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Smart Buildings as a Transactive Energy Hub

GWAC White Paper

Prepared by the

GridWise® Architecture Council

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About this Document
The GridWise Architecture Council was formed by the U.S. Department of Energy to promote and enable ***interoperability*** among the many entities that interact with the electric power system. This balanced team of industry representatives proposes principles for the development of interoperability concepts and standards. The Council provides industry guidance and tools that make it an available resource for smart grid implementations. In the spirit of advancing interoperability of an ecosystem of smart grid devices and systems, this document presents a Transactive Energy framework to provide the context for identifying and discussing development and application of this technology. This is an introductory document; however, some knowledge of interoperability, familiarity with the *GWAC Interoperability Context-Setting Framework*, and knowledge of energy markets and their business models will be helpful. The Executive Summary provides a description of the purpose and contents of the document. Other documents, such as checklists, guides, and white papers, exist for targeted purposes and audiences. Please see the website www.gridwiseac.org for more products of the Council that may be of interest to you.

GRIDWISE® Architecture Council

Executive Summary

Smart buildings and the smart grid have many mutual advantages for improving their direct interaction through greater interoperability. As buildings and their subsystems become smarter, more network-aware, and better able to adapt in real time, opportunities to provide substantial benefit to smart grid operators multiply. This convergence, through the deployment of transactive energy systems, has great potential to help the grid balance generation with load, optimize generation, and defer infrastructure investment through peak load shaving. Building owners, integrators, and design engineers need more interoperability between the various systems and components. This white paper introduces key concepts, values, and opportunities to all stakeholders to support better understanding and provide direction for making a building a transactive energy hub.

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About GridWise® and the Architecture Council

The GridWise vision rests on the premise that information technology will revolutionize planning and operation of the electric power grid, just as it has transformed business, education, and entertainment. Information technology will form the "nervous system" that integrates new distributed technologies—demand response and distributed generation and storage—with traditional grid generation, transmission, and distribution assets. Responsibility for managing the grid will be shared by a "society" of devices and system entities.

The mission of the GridWise Architecture Council ("the Council") is to enable all elements of the electricity system to interact. We are an independent body that believes tomorrow's electricity infrastructure can be made more efficient and secure by integrating information technology and e-commerce with distributed, intelligent networks and devices. To achieve this vision of a transformed electricity system, the Council is defining the principles for interaction among the information systems that will effectively and dynamically operate the grid. The Council, which is supported by the U.S. Department of Energy, includes 13 representatives from electric energy generation and delivery, industrial systems control, building automation, information technology, telecommunications, and economic and regulatory policy.

The GridWise Architecture Council is shaping the guiding principles of a highly intelligent and interactive electricity system—one ripe with decision-making information exchange and market-based opportunities. This high-level perspective provides guidelines for interaction between participants and interoperability between technologies and automation systems. We seek to do the following:

- Develop and promote the policies and practices that will allow electric devices, enterprise systems, and their owners to interact and adapt as full participants in system operations.
- Shape the principles of connectivity for intelligent interactions and interoperability across all automation components of the electricity system, from end-use systems, such as buildings or heating, ventilation, and air conditioning systems, to distribution, transmission, and bulk power generation.
- Address issues of open information exchange, universal grid access, distributed grid communications and control, and the use of modular and extensible technologies that are compatible with the existing infrastructure.

The Council is neither a design team nor a standards-making body. Our role is to bring the right parties together to identify actions, agreements, and standards that enable significant levels of interoperation among automation components. We act as a catalyst to outline a philosophy of inter-system operation that preserves the freedom to innovate, design, implement, and maintain each organization's role and responsibility in the electricity system.

Acronyms and Abbreviations

AI	artificial intelligence
API	application programming interface
ASHRAE	American Society of Heating Refrigeration and Air-Conditioning Engineers
BAS	building automation system
BIM	building information modeling
BMS	building management system
ESCO	energy service company
ESI	energy services interface
FERC	Federal Energy Regulatory Commission
GWAC	GridWise® Architecture Council
HVAC	heating, ventilating, and air conditioning
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISO	independent system operator
MW	megawatt(s)
NIST	National Institute of Standards and Technology
OEM	original equipment manufacturer
OpenADR	Open Automated Demand Response
RTO	regional transmission organization
SEPA	Smart Electric Power Alliance
TE	transactive energy

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1.0 Introduction

1.1 Why Should You Care About Smart Buildings as a Transactive Hub?

Buildings consume enormous amounts of electrical power: over 70% of all U.S. electric power usage can be attributed to buildings. Every day, energy managers wrestle with how to manage energy costs while supporting optimal occupant comfort and operational performance. A simplistic decision model can be likened to a slider control: move leftward for greater energy efficiency, move rightward for greater occupant comfort. When too many people complain of feeling hot or cold, move the slider to the right; when the Chief Financial Officer demands lower costs, move the slider to the left. Moving the slider in one direction or the other has cascading and rippling effects throughout the entire building, including lighting; heating, ventilating, and air conditioning (HVAC); plug loads; and other systems. Include fluctuating grid conditions, such as dynamic rates, time-of-use pricing, load shedding programs, and other incentives, and the decision factors compound. Add the ability to source power from a community microgrid or a local distributed energy resource (solar, wind, batteries), and the slider starts to function more as a joystick, navigating multiple influences concurrently.

Transactive Energy (TE) provides a means to support these interactions by associating measurable value with resources and conveying actionable information between the building and the grid. Interoperable applications coordinate the grid and the various building systems as a “hub,” helping to direct traffic. This transactive hub acts as a conduit or “traffic cop,” managing the needs of the various stakeholders.

Smart building systems, smart equipment, and even smart sensors and actuators are increasingly being used to improve occupant comfort and operational efficiency and manage costs. At the same time, utilities, developers, communities, and businesses grapple with reducing carbon emissions and increasing renewable energy supply. There is an increasing role for grid-aware, network-connected buildings in our energy future where smart buildings converge with the rapid change in methods for generating and delivering power.

Just as a sea of unconnected HVAC systems drives costly summer energy peaks for utilities, so too could an army of smart buildings with integrated behind-the-meter systems ramp up their energy use and storage when renewables are abundant. The same grid-connected buildings could ramp down when power is expensive or generated using fossil fuels. Many energy providers and policymakers are experimenting with ways to motivate building owners and operators to help keep power costs low and simultaneously meet carbon reduction goals. Facilities require continuous “grid connectivity” even if they have on-site distributed energy resources (DERs) to support reliability and resilience. This puts a strain on today’s grid operators to manage what is now a two-way flow of energy as well as a customer choice element, creating stabilization issues. Such issues provide opportunities for building developers, operators, and owners to capture subsidies or improve building cost-effectiveness by automating and aggregating various energy loads behind the meter that can provide energy flexibility as a service with value to the grid.

These factors create a need to understand how TE provides current and future value by establishing a means to manage and maintain a stable energy supply, regardless of the source or how it is to be used.

1.2 The Scope of This Paper and a Few Key Concepts

This paper introduces several key concepts relating to the interaction potential, value propositions, and some of the technical elements of building–grid interactions. This paper is an introductory overview for the novice. More sources of technical details, detailed studies, pilot projects, and use cases are provided in the references section. We advocate continued open dialog between the entities to foster an open, interoperable environment in which the buildings' energy consumption and their effects on the power grid can be harmonized for mutual benefit.

1.3 Transactive Energy Systems

Throughout this document, you will see the term "Transactive Energy" (TE) used to refer to tools and interactions within an electric power system. TE provides a model where independent agents such as building owners and electric grid operators exchange value that can be used to coordinate the generation, consumption, and flow of electric power. Using constructs such as price signals while considering grid reliability constraints, the term "transactive" refers to decisions being made based on the defined values of resources. Just as imbalances in supply and demand will influence any market, TE enables cost-effective operation of the power system through the exchange of mutual benefit among two or more entities.

1.4 Interoperability

Increasing incentives and smart controls make flexible building energy profiles more attractive as grid assets. However, when beginning any discussion of transactive loads and devices in buildings a building owner/operator can be overwhelmed by the vast potential and operational and architectural complexity.

Whether designing lighting, HVAC systems, energy submetering, pumps, condensers, water heating, or other essential energy-consuming and -producing applications, manufacturers want the ability to control their users' experience and interfaces. Each solution provider chooses their preferred standards, protocols, and interfaces to tailor customer experience. The extent to which these systems can communicate with each other and with outside entities determines their interoperability (Figure 1.1).

