ICEBO 2005 Conference Paper September 1, 2005
LBNL # 58179

ADVANCED CONTROL TECHNOLOGIES AND STRATEGIES LINKING DEMAND RESPONSE AND ENERGY EFFICIENCY

Sila Kiliccote Mary Ann Piette
Lawrence Berkeley National Laboratory
Berkeley, California

ABSTRACT

This paper presents a preliminary framework to describe how advanced controls can support multiple modes of operations including both energy efficiency and demand response (DR). A general description of DR, its benefits, and nationwide status is outlined. The role of energy management and control systems for DR is described. Building systems such as HVAC and lighting that utilize control technologies and strategies for energy efficiency are mapped on to DR and demand shedding strategies are developed. Past research projects are presented to provide a context for the current projects. The economic case for implementing DR from a building owner perspective is also explored.

INTRODUCTION

This paper provides an overview of the economic opportunities for demand responsive control technologies and strategies in commercial buildings. The economic opportunities focus on advanced controls from a building owner's perspective. The secondary objective is to evaluate the role of the commercial sector in providing DR around the US. Demand Response can be defined as electric load response techniques and strategies managed by electric utilities or electric grid operators for reliability purposes, electric load response managed by electric utilities or electric grid operators for procurement cost minimization purposes (e.g., load bidding), and (3) price response managed by end-use customers for bill management [1].

Research is underway to evaluate the DR capabilities of existing control systems in buildings and to develop a framework to define and establish the links between DR capabilities in building and advanced controls that support energy efficient building operations. Various layers of building operations including systems, components, controls and controls strategies and the interaction among these layers are being established from energy efficiency and DR perspectives. While the goal of energy efficiency is to reduce energy use (kWh), dynamic reduction of peak electricity demand (kW) is the goal for DR.

The first section of this paper presents an overview of DR, discussing its value for consumers and society. Next, definitions and commonly used terminology for DR are presented. Demand shedding, which is being enhanced with new control technology, is the focus of this paper. The discussion continues with the role of advanced control technologies and strategies to achieve DR by concentrating on the technologies that are a subset of energy efficiency technologies. Examples around the U.S. are included to make the case for linking DR and energy efficiency to yield better energy savings and to prepare buildings for their envisioned future toward zero energy buildings.

Table 1 outlines how DR fits into historical demand side management (DSM) concepts. Column three compares DR with energy efficiency and daily peak load management. The emphasis for DR is dynamic control and event driven building response.

	Demand Side Management		
	Energy Efficiency (Daily)	*Peak Load Management (Daily)*	*Demand Response (Dynamic Event Driven)*
Motivation	- Conservation - Environmental Protection	- TOU - Peak Demand Charges - Grid Peak	- Price - 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

Table 1. DR integrated with DSM Concepts

Building controls systems have been used to reduce electrical peak demands since the 1980s. Previous studies of peak load management in commercial buildings focused on demand control strategies such as demand limiting, thermal storage and daylighting [2]. CADDET's review of fifteen case studies from five countries showed significant savings with two basic strategies: duty cycling and demand limiting [3]. In the 1990s, research on Real-Time Pricing

(RTP) explored the feasibility of automation of DR load shedding by sending the utility signal over the telephone lines and connecting this signal to the control system were tested [4].

DEMAND RESPONSE

Reliable supply of affordable electricity has been in the spotlight since the blackouts in California, the grid shutdown events in New England and the terrorist threats nationwide. While the array of generation technologies and transmission safety issues have been widely discussed, capacity requirements and demand side management issues have also been revisited. Utilities develop DR programs to provide a variety of choices to the customers to manage their utility bills while assisting the utilities to manage their capacity. DR programs are managed by electric utilities and independent systems operators (ISO). ISOs provide open access to the electric grid while coordinating the daily operation and ensuring electric system reliability. More than 70 utilities distributed over the United States offer real-time pricing (RTP) programs with 75% of these states being on the eastern half of the country. The ISOs in New York, New England and the Pennsylvania, New Jersey and Maryland Region (PJM) as well as utilities in Baltimore and Georgia lead the RTP program design and implementation in the nation [5].

