Presented at *Second Carnegie Mellon Conference in Electric Power Systems:* Monitoring, Sensing, Software and Its Valuation for the Changing Electric Power Industry, January 12, 2006, Pittsburgh PA.
LBNL-59337

Advanced Controls and Communications for Demand Response and Energy Efficiency in Commercial Buildings

Sila Kiliccote, Mary Ann Piette
Lawrence Berkeley National Laboratory

David Hansen
U.S. Department of Energy

ABSTRACT

Commercial buildings account for a large portion of summer peak demand. Research results show that there is significant potential to reduce peak demand in commercial buildings through advanced control technologies and strategies. However, a better understanding of commercial building's contribution to peak demand and the use of energy management and control systems is required to develop this demand response resource to its full potential.

This paper discusses recent research results and new opportunities for advanced building control systems to provide demand response (DR) to improve electricity markets and reduce electric grid problems. The main focus of this paper is the role of new and existing control systems for HVAC and lighting in commercial buildings. A demand-side management framework from building operations perspective with three main features: daily energy efficiency, daily peak load management and event driven, dynamic demand response is presented. A general description of DR, its benefits, and nationwide potential in commercial buildings is outlined. Case studies involving energy management and control systems and DR savings opportunities are presented. The paper also describes results from three years of research in California to automate DR in buildings. Case study results and research on advanced buildings systems in New York are also presented.

1. INTRODUCTION

The blackouts in California and the northeast and terrorist threats nationwide caused new concerns about reliable supplies of affordable energy. In New York and California, blackouts caused billions of dollars of losses to businesses and individuals [1] [2]. While reliable power is an important goal, economic factors and market issues are key constraints in electricity systems. Recent improvements in developing and demonstrating demand response (DR) in electricity markets address these challenges. Two primary goals of demand response are to ensure electric supply reliability and improve price response to allow end-use consumers to see and respond to dynamic electricity prices. Demand side action is required to reduce load when contingencies such as emergencies and congestion occur that threaten system reliability and/or when market conditions raise supply costs. A Federal Energy Regulatory Commission (FERC)-commissioned study reported that a moderate amount of demand response could save about $7.5 billion annually by 2010 [3]. The New York Independent System Operator (NYISO) 2002 Emergency Demand Response Program provided 670 MW of load curtailment in a 31-GW power system with reliability benefits estimated at $1.7 to $16.9 million [4].

Advanced building controls in commercial buildings provide an excellent demand response resource for future electricity DR programs. Recent research activities include whole-building simulations of DR operating strategies in a new advanced office building in New York, and full automation of DR in over 20 buildings in California. This paper summarizes the integration of DR in demand-side management activities linking it closely to energy efficiency and peak load management. This approach requires the development of new commercial building control strategies and algorithms, which consider both energy efficiency and demand reduction. Decisions need to be made based on the relative value(s) of both issues, in the context of the business housed in the building and the specific utility providing the electricity. The DR potential of commercial buildings is discussed. The paper offers a snapshot of DR activities around the US and a description of commercial sector DR case studies.

2. COMMERCIAL BUILDINGS' CONTRIBUTION TO PEAK DEMAND

Understanding the magnitude and distribution of peak demand in the U.S. is crucial to developing goals and strategies to reduce it. One obstacle to assessing the opportunity for commercial buildings peak load reductions is that there is limited information on the contribution of commercial buildings to electric system peak loads. Two national sources of peak load data are the Energy Information Administration's (EIA) Commercial Buildings Energy Consumption Survey (CBECS) and National Energy Modeling System (NEMS). CBECS is a national survey of energy-related building characteristics, and energy consumption, and expenditures data for commercial buildings. In CBECS, commercial refers to any building that is neither residential (used as a dwelling for one or more households), manufacturing/industrial (used for processing or procurement of goods, merchandise raw materials or food), nor agricultural (used for the production, processing, sale, storage, or housing of agricultural products, including livestock). At least 50 percent of the floor space must be used for purposes other than these for a building to be considered "commercial." The 1995 CBECS data included a unique survey of electric peak demand data. Median peak demand intensity in the entire commercial sector was 5.4 W/ft^2, with office buildings at 6 W/ft^2. Two-thirds of the buildings were summer peaking.

