Automated Demand Response Strategies and Commissioning Commercial Building Controls

Mary Ann Piette, David Watson, Naoya Motegi, Sila Kiliccote
Lawrence Berkeley National Laboratory
PIER Demand Response Research Center

Eric Linkugel
Pacific Gas and Electric Company

Synopsis

California electric utilities have been exploring the use of dynamic critical peak pricing (CPP) and other demand response programs to help reduce peaks in customer electric loads. CPP is a new electricity tariff design to promote demand response. This paper begins with a brief review of terminology regarding energy management and demand response, followed by a discussion of DR control strategies and a preliminary overview of a forthcoming guide on DR strategies. The final section discusses experience to date with these strategies, followed by a discussion of the peak electric demand savings from the 2005 Automated CPP program. An important concept identified in the automated DR field tests is that automated DR will be most successful if the building commissioning industry improves the operational effectiveness of building controls. Critical peak pricing and even real time pricing are important trends in electricity pricing that will require new functional tests for building commissioning.

About the Authors

Mary Ann Piette is a Staff Scientist and Deputy Leader of the Commercial Building Systems (CBS) Group at LBNL, and is the Research Director of the PIER Demand Response Research Center. She has an MS in Mechanical Engineering from UC Berkeley and a Licentiate in Building Services Engineering from the Chalmers University of Technology, Sweden.

David S. Watson is a Staff Research Engineer in the Commercial Building Systems Group at LBNL. Prior to joining LBNL, David held engineering, management and product development positions at Honeywell, York International, Echelon and Coactive Networks. Mr. Watson graduated from California Polytechnic University, San Luis Obispo with a degree in Mechanical Engineering.

Naoya Motegi is a Senior Research Associate in the Commercial Building Systems Group in the Building Technologies Department at LBNL. He has a Master of Science in Architecture from University of California, Berkeley, and a Bachelor of Architecture and Master of Engineering in Architecture and Civil Engineering from Waseda University in Tokyo, Japan.

Sila Kiliccote is a Scientific Engineering Associate in the Lighting Systems Group in the Building Technologies Department at LBNL. She has a Master of Building Science in Architecture from Carnegie Mellon University and a Bachelor of Electrical Engineering Systems from the University of New Hampshire.

Eric Linkugel was the program manager with the Pacific Gas & Electric Company (PG&E) during the 2005 Automated CPP project. He is now coordinating DR programs within the account services organization of PG&E. He has an MS in Industrial and Technical studies and a Bachelor of Science in Industrial Technology from California Polytechnic University, San Luis Obispo.

Background

California electric utilities have been exploring the use of critical peak pricing (CPP) and other demand response programs to help reduce summer peaks in customer electric loads. CPP is a form of price-responsive demand response. Recent evaluations have shown that customers have limited knowledge of how to operate their facilities to reduce their electricity costs under CPP (Quantum Consulting and Summit Blue, 2004.). While the lack of knowledge about how to develop and implement DR control strategies is a barrier to participation in DR programs like CPP, another barrier is the lack of automation of DR systems. Most DR activities are manual and require people to first receive emails, phone calls, and pager signals, and second, for people to act on these signals to execute DR strategies.

Levels of automation in DR can be defined as follows. **Manual Demand Response** involves a labor-intensive approach such as manually turning off or changing comfort set points at each equipment switch or controller. **Semi-Automated Demand Response** involves a pre-programmed demand response strategy initiated by a person via centralized control system. **Fully-Automated Demand Response** does not involve human intervention, but is initiated at a home, building, or facility through receipt of an external communications signal. The receipt of the external signal initiates pre-programmed demand response strategies. We refer to this as **Auto-DR**. One important concept in Auto-DR is that a homeowner or facility manager should be able to “opt out” or “override” a DR event if the event comes at time when the reduction in end-use services is not desirable.

From 2003 to 2005 the PIER Demand Response Research Center has conducted a series of tests with fully automated electric demand response. The field tests have included 28 facilities, with average demand reductions of about 8% over the three to six hour DR events. Many electricity customers have suggested that automation will help them institutionalize their electric demand savings, improving overall response and repeatability. Table 1 shows the number of sites that participated in the 2003, 2004, and 2005 field tests along with the average and maximum peak demand savings. The electricity savings data are based on weather sensitive baseline models that predict how much electricity each site would have used without the DR strategies. Further details about these sites and the automated DR research are available in previous reports. The tests in 2003 and 2004 used fictitious electricity prices with no direct financial incentives for the participants (Piette et al, 2005). The 2005 test involved 12 sites on fully automated critical peak pricing from PG&E (Piette et al, 2006).

