Automated Demand Response and Commissioning

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Synopsis

This paper describes the results from the second season of research to develop and evaluate the performance of new Automated Demand Response (Auto-DR) hardware and software technology in large facilities. Demand Response (DR) is a set of activities to reduce or shift electricity use to improve the electric grid reliability and manage electricity costs. **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. We refer to this as Auto-DR. The evaluation of the control and communications must be properly configured and pass through a set of test stages: Readiness, Approval, Price Client/Price Server Communication, Internet Gateway/Internet Relay Communication, Control of Equipment, and DR Shed Effectiveness. New commissioning tests are needed for such systems to improve connecting demand responsive building systems to the electric grid demand response systems.

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Introduction

This paper describes preliminary results from the second season of research to develop and evaluate the performance of new Automated Demand Response (Auto-DR) hardware and software technology in large facilities. Demand Response (DR) is a set of activities to reduce or shift electricity use to improve the electric grid reliability, manage electricity costs, and ensure that customers receive signals that encourage load reduction during times when the electric grid is near its capacity. Levels of automation in DR can be defined as follows: **Manual Demand Response** involves labor-intensive approaches 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, a building, or a facility through receipt of an external communications signal. We refer to this as **Auto-DR**.

The overall goal of this project was to support increased penetration of DR in large facilities through the use of automation and better understanding of DR technologies and strategies in large facilities. DR has been identified as a key strategy to improve electricity markets and electric grid reliability (United States GAO, 2004). To achieve this goal, a set of four field tests was conducted. These tests examined the performance of Auto-DR systems that covered a diverse set of building systems, ownership and management structures, climate zones, weather patterns, and control and communication configurations. This paper summarizes the project methodology and some of the results of the second season of research. The discussion emphasis is on the retest of 5 buildings that were also tested in 2003. The tests took place from September through November 2004. A short discussion of the site characteristics and some limited results from 13 new sites added to the Auto-DR tests in 2004 is also provided.

As new techniques and technologies are developed to harvest demand response in commercial and industrial facilities, new commissioning methods are needed to ensure that these systems function as intended during DR events. The evaluation of the control and communications must be properly configured and pass the following stages: Readiness, Approval, Price Client/Price Server Communication, Internet Gateway/Internet Relay Communication, Control of Equipment, and Effectiveness. New commissioning tests are needed to improve connecting demand responsive building systems to the electric grid demand response systems. Furthermore, there is an important link between properly functioning building controls and development of DR strategies.

Result from 2003

During 2003, LBNL conducted a test to develop and test fully automated DR systems in large facilities (Piette et al, 2004). The study has demonstrated a number of key issues that relate to Automated DR, and DR in general. The 2003 tests were conducted in November, during mild weather. Of the 5 MW under control among the 5 building, a shed of nearly 10% was achieved. One key finding was that fully automated DR is technically feasible with minor enhancements to current state-of-the-art technology. The site-by-site enhancements involved custom software based on the emerging technology standards of “Extensive Markup Language (XML)” and “Web services”. Automation of DR is likely to foster greater participation in various DR markets by decreasing the time needed to prepare for a DR event, increasing the number of times a facility may be willing to shed loads, and perhaps improving the size of the DR response.

The 2003 tests involved extensive discussions and interactions with five large organizations and institutions. Overall we obtained excellent support and assistance in this research. The energy managers at these organizations believe that DR programs and tariffs will increase in their importance and prominence, and new technology will assist them in participating in these programs. One key finding from the 2003 test was that new knowledge is needed to procure and operate technology and strategies for DR, because it is a complex concept. Facility operators need to understand DR economics, controls, communications, energy measurement techniques, and the relation between changes in operation and electric demand. Such understanding may involve numerous people at large facilities. Facility managers need good knowledge of controls, and current levels of outsourcing of control services often complicate their understanding of control strategies and system capabilities.

