From the Buildings Perspective[1]

Sila Kiliccote and **Mary Ann Piette**, Lawrence Berkeley National Laboratory

Mahabir Bhandari, Oak Ridge National Laboratory

Technological advances in demand response and energy efficiency have increased the utility of residential and commercial buildings for owner and operators. Yet buildings still lack the capacity to adapt to both internal and external changes, such as occupant needs or grid stability concerns. Basic information about the energy portfolio of buildings is not readily available to owners and operators, leading to inefficiencies and lost opportunities within and beyond the building. This paper describes technologies and systems needed to transform buildings from the current state of siloed resources into transparent, reliable resources that participate in and benefit from an integrated "transactive energy" system. This transactive approach is described in more detail in the accompanying paper, "Buildings-to-Grid Technical Opportunities: Introduction and Vision."

Overview

The overall level of electricity use in buildings, the many different end uses, and the trends in technology indicate that buildings have an enormous potential and a critical role to play in an integrated transactive energy-based system. Buildings consume about 70% of total electricity use in the United States. The potential for transaction-based control schemes will be successful when behind-the-meter loads, generation, and storage assets seamlessly integrate into a collaborative, incentive-based network that, from the perspective of grid operations, functions as a virtual control system, and enables and motivates them to transact and deliver energy services to the grid at the lowest possible cost.

While it may be a challenging task to engage all building end-use categories, a few specific sub-categories can be engaged in the proof-of-concept stage and other sub-categories can be slowly added. There is limited data on the distribution of coincident peak loads by end use around the country. Data from California show that 25% of the total summer peak demand is attributed to HVAC and lighting systems in the commercial sector, and 15% and 12% from residential air conditioning systems and appliances, respectively.[2] Packaged air conditioning units are a large piece of the commercial sector peak load, consuming 40% of the total electric cooling energy, more than any other type of cooling equipment.[3] If the electricity use of packaged air conditioning units were coordinated and controllable they could provide benefits in helping to address challenges in managing the evolving electric grid. These challenges include reducing peak demand, increasing the use of variable generation, improving grid reliability and resiliency, and keeping costs and electric prices low.

With these potential benefits in mind, the U.S. Department of Energy's (DOE's) Building Technologies Office is conducting research at three DOE national laboratories that will deliver a "Transactional Network" that supports energy, operational, and financial transactions initially between roof top units (RTUs) and between RTUs and the electric power grid, using applications, or "agents" that reside either on the equipment, on local building controllers, or in the Cloud.[4] RTUs are the most common packaged air conditioner in small and medium commercial buildings. The purpose of this research is to demonstrate and propagate an open source, open architecture platform that enables a variety of site/equipment-specific applications to be applied in a cost-effective and scalable way.

To unlock the potential of building loads as a dynamic and responsive energy resource, there is also a need to ensure that persistent and long-lasting energy-efficiency measures are enabled by new approaches to diagnostics and controls. For the next level of dynamic response to internal and external power system condition and needs, we need better communication and control technologies that can flexibly and dynamically engage behind-the-meter assets and loads beyond current peak-management capabilities. These measures can complement existing systems where possible, or substitute technology where needed. A determining characteristic, however, will be their ability to provide building operators a return on investment from savings on electricity costs commensurate with current building sector technologies (a good "value proposition").

This paper begins with a description of potential transactive end-use loads in buildings, followed by a discussion of engagement in load control beyond traditional demand response and a review of energy efficiency in buildings. The next section reviews

1 This report is being disseminated by the U.S. Department of Energy (DOE). As such, this document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the DOE.

2 Brown Richard, J. G. Koomey. Electricity use in California: Past Trends and Present Usage Patterns. May 2002. LBNL-47992. *http://enduse.lbl.gov/info/LBNL-47992.pdf*

3 W. Goetzler, B. Zogg et al. 2011. *Energy Savings Potential and RD&D Opportunities for Commercial Building HVAC Systems*. Prepared by Navigant Consulting, Inc. for DOE. See Figure 1-4. Available from the DOE/EERE website at: *http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/savings_potential_comm_hvac.pdf*

4 For more information, see the Transactional Network webpage at *https://transactionalnetwork.org/*

challenges and barriers to progress in buildings-to-grid systems. The final section presents a vision for future technologies by describing the technological needs associated with new opportunities for buildings-to-grid transactive systems.