There are two basic types of demand response programs: price response and reliability. This distinction is related to market design and pricing, and there is a continuum of DR triggers to obtain demand response. These triggers can be price or system reliability. Both DR programs have shared goals of improving system reliability and improving the feedback between supply and demand. DR programs differ from historical load management programs to reduce peak demand because they are dynamic dispatchable programs. Although there are various designs for price responsive programs nationwide, the underlying goal of these programs are to modify participants' electricity consumption patterns by providing a fluctuating market price. End users modify their electricity use when the price is high. New critical peak and real-time pricing programs are examples of price-response DR programs emerging around the US that target commercial buildings [6][7]. The goal of price response is peak load reduction. However, the "success" to an end-use customer is measured by utility bill savings based on the development and execution of a demand response strategy.

Reliability (load) responsive programs are driven by the desire to address peak capacity shortage and grid reliability. These programs are typically dispatched by utilities or grid operators to avoid exceeding grid capacity. End-use customers participate in the program by reducing load upon request, and receive a financial incentive based on how much electric load (kW) is reduced.

VALUE OF DEMAND RESPONSE

There are numerous complex value streams associated with DR, as summarized in Table 2. In price response programs customers are typically introduced to higher on-peak prices 50-100 hours per year. The tradeoff for facility engineers is to understand their electric load shape, and the costs and benefits of modifying end-use services to obtain bill savings. In terms of reliability benefits, the marginal savings of an extra kW include not only the on-peak price but also the expected value of potential outage cost therefore revealing large benefits to the customer and society. As a result, the value of DR depends on complex interactions of many factors such as generation capacity, transmission, end-use intensity, weather, programs and tariffs as well as financial program incentives.

Benefits of DR[8]
Reliability of the System: Poor power quality and power interruptions are estimated to cost $100 billion to the nation every year [3]. DR enhances electric system reliability
Reduction of Costs: DR implementation can lower costs for generation, transmission and distribution charges and help reduce wholesale market prices
Efficient Markets: It is estimated that a 10% reduction in electricity demand in California may reduce wholesale price spikes 50% [4]. When customers change their electricity usage behavior and reduce or shift on-peak usage and costs to off-peak periods, it results in more efficient use of the electric system.
Risk Management: Prices in wholesale markets vary from day to day, and hour to hour. DR reduces suppliers' and customers' risk in the market. DR can especially help manage risks by being available, reliable, modular and dispatchable.
Environmental Impact: Demand response can help reduce environmental burdens placed on the air, land and water by reducing or delaying new power plant developments and by allowing the use of the current generation capacity more effectively. These benefits are highly regional and can be large in some areas and negligible in others.
Customer Service: DR helps customers understand and better manage their loads and reduce electricity bills.
Market Power Mitigation: DR programs help relieve market power of traditional and new energy suppliers especially, when there are tight supplies and/or transmission constraints that might lead to market power

Table 2. Benefits of demand response

The benefit of participation in DR programs can be significant for electric power system reliability and price of electricity [9]. In the New York Independent System Operator (NYISO) 2002 Emergency Demand Response Program, the 670 MW of load curtailment in a 31-GW power system provided system reliability benefits estimated at $1.7 to $17 million [10].

Advanced and enabling technologies that automate load management strategies for energy efficiency are expected to reduce the cost for implementing DR strategies and result in higher customer participation.

ADVANCED CONTROLS FOR DEMAND RESPONSE AND ENERGY EFFICIENCY

This research explores the premise that advanced controls for DR and energy efficiency reduce the cost of implementing DR, thus allow greater levels of electric load shedding capability in the commercial sector. Improved controls also often provide improved system monitoring and enhanced feedback to building operators to aid in decision making. Figure 2 shows the link between DR and energy efficiency from a building operator's point of view. A building operator requires energy efficient equipment, commissioning, fault detection, controls and feedback to run a building efficiently. Implementing DR requires the existence of controls and feedback mechanisms.