Methodology

The basic concept of the project in 2004 was to perform a set of tests of fully automated DR systems. The first two tests, referred to as the Retest, were to retest the five sites that participated in 2003 in warmer weather when DR is more likely needed and savings from reducing HVAC loads are greater. The second two tests, referred to as Scaled Up tests, were to “Scale Up” the participation rates. The tests consisted of providing a single fictitious continuous electric price signal to each facility. The technology used for the communications is known as ”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. All of the facilities had Energy Information Systems (EIS) or 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. A second stage price signal increased the price further to $0.75/kWh. Five sites participated in the Retest. Several of the sites that participated in the 2004 Scaled Up tests had learned about the 2003 tests and contacted LBNL to participate. LBNL worked with each site to explain the procedure for the Auto-DR tests. We began by collecting site information related to the following information:

- Site characteristics (size, type, location, HVAC systems, etc.)
- DR-Systems: software, firmware, and hardware, etc., installed at the site.
- Monitoring, control, and reporting attributes of the system
- Level of automation, human expertise and experience with DR
- DR-System and Energy Management capabilities and strategies used

LBNL provided the participants with an XML signal via the Internet that contains information to represent electricity prices. The participants agreed to work with their controls and DR system vendor and in-house staff to modify their system to be able receive or retrieve the XML signal, send back an acknowledgement, and initiate an automated shed. The tests were scheduled to take place during a 2-week period in September 2004. Within a test day, the response was not requested for more than 3 hours. The participants were able to override the test if needed. LBNL compiled HVAC, control, communications, energy, and other building time series data during the test to evaluate the shed. The development of this information was used to evaluate the success of the automated shedding strategy.

Selection Criteria and Sites Considered

In the 2004 Auto-DR tests, the criteria were relaxed so as to allow any large commercial building (over 200kW service) with an EMCS to participate. These criteria were in contrast to the 2003 Auto-DR tests in which the facilities selected for the (2003) Auto-DR test differed from most commercial buildings in California because each site had the capability to remotely monitor and control HVAC or lighting equipment over the Internet. Although these remote control and monitoring features, known collectively as telemetry, are becoming increasingly popular in newly installed EMCSs, they are still uncommon within the installed base of commercial buildings in California. For this reason, the 2003 Auto-DR sites were a select group.

Because the 2004 Auto-DR tests were intended to allow "typical" commercial buildings into the program, certain aspects of the Auto-DR communications architecture were altered to allow mainstream sites to participate, as further described below. Tables 1 and 2 list the characteristics and name of the five sites that participated in the Retest, and the 18 sites that participated in the two 2004 Scaled Up tests. Table 2 shows that two of the sites were outside of California. These sites choose to participate because of their interest in the XML communications and project design.

Table 1: Characteristics of Retest Sites

Site Name	Short Name	Location	Building Use	# of Bldg	Floor Space		Peak Load kW (Sept)
					Total	Conditioned	
Albertsons, Fruitville	**Albertsons**	Oakland	Supermarket	1	50,000	50,000	450
Bank of America Concord Data Center	**B of A**	Concord	Bank Office	1	200,000	176,000	1,120
GSA Ronald V. Dellums Oakland Federal Building	**OFB**	Oakland	Federal Office	1	1,105,000	978,000	4,100
Roche Palo Alto	**Roche**	Palo Alto	Cafeteria Auditorium	3	192,000	192,000	750
UC Santa Barbara Davidson Library	**UCSB**	Santa Barbara	Library	1	289,000	289,000	1,090
Total				7	1,836,000	1,685,000	7,510

* Only 1 of 4 buildings of B of A participated in the retest.

