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Field Experience with and Potential for Multi-time Scale Grid Transactions from Responsive Commercial Buildings

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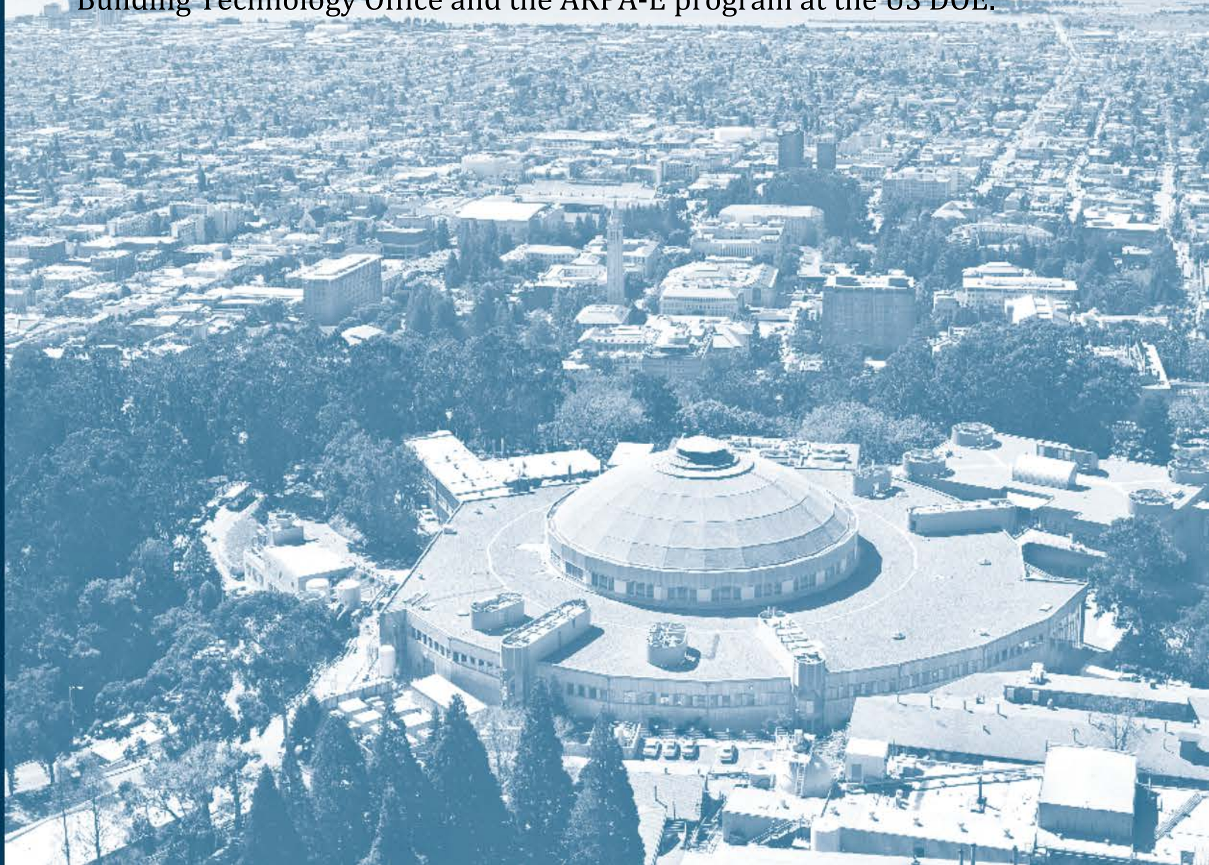

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ABSTRACT

The need for and concepts behind demand response are evolving. As the electric system changes with more intermittent renewable electric supply systems, there is a need to allow buildings to provide more flexible demand. This paper presents results from field studies and pilots, as well as engineering estimates of the potential capabilities of fast load responsiveness in commercial buildings. We present a sector wide analysis of flexible loads in commercial buildings, which was conducted to improve resource planning and determine which loads to evaluate in future demonstrations. These systems provide important capabilities for future transactional systems. The field analysis is based on results from California, plus projects in the northwest and east coast. End-uses considered include heating, ventilation, air conditioning and lighting. The timescales of control include day-ahead, as well as day-of, 10-minute ahead and even faster response. This technology can provide DR signals on different times scales to interact with responsive building loads. We describe the latency of the control systems in the building and the round trip communications with the wholesale grid operators.