Table 1: Average and Maximum Peak Electric Demand Savings during Automated DR Tests.

Results by Year	Number of participants*	Duration of Shed (Hours)	Average Savings (%)	Max. Savings (%)
2003	5	3	8	28
2004	18	3	7	56
2005	12	6	9	38

* Some of the sites recruited were not successful during the 2005 CPP events because of delays with advanced meters and control work, but are expected t be ready for the 2006 tests. The table below lists all 28 buildings that have participated over the three years of testing.

This paper begins with a brief review of terminology regarding energy efficiency, daily peak load management and demand response. The paper also includes a discussion of DR control strategies. Preliminary concepts related to a forthcoming guide on DR control strategies are presented. The final section discusses experience to date with these strategies, followed by a discussion of the peak electric demand savings from the 2005 Automated CPP program. One important concept identified in the automated DR field tests is that automated DR will be most successful if the building commissioning industry improves the operational effectiveness of building controls. Comments on the role and importance of building commissioning are presented in the discussion below.

Terminology and Controlling Electric Loads

Efficiency, Daily Load Management and Demand Response

During the past few decades, knowledge of practices to minimize energy use in commercial building design and operations has improved to achieve greater levels of energy efficiency. A related dimension of energy use is energy cost minimization. Electricity cost minimization in building operations requires close attention to the structures of electricity tariffs considering the time that electricity is used and the quantity that is used. Electricity pricing structures can be complex with time of use charges, demand ratchets, peak demand charges, and other related features. New demand response programs and tariffs provide even greater incentives to consider sophisticated building operational and control strategies that reduce electricity use during occasional events. Table 2 below provides three definitions for building design and operational control strategies. Key definitions are discussed briefly.

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Energy Efficiency and Conservation**:* **Energy efficiency** can lower energy use to provide the same level of service. **Energy conservation** can be defined as reducing unneeded energy use. Both energy efficiency and conservation provide environmental protection and utility bill savings. **Energy efficiency measures** can permanently reduce peak load by reducing overall consumption. In buildings this is typically done by installing energy efficient equipment and operating buildings efficiently. In California, ***Time Dependant Valuation is also in use for building energy evaluations within the state energy code to take into account the time that electricity is used during the year (CEC 2005). TDV acknowledges that some efficiency measures reduce summer peak electric demand more than others. **Energy efficient operations**, a key objective of new and retro-commissioning or existing building commissioning, require that building systems operate in an integrated manner.

Table 2: Demand Side Management Terminology and Building Operational Strategies

	Efficiency and Conservation (Daily)	**Peak Load Management (Daily)**	**Demand Response (Dynamic Event Driven)**
Motivation	- Economic - Environmental Protection - Resource availability	- TOU Savings - Peak Demand Charges - Grid Peak	- Price (economic) - Reliability - Emergency
Design	- Efficient Shell, Equipment & Systems	-Low Power Design	- Dynamic Control Capability
Operations	- Integrated System Operations	- Demand Limiting - Demand Shifting	- Demand Shedding - Demand Shifting - Demand Limiting

Daily Peak Load Management: Daily peak load management is conducted in many buildings to minimize peak demand and time-of-use rates. Typical peak load management methods include demand limiting and demand shifting. ***Demand limiting*** refers to shedding loads when pre-determined peak demand limits are about to be exceeded. Demand limits can be placed on equipment (such as a chiller or fan), systems (such as a cooling system), or a whole building. Loads are restored when the demand is sufficiently reduced. This is typically done to flatten the load shape when the pre-determined peak is the monthly peak demand. ***Demand shifting*** is achieved by changing the time that electricity is used. Thermal energy storage is an example of a demand shifting technology. Thermal storage can be achieved with active systems such as chilled water or ice storage, or with passive systems such as building mass.

Dynamic, Event Driven Demand Response: Demand response can be defined as short-term modifications in customer end-use electric loads in response to dynamic price and reliability information. Demand response programs may include dynamic pricing and tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control or equipment cycling. ***Demand limiting and shifting*** can be utilized for demand response. DR can also be accomplished with ***demand shedding,*** which is a temporary reduction, or curtailment of peak electric demand. Ideally a demand shedding strategy would maximize the demand reduction while minimizing any loss of building services.

