LBNL-1003924

Lawrence Berkeley National Laboratory

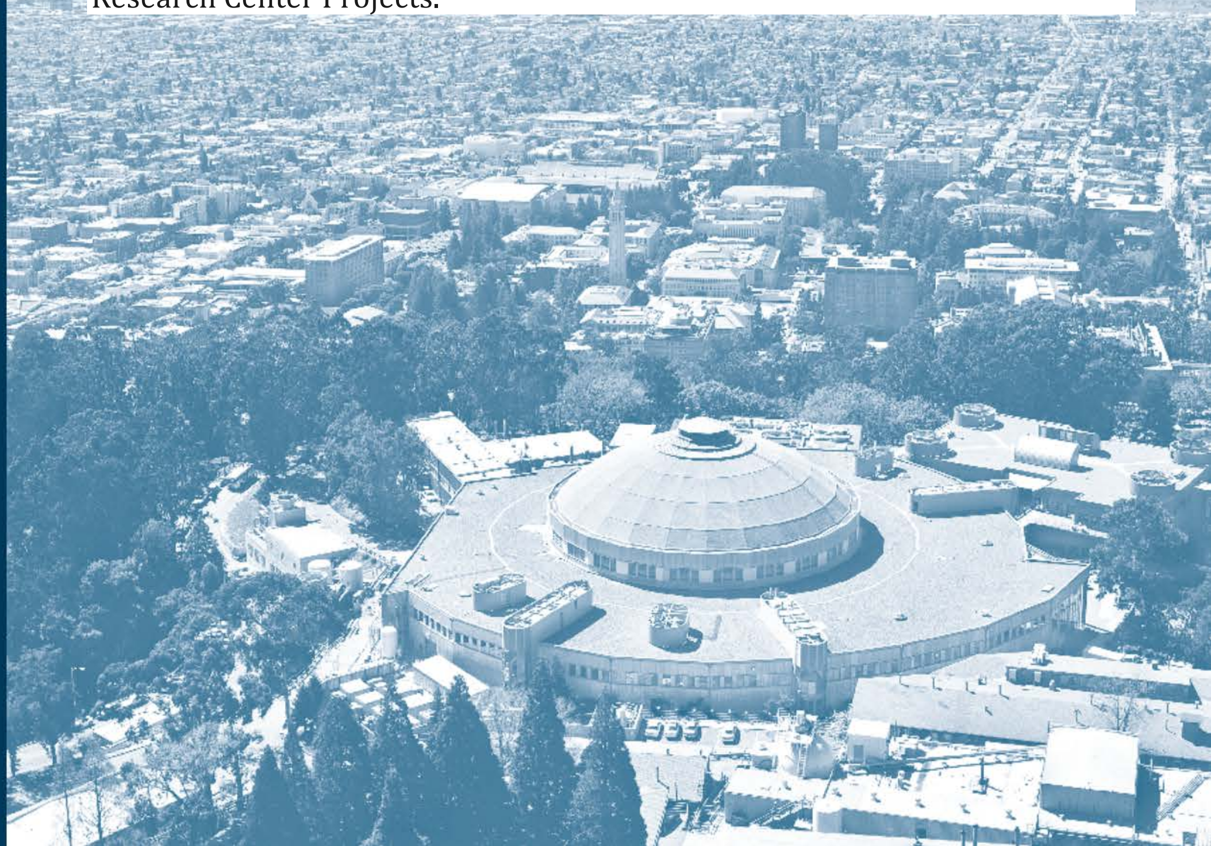
Costs to Automate Demand Response – Taxonomy and Results from Field Studies and Programs

Mary Ann Piette, Oren Schetrit, Sila Kiliccote, Iris Cheung, and Becky Zilu Li

Lawrence Berkeley National Laboratory

November 2015

The work described in this report was fund by the California Energy Commission (Energy Commission), Public Interest Energy Research (PIER) Program, under Work for Others Contract No.500-03-026 and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The authors would like to thank David Hungerford and Mike Gravely from the Energy Commission for their support in this and other Demand Response Research Center Projects.



Disclaimer

ACKNOWLEDGEMENTS

The work described in this report was fund by the California Energy Commission (Energy Commission), Public Interest Energy Research (PIER) Program, under Work for Others Contract No.500-03-026 and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The authors would like to thank David Hungerford and Mike Gravely from the Energy Commission for their support in this and other Demand Response Research Center Projects.

ABSTRACT

During the past decade, the technology to automate demand response (DR) in buildings and industrial facilities has advanced significantly. Automation allows rapid, repeatable, reliable operation. This study focuses on costs for DR automation in commercial buildings with some discussion on residential buildings and industrial facilities. DR automation technology relies on numerous components, including communication systems, hardware and software gateways, standards-based messaging protocols, controls and integration platforms, and measurement and telemetry systems. This report compares cost data from several DR automation programs and pilot projects, evaluates trends in the cost per unit of DR and kilowatts (kW) available from automated systems, and applies a standard naming convention and classification or taxonomy for system elements.

Median costs for the 56 installed automated DR systems studied here are about $200/kW. The deviation around this median is large with costs in some cases being an order of magnitude great or less than the median. This wide range is a result of variations in system age, size of load reduction, sophistication, and type of equipment included in cost analysis.

The costs to automate fast DR systems for ancillary services are not fully analyzed in this report because additional research is needed to determine the total cost to install, operate, and maintain these systems. However, recent research suggests that they could be developed at costs similar to those of existing hot-summer DR automation systems. This report considers installation and configuration costs and does include the costs of owning and operating DR automation systems. Future analysis of the latter costs should include the costs to the building or facility manager costs as well as utility or third party program manager cost.

Keywords: Demand response, automation, smart grid, demand response costs, grid integration, renewables.

Please use the following citation for this report:

Piette, Mary Ann, Schetrit, Oren, Kiliccote, Sila, Cheung, Iris. (Lawrence Berkeley National Laboratory). 2015. ***Costs to Automate Demand Response – Taxonomy and Results from Field Studies and Programs***. California Energy Commission. Publication number: CEC-500-YYYY-XXX

TABLE OF CONTENTS

List of Figures and Tables

EXECUTIVE SUMMARY

Project Purpose

During the past decade, the technology to automate demand response (DR) in buildings and industrial facilities has advanced significantly. Automation allows rapid, repeatable, reliable operation. This study focuses on costs for DR automation in commercial buildings with some discussion on residential buildings and industrial facilities. DR automation technology relies on numerous components, including communication systems, hardware and software gateways, standards-based messaging protocols, controls and integration platforms, and measurement and telemetry systems. This report compares cost data from several DR automation programs and pilot projects, evaluates trends in the cost per unit of DR and kilowatts (kW) available from automated systems, and applies a standard naming convention and classification or taxonomy for system elements.

Project Results and Benefits

Median costs for the 56 installed automated DR systems studied here are about $200/kW. The deviation around this median is large with costs in some cases being an order of magnitude great or less than the median. This wide range is a result of variations in system age, size of load reduction, sophistication, and type of equipment included in cost analysis.

One original goal of DR automation standards was to facilitate development of interoperable software, to reduce automated DR system cost. If standard DR software systems are built into a building's control software, there is no need for new hardware to automate the controls. The newest (2013) version of California's building code, Title 24, requires automated DR capabilities for lighting; heating, ventilation, and air conditioning; and electronic messaging centers (Ghatikar et al, 2015). These new control requirements for Title 24 also include acceptance tests. Thus, the cost to automate DR in new buildings that comply with the 2013 building code are expected to be less than the costs of retrofitting an existing building's DR system to automate it.

Future Directions

The costs to automate fast DR systems for ancillary services are not fully analyzed in this report because additional research is needed to determine the total cost to install, operate, and maintain these systems. However, recent research suggests that they could be developed at costs similar to those of existing hot-summer DR automation systems. This report considers installation and configuration costs and does include the costs of owning and operating DR automation systems. Future analysis of the latter costs should include the costs to the building or facility manager costs as well as utility or third party program manager cost.

CHAPTER 1: Introduction

During the past decade, the technology to automate demand response (DR) in buildings and industrial facilities has advanced significantly. As the field grows and deployment of DR technology broadens, it is important to understand the costs and benefits of automated DR systems. The Demand Response Research Center initiated research to develop low cost DR automation more than ten years ago. But the question remains, what are low cost automation systems? This report focuses on costs and covers two key areas. First, we present a common taxonomy or classification of the requirements, metrics, and costs associated with automated DR technology, including the costs of hardware, software, and installation, and maintenance. Second, we provide examples from automated DR programs and pilot projects and discuss the trends in the costs of automating DR.

DR programs provide financial incentives for customers to modify electricity use when requested by a utility, third party, or grid operator. DR can mitigate grid management problems such as generation, transmission, or distribution constraints. DR can also reduce electricity use during periods of high prices. Historically, DR has been used during hot summer afternoon and cold winter morning peak events. Recently, with the increased deployment of renewable energy, DR is being used to help address the effects of variable generation on the grid. DR can address challenges associated with increased penetration of renewable generation (Kiliccote 2010a). Increased flexibility of demand-side resources and availability of real-time signals from the electricity grid are key ingredients for successful supply and demand interactions. The rapid changes in renewable energy require automated DR to operate more rapidly than is necessary for peak-period DR programs.

With automated DR playing a growing role in grid modernization, it is important to understand the costs of automating DR and to analyze its benefits based on a common understanding. This report provides a taxonomy of the key elements in automated DR systems to aid researchers and practitioners in documenting and describing costs of DR automation in a consistent and comparable manner. Our overall goal is to improve understanding of these data and help drive down first costs. Although the data in this report are mostly from automated DR systems in California, some field tests from outside California are included. This study focuses on only the costs of automating DR systems. We do not address automated system performance. Much of the data from the demonstrations and DR programs described in this report were collected as part of the research conducted by the Lawrence Berkeley National Laboratory's Demand Response Research Center (DRRC).

