART alliance	BldgOps	Management, Supervisory	To promote the use of building information models. (http://www.nibs.org/?page=bsa)
			ClimateTalk Alliance	BldgOps	Devices, Control	To develop a common communication infrastructure for HVAC and Smart Grid devices, enabling the interoperability of diverse systems. (http://www.climatetalkalliance.org/)
			Consortium for Smart Energy Profile (SEP) 2 (IEEE 2030.5)	BldgOps, BldgCommun, BldgServProv, MrktServProv	Devices, Control	To develop common testing documents and processes for certifying SEP 2 interoperability. (http://www.csep.org)
			Consumer Technology Association (CTA)	BldgOps	Devices, Control	Trade association that is also an accredited standard development organization. http://www.cta.tech/
			EnOcean Alliance	BldgOps	Devices, Control	To develop and promote self-powered wireless monitoring and control systems for sustainable buildings by formalizing the

Stakeholder Name	Abbreviation	Description	Sample Organizations	Actor Domains	Automation Zones	Notes
						interoperable wireless standard. (http://www.enocean-alliance.org/en/home/)
			Haystack	BldgOps, BldgCommun, BldgServProv	Supervisory, Control	To develop tagging conventions and taxonomies for building equipment and operational data. (http://project-haystack.org/)
			IPSO Alliance	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	To establish the Internet Protocol as the network for the connection of Smart Objects. (http://www.ipso-alliance.org/)
			National Electrical Manufacturers Association (NEMA)	BldgOps, BldgCommun, BldgServProv, MrktServProv, DistrSysOps	Devices, Control, Supervisory, Management	Trade association that is also an ANSI accredited standard development organization. http://www.nema.org
			OpenADR Alliance	BldgOps, BldgCommun, BldgServProv, MrktServProv	Supervisory, Management	To foster the development, adoption, and compliance of the Open Automated Demand Response (OpenADR) standards through collaboration, education, training, testing and certification. (http://www.openadr.org/)
			USNAP Alliance	BldgOps	Devices, Control	To promote, certify and advance ANSI/CEA-2045, that enables any Home Area Network (HAN) or Demand Response (DR) standard. (http://www.usnap.org/)

Appendix E

Open Industry Standards Enabling Buildings Ecosystems

Appendix E

Open Industry Standards Enabling Buildings Ecosystems

The standards and initiatives are presented in the context of the buildings interoperability framework's four ASHRAE buildings automation zones (see Figure 3): management, supervisory, control, and devices. Each zone is broken down into three interoperability layers based on the GridWise Interoperability Context-Setting Framework: organizational, informational, and technical. Interoperability standards are discussed relating to each layer within a given buildings automation zone. As in the case of many standards, if a standard addresses interoperability across multiple zones/layers appropriate references are provided.

E.1 Open Source Hardware

Open source hardware refers to community supported, compatible hardware available from multiple sources based upon open schematics and circuit board designs. They provide the means to publish and replicate common specification patterns creating more of an opportunity for interoperability between devices. Examples include the following:

- BeagleBone Black
- Raspberry PI (currently single source but may become an open source platform)
- Arduino (Banzi 2009)

	Management	Supervisory	Control	Devices
Organizational				
Informational				✓
Technical				✓

E.2 Community Operating System Distributions

Operating systems are freely available, licensed, community supported, and enterprise class. They can be the open source equivalent of related commercially available operating system distributions. These operating systems can support servers, desktops, and handheld devices. Because they are actively maintained by community and industry partners, these operations systems increase the likelihood of replicating common baseline systems used in buildings energy as well as providing a common platform for distributing freely available software. Examples include the following:

- Linux
  - Debian (MacKinnon 1999), Ubuntu (Thomas 2007), CentOS (Tyler 2006), Fedora (Tyler 2006)
- Google Android

	Management	Supervisory	Control	Devices
Organizational				
Informational	✓	✓	✓	✓
Technical	✓	✓	✓	✓

E.3 Virtual Machines

Virtual machines allow you to run more than operating system emulated within another operating system. Your host's primary operating system can be commercially licensed (e.g., Windows or MacOS) and host a community operating system distribution. The advantage of using virtual machines at the enterprise level is that virtual machine owners can make upgrade requests (e.g., memory and storage expansion) as needed. Another advantage is the ability to build, clone, and distribute virtual machines as required. Open source and freely available commercial virtual machines are widely available. Examples of open source and freely available virtual machines include the following:

- Oracle VirtualBox (Oracle Corporation 2013)
- Xen (Barham 2003)

	Management	Supervisory	Control	Devices
Organizational				
Informational			✓	✓
Technical			✓	✓

E.4 Non-Proprietary Programming Languages

Non-proprietary programming languages are a current industry-wide standard. A number of languages are being more heavily relied upon for leading edge interoperability software technology because they support platform independence and their licensing promotes sharing in commercial and open source communities. Examples include the following:

- Python (Van Rossum 2003)
- Java (Gosling 2000)
- Mono (.NET) (Meyer 2001)
- Model view controller (MVC) Javascript (Armeli-Battana 2013)
- ANSI/ISO C++ (ANSI 2015b)
- ANSI C (Kalev and Schmuller 1999)
- Structured Query Language (SQL) (ISO/IEC 9075-1 2008)
- SPARQL Query Language (Prud'Hommeaux and Seaborne 2008)

	Management	Supervisory	Control	Devices
Organizational	✓	✓	✓	✓
Informational	✓	✓	✓	✓
Technical	✓	✓	✓	✓

E.5 Standards-Based Networking

Standards-based networking refers to community-developed and -supported networking protocols that are available from multiple sources. Examples include the following:

- Internet Engineering Task Force (IETF)/WiFi (Perkins et al. 2007) Alliance WiFi
- Z-Wave
- ZigBee

	Management	Supervisory	Control	Devices
Organizational				
Informational			✓	✓
Technical			✓	✓

E.6 Standards-Based Databases

Standards-based databases refer to community-developed and -supported software platforms for storing and querying data that are openly available from multiple sources. They provide the means to represent complex data structures using commonly understood structures such as tables, key/value pairs, and graphs. The databases also provide standardized interfaces for defining data structures and interacting with the databases. Examples include the following:

- ORACLE MySQL
- NOSQL – MongoDB, Cassandra
- Apache Hadoop/HBase – large scale distributed computing and storage
- OpenTSDB – Time Series Database
- Sesame Triple Store
- Virtuoso Universal Database
- SQL Server Analysis Services

	Management	Supervisory	Control	Devices
Organizational				
Informational		✓	✓	
Technical		✓	✓	

E.7 Open Application Programming Interfaces (APIs)

Open APIs refer to openly available community-developed and -supported programming interfaces for accessing data and services from a system. Examples include the following:

- ORACLEJDBC (Java Database Connectivity)
- Xerces XML Parser
- Jena API
- JSR
- Standard I/O Library
- Java Specification Requests (JSR)

	Management	Supervisory	Control	Devices
Organizational				
Informational		✓	✓	
Technical		✓	✓	

E.8 Open Source Code Licenses

Open source licenses refer to legal contracts specifying the rights associated with using specific software source code. These licenses permit the use of the specific software but define how the software can be used. Examples include the following:

- MIT
- Apache
- GPL

	Management	Supervisory	Control	Devices
Organizational	✓	✓	✓	✓
Informational	✓	✓	✓	✓
Technical	✓	✓	✓	✓

E.9 Open Data Initiatives

The Open Knowledge Foundation defines open data as "data that can be freely used, modified, and shared by anyone for any purpose." In 2013 the U.S. White House clarified open standards by executive order mandating: "Government information shall be managed as an asset throughout its lifecycle to promote interoperability and openness, and, *wherever possible and legally permissible, to ensure that data are released to the public in ways that make the data easy to find, accessible, and usable.*" The United States is not alone adopting open standards for sharing data, for example the G-8 has a charter [https://www.gov.uk/government/publications/open-data-charter] to "promote transparency, innovation and accountability" and the European Union has a Public Sector Information policy to develop better transparency for government information [http://ec.europa.eu/digital-agenda/en/legal-rules#revision-of-the-directive]. While many kinds of government, public sector, and scientific data can be defined as open data there are others such as private industry, personal data, and local and national security that are defined as closed data, where machine-to-machine interactivity and data usage and sharing is governed by far more restrictions. In buildings, energy data usage is strictly guarded with access controls to protect proprietary data and services, and constrained to only support critical infrastructure needs. However, even open data standards bodies are increasingly acknowledging the need to provide closed communities standards-based approaches to increase interoperability. At this time, World Wide Web Consortium (W3C) is proposing linkages for closed data communities that need to operate in a secure environment.

E.10 Community Vocabularies and Ontologies

Metadata based on familiar community vocabularies are key to the reusability of any scientific data. Community vocabularies are actively being developed, vetted, and shared within and across communities that wish to share their domain-specific data.

Organizations exist that help to facilitate development of these vocabularies, such as WC3 (www.w3.org), schema.org, and the Linked Open Vocabularies (LOV) (lov.okfn.org). These organizations contribute community vocabularies hoping to use them to help describe how data may be linked together. Some vocabularies are domain-specific and used to describe data from a scientific community's perspective. Others are used as foundational vocabularies. Foundational vocabularies emphasize the linkage of concepts spanning multiple domains such as, the Vocabulary of a Friend (VOAF) (lov.okfn.org), PROV-O (www.w3.org/TR/prov-o), and others. By applying these vocabularies to linked-open-data principles, relationships between resources and resource descriptions can be given a particular emphasis and/or meaning with a reduction in ambiguity and an increase in clarity.

