Northwest Open Automated Demand Response Technology Demonstration Project

Sila Kiliccote
Mary Ann Piette
Junqiao Han Dudley

Lawrence Berkeley National Laboratory

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Executive Summary

Introduction

Lawrence Berkeley National Laboratory (LBNL) and the Demand Response Research Center (DRRC) performed a technology demonstration and evaluation for the Bonneville Power Administration (BPA) in Seattle City Light's (SCL) service territory. This project was funded by BPA and SCL. This report summarizes the process and results of deploying open automated demand response (OpenADR) in the Seattle area to reduce winter morning electric peak demand in commercial buildings. The field tests were designed to evaluate the feasibility of deploying fully automated demand response (DR) in four to six sites in winter. DR savings were evaluated for various building systems and control strategies. The six month long project started in November 2008.

Methodology

The methodology for the study included site recruitment, control strategy development, automation system deployment and enhancements, and evaluation of the sites' participation in DR events. LBNL subcontracted with McKinstry and Akuacom for this project. McKinstry assisted with recruitment, site surveys, strategy development and overall participant and control vendor management. Akuacom established a new DR automation server and enhanced its operations to allow for scheduling winter morning day-of and day-ahead events. Each site signed a Memorandum of Agreement with SCL. SCL offered each site $3,000 for agreeing to participate in the study and an additional $1,000 for each DR event. Each facility and their control vendor worked with LBNL and McKinstry to select and implement control strategies for DR and developed their automation based on their existing Internet connectivity.

After the DR strategies were programmed, McKinstry commissioned the strategies before the DR events took place. McKinstry worked with LBNL to identify control points to archive and to use to evaluate the DR strategies. LBNL collected electric meter data and trend logs from the energy management and control systems of each site. The communication system (DRAS) allowed the sites to receive day-ahead as well as day-of proxies for price that indicate DR events.

Results

- **Recruitment is a lengthy and on-going effort.** The teams experience in the Northwest is similar to the early field test recruitment efforts in California. Recruitment is part education and part relationship-building. Participants must be comfortable with the following concepts:
    - the service levels in their facilities will be modified for a period of time;
    - ongoing assistance and monitoring will help them select detectable but at the same time acceptable DR strategies; and
    - they can modify strategies or choose not to participate in an individual event.
- **A large potential pool of customers enabled us to achieve the targeted number of participants.** Of the elevent facilities initially surveyed, eight sites indicated interest in participating in the study Of these eight, three of the sites could not participate in the test events due to at least one of the reasons outlined below:
    - Limitations within control systems and the increased cost of overcoming these limitations.

    - Communication problems within the control systems that prevented the research team to monitor and collect data from each test DR event.
    - Decision to back out of the field tests due to concerns from tenants.

- **Lighting provides year-round DR**. While detectable, lighting sheds have fast response times and can provide excellent year-round DR. However, lighting control systems are not often centralized and most new lighting control systems that integrate with daylighting in commercial buildings have local closed-loop controls that optimize for daylight availability.
- **Heating ventilation and air conditioning (HVAC) systems with natural gas heating have limited savings opportunities.** Two buildings with gas powered roof-top units selected duty cycling as a DR strategy. The DR opportunities in these types of systems come from fan power savings.
- **All electric heating systems are the low hanging fruit.** Global temperature adjustment strategy, which is often used in California to reduce peak demand during summer afternoons, worked well in the all electrically heated building. The zone temperatures were temporarily reduced to save on electric loads.
- **Auto-DR concepts work for winter DR in commercial buildings.** On average, the buildings that participated in the study delivered 14% demand reduction or 0.57 W/ft^2 over three hours. This study showed that HVAC and lighting remain to be the major opportunities for Auto-DR in commercial buildings. With or without electric heating, there are opportunities for HVAC systems to reduce demand for a period of time to relieve the stress on the electric grid. Summary of average demand reduction using the several baseline methods, energy savings, cost per customer and one-time control and commissioning cost per kW is presented below as well as the load profile of the aggregate demand reduction:

Average demand reduction (kW) for each DR event	730 kW
Total energy savings due to four DR events (kWh)	8763 kWh
Average per customer cost for control and commissioning	$4,057
Average control and commsionning cost per kW (one-time)	$76/kW

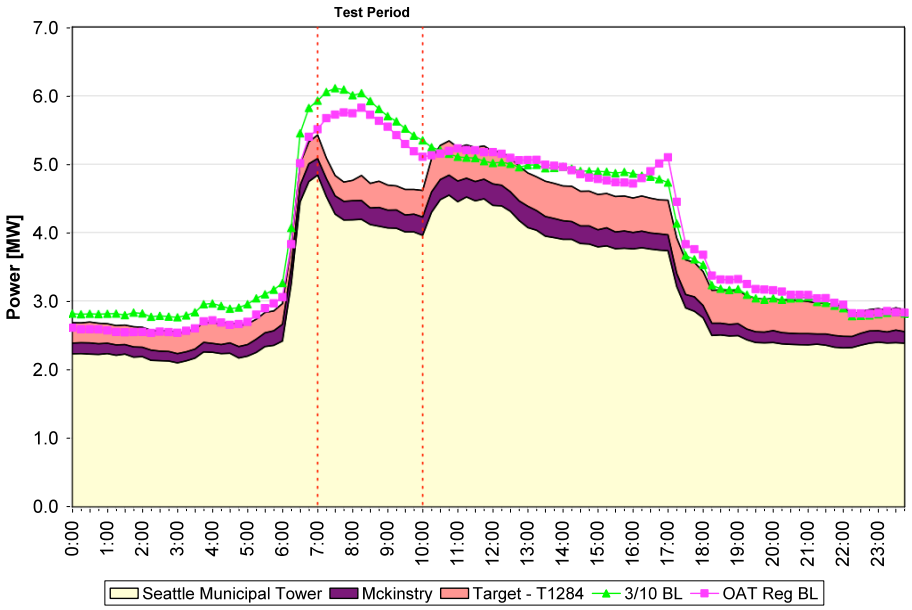

Figure 1. Aggregate load reduction

Recommendations and Future Directions

The project was a first step in demonstrating the use of OpenADR technology and its performance during winter. There is a need to study and develop cold morning DR strategies for consumers who would like to participate in DR programs. A guide that categorizes buildings and building systems and recommends DR strategies would be a suggested next deliverable. In addition, simulation tools that are developed for estimating DR capabilities for buildings in hot summer climates can be enhanced to support estimating cold winter morning DR capabilities in commercial buildings. We recommend a next phase for the project to evaluate the same technology and same test sites but consider DR strategies for demand savings summer days. The objectives of the next phase of the pilots are:

- To evaluate these same commercial buildings' capability to respond to DR events in dual peaking climates to address:
    - Year-round seasonal needs,
    - Fast demand response, and
- To develop methods for evaluating DR for buildings in dual peaking climates
- To consider the feasibility of geographically targeted DR.

OpenADR is currently in use by four electric utilities to automate their DR programs and has been adopted by a wide range of building and industrial controls companies. It is also identified by the Department of Energy (DOE) as one of "The initial batch of 16 National Institute of Standards and Technology (NIST)-recognized interoperability standards announced today will help ensure that software and hardware components from different vendors will work together seamlessly, while securing the grid against

disruptions[1]". A detailed specification for OpenADR was developed over a two year period and released as an official CEC/LBNL report (http://openadr.lbl.gov/pdf/cec-500-2009-063.pdf). The OpenADR specification will be the basis of ongoing DR communications standards development efforts within both the Organization for the Advancement of Structured Information Standards (OASIS - http://www.oasis-open.org/home/) and the UCA International Users Group (UCAIug - http://www.ucaiug.org/). Both are highly regarded organizations that are active within the emerging "Smart Grid" domain. With the ongoing efforts within OASIS and UCAIug, OpenADR is on a path towards becoming a formal standard within organizations such as the International Electrotechnical Commission (IEC. - http://www.iec.ch/)

[1] **http://www.energy.gov/news2009/7408.htm**

1. Project Background

California utilities have been exploring the use of critical peak pricing, demand bidding, and other form of electric demand response (DR) to help reduce needle peaks in customer end-use loads. These activities are forms of price-responsive demand response. Experience in California has shown that commercial building owners and facility managers have limited knowledge of how to operate their facilities to reduce their electricity costs under these programs. At the same time LBNL, through the California Energy Commission PIER-funded Demand Response Research Center and California utility-funded activities, has been conducting research to demonstrate how price-response can be automated using standard eXtensible Markup Language (XML)-based communications with customer owned control systems. Fully automated demand response accounts for over 60 MW of peak demand savings in California provided by over 200 customer facilities (Wikler et al. 2009). Many end-use customers have suggested that automation will help them institutionalize their electric demand reduction.

The overall goal of this research is to develop, demonstrate, and evaluate demand response technologies and strategies for commercial buildings in the Northwest. This initial effort is based on cold winter morning peaks to be addressed with DR that is automated based upon receipt of an emergency signal. In this system, a price signal,[2] was published on a single Web services server, available on the Internet using the meta-language, XML (eXtensible Markup Language). Each of the participating facilities monitored the DR signal using a Web services client application and automatically shed site-specific electric loads when the proxy price increased. This project demonstrated use of the Open Automated Demand Response Communication Specification (version 1.0) which is designed to facilitate DR automation without human intervention (Piette et al. 2009).

The structure of this report is as follows. **Section 1** provides a summary of previous work and additional background followed by a discussion of the project objectives (**Section 2**). **Section 3** outlines the project methodology covering the technology used for the automation, plus the DR event design and steps for participation. **Section 3** also discusses the technical coordination role and introduces the DR controls strategies. This section also covers the evaluation methods used in the study that include the baseline models, data collection methods, evaluation of the effectiveness of the automation, and surveys. **Section 4,** Results, discusses the characteristics of the participants, automation systems used, DR controls strategies automated, and the use and results of automated DR events for each site. The results section also provides an overview of the aggregated and individual facility demand reduction. **Section 5** is a discussion of key findings relative to the project objectives. **Section 6** presents recommendations and a discussion of next steps. **Section 7** lists key references. Extensive **appendices** provide details on the program design, technology, facility characteristics, and peak demand reduction data.

[2] DR events were mapped onto price signals. Price signals used for this project were either "Normal", indicating no change in the participants' actual rates, or "High", indicating a peak demand problem with the electricity grid.

1.1. Prior Work

The Demand Response Research Center (DRRC) has been working with California utilities to develop a low cost automation infrastructure to improve DR capability; evaluate the readiness of buildings to receive price and reliability signals and evaluate control capabilities of current and future buildings. DR experience in California has shown that customers have limited knowledge of how to operate their facilities in order to reduce their electricity costs under CPP (Quantum and Summit Blue 2004). While the lack of knowledge about how to develop and implement DR control strategies is a barrier to participation in DR programs, another barrier is the lack of automation of DR systems. Most DR activities are manual and require building operations staff to first receive emails, phone calls, and pager signals; and second, to act on these signals to execute DR strategies. About 15% of the time, the person in charge of responding to the DR events is not at the facility (Quantum and Summit Blue 2004).

The various levels of DR automation can be defined as follows (Piette et al. 2005). **Manual Demand Response** involves a labor-intensive approach such as manually turning off or changing comfort set points at each equipment switch or controller. **Semi-Automated Demand Response** involves a pre-programmed demand response strategy initiated by a person via centralized control system. **Fully-Automated Demand Response** does not involve human intervention, but is initiated at a home, building, or facility through receipt of an external communications signal. The receipt of the external signal initiates pre-programmed demand response strategies. We refer to this as **Auto-DR**[3]. One important concept in Auto-DR is that a homeowner or facility manager should be able to "opt out" or "override" a DR event if the event comes at time when the reduction in end-use services is not desirable.

The experience in California with DR automation infrastructure led LBNL to develop open and interoperable specifications and to work with standards organizations to facilitate its adoption as a standard. From the customer side, modifications to the site's electric load shape can be achieved by modifying end-use loads. Examples of demand response strategies include reducing electric loads such as dimming or turning off non-critical lights, changing comfort thermostat set points, or turning off non-critical equipment. These demand response activities are triggered by specific actions set by the utility or other electricity service provider, such as dynamic pricing or demand bidding. Many electricity customers have suggested that automation will help them institutionalize their demand response. The alternative is manual demand response where building staff receive a notification send via e-mail, fax or page and set in motion a set of activities to reduce demand. The LBNL research has found that many building Energy Management and Control Systems (EMCS) and related lighting and other controls can be pre-programmed to manage electric demand response.

[3] Previous terms such as Auto-DR and Open Auto-DR have also been used. OpenADR is an open, secure, two-way information exchange model that is used to publish Price and reliability signals for DR applications.

2. Project Objectives

The overall objective of this research is to understand commercial buildings' demand response technologies and strategies to address winter morning peaks in the Northwest upon receipt of an automated DR emergency or price signal or rise in the price of electricity.