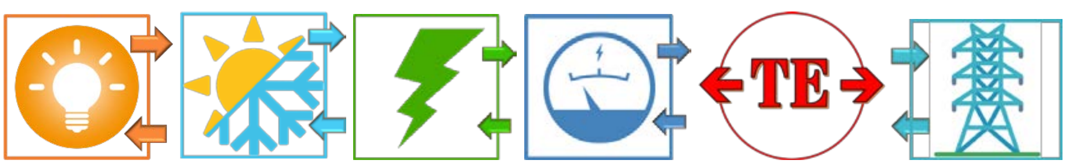

Figure 1.1. Controls for Lighting, HVAC, Power, and Metering Can Provide Interoperable TE Grid Interactions.

Interoperability, in this context, means that two or more entities can interact using a common communication protocol. The better the protocol is defined, and the interoperable context of its data is established, the more flexible, useful, and reliable the system will be. For example, if we are sharing temperature between systems, will the value be in Celsius or Fahrenheit? Establishing the interoperability data context, structure, and content is not necessarily easy when considering that all stakeholders must agree. Still, consensus is foundational to the viability of interoperable systems and is critical to the success of a TE system.

1.5 Buildings as Interoperable Transactive Hubs

A TE "hub" allows a building and an outside entity, such as a utility, to communicate with each other. This hub (Figure 1.2) is an interoperable interface that is typically delivered through a software application programming interface (API). The hub can be an edge server, a computer application, or even an embedded piece of equipment or controller. The hub receives information from the grid and acts as an agent to affect change within the building. The hub can also send status and other information back to the grid in a two-way communication system.

Figure 1.2. Building Systems and the TE Hub API Interfaces

Consider a pricing signal that is pushed to the hub. The hub, through its own logic, determines at what point the system sequences should change based on a rule in the control logic that adapts to energy price increases and decreases. Temperature set points may change, lighting may dim, or one elevator in a bank of elevators may go off-line, all to conserve energy while meeting operational performance requirements. A building could adapt to any of dozens of scenarios in response to a signal as simple as a real-time price influencing temperature set-point changes. However, there are many other useful interactions between a smart building and the grid. While much of this discussion uses commercial buildings as a basis, the same concepts can be applied to broad residential markets.

7.0Appendix A "Characterizing Interoperability," considers ways to understand and categorize various levels of interoperability regarding grid-connected smart buildings.

1.6 Intended Audience

There are many stakeholders in building-to-grid interactions. Each domain has its own expertise. However, as systems become smarter, there is greater need for a multidisciplinary approach and cross-domain expertise. This paper provides an overview of the key concepts, some terminology, and value for the following audiences:

- building owners – those who engage in transactive contracts for their facilities and responsible for the financial and contractual obligations
- design engineers and architects – those who develop the requirements, space allocation, system sizing, user interface requirements, cross-domain integrations, interoperability requirements, and similar tasks

- system integrators – those contracted entities who deploy solutions from one or more providers according to the engineer's—and architect's—design and provide the final commissioning, often balancing energy consumption with system performance through optimization algorithms
- product/solution developers/suppliers – those who design and build smart equipment, building controllers, supervisory systems, and the like
- building facility staff – the engineers, service technicians, facility managers, and others who make sure the building is functioning as required and direct performance optimizations, especially when balancing comfort, productivity, and energy management
- local utility/grid operators – those who develop relationships, programs, and incentives for building owners/operators to predict and manage loads, interact with systems in real time, and provide reporting and other services for energy load modification
- regulators/policy influencers – those who help generate the incentive programs, and provide access to systems with fair use, fair access, and privacy that are cost-effective, and consider other factors to make sure that eventual deployments meet regulatory and code requirements.

2.0 Stakeholder Context and Perspectives

Exchanging value involves identifying areas where two or more parties have closely aligned needs. In this section, we begin to outline some of the emergent needs of various stakeholders to help identify specific stakeholder value.

2.1 Minimizing Occupant Impact in a Grid Responsive Building

When every single smart device requires a separate login, interface, and communication protocol, and each aspect of each system is prone to breaking, requiring updates, and demanding periodic password refreshes, the overall experience for homeowners, building operators, and energy management platform providers is annoying. Those trying to adopt and operate these systems will reject them as too much trouble. Typical utility demand response programs and energy management platforms struggle to overcome the frustration factor to gain substantial traction. The building owner is challenged to balance energy cost reduction through grid interaction with occupant comfort and satisfaction.

A building owner can use automation, architecture, and interoperability to turn their buildings into transactive hubs. The coordination achieved with transactive systems will allow the owner to optimize user experience and transactive interfaces to yield the best results for the grid and building owners without significantly compromising user comfort and performance. This document provides context that can help owners make trade-offs in design to provide cost-effective net-zero, green, or smart buildings at competitive prices.

2.2 Building Designers, Owners, and Operators

The building designer, owner and operator stakeholder group primarily focuses on the balance between operational costs, occupant comfort, and overall system reliability. Combining energy load management and grid demand response interactions with typical building control systems provides a platform for this stakeholder group to enhance the decision process for system operations. Understanding these characteristics will allow building designers, owners, and operators to meet their goals while also exchanging the value of their building's consumption flexibility with grid operators and energy service providers.

While some building operators might prioritize minimizing costs, others might aim first to reduce carbon emissions. Understanding the trade-offs will allow designers to weigh the advantages and disadvantages of various devices regarding capabilities, available incentives, and building occupants' needs. In this way, the designer can meet each project's broader goals without unnecessary complexity.

The overall design of a facility and how it interacts with both the electricity grid and any local DERs fall in the domain of design engineering, aside from limitations via regulations, policies, and codes. Figure 2.1 shows a high-level view of the interrelation of the various elements of building-to-grid design criteria.

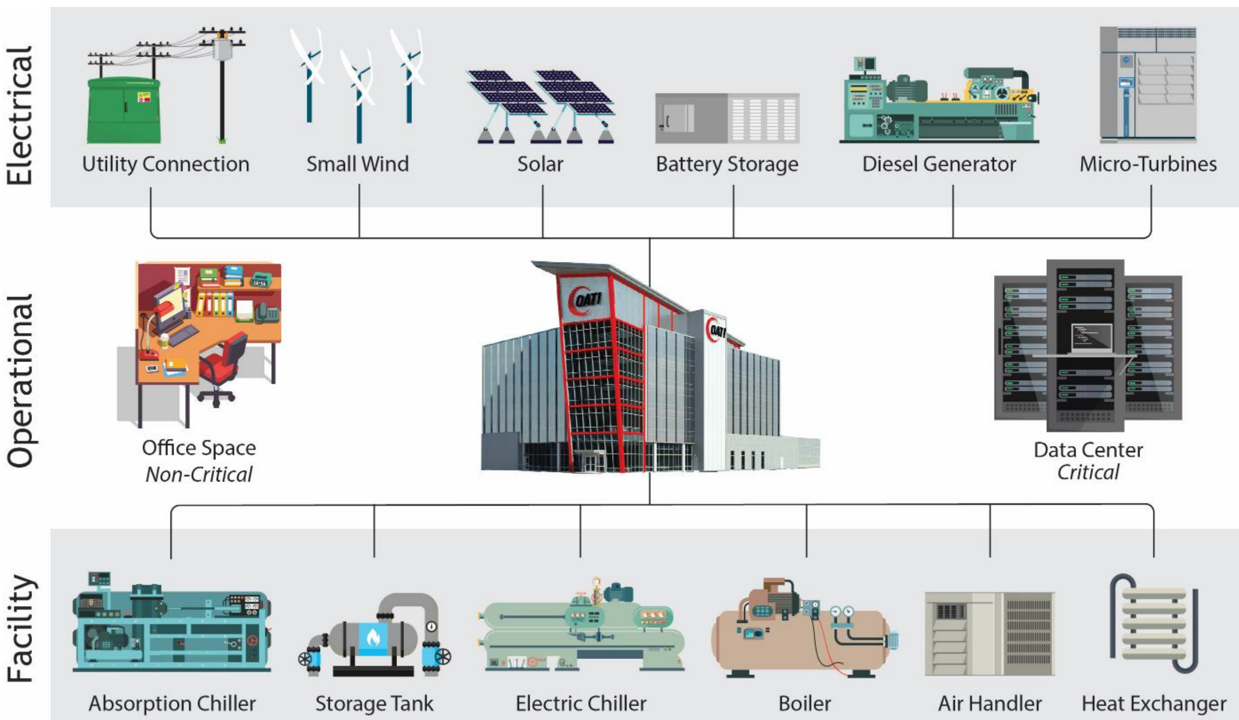

Figure 2.1. Example Microgrid Energy Sources and Key Building Equipment Energy Loads. (Source: Rahimi and Ipakchi 2016)

2.3 Regulators and Policy Influencers

Building inspectors, code officials, state utility commissioners, and other legislators and regulators often find ways to enact policy change through standards and requirements for buildings, appliances, and devices. Allowing transactive mechanisms to autonomously adjust energy use in buildings in response to pricing and energy supply changes in the energy system is one means to cost-effectively integrate more renewable energy. Understanding how building systems and automation can be harnessed to address energy system constraints is a vital means of discovering which enabling policies will speed adoption and compliance.