Table 2: Characteristics of Scaled-Up Test Sites

Site Name	Short Name	Location	Building Use	# of Bldg	Floor Space Total	Floor Space Conditioned	Peak Load kW (Sept)
300 Capitol Mall	**300 CMall**	Sacramento	Office	1	426,000	383,000	1,580
Albertsons, Fruitville	**Albertsons**	Oakland	Supermarket	1	50,000	50,000	450
Bank of America Concord Data Center	**B of A**	Concord	Bank office	3	616,000	708,000	5,380
Joe Serna Jr. Cal/EPA Headquarters Building	**Cal EPA**	Sacramento	Office	1	590,000	590,000	1,990
CANMET Energy Technology Centre - Varennes	**CETC**	Varennes (Quebec, Can)	Research Facility	1	45,000	18,000	240
Cisco Systems	**Cisco**	San Jose Milpitas	Office Tech Lab	24	4,466,000	4,466,000	27,860
Contra Costa County 50 Douglas	**50 Douglas**	Martinez	Office	1	90,000	90,000	500
Contra Costa County Summit Center	**Summit Ctr**	Martinez	Office	1	131,000	131,000	500
Echelon San Jose Headquarter	**Echelon**	San Jose	Office	1	75,000	75,000	410
GSA Phillip Burton San Francisco Federal Building	**450 GG**	San Francisco	Federal Office	1	1,424,000	1,424,000	2,130
GSA National Archives & Records Administration	**NARA**	San Bruno	Archive Storage	1	238,000	202,000	280
GSA Ronald V. Dellums Oakland Federal Building	**OFB**	Oakland	Federal Office	1	1,105,000	978,000	4,100
Kadant Grantek	**Kadant**	Green Bay (WI)	Material Process	1	100,000	0	1,440
Monterey Commerce Center	**Monterey**	Monterey	Commercial	1	170,000*	170,000*	N/A
OSIsoft	**OSIsoft**	San Leandro	Office	1	60,000	60,000	300
Roche Palo Alto	**Roche**	Palo Alto	Cafeteria Auditorium	3	192,000	192,000	750
UC Santa Barbara Davidson Library	**UCSB**	Santa Barbara	Library	1	289,000	289,000	1,090
US Postal Service, San Jose Process & Distribution Center	**USPS**	San Jose	Distribution Center	1	390,000	390,000	1,630
Total				36	10,287,000	10,046,000	50,630

* Monterey is not included in the total, because this site was used only for communication test.

Automated Demand Response System Description

During the recruitment phase of the 2004 project, it became apparent that many building managers were interested in participating in our study, but were unable to do so because their buildings and organizations lacked two key attributes: 1) an Internet Gateway (connects the EMCS to the Internet) and 2) Computer programming skills that would enable them to create the necessary custom “Price Client” software. Overcoming these impediments directly can be daunting. The feasibility of adding an Internet gateway to a legacy EMCS depends upon the EMCS manufacture, the communication protocol, the EMCS vintage and other factors. These

Internet gateway issues prompted a less expensive method for EMCS Internet connectivity, identified in this work as Internet Relays. The communication options are described below.

- **Internet gateway.** Gateways used in building telemetry systems provide several functions. First, they connect two otherwise incompatible networks (i.e., networks with different protocols) and allow communication between them. Second, they provide *translation* and *abstraction* of messages passed between two networks. Third, they often provide other features such as *data logging*, and control and monitoring of I/O points.
- **Internet relay.** A device with a relay or relays that can be actuated remotely over a LAN, WAN or Internet using Internet Protocols (IP).

Figure A shows the communication sequence for each system type used in the Auto-DR tests.

1. LBNL defines the price versus time schedule and sends it to the price server.
2. The price is published on the server.
3. Polling clients request the latest price from the server every few minutes.
4. The Energy Management Control System (EMCS) initiates shed commands based on current price.