.

CHAPTER 2:
Demand Response and Automation Technology

DR programs are typically managed by utilities, independent system operators (ISOs), third-party aggregators, or program administrators. Several types of DR programs are available that use a variety of frameworks. Table 1 shows one framework that combines price-based options with incentive- or event-based DR. Price-based DR programs include time-of-use (TOU) pricing,[1] critical-peak pricing (CPP), and real-time pricing (RTP).

Price Options	Incentive- or Event-Based Options
TOU rates: Rates with fixed price blocks that differ by time of day.[a]	**Direct load control:** Customers receive incentive payments for allowing the utility a degree of control over certain equipment.
CPP: Rates that include a pre-specified, extra-high rate that is triggered by the utility and is in effect for a limited number of hours.	**Demand bidding/buyback programs:** Customers offer bids to curtail load when wholesale market prices are high.
RTP: Rates that vary continually (typically hourly) in response to wholesale market prices.	**Emergency demand response programs:** Customers receive incentive payments for load reductions when needed to ensure reliability.
	Capacity market programs: Customers receive incentive payments for providing load reductions as substitutes for system capacity.
	Interruptible/curtailable: Customers receive a discounted rate for agreeing to reduce load on request.[b]
	Ancillary services market programs: Customers receive payments from a grid operator for committing to curtail load when needed to support operation of the electric grid (i.e., ancillary services).[c]

Table 1. Common types of DR programs (Goldman 2010)

a – Some analysts don't consider TOU to be DR because the times and rates are fixed and customers on TOU are not dispatchable loads. However a well-designed TOU may reduce peak demand. b – Some utilities consider interruptible rates as a price based option, particularly if the tariff includes dynamic pricing provisions during emergency events. c – Ancillary services DR arrangements can also be viewed as a pricing program because real-time pricing signals can be set up under a tariff to trigger event specific customer behavior.

A key feature of incentive-based programs is that they require baselines for evaluating the response during a DR event. A growing class of advanced DR programs incentivizes participation in ancillary services that require fast response times and sophisticated automation, as discussed below. Both price-/incentive-based and advanced DR programs reward customers

---

[1] Because TOU pricing is the same every day, it is often considered a daily load-management program rather than a DR program. However, some frameworks include TOU pricing in the DR category (FERC 2013).

for reducing electrical loads on request from the program administrator or for giving the program administrator direct control over the customer's electricity-using equipment.

Automated DR programs typically cover the first costs to design, install and configure building or industrial electrical loads to shift or shed demand in response to a signal. In some automated DR programs the loads can increase electric use as well as shift or shed electric use. The increase might be to store some load for later use, such as with hot or chilled water, or to ancillary services further discussed below that require systems to increase as well as decrease electric loads. Automated DR has three key operational elements: **communication**, **control**, and **telemetry**. Each element has various configurations and requirements in different DR programs. All are described in more detail in the following three subsections. Figure 1 represents a generic DR automation architecture, showing how the three elements inter-relate. In Figure 1, the communication is hosted by a gateway, which is a hardware or software system capable of joining two networks that use different base protocols.

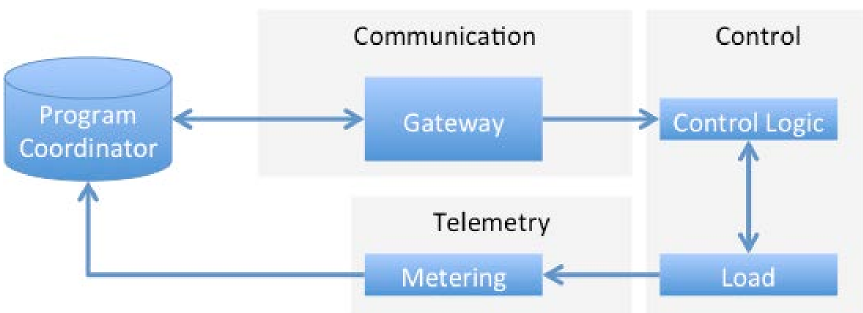


Figure 1. A common architecture of automated DR systems

Communication of Demand-Response Signals

The first step in automating DR is enabling receipt of messages that communicate an upcoming DR event and relevant event information. Private, proprietary systems exist for DR communications, but there has been extensive development of open standards during the past decade. An open standard allows third-parties to develop technology that supports or is compatible with a communication system provided by another vendor. Open standards encourage competition and minimize the opportunity for vendors to maintain expensive, limiting proprietary systems. Another goal of open standards is to allow information and communication technology (ICT) platforms to provide broad functionality at relatively low cost. Open standards can foster low-cost interoperable DR platforms with high functionality, similar to the advanced performance seen in consumer electronics, computers, tablets, and smart phones.

California has played a major role in organizing efforts to develop open standards for DR automation. Open standards are important because they allow multiple vendors to develop interoperable systems while minimizing the use of propriety standards that may result in vendor lock in. These open standards can lower the cost for technology by allowing a open completive market for technology.

Experience with the development of OpenADR is described in Piette et al. (2010). Early DR automation programs using what evolved into OpenADR were called AutoDR programs. Today, two main open communication standards are used for DR automation in California: Open Automated Demand Response (OpenADR) and the Smart Energy Profile (SEP). Each of these standards has two versions: OpenADR 1.0 and 2.0, and SEP 1.0 and 2.0. Some third- party organizations certify compliance with OpenADR 2.0 and SEP 1 and 2 systems (Zigbee Alliance 2011, Piette et al, 2009, OpenADR Alliance 2013 and ZigBee Alliance and HomePlug Powerline Alliance 2011.). These standards communicate DR event information, such as event start and end times and price. There are also propriety systems in use by aggregators, direct load control system developers, and technology vendors.

There are important distinctions between manual and DR automation. In day-ahead manual DR programs, a building participates manually in a DR event. The building manager typically receives DR event messages via text, email, and phone. The messages offer the manager an opportunity to opt out of the event by responding to the message. In the case of fully automated DR (AutoDR) programs, the homeowner or building manager receives a notification similar to that sent in a manual DR program (text, email, etc.) but more importantly their DR automation system receives a software-based signal that initiates automated load-shedding.

For AutoDR, the building requires a gateway that can receive a standardized message to be interpreted by the building control system. In some cases, such as Wi-Fi-enabled thermostats, direct-load-control switches, or modified roof top units, the control (logic) device can receive DR messages directly and translate them into the necessary load-shedding control sequences.

Standards-based messaging protocols are used to ensure that customers' installed AutoDR communication equipment is capable of receiving a DR signal and translating it into an appropriate set of control logic sequences. The communication architecture of the AutoDR messages can be described using the Open Source Interconnection model. The communication architecture can be separated into two elements: the physical interface and the logical interface as shown in Figure 2

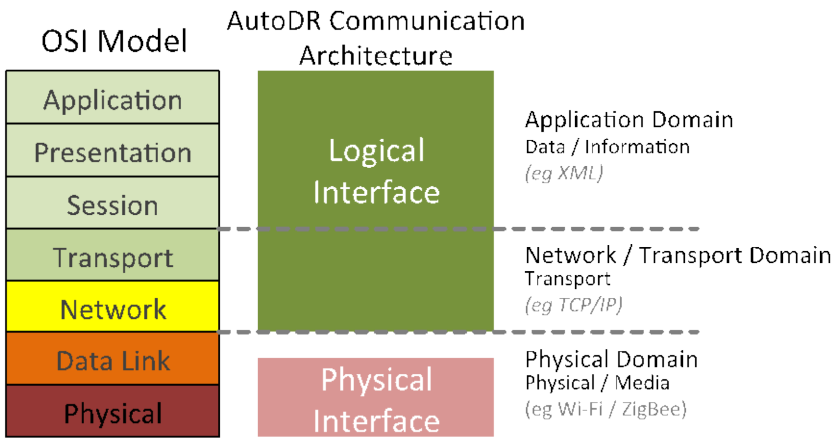


Figure 2. AutoDR control and communications system framework

The *physical interface* includes a one- or two-way communications interface and transport system specified by the building's DR program coordinator, information update service, or DR service provider. Either on-board communications devices or a communications module embedded in the control logic system enables the physical interface. The *logical interface* consists of the information model used to represent messages sent to AutoDR controllers. For interoperability, AutoDR systems must support compliance for both network/transport and application domains, or the logical interfaces. AutoDR systems can be designed with a software client that communicates with a certified AutoDR server. The DR program administrator hosts the certified AutoDR server, which communicates over a secure network link to a certified AutoDR client residing in the communications gateway. The control system hosts the DR control strategy logic, which is then propagated to the electrical end-use loads. The purpose of a DR client is to translate and communicate a standard set of DR signals and data models from grid operators, homes, buildings, and industrial control systems. This allows these control systems to take pre-programmed or dynamic actions based on the DR signal, so that a DR event can be fully automated and require no manual intervention.

Demand Response End-Use Load Control

DR control occurs after a building receives a signal from the DR communication system and translates the signal into a control action, such as an electrical load shift or shed. In a large commercial building with a dedicated building automation system (BAS), DR load control is carried out through sequences that manage heating, ventilation, and air conditioning (HVAC) equipment schedules and operating set points. An example of enabling DR in a BAS would be programming control sequences to be applied in response to a DR request. Automation sequences could increase chilled-water reset temperatures, zone temperature set points, or condenser water set points, for example. Often, a BAS is capable of instituting alternative control sequences but is not equipped to receive DR messages directly. In such cases, a gateway device must be installed to receive the DR messages and translate them to a format compatible with the BAS.