The second source of electric peak demand data, NEMS, is the primary midterm forecasting tool of the EIA. NEMS consists of a group of simulation modules that represent all major energy supply, demand, and conversion sectors of the U.S. economy, as well as general domestic macroeconomic conditions and world oil markets. The commercial sector in the Commercial Demand Module (CDM) of NEMS considers business establishments that are not engaged in industrial or transportation activities as commercial building. Its floor space module uses the CBECS floor space as its base with future year floor space forecasted with new construction trends. Lawrence Berkeley National Laboratory (LBNL) researchers extracted three years of peak demand data (1999, 2003 and 2005) in all sectors within the thirteen regions in the United States from one run that represents the AEO2005 Reference Case.

Table 1 summarizes the comparison of estimates of the maximum summer national peak electric demand from CBECS and NEMS for 1995 and 2003. The CBECS data (http://www.eia.doe.gov/emeu/cbecs/public_use.html) have been extrapolated to total coincident demand in two ways: 1) assuming a normal distribution of peak demand power density over the floor space and 2) using the median peak demand density and multiplying it with corresponding floor space associated with the same year.

	1995 (GW)	2003 (GW)
CBECS Estimation 1	273	333
CBECS Estimation 2	317	387
NEMS Coincident Peak	291	328
NEMS Non-coincident Peak	317	349

Table 1: Comparison of CBECS and NEMS based estimates of commercial sector electric peak demand.

According to the 2003 NEMS data extracted from AEO2005 reference case, while the ratio of commercial building total load to U.S. total load is 35%, commercial buildings account for 45% on average of summer electric peak coincident demand [5]. Twelve of the 13 NEMS regions are summer peaking, the exception being Region 11 that covers the Pacific Northwest.

The CBECS and NEMS data suggest that the maximum electric peak demand from the commercial sector is about 330 GW nationwide. Further research is needed to refine this estimate. There are significant discrepancies between regional results from NEMS and state data. The California Energy Commission's (CEC) forecasting model for peak load data for 2003 estimates commercial building's peak load to be around 19 GW [6]. The NEMS 2005 data suggests that the coincident peak in California is greater at 30GW. It is important to note that NEMS CNU region is not exactly comparable to California because it excludes some Sierra and North California areas.

In summary, commercial buildings account for a large portion of summer peak demand, and are perhaps the largest end-use sector. Research results on automated DR further described below show that there is significant potential to reduce peak demands in commercial buildings, offering an important future resource for DR. A better understanding of building sensors and controls are needed to use this new resource.

3. DEMAND RESPONSE IN COMMERCIAL BUILDINGS

Electricity demand varies constantly. At times of low demand, only the lowest marginal cost plants operate, while at peak times, almost all of available power plants run to meet demand. Electricity providers and their customers are concerned with peak demand because of the financial and environmental challenges of providing growing electric system capacity. The value of DR is summarized by the Peak Load Management Alliance (http://www.peaklma.com/) [7] as having impact on the reliability of the electricity system; reducing costs associated with generation, transmission and distribution; creating efficient markets; reducing supplier's and customer's risk in the market; and reducing environmental impact by reducing or delaying new power plant developments.

The demand-side management (DSM) framework presented in Table 2 provides three major areas for changing electric loads in buildings: energy efficiency (for steady state load optimization); peak load management (for daily operations); and demand response (DR) (for event driven dynamic peak load reduction). In this paper, we present the DSM framework from a buildings perspective concentrating on EMCS based options. In this paper, load and demand are used interchangeably.