Specific project objectives are:

- to demonstrate open automated DR communication systems in the Northwest, and
- to conduct an initial evaluation of opportunities for winter DR commercial building control strategies.

Additional points of consideration include:

- to evaluate DR baseline measurements and baseline methods for the winter commercial building shifts and sheds,
- to develop initial analysis methods for cold weather DR control strategies in commercial buildings, and
- to evaluate Northwest DR program design issues.

To achieve these objectives, LBNL assembled the following team for the project:

- LBNL - Developed and executed overall final project plan, developed evaluation methods, collected data, performed analysis and developed final report.
- Akuacom – Developed and maintained the DR automation server (DRAS) throughout the demonstration.
- McKinstry – Local engineering firm assisted in recruitment, DR audits, installations, configurations and commissioning of OpenADR compliant automation of DR.

3. Methodology

3.1. Technology

3.1.1. Control and Communication System Configuration

OpenADR systems use the public Internet and private corporate and government intranets to communicate DR event signals that initiate reductions in electric loads in commercial buildings. The DR event signals are received by energy management and control systems, which perform pre-determined demand response strategies at the appropriate times. This section describes this system's technical details.

LBNL provided the participants with either:

- A Web Services DR automation server (DRAS) Software Client development template [4]
- Or a client logic with integrated relay (CLIR) Box (see Appendix C)

The Web Services (WS) client is a software client that is typically embedded into an existing gateway device or building automation system. DR automation server currently supports Rest WS with plans to support Simple Object Access Protocol (SOAP) and BACnet WS (Piette et al. 2009). The CLIR box is a hardware device that maps price and event signals into dry contact relay closures.

The commercial building participants recruited for the demonstration agreed to work with their control vendor or in-house staff to modify their system to be able to retrieve the XML signal or a control signal, and initiate an automated demand response. McKinstry coordinated installation, configuration and commissioning of the DR automation.

Once the OpenADR system setup was completed, LBNL published XML DR event signals via the Internet that contained information to represent electricity prices for the DR event days. The project simulated a two-level price schedule: normal and high. The prices were "high" during the three hour DR events. The participant was able to override the test and "opt out" if needed. Since these were tests, the participant's actual price of electricity was not affected. Seattle City Light offered $3,000 to each participant for their initial efforts and $1,000 per event for their participation.

The Demand Response Automation Server (DRAS) is an Internet-based system used to enable OpenADR. The DRAS provides a common signaling infrastructure for economic and contingency-based demand response. Since published open standards are used, ESCOs, aggregators and "trans-utility" statewide customers minimize development effort through use of the common interface. Industry standards such as XML, SOAP and Web services are used.

3.1.2. Automated Demand Response System Description

[4] http://www.openadr.org/pdf/openadr-client-develop.pdf

The DRAS is used to initiate DR control strategies through virtually any control system. Publishing the OpenADR specification and making the DRAS Web services client template available to the software client developers minimizes the effort required by developers who wish to interface their systems to the DRAS (Piette et al. 2009). Sample files and descriptions are in the public domain. The client software continuously polls the DRAS to determine the timing and magnitude of demand response events. Logic to shift or shed electric loads based on DR signals and connectivity to each system is created using the existing control systems based on the requirements of the site.

Figure 2: OpenADR system architecture

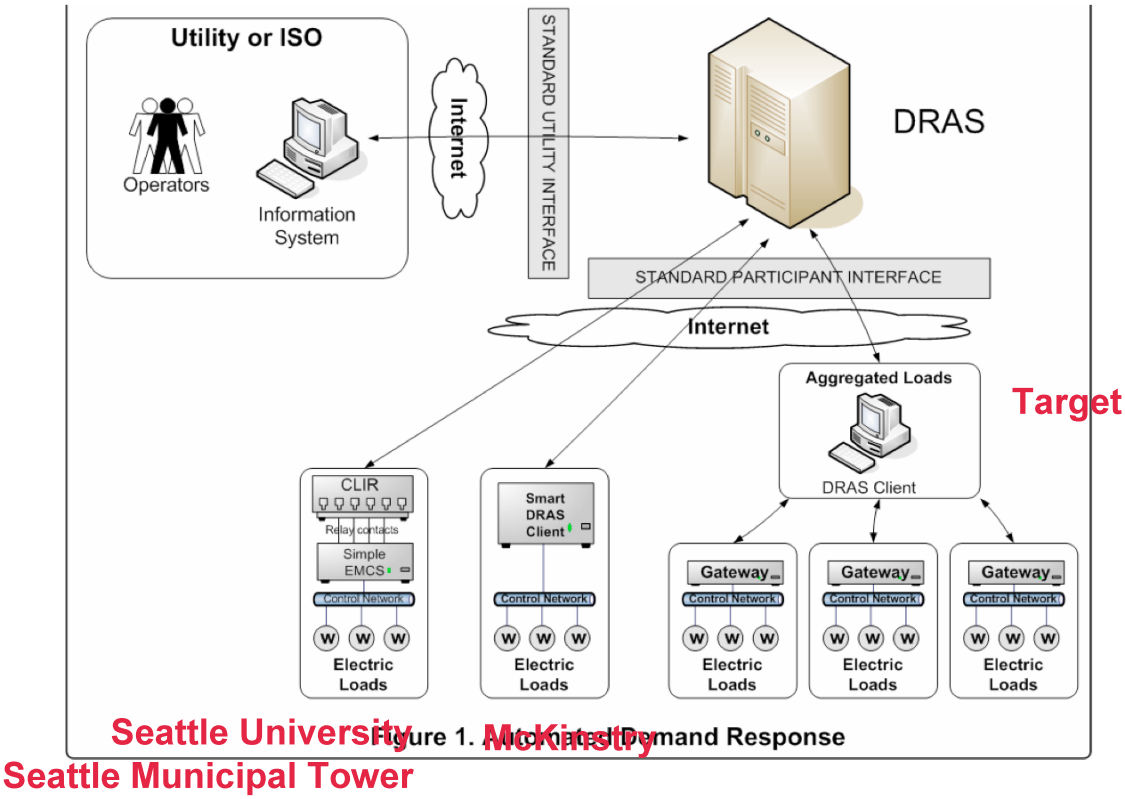

Figure 2 shows the architecture and the type of clients utilized at each facility. Seattle University and Seattle Municipal Tower both used CLIR boxes to communicate with the DRAS. McKinstry has a Richards-Zeta Mediator gateway device. Richard-Zeta developed a software client that communicates with the DRAS and embedded this client into Mediator that is located at McKinstry. Target developed a software client and embedded it into their enterprise control system in Minneapolis. This software client polled the DRAS every minute and sent the DR event information down to Target stores' control equipment as soon as it received it.

3.1.3. The DR Automation Server

Several enhancements were made to the DR Automation Server for this project. The specification that this DRAS was built to was published in April of 2009 (Piette et al. 2009). The OpenADR compliant DR Automation Server supported the DR test requirements for the Bonneville Power Administration (BPA) and Seattle City Light (SCL) DR events. Figure 3 displays the front page of the DRAS Web interface.

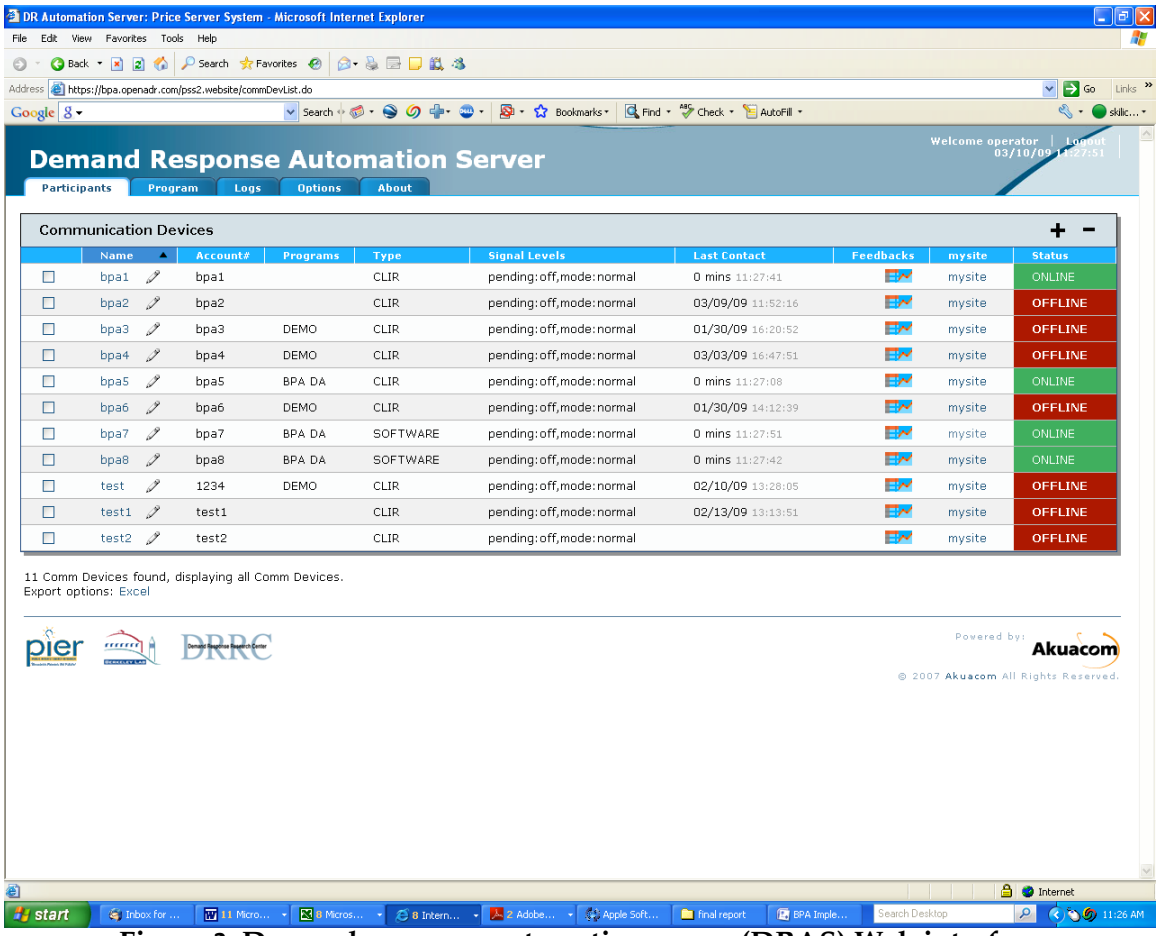

Figure 3: Demand response automation server (DRAS) Web interface

The front page of the DRAS displays all the necessary information for a utility operator to monitor each DRAS client, including the DR program the DRAS client is participating in, the type of DRAS client (CLIR vs. WS software), current DR event signals, last contact with the client, a link to the meter data and online portal to the client, which is called "mysite". The link to each site's meter data, called "feedback", was not used in this project. The far right column shows whether the client is on-line or off-line. For these tests, each client was named "bpa" followed by a number. The clients remained in the "DEMO" program until tests were complete and they were assigned to either day-ahead (DA) or day-of (DO) events. For day-ahead DR events, a pending signal was sent at 3 pm the day before. For day-of events, the pending signal was scheduled to be sent at 6 am for an event starting at 7am. This process was hard-coded into the system so that whenever a day-of event was scheduled, event notification was sent at 6 am on the day of the test DR event. During events, the pending is set to "on" and mode is set to "high".

3.2. DR Event Design

3.2.1. Requirements for Participation

The basic requirements to participate in the DR events are as follows:

- Since SCL indicated that their system peak demand period was between 7 am and 10 am, the team looked for facilities that could reduce loads during this period.

- The sites are screened for use of an energy management control system (EMCS) or energy information system (EIS), or similar end-use devices.
- Since the DR automation infrastructure uses the internet to send DR event signals, access to the Internet (be able to access the Web at the site) is required. Having a Web-enabled EMCS was preferred but not required.
- Each site was encouraged to select DR control strategies that fit with their daily operations. Global zone temperature set point setback, lighting reductions, or shutting off other non-critical loads are examples of such strategies. Each site's facilities staff was to develop these and other strategies that were best suited to their facility.
- Program or hardwire energy management control systems to curtail loads based on CLIR relay contact or XML signal. Simple program changes were conducted by staff or contractor.