Control Concepts for Demand Response

One practical concept is our preference to recommend ***closed loop control*** strategies with resets that maintain control within zones and systems. ***Open loop control***, such as a demand limit, may constrain building systems and produce zones and areas of a building that are “out of control”.

Another important concept is that as we develop demand responsive buildings, we no longer have simple modes of operation such as warm up, full occupant, and night set back. Rather, we have ***dynamic set point control*** relative to the electric load shape objectives for the building and the time varying cost of electricity. Thermal mass storage systems have used this property for some time. Results from our field tests suggest that existing buildings can provide significant levels of demand response with minor modifications to existing control strategies. These control strategies are discussed below. Critical peak pricing and even real time pricing are important trends in electricity pricing that will require new functional tests for building commissioning.

A third important concept on advanced controls for demand response is that as we improve the ***granularity of control***, we increase the DR capability. This is true for heating, ventilation and air conditioning (HVAC) and lighting systems. Improvements in controllability, such as zonal HVAC or zonal lighting, allow us to potentially work with some parts of the building for a DR event, but perhaps not all of it. Or, advanced controls and increased levels of granularity allow us to define explicit steps in building services (lighting or temperature) that can potentially be exercised during DR events. These same concepts will become useful in optimizing energy services and energy use patterns with on-site energy and renewable systems, again suggesting new functional tests for commissioning.

Automated CPP Project Description

The 2005 Auto-DR project design of was a collaboration between LBNL, the DRRC, and PG&E. We recruited 15 facilities to participate in fully automated response critical peak pricing (only twelve are included in some of the tables because of problems and late results from three sites). PG&E triggered the price signals that propagated to each facility to provide variable pricing for electricity. Qualified sites were be configured to respond to automated price signals transmitted over the Internet using relays and gateways that send standardized signals to the energy management and control system (EMCS). During the 2005 summer test period, as the electricity price increases during a CPP event, pre-selected electric loads were automatically curtailed based on each facility's control strategy. PG&E's critical peak pricing (CPP) program is a voluntary alternative to traditional time-of-use rates. The CPP program only operates during the summer months (May 1 through October 31). The additional energy charges for customers on this tariff on CPP operating days are as follows (Figure A):

- **CPP Moderate-Price Period Usage**: The electricity charge for usage during the CPP Moderate-Price Period was three times the customer's summer part-peak energy rate under their otherwise-applicable rate schedule multiplied by the actual energy usage. The CPP Moderate-Price period was from 12:00 Noon to 3:00 PM on the CPP operating days.
- **CPP High-Price Period Usage**: The total electricity charge for usage during the CPP High-Price Period was five times the customer's summer on-peak energy rate under their otherwise-applicable rate schedule multiplied by the actual energy usage. The CPP High-Price period was from 3:00 PM to 6:00 PM on the CPP operating days.

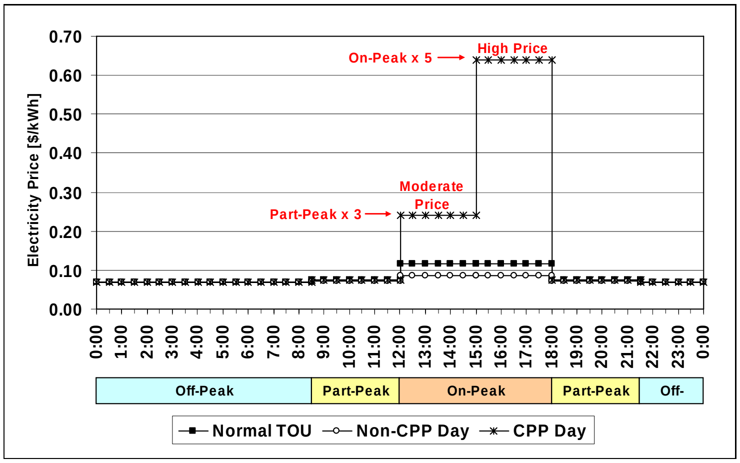

Figure A: Example of a CPP Tariff

Previous papers have provided detailed descriptions of the DR automation systems, which are not provided in this paper. The automated demand response system uses the public Internet and private corporate and government intranets to communicate CPP event signals that initiate reductions in electric load in commercial buildings. The CPP signals are received by the EMCS, which performs pre-determined demand response strategies at the appropriate times.