	Demand Side Management		
	Efficiency and Conservation (Daily)	*Peak Load Management (Daily)*	*Demand Response (Dynamic Event Driven)*
Motivation	- Conservation - Environmental Protection	- TOU Savings - 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 - Demand Limiting

Table 2. Energy efficiency, daily load management and DR

- *Energy Efficiency:* Energy efficiency can lower energy use to provide the same level of service. Driven by conservation, environmental protection and utility bill savings, energy efficiency measures permanently reduce peak load by reducing overall consumption. In buildings this is typically done by installing energy efficient equipment and operating buildings efficiently.
- *Daily Peak Load Management:* The advance of metering technology made it possible to differentiate electricity usage patterns of buildings. Peak load management is motivated by high charges for 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. 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 shifting the loads from peak times to off-peak periods. Figure 1 displays the typical demand profile of a commercial building employing these methods.
- *Demand Response:* Demand response refers to the modification of customer electricity usage at times of peak usage in order to help address system reliability, reflect market conditions and pricing, and support infrastructure optimization or deferral. 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. DR methods such as demand limiting and shifting can be utilized when the economics and reliability issues are predicted and communicated to each site in advance. *Demand shedding* is dynamic temporary reduction, or curtailment of peak load when dispatched and refers to strategies that can be possibly implemented within a shorter period of response time.

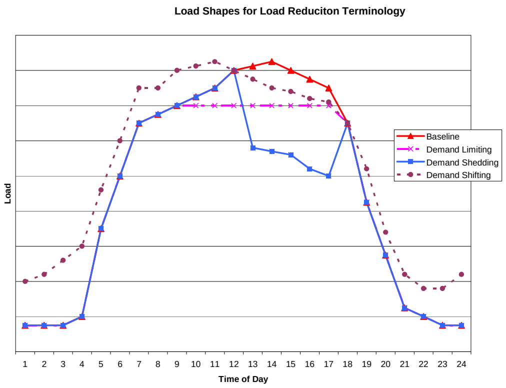

Figure 1: Demand profile of various demand response methods.

Nearly half of all U.S. states are implementing or piloting technology for load management. Load Management is defined by the EIA as any activity other than Direct Load Control and Interruptible Load that limits or shifts peak load from on-peak to off-peak time periods. It includes technologies that primarily shift all or part of a load from one time-of-day to another and secondarily may have an impact on energy consumption. Examples of systems loads subject to load management include space heating and water heating storage systems, cool storage systems, and load limiting devices in energy management systems.

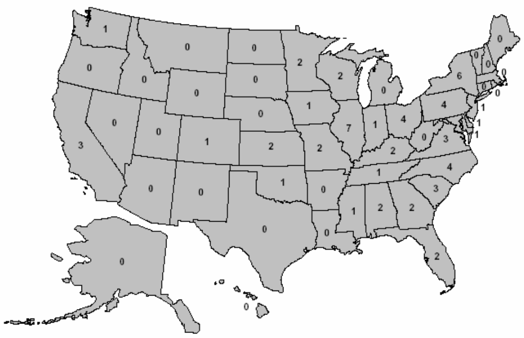

Figure 2. Number of utilities in each state offering a voluntary RTP tariff in 2003 [8]

Daily peak load management category (i.e., limiting and shifting) also includes programs that aggressively promote time-of-use (TOU) rates and other innovative rates such as real time pricing. These rates are intended to reduce consumer bills and shift hours of operation of equipment from on-peak to off-peak periods through the application of time-differentiated rates. Figure 2 shows number of utilities in each state offering a voluntary RTP tariff in 2003. Shorter response times and greater understanding of peak load is required to be truly responsive to any real-time price or reliability related concerns. LBNL's DR research has been concentrating on controls and communications infrastructures to achieve DR.