2.4 The Grid Operator

The grid operators rely on, and pay for, products and services they need to operate the grid reliably. Traditionally, these services—collectively referred to as grid services—have been provided by conventional generation resources. With smart devices proliferating, new players are emerging on the scene with the ability to provide such services cost effectively; these include smart buildings, microgrids, and other prosumers. At a high level, these services may be categorized into two broad categories:

- grid services needed for bulk power and transmission operations
- grid services needed for distribution operations.

With proper market platforms in place, smart buildings can provide both categories of services and receive compensation based on the market value of the services. Depending on the grid service, the size of the building, and prevailing regulations, the transaction for provision of the service may be between the utility (or the grid operator) and owners and operators of individual buildings, groups of buildings in a neighborhood, a campus microgrid, or an aggregator dealing with both the grid operator and the buildings. Bulk power/transmission grid services and distribution grid services are further explained in 7.0Appendix D.

2.5 Building System Integrators, PPPs, and ESCOs

Building system integrators, sometimes referred to as controls contractors or facility master systems integrators (FMSI), provide the expertise to connect the various separate automation systems and have them communicate with each other so that the system incorporates the required logical control sequences. They work with system controls, applications, and interfaces to optimize the operations and energy use in keeping with the required levels of safety, security, and comfort. These services can be provided under traditional consulting contracts or other, innovative approaches, such as sharing in the quantifiable cost reductions achieved, a model commonly used by Energy Service Companies (ESCOs).

A public-private partnership (PPP, 3P, or P3) is a cooperative arrangement between two or more public and private sectors, typically of a long-term nature. It involves an arrangement between a unit of government (public) and a business (private) that brings better services or improves an organization's capacity to operate effectively. Public-private partnerships are primarily used for infrastructure provisions, such as building and equipping schools, hospitals, transport systems, and water and sewer systems. Evidence of PPP performance in terms of value for money and efficiency is mixed and often unavailable. The complexities of buildings designed and operated by the same entity will offer areas of possible improvements as TE and energy storage options become more prevalent.

ESCOs often provide performance contracts to existing building owners that have the ESCO invest in the retrofit options that will lower the energy usage and be paid for their investment based on measured performance—typically utility cost savings. Many buildings need upgrades but do not have financing available. While there may be a financing cost involved, because the ESCO must invest in the capital and operating improvements, these financing costs likely are much smaller than the returns on the performance contracts, so that both parties benefit. In many cases, the utility also provides financial incentives for deep retrofit measures that the electricity customer would not have implemented without the ESCO. As major firms address effects of climate change, ESCOs are expanding their mandate beyond energy savings. The firms now offer to include renewable energy and energy storage options that can be repaid over the contract period using the monetary and environmental benefits they provide.

3.0 Putting the Pieces Together

3.1 Flexibility Potential of Devices and Processes

As a starting point for discussing the grid-integrated capabilities that devices can provide, consider the work of the Flexible Power Alliance Network. This large consortium of research, business, and community actors in the Netherlands has been integrating behind-the-meter flexible devices in net-zero cities, communities, and projects across Northern Europe since 2007. Their work led to the categorization of devices into four types of energy flexibility regarding device energy use and integration with the grid (Table 3.1).

Table 3.1. Energy Flexibility Categories for Devices. (Source: FAN n.d.)

Name	Description	Examples
Inflexible	Cannot be controlled and has no actual flexibility, but is measurable and may provide forecasts	Photovoltaic panels[1], domestic loads, wind turbines, solar collectors
Shiftable	Process that can be shifted in time, e.g., has a deadline	Washing machines, dryers, dishwashers
Adjustable	Flexible in production/consumption level and not constrained by a buffer or storage. These devices have a wide range of control possibilities without many restrictions and are usually very flexible.	Generators, dimmable lighting, heat pumps, gas heaters
Storage	Flexible in production/consumption level, but bounded by a buffer or storage. Deadlines and required fill levels constrain the flexibility of this category.	Freezers, combined heat and power systems, thermal buffers, stationary batteries, electric vehicles

It should be noted that this is a more nuanced understanding of flexibility than a traditional demand-response on/off view of load flexibility or renewables curtailment. More specific processes, devices, and resources could fit in the example's column; however, the point here is to emphasize that before enrolling or procuring devices or processes for grid integration, one must understand and realistically categorize the capabilities of such devices to maximize their benefit. Understanding the potential flexibility of a device will help better match it to the value streams and applications it can reasonably produce.

[1] Note that this situation is changing. Photovoltaics may be curtailed through smart inverter controls that adjust output. What has been lacking is incentive mechanisms to compensate the owners for curtailment. Transactive energy systems are one approach that addresses this need for incentive mechanisms.

4.0 The Value that Integrated, Flexible Devices and Processes Can Provide

To identify good uses for smart devices, it is also important to think about common ways that integrated devices, systems, processes, buildings, etc., can offer valuable services when connected to and communicating with energy markets and grid operators.

From a power operations and market perspective, dispatchable flexibility from grid-integrated buildings can help mitigate potentially disruptive, costly operational problems resulting from regional constraints, congestion, pricing spikes, and oversupply of renewable energy. Some examples of economic and operational challenges/opportunities are shown in Table 4.1.

Compensation to building owners is available for load shifting and load shedding services through aggregators in energy, demand response markets, capacity and ancillary services markets (where available), and utility energy-efficiency and load-reduction incentive programs.

Forecastable renewable generation above certain power level thresholds will automatically be monitored by grid operators and markets. However, large installations that combine storage, regulation, and demand response with autonomous controls to avoid renewable curtailment might also be able to provide capacity and regulation services as energy markets and the grid continue to evolve.

Many advanced energy markets have begun defining codes, standards, and processes to create ways building designers, owners, and operators can increase interoperability and the potential to transact their buildings' flexibility with the grid, or to manage their loads internally during outages.

Appendix B, "Emerging Standards and Codes," provides more specific information and references.

Table 4.1. Economic and Operational Challenges and Opportunities for Device Services – (Source: Flexible Power Alliance)

Service	Benefits to Economic and Operational Dispatch	Examples
Forecasting	Forecasting and/or curtailment can be used to better balance bulk resource scheduling, pricing, and optimization, and to avoid overall locating capacity resources to make up for shortfalls.	Data from photovoltaic panels, domestic loads, wind turbines, and thermal solar collectors can be combined with historical load data to optimize building systems for self-consumption or grid services.
Load Shifting	Some processes can be shifted in time to promote consumption of surplus renewable energy or to reduce peak loads that require fossil-fuel power or costly grid resources to meet demand. These are resources that typically could be shifted to increase usage when renewable energy is abundant to avoid using energy when system loads are peaking.	Thermal loads (such as preheating, precooling, refrigeration, pumping, or water heating and cooling); batch processes (such as data center batch processes), or pumping/condensing could be autonomously controlled to operate when renewables are abundant to use less energy during peak system load.
Load Shedding and Reduction	These distributed resources could be called upon to either significantly reduce consumption or increase production when weather events, outages, or grid constraints cause price spikes in response to imbalances between supply and demand. Such capacity resources can be called upon to reliably reduce system peaks.	Generators, dimmable lighting, heat pumps, gas heaters, or other resources that can switch fuel source or provide extra capacity on short notice
Regulation and Ancillary Services	As long as system controls account for constraints, schedules, and reserve capacity at the device, system, and/or process level, some of these resources' capacity can be set aside for autonomous dispatch based on highly granular load (5 minute) and regulation (4 second) signals, through turbine-governor control, or load-frequency control. IEEE 1547 (IEEE 2018), California Rule 21 (CPUC 2020), and similar standards provide an evolving guideline for such controls; however, as of this writing, they do not include comprehensive guidance on control settings for providing more advanced regulation services for inverter-based power.	Thermal generators, flywheels, microgrids, renewable + battery systems, combined heat and power systems, thermal buffers (heating and drying processes), stationary batteries, and electric vehicles with grid-connected charge and discharge settings

5.0 Designing a Smart Transactive Hub

Recent results from the U.S. Department of Energy Grid Modernization Laboratory Consortium (GMLC) (Widergren et al. 2018, Taft et al. 2016, GMLC 2017) on grid architecture and interoperability provide some starting points for designing a smart transactive hub. From the grid architecture work, we can apply the concept of laminar coordination (Figure 5.1). This approach breaks the overall problem into subproblems, which may be further broken down into sub-sub-problems, and so on, to whatever depth is necessary. This approach results in well-specified interfaces both between the layers, where objectives and constraints are exchanged, and within the layers, where coordinating information is exchanged between the agents solving that layer's subproblem.