Demand Response Control Strategies

We are in the process of developing a guide to demand response control strategies based on the field test conducted during the last three years of Auto-DR activities. The guide will provide an overview of potential DR control strategies for commercial building and is intended to provide building engineers and operators with an introduction to potential DR control strategies that can be implemented in California commercial buildings. The discussion is based on recent field tests results in California, case studies, and building HVAC and lighting control theory. Nearly all of the strategies discussed in this guide have been tested in actual buildings with positive results. The reduction in peak electric demand from implementing these strategies in any given building can vary. The guide shows the range of savings that have been demonstrated in actual buildings. Numerous factors can influence the range of savings that can be achieved using a particular strategy for a given building. Some of these factors include weather, internal loads, equipment sizing, balancing and commissioning issues, controls, and other such issues. The new guide will review the end-use control strategies used among the 28 field test sites listed below (Table 4). Results from other DR projects around the US will also be explored. The next subsections provide a brief introduction into the HVAC and lighting controls strategies.

HVAC Strategies

The guide will include the following type of information:

- Decision Flow Chart
    - Categorization of building HVAC systems
    - Identification of strategies for major HVAC types
    - Description of control system features related to HVAC systems
- Discussion of Specific strategies, such as:
    - Global Temperature Adjustment
    - Supply Air Temperature Adjustment
    - Chilled Water Temperature Adjustment

We have been most successful in buildings that incorporate a global zone set point setup to increase the temperature of all zones by a preset temperature differential. In general, this strategy requires zone level Direct Digital Controls. Some buildings require reprogramming of controls to globally command all of the zones from one command location or setting. If the zone set points are set individually, significant work is required to reprogram each thermostat setpoint to respond to the demand response signal. The global temperature adjustment strategy has proven to be an effective and minimally disruptive technique for achieving good HVAC demand response in moderate California climates. Additional work is needed to test these strategies in more severe, hotter California climates. Table 3 below shows the ANSI/ASHRAE Standard 55-2004, Acceptable Temperature Change Rates. From the EMCS trend logs with the field tests and related measurements we've gathered from the Auto-DR tests, the buildings were able to remain in these acceptability ranges during the tests.

Table 3: Acceptable Temperature Change Rate

Maximum change in temperature	Period of time
± 1.1 °C (2.0 °F)	15 minutes
± 1.7 °C (3.0 °F)	30 minutes
± 2.2 °C (4.0 °F)	1 hour
± 2.8 °C (5.0 °F)	2 hours
± 3.3 °C (6.0 °F)	4 hours

Figure B shows an example of the DR control strategy flow chart used to help identify DR control strategies for a given combination of HVAC and control systems. This is a high level chart and the guide will include additional details. Our current strategies have not evaluated duty cycling because the sites we have worked with have not tried such strategies. Duty cycling may be worth considering in some cases, but can be problematic if systems are stopped and started too frequently.