4. ADVANCED CONTROLS FOR DEMAND RESPONSE*:*

Understanding DR potential in commercial buildings requires examining existing control systems. Energy Management and Control Systems (EMCS) in commercial buildings facilitate heating ventilation and air conditioning in buildings (HVAC). Some EMCS provide lighting, plus fire, life, and safety control. According to the 2003 CBECS, 7% of commercial buildings, making up 31% of the national floor space, 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 [9]. Day-to-day energy savings potential of EMCS is estimated to be 10-20% [10]. EMCS used for DR automation has the potential to reduce peak load by additional 10-15 % as further discussed below.

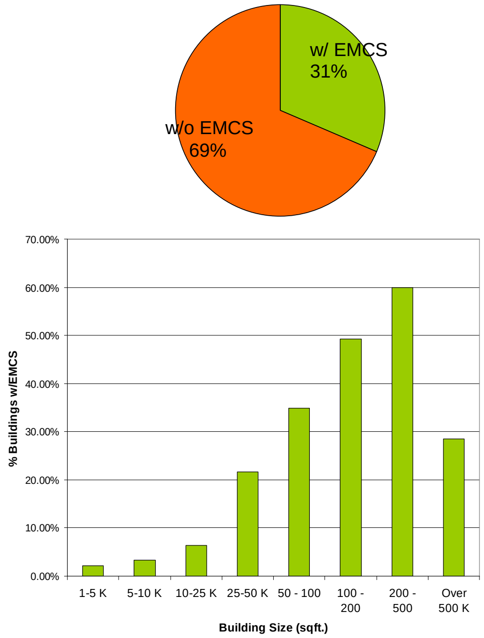

Figure 3a and 3b: Distribution of commercial building floor area with EMCS in the U.S.

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

Table 3. Characterization of EMCS in commercial buildings in the U.S.

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.

“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.

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 DR, with a person initiating a pre-programmed DR strategy.
- *Fully-Automated Demand Response* does not involve human intervention, but is initiated at a

facility through receipt of an external communications signal.

EMCS in commercial buildings can be utilized in two ways to ensure DR participation: automating DR events and corresponding DR control strategies; and integrating new technologies and intelligently processing energy related data to optimize electricity use. In this section, both of these ideas are going to be discussed. Past and current research related to DR automation will be discussed with in the DR in California section. EMCS integration and use for DR will be discussed in detail within the context of the New York Times project in New York.

Currently, advanced building controls allow the programming of several modes of operations such as occupied, unoccupied, maintenance, cleaning, night purge, warm up and cool down. These modes are triggered typically by daily or weekly schedules. New technologies and systems: including DR, on-site, and distributed generation, need to be integrated as a mode of operation within the EMCS. Future buildings will need dynamic control modes triggered not only by a schedule but by information provided to and processed by the EMCS. A master controls concept, where price and reliability information is processed whether the building is on the grid or off the grid, could examine daily operating scenarios between multiple operational criteria. Such criteria might include weather, scheduled building services (occupancy levels), cost minimization, indoor environment quality, and availability of on-site generation or renewable energy sources.

An investment in EMCS to enhance DR capability has the potential to lower the time it takes to respond to a price or reliability driven DR constraint, lower the costs of participation, and increase the frequency of participation. A study conducted by Quantum Consulting states that 10-15% of the sites that participated in their study could not participate in the DR event because the person in charge of the demand reduction was not in the facility on the day of the event [11]. Enhanced DR capability of a building's EMCS could allow customers to participate in more programs and/or increase revenues from their participation.

5. DEMAND RESPONSE IN CALIFORNIA

California's need for a real-time demand-side infrastructure to respond to supply-side problems led to the establishment of a Demand Response Research Center (DRRC) (drrc.lbl.gov) funded by The California Energy Commission's Public Interest Energy Research (PIER) program and run by Lawrence Berkeley National Laboratory (LBNL) . The main objective of the DRRC is to develop, prioritize, conduct, and disseminate multi-institutional research that develops broad knowledge to facilitate DR. The initial projects of the DRRC include: evaluation of real-time pricing for large users, demand shifting with thermal mass and automated DR in commercial facilities. This section will concentrate on the automated DR research that has been conducted by the DRRC in the last three years.