Current State of Engaging Building Loads

Transactive energy approaches, including demand response (DR), allow end-use operations to be changed dynamically to improve electric grid reliability and manage customers' electricity costs. While DR started as a way to manage peak load, it has in recent years been applied to solve intermittency of renewable generation, participate in ancillary services markets that require real-time market transactions, and even to solve operational problems with electricity distribution systems in real-time.

Demand response resources today participate in grid transactions mainly through utility programs that are designed to reduce load during peak and emergency periods. The Federal Regulatory Commission estimated the potential resource contribution from all U.S. DR programs to be nearly 72,000 megawatts (MW), or about 9.2% of U.S. peak demand.[5] DR also has shown the ability to participate in ancillary services. Typically only large commercial and industrial loads have been allowed to participate in structured wholesale markets because of grid operator limitations on resource size, measurement, and aggregation. While individual and aggregation of commercial buildings participate in ancillary services

grid transactions in PJM's territory,[6] Pacific Gas and Electric Company is experimenting with transactions of their commercial and industrial customers in CAISO's Proxy Demand Response model through the Intermittent Resource Management pilot.[7]

Over the last decade, the end uses listed in Table 1 have been considered and evaluated to address peak-load problems and to increase capacity utilization of generation resources. In the residential sector, direct load control of air conditioning units has been widely adopted. Switches installed at the compressor of residential air conditioning units are controlled either remotely or through an under frequency relay at the site. In this particular implementation, no measurement at the site is required and customers are rewarded for signing up for the programs. However, over time, because the only way customers can opt out of the program is by disconnecting the switches, the switches are disconnected and participation has decreased in some parts of the country. This technology provided inexpensive automated control of this end use through a utility or an aggregator.[8] Nowadays, there is a growing number of communicating devices and appliances within residential buildings where ~90% of all installed smart meters can be found. Aggregating these small loads and enabling them to transact can lead to benefits for the entire energy system.

Table 1. Summary of End Uses and Distributed Energy Resources/Assets in Scope

Residential	Commercial	Distributed Energy Resources and Assests
• HVAC • Washers • Dryers • Refrigerators • Hot Water Heaters • Pool Pumps • Lighting	• HVAC • Lighting • Refrigeration • Plug Loads	• Electric Vehicles • Photovoltaic Systems • Storage • Combined Heat and Power • Microturbines • Gensets • Fuel Cells

In the commercial sector, roughly 5% of the buildings have energy management and control systems (EMCS), according to the most recent EIA data.[9] These tend to be large buildings over 50,000 ft^2 and represent 25% of total commercial building floor area. The adoption of DR in this sector has been slow because strategies are site specific; implementations require skilled labor and thus are expensive; and the value to the building stake holders (e.g., owner, tenant, etc.) is not well understood because it changes at each market with different timescales of participation. In addition, many areas in the United States do not have DR programs. These factors make it difficult for EMCS vendors to articulate the energy cost savings offered in various markets around the country.

Small (less than 5,000 ft^2) and medium sized (under 50,000 ft^2) commercial buildings constitute 95% of all buildings. The sum of the HVAC, lighting, and plug load end-uses account for almost 90% of energy consumption for this category of buildings.[10] In spite of having large potential for conventional DR, where day-ahead peak demand is the main driver, adoption has been minimal. The cost of implementing communicating controls is the main barrier in the adoption of DR in these buildings given that they are small and transactions costs are

5 FERC. 2012. *Assessment of Demand Response and Advanced Metering Staff Report*. Available at *http://www.ferc.gov/legal/staff-reports/12-20-12-demand-response.pdf*

6 See the PJM website at: *http://www.pjm.com/~/media/about-pjm/newsroom/fact-sheets/price-responsive-demand.ashx*

7 See the PG&E website at: *http://www.pge.com/nots/rates/tariffs/tm2/pdf/ELEC_4077-E-A.pdf*

8 DOE/Energy Information Administration Frequently Asked Questions homepage, accessed 2013-06-01: *http://www.eia.gov/tools/faqs/faq.cfm?id=108&t=3*

9 DOE/EIA Commercial Building Energy Consumption Survey 2003, released 2006. *http://www.eia.gov/consumption/commercial/index.cfm*

10 Katipamula S., R.M. Underhill, J.K. Goddard, D.J. Taasevigen, M.A. Piette, J. Granderson, R.E. Brown, S.M. Lanzisera, and T. Kuruganti. 2012. Small- and Medium-Sized Commercial Building Monitoring and Controls Needs: A Scoping Study. PNNL-22169, Pacific Northwest National Laboratory, Richland, WA. *http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22169.pdf*

challenging. Communicating control systems are key elements of a future transactive energy system.