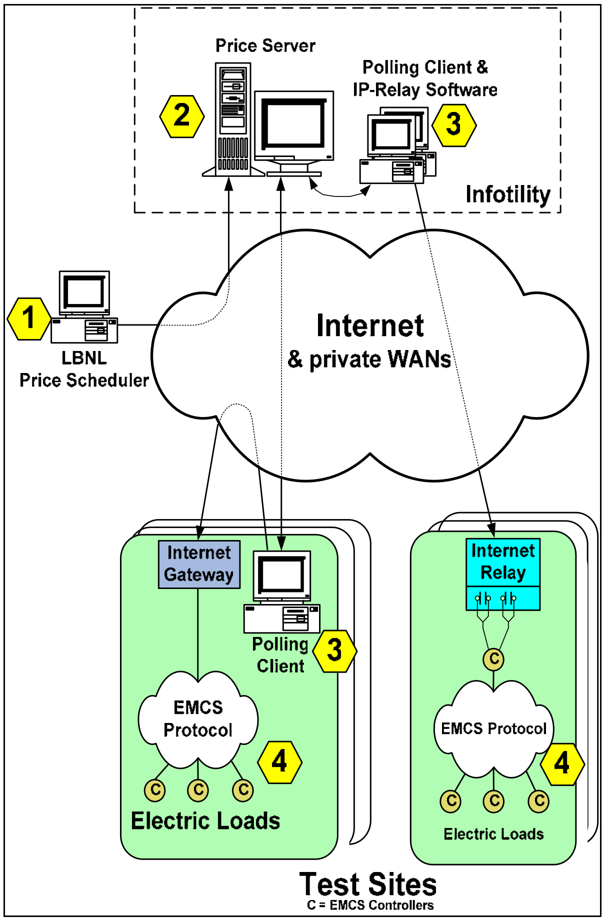

Figure A: ADR2 Sequence of Communication

Systems using Internet gateways and those using Internet relays were both successful in conducting Auto-DR tests. Systems with Internet gateways tend to be more powerful and flexible due to their ability to enable two-way translation between EMCS and Internet protocols as well as other additional features. Through their simplicity, Internet relays tend to be easier to integrate into existing buildings and easier for most building operators to understand.

Evaluation Techniques

Demand savings were derived by subtracting the actual metered electric demand from the baseline demand. The baseline demand is an estimate of how much electricity would have been used without the demand shedding. The methodology was developed based on a review of KEMA-Xenergy (2003). Figure B shows an example of the measurement and evaluation results for one building for one test. The baseline electric load shape is estimated. This figure shows results from the first Retest for the Oakland Federal building that took place on September 8, 2004. This site shed over 1 MW during the second hour of the three-hour test.

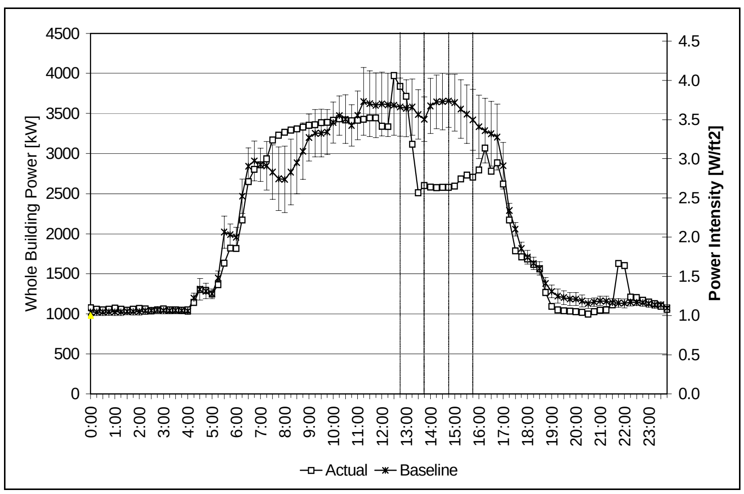

Figure B: Whole-Building Baseline Time-Series Chart Example

The evaluation also includes a detailed review of problems that may occur in the control and communication systems. The “system” from the price server to the end-use control strategy has the following six milestones:

- **Readiness**: The system was configured and ready to be tested by the research team.
- **Approval**: Organizational approval to perform demand responsive load control granted.
- **Price Client/Price Server Communication**: The price client successfully obtained the correct electricity prices from the price server. Failures to pass this milestone were generally caused by the overload of the price server with requests from clients. When this condition occurred, it would send out faulty messages that contain no price values (also known as “null values”). When some price clients received null values, they failed to handle the error gracefully. This faulty condition caused communication between the client and the server to fail. The software for some other price clients was written so as to be more robust. These price clients ignored null values and other faults and continued to operate normally until valid data was restored.