The goal of the automated DR is to demonstrate and evaluate the feasibility of automation in large facilities. Hardware and software infrastructure as well as DR strategies for commercial buildings has been the focus of this project. Figure 4 shows the overall sequence of the automated DR network communication.

Sequence of operations in Figure 4 are as follows:

1. LBNL defined the price vs. time schedule and sent it to the price server. In 2005, the Critical Peak Pricing (CPP) event was published by the utility a day ahead assigning a time schedule. This schedule, instead of price, published the price multipliers since participants had varying price structures.
2. The current price was published on the server.
3. Clients requested the latest price from the server every few minutes.
4. Business logic determined actions based on price.
5. EMCS (energy management control system) carried out shed commands based on business logic.

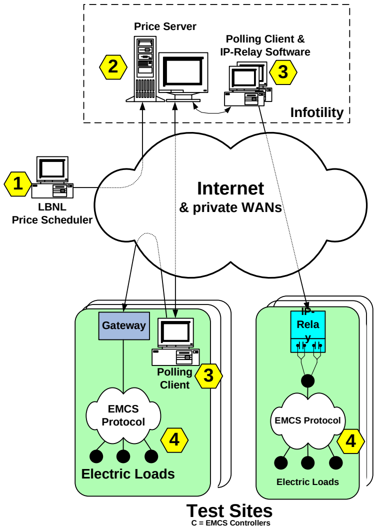

Figure 4: Automated DR infrastructure

In 2003, one objective of this research was to perform a two-week test of fully automated DR test at four to six facilities. LBNL worked with facility staff to develop a DR strategy that would maximize the electric shed while minimizing any loss of service. The test consisted of providing a single fictitious continuous electric price signal to each facility. The technology used for the communications is known as Extensible Markup Language (XML) with "Web services". Control and communications systems at each site were programmed to check the latest electricity price published by the price server and automatically act upon that signal. Connectivity from the price server to the site was established through Internet gateways that enable "Machine-to-Machine" translation. A polling client software enabled each site to pull information from the price server. All of the facilities had Energy Information Systems (EIS) and Energy Management and Control Systems (EMCS) that were programmed to automatically begin shedding demand when the price rose from $0.10/kWh to $0.30/kWh. The second level price signal increased to $0.75/kWh. Five sites successfully participated in the test.

In 2004, there were a number of new objectives in the field tests. One objective was to explore new control and communication systems; both gateway and relay technologies were tests. While the gateway is expensive and requires software development, an Internet relay is a low-cost device with relay contacts that can be actuated remotely over a LAN, WAN or the Internet using Internet Protocols (IP). The Internet is based on a standard protocol (TCP/IP) and all EMCS can sense the state of relay contact closures (regardless of their particular EMCS protocol). Because of this, Internet relays can be used on virtually any commercial building that has a standard connection to the Internet (i.e., Internet connectivity directly to the EMCS is not required). Another objective was to evaluate the size of the electric shedding potential of the 2003 Phase 1 buildings in warmer weather test events than our schedule permitted in 2003. These buildings participated in a warm weather 2004 "Retest". A third objective was to evaluate how the test could be scaled up to allow more buildings to participate. A fourth objective was to better understand the range of electric shed strategies that are used in large facilities. These last two objectives were evaluated in a "Scaled Up" test. All of the 2004 tests were three hour shed events conducted at different times. The facility managers were unaware of the impending DR events.

The communication systems for the 2004 tests differed from the 2003 tests in that new methods of communication were used. During the 2003 test all of the sites had some sort of Web-based Energy Information System (EIS) and Energy Management and Control System (EMCS) installed on a PC. During 2004, five of the 18 sites used an Internet relay that connected directly to the EMCS control panel. This new method allowed buildings with conventional control systems to participate in the test.