From the GMLC interoperability project (GMLC 2018), we can apply the concept of an energy services interface (ESI). An ESI is a logical abstraction, not a physical specification, that describes the way two entities expose needs, responses to needs, and the conditions under which they will interact—that is to say, the contract. From a broad point of view, the layered system will often include physical layers corresponding to things like the grid edge. Thus, collections of smart transactive hubs representing buildings or groups of buildings within a given electricity distribution system would form such a layer. Depending on the sophistication of the buildings connected to the smart transactive hub, the layering may continue within the domain of the buildings. The ESI would exist at the point of interconnection between the smart transactive hub and the grid, providing the logical construct for the interactions with physical implantations on the respective sides, enabling the logical interaction defined by the ESI.

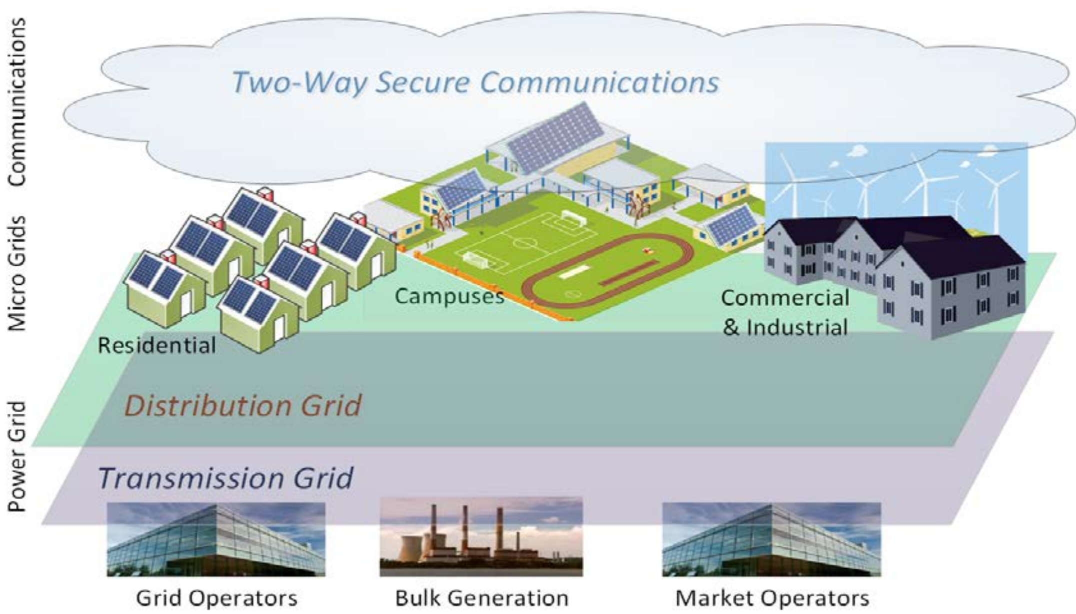

Figure 5.1. TE Layers. (Source: Rahimi and Ipakchi 2012)

More simply stated, a smart, transactive hub provides the core information-sharing model, a method to account for the transaction, and a validation of the information being shared by multiple parties. As an example, energy meter data translate to a monthly energy bill and a payment for that bill. The meter, in this case, is the hub, the "smart" is the ability to measure the energy usage and share those data to a network (via smart networked meters), and the utility collecting those data, aggregating and processing them, and billing the customer. If the device sharing the meter data were no longer the utility meter but an "appliance" owned and operated by the building owner, an ESCO, or another third party, this "hub" could now be the traffic director for a TE application. It could not only share usage data but could receive and react to pricing signals—a two-way communicating hub.

6.0 Building System Architectures

Now that we've set the high-level context for considering smart buildings as transactive hubs, it is useful to look in more detail at the architecture of modern building automation and management systems. By looking at these architectural views we can see the possible points of integration for transactive energy hubs. Traditional building automation and management systems would put the point of integration at the "front-end." However, current distributed system architectures allow for the point(s) of integration to be placed anywhere that makes sense in the architecture.

As the complexity and increasing number of potential stakeholders fill the market for building-to-grid interactions, a new model for how to manage these complexities is required. The American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE)[2] has developed a four-tier structure for building automation system architecture (Figure 6.1, Figure 6.2). ASHRAE's Guideline 13, *Specifying Building Automation Systems* (ASHRAE 2015) provides the initial interoperability context for the various components within the building, which are enabled via open communication protocol standards. As building components interact with systems and entities beyond the building, integration and interoperability become paramount. High energy-consuming equipment may be enabled, disabled, or have its operation shifted via a TE process to respond directly to third-party entities and curtail load based on agreed criteria. Understanding how the core building level systems, architectures, and components fit together will help identify opportunities for buildings to take roles in the grid market.

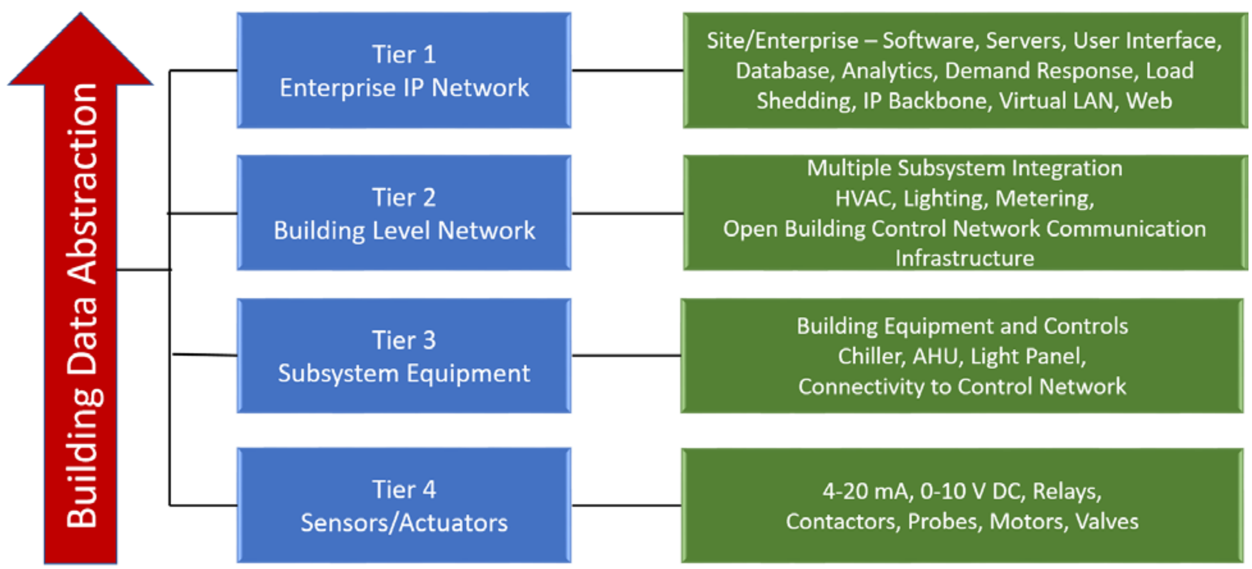

Figure 6.1. ASHRAE Four-Tier Building Model. (Source: ASHRAE 2015)

The ASHRAE model clearly delineates the roles and responsibilities of the contractors, integrators, and designers of building systems. The model establishes control and communications requirements and

[2] ASHRAE – American Society of Heating, Refrigeration and Air-Conditioning Engineers. 2019. Atlanta, Georgia. Accessed May 27, 2020, at https://www.ashrae.org/.

enables Internet-of-Things (IoT) and enterprise applications to interoperate with the facility. The transactive hub can reside on any of the four tiers as long as the interactions and integrations are well defined. This model was initially developed for larger commercial applications with full building management systems. One should note that the model has been applied to smaller commercial and residential buildings and campuses of buildings where embedded IoT web servers are grid-aware and provide the necessary functionality and integration.