- **Internet Gateway/Internet Relay Communication**: The communication was successful between the computer containing the price client and associated business logic software and the Internet gateway or Internet relay located at each site. Failures to pass this milestone were generally caused by 1) blockages of the Internet based command signals due to firewalls, disconnection or network reconfiguration or 2) failures in the Internet gateway or Internet relay devices themselves.
- **Control of Equipment**: Target equipment was controlled as planned. Target equipment included HVAC equipment, lighting and other equipment that generate electric loads. Failures to pass this milestone were generally caused by HVAC equipment not responding to command signals over the EMCS network. An example of this type of failure occurred when an HVAC EMCS controller had had been placed in manual operation (as opposed to automatic operation). In this case, control signals coming over the EMCS network were ignored.
- **Effectiveness**: To pass this milestone, the planned shed strategy must have been proven to effectively reduce electric demand. Effectiveness was tested by comparing the average power (kW) shed during the test to the average standard error of a regression model. The shed strategy was considered effective if one or more of hourly average power savings in the 3-hour shed period was larger than the hourly average of the standard error.

Results

A detailed analysis of the entire set of results is still under development. All 18 sites successfully shed load during the 2004 Auto-DR tests. In no test did all the sites work correctly, but there was at least one successful test at each site. Table 3 lists the DR shed strategies used at each site for the first level ($0.30/kWh) and second level ($0.75/kWh) sheds. Overall the tests were successful in demonstrating fully automated electric demand sheds. The maximum electric shed among the entire set of buildings totaled 4 MW.

Tables 4 and 5 show the success or failure in passing each important milestone mentioned earlier. All the sites were ready and succeeded in the first test (September 8), except Roche. The problem occurred because the site had not re-enabled the systems for the 2004 tests. The supermarket executed their anti-sweat door heater shed strategy, but the anti-sweat heater was already in low-mode due to low humidity for both tests During the September 21st test we identified 4 problems. The power reductions at B of A and OFB were small, with limited effectiveness. The problems at B of A related to difficulties in working with the entire 3 building site and the underlay EMCS strategy. The problem at OFB was related to a highly variable baseline load that complicated the statistics and measurement of savings. The problem at Roche was related to the duration of the test and the operations staff opting out manually in the third hour. UCSB failed for the second test because of a communication failure where the relay device was unable to receive the signal from the web-client server because network security reconfiguration blocked the signal from outside of campus.

Table 3. Summary of each Site's Shed Strategy

Site Name	$0.30/kWh	$0.75/kWh
300 CMall	Chilled water temp 44°F → 47°F Annex building modify monitored average zone temp down by 1.5°F Supply fan VFD* lock Fountain pump off Loading deck fan off Lobby lights off	Chilled water temp → 55°F Annex building avg. zone temp down 3°F
Albertsons	Overhead light 35% off	Anti-sweat door heater night-mode
B of A	Supply air temp reset 55°F → 59°F Duct static pressure 2.2 IWC → 1.8 IWC	Supply air temp reset → 59°F Duct static pressure → 1.4 IWC
Cal EPA	Duct static pressure 1.0 IWC → 0.5 IWC	Turn off light where daylight is available
CETC	Unload chiller and cool with ice storage Two air handling units off Electric humidifier off	
Cisco	VAV zone setup 2°F Computer Room AH setup 2°F Boiler pump off & stairwell fan-coils off Sweep lighting where daylight is available. Stairwell, lobby, hallway lights off	
50 Douglas	Global zone setup 76°F → 78 °F	Global zone setup → 80°F
Summit Ctr	Global zone setup 76°F → 78 °F	Global zone setup → 80°F
Echelon	Zone setpoint increase Dim office lighting	Rooftop units off (100%) Lobby, common area light off Hallway light 33~50% off
450 GG	Global zone setup 72°F → 74°F Global zone setback 70°F → 68°F	Global zone setup → 78°F Global zone setback → 66°F
NARA	Global zone setup 75°F → 76°F Global zone setback 70°F → 68°F	Global zone setup → 78°F Global zone setback → 66°F
OFB	Global zone setup 72°F → 76°F Global zone setback 70°F → 68°F	Global zone setup → 78°F Global zone setback → 66°F
Kadent	Transfer pump off	
Monterey	Lobby lights 33% off	
OSIsoft	Global zone setup 72°F → 76°F Global zone setback 72°F → 76°F	Global zone setup → 78°F Global zone setback 72°F → 76°F
Roche	Building-A2 supply fans off (50%)	Building-FS supply fans off (50%) Building-SS supply fans off (50%)
UCSB	Supply fan VFD 70% limit Economizer 100% open	Supply fan VFD 60% limit Duct static pressure reset 0.4 IWC (partial) Heating/cooling valve close
USPS	Chiller demand 60% limit	Chiller demand 40% limit

* VFD: Variable Frequency Drive, IWC = Inch Water Column

** Strategies chosen for $0.30/kWh level are continued in $0.75/kWh level (except for deeper increase or decrease of parameter setpoint chosen in $0.30/kWh level).