In 2005, with additional funding from Pacific Gas and Electric Company, the research to date was applied under the Critical Peak Pricing (CPP) Program. The main objective of this pilot study was to evaluate automation under a specific program and consider issues related to the cost of implementation and DR economics of the program as well as researching scaling up issues regarding the infrastructure. A maximum of 12 CPP days depending on weather forecasts are callable between May 1st and October 31st. On each CPP day between 12 pm and 3 pm time-of-use rates (TOU) are tripled, and between 3 pm and 6 pm TOU rates are quintupled. On all other days during the CPP period, a small credit is applied for each kWh consumed. Since participation in the study had economic impact for each site, recruitment efforts included signing the sites onto the CPP program, getting interval meters installed, communication tests between the participant and its utility, and the set up of an energy information system by the utility. A total of twelve sites participated in the pilot. Due to growing concerns about security of the network, in addition to the Internet relay and gateway connections, a secure and self – configuring alternative to both called the Client & Logic with Integrated Relay (CLIR) box was developed. The CLIR box connects an EMCS to the price server over the site local area network (LAN) and the Internet. It signals the EMCS through a standard relay contact interface and joins the LAN at commercial building sites without assistance required from the IT administrator. No reconfiguration of the site firewall is required. Predetermined shed strategies are programmed into the EMCS. The EMCS then responses to price or contingency based events generated in the price server and communicated via the CLIR Box.

The results of the automated DR research over the last three years described above can be summarized as follows:

- *Most building controls and communication technologies are capable of DR automation*: The price server infrastructure is designed such that any building with an EMCS and an Internet connection can participate in automated DR [12]. The variety of connections such as the Internet relay, Internet gateway and the CLIR box provide a variety of solutions that can be employed by each site.
- *Large sheds without complaints from occupants are feasible*: On September 8th, 2004, the total demand savings from five automated DR sites reached 1 MW (Figure 5). There were no complaints from any of the occupants in any of these buildings.

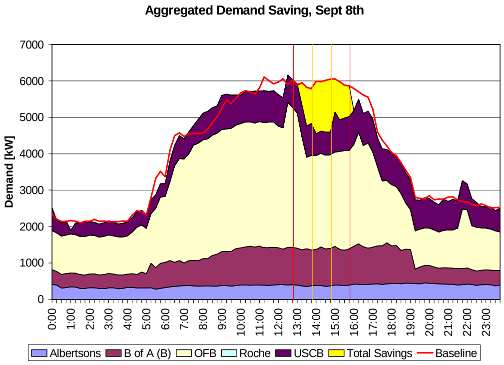

Figure 5: Aggregated shed for five sites on September 8, 2004.

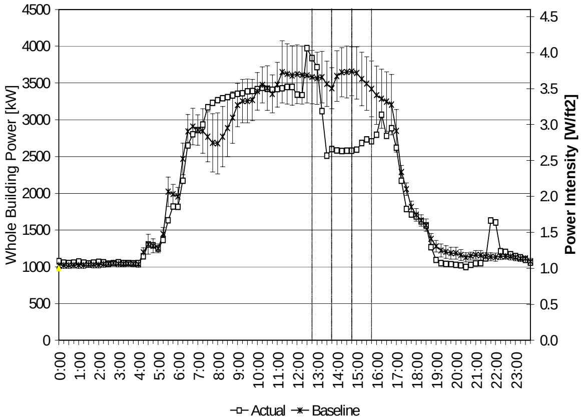

Figure 6: The demand shedding effect of global set point adjustment

- *Range of strategies are developed and evaluated for each site to shed loads:* Depending on the type of equipment and control system at each site, HVAC and lighting shed strategies were developed. As a result of this work, global set point adjustment was proposed as a California Energy Standard (Title 24). Global set point adjustment is the ideal DR strategy for HVAC systems. It 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 adjustment 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 6 displays the demand shedding effect of global set point adjustment in one of the Automated DR test sites in California.