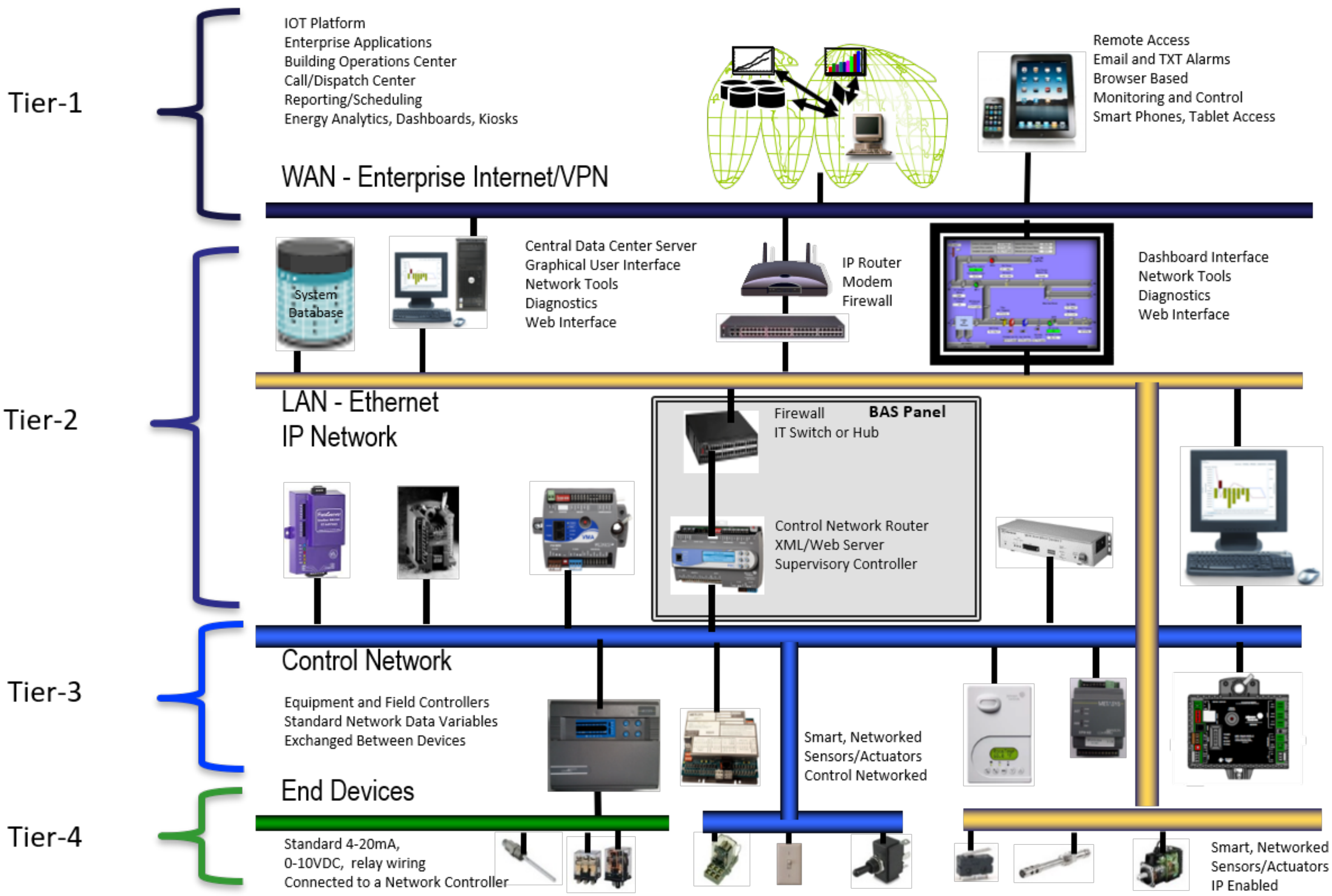

Figure 6.2. ASHRAE Four-Tier Building Automation System Architecture (Source: ASHRAE 2015).

6.1 Building Management System (BMS) –Tier 1

Typically, the building management system or "BMS front end" is the central management system responsible for any necessary management, oversight, visualization, configuration, and performance monitoring of the building subsystems. A typical BMS provides ancillary oversight responsibility for a given building automation system (BAS). However, a BMS is not typically providing operational interaction or directly controlling operational sequences of the BAS. If a BMS interface goes offline, the BAS continues to perform its required functions, reducing the potential for a single point of failure.

Tier 1 from ASHRAE Guideline 13 (ASHRAE 2015) (BMS) defines the enterprise-level connections with other systems such as demand-response APIs, analytics, reporting, and many other interfaces. Tier one responsibilities include coordinating the information technology (IT) integration team with the master systems integrator and establishing network connectivity, communication, network security, and reliability, and workstation setup and configuration. Tier one integration includes establishing connectivity to each Tier 2 subsystem, creating and configuring graphical visualizations and dashboards for each subsystem, and implementing any analytics, reporting, trending, and other supervisory applications and responsibilities.

6.2 Building Automation System (BAS) – Tier 2

Tier 2 BASs are the facility control systems comprising mechanical and electrical systems, such as HVAC, lighting, elevators, refrigeration, water/wastewater, steam, and many others. The BAS is responsible for the operational functionality of each system. The BAS may run autonomously from other systems and may not require a central building management system (BMS) to operate. If communication to a BMS server is lost, the BAS continues to operate. The BAS is typically built on a common network infrastructure where multiple systems can communicate in a peer-to-peer fashion without the requirement for translators or gateways. This infrastructure typically includes sensor and actuator low-voltage wiring, control network wiring, routers, bridges, raceways, and interfaces, as required for connecting all subsystems and devices.

Transactive hubs and interfaces may exist at the Tier 2 layer, such as a lighting supervisory controller for lighting dimming based on a demand response signal, or an HVAC supervisory controller to adjust airflow/temperature based on the same demand-response signal.

Alternatively, the Tier 1 BMS front end could be the "hub" and orchestrate all load shedding as a supervisory function, then communicating to the Tier 2 controllers to perform the required control changes. Whether a decentralized approach or a centralized approach is chosen, communication and control must meet interoperability standards.

6.3 Building Systems and Equipment – Tier 3

Tier 3 defines the control equipment and its related systems. Lighting, HVAC, and refrigeration are common Tier 3 systems, and each has many networked components that communicate and control the environment. The systems and equipment typically communicate using a common network protocol with well-defined data structures and context, which are critical to intersystem integration. A simple example is the lighting occupancy sensor that shares presence/absence information with the temperature control system. While this is a simple example, a strong interoperability framework between both systems is required. Interoperability is also required for the TE hub, which could potentially reside in an HVAC supervisory controller, a lighting panel, or an energy management system.

6.4 End Devices – Tier 4

Tier 4 defines the physical sensors and actuators, their ranges, resolutions, accuracies, environmental requirements, and interfaces with controllers. Until recently, Tier 4 end devices have typically not been connected to BAS networks, and therefore have not been considered "smart" or "networked" devices. However, with advancements in IoT, networked sensors and actuators can have direct access to Internet Protocol (IP) networks, and therefore can act and react to external transactive signals.

6.5 Four-Tier Architecture and Smart Buildings

This four-tier architecture for smart buildings is a useful and practical approach adopted by key market influencers such as ASHRAE. It provides a structure for specifying and contracting the various elements of a building control system by allowing each tier to be bid in a separate contract, if needed. The four-tier model provides a foundation for clearly defined roles and responsibilities for the various contractors, designers, suppliers, and others where competitive bidding is enabled. The model helps improve integration, through common interoperability definitions, between the various tiers at the device, system, and enterprise level. It facilitates better open systems through better specifications and up-front design.

Key to the development of smart buildings is the requirement for a comprehensive communications platform with which all elements of the systems have a standard way to pass information and a common interpretation of that information. The communication platform is especially important when buildings interact with the grid. The definitions around interoperable information-producing and -consuming components require well-defined context, scope, units, range, resolution, and more. Sensors that produce signals, such as a 4–20 mA analog input, must be interpreted to "mean" something to the system. Signals must be converted to data and eventually used as information for how best to manage the system. As data become information, and then knowledge, and beyond, more context is added (Figure 6.3).