In preparation for the winter morning DR events days, the participating sites and subcontractor worked with LBNL on the following tasks (see Appendix A):

1) **Sign Memorandum of Understanding (MOU) -** The MOU was designed for mutual communication purposes. It outlined responsibilities and described the payment of the participation incentive (Appendix B).
2) **Provide General Site Data -** LBNL requested general information about each site including: facility size, use, HVAC equipment type, etc. (Surveys for each site are located in Appendix D).
3) **Define Electric Data Collection Methods** - Some commercial sites have local databases that archive data from electric meters, Energy Management Control Systems (EMCS) or Energy Information Systems (EIS). The MOU describes allowing access by LBNL project staff and the project subcontractors.
4) **Define Shed Strategies -** Successful strategies that were used in summer peaking climate were global zone temperature adjustment, duct static pressure reset, variable frequency drive (VFD) position limiting, chilled water valve position limiting, and reductions in lighting level (Motegi et al. 2007). Facility staff were encouraged to come up with innovative shed strategies that are appropriate for winter morning periods.
5) **Establish Connectivity -** Each site was configured to receive the DRAS generated DR event signals with one of the two following methods:
    - **Client Logic Integrated Relay Box (CLIR Box)** (see Appendix C)
    - **Web services client** – for sites that already have a gateway that connects the EMCS/EIS to the Internet
6) **Program DR Strategies into EMCS –** Once a method of receiving the price signals was established, the EMCS was programmed by the site's control vendor to facilitate the desired sheds upon a rise in price.
7) **Price Signal -** During the DR event each participating site and LBNL received e-mail notifications from the DRAS. SCL and LBNL worked together to select the coldest days to schedule the DR events. Akuacom scheduled DR events directly from the DRAS. During each DR event, each participating site automatically reduced predetermined electric loads.
8) **Documenting the Shed** – LBNL and McKinstry collected whole-building/facility electric demand data for each site in the pilot. When available, detailed data from

an EMCS or other end-use meters was collected and analyzed to understand the dynamics of the DR control strategies.

3.2.2. Recruitment Process

The goal was to recruit 4 to 6 different types of facilities with varying HVAC systems. SCL and McKinstry identified and approached facility managers. Each site was offered a DR audit to determine if the site would be a "good candidate" for the study. A "good candidate" is identified as one that had loads in the morning periods and could be ready for testing by the beginning of February. Sites with interval meters and connection to SCL's MeterWatch utility information system were preferred.

3.2.3. Technical Coordination

The project team identified a need to work with a local engineering firm to assist in the coordination of fieldwork. McKinstry was retained to assist with recruitment, DR audits, DR strategy development, as well as overseeing controls vendors' activities at each facility to program and commission DR strategies. McKinstry was also instrumental in collecting meter data and trend logs.

3.2.4. Pre-evaluation of Sites

A pre-evaluation of sites to assess weather sensitivity and load variability was conducted by LBNL to develop the DR baselines. Most of the sites that were approached for recruitment did not have meters that record and archive demand data in 15 minute intervals. There were two sites with archived demand data that LBNL evaluated to determine weather sensitivity and load variability. One of these sites did not participate in the study because the building was a retail store that did not start up HVAC operations until 9 am to get ready for a 10 am store opening. The other site was Seattle Municipal Tower. Figure 3 plots the Seattle Municipal Tower's weekday average, minimum and maximum 15-minute demand kW for January through March 2008. Standard error bars for the average demand as well as 15-minute minimum and maximum demand values are provided. This site has a peak electric demand of 6 MW at 8am. Initial assessments showed that it is weather sensitive because the demand is highly correlated with outside air temperature. The demand has low variability during the winter months. Variability is defined as the deviation of the load in each hour from an average calculated over all the weekdays.

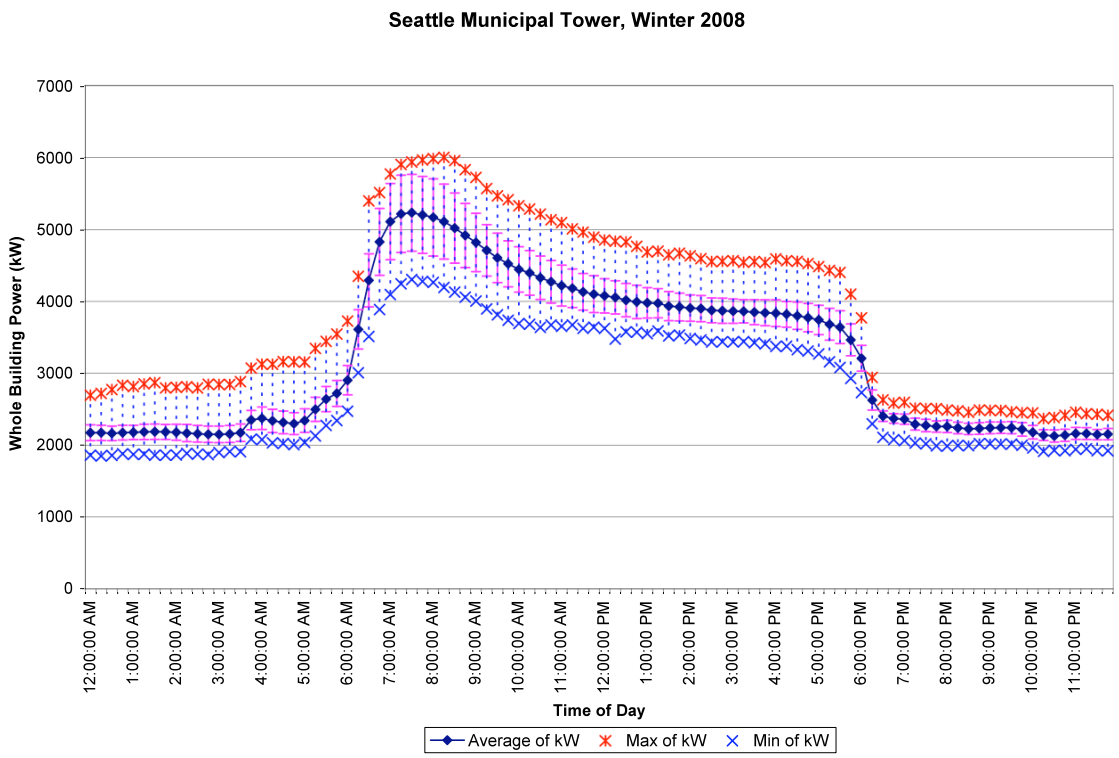

Figure 4. Seattle Municipal Tower 15-minute demand characterization for winter 2008

3.2.5. DR Control Strategies

After the final site selection, potential DR control strategies were developed for each site. McKinstry visited each site to review the DR strategies with the customer and select the final plans. For a site to have a successful automated DR plan, they need to achieve a demand reduction consistently more than the standard error of the baseline over three hours during the DR event period (see Section 3.3.1 for the methodology). Later, the criteria was expanded to include load shape evaluation and require that a "successful" site would have a smooth load shape, free of oscillations during the DR period, with no after event rebound.

One challenge was to identify DR strategies for facilities with gas heating. When the HVAC system is not the largest contributor to the peak electric demand within a building, demand reduction due to HVAC DR strategies may not be large enough compared to the whole building loads. While a combination of lighting and HVAC strategies were selected for one site, another site chose to reduce temperature set points and duty cycle roof-top units. Another challenge was to get the sites ready for test events by the beginning of February. Completing all the steps outlined in the previous section takes on average six months depending on the effort required for coordinating the process among facility managers, controls contractors, and upper management decision-makers (Wikler 2009). In addition, there are often sites that go through the entire process and drop out due to unforeseen issues.

3.3. Evaluation

3.3.1. Peak Demand Baseline Models

LBNL has developed a number of baseline models to estimate the demand savings from the DR strategies (Coughlin et al. 2008). Three baseline models were used to calculate demand reductions for this project. These are outside air temperature regression (OATR) model, three-in-ten (3/10) baseline model and average of similar day baseline model. OATR baseline model works best for weather sensitive buildings. 3/10 baseline model is the preferred baseline model used by utilities in California. The average of similar days model can be used when there is insufficient archived data to develop the other two baselines (this was the case for the Target stores). An afternoon adjustment factor calculation was evaluated as part of this project and is proposed to improve the accuracy of the baseline model. This section describes the three baseline models and the afternoon adjustment calculations.

Outside air temperature regression model baseline

The electric consumption data for each site were collected either through meter data monitoring and logging equipment installed at each facility or through Seattle MeterWatch which is available through SCL. The actual metered electric consumption was subtracted from the baseline-modeled demand to derive an estimate of demand savings for each 15-minute period. Previous research recommends a weather sensitive baseline model with adjustments for morning load variations for accuracy (KEMA-XENERGY, 2003). The LBNL model, which is used to calculate the summer afternoon demand reductions, uses OATR with a scalar adjustment for the morning load. Since the morning periods are when the DR events took place in Seattle, a morning adjustment component was replaced and tested with afternoon adjustment multiplier component.

First, the whole building power baseline is estimated using a regression model that assumes that whole building power is linearly correlated with OAT. The source of the OAT data is Boeing Field. Input data are 15-minute interval whole building electric demand and 15-minute interval or hourly OAT. The model is computed as shown in equition 1;

$$Li = ai + bi\ Ti \qquad (1)$$

where Li is the predicted 15-minute interval electric demand for time i from the previous non-DR event workdays. Depending on the frequency of the available weather data, Ti is the hourly or 15-minute interval OAT of time i. ai and bi are estimated parameters generated from a linear regression of the input data for time i. Individual regression equations are developed for each 15-minute interval, resulting in 96 regressions for the entire day (24 hours/day, with four 15-minute periods per hour. i is from 0:00 to 23:45). To develop the baseline electric loads for the demand savings 10 "non-demand response" days were selected. These 20 baseline days were non-weekend, non-holiday Monday through Friday workdays.

The demand savings estimates for most of the buildings that participated in the study are based on the baseline OATR model. The exception to this rule is that the Target facilities did not have archived data so for the first site and for the first events, as the average of similar days model was used based on as many non-DR days as were available. If the model predicts a lower baseline than the actual demand at any given 15-minute of hourly period, it indicates negative demand savings. Negative demand savings are often found after a DR period as part of a "rebound" or recovery peak in which the HVAC or cooling systems tries to bring the thermal zones back to normal conditions.

The evaluations performed includes quantifying the demand savings (kW) at each site, along with the savings in whole-building power reduction by percentage, and the demand intensity (W/ft²). The demand savings are calculated by subtracting the actual whole building power from its baseline demand. The demand saving percentage is defined as the percentage of savings in whole building power. The demand-saving intensity (W/ft²) is the demand reduction (W) normalized by the building's conditioned floor area (square footage).

Three-in-ten (3/10) baseline

Utilities in California use the 3/10 baseline. This baseline electric load shape is the average hourly load shape of the three highest energy consuming days in the last ten work days (excluding holidays). The baseline algorithm for this project considers the site electric consumption from 7 am to 10 am when selecting the highest three days. DR event days are excluded from the reference days. A disadvantage of the 3/10 baseline method is that it may calculate a baseline that is lower than the actual demand if the site's demand is weather-sensitive. This can occur if a DR event is called on a day with more extreme outside temperatures than the previous ten days. When cooling loads are shed for DR (typically done in warm climates), baseline demand curves can be biased low if the previous ten working days are cooler than the DR event day. The (low) bias problem can also occur when heating loads are shed for DR as was done for this test. This can occur because the previous ten days are likely to be warmer than on the day of the DR event. For commercial buildings, OATR baseline provides a more accurate and less biased baseline than the 3/10 baseline (Coughlin et al. 2008).

As an example, Seattle Municipal Tower's participation in the March 3rd DR event is displayed in Figure 4. The chart shows the actual whole building power, the LBNL OAT regression baseline, indicated as "baseline", and the 3/10 baseline. These baselines estimate what the whole-building power would be if the demand response had not occurred. The vertical line at each baseline power data point is the standard error of the regression estimate. The vertical lines at 7 am and 10 am identify the DR event period. On this day, the 3/10 baseline is higher than the OATR baseline because there have been cooler days within the last 10 days used to develop the baseline. A more accurate baseline may be to use an OATR baseline with afternoon adjusted loads (OAT_AA). In OAT_AA baseline, an afternoon adjustment factor (ra) is multiplied by the each 15-minute-load. The factor ra is defined as the ratio of the actual to the predicted load in the four hours in the afternoon of the event day, as shown in Equation

$$r_a = \sum_{i=1}^{n} L_{a,i} \Big/ \sum_{i=1}^{n} L_{p,i} \qquad (2)$$

Where, r_a is the afternoon adjustment factor,

$L_{a,i}$ is the actual hourly average loads on DR day at the hour's start at *i pm* ;

$L_{p,i}$ is the predicted load by baseline at the hour's start at *i pm*.; and

n is the number of hours which are used for adjustment (*n*=4 for this analysis).