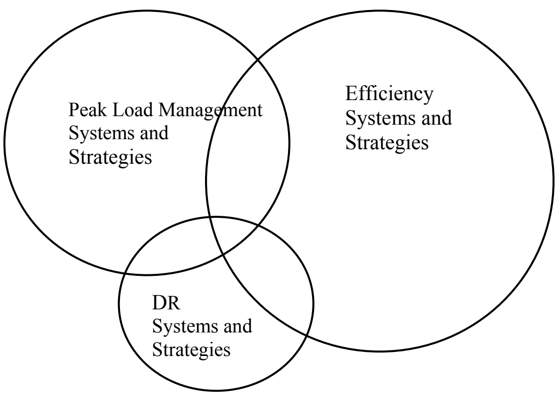

Figure 1. Linking DSM concepts

The key definitions for this work are as follows: **Energy efficiency** is lower energy use to provide the same level of service. **Demand limiting** refers to shedding loads when pre-determined peak demand limits are about to be exceeded. This is historically done in daily load management activities to minimize peak demand charges [3]. Loads are restored when the building demand is sufficiently reduced. Demand limiting is done to flatten the load shape when the electric load shape is nearing a pre-determined peak. **Demand shifting** moves electric loads from peak times to off-peak periods. The most common technologies to support diurnal demand shifting are thermal energy storage systems, which are often designed with ice or chilled water. We define **demand shedding** as dynamic temporary reduction of peak load that can be dispatched manually or with automated controls. Figure 3 demonstrates general features of the building electric load shape for these strategies for an office-type building.

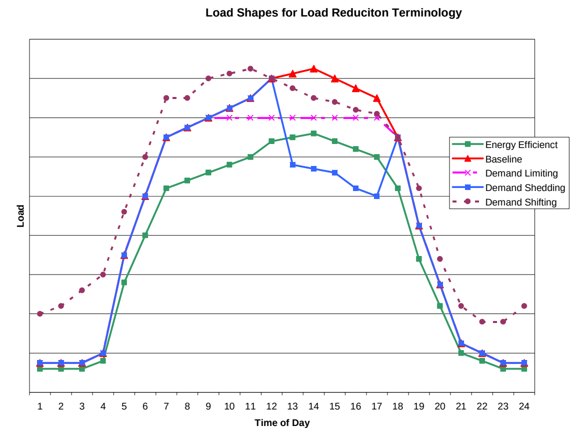

Figure 2. Examples of load shapes for various load reduction terminology

Recent research in California has shown that technology needed for demand shedding is a subset of technology currently being used in buildings for energy efficiency measures and can be directly utilized [11]. New research is needed to achieve broader scale deployment of such techniques. Expanded use for existing technology has a small impact on cost. However, depending on the DR program economics, it may have a major impact on utility bill savings. Similarly, the benefits of DR become apparent when two alternatives such as loss of electricity for a long period of time is compared with limited services and amenities for a short period of time. For example, in New York and California, blackouts caused billions of dollars of losses to businesses and individuals.

DEMAND RESPONSE BUILDINGS RESEARCH

Recent research has explored DR strategies at the building level to reduce peak demand during a limited DR event. Levels of automation in DR can be defined as follows. **Manual Demand Response** involves a labor-intensive approach such as turning off unwanted lights or equipment. **Semi-Automated Response** involves the use of controls for load shedding, with a person initiating a pre-programmed load shedding strategy. **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.

In 2004, the Demand Response Research Center (DRRC) conducted fully automated demand shedding projects in 18 sites in California, Wisconsin, and Canada demonstrating over 4 MW of DR capability in a series of tests [12]. During the process to develop operations strategies to reduce peak loads, facility managers carefully review control systems operations. This process leads to gaining more understanding about electric load shapes and the relation between operational set points and electric loads. Proactive building operators use this understanding to gain further understanding between control schedules, sequences, and set points and both peak and total energy use patterns [13].

There is increased awareness of the need to implement multiple modes of operations in buildings. Not only building control systems have limitations that vary yearly with seasons and daily with occupancy, but also the facilities are starting to prepare for electric grid overloading as well as disaster and emergency situations. In addition, with the approaching timeline for DOE's Zero Energy buildings concepts, there is even more urgency to define and develop multiple modes for operational states [14].