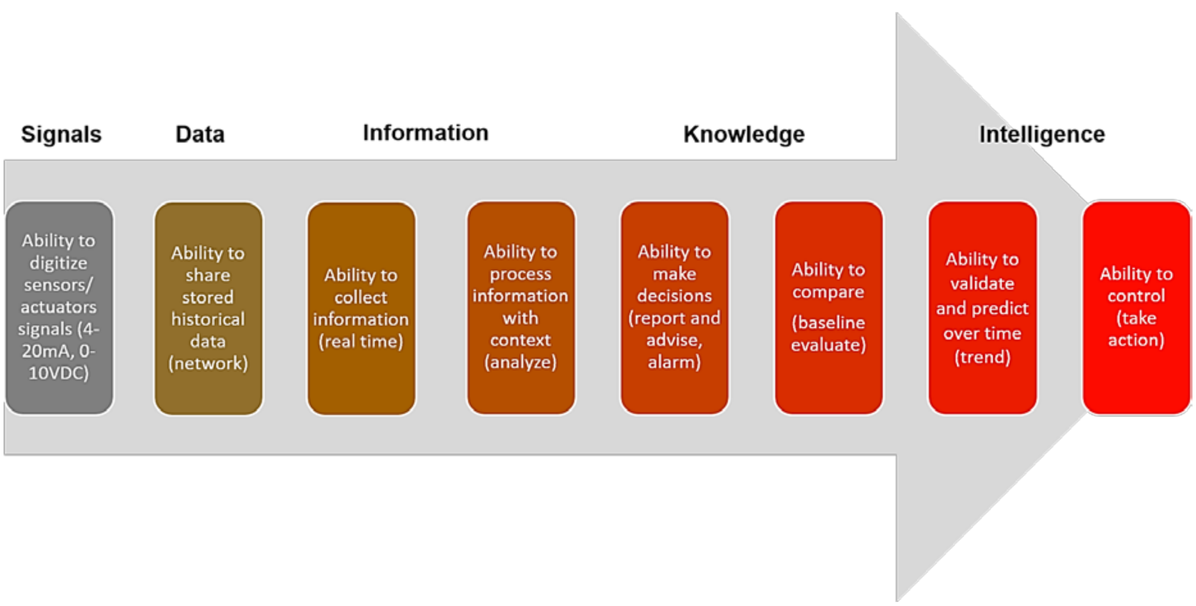

Figure 6.3. Smart Building System Key Performance Indicators. (Source: RBCG Consulting. Used with permission).

As interoperability becomes more defined, the economic and operational benefits improve and can help reduce implementation costs at scale. Simple data become useful “intelligence,” which our TE model requires.

As control systems evolve, they have become smarter and more integrated, and provide the owners/operators with more tools and information to help make better decisions. Information emanating from systems within the building can now be “mirrored,” virtually creating a digital representation or twin. Energy services stakeholders such as aggregators and ESCOs can benefit from having a digital representation of the building tor modeling TE platform implementations. As buildings integrate more with the electricity grid, building on these principles is key to successful implementations. The benefits of energy savings, cost savings, greater visibility, and more efficient systems will spur adoption and reduce the barriers of the past.

Appendix B, “Emerging Standards and Codes,” and Appendix C, “References and Resources”, provides more information for the solution designer and system architect.

Appendix D, “Advanced AI-Enabled Buildings,” delves into advanced applications that can be applied once the building blocks are established in a smart building as a transactive hub.

7.0 Charting the Path Forward

Smart-building designers must recognize that there is a patchwork of differing rules and regulations across the country that will affect the speed and economic attractiveness of adopting building solutions in the various jurisdictions. Also, those regulations may be in a state of flux triggered by many competing dynamics.

Nevertheless, no innovators wait for a perfect set of rules and regulations, nor is it a prerequisite to advancing building solutions. The value streams, enterprise goals, and personal interests beyond pure economics are likely to make smart building solutions very attractive to owners and tenants, in even those jurisdictions perceived as not economically supportive. Furthermore, many initial smart-building and related grid investments may not be based solely on the expected return on investment but anticipate the future benefits and opportunities that such investments will bring.

To some extent, the pursuit of smart buildings and their use as a TE hub may be informed by trial and error. Certain investments and implementations will be more beneficial than others. Changing regulatory and market conditions may require midstream adjustments.

Like many new endeavors, engagement with others who are like-minded will be key to advancing the development and utilization of smart buildings. There is a significant and growing community offering multiple opportunities for such engagement. For example, the GridWise® Architecture Council (GWAC),[3] whose meetings are open to the public, offers multiple opportunities to engage in all manner of activities relating to TE and smart buildings. In addition, GWAC is a good source of information regarding the related activities of other leading groups. Such groups include the Smart Electric Power

[3] GridWise® Architecture Council (GWAC), https://www.gridwiseac.org/.

Alliance (SEPA),[4] the Institute of Electrical and Electronics Engineers (IEEE),[5] ASHRAE, the Consumer Technology Association (CTA),[6] the Illuminating Engineering Society,[7] and many others.

Numerous conferences, meetings, and publications each year inform and help advance discussions among interested parties. For example, the IEEE and GWAC organize a yearly Transactive Energy Systems Conference. Similarly, the National Institute of Standards and Technology and the U.S. Department of Energy are organizing important meetings and developing thought-leading publications. The annual International Air-Conditioning, Heating, and Refrigerating Exposition (AHR Expo) is an excellent source of both practical and theoretical information.

[4] Smart Electric Power Alliance (SEPA), Washington, D.C. https://sepapower.org/.
[5] IEEE – Institute of Electrical and Electronics Engineers, Piscataway, NJ. https://www.ieee.org/.
[6] Consumer Technology Association (CTA), Arlington, VA. https://www.cta.tech/.
[7] Illuminating Engineering Society, New York, NY. https://www.ies.org/.

Appendix A - Characterizing Interoperability

To explain the importance and relevance of interoperability, the GridWise Architecture Council organized the following set of scenarios to define the various types of interactions between building systems and interfaces:

- Device to Device – Enabled through peer-to-peer communication at the device/subsystem level; for example, a smart, networked thermostat shares temperature information with an air handler.
- System to System – The building lighting system shares occupancy data with the heating, ventilating, and air conditioning (HVAC) system, negating the need for redundant sensors.
- Device to System – An energy submeter attached to a lighting panel shares energy usage data in real time with the lighting panel.
- System to BMS – The HVAC subsystem communicates status, alarm, and energy data to a central building management system front-end user interface.
- System to Enterprise (multiple buildings, campus, data center, server, central monitoring and maintenance system) – The building control system shares information such as alarms and diagnostic information with an enterprise-based alarm monitoring system. The operator can manage many buildings from one user interface, which increases operational efficiency.
- System to App/Tool (Lighting to Cloud IoT/Application) – Third-party tools, analysis, and reporting applications communicate with building subsystems to provide efficiency, compliance, and decision-relevant information to stakeholders.
- Device to Grid, IoT – Incentive programs that allow direct control of thermostat set points to reduce energy use during critical periods (common).
- System to Grid, Lighting Panel to Grid, OpenADR (Open Automated Demand Response) – Interfaces between systems with autonomous subsystem control and third-party influencing applications to adapt and adjust sequences and strategies.
- Enterprise to Grid – Host interfaces that manage multiple buildings interact with grid players via an API where aggregated energy load/demand information helps define operational strategies and efficiencies.

Standard ISO/IEC/IEEE 24765 (2017) defines interoperability as follows: “The ability of two or more systems or components to exchange information and to use the information that has been exchanged.” A key goal of interoperability is to reduce costs associated with integration. In this context, integration is a process, and larger systems such as buildings have more extensive integration processes. Building interoperability standards suffer from a lack of standard interaction processes and common business objectives for interactions with which to align technology decisions. This problem is further compounded by the existence of many competing standards addressing interoperability.

A.1 Communication Mechanisms

From a transactive energy perspective, smart building interoperability must encapsulate the entire ecosystem of building activities. This interoperability includes intrabuilding communications, direct building-to-building communications, and building-to-grid communications, which also includes communications with other entities connected to the grid.

Appendix B - Emerging Standards and Codes

Standards and specifications can come from recognized standards bodies, trade organizations, or collaboration groups, or be developed within a commercial organization. Standards can help accelerate implementation by establishing the rules for interoperability because they specify an agreement between interacting stakeholders. There is a growing trend to use open standards, because they can encourage a competitive, multi-supplier environment. Competition between solution suppliers encourages innovation in features and performance. This competition reduces the likelihood that a system or subsystem will become impossible to maintain if a supplier stops supporting a component.

However, using a standard, even an open standard, is not a guarantee of long-term supportability. Technology changes, and standards go through life cycles, both in commercial adoption and technical maturity. Today's state-of-the-art standard is tomorrow's legacy specification. There is no shortage of standards across the complicated landscape of interface specifications in electric power, manufacturing, building automation, and information technology in general. As envisioned in the *GridWise®* *Interoperability Context-Setting Framework* (GWAC 2008; Figure B.1), the right people and organizations can harmonize the standards together and produce an implementation that can best meet users' needs and be widely adopted.