Table 3: Response Results for September 8th

Site Name	Readiness	Approval	Server/Client Communication	Gateway/Relay Communication	Control of Equipment	Effectiveness
Albertsons						
B of A						
OFB						
Roche						
UCSB						

Succeeded Failed Not Applicable

Table 4: Response Results for September 21st

Site Name	Readiness	Approval	Server/Client Communication	Gateway/Relay Communication	Control of Equipment	Effectiveness
Albertsons						
B of A						
OFB						*1
Roche					*2	
UCSB						

*1: Standard error was too large due to several irregular load shape.
*2: Shed control partially didn't work.
Succeeded Failed

Figure C shows the whole building power from all sites and total demand savings of the first retest (September 8th). The aggregated shed during the second hour was about 1400 kW, with 44 kW from Albertsons, 51 kW from B of A, 1066 kW from OFB, and 263 kW from UCSB. These savings are over 20% of the 6 MW aggregated baseline.

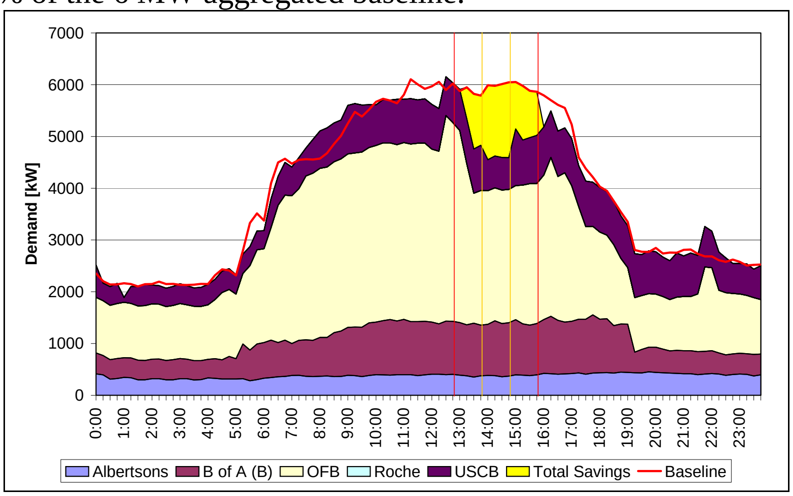

Figure C: Aggregated Demand Savings from 5 Buildings, September 8 2004

To advance knowledge in how to develop and conduct demand sheds in large facilities it is critical to understand the capabilities of the building controls, since there are numerous ways to organize control strategies. Table 4 shows a summary of five HVAC and two lighting shed types, where we are beginning to construct a framework that identifies which type of shed strategies are possible with certain building control attributes.

Table 4: Shed Strategies vs. Building Control Attributes

		Building Control Attributes			
	Shed Strategy Types	EMCS Zone Temp. Control	EMCS Equip. Control	Variable Frequency Drives	Central Lighting Control
HVAC	Thermostat Setup/Setback	✓	✓		
	Cooling Limit		✓		
	Duct Static Setback		✓		
	Fan Speed Limit		✓	✓	
	Equip. Lock-out		✓		
Lighting	Reduce Common Area Lighting				✓
	Reduce Private Office Lighting				✓
Misc. Equip.	Equip. Lock-out		✓		

Another method we are developing uses a decision tree process as depicted in Figure D. This is a preliminary draft of a method to identify which strategies may be appropriate for a given building based on the control system capabilities. This process could assist building operations engineers in the DR strategies. A similar process could be developed to commission and trouble shoot DR shed strategies. The flow chart helps illustrate design intent concepts that need to be better articulated in DR systems.