Lawrence Berkeley National Laboratory researchers work with The New York Times to integrate the daylighting, shading and electrical lighting systems at the new headquarter facility in Manhattan. This building is equipped with advanced building systems and controls in order to reduce energy consumption and capitalize on the building's unique features. The installed power density of lights in this facility is 1.3 W/ft^2. However, due to extensive daylight in the space, with its proper integration with dimmable ballasts and shading devices, the actual consumption is expected to be about 1 W/ft^2. DR strategies for the ambient lighting system:

1. 30% relative dimming: The lighting control system is set up to send global commands. It registers the current value of dimming and lowers light levels by 30%.
2. Power shaving to 30%: at 10% light output, the ambient lighting system consumes about 30% of power. A global command can be set to lower all the lights that are on to their 10% light output value.
3. All ambient lights off: This strategy will be implemented in case of emergency. The occupants will have access to 9W light emitting diode (LED) task lights.

DR Strategy	Expected Δ W/ft^2
30% Relative dimming	0.2
Dimming down to 10% light output	0.5
All ambient lights off	0.9

Table 3. DR strategies for the ambient lighting system with expected power consumption

The advanced lighting control system allows for global command set up thus, the cost of implementing these strategies is expected to be insignificant.

DEMAND RESPONSE AND ENERGY EFICIENCY ENABLING TECHNOLOGIES

Energy efficiency programs offered by utilities promote the installation of efficient equipment. In California, four investor-owned utilities created the Express Efficiency program where cash rebates are available for energy efficient lighting, refrigeration and HVAC equipment. However, efficient equipment provides energy savings only if the systems are properly installed, operated and maintained. New technologies and practices to provide energy efficiency include, commissioning, fault detection, advanced controls and feedback to operators. In building operations, the overlap between DR and energy efficiency in a building occurs at the energy management and control systems (EMCS) level (see Figure 2). EMCS provides customers with the ability to centrally monitor, analyze, and control their facilities' building systems and equipment to achieve energy-efficient operation.
According to the 2003 Commercial Buildings Energy Consumption Survey, 7% of commercial buildings, making up 31% ft^2 nationwide, have EMCS (figures 3a and 3b). Seventy percent of all the commercial buildings with EMCS have 50,000 ft^2 or more floor space. Similarly, office buildings and educational facilities show the highest use of EMCS [15]. Day-to-day energy savings potential of EMCS is estimated to be 10-20% [16]. EMCS also provide ample opportunities for peak load reduction with their monitoring, control and feedback features.

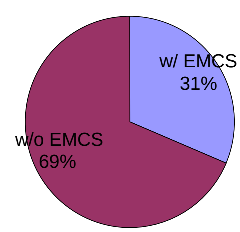

Figure 3a. Square footage ratio of buildings with and without EMCS

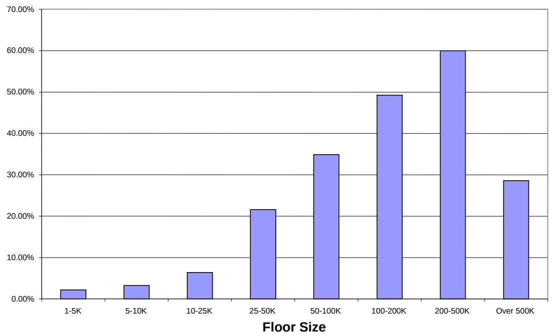

Figure 3b. Percent buildings with EMCS categorized by floor size

CHARACTERIZATION OF EMCS

We provide a simple characterization of EMCS functionality in existing commercial. The buildings in the inventory are categorized as “advanced”, “common” and “basic” buildings. “Advanced” buildings refer to newer or larger buildings with sophisticated EMCS. “Common” buildings refer to the average size and age buildings with standard EMCS. “Basic” buildings are older and tend to be smaller in floor space with limited or dated EMCS capabilities.

“Advanced” buildings typically use Direct Digital Controls (DDC). DDC contains networked microprocessor-based controllers, which are connected to sensors and actuators. DDC is the most common EMCS technology currently being installed. These systems are scalable, and employ precise sensors and accurate controls. DDC is easily integrated or bundled with other building systems with user-friendly interfaces and provide ease of monitoring, maintenance and controls, which as a result reduce maintenance and calibration costs. EMCS built upon DDCs establish the potential for real-time monitoring of all sensor, control, and data points from a central location. The data can be logged, trended, used for fault detection and as feedback to refine system operation and energy usage. EMCS and DDC implementation enables sophisticated control strategies to maximize operational efficiency and remote connection via Internet. In addition, EMCS functions for DDC type controls include DR strategy implementation and data analysis tools for energy accounting, making “advanced” buildings the ideal target for DR.