New Engagement Approaches Beyond Demand Response

The introduction of ubiquitous metering and sensing technology enabled by information and communications technology (ICT) is promising an entirely new value proposition beyond the incremental benefits from the current DR model. As several pilots around the country are showing, the ongoing technological evolution is promising a wholesale transformation of building operation and control as currently implemented.

For example, Whirlpool Corporation's Smart Appliance project is seeking to develop and commercialize home appliances (clothes washers, dishwashers and refrigerators) with wireless communications and advanced control software.11 The objectives are to (1) develop a wireless communications protocol for home appliances, (2) design appliance control and interface software optimized for demand response and time-based rate programs, and (3) produce cost-effective communications hardware for appliances. A Smart Grid Investment Grant provided under the American Recovery and Reinvestment Act of 2009 provided funding to this project.

Conceptually, these technological developments will shift the current centralized control model to a distributed, two-way communication and control paradigm that would allow fully automated interaction of large individual and many small aggregated assets within the building envelope, between buildings, and between buildings and the electricity grid. Taking advantage of novel and granular insights to buildings' energy profiles—as well as information flows providing price and forecasted resource availability in a variety of timescales, and within different markets—the new transactive-based model would enable continuous management of energy use. The new control paradigm also would fully integrate loads and assets in the building's vicinity, such as solar panels and other distributed energy resources, EVs charging on adjacent parking lots, or street lights illuminating the buildings' perimeter. Yet, to realize this concept and to scale the current efforts, technical challenges need to be addressed.

Current State of Energy Efficiency in Buildings

There are great opportunities to reduce energy use in residential and commercial buildings with new energy-efficiency measures. Driven usually by utility incentive programs, appliance and equipment standards, and codes, these measures can deliver cost effective solutions for most buildings. In commercial buildings, major energy-efficiency retrofits tend to be sporadic, but significant savings can be achieved through retuning and retrofitting HVAC and lighting control systems. Small commercial and residential buildings lack sophisticated control systems. There are growing opportunities in small buildings as information technologies integrated with advanced controls develop, competition in communicating controls grows, and prices for these systems fall.

One important step to reducing energy consumption in buildings comes from understanding operating conditions. State-of-the-art measurement systems such as temperature, pressure, flow, illumination, and power help determine operational issues and quantify energy savings potential in buildings. Once operators can actually see where, when, and how energy is used in a building, they can start building better control systems that automatically target efficiency opportunities, thus leading to energy and cost savings. With the advent of advanced building monitoring and controls, a transactive energy management structure carefully designed, developed, and implemented can additionally support building operators with new revenue streams, resulting from continuous optimizations of energy use, as described earlier.

Challenges and Barriers

Realizing the transactive energy vision will require a restructuring of the layers of controls used today. Specifically, it will require advances in precision monitoring that are autonomous, affordable, and cost competitive relative to existing technology, and that are not labor intense to install. Figure 1 shows the traditional and proposed control layers in large commercial buildings today with an added optimization layer. At the lowest layer, there are end uses, which are sensors, actuators, or a combination of the two. The end uses are common to each sector. Systems are developed by gathering end uses and by adding control algorithms and communications capabilities, as well as additional sensors to monitor the system as a whole. These systems are operated to deliver certain traditional services, such as comfort. Energy information is not a typical service offered by building controls but is a growing additional service. There are industry-accepted targets for these services supported by codes and standards. A growing trend is cloud-based services, where data is captured from buildings and processed to provide additional services to consumers. Because data typically are trapped in proprietary systems, redundant sensors are installed to capture the same data from devices and systems.

The right side of Figure 1 is a more evolved building controls concept in which the devices also are exposed to services and may deliver services without compromising objectives of the systems. This kind of breakdown of control system layers requires access to devices and allows for low-cost aggregation of devices to deliver additional services such as fault detection, grid transactions, etc.