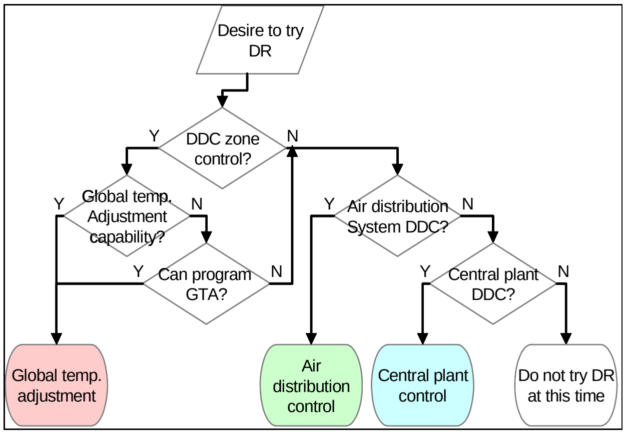

Figure B: Flow Chart for DR Control Strategy Development

Links between Auto-DR Strategies and Commissioning

One common question regarding DR strategies is: ***if you can use a strategy for a short period, why not use it all the time***? Answer: ***Maybe you can***! One of the best examples we've seen is the pursuit of duct static reset strategies for a building with pneumatic zone controls. In the effort to develop short-term DR strategies, the duct static pressure was reset to operate lower during all operating hours. The process of developing DR control strategies will often identify commissioning issues and opportunities. Similarly, when examining electric load shapes we have found equipment, such as fans, running during unnecessary nighttime operation. In one supermarket, as the DR control strategies were tested, it was discovered that the rotisserie was circuited on the demand-shed circuit. The automation testing demonstrated a DR strategy control problem that existed prior to LBNL's involvement[1]. Commissioning of DR control strategies would ideally take place during new construction commissioning, as is being planned at the New York Times Headquarters building (Kiliccote et al, 2006).

Lighting Strategies

Lighting control strategies for DR depend on the initial design and installation of the wiring infrastructure and as mentioned above can be categorized based on their control granularity. We list five types of controls from most coarse to most granular: Zone Switching, Fixture Switching. Lamp Switching, Stepped Dimming, Continuous Dimming.

***Zone Switching* -** Switch off lighting where daylight is available. Since this is simple on/off control, it is quite noticeable to the occupants. This can be adequately applied to common spaces such as lobbies, corridors, and cafeterias. This may not be appropriate for office spaces even though they may be daylit.

[1] The problem had to due with new equipment added to a load shed circuit that should not have been because the chicken rotisserie was not curtailable.

***Fixture/Lamp Switching* -** Fixture or lamp switching can be done by bi-level switching. California's Title 24 Energy Efficiency Building Standard requires multiple lighting level controls in all individual offices. With bi-level switching, each office occupant is provided with two wall switches near the doorway to control their lights. In a typical installation, one switch would control 1/3 of the fluorescent lamps in the ceiling lighting system, while the other switch would control the remaining 2/3 of the lamps. This allows four possible light levels: OFF, 1/3, 2/3 and full lighting. Because it has been required by building code since 1983, bi-level switching is common in California office buildings. The 2001 standards state that bi-level switching can be achieved in a variety ways such as:

- Switching the middle lamps of three lamp fixtures independently of outer lamps (lamp switching).
- Separately switching "on" alternative rows of fixtures (fixture switching)
- Separately switching "on" every other fixture in each row (fixture switching)
- Separately switching lamps in each fixture (lamp switching)

Although the standard does not specify centralized controls and most of the dimming controls is done by local photo-sensors and control hardware integrated at the ballast level, the existence of dimming ballasts and division of circuits or separations of ballasts does lay the foundation for manual and with some technical augmentations semi-automatic demand response.

Step Dimming – Through the use of ON/OFF switches, controls to regulate the lighting, such as step dimming, are a popular energy-saving retrofit solution for applications where existing fixtures are not equipped with dimming ballasts. Stepped dimming can be based on a time-of-day schedule or on sensed quantity of daylight. Stepped dimming is often called bi-level dimming because the strategy often involves two levels of light output, usually 100% and 50%. However, if more flexibility is required, stepped dimming can involve three levels of light output.

***Continuous Dimming* -** Based on a schedule or sensed quantity of daylight, fixture light output can be gradually dimmed over the full range, from 100% to 10% (fluorescent) or 100% to 50% (HID). Continuous dimming can provide excellent dispatchability for DR, but the ballasts and controls are expensive and will involve additional research and market developments to bring costs down.

Automated Demand Response Field Test Results

Over the past three years we have conducted Automated DR tests with 28 buildings. Figure C shows a sample electric load shape for a 130,000 ft² Contra Costa County office building. The graph shows the electric load shape during an actual Auto-CPP event. The baseline power is about 400 kW and the weather sensitive LBNL baseline and the PG&E CPP baseline[2] are also shown. The vertical line at each baseline power datum point is the standard error of the baseline regression estimate. The vertical lines at noon, 3 pm, and 6 pm indicates price signal changes.

[2] The CPP baseline used by PG&E does not include weather data, but is based on the average hourly load shape of the three highest consumption days in the last ten work days (excluding holidays). The baseline algorithm considers the site electric consumption from the period of noon to 6 pm when choosing the highest three days.