“Common” buildings utilize either pneumatic or electrical control infrastructures. Pneumatic systems employ an air compressor that supplies pressurized air through a system of distribution lines to sensors and devices like thermostats, valves, dampers, and actuators to control operations. Pneumatic systems are reliable and the least expensive. Electric control systems are comprised of electric system controllers, sensors, thermostats, switches, relays, and actuators connected by electrical wiring. However, both systems require preventive maintenance and are hard to modify and expand. EMCS in “common” buildings have limited capabilities. These monitor only selected sensors, collect limited trend records and provide rudimentary, and provide preset strategies such as economizers, variable speed drives (VSDs), and night ventilation, and do not typically include energy use data.

Control Systems			
Controls	**Basic**	**Common**	**Advanced**
Type	Pneumatic / Analog	Pneumatic / Analog	DDC
EMCS			
Alarms	●	●	●
Remote Access	○	●	●
Operation Information	○	●	●
Trend logs	○	○	●
Energy Use Info	○	○	●
Real-time monitoring	○	○	●
Internet Connection	○	○	●
Control Capability	Preprogrammed with fixed parameters	Rudimentary with capability to implement Economizer, VSD, night ventilation, etc.	Sophisticated control algorithms
Installation Costs [17] Average ($/ ft^2)	$ 1.75	$ 3.00	$ 4.00

Table 4. EMCS characterization

“Basic” buildings utilize pneumatic or electrical controls with limited EMCS capability. The EMCS in “basic” building types monitor pre-selected data points and display limited alarms, trends or sometimes energy use data. The control algorithms are based on fixed parameters and modifications to control strategies are hard to implement.

The cost of the EMCS depends on the type of building systems and implementation of the associated controls. As the systems diverge from the standard, their costs increase. Simpler systems, with no or little customization options that simply run the building without collecting information for analysis, are least expensive. Innovative systems that require more sophisticated implementation are more expensive but the additional features allow for more effective and efficient use of the buildings. Therefore, the additional cost of the more advanced EMCS may be justified by reduction in utility bills due to timely fault detection and maintenance, DR savings and labor costs.

CONTROLS FOR DEMAND RESPONSE

The success of control strategies for DR depends on three factors: frequency, duration, and depth. Most demand response operates 50 to 100 hours per year, so they do not occur frequently. If they occur more often, the DR strategies can be problematic for the occupants and tenants. In California, critical peak pricing programs are called 10-15 days a year with 4-6 hours each day. Longer shed periods, with over 6 hours of duration, can also be a problem. HVAC loads can often not be shed for such a long period. Depending on the type of program a building is enrolled in, DR days may be dispatched due to the local weather patterns or electric grid conditions.

According to the California Energy Commission's Demand Analysis Office findings, commercial and residential air conditioning and commercial lighting contribute 40% of peak load [18]. Similar cooling end-use loads drive peak demand in much of the U.S. Therefore, DR strategies often target HVAC and lighting equipment (Figures 4a and 4b). The choice of DR and energy efficiency strategy is limited by the type of equipment and type of controls in a building. Figures 4a and 4b illustrate types of controls depending on the type of building system equipment and sort it by the intended uses. Strategies written in bold letters require central controls or EMCS either for timely or less labor-intensive implementation. For example, daylighting with photocell-based controls can be achieved with local closed-loop controls. This implementation does not allow control over the dimmable ballast and prevents them from being used for DR. The marginal cost of an addition of a central dimming feature to an already dimmable lighting controls system can be justified by the extended benefits of DR implementation. However, the current cost of centrally controllable dimmable ballasts, such as DALI or Zigbee[19], prohibit their wide adoption leaving the deployment of disruptive switching options for lights as the only option for DR.

Some DR strategies may reduce peak demand, but cause minor increases in energy use [20]. Depending on the pricing structure, these strategies may result in utility bill savings. Examples of these strategies are those that shift thermal loads using active thermal storage or passive building mass storage. Thermal storage can be used for daily peak load management or dispatchable, event driven DR.