In the case of residential or small commercial buildings with split systems or rooftop air-handling units, control strategies can include a relay that temporarily disables the compressors. Another option is installation of a “smart” programmable thermostat that can increase zone temperature set point for the duration of a DR event. Other cases include systems in which HVAC equipment is outfitted with control logic hardware capable of receiving remote messages and translating them to “low-power” operating modes. Where there are local relays or programmable thermostats, installed gateways are not always necessary because the devices can communicate via local Wi-Fi networks or other physical interfaces (e.g., ZigBee, cellular).

Where DR is manual or semi-automated, an event notification is sent directly to the building manager with instructions about the time and duration of the event as well as expected or required load-shed. The homeowner or building manager then manually implements control sequences to reduce electricity demand. For AutoDR applications, the message is sent directly to the automation system via messaging protocol, delivered via logical interface, and then translated into operating sequences by the control logic system.

Demand-Response Measurement and Telemetry

The third group of elements in the DR automation system encompasses the electric meter, measurement systems, and communication of measured data. In most of California, DR automation costs do not include the meter or telemetry because most electric utilities have advanced meters and interval data that are collected for all customers (both those in DR programs and those that are not). Some DR programs require near-real-time power measurements, often called power measurement telemetry. Telemetry in the general sense consists of automated communication of measurements to a remote site. Telemetry requirements for automated DR systems range from fast (such as four-second, real-time power measurements over dedicated system-operator networks) to slower, once-a-month electricity data retrieved from utility meter data management systems. There are three telemetry specifications for DR systems: measurement accuracy, communications speed, and data granularity (such as time stamps).

Most of today’s DR programs in California are designed for seasonal grid stress or peak-load reduction on hot summer days (Kiliccote 2010). Customers are notified one day or a few hours in advance of a DR event that they must provide a certain level of load reduction for a pre-determined period of time. As mentioned above, real-time telemetry is often not required for such programs, and the control strategies do not require full automation or fast response. Operators can choose to automate a particular building system to participate in the DR event or can opt to control systems manually. Semi-automated participation is also an option, in which sequences are automated, and, upon receipt of a DR notification from the program coordinator, the facility manager manually initiates those sequences. There is a growing desire among utility planners, however, to more fully automate DR because it is does not require a person to directly manage event response—reducing participation costs and increasing reliability.

Ancillary services are provided to grid operators to address short-term imbalances in electricity systems. Short-term imbalances can result from generation or transmission resources that temporarily become unavailable, or intermittent or inconsistent renewable generation (solar, wind, etc.). The nature of these short-term imbalances requires a response within seconds or minutes as well as quantifiable load-shed to help grid operators balance supply and demand. Ancillary services have historically been provided by fuel-burning power plants; however, research has shown that AutoDR can provide ancillary services with the same degree of reliability (Kiliccote et al., 2010).

The time scale and nature of ancillary services requires that DR be completely automated in order to participate. Additional telemetry may be required that functions on the time scale required for the particular service. For programs that do not require real-time visibility, such as capacity markets and energy markets, an interval meter that offers a delayed bulk meter reading may be sufficient (MacDonald et al, 2012). Table 2 highlights key features of ancillary services programs.

Products		Physical Requirements			
Product Type	**General Description**	**How fast to respond**	**Length of response**	**Time to fully respond**	**How often called**
Regulation	Response to random unscheduled deviations in scheduled net load (bidirectional)	30 seconds	Energy neutral in 15 minutes	5 minutes	Continuous within specified bid period
Flexibility	Additional load-following reserve for large un-forecasted wind/solar ramps (bidirectional)	5 minutes	1 hour	20 minutes	Continuous within specified bid period
Contingency	Rapid and immediate response to a loss in supply	1 minute	≤ 30 minutes	≤ 10 minutes	≤ Once per day
Energy	Shed or shift energy consumption over time	5 minutes	≥ 1 hour	10 minutes	1-2 times per day with 4-8 hour notification
Capacity	Ability to serve as an alternative to generation	Top 20 hours coincident with balancing authority area system peak			

Table 2. Summary of ancillary services and requirements for DR participation

CHAPTER 3:
Candidate End-Use Loads for Demand Response

In general, thermostatically controlled loads are good candidates for DR because they have inherent storage. We provide some discussion of DR end-use systems to provide the reader with more background on various DR automation systems. Thermostatically controlled loads are space heating or cooling and domestic water heating or laundry systems. The emphasis in California DR programs has been on space cooling because this prevalent load drives electricity grid peak demand in most parts of the state. These loads normally have inherent building mass that can be managed to provide comfort and services to occupants during DR events.

Large Commercial Buildings

Large commercial buildings, which are typically over 200 kW, often participate in DR programs through adjustments to the HVAC central-plant sequence of operations for large equipment, or zone-level adjustments such as zone temperature reset, lighting control, or large equipment (e.g., elevator) shutdown. The following are key candidates for end-use control:

- **Chillers -** Chillers can participate in DR by resetting of chilled-water or condenser-water temperature. Chillers can be turned down, and variable-speed-drive controls can be adjusted to meet energy-reduction needs.
- **Pumps -** Similar to chillers, pumps with variable-speed drives can be adjusted or shut down to reduce energy demand.
- **Zonal HVAC Systems**– Zonal HVAC systems can be reset to reduce electrical loads. The most common DR response is to reset the zonal space temperature. Other strategies include reducing fan energy use by resetting the supply-air-duct static pressure on variable-air-volume systems.
- **Lights** – Lighting controls can provide DR, especially in large commercial settings. Lighting power can be achieved by turning off some fixtures or lamps or dimming the light level.

Small Commercial Buildings

Small commercial buildings are less than 200 kW and have loads dominated by HVAC, lighting, and refrigeration systems.

- **HVAC Systems** – These buildings typically have packaged roof-top units. Cooling energy can be reduced in several ways during DR events. Air compressors, air handlers, and ventilation systems can be shut down entirely, or loads can be cycled and temperatures reset. If pre-cooling is employed, doors and windows are closed for the conditioned space to be pre-cooled, and rooftop units are then shut down during the DR event.
- **Lights -** Lighting can be controlled as described above for large commercial buildings.
- **Refrigerated Cases -** Retail locations often participate in DR by turning of lights within refrigerated cases or reducing the use of anti-sweat heaters.

Residential Buildings

- **Air-Conditioning Units -** A smart thermostat can be used to respond to a DR signal by adjusting the home's temperature set point based on pre-programmed DR settings. That set point would then control compressor cycling.
- **Pool Pumps** – A pool pump controller can shut off the pump motor to save energy.
- **Electric water heaters -** can be an effective load reduction strategy with low negative effects on customers; however they were not included in this study because of low market penetration in California.

CHAPTER 4: Characteristics that Impact Costs for Enabling Automated DR Systems

This section discusses factors that contribute to the total costs of automated DR systems. The majority of this discussion focuses on OpenADR 1.0 and 2.0 systems although some comments are provided on other systems.

Communications Software

Stand-alone hardware and software are often required to receive DR signals. The signals include information such as event start time, end time, required load-shed, and price. Many OpenADR-based communication systems use standard gateway boxes. A number of vendors offer communication gateways to host OpenADR software clients. These gateways come in a variety of shapes and sizes and can be purchased with simple or sophisticated software platforms. Many of them host MODBUS and BACnet protocols to integrate with common building control platforms. Some control systems come with embedded OpenADR clients for communication; in these cases, no additional hardware is needed.

Early OpenADR 1.0 systems used a simple gateway that was a small Linux personal computer (PC) with relays to communicate with existing control systems. This first platform was known as the Client and Logic with Integrated Relay (CLIR) (Ghatikar and Hennage, 2010). More recently, OpenADR has become available in third-party common gateway systems. DR automation system costs include purchase, installation, and configuration of the gateway. The gateway software must be configured to communicate both with the DR program managers' DR automation server and with the control logic for customer end-use loads. Early OpenADR systems used customers' existing Internet for the physical communications layer. In some cases, enabling the DR communication system includes installing new or dedicated Internet connections.

Controls

One element that contributes to cost of DR automation is the purchase of control hardware or software. During the first few years of OpenADR field trials, most test sites incurred no extra costs for controls because existing controls were used. Building automation systems and lighting controls were programmed to receive signals from the CLIR boxes. Programming was needed, which entailed labor, but no additional control systems were installed. Recently, many utility DR programs have covered costs for control system upgrades. Controls hardware can include thermostats, new direct digital control HVAC systems, BASs, and dimming or switches for lighting. Sometimes software is upgraded for DR capabilities. Software programming costs are entailed in automating most DR systems.

Labor

Labor costs to design and configure OpenADR communications and DR control system logic can include up-front engineering, installation by a technician, and commissioning tests. In some cases, the hardware installation contractor is not able or qualified to make changes to the control system. In these cases, a control systems expert must be retained to program the changes to the building control sequences.

Telemetry

In California's ancillary services market, a DR resource needs to connect to the California ISO (CAISO) energy controls network (ECN) with an ongoing network service connection contract (Kiliccote et al, 2014). A schematic of this system is shown in Figure 3. For internet-based telemetry and controls, an existing internet connection at the building provides access to internet-based grid integration services at no additional cost. Otherwise, a data connection (e.g. local-area network, cellular) may be required. Unlike OpenADR 1.0, OpenADR 2.0b can provide telemetry services needed for the ECN connection. The utility or ISO DR program may need only a fraction of the communication system features, or may require a full set of OpenADR 2.0b features.