The building shed about 20% of its electric load over six hours by setting up the zone temperatures from 74 to 76 °F during the first three hours and from 76 to 78 °F during the second three hours. This strategy reduced the whole-building power density by an average of 0.8 W/ft² during the six hours. Figure D below shows an aggregated load shape for ten buildings from the fully automated shed on September 29, 2005. The load shape shows a total peak demand of about 8 MW. The automated DR provided a maximum reduction of nearly 1 MW during this event without operator's intervention. Most of the building mangers did not report any complaints or comfort issues following our event interviews.

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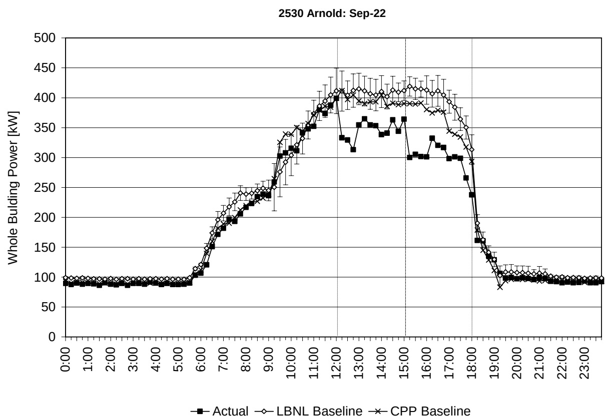

Figure C: Baseline and Office Building Electric Load Shape during Auto-DR Event

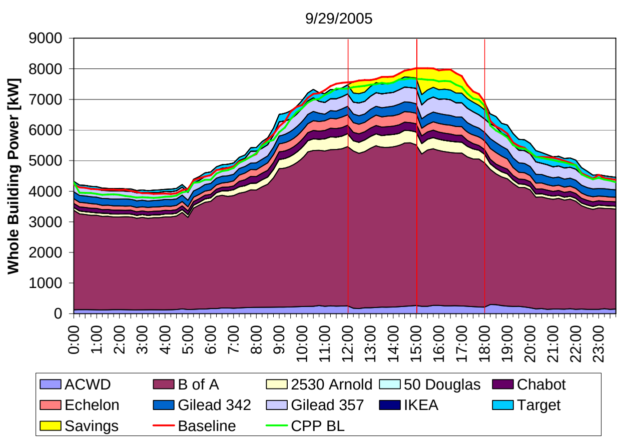

Figure D: Automated CPP Aggregated Demand Saving Results, September 29th

Table 4 shows the entire list of sites, building type, size, which year they participated in, and the DR control strategies. The tests have included numerous building types such as office buildings, a high school, a museum, laboratories, a cafeteria, data centers, a postal facility, a library, retail chains, and a supermarket. The buildings range in size from large campuses to small research and laboratory facilities. The global zone temperature adjustment was the most commonly used strategy, though 16 other strategies are listed. Nearly all of these strategies were based on direct connections to the EMCS.

Table 4. Building Name, Type, Size, Participation, and DR strategies**.**

				Participation			HVAC														Light, Misc.				
	Building use	Total conditioned area	# of bldg	2003	2004	2005	Global temp. adjustment	Fan-coil unit off	SAT reset	Fan VFD limit	Duct static pres. reset	Fan quantity reduction	Electric humidifier off	CHW temp. reset	CHW current limit	Chiller demand limit	Boiler lockout	Pre-cooling	Extended shed period	Slow recovery	Common area light dim	Office area light dim	Anti-sweat heater shed	Fountain pump off	Transfer pump off
300 CapMall	Office	383,000	1		X		X			X		X		X										X	
ACWD	Office, lab	51,200	1			X	X		X		X			X	X		X		X						
Albertsons	Supermarket	50,000	1	X																	X		X		
B of A	Office, data center	708,000	4	X	X	X			X	X	X			X	X										
Chabot	Museum	86,000	2			X	X											X							
Cal EPA	Office	950,000	1		X						X										X	X			
CETC	Research facility	18,000	1		X							X	X												
Cisco	Office, tech lab	4,466,000	24		X		X	X									X				X	X			
2530 Arnold	Office	131,000	1		X	X	X													X					
50 Douglas	Office	90,000	1		X	X	X													X					
Echelon	Corporate Headquarter	75,000	1		X	X	X		X		X	X									X	X			
GSA 450 GG	Federal office	1,424,000	1		X		X																		
GSA NARA	Archive storage	202,000	1		X		X																		
GSA Oakland	Federal office	978,000	1	X	X		X																		
Gilead 300	Office	83,000	1			X			X																
Gilead 342	Office, Lab	32,000	1			X	X		X																
Gilead 357	Office, Lab	33,000	1			X	X		X																
Irvington	Highschool	N/A	1			X	X											X							
IKEA	Retail	300,000	1			X	X																		
Kadent	Material process	-	1		X																				X
LBNL OSF	Data center, Office	70,000	1			X	X											X							
Monterey	Office	170,000	1		X																X				
Oracle	Office	100,000	2			X	X				X														
OSIsoft	Office	60,000	1		X		X																		
Roche	Cafeteria, auditorium	192,000	3	X	X							X													
Target	Retail	130,000	1			X						X									X				
UCSB Library	Library	289,000	3	X	X					X	X				X										
USPS	Postal service	390,000	1		X	X										X				X					