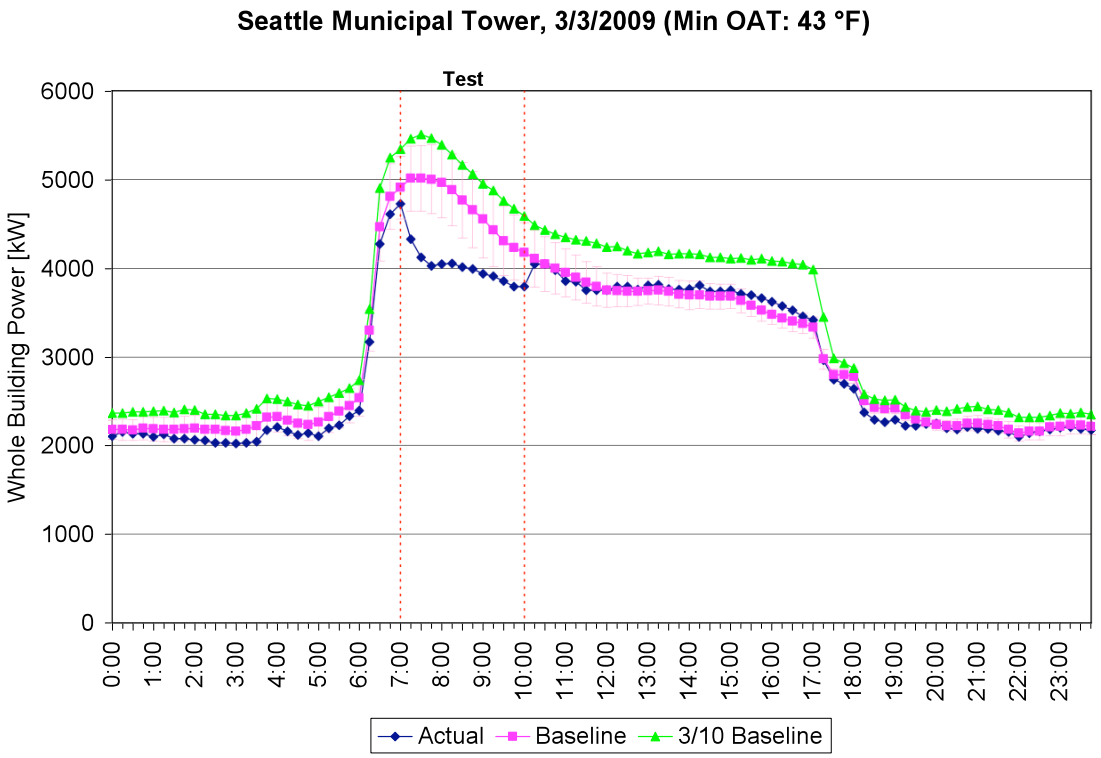

Figure 5: Whole building demand profile

Average of similar day baseline

For two of the Target sites whose interval meters were installed two days before the test events, the average of similar day baseline is used due to the limitation of accessible data range. For these sites, available data are averaged to develop the baseline. As the events progressed, the average included non-test days to develop the baseline.

3.3.2. Data Collection

LBNL requested the collection of various types of data to evaluate the demand savings and changes in building systems and conditions. For all the participating sites, 15-minute whole building interval data were collected. A minimum of ten days of data prior to each DR event was required to develop a baseline model. Some sites did not have interval meters so 15-minute demand data logging devices were installed. HVAC, control, communications, energy, and other building-related time-series data relevant to their demand response strategies were collected. The data collection methods are described in Appendix E. Additional information about the effectiveness of the demand response strategies and issues that arose as a result of the tests were obtained by interviewing the responsible building engineer after each DR event. Section 4.7 documents the results obtained from the post-test surveys.

3.3.3. Successfulness of Participation

Each DR event was evaluated after each event with special attention give to the first event. After the first event, depending on the load amount and load profile, each site

received a "pass" or "fail" indication. Testing continued as initially implemented on the passed sites, while the failed sites had to re-visit their DR control strategies and make changes. LBNL worked with them to develop new strategies and the project provided funds to revise the strategies. There are five milestones that the "system", from the DR Automation Server to the end-use control strategy, has to meet in order for the system to work properly. These milestones are:

1. **Readiness**: The system was configured and ready to for commissioning.
2. **Commissioning of DR strategies**: At each site, DR strategies were commissioned by the control vendor or McKinstry and trend logs were set up before the site participated in the DR events.
3. **Client to DR automation server communication**: When clients are brought on-line or when they go off-line, DRAS operator and site personnel receives an e-mail message. Failures to pass this milestone were generally caused by a defective client or network.
4. **Control of equipment**: End-use systems and equipment were controlled as planned. These included HVAC equipment, lighting and other equipment that generates electric loads.
5. **Effectiveness**: To pass this milestone, the planned demand response strategy must have been proven to effectively reduce electric demand. Effectiveness was tested by comparing the average power (kW) saving during the test to the average standard error of the regression model. The demand response strategy was considered effective if in the high price period, the average power savings over the 3-hour period was larger than the average of the standard error in the baseline model.

3.3.4. Surveys

Site Survey

Detailed surveys were conducted to collect the following information from each site:

- Site contact information
- Building information
- Electric demand
- HVAC system description
- Domestic hot water
- Lighting system information
- Process and other equipment loads

Appendix D contains the site survey that was used. Site summaries for the sites that participated in DR events are provided in Appendix E.

Post-Event Survey

After each DR event, each site's facility operator was reminded to answer the post-event survey. Questions about the automated DR event day included:

- Was the operator on site and watching the event?
- Did he notice a change?
- Were there any operational issues?
- Did the occupants notice any difference?
- Were there any complaints?

3.3.5. Project Timeline

Table 1 summarizes the project timeline and progression. The project started in early November 2008. The first training session for the team took place on November 18th. BPA, SCL, McKinstry, Akuacom and LBNL participated in the all-day training which consisted of a presentation by LBNL on project methodology and a presentation and hands-on training by Akuacom on the DR automation server and client technologies. Recruitment started right after the training and lasted three months. Ten sites filled out the site survey – of these, six were selected to participate in DR events (five sites ended up participating in DR event days). LBNL scheduled a half-day training session for the installation contractors to explain DR and DR strategies. While Akuacom configured the DR automation server (DRAS), site installations and commissioning of DR strategies continued. Winter DR events started on February 28th and ended with the last event on March 20th. LBNL analyzed collected data after each event and provided feedback to the participants on their performance. The draft project report was completed in early June.

Table 1. Actual project timeline

Task	Timeline
Team Training	11/18/2008
Recruit Sites	12/1/2008 - 3/1/2009
Site Audits	12/18/2009 - 3/1/2009
Train Installati on Contractor	1/13/2009
Confi gure DRAS	12/1/2008 - 2/1/2009
Site Installati ons	2/1/2009 - 3/5/2009
Winter DR Test Events	2/18/2009 - 3/20/2009
Evaluate Results	2/18/2009 - 4/20/2009
Report Findings	6/1/2009

4. Results

This section outlines the key results from the 2009 Northwest OpenADR technology demonstrations. This section begins with a review of the participant characteristics followed by DR strategies and results from their participation in four DR events.

4.1. Site Profiles

Five sites were automated and participated in the 2009 Northwest OpenADR technology demonstration tests. Table 2 lists the site names, locations, building use, floor area, year built, and peak electric demand for winter 2009. The participant buildings include two office buildings, one higher education facility and two retail stores. Each site participated in three day-ahead events and one day-of event as described in Section 3.1.3.

Table 2: Summary of site information

Site	Site Address	Building Type	Gross Floor Area ft ²	Year Constructed	Peak Load kW	Peak W/ft
McKinstry	5005 3rd Avenue S	Offi ce	100,000		347	**3.5**
Target - T1284*	302 NE Northgate Way	Retail	165,667	2000	685	**4.1**
Target - T0637*	2800 SW Barton St.	Retail	99,471	1990	225	**2.3**
Seatt le Municipal Tower	700 Fift h Avenue	Offi ce	1,200,000	1989	6168	**5.1**
Seatt le University	901 12th Avenue	Educati on	99,840	2001	841 kVA	**8.4**

The following sections describe the test results from all sites except Target - T0637. Although this store participated in the study, metering data were unavailable due to problems with logging instrument. Therefore, this site was eliminated from the results section. Northwest OpenADR System Profiles

4.1.1. OpenADR Communications

Table 3 summarizes the connectivity options used by the sites. Of the five sites the two Target stores and McKinstry utilized the software clients. Target built on their experience with Auto-DR in California for their software client development effort. The new software client they built adheres to the OpenADR Specification Version 1.0. McKinstry worked with Richards-Zeta which developed the software client and embedded it into Mediator™ gateway device. The remaining two sites installed CLIR boxes onsite. No information technology problems occurred during or after the installation of the CLIR boxes. In one facility, the CLIR box had to be replaced because it required repeated reboots. This box was tested before it was shipped out and it is believed that damage during shipping caused the hardware failures.

Table 3: Communication profiles by site

Site	Client UN	Client Type
McKinstry Seatt le	bpa7	WS Client
Target - T1284	bpa8	WS client
Target - T0637		
Seatt le Municipa Tower	bpa5	Hardware Client (CLIR)
Seatt le Univ.	bpa1 (formerly bpa2)	Hardware Client (CLIR)

4.1.2. Site Data Collection

Table 4 lists the distance from each site to the outside air temperature (OAT) data source used for each participating site. The data were used to develop the OATR baseline. EMCS data were collected and analyzed at each facility. These EMCS data allowed to confirm the operation of the strategies and to evaluate the indoor conditions during DR events. The detail analysis of the EMCS data is described in Appendix D.

Table 4: Outside air temperature source by site

Site	Distance to Boeing Field
McKinstry	2.3 miles
Target - T1284	12.4 miles
Target - T0637	3.2 miles
Seattle Municipal Tower	5.4 miles
Seattle Univ.	5.6 miles

4.1.3. DR Strategies at Each Site

Throughout the previous studies in California, which addressed the summer afternoon peak demand, the global temperature adjustment (GTA) strategy was found to be effective and one of the least disruptive DR strategy (Motegi et al. 2007). To develop heating strategies, the heating system had to be studied in detail. If the building system used gas for heating, the only potential saving from GTA is the savings from fan power in variable air volume (VAV) systems. When the heating setpoint is reduced, the fans that supply heat to a zone will temporarily slow down thus reducing the electric demand. Of the five buildings that participated in the OpenADR events, two Target stores participated with both lighting and HVAC system reductions. SMT has all electric heating and employed the GTA as a strategy. Seattle University selected preheating as a strategy and turned off electrical heating units as well as adjusting temperature setpoints. McKinstry duty cycled roof-top units. HVAC and lighting systems in each of the facilities are summarized in Table 5 .

Table 5. Description of systems

	HVAC System		Lighting System
Site	**Primary System Attributes**	**Secondary System Attributes**	**Switching/Dimming**
McKinstry (McK)	Gas heating combination of VAV (7) and CAV (16) RTUs (total - 23)	Single duct; 10 single zone, 13 multi-zone	Central Scheduled Sweep
Seattle Municipal Tower (SMT)	Electric heating VAV (690)with AHUs (48)	Single duct; multi-zone	Central Scheduled Sweep
Target (both stores)	Gas heating VAV RTU (15)	Single duct; single zone	Central fixture switching (checker board)
Seattle University (SU)	Electric heating; VAV (102) with AHUs (4), cabinet and unit heaters	Single duct; multi-zone; with reheat	Central Scheduled Sweep

Detailed description of the strategies and comments on these sites are as follows:

- **Target (both stores):**
  - **DR Strategy:** Turn off 50% of sales area lights, turn off two out of 12 roof-top units and decrease setpoints by 2 ºF.
  - **Recovery:** No known recovery strategy
  - **Issues:** stores did not have interval meters therefore additional meters had to be installed.
- **Seattle Municipal Tower**
  - **DR Strategy:** Decrease setpoints from 72 ºF to 68 ºF on selected 24 floors out of 62 floors. Cycle VAV boxes (690) and corresponding air handling units (AHUs) (48).

- **Recovery:** Set setpoints back 1º every 15 minutes and bring back quarter of the equipment on line every five minutes.
- **Issues:** The site completed the DR strategies programming only on selected floors due to time limitations.

- **McKinstry**
  - **DR Strategy:** Uniformly turn off half of the 23 roof-top units for 15 minutes and alternate with the remaining units every 15 minutes.
  - **Recovery:** Stage turning on equipment every 2 minutes.
  - **Issues:** This site was also not connected to SCL's MeterWatch utility information system.
- **Seattle University**
  - **DR Strategy:** Pre-heat at 5 am at 74 ºF (only on the day-ahead days because pending signal for day-of events are received at 6 am) Decrease set point to 68 ºF. Cycle cabinet heaters (7) and unit heaters (2) 20 minutes every 30 minute. Cycle through half of variable air volume (VAV)/Air terminal boxes (75) and AHU fans (4) every half hour. Set CO_2 setpoint up by 200 ppm. Turn off hot water panel radiator.
  - **Recovery:** Return setpoints to original levels (maximum rate of setpoint change is 1º per 15 minutes) and turn half of units on, then turn remainder of units on five minutes later.
  - **Issues:** This site also did not have an interval meter. A logger was installed for the duration of the project.