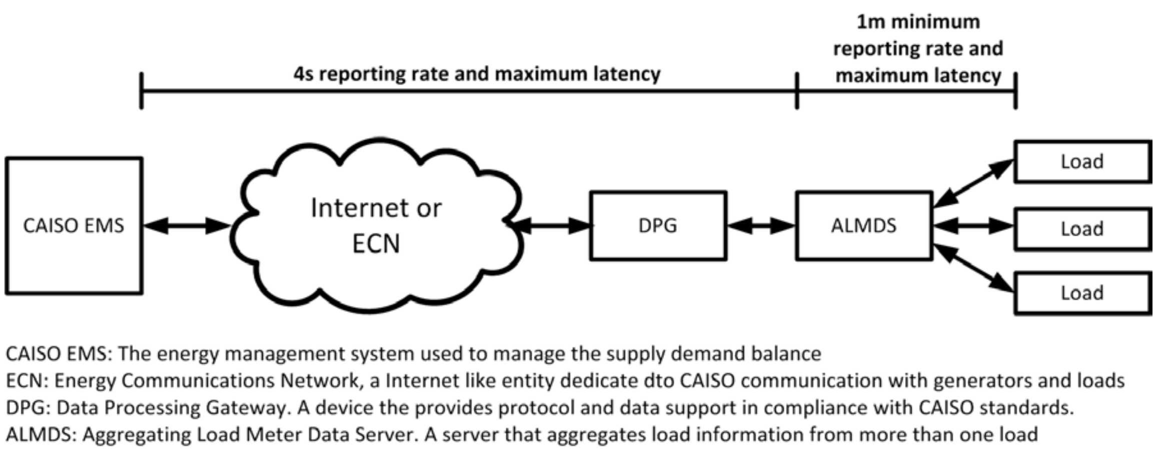


Figure 3. Schematic showing CAISO communication latency and reporting rate requirements for demand-side aggregated loads

As mentioned, many OpenADR systems use a customer's existing Internet for DR automation. The fast signaling required by ancillary services needs a DR automation client that can function more rapidly than is required for seasonal grid-stress DR programs. The main difference is that the fast DR programs have used a push strategy for the Internet client with a dedicated Internet connection. However, within the building many of the DR control strategies, such as the HVAC DR control, have been shown to meet the requirements of California's proxy DR programs that require fast response (Kiliccote et al, 2012).

Cellular data services can be an attractive option for telemetry. Cellular data can allow a utility or energy service provider to provide an DR enabling package (e.g., ship a "connected switch for the building occupant to install) (Cadmus 2013) that is "plug and play," requiring no setup. Examples of these costs are show below. This is advantageous because some commercial customers are reluctant to allow third-party energy devices in their business information technology (IT) network for reasons including: IT network Wi-Fi passwords change with security updates, corporate log-in procedures, or wireless router upgrades; moreover, network connectivity might not be available at the point of install for the DR telemetry device. Using cellular data simplifies enabling of the DR system, and cellular telemetry is economically attractive.

Using OpenADR 2.0b over a cellular data connection is relatively data intensive for ancillary services applications. Every reporting/control transaction is 16 kilobytes (kB) (hypertext transfer protocol [HTTP]); extensible messaging and presence protocol (XMPP) reduces each transaction to 12kB. (These values include all of the protocol communications overhead and were measured at the network interface rather than at the application.) We analyzed the cost of enabling ancillary services using available machine-to-machine data costs today.

Electric utilities typically archive 5- or 15-minute data from smart meters (customers can get these data through their on-line account or a green button application). However, smart meters are capable of providing 10-second data to an SEP device, and these data can be ported over to an aggregator. Research is under way to evaluate how these data can be aggregated and used to meet ISO ancillary services requirements (Page et al. 2015). This research platform, known as an open smart energy gateway (OpenSEG) links to the smart meter. OpenSEG is an open-source data management platform designed to work with ZigBee SEP 1.x to provide consumers with access to the most recent 48 hours of their consumption data. Data are stored locally in a circular cache that can be accessed by the consumer. These systems may cost less than $100 to install.

An Accounting Framework for Automated Demand-Response Costs

Given the highly variable nature of the costs of enabling AutoDR, it is important to develop a framework that can help program administrators compare and contrast these costs among various programs. Table 3 shows, in a generic accounting framework, the 11 categories of costs that might be involved in automating a DR system. These costs encompass first costs of installing and configuring the AutoDR application and do not include program administration or system maintenance costs. The cost for an individual site will depend on what end-use loads are being automated and the vintage of the existing equipment. In general, it is less expensive to automate DR in newer buildings that have newer control systems.

	Price	Quantity	Total Cost
System Evaluation, Design, Commissioning			
Labor	$x/hr	y - hrs	xy
Communication			
Communication Service	$x/year	yr	xy
Hardware (Gateway)	$x	y	xy
Software (Client)	$x	y	xy
Configuration Labor	$x/hr	y - hrs	xy
Controls			
Equipment	$x	y	xy
Installation Labor	$x	y	xy
Controls Programming	$x/hr	y - hrs	xy
Telemetry			
Hardware (meters, meter comm.)	$x	y	xy
Installation Labor	$x/hr	y - hrs	xy
Configuration Labor	$x/hr	y - hrs	xy

Table 3. Proposed accounting framework for cost of enabling AutoDR capability

CHAPTER 5: Field Data on Costs of Automated Demand-Response Systems

For this study, we reviewed cost data from several DR pilot programs carried out during the past 10 years. These programs ranged from residential direct load control to enabling AutoDR in small and large commercial buildings. The biggest challenge in making these comparisons is the variation in what is included in the costs. Where possible, we reference the categories shown in Table 3. Table 4 gives data on the cost of enabling AutoDR from six sources. The costs vary by more than a factor of 5, from $73/kilowatt (kW) to $373/kW. We briefly summarize each of the data sources. To improve our ability to compare, we have converted the data to 2015 constant dollars. This is about a 13% increase for the 2007 costs to 2015 values. The values were converted from the published cost in their respective project year to January 2015 dollars using the Consumer Price Index (CPI)[2].

	Avg $/kW	Number of sites	Type of automation and sites
Pacific Gas & Electric (PG&E) 2007*	$108	82	School, Retail, Commercial, Industrial (OpenADR 1.0)
Bonneville Power Admin-Seattle City Light 2009	$117	5	Small/Large Commercial Buildings (OpenADR 1.0)
Cadmus Group 2013 (Pacific Power)	$93	NA	Small Commercial Direct Load Control (pager system)
Cadmus Group 2013 (Rocky Mountain Power)	$73	NA	Small Commercial Direct Load Control (pager system)
New York State Energy Research and Development Authority 2013	$373	4	Large Commercial / High Rise (OpenADR 1.0, Unique Platform)
PG&E 2013-2015	$362	25	Small Commercial / Large Commercial (OpenADR 2.0)

Table 4. Summary of $/kW for AutoDR systems, in 2015 constant dollars

[2] All costs in Table 4, Fig. 7, 8 and 9, and Table A1-A5 in appendices are converted to 2015 cost, while other graphs and tables taken directly from previous papers are historical values. For the 2015 data we used the most recent published value when the data were collected, which was January 2015 CPI.

Pacific Gas and Electric Company 2007

For many years, Pacific Gas and Electric Company (PG&E) offered incentives to install OpenADR automation in commercial and industrial facilities. The data in this subsection come from a study by the Demand Response Resource Center (DRRC) on installation and commissioning of AutoDR systems. This study described the categories of costs involved in installing OpenADR systems (Kiliccote et al, 2008a). Those costs included labor, hardware, software, and configuration. Available programs included CPP and demand bidding. Most of the sites automated using existing controls and the early low-cost gateway CLIR box. Figure 4 and Table 5 show the cost data for these sites. At the time of this program, up to $300/kW was available to install DR automation, to cover the following types of costs:

- **Up to $40/kW for Recruitment** – This went to the recruiter as an incentive to participate in the program.
- **Up to $140/kW for Installation** – This covered hardware and software to enable the automation.
- **Up to $70/kW for Technical Coordination –** The technical coordinator worked with the building owner and controls vendors as needed.
- **$50/kW Payment to the Customer** – Customers were paid a one-time incentive to participate.

Recruitment and installation costs were paid based on an estimated demand reduction. Portions of technical coordination (TC) (30%) and customer (50%) payments were based on actual demand reduction. Figure 4 shows data for 23 AutoDR sites from a paper published by Kiliccote et al (2008). The data here are in the original year's dollars (2007). The X axis in Figure 4 is a log scale. One large site provided a 10-megawatt shed at a single site. The costs can be grouped into three main categories: 1) CLIR box installation, 2) DR shed strategy development and programming, and 3) installation of new equipment or upgrade of old equipment to accommodate automation. Median total cost of automation was $71/kW. Installation costs were lower for new industrial customers (median $37/kW) and higher for new commercial customers (median $94/kW). These costs are all below the $140/kW limit set by the DR program. Legacy customer installation costs were compiled from 2005 and 2006 pilot studies. TC costs from 2007 were added to calculate the total cost of automation. Overall, automation for all the sites was installed and enabled within the $210/kW allocated by PG&E's technical audit and technical incentive program. We have found that many of the providers organized the installations to take greatest advantage of the technical audit and incentive payments, making it difficult to understand the range of costs required to install the automation.