This large federal facility (about 1 million ft^2) reduced its 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 [15]. Figure 6 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.

- *Average of 8% with a maximum of 56% demand shedding was achieve*d. Average demand savings of individual buildings for all the test days and maximum demand savings for the best performing building on one test day for each year is summarized in Table 4.

Research Year	**Number of Sites**	**Average Demand Savings (%)**	**Maximum Demand Savings (%)**
2003	5	8	28
2004	18	7	56
2005	12	10	38

Table 4. Average and maximum demand savings results from three years of research

	Global temp. adjustment	SAT increase	Fan VFD limit	Duct static pres. reduction	Rooftop unit shutdown	CHW temp. increase	CHW current limit	Chiller demand limit	Boiler lockout	Pre-cooling	Extended shed period	Slow recovery	Common area light dim	Office area light dim
Office A	X	X		X		X	X		X		X			
Office B			X	X		X	X							
Office C	X											X		
Office D	X											X		
Office E		X		X	X								X	X
Office F		X												
Office G	X	X												
Office H	X	X												
Office I	X			X										
Retail A	X													
Retail B					X								X	
Post Office								X						
Museum	X									X				
High School	X									X				
Data Center	X									X				

Figure 7: Strategies implemented in 2005 automated CPP sites.

6. DEMAND RESPONSE IN NEW YORK

One of the states that has been a leader in DR is New York. For example, recent research has examined the results of real-time pricing (RTP) in Niagara Mohawk service territory in upstate New York. All large Niagara Mohawk customers (those with over 2 MW of service) have been offered an RTP tariff, or they may opt out for another service provider. The RTP tariff has successfully provided DR while operating with the reliability based Emergency Demand Response Program (EDRP) run by the NY Independent System Operator [13].

In lower New York, LBNL researchers have been working with the design of the new New York Times (NYT) headquarters building in Manhattan to integrate lighting and shading devices, commission the lighting systems, and to develop DR strategies and DR controls specifications for the building.

The building was designed to promote "transparency" to the public (being a news organization that provides factual information to its customers) via floor-to-ceiling clear glass windows shaded by a unique exterior shading system and combined with interior shades. Enhancing the way employees work was the key objective, with sustainable building design as a secondary objective. Given the constraints of the building's geometry, systems design attention concentrated on energy efficient building components and systems. The overall intent for interior shades is to keep the shades up as much of the time as is possible without causing thermal or visual discomfort. Thermal comfort is assured by solar tracking and the geometry of the external sun screens. Visual comfort is assured by managing the luminance on the window wall. The specified lighting controls system is a DALI (Digital Addressable Lighting Interface) based system with dimmable fixtures throughout the interior space. This allows the system to dim down the electric lighting in response to daylight levels registered by a luminance sensor located on the ceiling as well as enable dimming of all lighting from a central location via central command. An under floor air distribution system is utilized for heating, air conditioning and ventilation of the spaces. This system is supported at the perimeter with fan coil boxes.

The building is one of the first to use Energy Plus to evaluate DR strategies. The following set of strategies were developed and evaluated to understand its demand shedding potential:

- **Lighting Level 1:** Reducing lighting to 50% in core, 70% in PC dominated interior and perimeter zones.
- **Lighting Level 2**: Reducing lighting to 50% in core, 70% in interior zones and off in perimeter zones.
- **Temperature Setup 1**: Cooling set point increase from 74F to 76.5F
- **Temperature Setup 2:** Cooling set point increase to 78.5F
- **Fan Box:** Reduce perimeter fan boxes to 30% capacity from 2pm. to 6pm.
- **Supply Temperature**: Cooling supply temperature is set to 54 F until 2 pm. At 2 pm, it is increased to 59.5 F until 6pm.

Various sequences of these strategies were simulated; including pre-cooling that will consider operating at lower levels of the comfort range during the morning when DR events are expected in the afternoon. Occupant comfort under these sequences is still not well understood. Therefore, these operational sequences will be programmed into the controls as a starting point and fine-tuned during commissioning of the building.