Table 6 displays a range of DR strategies that were discussed with the sites and summarizes the DR control strategies chosen by each site.

Table 6. Summary of DR control strategies

	HVAC												Lighti ng					Other		
Site	Global temp. adjustment	Duct stati c pres. decrease	SAT decrease	Fan VFD limit	RTU Shut off	Duty Cycling RTUs	Pre-heati ng	Fan-coil unit off	Cycle electric heaters	Cycle AHU Fans	Cycle VAVs	Set up CO2 Setpoints	Common area light dim	Offi ce area light dim	Turn off light	Dimmable ballast	Bi-level switching	Non-criti cal process shed	Elevator cycling	Slow Recovery
McKinstry						X														X
Target - T1284	X				X												X			
Seatt le Municiple Tower	X									X	X									X
Seatt le University	X					X	X		X	X	X	X								X

4.2. Automation of Events

This project successfully demonstrated that using the OpenADR specification to deliver automated DR is technically feasible with existing technology and buildings can provide significant levels of automated demand response on winter mornings. This section discusses the key results starting with a summary of each site's participation in the DR

test process and events. See Appendix E for further information and detailed event results for each site.

4.2.1. Participation Summary

OpenADR events started on February 18th. A total of 12 events were scheduled to make sure that all sites participate in four events, one of which is a day-of event. As the sites were enabled, events were called to capture cold winter mornings. There is no one event that all the sites participated. However, on March 11th, four out of five sites participated.

Table 7: Summary of Event Participation

	18-Feb	25-Feb	3-Mar	5-Mar	9-Mar	10-Mar	11-Mar	12-Mar	16-Mar	18-Mar	20-Mar
Site	**Test 1**	**Test 2**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**	**Test 10**	**Test 11**	**Test 12**
McKinstry Seattle	Day Ahead	Day Ahead		Day-Of			Day Ahead				
Target - T1284			Day Ahead	Day-Of	Day Ahead		Day Ahead				
Target - T0637							Day Ahead		Day-Of	Day Ahead	Day Ahead
Seattle Municipal Tower			Day Ahead	Day-Of	Day Ahead		Day Ahead				
Seattle Univ.						Day Ahead		Day Ahead	Day-Of	Day Ahead	

4.3. Demand Savings

This section describes the results of the demand reduction savings analysis. Throughout this report, the demand savings are based on LBNL's OATR model baseline unless otherwise noted. Savings estimates based on the 3/10 baseline are also shown. First, a summary of each site's performance is presented, followed by aggregated savings on March 11 where four out of five sites participated in the test event.

4.3.1. Individual Sites

In this section, for each site, the demand profiles for are discussed.

McKinstry

McKinstry's initial strategy was to uniformly turn off half of the 23 roof-top units for 15 minutes and alternate with the remaining units every 15 minutes. Figure 5 shows the resulting demand profile for the February 18th event. While demand savings were realized, there are two problems with this demand profile: 1) the shape itself is not smooth and displays unsteadiness; and 2) the "successful" criteria was not met. For a site to be "successful", they need to achieve demand reduction consistently more than the standard error of the baseline over three hours during the DR event period. After this feedback, the site extended the duty cycling period, ensured duty cycling of equivalent load, and worked on slow DR recovery strategies that staged turning the roof-top units on every two minutes instead of every minute. Table 8 displays maximum and average demand reduction amount, demand reduction intensity and percent demand reduction from whole building power for each hour and for the DR event period using outside air temperature regression and three-ten baseline methods.

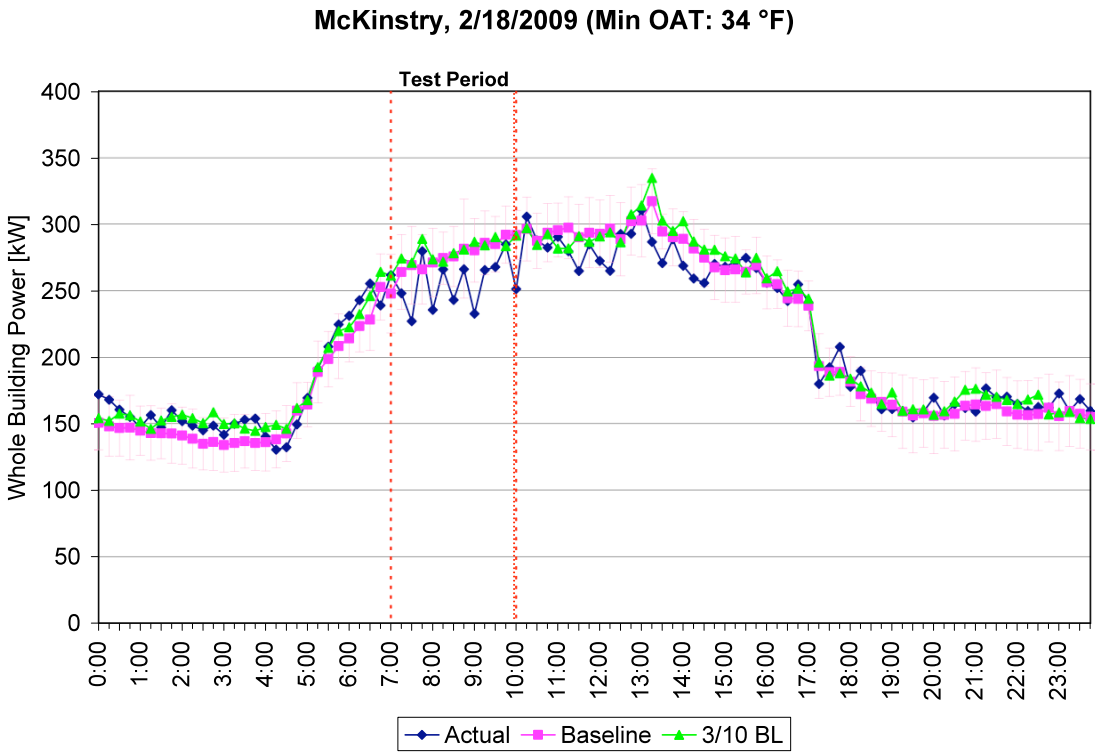

Figure 6. Demand profile of McKinstry from DR test on February 18, 2009

Table 8. Hourly average and maximum demand savings of McKinstry on February 18, 2009

Date	Baseline	Period	kW		W/ft²		WBP%	
			Max	Ave	Max	Ave	Max	Ave
Feb-18	OAT BL	7:00-8:00	42	20	0.42	0.20	16%	7%
		8:00-9:00	48	26	0.48	0.26	17%	9%
		9:00-10:00	41	21	0.41	0.21	14%	7%
		7:00-10:00	48	22	0.48	0.22	17%	8%
	3/10 BL	7:00-8:00	44	29	0.44	0.29	16%	11%
		8:00-9:00	54	27	0.54	0.27	19%	10%
		9:00-10:00	40	20	0.40	0.20	14%	7%
		7:00-10:00	54	26	0.54	0.26	19%	9%

The impact of changing the staging interval are displayed in Figure 7. This site achieved a deeper shed which remained outside of the standard error during the DR period. The summary of the three hour DR test period is displayed inTable 9.

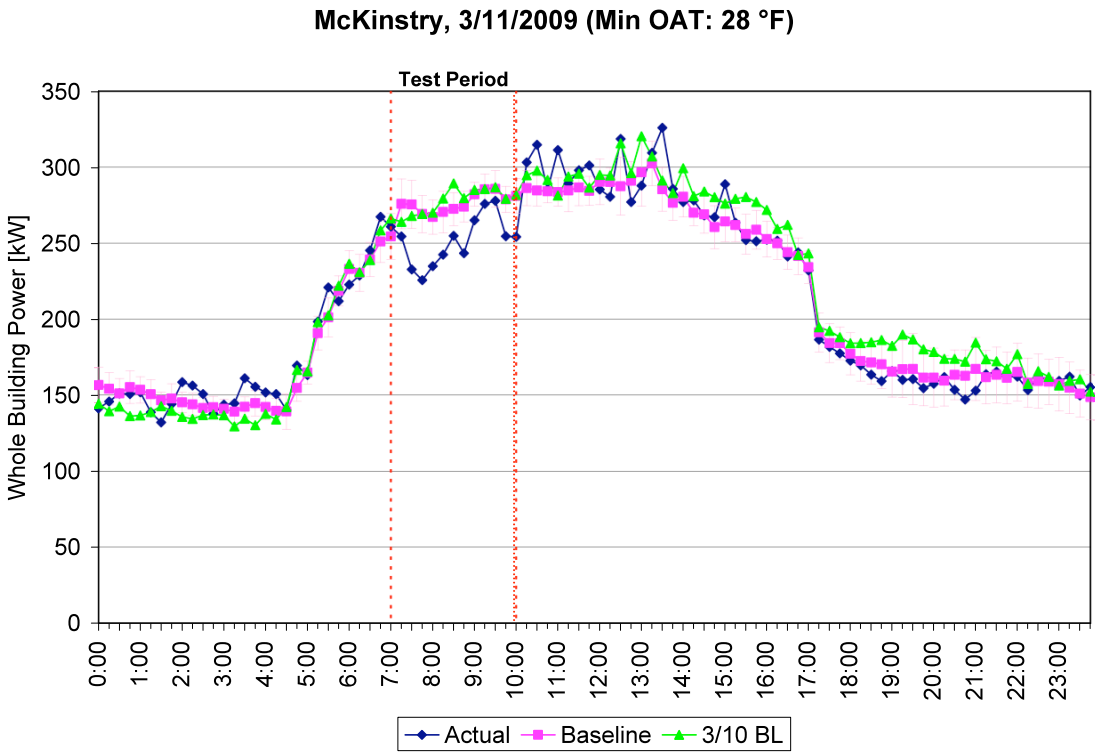

Figure 7. Demand profile of McKinstry from DR test on March 11, 2009

Table 9. Hourly average and maximum demand savings of McKinstry on March 11, 2009

Date	Baseline	Period	kW		W/ft²		WBP%	
			Max	Ave	Max	Ave	Max	Ave
Mar-11	OAT BL	7:00-8:00	44	35	0.44	0.35	16%	13%
		8:00-9:00	31	23	0.31	0.23	11%	9%
		9:00-10:00	27	17	0.27	0.17	10%	6%
		7:00-10:00	44	25	0.44	0.25	16%	9%
	3/10 BL	7:00-8:00	44	31	0.44	0.31	16%	11%
		8:00-9:00	37	32	0.37	0.32	13%	11%
		9:00-10:00	28	18	0.28	0.18	10%	6%
		7:00-10:00	44	27	0.44	0.27	16%	10%

Target Stores

None of the Target stores were on SCL's MeterWatch system and both required the installation of meter data collection and monitoring devices. Both monitoring devices were then connected with Target's enterprise EMCS system. Due to a problem that occurred in this system, the meter data and trend logs were not available for the second store. Therefore, in this section, only data for Target T1284 is presented. The baseline used is an averaging baseline explained in detail in Section 3.3.1 and does not have the standard error bars. There were only two days of data collected before the first event.