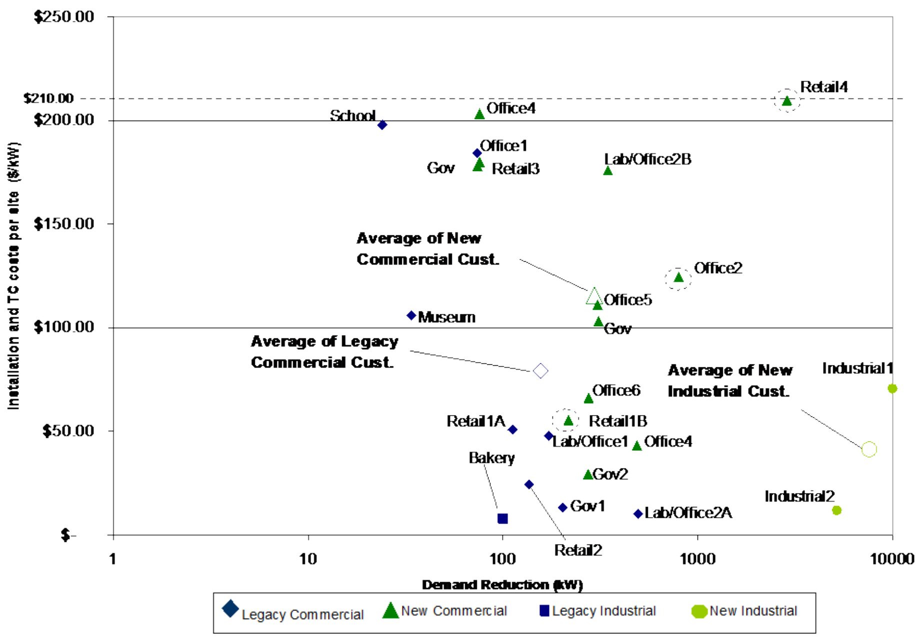


Figure 4. Costs for automated DR systems for 23 facilities in 2007 dollars

Customer Type	All Customers (N=82)	New Industrial (N=2)	New Commercial (N=66)	Legacy Industrial (N=1)	Legacy Commercial (N=13)
Shed (kW)	22642	15175	6116	100	1251
TC Cost ($)	$357,075	$59,021	$286,215	$800	$11,039
Installation ($)	$1,390,240	$709,706	$629,878	$0	$50,656
Av. TC $/kW	24	5	35	8	12
Min. TC $/kW	-	3	4	8	-
Max. TC $/kW	70	7	70	8	47
Med. TC $/kW	11	5	32	8	9
Av. Inst. $/kW	69	37	88	-	67
Min. Inst. $/kW	1	5	33	-	1
Max. Inst. $/kW	187	68	180	-	187
Med. Inst. $/kW	71	37	94	-	45
Av. Total $/kW	96	41	123	8	79
Min. Total $/kW	8	12	29	8	10
Max. Total $/kW	210	72	210	8	198
Med. Total $/kW	71	41	118	8	49

Table 5. Summary of $/kW for early PG&E AutoDR programs, in 2007 dollars

Bonneville Power Administration - Seattle City Light Study AutoDR Project 2009

In 2009, DRRC worked with the Bonneville Power Administration (BPA) to enable AutoDR in five commercial buildings in the Seattle City Light (SCL) territory, with the goal of reducing cold-winter-morning and hot-summer-afternoon peak electricity demand. We performed this demonstration for BPA at five sites in the SCL service territory: Seattle Municipal Tower, Seattle

University, McKinstry, and two Target stores. Table 6 shows the reported costs, which included labor, hardware, software, and configuration. The project started with cold-winter-morning DR. The table shows two sets of costs, winter (highlighted) and summer, for each building. The pilot program offered incentives for fully automated DR. The project partner, McKinstry, recruited customers with energy management control systems that were also already on SCL's MeterWatch meter data collection and monitoring system, so no telemetry costs were incurred. The costs of programming the BAS are included in the controls costs. These would have been lower if the winter and summer DR strategies were pre-programmed at the same time.

Site	Controls Vendor	Controls Cost	Material	Electrical Labor	Commissioning DR Strategies	Total	Total ($/kW)
McKinstry	ATS	$ 3,780	$ 1,064	$ 1,005	$ 1,071	$ 5,915	282
		$ 2,470	$ 200	$ 609	$ 1,530	$ 4,200	105
Seattle Municipal Tower	Siemens	$ 4,007	$ 1,500	$ 1,005	$ 1,071	$ 6,578	13
		$ 6,800	$ -	$ -	$ 1,530	$ 8,330	46
Target (both stores)	ALC	$ 6,500	$ 1,582	$ 2,000	$ -	$ 8,082	40
		$ 2,850	$ -	$ -	$ -	$ 2,850	10
Seattle University	ESC	$ 2,783	$ 1,000	$ 1,005	$ 1,071	$ 4,854	40
		$ 6,975	$ 927	$ 2,438	$ 1,530	$ 9,432	269

Highlighted rows indicate winter costs.

Table 6. Costs for AutoDR Systems in the Bonneville Power Administration - Seattle City Light Study. Highlighted rows are winter costs; non-highlighted rows are summer costs.

The costs vary from $10/kW to $282/kW. The cost for the Target stores was among the lowest for all of the sites described in this report because Target had OpenADR 1.0 available in their automated logic control system. Because Target had extensive experience with OpenADR in other buildings, it was easy to configure the buildings for this demonstration. The overall program costs ranged from $76/kW for winter DR to $108/kW for summer.

	Winter	Summer
Average demand reduction (kW) for each DR event	767 kW	338 kW
Total energy savings from four DR events (kWh)	8,589 kWh	6,455 kWh
Average per customer cost for control and commissioning	$4,057	$4,962
Average control and commisionning cost per kW (one time)	$76/kW	$108/kW

Table 7. Costs for aggregated DR from AutoDR Systems in the Bonneville Power Administration – Seattle City Light Study, in 2009 dollars

Cadmus Group

A report from the Cadmus Group analyzed results of a direct load control program for cost and efficacy of dispatchable DR and for ancillary service. The program sent field technicians to install a switch on home air-conditioning units; the switch reduced energy usage by reducing the duty cycle to approximately 50%. Figure 5 shows this system. The switches were enabled with radio control through an individually addressed pager system. Each switch would initiate cycling upon receipt of a control signal from the program operators. An important detail to note about the program analysis is that costs of enabling this DR were amortized over the life of the program and included utility costs for administering the program. The resulting data highlighted a levelized cost of energy represented in $/kW-yr. This example is included in this study as a reference point for another way to describe the costs. There are different perspectives regarding direct load control and DR automation. DLC systems do not provide customer choice like some DR automation system platforms.

Figure 5. Schematic of direct load controller switching system. Source: Oregon PUC

New York State Research and Development Authority Automated DR Project

Between 2011 and 2013, the DRRC Laboratory and New York State Energy Research and Development Authority (NYSERDA) conducted a demonstration AutoDR project in large commercial buildings in New York City, using OpenADR communication protocols.

The project focused on demonstrating:

- How OpenADR can automate and simplify interactions between buildings and various stakeholders in New York state, including the New York ISO, utilities,.
- Automating building control systems to provide event-driven DR, price response, and demand management in response to OpenADR signals; and
- Providing cost savings to large customers by actively managing day-ahead hourly prices and demand charges.

As part of the demonstration, facility managers for four buildings in New York City were given granular, equipment-level, opt-out capability to ensure full control of their sites during the AutoDR implementation. The expected bill savings ranged from 1.1% to 8.0% of the total dynamic pricing bill. The automation and enabling costs ranged from $70 to $725 per kW shed. The enabling cost in one of the buildings was unusually high because it was an educational facility, and managers were never able to perform full-scale load-shed because of conflicts with classroom schedules and academic activities. It is likely that the university and colleges will need more time to develop shed strategies because of their complex schedules.

Results of the pilot showed that OpenADR can facilitate the automation of price response, deliver customer savings, and provide opt-out capability so that facility managers can retain control of sites. Figure 6 shows the cost breakdown for this demonstration project.

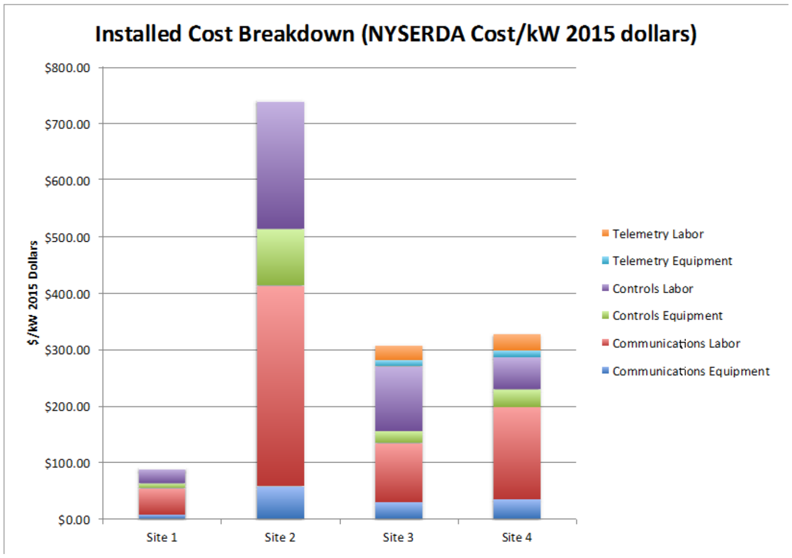


Figure 6. Costs for AutoDR systems in NYSERDA territory, in 2015 dollars

Pacific Gas and Electric 2013-2015

Lawrence Berkeley National Laboratory (LBNL) collaborated with PG&E from 2013 to 2015 to track AutoDR implementation costs in several commercial buildings. Figure 7 shows the costs per kW of enabling AutoDR, plotted against the kW of load-shed enabled. These costs include labor, hardware, software, and configuration and may be higher than at some of the previously described sites for two reasons. First, these are the first data collected for OpenADR 2.0, which is more sophisticated than OpenADR 1.0. We expect costs to come down as more experience is gained. Second, as shown in green in Figure 7, several of these sites undertook control upgrades in response to incentives for upgrades that would reduce overall energy use. The blended costs at these sites make it difficult to compare AutoDR costs only.