Introduction to Demand Response

The need for and concepts behind demand response (DR) are evolving. DR consists of programs or market designs to incentivize electricity customers to modify their electric load shape when requested. Traditional DR was designed to reduce peak loads during hot summer days or mitigate problems during emergencies. As the electric system changes with more intermittent renewable electric supply systems, there is a need to evaluate the technical and economic opportunities to use building loads to provide more flexible demand in response to new and continuing challenges in managing the electric grid. Flexible building loads may provide capabilities for future transactional systems. The technical concept described in this paper is that many commercial building end-use loads can be called, participate in, or dispatched to respond to demand response or transactional signals. This paper touches on the emerging vision of developing a more transactive grid where supply and demand are more dynamically linked.

Commercial building electric end-uses are good candidates for grid transactions for a variety of reasons. Buildings consume about 70% of total electricity use in the US, with commercial buildings accounting for about half of that total. Office and retail buildings account for nearly 40% of the commercial sector and tend to have regular schedules and operating patterns, and among the most predictable loads. Predictable load shapes are better candidates for DR and grid transactions than buildings or industrial loads or irregular operating patterns. This is true for dynamic pricing or capacity market-based DR program. Facility managers will have more confidence in DR strategies that are predictable. This paper summarizes results from past work in automated demand response activities that historically focused on hot summer DR events. We present results from automated DR for cold winter morning events as well as results from a variety of demonstrations of fast demand response designed for ancillary services. We provide a short discussion section following a review of the past pilots, and some discussion on the economics for the DR automation systems.

Background

This paper provides a summary of research conducted by the Demand Response Research Center (DRRC) at Lawrence Berkeley National Laboratory. The DRRC was formed to help develop low-cost DR automation technology and evaluate how end-use loads can participate in automated DR programs. The theory was that if the California building stock had dynamic pricing, and price response could be automated, we could lower the possibility of having future black or brown outs. Price response was seen as the most equitable form of DR because when tariffs are used there is no baseline measurement challenge, and there is choice – customers can decide to participate or not in a DR price event (Bornstein et al, 2002). Customers could opt out of an automated high price event if they choose.

The technology for automated price and reliability signal response has evolved quickly as further described below. One example of this technology is known as Open Automated Demand Response, or OpenADR. The word "open" refers to the open application-programming interface to allow the communication systems to be implemented on many platforms. here are a wide variety of price response, reliability, and newer more advanced pilots to evaluate how DR can help to integrate more renewables on the electric grid. The DRRC has developed automation technology and field studies to support deployment of low cost DR in California, around the US, and abroad. One aspect of the research is to understand how the DR strategy relates to the daily energy efficiency. While the definition of energy efficiency can be thought of as getting the most service out of every kWh, the issue with DR is not how much you use, but when you use it. Figure 1 shows the scale from efficiency to daily time of use, to day-ahead, hour-ahead or very fast demand response. There is increasing value to the grid for fast DR. However, this fast DR needs faster telemetry systems and response from control systems.

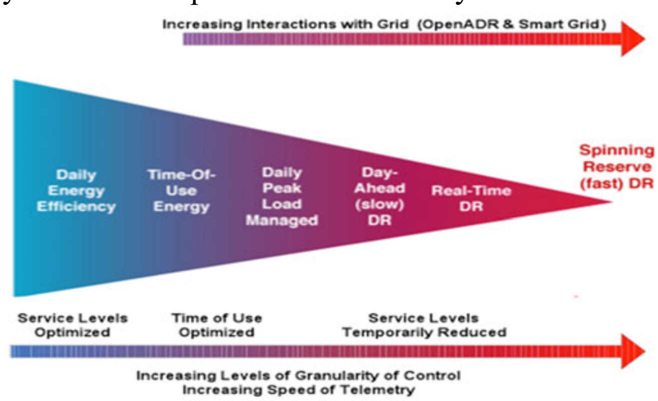

Figure 1. Relation between efficiency, day-ahead and fast DR related to controls and telemetry.

During the last 10 years, the majority of DR programs in California and across the US have been designed to address seasonal problems such as peak summer demand. Reducing hot summer demand can help ensure that utilities and grid operators procure less electricity at high price times. These programs can also help defer the need for new power plants and make better use of the existing transmission and distribution systems. Peak summer DR programs can also improve grid reliability by reducing the hours when a local or larger system grid is running near capacity.

Over 1300 buildings and industrial facilities in California now have OpenADR technology installed to participate in automated DR programs, providing about 250 MW of DR (Ghatikar et al. 2014). The most common strategy for commercial buildings to respond to these DR signals is through resetting heating, ventilation and air conditioning (HVAC) systems. The most common HVAC strategy is a global temperature reset, or a zone reset of 4 or 6 ^{o}F to unload the cooling systems. Fan energy is also reduced if the building uses variable air volume systems. The HVAC reset has been shown to respond quickly, although the speed of the response varies by building. These DR strategies use the inherent mass in the building. When the zone temperature is reset, there is thermal lag and the occupants may be comfortable or have minimal awareness of the reset. Some buildings develop pre-cooling strategies that allow the building to prepare for the DR event and increase comfort and the duration of the event (Xu et al., 2004). Buildings with more mass and less glazing area are better candidates for this strategy.