Figures 4a and 4b show the relation between energy efficiency and DR. On the right is a list of control strategies for energy efficient daily operations. Some features of these control strategies simultaneously support DR. On the left is a list of DR strategies. Some features of these DR strategies support energy efficient daily operations. Controls in bold indicate the use of an EMCS system. It is important to notice that while there are specific controls for HVAC and lighting that just work for energy efficiency or DR, there are some overlapping controls that cater to both goals. For example, equipment lockout, pre-cooling, thermal energy storage, cooling load reduction and direct fan, pump or chiller quantity reductions provide DR capability. Duct static pressure reduction and global set point adjustments are the only recommended controls that are able to fulfill the goals of both DR and energy efficiency.

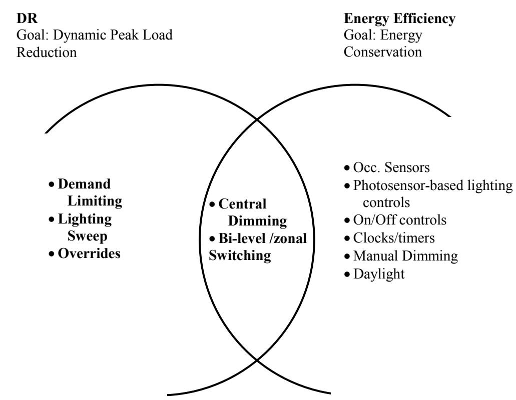

Figure 4a. Lighting controls

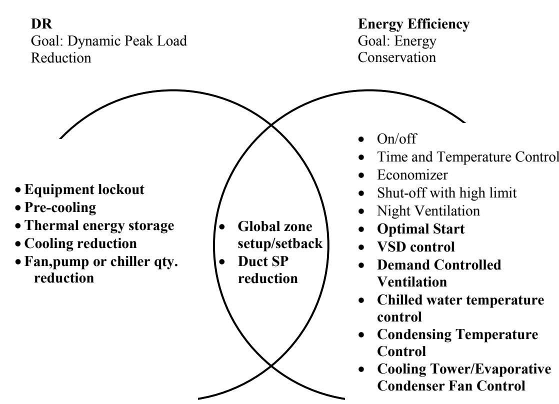

Figure 4b. HVAC controls

For HVAC systems, the DRRC generated a flow diagram to guide building operators with their decision making process. Table 5 summarizes and maps the DR strategies on relative HVAC and lighting systems.

System	Strategy
HVAC	
Global Zone control with EMCS Zones (VAV)	Global set point relaxation
EMCS (DDC) Zones (VAV)	Set point relaxation at zones Reduce fan speed or volume Reduce duct pressure set point
Any equipment with EMCS	Depending on equipment
Roof Top Units without EMCS	Quantity reduction
Constant Volume, Pneumatic	Reduce cooling
Lighting	
Zoned lighting with dimmable ballasts and central control	Dimming
Zoned lighting with small zones and central control	Switching perimeter zones or bi-level switching
Zoned lighting with local control	Panel based switching
Local switches in workplaces	Panel based switching

Table 5. DR strategies for various lighting and HVAC systems

Global set point "relaxation" is the ideal DR strategy for HVAC systems. Global set point "relaxation" is a term used for increasing the cooling set point and decreasing the heating set point therefore relaxing the lower and upper limits of the set point dead band. The acceptability of set point "relaxation" strategy depends on how much, how fast, how often it is executed and other occupant related issues such as their layers of clothing, information provided to them, etc. Figure 5 displays the demand shedding effect of global set point adjustment in one of the Automated DR test sites in California. This large federal office (about 1 million ft) reduced the whole building power by an average of 811 kW during this three-hour test by raising the zone temperature set point from 72 to 78 F. Figure 5 shows whole building power for the shed (the lower curve) and the whole-building baseline power predicted if the shed had not occurred. The vertical line at each baseline power data point is the standard error of the regression estimate. The baseline load reached 3700 kW, and the demand shed is show in the lower curve from 1pm to 4pm. There were no thermal comfort complaints at this test site.