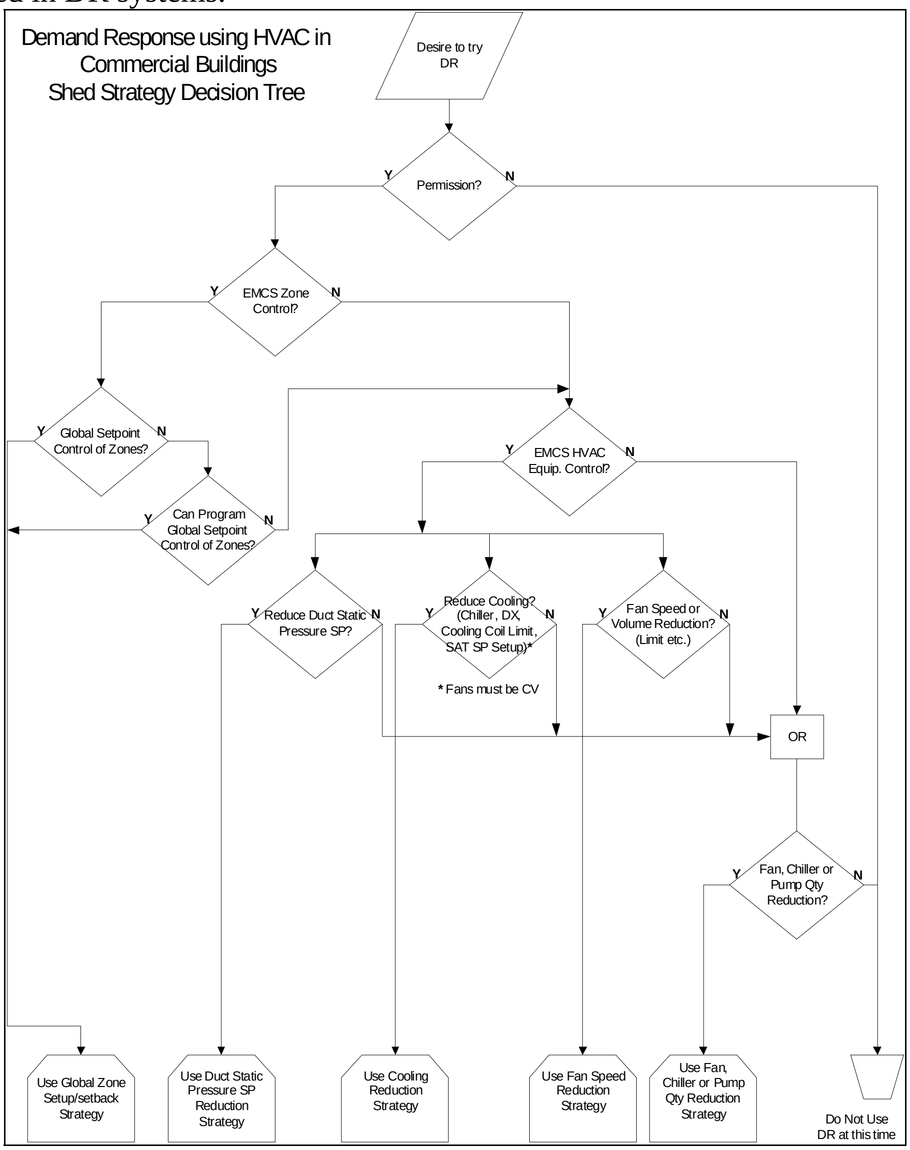

Figure D: Preliminary Design for a Demand Response Control Decision Tree

Figure E shows demand saving intensity [W/ft^2] by the shed strategy for the November 5, 2004 Scaled Up test. The purpose of this graphic is not to show the absolute savings that can be achieved by different shed strategies, but to show that there is a range of savings that can be achieved with different strategies. The peak power savings available for HVAC systems is highly weather dependant and this test day was a mild, not a hot day with outside temperatures in the mid sixties. For sites where there was more than one strategy used, it is often difficult to evaluate the savings attributed to a strategy with whole-building data. End-use metered data were available for the sites that show the lighting shed strategies. We will continue to explore the range of savings for different strategies under different weather conditions and internal conditions.