In the first hour of the DR event, the store turned off two of their twelve sales area rooftop units and reduced setpoint temperatures by 2°F. At 8am, half (rather than all) of the sales area lighting was turned on to prepare for store opening. The effect of these strategies can be seen in the demand profile in Figure 7. Hourly demand savings is presented in Table 9. The store maintained on average 19% load reduction for the duration of the DR test. Both strategies provided demand savings, but the lighting strategy provided a larger fraction of the savings. After the test, there is a slight rebound peak that can be attributed to the lack of recovery strategies. The existing data collected from this site showed that there is no variation in demand reduction among the events and consistent demand reduction was maintained during the events

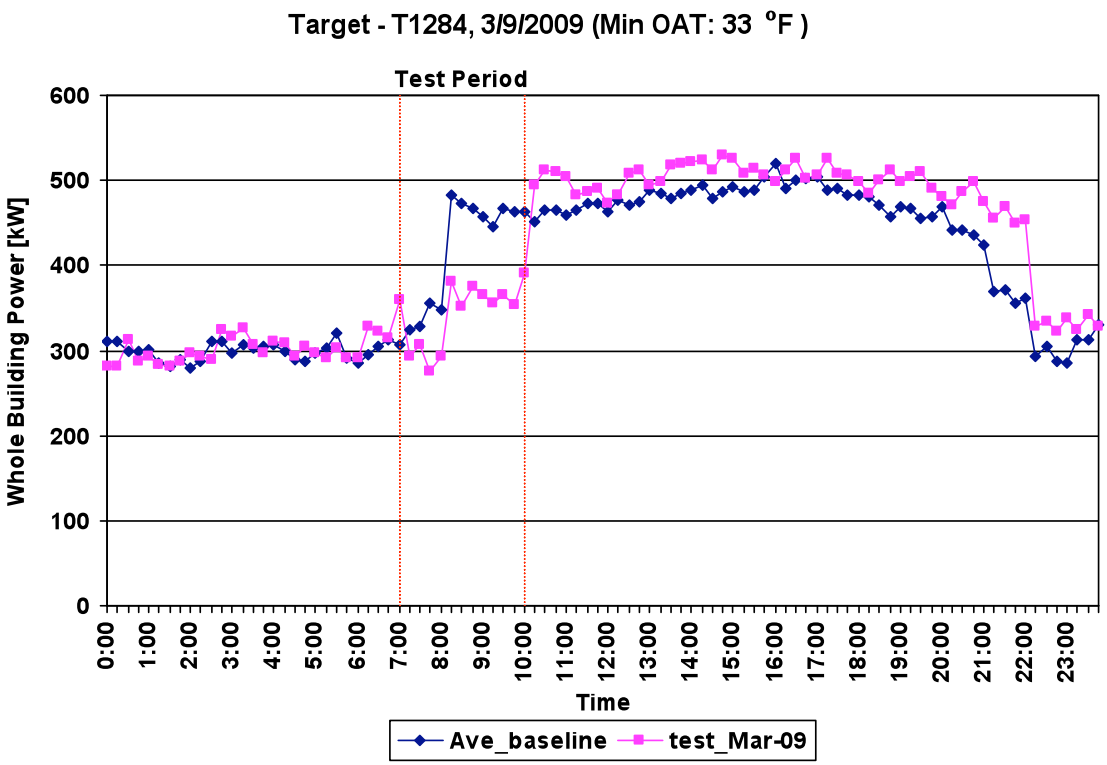

Figure 8. Demand profile of T1284 from DR test on March 9, 2009

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Table 10. Hourly average and maximum demand savings of T1284 on March 9, 2009

Date	Baseline	Period	kW		W/ft²		WBP%	
			Max	Ave	Max	Ave	Max	Ave
Mar-09	Ave BL	7:00-8:00	80	47	0.48	0.29	22%	14%
		8:00-9:00	122	101	0.74	0.61	26%	22%
		9:00-10:00	109	93	0.66	0.56	24%	20%
		7:00-10:00	122	81	0.74	0.49	26%	19%

Seattle University Student Center

The first event day for this facility was March 10th, 2009. This site successfully participated in three of the DR events after that, with March 10th being their most successful day (141 kW, 20% demand savings). The lowest average reduction for this site was on March 12th, 2009 (Figure 9), with an average shed of 15%. While the trend logs show that all of the DR strategies took place as designed, the site did not achieve the same level of reduction calculated on other DR test days. A closer observation of the demand profile and the baselines show that the baseline was lower that the actual demand recorded on the afternoon on the same DR test day. Therefore the variation in the demand reduction may be due to the variation in the baseline.

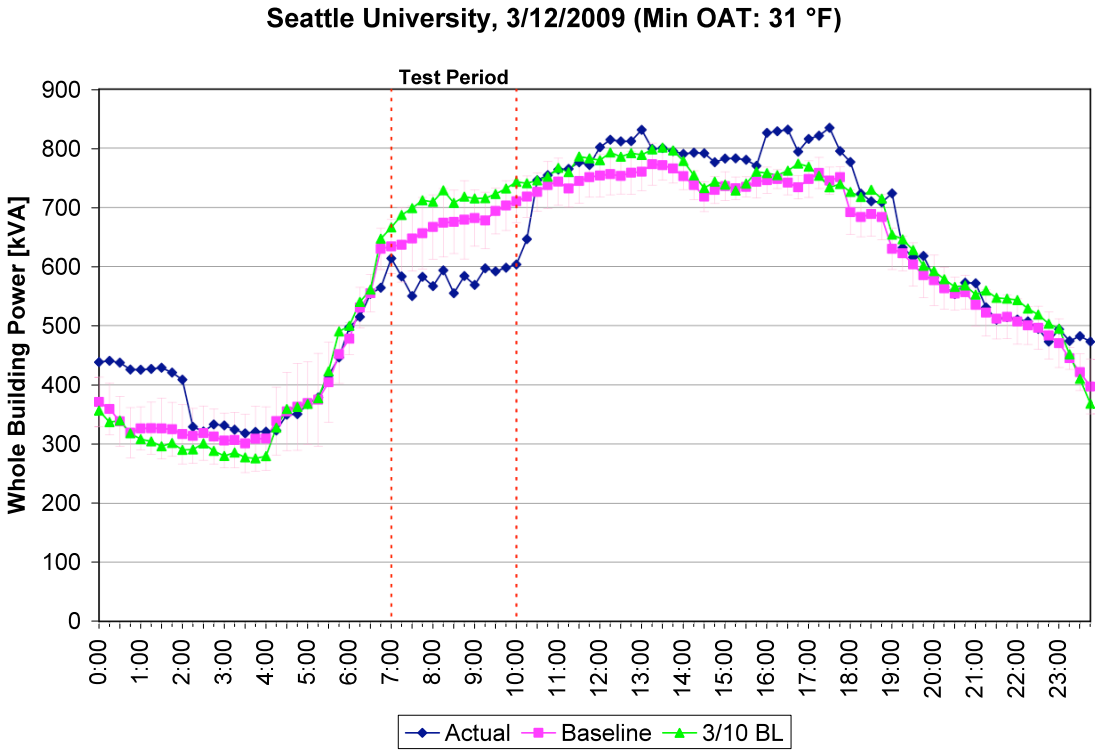


Figure 9. Demand profile of Seattle University Student Center from DR test on March 12, 2009

Table 11. Hourly average and maximum demand savings of Seattle University Student Center on March 12, 2009

Date	Baseline	Period	kVA		VA/ft²		WBP%	
			Max	Ave	Max	Ave	Max	Ave
Mar-12	OAT BL	7:00-8:00	100	81	1.00	0.81	15%	12%
		8:00-9:00	121	102	1.21	1.03	18%	15%
		9:00-10:00	107	99	1.07	0.99	15%	14%
		7:00-10:00	121	94	1.21	0.94	18%	14%
	3/10 BL	7:00-8:00	149	131	1.49	1.31	21%	19%
		8:00-9:00	153	142	1.53	1.42	22%	20%
		9:00-10:00	140	131	1.40	1.31	19%	18%
		7:00-10:00	153	135	1.53	1.35	22%	19%

March 10th was the first day Seattle University participated in a DR event. On one of the coldest test days, the site's average reduction was 21% and well outside of the standard error of the baseline. Note the higher early morning load that may be due to colder nighttime temperatures and a colder morning. The trend log collection started at 5 am on the test day so there is not enough system information to conclude why the loads were higher than usual on the DR event day.

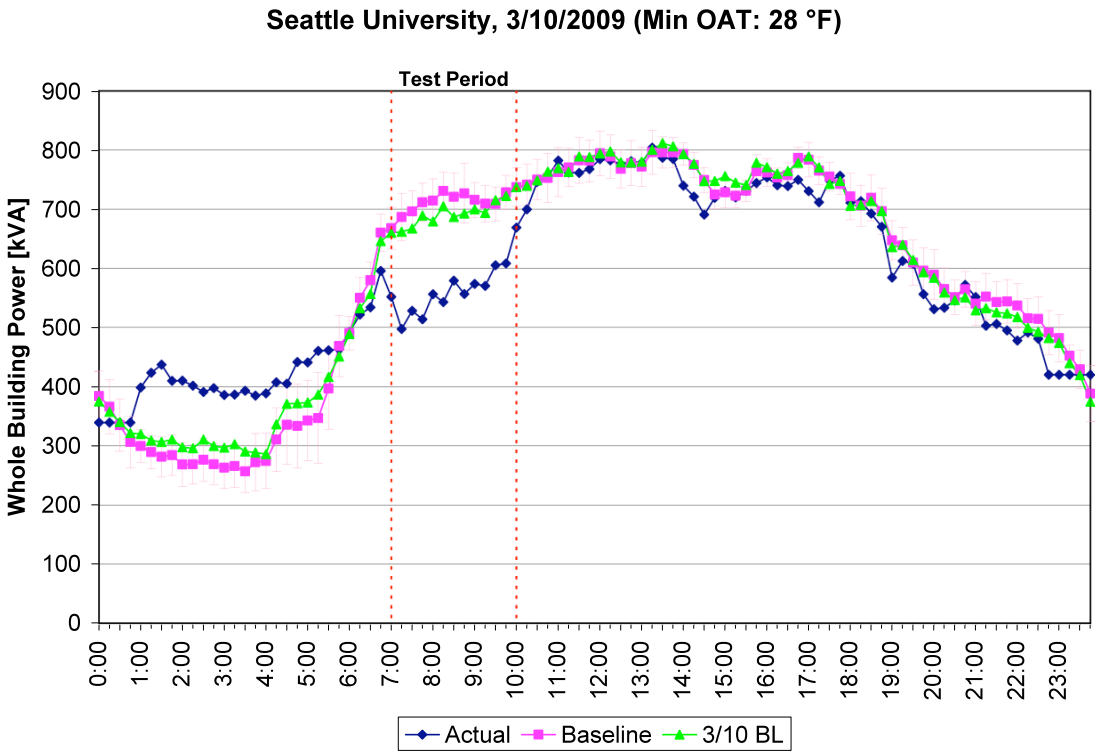


Figure 10. Demand profile of Seattle University Student Center from DR test on March 10, 2009

Table 12. Hourly average and maximum demand savings of Seattle University Student Center on March 10, 2009

Date	Baseline	Period	kVA		VA/ft²		WBP%	
			Max	Ave	Max	Ave	Max	Ave
Mar-10	OAT BL	7:00-8:00	198	178	1.98	1.79	28%	25%
		8:00-9:00	188	160	1.88	1.61	26%	22%
		9:00-10:00	139	108	1.39	1.08	20%	15%
		7:00-10:00	198	149	1.98	1.49	28%	21%
	3/10 BL	7:00-8:00	175	150	1.75	1.51	25%	22%
		8:00-9:00	162	133	1.62	1.33	23%	19%
		9:00-10:00	123	104	1.24	1.04	18%	15%
		7:00-10:00	175	129	1.75	1.29	25%	19%

Seattle Municipal Tower

Seattle Municipal Tower's demand profile shows a large winter morning peak. This all electric heat building has over 6 MW of demand that peaks between 7 am and 10 am on cold winter mornings. This site implemented DR strategies in 24 of their 62 floors, resulting in sheds visible in the whole building loads. While the March 9th shed is clearly identifiable from the demand profile (Figure 10), the load profile over the test day is significantly different from that of the March 10th baseline (Figure 11). The baselines for the two days are similar in shape, however the March 9th baseline generated remained below the actual demand in the early hours and late morning. Possible reasons could that the test day's nighttime and early morning outside temperatures were much lower than the baseline days, Monday morning startup or other unusual operation pattern. As such, the baseline generated seems not to be representative of the DR event day and results in a low calculated demand savings.