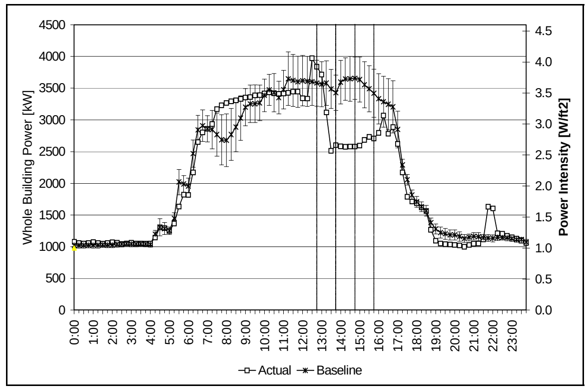

Figure 5. The demand shedding effect of global set point adjustment

ASHRAE Standard 55-2004, Paragraph 5.2.5.2 on Drifts or Ramps (Table 5) recommends that the maximum change in operative temperature allowed during a period of time is the most restrictive of the following:

Change in Temperature		
C	**F**	**Time Period**
+/- 1.1	2.0	15 minutes
+/- 1.7	3.0	30 minutes
+/- 2.2	4.0	1 hour
+/- 2.8	5.0	2 hours
+/- 3.3	6.0	4 hours

Table 6. Maximum change in operative temperature

Many facilities avoid using their lighting system for peak load reduction. Switching is an intrusive and disruptive option because it creates an unwarranted change in the visual environment. Dimming with its continuous energy saving potential with photocell controls and less intrusive qualities is the best option. The ideal dimming strategy is 30% dimming of the instantaneous light levels over 10 seconds [21]. In order to truly reduce peak load, instead of lowering all lights to 70% (when some of them already may be operating at 60%) lights must be dimmed by 30% of their "current" value. The dimming characteristics of the ballast should be known because for example in DALI systems, a 30% reduction in dimming steps does not result in 30% light output reduction since 1-100% dimming corresponds to dimming levels between 155 and 255. Therefore, reducing the dimming level from 255 to 180 (30%) will result in 80% light output reduction in systems where DALI ballasts are utilized.

Table 7 summarizes the building systems and associated equipment control strategy types in 18 buildings whose load shedding operations were fully automated by DRRC in 2003 and 2004. Four tests conducted in these sites reveal an average peak load reduction of 0.3 W/ft^2 with maximum average reduction of 0.4 W/ft^2.

Date	**Total number of sites**	**Average W/ft^2**	**Max W/ft^2**
September 8	5	0.67	0.97
September 21	5	0.22	0.29
October 13	8	0.07	0.13
November 5	14	0.14	0.20

Table 7. Summary of power density reduction from 2004 automated DR sites

Considering the first test day (Sept. 8th) was hot and the other three were milder days, these numbers imply significant potential for peak load reduction. Moreover, through the peak load reduction exercise, some sites realized that temporary global set point adjustment and even reduction in illuminance was tolerable to their occupants. In one case, the duct static pressure in a facility was realized to be too high and was reduced yielding long-term energy savings for the facility. In another case, the energy information system installed for DR evaluation was used for daily efficiency measures [12]. The experiments with DR strategies allow the building operators to learn more about the capabilities of their buildings and to push the limits of guidelines designed over decades ago with older technologies in mind. This experimentation is possible only by advanced control systems that provide the necessary information to evaluate their effectiveness.

CONCLUSION

The goal of this research is to develop a framework describing how advanced controls can support multiple modes of operations including both energy efficiency and DR. This paper describes how advanced controls provide a link between DR and energy efficiency in buildings. Advanced controls for DR and energy efficiency reduce the cost of implementing DR, thus improving demand shedding potential. EMCS provide feedback to building operators by logging and trending data to be used in decision-making and allow for various modes of operations in buildings to enable integration of new technologies. In addition, this paper examined HVAC and lighting controls that link DR and energy efficiency. Case studies around the country indicate that there are important synergies between dynamic peak load reduction technologies and new energy efficiency equipment and advanced EMCS.