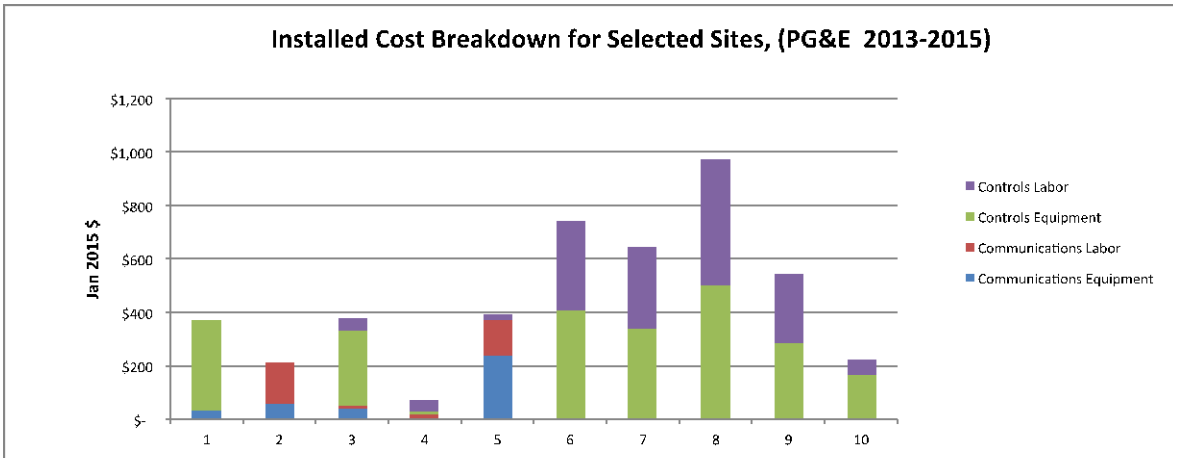


Figure 7. Costs for recent PG&E AutoDR sites using OpenADR 2.0.

Comparison of Costs for AutoDR Systems for Seasonal Grid Stress

In this section we describe how the costs to install automated DR systems compare among the projects from BPA, NYSERDA, and PG&E. Figure 8 shows the data from 56 individual building and industrial facilities. The four data sources are identified by symbols shown in the figure legend. The X-axis of kW shed for each site uses a log scale to accommodate the large 10 MW site. The Y-axis shows the $/kW. A set of detailed tables of these data are presented in Appendix A. The graphics shows a few key trends. As previously mentioned, the newer PG&E data show higher $/kW. There are two elements to this. First these sites use the newer, more sophisticated OpenADR 2.0. It is likely that the costs to install these systems will decrease over time because we anticipate more competition on the market for these products. There are only a handful of gateways and control products that are certified for OpenADR at this time. Second, a number of these systems include control system upgrades as part of their automation projects. As mentioned before, the BPA sites had low costs. The Target site has low costs because the DR automation was available through the control system and Target had prior experience with OpenADR. The NYSERDA costs are relatively high because of complexities of the New York buildings and the structure of the incentives made available for the automation.

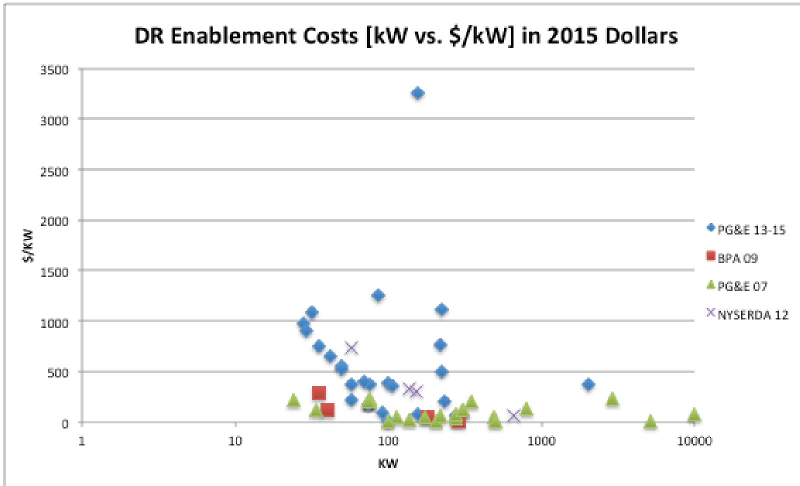


Figure 8. Comparison of costs for AutoDR systems from 2007 to present from PG&E, NYSERDA, and BPA programs

One key trend we see is lower $/kW for larger systems. This is likely a result of scale. In general if a DR load-shed is large, the total $/kW is likely to be lower because the cost for audits, labor, gateways, and configuration are similar regardless of the size of the load. In order to have a more realistic assessment of the DR cost, we trimmed the cost outliers in two ways. In the first case, the outliers are defined as the five highest $/kW and five lowest $/kW. In the second case, the outliers are defined as four highest $/kW and four largest kW. Figures 9 show the cost data for with trimmed data set with the high kW shed sites removed. The trends show the strong reduction $/kW with shed size. However it is worth noting that all of the more recent OpenADR 2.0 sites did not provide reductions greater than 300 kW, so the data sets cover different ranges of shed capabilities. The summary statistics of the entire data set and the trimmed data sets are shown in Table 8 and Figure 9.

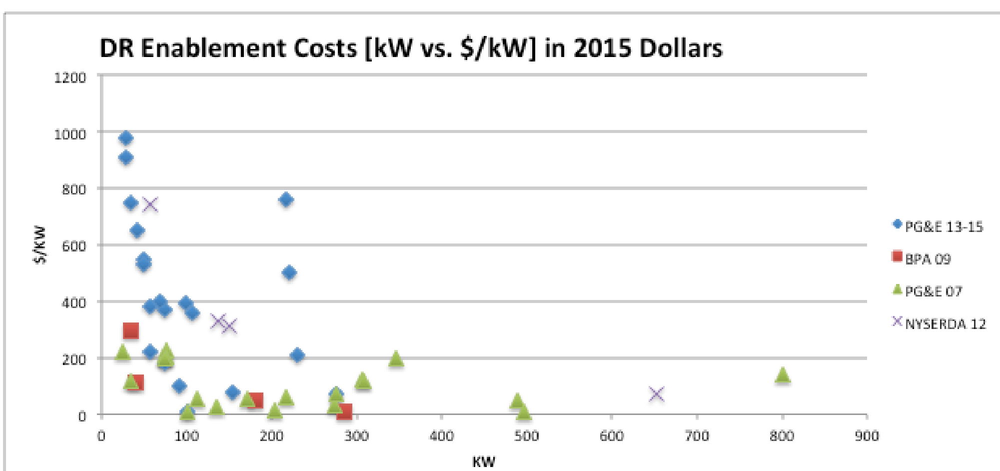


Figure 9. Comparison of costs for AutoDR systems from 2007 to present from PG&E, NYSERDA, and BPA with trimmed sample of highest outliers

	Untrimmed	Trimmed1	Trimmed2
Number of Observations	56	46	48
Average ($/kW)	355	264	260
Minimum ($/kW)	8	15	8
Maximum ($/kW)	3250	910	980
Stand Deviation ($/kW)	511	226	254
Median ($/kW)	203	205	200

Table 8. Costs ($/kW) for aggregated DR from AutoDR Systems in the Bonneville Power Administration – Seattle City Light Study, in 2009 dollars

The average cost reduced from $355/kW to about $260/kW after trimming the outliers in both methods. There's still a wide range within the cost data, but the standard deviation is reduced almost in half. The median costs for DR automation are about $200/kW with all three samples. Not that the standard deviation is similar in magnitude to the median value, so the spread in the costs/kW are large.

Comparison of Costs for AutoDR Systems for Ancillary Services

As described above, one of the biggest challenges in evaluating the costs of automated DR systems is benchmarking their capabilities. We are exploring how to shift conventional AutoDR systems that are developed for hot-summer-day programs to advanced ancillary services projects that have greater speed and telemetry requirements.

In California, customers can participate in wholesale ancillary services through a load-serving entity, scheduling coordinator, or DR provider. The customer connects with one of these entities, and the entity connects to the CAISO system. The customer costs are specified in the contract. Therefore, reporting the cost of AutoDR systems for ancillary services participation is even more complicated than reporting cost as described previously for straightforward DR participation. Some DR models in the ancillary services markets, such as Proxy Demand Resource, do not require telemetry. The revenue meter is used for settlements. Therefore, transitioning from retail to wholesale DR participation can be seamless from the customer's perspective. However, there are additional set-up and ongoing operational costs for a load-serving entity or scheduling coordinator; these are approximately $25,000 for the former, and $2,000 to 10,000 for the latter, for Proxy Demand Resource (Kiliccote et al. 2015). For the Participation Load model or Non-Generating Resource, there are varying telemetry requirements, so the customer would incur additional telemetry installation and configuration costs. The telemetry speed requirements change based on the ancillary services model. In addition, there are special monthly secure communication connection costs (e.g., for the ECN).