While hot summer peak load growth is still a problem in many parts of the US, there is a growing desire to explore how DR can be used to help integrate more renewables on the grid. Figure 2 provides the well-known "duck" curve from the California Independent System Operator (CAISO) that shows the steep afternoon and early evening ramp in the electric grid net load as future solar resources decline in the late afternoon. This change of over 10 GW in 3 hours suggests the grid operators will need a set of fast responding resources to manage this ramp. Researchers and grid operators are evaluating how DR might provide some fast acting services that have historically been provided by generators. One key question is can DR provide these services at lower prices than traditional ancillary services? Can we leverage smart meters and other communication and information systems for the electric grid to offer both new telemetry and control platforms?

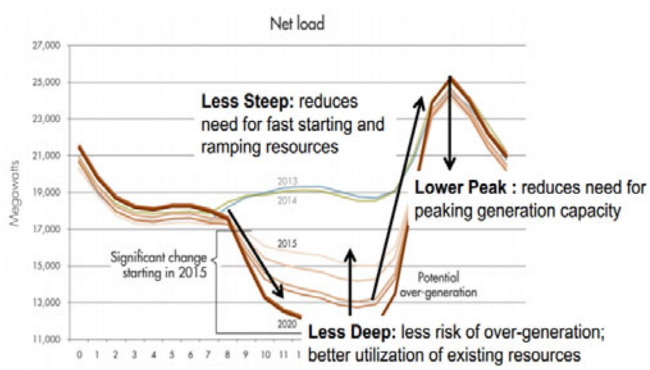

Figure 2. Illustrative change in MW of net load and production profiles from March 2013, CAISO.

Fast Demand Response Transactions for Ancillary Service Markets

Ancillary services provide support to the power system and are essential in maintaining power quality and reliability. There are typically three types of ancillary services products that DR can participate in. From the faster to the slower acting, these are: regulation, spinning reserve and non-spinning reserve. Table 1 lists examples of ancillary services and requirements for the response time, duration, and market cycle for the different products. There is a significant interest in evaluating how DR resources can offer these services. One key question is how a building load represents itself to grid operators, what resources are available and on what time scale? This might include the size of the DR load in kW, the time of day and for how many hours, how often it can be called, and other such factors.

Table 1. Summary of ancillary services

Service	Service Description		
	Response Speed	*Duration*	*Market Cycle*
Operating Reserves			
Regulating Reserves, or Regulation up/down	Online/Spinning reserve, responds to Automatic Generation Control to to meet Real Power Balancing Control Performance.		
	<1 minute; able to reach max amount of Reg in 10-30 min	*30 min (Real Time); 60 Min (Day Ahead)*	*Hourly; every 15 minutes looking ahead 2 hours*
Load Following or Fast Energy Markets	Similar to regulation but slower. Bridges between the regulation service and the hourly energy markets.		
	~10 Minutes	*10 minutes to hours*	*5 min*
Contingency Reserves			
Spinning Reserves	Online Generation, synchronized to grid, increase response to major generator or transmission outage reaching full output within 10 minutes		
	Instantaneous response; <10 minutes for full output	*30 minutes*	*10 min*
Non-Spinning Reserve	Same as spin reserve, need not be immediate; can be offline but capable of reaching full bid within 10 minutes		
	< 10 minutes	*30 minutes*	*10 min*

The need for understanding how to facilitate DR market transactions is important as DR offers services beyond hot summer day grid resources. Historically most DR has been manually controlled but with new automation technology building end-use loads are able to participate in faster DR markets because of the ability to respond quickly. Such automation systems provide the underlying capability for building loads to transact with the grid more frequently and continuously. There are questions, however on what is required of the HVAC and lighting control systems to provide these services. Fast real-time power measurements are needed for some applications. It is useful to evaluate the DR and transactional load concepts and the general capabilities of the loads in commercial buildings. Key attributes in evaluating the potential for transactional loads in commercial buildings are listed in Table 2.

Table 2. Attributes for modeling the potential of demand response resources

Attributes	More /Less Flexibility
Response frequency	High /Low frequency
Response duration	Long /Short duration
Response time (advance notice & latency)	Fast/Slow
Energy re-charge/pre-charge	Not required/Required
Cost of automation	Inexpensive/Expensive
Resource magnitude per control unit	Large/Small
Alignment of availability	Aligned/Counter -aligned

While we are starting to consider and evaluate the potential for building loads to provide these new grid services, much more is needed to build, deploy, and evaluate cost-effective control systems that can communicate with grid operators. There are many questions about how quickly HVAC or lighting, or other commercial building loads can respond. It is useful to consider questions such as how frequently can the load respond, and for how many hours? Perhaps the load can respond continuously, meaning that the end-use service is dynamic and flexible. The speed or response time for a load to be reduced depends on the latency of the controls and the nature of the load. Lighting is often faster in responding to DR signals than HVAC systems. HVAC systems often have motors and compressors that have inherent inertia and so they are ramped up and down more slowly. Cooling systems, however, have the potential to pre-cool loads and offer more flexible services when the mass of the building is considered.