Future Opportunities for the Commissioning Industry

This paper has outlined the building control strategies used in automated demand response field tests conducted over the last three years. Members of the building commissioning industry are likely to be important developers and providers of demand response control strategies and services in commercial buildings. The key reason for this is the knowledge and skills that the commissioning firms have are similar to the ones needed for DR control strategy development. Commissioning providers understand the needs of building owners and operators, have interacted with a wide variety of control systems, and focus on assessment of building operations as opposed to building design.

Ideally, Auto-DR systems would be evaluated as part of the Integrated Audits now being developed by the electric utilities in California. Retro-commissioning projects are another excellent activity to link with Auto-DR control strategy and communications infrastructure development because of the detailed review of control system capabilities and operational status. Recent work with PG&E began to explore the economics and efforts required to program EMCS to include DR strategies and configure automation. Preliminary results from the 2005 Auto-CPP research suggest the cost for the controls automation and programming can be provided by existing technical incentive funds currently provided by the California Investor Owned Utilities for their Demand Response programs. During 2006 LBNL and the DRRC will collaborate with other California utilities to continue to pursue DR automation and controls strategy development. The DR Control Strategy Guide will be available in late spring or early summer, 2006.

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References

ASHRAE/ANSI, 2004. American National Standards Institute, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Standard 55-2004.Thermal Environment for Human Occupancy.

California Energy Commission. 2005. Nonresidential Compliance Manual For California's 2005 Energy Efficiency Standards. CEC-400-2005-006-CMF. April 2005.

Kiliccote, S., M.A. Piette, and G. Hughes, Dynamic Controls for Demand Response in New and Existing Commercial Buildings in New York and California. Forthcoming *Proceedings of 2006 ACEEE Summer Study on Energy Efficiency in Buildings.* Pacific Grove, CA.

Piette, M. A., D. Watson, N. Motegi, Norman Bourassa and C. Shockman, “Findings from the 2004 Fully Automated Demand Response Tests in Large Facilities” September 2005. CEC-500-03-026. LBNL-58178. Available at http://drrc.lbl.gov/drrc-pubs1.html

Piette, M. A., O. Sezgen, D. Watson, N. Motegi, and C. Shockman, “Development and

Evaluation of Fully Automated Demand Response in Large Facilities", January 2005. CEC-500-2005-013. LBNL-55085. Available at http://drrc.lbl.gov/drrc-pubs1.html.

Piette, M.A., D.S. Watson, N. Motegi, S. Kiliccote, 2006. Automated Critical Peak Pricing Field Tests: Program Description and Results, LBNL Report 59351. March.

Quantum Consulting Inc., and Summit Blue LCC, Working Group 2 Demand Response Program Evaluation – Program Year 2004, Prepared for the Working Group 2 Measurement and Evaluation Committee, December 2004, http://www.energy.ca.gov/demandresponse/documents/working_group_documents/2004-12-21_WG2_2004_REPORT.PDF

Xu, Peng, Philip Haves, and Mary Ann Piette (LBNL), and James Braun (Purdue). 2004. Peak demand reduction from pre-cooling with zone temperature reset of HVAC in an office. *Proceedings of 2004 ACEEE Summer Study on Energy Efficiency in Buildings.* Pacific Grove, CA. LBNL-55800. 2004.

Xu, Peng, Philip Haves. 2005. Case Study of Demand Shifting With Thermal Mass in Two Large Commercial Buildings. *ASHRAE Transactions.* LBNL-58649.