In a study funded by the US DOE Advanced Research Projects Agency-Energy, DRRC researchers evaluated the costs of participating in ancillary services markets using cellular data networks to pass data to the ISO or program coordinators. The team evaluated two cases: participation in regulation markets that require four-second telemetry and participation in spinning reserve markets that require one-minute telemetry. Table 8 shows the data required for regulation and spinning reserve services in California when using OpenADR 2.0b, and it also shows the data cost and typical compensation values for the services. The last line of the table shows the data cost divided by the compensation, which indicates a break-even point for the minimum load under control, for the given participation payments and data transmission costs.

	Regulation (4s)	**Spinning Reserve (1m)**
Data/hour (in megabytes [MB][1]	15 MB	1 MB
Cellular data cost / h[2]	$0.73	$0.05
Compensation[3] /kW per hr	$0.007	$0.004
Minimum load under control	420 kW	49 kW

[1] Based on measured results using OpenADR2.0b HTTP method; XMPP is ~25% better
[2] Cellular data costs using $\$5x10^{-8}$/B from Verizon; public data show $\$4x10^{-7}$/B,
[3] MacDonald et al., “Demand Response Providing Ancillary Services: A Comparison of Opportunities and Challenges in the US Wholesale Markets”, LBNL-5958E, Nov. 2012

Table 9. Costs of automating DR for regulation and spinning reserve products

One goal of the project was to identify electrical loads that have the greatest potential to participate in ancillary services as well as to identify control, monitoring, and telemetry technology for these loads with the following key attributes in mind: security, low latency, scalability, low cost, accuracy, and repeatability. As part of the project, an LBNL-led team developed a series of pilot deployments that demonstrated the low-cost potential of an integrated AutoDR solution using OpenADR small loads and buildings. The prototype system combined all three elements – communication, control, and telemetry – into a single package and showed how such a system could be deployed and controlled by DR program operators. The team developed a framework and specification for such a system, illustrated schematically in Figure 10. Of note, the system leveraged the home area network available in PG&E smart meters for telemetry (four-second readings), and combined an embedded PC with a thermostat to offer both communication and control logic.

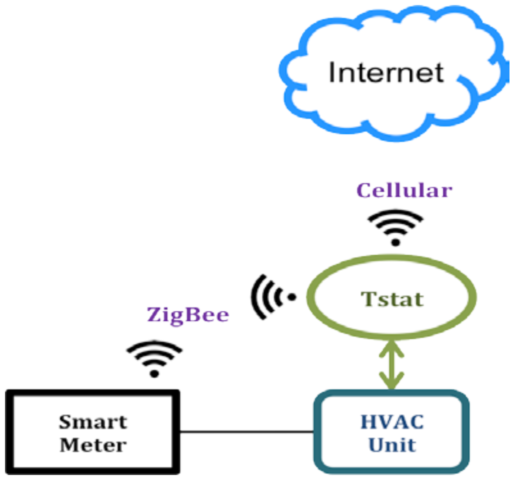


Figure 10. System architecture of an engineered thermostat capable of control and telemetry

The system deployed by LBNL was a prototype with a number of disparate parts connected and configured only for the purposes of the demonstration. Tables 9 and 10 describe the cost of the prototype system elements and show how they are combined into a complete system offering communication, control, and telemetry. These two tables compare the cost of the system described above to the observed costs of the various telemetry and control architectures deployed throughout the project.

	LBNL Prototype	**Engineered System [2]**
Electric Meter Hardware	$700	$200
Embedded PC	$50	Included in thermostat
Wi fi Thermostat	$200	$100
3G modem	$400	Included in thermostat
Installation[1]	$1,200	$1,200
Total	**$2,600**	**$1,500**
Enablement $/kW [2]	**$170**	**$100**

[1]Based on price quotes and LBNL experience

[2] Assumes 5-ton (15kW) air conditioner under control

Table 10. Costs of DR automation of ancillary services for small and medium commercial buildings. As indicted in the first row, these costs include electric meters

	LBNL Prototype	Engineered System [2]
Meter Connectivity	$50	Included in thermostat
Embedded PC	$45	Included in thermostat
Wi-fi Thermostat	$200	$100
3G modem	$400	Included in thermostat
Installation	$200	$200
Total	**$895**	**$300**
Enablement $/kW [1]	**$60**	**$20**

[1]Assume 5 ton (15kW) air conditioner under control

[2]Based on price quotes and LBNL experience (<$10 for added components/functions)

Table 11. Cost of DR automation of ancillary services for small and medium commercial buildings using smart meter connection such as OpenSEG

CHAPTER 6: Discussion and Trends in Costs for DR Automation

This study shows that data on the costs of automating DR systems are complex and affected by a number of factors, such as the requirements of the DR program, the systems existing prior to automation, and the ease of installation for the components of the automation. In this analysis, costs are also influenced by the fact that many providers organized installations in one program to take greatest advantage of utility incentives, which made it difficult to understand the range of costs required to install the automated systems in that program. Some projects in that same program also included control system upgrades that saved energy beyond the automated DR capabilities; in those cases, it was difficult to separate the AutoDR costs from the overall retrofit costs. From a building owner's perspective, the goal of such a project is to reduce utility bills, so the owner has no motivation to distinguish between energy-efficiency and DR costs. Another factor is that we are only beginning to see with the deployment of OpenADR 2.0 is the difference in costs between OpenADR 1.0 and OpenADR 2.0, with higher costs for OpenADR 2.0. This is likely to be related to the larger variety of available systems and greater variety of control upgrades in OpenADR 2.0.

The costs for the automated DR systems are related to the following factors

- **scope of DR automation**- installation and configuration requirements
- **size of load reduction** – the larger sites had lower $/kW
- **version of DR automation protocol** – OpenADR 2.0 costs have been higher but are expected to come down over time. The sample for the OpenADR 2.0 system costs are small and the data are not well understood yet.
- **type of demand reduction** – seasonal grid stress vs ancillary services

The majority of the field data evaluated in this study are based on programs that are providing DR for seasonal grid stress, such as hot summer days or cold winter mornings. We did find that the winter DR was similarly priced as the summer DR automation. The DR for ancillary services requires more sophisticated systems with higher costs. One of the original goals of the DRRC's DR automation research was to develop interoperable software to reduce the costs of automated DR systems. If OpenADR is included in a building or facility native control software systems, no additional hardware is required to automate DR. Some of the lowest costs per kW observed in these data sets is the BPA Target site where the DR automation was available in the native control system. The BPA data were OpenADR 1.0 systems. We have yet to seen this cost reduction in OpenADR 2.0.

As noted previously, the newest version (2013) of the California Building Code, Title 24, which took effect in 2014, requires AutoDR capabilities for lighting; HVAC; and electronic messaging centers (CEC 2014). The cost to automate DR in buildings that comply with the 2013 building code may be far less than the costs required for retrofitting an existing building. This is a new requirement and there are minimal data on the cost savings for the code requirements compared to retrofits of automated DR systems.

In regards to ancillary services, while the technical opportunity to develop low-cost, fast DR automation is clear, there is little experience with developing these systems at scale because the DR wholesale markets are just emerging. Initial products tests show that these systems can be developed for less than $100/kW, compared to the current costs which can be a factor of ten higher. Set up costs for California's Proxy DR program in the Intermittent Renewable Management Pilot Phase 2 (IRM2) are about $25,000 per site. A site can produce 100 kW or 1 MW. Thus the 100 kW site is already requiring $250/kW just for the scheduling coordinator (Kiliccote et al, 2015). Through the experience gained from recent pilots of fast DR systems, we are moving from understanding feasibility and controls and communications issues to quantifying costs. PG&E's IRM2 pilot is the first in which the costs related to CAISO participation are reported. That pilot provided capacity payments, and the utility covered the scheduling coordinator costs to incentivize participation while also reporting on the scheduling coordination costs.

CHAPTER 7:
Summary and Future Directions

To drive broad adoption of automated DR systems, it is important to understand the costs associated with their installation and performance. This paper compares cost data from several DR automation programs and pilots and evaluates trends in the costs per unit of DR or kW of load-shed available from the automated system. We also summarize the types of costs entailed in installing and enabling AutoDR systems, documenting widely varying costs in several pilot projects and utility programs. Median costs are about $200/kW with more than a factor of 10 difference in minimum and maximum costs from the field data. The wide range is a result of the variety in the systems, including system capabilities, age of controls, scope of communication systems, complexity, and other factors. Future research should further explore the total cost to install, operate, and maintain these systems. Ownership and operational costs of these systems should include the building or facility manager's costs as well as those of the utility or third-party program manager.

Cost comparisons can only be made if there are standard methods of defining the costs for hardware, software, installation, configuration, and commissioning. We propose adoption of a standard accounting practice that will enable comparison of the costs of enabling AutoDR and allow for analysis to identify the category of building stock best suited for AutoDR systems.

The lowest cost sites have been those with the DR automation native to the controls. This lower cost automation may continue to become more common as the standardization in DR automation continues and more vendors provide native DR automation in software. Similarly, the existence of new building code requirements for DR automation may continue to reduce the costs for DR automation.

Further work is needed to better understand the costs to automate demand response. This study provides an initial framework for this topic. More data from a broad set of utility programs should be collected to better evaluate trends and opportunities. There is also a need to extend this effort to evaluate DR automation costs in new buildings and explore the value of the code requirements for DR.

CHAPTER 8: References

Cadmus Group, Inc. Assessment of Long-Term, System-Wide Potential for Demand-Side and Other Supplemental Resources, 2013-2032 Volume I. Mar. 2013

Cadmus Group, Inc. Assessment of Long-Term, System-Wide Potential for Demand-Side and Other Supplemental Resources, 2013-2032 Volume II", Mar. 2013

Capper, P., J. MacDonald, and C. Goldman. Market and Policy Barriers for Demand Response Providing Ancillary Services in U.S. Markets., LBNL-6155E, Mar. 2013

Federal Energy Resource Commission..Assessment of Demand Response & Advanced Metering. Staff Report by FERC. October 2013.