Another important attribute for DR resources is the cost to automate the DR. These costs have to be considered when designing a DR program to understand what is necessary to deploy the DR infrastructure. It is often less expensive to automate large buildings with energy management systems because the cost to install and enable the DR automation provides a much larger, centralized load than a similar approach with small buildings. One major building automation control manufacturer provided OpenADR software in their operating system before many of the others. Buildings that use this control systems with native OpenADR capability can configure automated DR strategies for under $50/kW (as further described below in Table 9). California building codes now require lighting and HVAC control systems to have the ability to receive demand response signals like those available in OpenADR. The lowest cost future for DR is for control systems to have common software capabilities for receiving and responding to grid signals. The final attribute listed in Table 2 is alignment of availability. DR for cooling loads are, for example, well aligned with summer peak demand programs because that peak is often driven by this end-use demand. Winter electric heating may be aligned with cold winter morning DR programs developed in regions with winter peak demand challenges.

Another important attribute for DR resources is the cost to automate the DR. These cost have to be considered when designing a DR program to understand what is necessary to deploy the DR infrastructure. It is often less expensive to automate large buildings with energy management systems because the cost to install and enable the DR automation provides a much larger, centralized load than a similar approach with small buildings. One major building automation control manufacturer provided OpenADR software in their operating system before many of the others. Buildings that use this control systems with native OpenADR capability can configure automated DR strategies for under $50/kW (as further described below in Table 9). California building codes now require lighting and HVAC control systems to have the ability to receive demand response signals like those available in OpenADR. The lowest cost future for DR is for control systems to have common software capabilities for receiving and responding to grid signals. The final attribute listed in Table 2 is alignment of availability. DR for cooling loads are, for example, well aligned with summer peak demand programs because that peak is often driven by this end-use demand. Winter electric heating may be aligned with cold winter morning DR programs developed in regions with winter peak demand challenges.

In evaluating the flexibility of electric loads in commercial buildings it is also useful to consider issues such as the size of the flexible load, how easy it is to control, and how acceptable a change is to the occupants. It is useful to consider lighting systems in commercial buildings, which are large loads often accounting for 30% of electricity use with 1- 2 W/sqft. Many DR strategies consider lighting, and a reduction could provide 0.3 W/sqft. The ability to enable the transaction for this lighting will depend on the capabilities of the control systems. Unlike HVAC systems, most lighting controls are not centralized and significant retrofits are needed to automate the DR. Past research on occupant acceptability of lighting load reductions has explored understanding both what occupants perceive as “detectable” as well as “acceptable”. These attributes in combination help frame what transactive loads may be available from commercial buildings.

Field Data from Previous Pilots

This section provides a summary of data on the field performance of DR strategies in existing DR programs and grid integration pilots that have taken place over the last several years. As mentioned, over 1300 customers in California now use OpenADR. Some of these customers have been on peak day pricing, also known as critical peak pricing. Figure 3 displays average peak demand reduction for 36 DR events between 2006 and 2008; there are about 12 events each summer. These events were 6 hours in duration.

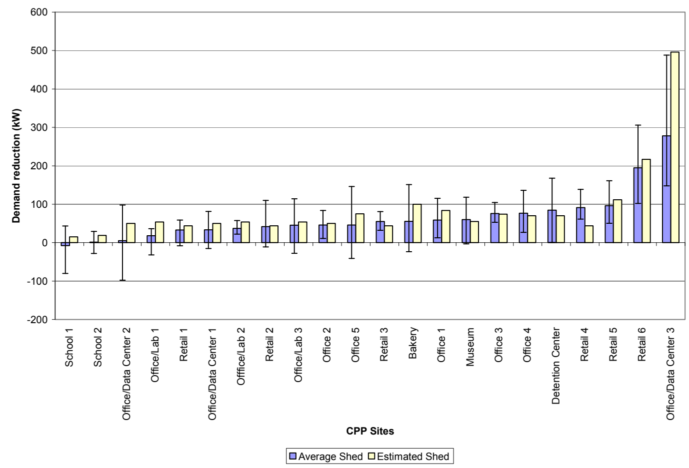

Figure 3. Estimated, average, minimum and maximum demand reduction from automated dynamic pricing for 22 buildings.