[11] SmartGrid.Gov Project Information, accessed 2013-12-31, *http://www.smartgrid.gov/project/whirlpool_corporation_smart_appliance_project*

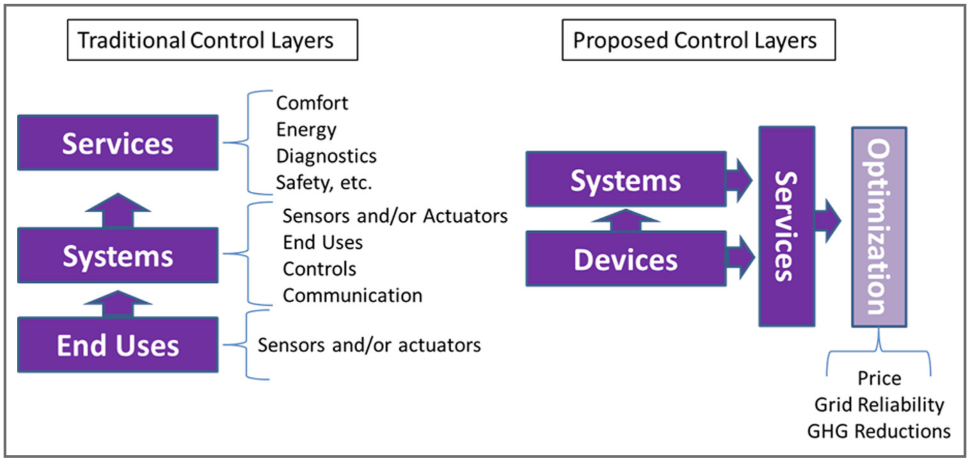

Figure 1. Traditional and proposed control layers

Owning and operating costs for commercial buildings can be reduced from the use of advanced capabilities provided by open control and interoperable systems architectures that provide continuously automated energy management and optimization. These systems facilitate the integration of a variety of end-use control applications for low-energy control and coordination with grid signals.

Technical Challenges

The main technical challenge for buildings-to-grid integration is to design a flexible and overarching control framework that will seamlessly coordinate the appliances and end-use load control mechanisms within buildings with external systems. These external systems include adjacent distributed energy resources and new loads, such as EVs, as well as the electric grid. This will require micro- and macro-level control tools that will allow building operators and consumers to optimize their assets while creating new cash flows, and at the same time will facilitate grid balancing by relaying appropriate incentive and feedback signals. These controls need to be affordable, semi-autonomous, ideally open, non-proprietary, highly interoperable, and easily embedded in devices across all buildings as well as easily installed, commissioned and maintained.

The three main parameters of transactions between end uses and the electricity grid are price, bids, and time. Price is the value of the transaction to the electricity grid. Depending on the price offered, the resource may decide to participate in the transaction or not. A bid is the available resource for a transaction for a given duration based on certain required granularity. Time can be defined in many ways, but it indicates the timing of the transaction including the duration.

Technical challenges common to all sectors are:

- *Lack of signals (e.g., price or incentive signal, cost effective feedback/ response in buildings, etc.) from the grid and price discovery capabilities in buildings:* Traditional building systems and end uses are designed to deliver services (such as comfort, air quality, illumination, and refrigeration) and are not capable of handling price and energy performance information.
- *Lack of low-cost control networks and optimization capabilities focused on engaging assets while not disrupting the comfort of building occupants:* Ideally, no end use and building should be left behind.
- *Lack of accuracy, access to, and granularity of data to develop bids:* In some buildings where data are accessible, it may not be accurate or at the granularity required to develop bids to perform a transaction. Additional sensors to enable additional actuation of new end-use loads are needed.
- *Lack of measurement and verification technology and protocols that can track whether control systems actually deliver the response requested:* This technology needs to be inexpensive, easy to install into existing buildings, and able to provide traceable data and reliable outcomes.
- *Proprietary systems that limit interoperability with new technologies, as well as development of new services and decision support tools to plan, integrate, and operate distributed energy resources.*

In addition to these basic challenges in building systems, there are several sector-based challenges.

- Residential and small commercial buildings have seen the uncoordinated installation and use of appliances and systems that currently operate independently. While integration platforms such as home area networks exist, the relatively small financial benefit, the potential for discomfort, and a long payback time horizon have prevented these systems from being widely adopted.
- Commercial buildings have incorporated a collection of systems that interact with each other and impact each other's performance. These systems are proprietary at the lowest levels, locking customers to the same device manufacturer and thus preventing the development of innovative applications and interoperation with other systems. Furthermore, these systems deliver blanket services rather than customized services and do not have advanced control capabilities such as optimization of various services.

- EVs and distributed resources lack standards for communicating data, data analytics, and tools to integrate and assist with optimization of these resources. Also, customers do not have access to their PV data directly to collect and analyze their premise data and share it with others who can provide support services or additional analytics.