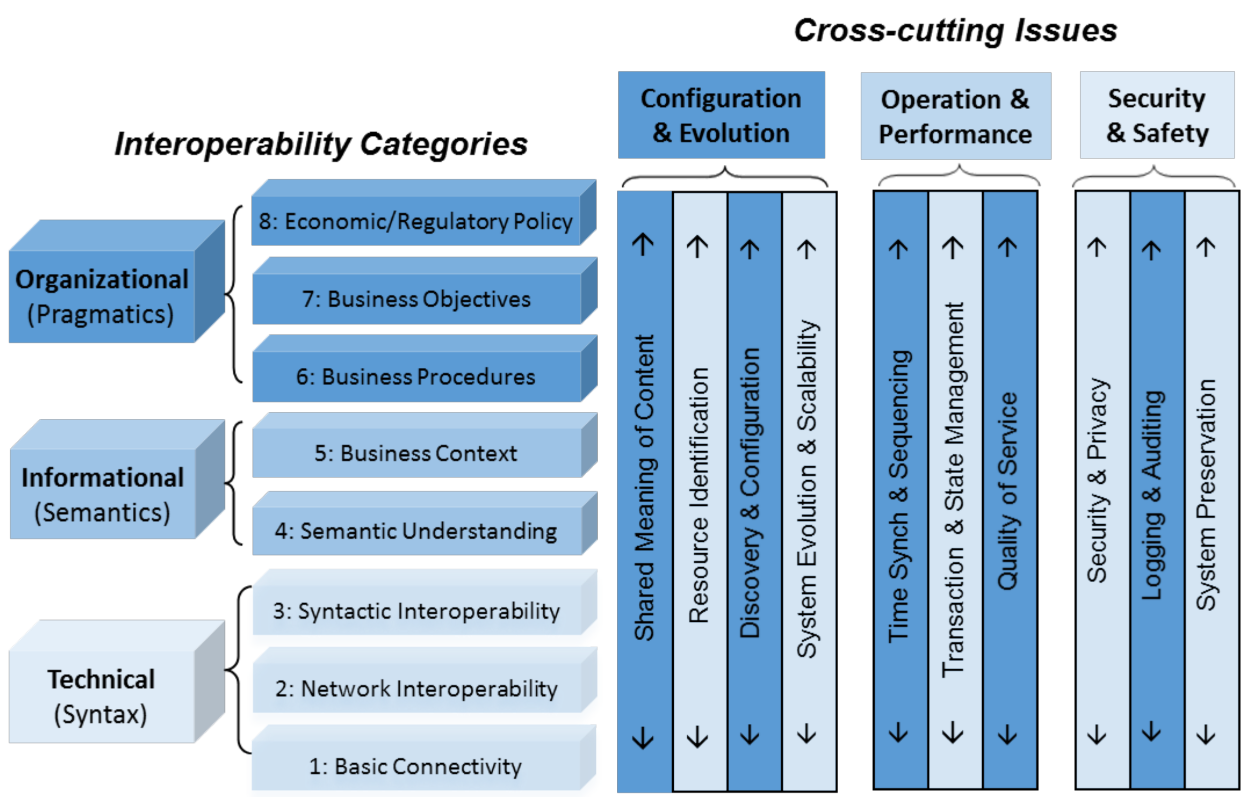

Figure B.1. GWAC Interoperability Context-Setting Framework, a.k.a. "GWAC Stack"

(Source: GWAC 2008)

B.1 Available Standards and Resources

The smart grid architecture view in Figure B.2 provides a graphic overview of the electricity grid based on the smart grid logical model of systems mapped onto the conceptual domains, as described by the National Institute of Standards and Technology (NIST) (NIST 2014). It includes domains, subdomains, and components that form the smart grid landscape. Components are the actors of the grid and are in topological communities that form functional domain and subdomain clusters. The architecture map in Figure B.2 provides a high-level view of the various smart-grid-related standards. A detailed, interactive map is available on the SEPA website (SEPA 2020).

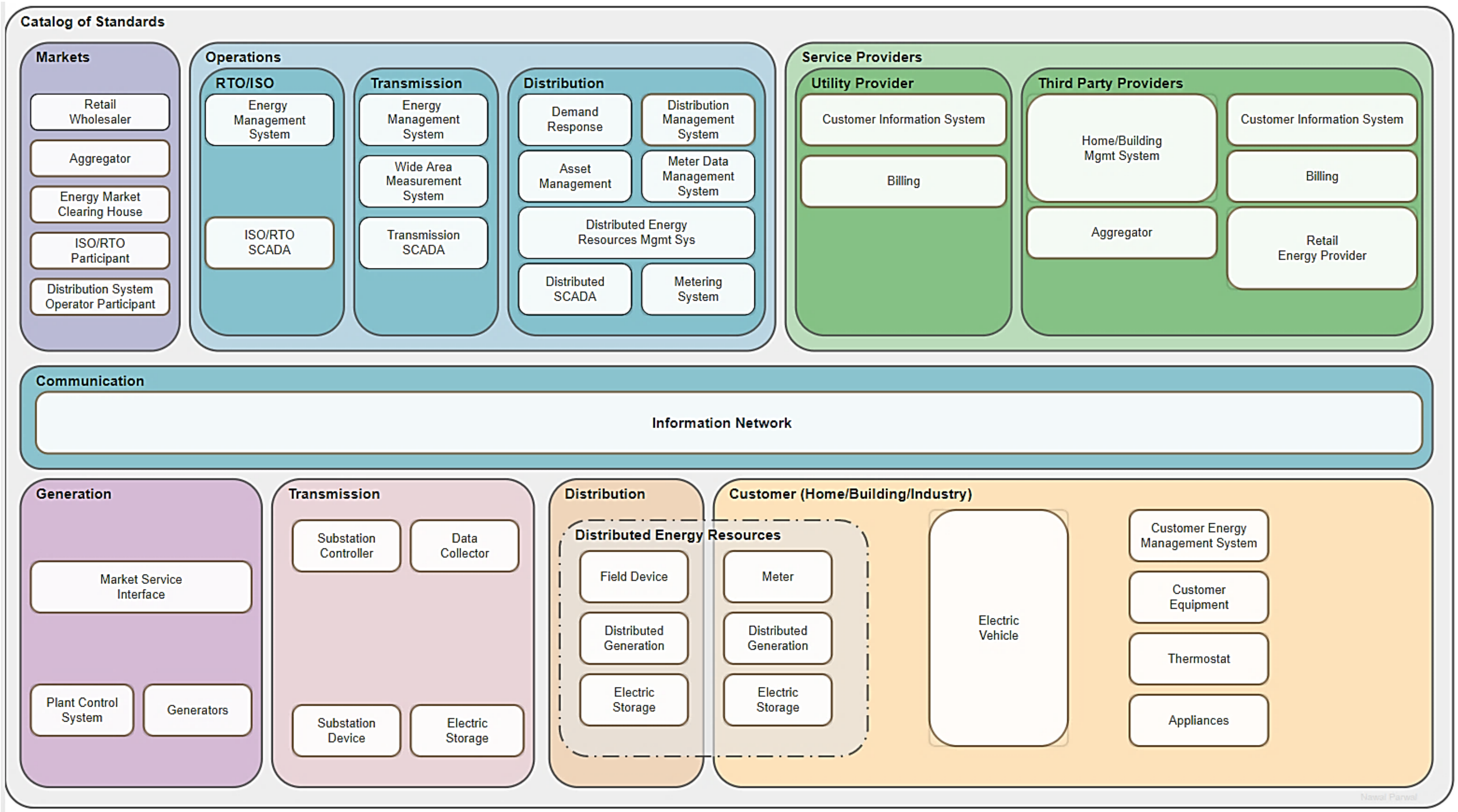

Figure B.2. SEPA Catalog of Standards Navigation Tool

B.2 Codes, Regulations, Compliance, Legal, and Policy

In response to market demand, policy setting requirements, and user needs, a variety of codes and regulations have been adopted. Many are the result of industry trade associations, utility incentives, or state and federal government initiatives. Several of these directly affect the energy consumption, demand limiting, and overall performance of a building. The following are key references and resources related to buildings and the grid that may not directly address smart buildings and transactive hubs, but provide context for implementing such approaches:

- California Energy Commission – *Building Energy Efficiency Standards - Title 24* (CEC 2020). California's energy code is designed to reduce wasteful and unnecessary energy consumption in newly constructed and existing buildings. The California Energy Commission updates the *Building Energy Efficiency Standards* (Title 24, Parts 6 and 11) every three years by working with stakeholders in a public and transparent process. Resources available include the Online Resource Center, the *Blueprint* newsletter, a California climate zone map, a list of manufacturer certified equipment, products, and devices, and discussions of special cases and compliance options.
- ANSI/ASHRAE/IES Standard 90.1-2019 – *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ANSI/ASHRAE/IES 2019). This standard provides the minimum requirements for energy-efficient design of most buildings, except low-rise residential buildings. It offers, in detail, the minimum energy-efficiency requirements for the design and construction of new buildings and their systems, new portions of buildings and their systems, and new systems and equipment in existing buildings, as well as criteria for determining compliance with these requirements. It is an indispensable reference for engineers and other professionals involved in the design of buildings and building systems. Standard 90.1 has been a benchmark for commercial building energy codes in the United States and a key basis for codes and standards around the world for more than 35 years.
- ASHRAE Guideline 13-2015, *Specifying Building Automation Systems* (ASHRAE 2015). ASHRAE Guideline 13 is intended to provide a designer of building automation systems (BASs) with background information, recommended practices, project considerations, and detailed discussion of options for designing a BAS. It includes specification language for integration, interoperability, control networking, protocol design and architecture, subsystem integration for heating, ventilating, and air conditioning (HVAC), lighting, fire and life safety, energy and power, and more.
- ANSI/ASHRAE/NEMA Standard 201-2016, *Facility Smart Grid Information Model* (ANSI/ASHRAE/NEMA 2016), provides a common basis for electric energy consumers to describe, manage, and communicate about electric energy consumptions and forecasts. The standard is part of ASHRAE's supporting efforts for the Smart Grid Interoperability Panel (SGIP) (NIST 2018), a private-public partnership initiated by the National Institute of Standards and Technology to speed development of interoperability and cybersecurity standards for a nationwide smart electric power grid. A "facility," in the context of this standard, can be a single-family house, a commercial or institutional building, a manufacturing or industrial building, or a set of multiple buildings, such as a college campus. There is a range of control technology used in these facilities and standards to support them. The Facility Smart Grid Information Model provides a common framework to guide the development of these control technologies so that they can meet the control needs of a smart grid environment.