The graph shows the estimated DR reduction (which ranges from about 15 kW to nearly 500 kW) for each of the 22 sites. The estimated shed was based on the initial audit and the average shed is the 6-hour average reduction from the 36 events. The graphic also shows the error bars on the average shed indicate minimum and maximum demand reduction for the 36 events (Piette et al. 2006). There is no general trend, up or down, in the shed variation of all the sites. Negative sheds occur when the building consumes more electricity than the baseline modeled electric load. Following several years of research on hot summer DR programs the DRRC has conducted five pilots on new DR markets and fast DR capabilities. These include:

- Cold morning DR in winter peaking electric regions (Seattle)
- Non-spin reserve ancillary services (Northern California)
- Regulation ancillary services (Northern California)
- Economic dispatch of integrated price signals (New York)
- Fast telemetry for small commercial (Northern California)

We describe the commercial building electric loads that participated in these programs below.

Cold Morning DR in Winter Peaking Electric Regions

We worked with the Bonneville Power Administration and Seattle City Light to develop two research demonstrations (Kiliccote et al 2010, Piette et al. 2013). We conducted fully automated DR tests of cold winter morning events and then showed that the DR system could provide both winter and summer response with same automation platform. Table 3 provides a summary of the HVAC and lighting systems at five buildings that were recruited for the tests.

Table 3. Building name, type, size, peak demand and end-use systems in 5 test buildings

Name	Type	Area (sqft)	Peak (kW)	Lighting	HVAC
Seattle Tower	Office	126,000	6168	Centrally scheduled with sweeps	Electric heat, VAV, AHUs
Target – T1284	Retail	17,500	685	Central fixture switching	Gas heat, VAV RTUs
McKinstry	Office	10,530	347	Centrally scheduled with sweep	Gas heat, both VAV and CAV RTUs.
Seattle University	College	10,505	941	Centrally scheduled with sweep	Electric heat, VAV, AHUs, Cabinet and unit heaters
Target – T0637	Retail	10,463	225	Central fixture switching	Gas heat, VAV RTUs

VAV – Variable air volume; CAV- Constant air volume, RTUs – Roof top units, AHU – Air Handler Units.

Table 4 lists 21 DR strategies that have been used at other facilities. The 12 control strategies used in these 5 sites are identified for either winter (W) or summer (S) use. For buildings with gas heat, the only potential savings from changing zone temperatures would be the savings from fan power in variable air volume (VAV) systems. When the heating set point is reduced, the fans that supply heat to a zone will temporarily slow down, which reduces electricity demand. The Target stores with gas heated RTU units participated with both lighting and HVAC strategies. SMT, which has all-electric heating and chillers for cooling, employed global zone temperature adjustment for both winter and summer with pre-heating and pre-cooling to prepare for the DR event. Seattle University, which receives steam and chilled water from the campus, selected preheating as a winter strategy but turned off local electrical heating units and adjusted temperature set points to reduce demand. McKinstry duty-cycled RTUs in the winter, adjusted temperature set points, and reduced lighting in the kitchen area.

Table 4. Strategies for Seattle building for winter and summer DR programs

	HVAC													Lighting					Other		
Site	Global temp. adjustment	Duct static pres. decrease	SAT decrease	Fan VFD limit	RTU Shut off	Duty Cycling RTUs	Pre-heating	Pre-cooling	Fan-coil unit off	Cycle electric heaters	Cycle AHU Fans	Cycle VAVs	Set up CO2 Setpoints	Common area light dim	Office area light dim	Turn off light	Dimmable ballast	Bi-level switching	Non-critical process shed	Elevator cycling	Slow Recovery
McKinstry	S					W		S								S					W
Target - T1284	WS				WS													WS			
Seattle Municiple Tower	WS										W	W									WS
Seattle University	WS					W	W	S		W	W	W	W								W

The research project conducted a series of 16 summer and winter test events. Figure 3 shows the aggregated demand reduction during the winter tests for a March 5 2009 event. The average demand reduction over 3 hours was 767 kW, or 14% of the aggregated load relative to the baseline model that uses an hourly outside air temperature regression.

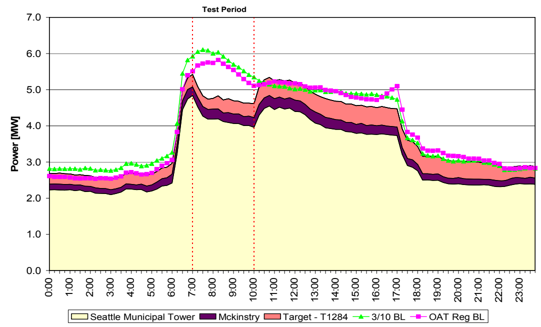

Figure 4. Winter morning automated DR event from Seattle.