Technical Opportunities

In this section, we discuss technical opportunities for realizing the transactive energy vision described in the accompanying Vision and Introduction paper, and characterize their needed attributes.

Access to Device and Systems-Level Data

Improving access to device and system-level data will enable the flexibility of building loads. Open and secure access to demand and the state-of-device information is needed to create transparency and facilitate the development of better analytics to support automated, continuous energy management and transactions with the electricity through advanced fault-detection and system-performance analytics. An example here includes Non-Intrusive Load Monitoring. Many companies are developing this method for analyzing single-point measurements and disaggregating loads for electrical load monitoring. It can be applied to gas and water consumption as well. Small form factor wireless networked sensors, common in industrial uses, are being tailored to commercial and residential building applications. These types of sensors will provide the necessary data for more sophisticated systems and whole-building control technologies.

Open Architecture and Interoperable Systems

Open architecture allows a combination of distributed and centralized systems to co-exist and facilitate their integration while ensuring reliability and security. Open-source systems and open Application Programming Interfaces (APIs) support the development of collaborative services environments. Open architecture control systems and standards will facilitate "plug-and-play" interoperability capability while fostering the development of innovative applications that run on a variety of platforms from multiple vendors. True plug-and-play systems will remove the vendor dependencies within these systems and will reduce costs by fostering competition.

New analysis and modeling tools are needed to evaluate the effectiveness of interoperable systems to achieve key grid integration goals and metrics. Developing co-simulation environments to test these systems by creating interoperability between existing software tools is a key solution for fully integrating buildings and their end-uses into systems-level solutions. There are few examples of co-simulation environments; however, the effort also has to be based on open standards that facilitate the integration of a variety of tools and the development of large object and applications libraries.

Innovative Advanced Controls

The more dynamic, frequent, and grid-aware the transactions are, the more these require automation and two-way communication. This requires that the building or aggregation of devices, systems, or buildings—such as a neighborhood or portfolio of buildings—are aware of the state and energy consumption of its end uses and systems, grid conditions (price, reliability, and other measurements at its location), and local environmental conditions (weather, etc.). In addition, the end use, system, or an aggregate of end uses and systems should be able to supply key information about the assets and their availability.

Development of low-cost sensors and actuators with open, secure, and scalable platforms will facilitate the development of more sophisticated algorithms to dynamically aggregate and transact diverse loads and facilitate better measurements, verification, and settlement of these transactions. Model-based predictive and agent-based or learning-based control algorithms also will advance the transactional environment. One of the major challenges is that, regardless of how smart and sophisticated these advanced controls may be, to building stakeholders, such as owners, tenants, energy managers, facility engineers, EV fleet managers, they need to be transparent, simple to operate, and easy to commission.

At the same time, the sensing, communications, and control infrastructure within buildings can be developed and configured to support advanced energy-efficiency and cost-saving opportunities. A partial list of such opportunities follows:

- More sophisticated, plug-and-play controls and home/building automation systems
- Diagnostics and automated commissioning for appliances, equipment, and systems, irrespective of whether a building or home automation system is in place
- Identification of energy savings opportunities ranging from automated scheduling, advice on equipment replacement, and retrofit opportunities.

Conclusion

Incorporating both energy efficiency and DR, integrated demand-side management (IDSM) is increasingly becoming one promising approach to accelerating the transition to a clean energy economy. However, successful mechanisms to deliver IDSM programs have not been widely demonstrated, particularly in the southeastern United States. Integrating DR in residential energy-efficiency programs has, however, shown great promise in California, which adopted a statewide IDSM program in 2010.

The impacts expected from realizing the above technical opportunities at scale for residential and commercial buildings include:

- Increased energy efficiency from traditional measures, such as envelope and equipment measures
- Additional energy efficiency from improved building operations and other occupant behavioral changes
- Lower costs for combined deployment of energy efficiency and smart grid technologies
- New business models that spur such deployment and enlist third-party investments in it
- Lower electricity bills due to reduced consumption
- More rapid and higher levels of penetration of variable generation and renewable supply systems.

In summary there are exciting opportunities for new technologies to provide dual value to building owners and grid operators as building loads can be reduced, shifted, and shed. New information technology, controls, communications, and energy-aware end-use systems can help the United States develop a low-carbon, low-cost and reliable electric grid.

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

For more information, visit:
buildings.energy.gov

DOE/EE-1052 • March 2014
Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post consumer waste.