	Management	Supervisory	Control	Devices
Organizational				
Informational	✓	✓	✓	✓
Technical				

E.11 Modeling Language Standards

Models are used to represent real-world concepts as interrelated data structures to serve a particular need: transient (e.g., web data entry form), persistent (e.g., database schema), or data exchange (e.g., common information model (IEC 2006) (DMTF 2015) or National Information Exchange Model (NIEM 2013)). The basic building blocks of models are key search terms (concepts) with human understandable definitions, thesauri from these terms, and models to show how the terms are organized and interconnected. Modeling languages can be powerful interoperability tools because they are technology agnostic but they can be used as a specification to generate data structures and software. A model can be shared between organizations allowing both organizations to use the same standardized approach but written using software or data structures that mesh within their current infrastructure. Examples include the following:

- W3C Resource Description Format (RDF) (Adida et al. 2010)
- Unified Modeling Language (Rumbaugh et al. 2004)

	Management	Supervisory	Control	Devices
Organizational				
Informational	✓	✓	✓	✓
Technical	✓	✓	✓	✓

E.12 Open Standards-Based Data Encoding

Open data encoding protocols refers to community-developed and -supported methods for encoding messages that are and openly available for use. Examples include the following:

- IETF JavaScript Object Notation (JSON) (Ishaq et al. 2013)
- W3C Extensible Markup Language (XML) (Bosak et al. 1998)
- IETF AtomPub (Atom Publishing Protocol) (Hoffman and Bray 2006)
- W3C OWL (Web Ontology Language) (McGuinness and van Harmelen 2004)
- IETF comma-separated values (CSV) (Shafranovich 2005)

	Management	Supervisory	Control	Devices
Organizational	✓	✓	✓	✓
Informational	✓	✓	✓	✓
Technical	✓	✓	✓	✓

E.13 Secure and Open Messaging

Communication protocols developed by IETF allow for the secure international communication of many scientists and engineers. These protocols include the Secure Hypertext Transfer Protocol (HTTP), File Transfer Protocol (FTP), Secure-shell FTP (SFTP), Secure Copy (SCP), and Rsync. Other non-proprietary scientific protocols such as GridFTP and Globus Online allow scientific communities to share data across high-performance networks and through heavy network traffic. The Energy Sciences Network (ESnet) is a high-performance, unclassified national network built to support scientific research. Funded by the U.S. Department of Energy's (DOE's) Office of Science (SC) and managed by Lawrence Berkeley National Laboratory, ESnet provides services to more than 40 DOE research sites, including the entire National Laboratory system, its supercomputing facilities, and its major scientific instruments. In addition, ESnet connects to 140 research and commercial networks, permitting DOE-funded scientists to productively collaborate worldwide partners.

	Management	Supervisory	Control	Devices
Organizational				
Informational				
Technical		✓	✓	✓

Open messaging refers to community-developed protocols and standards used by software platforms for exchanging messages on networks that are openly available from multiple sources. Open messaging provides the means for distributed software systems (e.g., web services) to interoperate despite the fact that they were written in different software languages and run on different operating systems. They also provide the means to automatically generate client interfaces to interact with the service. Examples include the following:

- Representational State Transfer (REST) RESTful HTTP – Internet-scale client-server PULL messaging
- Simple Object Access Protocol (SOAP) HTTP
- IETF XMPP – Internet-scale point to point PUSH and publish-subscribe instant messaging bus
- OASIS MQTT – Publish-subscribe telemetry messaging bus
- OASIS AMPQ – Publish-subscribe enterprise queuing bus

	Management	Supervisory	Control	Devices
Organizational				
Informational				
Technical		✓	✓	✓

E.14 Internet of Things (IoT)

Many definitions exist for the IoT but, in general, it refers to the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.[1] Examples include the following:

- IEEE P2413 – Standard for an Architectural Framework for the IoT
- IEEE IoT Related Standards
- IEEE 1547 – Interconnecting Distributed Energy Resources
- IEEE 11073 – Health Informatics
- IEEE 21450/1 – Smart transducer interface for sensors and actuators
- IETF IoT Standards (Ishaq et al. 2013) – Integration of Constrained Devices into the Internet
- IETF 802.15.4
- IETF 6LoWPAN Working Group (IPv6)

	Management	Supervisory	Control	Devices
Organizational				
Informational			✓	✓
Technical			✓	✓

E.15 Business to Business (B2B)

B2B interoperability refers to business transactions involving the exchange of products, services, and information between companies. These interactions are important for enabling the growth of buildings ecosystems as collections of product and service providers coordinate internally and with each other to provide interoperable products and services to buildings customers. Examples include the following:

- Construction Operations Building Information Exchange (COBie) – a data format for the publication of a subset of buildings model information
- MasterFormat – A standard for organizing specifications and other written information for commercial and institutional building projects in the United States and Canada
- OMG Business Process Model and Notation (BPMN)
- SAP Business Process Library
- ERIS Event-Driven Process Chains (EPC)

	Management	Supervisory	Control	Devices
Organizational	✓	✓		
Informational				
Technical				

[1] http://www.gartner.com/it-glossary/internet-of-things/

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