As shown in Table 5, average winter DR whole building power reductions for these buildings ranged from 8 to 18% for the 3 hour events (Kiliccote et al 2010).

Table 5. Result for winter automated DR tests - whole-building power, power density and percent of whole building power

Site	Test	Test 1	Test 2	Test 3	Test 4	Average
McKinstry	W/m2	2.3	1.5	1.4	2.5	**1.9**
	kW	25	16	15	27	**21**
	WBP%	9%	6%	5%	10%	**8%**
Target - T1284*	W/m2	4.7		4.7		**4.7**
	kW	102		104		**103**
	WBP%	19%		19%		**19%**
Seattle Municipal Tower	W/m2	5.3	5.6	1.7	3.72	**4.1**
	kW	678	717	220	477	**523**
	WBP%	15%	15%	4%	9%	**11%**
Seattle University	W/m2	13.1	9.5	11.8	10.4	**3.3**
	kW	141	102	127	112	**121**
	WBP%	20%	15%	19%	17%	**18%**
All Sites	W/m2				**Average***	**3.5**
	kW				**Total***	**767**
	WBP%				**Average***	**14%**

Sheds are calculated using OATR model with no adjustments
* Total value is the sum of the averages for each site
** Average Value is the average of each site's average

The summer tests delivered an average (i.e., average of each site's average) 16% demand reduction or 04 W/ft^2 over five hours with a cumulative energy savings of 6.5 MWh.

Non-Spinning Reserve Ancillary Services (Northern California)

In 2009 California organized the Participating Load (PL) Pilots as a first step towards allowing DR resources to participate in the California Independent Systems Operator's wholesale ancillary services non-spinning reserve markets. The objective of these pilots was to assess the technical and financial feasibility of using retail DR resources as participating load. The program was organized as follows. PG&E submitted two bids through the Scheduling Infrastructure Business Rules, a web-based user interface for each of the participating loads: load bid and generating (pseudo generating resource) bid. The generating bid represents the demand reduction portion of the non-spinning reserve provided by the participating load and it is also generated two-days in advance through forecasting. A participating load resource can participate in day-ahead energy, day-ahead non-spinning reserve ancillary service, and real-time imbalance energy markets.

The DRRC recruited 3 facilities to participate in the PL Program. These sites had been on day-ahead automated critical peak pricing. They were selected because their hourly load shapes and demand response was among the most predictable in the automated program. The three facilities were a retail store, a local government office building, and a bakery (Kiliccote et al, 2009). Four-second near-real-time whole building power data were used to monitor the performance of the strategy and evaluate if it met the bid requirements. If the initial strategy did not meet the bid requirements, the strategy was adjusted by the OpenADR automation server by sending another load level information that adjusts the temperature set points up or down within the initial parameters set and programmed by the participant. Figure 5 displays the actual 5-minute load data for a DR event at the office building and the hourly forecasts. A PLP event was dispatched between 2 to 6 pm. The DR strategy for this facility was programmed such that four DR load reduction levels were mapped onto four 1ºF incremental temperature adjustment strategies. At the PLP event start, a 2ºF adjustment was dispatched. The HVAC DR strategy was able to follow the bid fairly well of the 2 hour event. This non-spin service required that the DR resource be available within ten minutes of the call of the event and this time requirement was easily met by the HVAC strategy. The load reduction was sustained during the entire two-hour event. In this case there was no rebound because the building goes into after hour, evening operations.

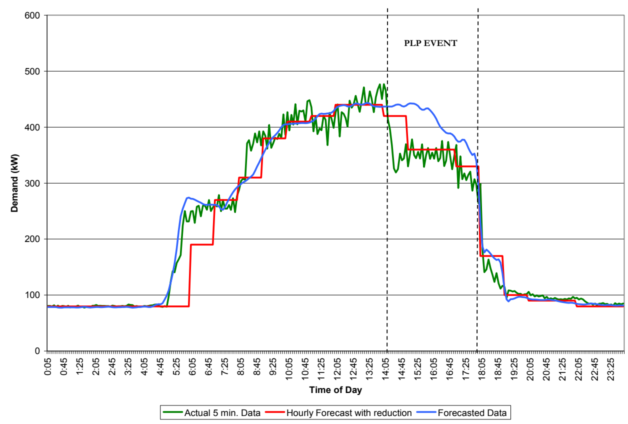

Figure 5. Non-spin fast DR event for an office building. Load is reduced in less than 10 minutes.