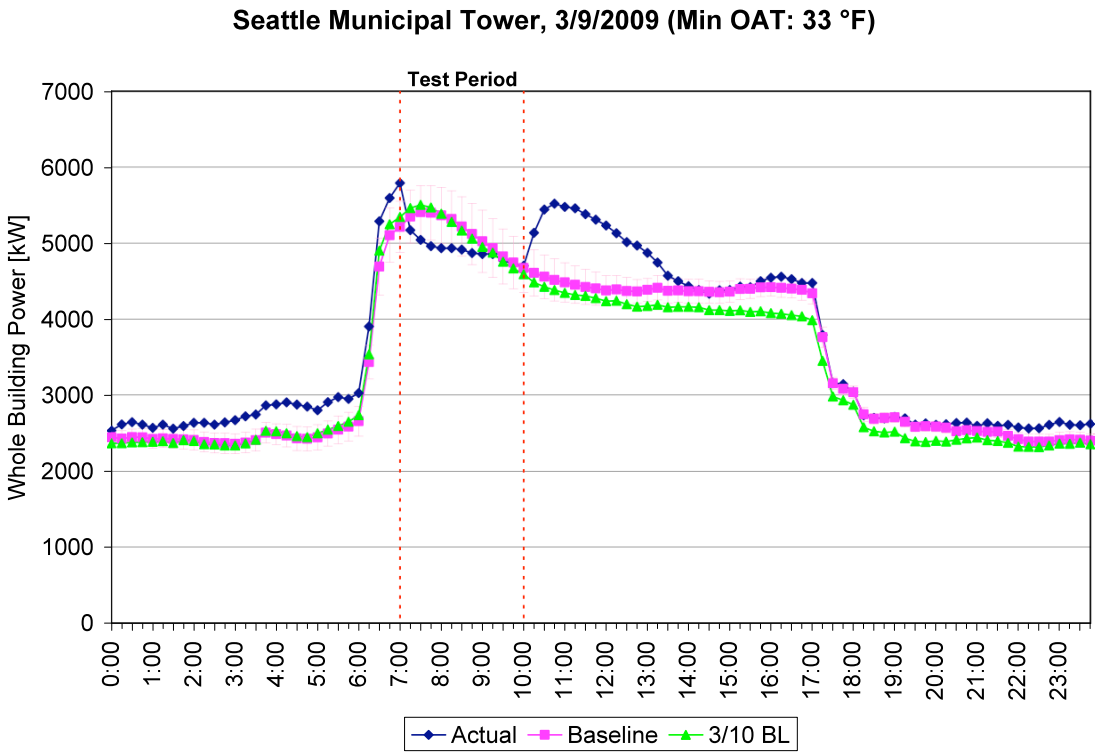


Figure 11. Demand profile of Seattle Municipal Tower on March 9, 2009

Table 13. Hourly average and maximum demand savings of Seattle Municipal Tower on March 9, 2009

Date	Baseline	Period	kW		W/ft²		WBP%	
			Max	Ave	Max	Ave	Max	Ave
Mar-09	OAT BL	7:00-8:00	440	353	0.37	0.29	8%	7%
		8:00-9:00	384	277	0.32	0.23	7%	5%
		9:00-10:00	78	31	0.07	0.03	2%	1%
		7:00-10:00	440	220	0.37	0.18	8%	4%
	3/10 BL	7:00-8:00	509	428	0.42	0.36	9%	8%
		8:00-9:00	348	220	0.29	0.18	7%	4%
		9:00-10:00	18	-41	0.02	-0.03	0%	-1%
		7:00-10:00	509	202	0.42	0.17	9%	4%

The March 11th demand profile for this facility looks better and results in 9% demand savings. On this cold day, the shed was outside of the standard error and averaging 8% reduction. The baseline remains below the actual demand immediately before and several hours after the event.

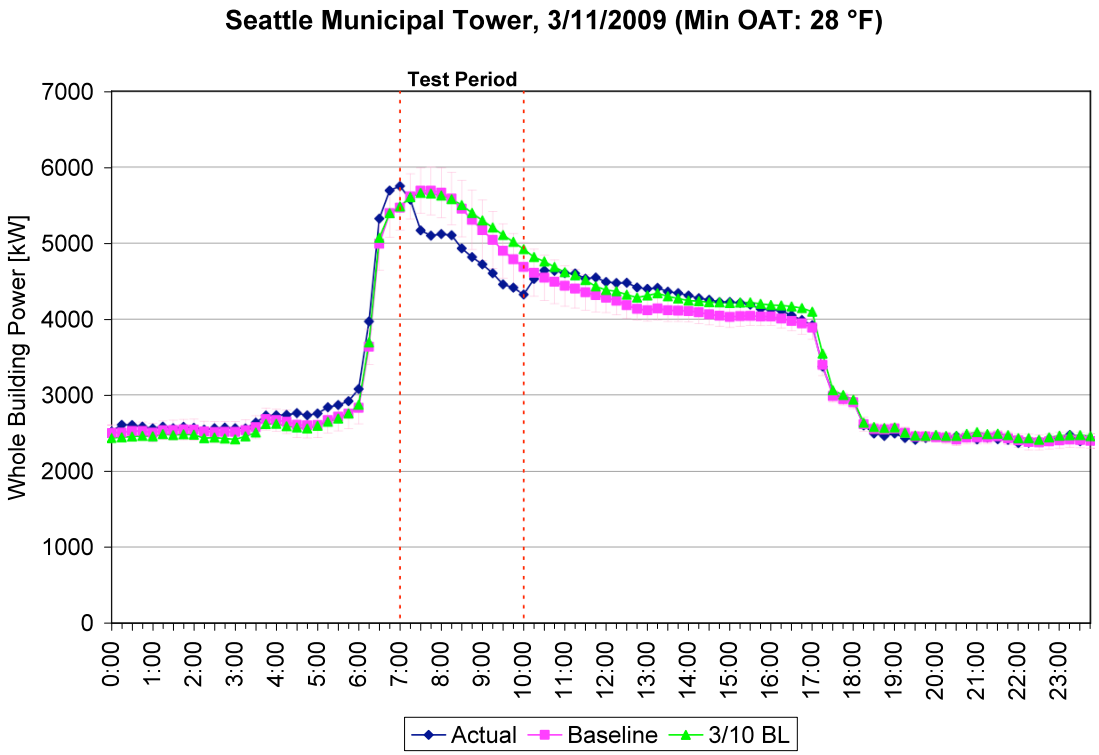


Figure 12. Demand profile of Seattle Municipal Tower on March 11, 2009

Table 14. Hourly average and maximum demand savings of Seattle Municipal Tower on March 11, 2009

Date	Baseline	Period	kW		W/ft²		WBP%	
			Max	Ave	Max	Ave	Max	Ave
Mar-11	OAT BL	7:00-8:00	590	424	0.49	0.35	10%	7%
		8:00-9:00	523	487	0.44	0.41	10%	9%
		9:00-10:00	441	403	0.37	0.34	9%	8%
		7:00-10:00	590	438	0.49	0.37	10%	8%
	3/10 BL	7:00-8:00	554	396	0.46	0.33	10%	7%
		8:00-9:00	581	551	0.48	0.46	11%	10%
		9:00-10:00	650	613	0.54	0.51	13%	12%
		7:00-10:00	650	520	0.54	0.43	13%	10%

4.3.2. Aggregated Results from March 5, 2009

Three sites (McKinstry, Target T1284 and Seattle Municipal Tower) participated in the DR event on March 5th, however the meter data from Target store was lost due to communications problems. The aggregate data shown in Figure 12 is the non-coincident

aggregate that was developed based on the March 5th data from Seattle University and Seattle Municipal Tower and the average of the March 3rd and March 9th data from Target. The expected demand reduction from three of the sites is summarized in Table 15.

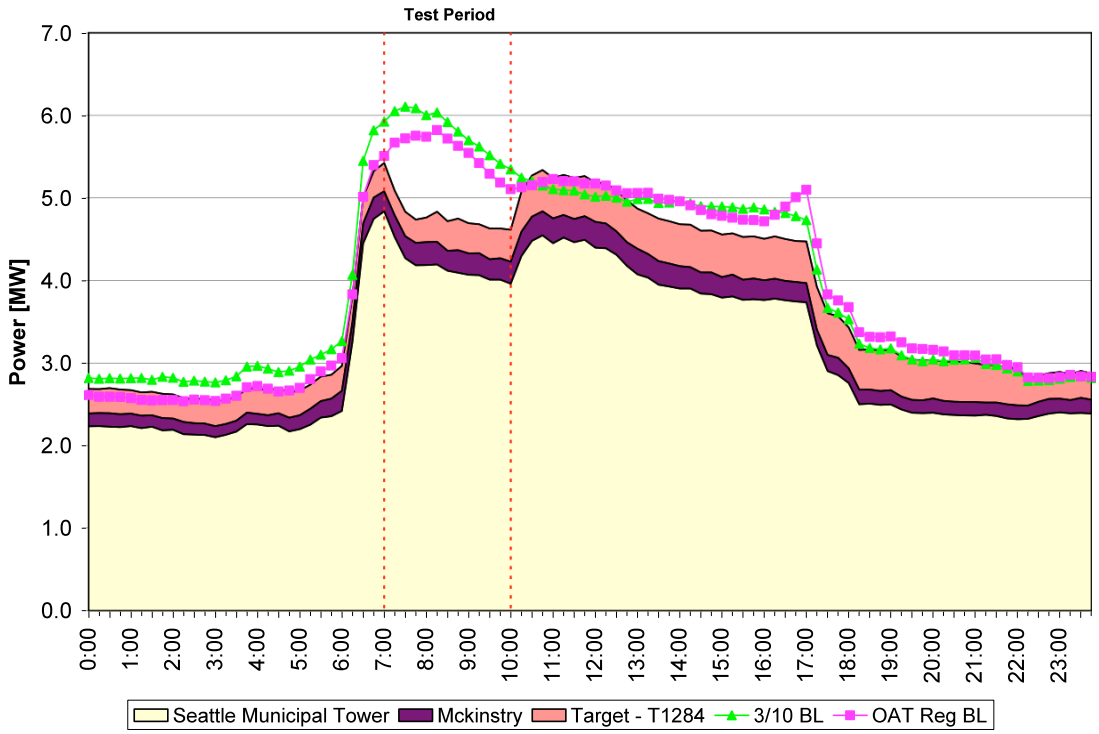


Figure 13. Aggregate demand reduction

Table 15: Summary of Demand Savings, March 5, 2009

Baseline	Period	kW		W/ft²		WBP%	
		Max	Ave	Max	Ave	Max	Ave
OAT BL	7:00-8:00	1014	865	0.69	0.59	18%	15%
	8:00-9:00	1002	929	0.68	0.63	17%	16%
	9:00-10:00	742	613	0.51	0.42	13%	11%
	7:00-10:00	1014	802	0.69	0.55	18%	14%
3/10 BL	7:00-8:00	1348	1206	0.92	0.82	22%	20%
	8:00-9:00	1202	1115	0.82	0.76	20%	19%
	9:00-10:00	941	836	0.64	0.57	17%	15%
	7:00-10:00	1348	1052	0.92	0.72	22%	18%

4.4. Summary of Demand Savings

Table 16: Summary of average demand saving by each site

Table 16 shows the demand savings of each site for the test period (7 am to 10 am) for all the test events. Except for the Target site, the sheds in table 16 are calculated using OATR model with no adjustments. The Similar day average baseline model was used for

the Target site due to the lack of historical data. The average saving was 192 kW (14%) for average 1.4 participant sites per event. The average of site average savings is defined as;

$$Average\ of\ site\ average\ saving\ kW = \sum_{i=1}^{i=N}\left(\sum_{i=1}^{i=n} Average.kW \Big/ n\right) \tag{3}$$

(N: number of participant sites, n: number of event days)

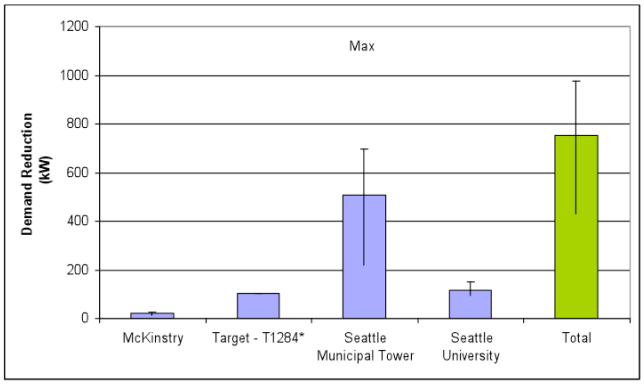
$$Average\ of\ site\ average\ saving\ \% = \tag{4}$$

$$\frac{Average.of.site.average.saving.kW}{\sum_{i=1}^{i=N}\left[\sum_{i=1}^{i=n}\left(Average.baseline.kW\right)\Big/ n\right]} \frac{Average.of.site.average.saving.kW}{\sum_{i=1}^{i=N}\left[\sum_{i=1}^{i=n}\left(Average.baseline.kW\right)\Big/ n\right]}$$

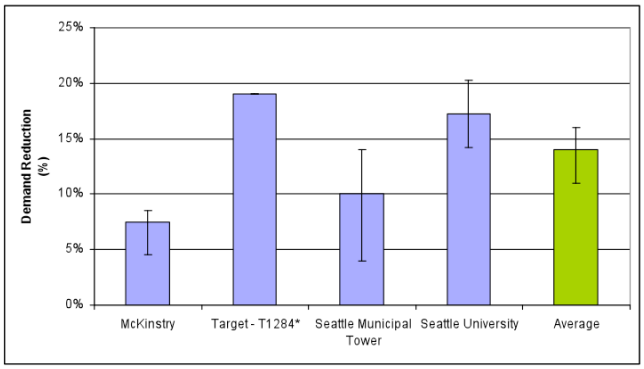
Site	Test Date	Feb-18	Feb-25	Mar-03	Mar-05	Mar-09	Mar-10	Mar-11	Mar-12	Mar-16	Mar-18	Average
	OAT (DegF)	41	41	43	38	33	28	28	31	37	39	36
McKinstry	W/sqft	0.25	0.16		0.15			0.27				**0.21**
	kW	25	16		15			27				**21**
	WBP%	9%	6%		5%			10%				**8%**
Target - T1284*	W/sqft			0.50		0.51						**0.51**
	kW			102		104						**103**
	WBP%			19%		19%						**19%**
Seattle Municipal Tower	W/sqft			0.57	0.60	0.18		0.40				**0.44**
	kW			678	717	220		477				**523**
	WBP%			15%	15%	4%		9%				**11%**
Seattle University	W/sqft						1.41		1.02	1.27	1.12	**1.21**
	kW						141		102	127	112	**121**
	WBP%						20%		15%	19%	17%	**18%**
All Sites	W/sqft											**0.59**
	kW											**192**
	WBP%											**14%**

Sheds are calculated using OAT regression model with no adjustments
*Baseline calculations for Target sites lack historical data.