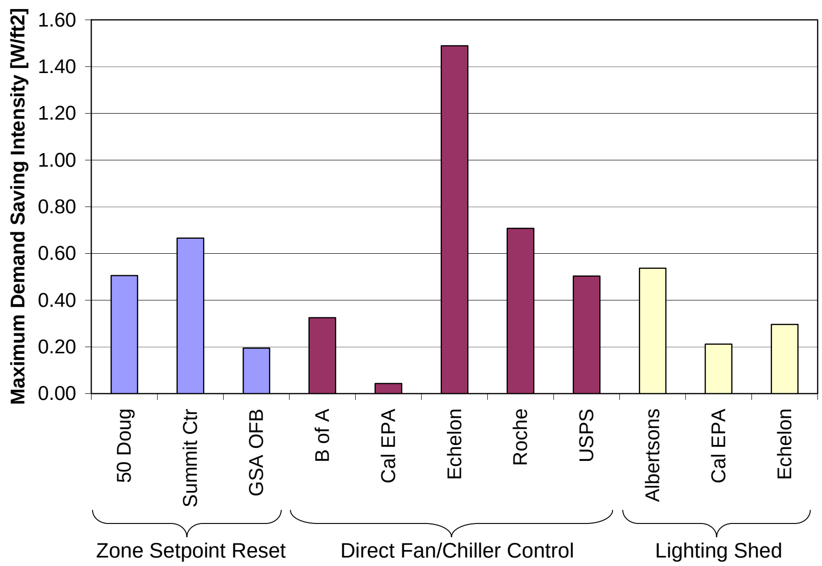

Figure E: Demand Saving Intensity [W/ft^2] by Shed Strategy

The zone set point reset strategies are valuable because they are closed loop control strategies that generally require the presence of full direct-digital control. Direct fan and chiller control is possible, but may be problematic because of open loop conditions that have limited zone feedback. As the technology in DR systems is developed, there is a need to expand the methods for building commissioning beyond energy efficiency into DR oriented system analysis.

There are numerous types of demand reduction strategies that have been tested in 2003 and 2004 among the buildings that have participated in this research. The DR HVAC strategies include concepts such as global zone set point increase (from 72 °F-75 °F), resetting duct static pressure, locking fan and chiller demand using VFDs, resetting supply air and chilled water supply temperatures. The development and execution of DR strategies nearly always results in uncovering commissioning issues. It is common to find that the installed equipment does not operate exactly as hoped. One problem in controls programming resulted in heating modes turning on when zone set points were increased. Numerous projects had problems with control sequences that would work for one test, but unintended changes in sequences defeated full execution of the load shed strategy. In one case we found the supermarket chicken rotisserie incorrectly circuited on the anti-sweat heater load control.

All of the problems encountered could be addressed with traditional commissioning approaches. For example, there is a need for careful design-intent documents to outline the concept behind a load-shed strategy. Functional tests are needed to define the conditions for a load-shed test, methods to conduct the test, and evaluation concepts to determine if the test was successful. Since many HVAC load-shedding strategies are weather dependent, new evaluation techniques are needed to understand how a load shedding strategy behaves in different weather. Further work in this area is needed to support the growing number of buildings that will participate in future DR programs. One other key issue is to develop better monitoring and energy data tracking systems. Today's building operators have minimal to no feedback concerning operating strategies and energy use patterns. Previous work in this area has been reported by Motegi et al (2003a and 2003b), and Piette et al, 2001.

Summary and Future Work

This paper has presented an overview of research in California to Automate DR in large facilities. Eighteen sites, representing over 10 million ft^2 of facility floor area were evaluated for automated DR shedding in 2004. A forthcoming report will present a more detailed discussion of the issues discussed above. DR brings new challenges for building controls, communication systems, and commissioning. The "system" that the commissioning agent interacts with will expand beyond the boundaries of the building, to communications systems with the electric grid utility or system operators. Future work will also examine the link between the use of advanced controls for both energy efficiency and demand response strategies.

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