Regulation Ancillary Services

Regulation is a product in the ancillary services market whereby the provider of the service is equipped with automated controls allows the system operator to request upward or downward changes in output. Regulation is used to track and balance system wide generator output with system wide load on a sub-minute by minute basis (Hefnerr et al, 2007). In California and Texas regulation is separated into two products; these are regulation up and regulation down. In other US markets regulation products are symmetric, meaning the generator signs up to deliver as much regulation up as down product. The DRRC conducted a series of field tests with the California ISO and PG&E to evaluate how to use building loads and OpenADR for regulation services (Kiliccote et al 2010). The project evaluated the latency of the round trip control signals. During the initial tests with the CAISO the time it took for the

OpenADR server to receive the signals and the latencies associated with ICCP over the energy communication network was about 2 seconds. We conducted a series of tests to evaluate the characteristics of DR and how it may look like a regulation resource. Figure 5 displays results of a “take” strategy tests on August 3rd.

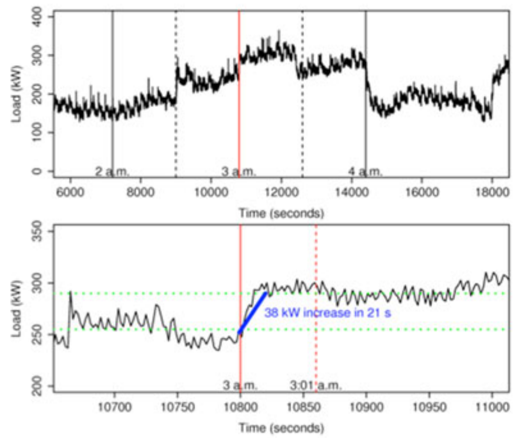

Figure 6. Automation system for DR to provide regulation services.

The graphic on the top displays the 2 to 4 am test period where the ventilation was manually increased every half hour starting at 2 am. A closer evaluation of the load shape in the picture at the bottom of Figure 5 displays the difficulty of identifying the ramp rates in this noisy data environment. The blue line is selected as a conservative estimate of the ramp to calculate the ramp rate. Table 6 shows the DR characteristics of each of the sites. While these values were derived from tests at UC Merced and SMCC, the values for WHF were derived from engineering estimates. Compared to the single ramp rate that the generators are certified for, the DR resources have varying ramp rates depending on whether they implement take or shed strategies. This is indicated in Table 3 as separate ramp rates for SMCC.

Table 6. Power reduction and DR ramp from 3 commercial buildings

Site	Available Capacity (MW)	Min. Operating Limit (MW)	Max. Operating Limit (MW)	Ramp Rate (MW/min.)
UC Merced	0.16	0	0.17	Reg up: 0.022 Reg down: 0.022
West Hill Farms	0.03	0	0.16	Reg up/down:0.03
SMCC	0.2	0	0.2	Reg up: 0.05 Reg down_1: 0.066 Reg down_2: 0.134

*SMCC – San Mateo Community College, WHF is a Pistachio Farm

Economic Dispatch of Integrated Price Signals

During the last 3 years the DRRC has conducted a research pilot in New York (NY) to evaluate the feasibility of automating DR for commercial buildings in NY City, NY (Table 7). NY has a deregulated market and large customers are exposed to day-ahead hourly pricing. This project explored how to provide a practical solution for continuous energy management to integrate electricity prices and DR event. The economic analysis for energy management considered peak demand charges, day ahead hourly prices, and DR events called by the NYISO.

Table 7. High mode savings at NY City DR automation test sites

Building Site	High DR Mode								
	kW			W/ft2			%		
	Min	**Ave**	Max	Min	**Ave**	Max	Min	**Ave**	Max
Office 1	588	**652**	720	0.42	**0.47**	0.51	10%	**12%**	13%
Office 2	95	**137**	187	0.06	**0.08**	0.11	3%	**4%**	5%
Office 3	112	**151**	182	0.08	**0.11**	0.13	3%	**4%**	5%
University Building	37	**57**	74	0.30	**0.47**	0.61	10%	**15%**	20%

The demonstration provides a framework to develop and test control algorithms that minimize energy use and costs in large commercial buildings under this rate. This project demonstrates how large buildings can use their flexible loads to automatically respond to hourly price signals. Large office buildings have elasticity in their operations with automation; it is feasible for this flexibility to be used on a regular basis without impacting the occupants. Similar to results above, we see average "High Mode" DR reductions of 0.1 to 0.5 W/sqft representing 4% to 15% of the whole building load.

Fast Telemetry for Small Commercial Buildings

We provide new results from a technology develop project that is part of a nearly complete Advanced Research Project Agency – Energy (ARPA-E) project (Kiliccote et al, 2014). Our role in this project was to develop and test technology to facilitate control of building loads simultaneously and with low latency across multiple sites within a specified response time. The project evaluated how reliability of the Internet or 4G cellular networks can be as the mode of control and metering. Table 8 lists the power reduction from changes in thermostats that were measured for short and fast DR events. This project is demonstrating low-cost telemetry for advanced DR markets.