ACKNOWLEMENTS

The authors thank David Hansen at the US DOE for his support and interest in this research. Research funding was also provided through the Demand Response Research Center (drrc.lbl.gov) and funded by the California Energy Commission, Public Interest Energy Research Program, under Work for Others Contract No.150-99-003, Am #1 and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

REFERENCES

[1] M.A. Piette, O. Sezgen, D. S. Watson, N. Motegi, C. Shockman, “Development and Evaluation of Fully Automated Demand Response in Large Facilities” Prepared For California Energy Commission, Public Interest Energy Research (PIER) Program, March 30, 2004. LBNL-55085

[2] M.A. Meal, M.A. Piette, B. Gardiner, “Evaluating the measured results of Demand Control Strategies in new and retrofitted commercial buildings”, 1985 ASHRAE Transactions, Vol. 91 Pt. 2, LBL Report No. LBNL-24852.

[3] M.A. Piette, “Learning from Experiences with Controls to reduce Electrical Peak Demands in Commercial Buildings” Center for Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), IEA/OECD Analyses Series No. 7. August 1991.

[4] S. Gabel for EPRI, “Development and Demonstration of Energy Management Control Strategies for Automated Real-Time Pricing”, Technical Report, December 1997.

[5] G. Barbose, C. Goldman, and B. Neenan, "A Survey of Utility Experience with Real Time Pricing" (December 1, 2004). LBNL-54238.

[6] G. Barbose, C. Goldman, R. Bharvirkar, N. Hopper, M. Ting, B. Neenan “Real Time Pricing as a Default or Optional Service for C&I Customers: A Comparative Analysis of Eight Case Studies” LBNL-57661

[7] Quantum Consulting, Inc. “Working Group 2 Demand Response Program Evaluation – Program Year 2004”

http://www.energy.ca.gov/demandresponse/documents/index.html#group2

[8] The Peak Load Management Alliance, "Principles of Regulatory Guidance" February 2002.

[9] M.R Brambley, D Hansen, P Haves DR Holmberg, SC McDonald, KW Roth, P Torcellini. "Advanced Sensors and Controls for Building Applications: Market Assessment and Potential R&D Pathways" January 2005.

[10] B. Neenan, D. Pratt, P. Cappers, J. Doane, J. Anderson, R. Boisvert, C. Goldman, O. Sezgen, G. Barbose, R. Bharvirkar, M. Kintner-Meyer, S. Shankle, and D. Bates. *How and Why Customers Respond to Electricity Price Variability: A Study of NYISO and NYSERDA 2002 PRL Program Performance.* PNNL-14220./LBNL-52209.

[11] M.A. Piette., D.S. Watson, N. Motegi, N. Bourassa "Findings from the 2004 Fully Automated Demand Response Tests in Large Facilities". LBNL-58178.

[12] California Energy Commission, Enhance Automation Case Study No. 2, www.consumerenergycenter.org/enhancedautomation.

[13] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Building Technologies Program, Building America Website, http://www.eere.energy.gov/buildings/building_america/about.html#zeh.

[14] S. Katipamula, S. Gaines "Characterization of Building Controls and Energy Efficiency Options Using Commercial Building Energy Consumption Survey" prepared for the Iowa Energy Center, Iowa State University, February 2003, p.24.

[15] S. Katipamula, S. Gaines "Characterization of Building Controls and Energy Efficiency Options Using Commercial Building Energy Consumption Survey" prepared for the Iowa Energy Center, Iowa State University, February 2003, p.52.

[17] California Energy Commission, "Enhanced Automation Technical Options Guidebook", www.consumerenergycenter.org/enhancedautomation, p.28.

[18] S. Bender, "Energy Efficiency and Conservation: Trends and Issues" Energy Policy Report Proceeding Docket 02-IEP-01, June 2003.

[19] F. Runbinstein. "After DALI: A look at what is next" Architectural Lighting, January 2005 http://www.archlighting.com/architecturallighting/al/details/article_display.jsp?vnu_content_id=1000808292

[20] P. Xu, P. Haves and M.A. Piette, J. Braun "Peak Demand Reduction from Pre-Cooling with Zone Temperature Reset in an Office Building" *Proceedings from the ACEEE 2004 Summer Study on Energy Efficiency in Buildings,* August 22-27, 2004, Asilomar, Pacific Grove, CA. LBNL 55800.

[21] Lighting Research Center study presented at the CEC PIER Lighting Research Review and CEC's Load Shedding technologies meeting at PEC, 2004.