- OpenADR 2.0: The OpenADR Alliance was created to standardize, automate, and simplify demand response and distributed energy resources. This standard enables utilities and aggregators to cost-effectively manage growing energy demand and decentralized energy production. OpenADR also allows customers to control their energy future. The OpenADR 2.0a and b Profile Specifications (OpenADR Alliance 2012, 2015) define an open, highly secure, two-way information exchange model and smart grid standard.

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Appendix D - Advanced AI-Enabled Buildings

As buildings become connected to the internet, and new software programs replicate the building automation functions, companies are starting to offer solutions that extend analytical capabilities. These systems are built on Cloud platforms to provide intelligent edge systems and software, enabling a data platform on which people can build smart-building designs.

The types of devices that incorporate artificial intelligence (AI) can multiply with the availability of aids such as facial recognition, the Cloud, Big Data, and the Internet of Things. Data from these devices can be integrated to inform a smart building, increasing its ability to work autonomously, and enhance its functions.

Parallel to the collection and analysis of building data is the need to define the basic context and semantics of the data. Many efforts exist or are in development to help with this. One model that helps bridge the design and architecture of a building as well as its operation and management is building information modeling (BIM). Marrying the engineering design and architecture to the actual real-time data requires a coupler, where BIM has great potential. Tools that can read BIM data and provide direct value to an owner can help minimize the data integration requirements that, in the past, have made such modeling costly. Combining BIM with digital modeling has great promise.

As discussed in Section 6.0, a smart building’s intelligent devices can combine to form a digital “twin” of the building; this digital representation integrates and analyzes information from all subsystems to autonomously control the entire building and provide advanced system analytics and decision making. It can report a need for maintenance or restocking, activate alarms for fire, security, and system malfunctions, and operate switches for lights, curtains, thermostats, locks, or a myriad of other processes. With enough accumulated operations data, it can detect patterns and use them to optimize building operations, provide predictive maintenance alerts, improve energy efficiency, and manage occupant comfort. The user interface, where building owners and managers can monitor and adjust operations, may be voice activated.

For the building-to-grid interface, the focus is on how a smart building with a digital twin can simulate a variety of transactive energy options and see the results before changing the current sequence of operations in the building automation system (BAS).

Appendix E - Grid Services

E.1 Bulk Power/Transmission Grid Services

The grid services procured and used by bulk power system operators include the so-called ancillary services that were mandated, at the dawn of U.S. electricity restructuring, in Federal Energy Regulatory Commission (FERC) Orders 888 (18 CFR Parts 35 and 385) and 2000 (18 CFR Part 35):

- regulation and frequency response
- spinning reserve
- non-spinning/supplemental reserve
- energy imbalance service
- reactive supply and voltage control
- scheduling, system control, and dispatch.

The first three of these services are standard products in existing spot markets that are operated by independent system operators and regional transmission organizations (ISOs/RTOs). The providers of these services receive a reservation payment ($/MWh) in addition to compensation ($/MWh) for providing energy or reducing consumption when deployed. The energy imbalance service is generally paid based on provision of energy, or reduction of supply ($/MWh) with no additional reservation payment. The fifth service (reactive supply and voltage control) is procured by the grid operators on a forward contractual basis. Smart buildings can provide all but the last of these services (scheduling, system control and dispatch), either directly or through the local utility or an independent aggregator.

In addition to these services, grid operators pay for a longer-term service, referred to as capacity, to support adequate longer-term supply for reliable operation of the grid. Typically, these are procured on a seasonal, semiannual, or annual basis. In some ISO/RTO markets, capacity auctions are conducted in which demand-side assets (including smart buildings) can potentially participate.

Table E.1 shows representative revenues per MW of demand response (from buildings and loads) in some of the ISO/RTO markets based on several years of historical price data. The ancillary service prices are expressed in $/MWh and the resource adequacy capacity prices in equivalent $/kW-year values (some markets procure such capacity on a seasonal or capability period basis; those are normalized to annual equivalent values in the table).

Table E.1. Average Ancillary Service Prices and Capacity Values (Source: OATI, Rahimi)

ISO/RTO	CAISO	PJM	MISO	NYISO (West)
Nonspinning reserves ($/MWh)	1.50	0.40	1.50	1.05
Spinning reserves ($/MWh)	5.00	10.00	4.00	4.34
Regulation ($/MWh)	10.00	30.00	12.00	10.00
Capacity value ($/kW-year)	30.00	40.00	2.00	64.00

CAISO = California Independent System Operator
PJM = PJM, Inc.
MISO = Midcontinent Independent System Operator
NYISO = New York Independent System Operator

Based on Table E.1the potential revenue streams for smart buildings from participation in ancillary service and capacity markets, is estimated in the range of about $100 to $250 per kW-year demand response capability per year ($100,000to $250,000 per MW-year capability).

The payments for energy ($/MWh) have a wide range and high variability. Participating smart buildings will likely be paid the higher prices for energy when instructed by the grid operators, since it is likely to be summoned when energy is scarce, and prices are high.

In the decades since FERC Orders 888 and 2000, the North American Electric Reliability Corporation has stipulated other interconnected operations services with the growth of renewable generation, the associated reduced system inertia and damping, and increasing ramping requirements. Accordingly, some new bulk power services have emerged, including flexible ramping, primary frequency response, fast frequency response, synthetic damping, and synthetic inertia.

Some ISO/RTO markets (CAISO and MISO) have formally added ramping products that they procure, price, and pay for competitively to their spot markets. Some have split the regulation and frequency response service into two products, namely, frequency regulation and primary frequency response. Frequency regulation is procured competitively in spot markets as before, but primary frequency response obligation is procured bilaterally on a contractual basis based on trades between balancing areas. Demand-side assets, including smart buildings, can provide flexible ramping and collect the associated market-clearing prices. The flexible ramping prices are generally based on lost opportunity costs and expressed in $/MWh. The expected range is somewhere between the regulation and spinning reserve prices in Table E.1.

E.2 Distribution Grid Services

In contrast with bulk-power/transmission-grid services, there are no standard services, metrics, or market-based historical prices for electricity distribution. Generally, distribution grid services may include one or more of the following:

- Feeder load relief. This service is use of demand-side assets by distribution operations to curtail or reduce load to relieve feeder overload. Compensation is contractually agreed upon based on approved distribution tariffs and may amount to a reduction of a few dollars per bill for participating consumers. Feeder load relief is a de facto standard service.

- Reactive power and voltage support. Customers with local power resources such as photovoltaic or wind generation may supplement utility power when needed. There are many emerging standards and associated metrics, specifically for inverter-based resources. But there is no standard metric for compensation of demand-side assets providing this service. Compensation is generally based on contractual arrangements between the distribution utility and the prosumer providing the service.
- Non-wires alternatives (NWA). This service involves employing demand-side assets (including smart buildings, microgrids, etc., with active generation and storage) to defer or eliminate certain distribution infrastructure upgrades. The cost-effectiveness and associated value compensation levels depend greatly on the specific distribution system bottleneck. When cost-effective, the compensation may range from a few dollars per kW-year to hundreds of dollars per kW-year of demand-side capacity offered in competitive NWA auction.
- Phase balancing. In bulk power operation, the three phases of power are usually balanced. That is not the case in the distribution system. Distribution phase imbalances may occur as a result of supply and demand not balanced across the phases. The demand-side assets can offer to adjust the supply and demand on the phases to alleviate these phase unbalances. Currently, though, no such services are procured from demand-side assets or paid for by distribution operators.