Table 8. Fast DR results for 4 small offices in telemetry research

Site	Ave. Load Reduction (W, W/ft^2, %)	Latency (Control-to-response)	Latency (Transition)
Small Commercial 1	5 kW, 0.8 W/ft^2, 17%	<30 sec.	<1 min.
Small Commercial 2	9 kW, 1.5 W/ft^2, 52%	<30 sec.	<1 min.
Small Commercial 3	15 kW, 1 W/ft^2, 37%	<30 sec.	<1 min.
Small Commercial 4	34 kW, 0.4 W/ft^2, 16%	<30 sec.	<1 min.

Discussion

As presented above, DR resources are technically capable of providing fast DR services. It is likely that as the technology and markets for DR evolve, the cost for the DR resources will be much lower cost than conventional supply resources. They may be cleaner and support green house gas reduction goals. **The lowest cost vision for the future would be one in which the building loads can transact against multiple value streams at different time scales**. Thus, one principle for area is **Automate Once – Use Many Times.** This means that a building load can participate in both summer or winter DR programs and ancillary services market. There are a number of questions behind this statement. One is – how can DR automation platforms and end-use loads provide a broad set of grid transactions? Can buildings be in more than one DR program? Will there be "fatigue" for frequent DR events? In this study, we have demonstrated that flexible DR resources can participate in wholesale energy, capacity, or ancillary services markets. HVAC as an end use and global temperature adjustment as a DR strategy meet the 10-minute response time and two-hour duration requirements for wholesale ancillary services such as contingency reserves. We have demonstrated that the Internet can be used to enable fast DR-based non-spinning products in ancillary services markets. This is critical for low-cost automation.

It is important to acknowledge that forecasting individual building loads is a complex process and highly variable loads are difficult to forecast. Buildings with more predictable loads are better candidates for advanced fast DR programs. Another important challenge is that the cost of high-speed telemetry required by the grid operators is major barrier to fast DR. A companion paper reports on research on low-cost, high-speed telemetry platforms (Kiliccote et al, 2014). A recent paper estimates the demand response availability profiles for thirteen end-use loads, four of which are from commercial buildings, for the Western Interconnection for the year 2020 (Olsen et al. 2013). These load profiles are further evaluated and filtered to obtain an estimate of the amount of load available to participate in five products (three ancillary services, an energy product, and a capacity product) for each hour of the 2020 calendar year.

Current utility programs in California provide about $200/kW to install automation systems using an open automated demand response communication standard (OpenADR). This technology can provide DR signals on different times scales to interact with responsive building loads. Table 9 shows the cost per kW required to install the DR automation platforms for the Seattle project. The Target stores were the lowest first costs because the facility has native OpenADR software in the control systems. The goal of our research is to continue to evaluate how to bring down the price of DR automation.

Table 9. Costs to install automation for Seattle automated DR study

Site	Controls Vendor	Controls Cost	Material	Electrical Labor	Commissioning DR Strategies	Total	Total ($/kW)
McKinstry		$ 3,780	$ 1,064	$ 1,005	$ 1,071	$ 5,915	282
	ATS	$ 2,470	$ 200	$ 609	$ 1,530	$ 4,200	105
Seattle Municipal		$ 4,007	$ 1,500	$ 1,005	$ 1,071	$ 6,578	13
Tower	Siemens	$ 6,800	$ -	$ -	$ 1,530	$ 8,330	46
Target (both stores)		$ 6,500	$ 1,582	$ 2,000	$ -	$ 8,082	40
	ALC	$ 2,850	$ -	$ -	$ -	$ 2,850	10
Seattle University		$ 2,783	$ 1,000	$ 1,005	$ 1,071	$ 4,854	40
	ESC	$ 6,975	$ 927	$ 2,438	$ 1,530	$ 9,432	269

Conclusions and Future Directions

This paper has presented a series of examples from field studies on advanced DR automation in commercial buildings. Many commercial buildings have the capability to provide DR on different time scales. In fact, it is likely that the same building can provide both slow and fast DR. More work is needed to incorporate decision-making and analysis tools for building owners and managers to support this concept. The building control or related transactive system agent needs to identify and provide an estimate of the DR available for the DR program managers and grid operators. New work funded by DOE is starting to explore the needs in this area using an agent based decision analysis platform for grid integration. LBNL has developed an automated measurement and verification tool to support the transactive platform. The development and deployment of common interoperable software for DR and grid transactions will help control companies, utility and grid operators ensure software can be integrated at low costs. It is critical to describe the features of end-use loads as they transact with grid systems. We often describe the costs to automate the load in terms of the $/kW, but more research is needed on the costs to install and maintain these telemetry platforms over time, and to evaluate the economic value of a transactive building.

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