In addition to the development of DR sequences, an energy services company is evaluating the potential financial impacts of DR implementation under various programs. The amount of financial savings will depend on the financial structure of these programs available from the local utility and the NY Independent System Operator (NYISO).

Each strategy, under a potential future envisioned master controls concept, would be implemented as an optimized sequence of operations, but as needed with financial feedback from the utility and energy performance feedback from the building allowing for decision making with available short-term information. The control system could then fine-tune itself daily and start operating the building intelligently.

7. SUMMARY AND FUTURE DIRECTIONS

This paper has shown that commercial buildings are major drivers in peak electric demands throughout much of the United States. While the commercial sector is a major contributor to peak demands, new research has shown there is significant potential from new and existing controls to provide DR. DR capabilities in buildings revolve around advanced sensors and controls. Field tests show many buildings with EMCS have the potential to reduce peak demands by 5-10%, yet there is limited knowledge on how to develop DR strategies. Further research is needed to evaluate DR control capabilities in the existing stock of buildings considering characteristics such as control vintage, upgrade capabilities, market segments, and new construction trends.

One important aspect of improving control capabilities in buildings is the DR capabilities will not be major drivers for new control system. Rather, high performing building controls must require low maintenance that simultaneously supports energy efficiency and healthy indoor environments. Future control systems need to provide improved feedback, continuous diagnostics, and help operators identify and implement low-cost operating scenarios that consider dynamically varying electricity costs and potential on-site generation and renewable energy systems.

8. ACKNOWLEDGEMENTS

The authors thank Chris Marnay and Kristina Hamachi LaCommare for their support in the NEMS runs and Galen Barbose and Ron Hofmann for their review. Research funding was provided by the New York State Energy and Research Development Authority (NYSERDA) and the Demand Response Research Center (drrc.lbl.gov) 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.

9. REFERENCES:

[1] "The Economic Impacts of the August 2003 Blackout," Electric Consumer Research Council (ELCON), February 2, 2004. http://www.elcon.org/Documents/EconomicImpactsOfAugust2003Blackout.pdf

[2] L. Lawton , M. Sullivan, K. Van Liere, A. Katz, and J. Eto, "A framework and review of customer outage costs: Integration and analysis of electric utility outage cost surveys" (November 1, 2003). Lawrence Berkeley National Laboratory. Paper LBNL-54365. http://repositories.cdlib.org/lbnl/LBNL-54365

[3] U.S. Department of Energy. April 30, 2003. Report to Congress: Impacts of the Federal Energy Regulatory Commission's Proposal for Standard Market Design. DOE/S-0130

[4] 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.

[5] K. Hamachi LaCommare, December 2005. Personal Communication with Sila Kiliccote: results of NEMS runs for 1995 and 2003, e-mail.

[6] Tian, M., November 4, 2005. Personal Communication with Rich Brown: CEC HELM model annual energy and peak load estimates by end-use. California Energy Commission, e-mail.

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

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

[9] 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.

[10] 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.

[11] Quantum Consulting Inc. and Summit Blue Consulting, LLC "Working Group 2 Demand Response Program Evaluation – Program Year 2004 Final Report" p. 5-11, 5-14

[12] M.A. Piette, D. S. Watson, N. Motegi, S. Kiliccote, P. Xu, "Automated Critical Peak Pricing Field Tests: Program Description and Results" Prepared for Pacific Gas and Electric Company Emerging Technologies Program and the California Institute for Energy and the Environment, Draft December 20, 2005.

[13] 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

[14] Barbose, G., C. Goldman, R. Bharvirkar, N. Hopper, and M. Ting, Lawrence Berkeley National Laboratory; and B. Neenan, Neenan Associates "Real Time Pricing as a Default or Optional Service for C&I Customers: A Comparative Analysis of Eight Case Studies". LBNL-57661. August 2005