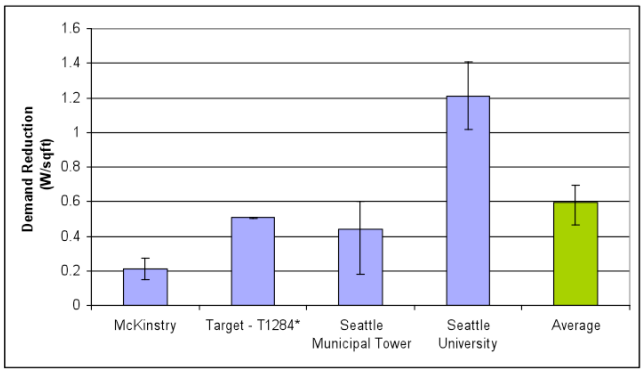
Figure 14 summarizes the site-specific and overall average demand reduction data measured in the test events shown in Table 16 in terms of absolute demand savings (kW), demand savings as a percentage of the peak demand (%) and demand savings per square foot of conditioned space (W/sqft). For each average value (bars), maximum and minimum savings (top and bottom of each vertical line, respectively) are also included to indicate the variation in savings. The variations are due to variations in the whole building demand and baseline. Seattle Municipal Tower achieved the largest absolute demand savings because it is the largest building in the sample. A better comparison is the demand savings as a percentage of the peak demand. Both Target and Seattle University have average savings around 20%. However, the demand savings intensity graph shows that Seattle University achieved deeper savings intensity to achieve the same level of whole building percentage demand savings. Two days of data for Target is not enough to assess demand reduction variations.



Absolute Demand Reduction (kW)



Percent of Peak Reduction



Demand Intensity (W/sqft)

Figure 14. Average, minimum and maximum demand savings at each site by demand (kW), percentage (%) and demand intensity (W/sqft)

4.5. Cost of Automating DR at Participant Facilities

In this section, we summarize the cost to enable Auto-DR for each site. These costs include electrical installation costs as well as costs for labor, programming and commissioning the systems. The cost data was collected after the payments were finalized for each facility. Table 17 shows the breakdown of costs for each site.

Table 17. Cost of automated DR implementations

Site	Controls Vendor	Controls Cost	Commissioning DR Strategies	Total
McKinstry (McK)	ATS	$ 3,780	$ 1,071	$ 4,851
Seatt le Municipal Tower (SMT)	Siemens	$ 4,007	$ 1,071	$ 5,078
Target (both stores)	ALC	$ 6,500	$ -	$ 6,500
Seatt le University (SU)	ESC	$ 2,783	$ 1,071	$ 3,854
Average costs per site		**$ 3,414**	**$ 1,071**	**$ 4,057**

*These values do not include CLIR box installation and pulling wires to the controllers. If needed, average additional cost is $1,000.

Control costs include the DR strategy development, programming, hardware or software client development or installation costs at each facility. Material costs include metering or logging devices that were installed to collect the required data. Although the controls companies did test the DR strategies they programmed, McKinstry also commissioned each DR strategy prior to testing. Target facilities were thoroughly commissioned by their controls vendor. In addition, not reported in the table above, there is on average $1,000 electrical cost per site that includes the installation of CLIR boxes and pulling wires to the controllers.

Table 18 presents these same automated costs based on per unit of demand (kW) reduced. One-time costs of automation of DR presented as cost per kW can be directly compared with on-going generation costs. Experience in California agrees with the findings in the Northwest: Automation is least costly for larger commercial buildings (Kiliccote at al. 2008).

Table 18. Summary of costs per average demand reduced (kW)

Site	Controls Vendor	Controls Cost ($/kW)	Commissioning DR Strategies ($/kW)	Total ($/kW)
McKinstry (McK)	ATS	180	51	231
Seatt le Municipal Tower (SMT)	Siemens	8	2	10
Target (both stores)	ALC	33	0	33
Seatt le University (SU)	ESC	23	9	32
Average costs		**61**	**21**	**76**

4.6. Participant Survey Results

While the project team intended to collect feedback from building mangers after each event, due to the short span of the test period and repeated events within a given week, the sites provided overall feedback on the comfort conditions and overall automation issues at the end of the test event period. The summary of the feedback form each site is as follows:

- McKinstry: No comfort or automation issues.
- Target: There were issues with the reduced sales floor lighting due to zoning. When lighting was reduced to 50% the fitting rooms were too dark for guests.

However, this is directly related to the switching zoning selected by Target. Lighting zones for switching half of the lighting fixtures is suspected to be set up incorrectly. The store had no complaints regarding thermal comfort. Problems with notifications were observed. The DRAS accommodates notifications to three e-mail addresses for each client while eight people had to be notified for Target. A distribution list was created but was neglected to be included in one of the e-mail slots available. No automation issues.

- Seattle University: No comfort issues. The CLIR box may have been damaged during shipment. A new CLIR box was installed and worked fine throughout the DR test events.
- Seattle Municipal Tower: Of the four test DR events, one day, Monday, March 9th, four tenants complained that it was too cold. Facility management speculated that because the building was shut down over the weekend, the temperature adjustment may have been more noticeable. No automation issues.

5. Discussion

Automated DR technology demonstration field tests in the Northwest demonstrated open automated DR communication systems and identified opportunities for winter DR control strategies. Results from the four sites that participated in the study were presented in this report. Key issues are discussed in detail below:

- **Recruitment is a lengthy and on-going effort.** The teams experience in the Northwest is similar to the early field test recruitment efforts in California. Recruitment is part education and part relationship to get participants comfortable with the ideas that:
    - the service levels in their facilities will be modified for a period of time;
    - on going assistance and monitoring will help them select detectable but at the same time acceptable DR strategies; and
    - they can modify or choose to not participate in an individual event.
- **A large potential pool of customers enabled us to achieve the targeted number of participants.** Seven sites had indicated interest in participating in the study after the completion of initial sites surveys at ten facilities. Three of the sites could not participate in the test events due to:
    - Limitations within control systems and the increased cost of overcoming these limitations.
    - Communication problems within the control systems that prevented the research team to monitor and collect data from each test DR event.
    - Decision to back out of the field tests due to concerns from tenants.
- **Lighting provides year-round DR**. While detectable, lighting sheds have fast response time and can provide excellent year-round DR. However, there are less centralized lighting control systems, most new lighting control systems that integrate with daylighting in commercial buildings have local closed-loop controls that optimize for daylight availability.
- **Heating ventilation and air conditioning (HVAC) systems with natural gas heating have limited savings opportunities.** Two buildings with gas powered roof-top units selected duty cycling as a DR strategy. The DR opportunities in these types of systems come from fan power savings.

- **All electric heating systems are the low hanging fruit.** Global temperature adjustment strategy, which is often used in California to reduce peak demand during summer afternoons, worked well in the all electrically heated building. The zone temperatures were temporarily reduced to save on electric loads.
- **Auto-DR concepts work for winter DR in commercial buildings.** On average, the buildings that participated in the study delivered 14% demand reduction or 0.57 W/ft^2 over three hours. This study showed that HVAC and lighting remain to be the major opportunities for Auto-DR in commercial buildings and with or without electric heating, there are opportunities in HVAC systems to reduce demand for a period of time to relieve the stress on the electric grid. Summary of average demand reduction, energy savings, cost per customer and one-time control and commissioning cost per kW is presented below as well as the load profile of the aggregate demand reduction:

Average demand reduction (kW) for each DR event	730 kW
Total energy savings due to four DR events (kWh)	8763 kWh
Average per customer cost for control and commissioning	$4,057
Average control and commsionning cost per kW (one-time)	$76/kW

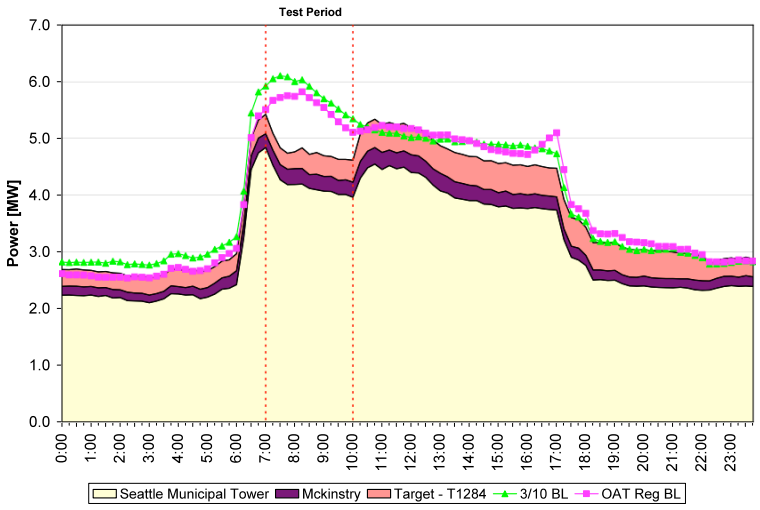


Figure 15. Aggregate load reduction

6. Summary and Future Directions

This section summarizes the recommendations for the next phase of the project and plans for the future directions for OpenADR.

The project was a first step in demonstrating the use of technology and its performance. There is a need to study and develop cold morning DR strategies for consumers who would like to participate in DR programs. A guide that categorizes buildings and building systems and recommends DR strategies would be a suggested final deliverable. In addition, simulation tools that are developed for estimating DR capabilities for buildings in hot summer climates can be enhanced to support estimating cold winter morning DR capabilities in commercial buildings. We recommend a next phase for the project to evaluate the same technology and same test sites but consider DR strategies for demand savings summer days. The objectives of the next phase of the pilots are:

- To evaluate the commercial buildings capability to respond to DR events in dual peaking climates to address:
    - Year-round seasonal needs,
    - Fast demand response, and
- To develop methods for evaluating DR for buildings in dual peaking climates
- To consider the feasibility of geographically targeted DR.

Automation of Demand Response (DR) programs has proven to be an effective means of obtaining more reliable and consistently higher performing electric load shifts and sheds than using manual techniques. Furthermore, OpenADR is potentially an important component in automating the response of the facilities participating in DR programs by specifying a standardized communications data model between the Utilities and Independent System Operators (ISO's) and the energy management systems within the facilities.

OpenADR is currently in use by four electric utilities to automate their DR programs and has been adopted by a wide range of building and industrial controls companies. A detailed specification for OpenADR was developed over a two year period and soon to be released as an official CEC/LBNL report (http://openadr.lbl.gov/). The OpenADR specification will be the basis of ongoing DR communications standards development efforts within both the Organization for the Advancement of Structured Information Standards (OASIS - http://www.oasis-open.org/home/) and the UCA International Users Group (UCAIug - http://www.ucaiug.org/). Both are highly regarded organizations that are active within the emerging "Smart Grid" domain. With the ongoing efforts within OASIS and UCAIug, OpenADR is on a path towards becoming a formal standard within organizations such as the International Electrotechnical Commission (IEC. - http://www.iec.ch/)

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Glossary

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AHU - Air Handling Unit

CEC – California Energy Commission

CLIR Box – Client Logic Internet Rely – an internet gateway device designed, built, and provided to PG&E clients (where needed) to accept DR event signals and transmit them to the customer's EMCS for this project

CPUC – California Public Utility Commission

DHCP – Dynamic Host Configuration Protocol

DR – Demand Response – strategies and programs to facilitate load shedding during peak system demand periods.

DRAS - DR Automation Server – an internet-based communications server and database system that produces a computer-readable, electricity price signal on a Web services server, using the meta-language XML (Extensible Markup Language).

DRRC – Demand Response Research Center – A program at LBNL funded primarily by the California Energy Commission's PIER Program.

EMCS – Energy Management and Control System

IT – Information Technology

LBNL – Lawrence Berkeley National Laboratory performs Work for University on this Research Project Contract

LAN – Local Area Network

MOU – Memorandum of Understanding

OpenADR – Open Automated Demand Response – an information exchange model to communicate price and reliability signals for demand response.

PIER – California's Public Interest Energy Research Program

URL - an internet Uniform Resource Locator

VAV – Variable Air Volume

VFD – Variable Frequency Drive

XML – Extensible Markup Language