Ghatikar, G. and D. Hennage. 2010. Client and Logic with Integrated Relay User Guide: Installation and Troubleshooting for Auto-DR. http://poet.lbl.gov/drrc/pubs/CLIR-UserGuide_6-R3.pdf

Ghatikar. G., D. Reiss, and M.A Piette. Analysis of Open Automated Demand Response Deployments in California and Guidelines to Transition to Industry Standards" LBNL-6560e Jan. 2014.

Ghatikar, G, E. H. Y. Sung, and MA. Piette. Diffusion of Automated Grid Transactions Through Energy Efficiency Codes. Proceedings of the 2015 Summer Study of the European Council for an Energy efficiency Economy. June. Hyères France. 2015.

Goldman C., M. Reid, R. Levy and A. Silverstein. Coordination of Energy Efficiency and Demand Response. LBNL-3044E, Jan. 2010

Kiliccote, S. M.A. Piette, G. Wikler, J. Prijyanonda, and A. K. Chiu. Installation and Commissioning Automated Demand Response Systems. *Proceedings of the 16th National Conference on Building Commissioning,* Newport Beach, CA April 22-24, 2008. LBNL-187E.

Kiliccote, S. M.A. Piette and J. Dudley. Northwest Open Automated Demand Response Technology Demonstration Project. LBNL-2573E, Mar. 2010.

Kiliccote, S. P. Sporborg, I. Sheikh, E Huffaker, and M.A. Piette. Integrating Renewable Resources in California and the Role of Automated Demand Response. LBNL-4189E. 2010.

Kiliccote, S., P. Price, M.A. Piette, G. Bell, S. Pierson, E. Koch, J. Carnam, H. Pedro, J. Hernandez, and A. Chiu. Field Testing of Automated Demand Response for Integration of Renewable Resources in California's Ancillary Services Market for Regulation Products. LBNL-5556E. 2012.

Kiliccote, S., S. Lanzisera, A. Liao, O. Schetrit, M. A. Piette. Fast DR: Controlling Small Loads over the Internet. Proceedings of ACEEE 2014 Summer Study. Asilomar, CA.

Kiliccote, S., G. Homan, R. Anderson, J. Hernandez. Intermitent Renewable Management Pilot – Phase 2. LBNL number forthcoming. March 2015.

MacDonald, J., P. Cappers, D. S. Callaway, and S. Kiliccote., Demand Response Providing Ancillary Services: A Comparison of Opportunities and Challenges in the US Wholesale Markets. LBNL-5958E, Nov. 2012

OpenADR Alliance, OpenADR 2.0. Profile Specification - A and B Profiles. Document Number: 20110712-1 and 20120912-1. 2013.

Page, J. C. McParland, M. A. Piette, and S. Czarnecki. Design of an Open Smart Energy Gateway for Smart Meter Data Management. LBNL (in review) 2015.

Piette, M.A., G. Ghatikar, S. Kiliccote, D. Watson, E. Koch, and D. Hennage. 2010. Design and Operation of an Open, Interoperable Automated Demand Response Infrastructure for Commercial Buildings. *Journal of Computing Science and Information Engineering*. Vol 9 no 2, Transactions of the ASME. LBNL-2340E.

Piette, Mary Ann, G. Ghatikar, S. Kiliccote, E. Koch, D. Hennage, P. Palensky, and C. McParland. 2009. Open Automated Demand Response Communications Specification (Version 1.0). California Energy Commission, PIER Program. CEC-500-2009-063 and LBNL-1779E.

Piette, M.A., G. Ghatikar, S. Kiliccote, E. Koch, D. Hennage, P. Palensky, and C. McParland. 2009. Open Automated Demand Response Communications Specification. California Energy Commission, CEC-500-2009-063 and LBNL-1779E.

Southern California Edison, "Demand Response Technology Evaluation of AutoDR Programmable Communicating Thermostats", Dec. 2012

Zigbee Alliance, Smart Energy Profile Specification Revision 16, Version 1.1, 23 March 2011.

ZigBee Alliance and HomePlug Powerline Alliance. Smart Energy Profile 2.0 Public Application Protocol Specification. 2011.

Appendices

Table A1-A5 summarized the costs for different pilot projects compared in this paper.

Table A1 summarizes DR automation costs for 11 projects (PG&E 1-11) implemented at PG&E customer sites, in the years 2013-2015. The table lists the total project cost, PG&E incentives, total load shed in kW, and the cost per kW across all projects. Total project costs are broken down into the following categories:

- Communications Equipment
- Communications Labor
- Controls Equipment
- Controls Labor

Table A1 - ADR Cost Breakdown for Selected PG&E sites

	PG&E 1	**PG&E 2**	**PG&E 3**	**PG&E 4**
Project Year	2014	2013	2014	2013
Cost Year	Jan, 2015	Jan, 2015	Jan, 2015	Jan, 2015
Total Incentives ($)	$20,100	$46,300	$11,300	$26,300
Total Cost ($)	$20,100	$49,000	$12,600	$27,800
Total Shed (kW)	275	231	57	75
$/kW	**$70**	**$210**	**$220**	**$370**
Breakdown ($/kW)				
Communications Equipment	$7	$59	NA	$34
Communications Labor	$13	$153	NA	NA
Controls Equipment	$10	NA	$169	$336
Controls Labor	$42	NA	$53	NA

	PG&E 5	PG&E 6	PG&E 7	PG&E 8
Project Year	2013	2014	2015	2015
Cost Year	Jan, 2015	Jan, 2015	Jan, 2015	Jan, 2015
Total Incentives ($)	$19,200	$19,500	$9,800	$8,400
Total Cost ($)	$21,700	$39,100	$26,700	$27,200
Total Shed (kW)	57	99	49	42
$/kW	**$380**	**$390**	**$550**	**$650**
Breakdown ($/kW)				
Communications Equipment	$43	$240	NA	NA
Communications Labor	$8	$131	NA	NA
Controls Equipment	$279	NA	$289	$337
Controls Labor	$50	$25	$256	$310

	PG&E 9	PG&E 10	PG&E 11
Project Year	2015	2015	2013
Cost Year	Jan, 2015	Jan, 2015	Jan, 2015
Total Incentives ($)	$7,000	$5,600	$77,600
Total Cost ($)	$26,100	$27,300	$245,900
Total Shed (kW)	35	28	221
$/kW	**$750**	**$980**	**$1,110**
Breakdown ($/kW)			
Communications Equipment	NA	NA	NA
Communications Labor	NA	NA	NA
Controls Equipment	$405	$506	$827
Controls Labor	$342	$470	$286

NA – Not Available

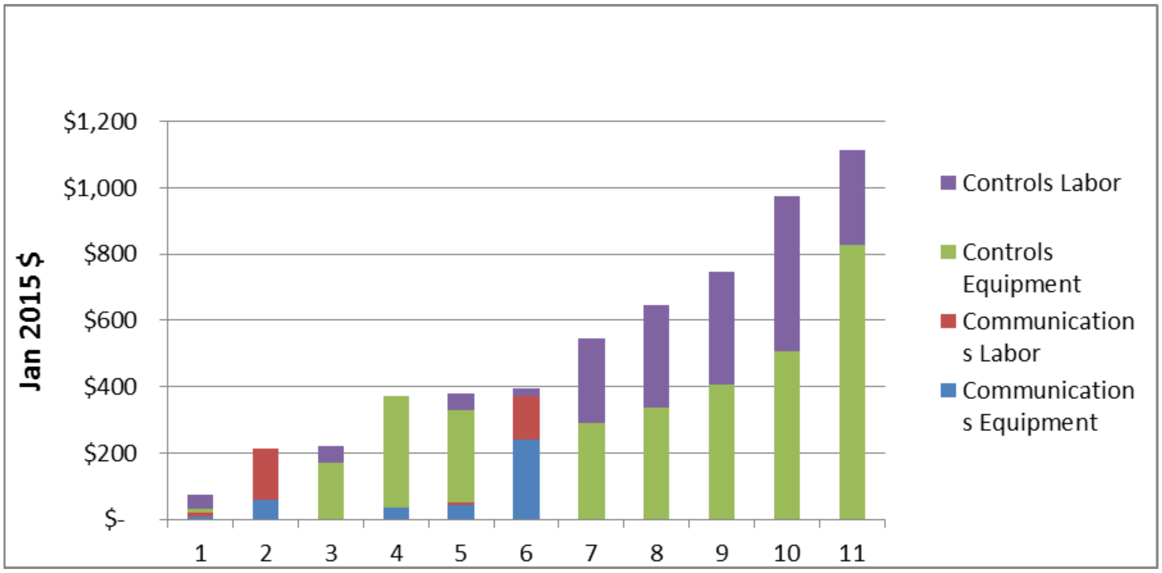


Figure A1 – Installed Cost Breakdown for Selected Sites (PG&E 2013-15)

Project costs varied widely ranging from $70 to 1,110 per kW, depending on the retrofit type (e.g. lighting, rooftop unit controls, or thermostat) and existing system configuration, among other factors. Some projects such as "PG&E 11" included energy efficiency retrofits that were not covered by utility incentives, causing a significant higher cost per kW shed compared to similar projects. In fact, Project "PG&E 6" through "PG&E 11" incurred much higher installation costs compared to the incentives provided by PG&E, suggesting that the high project costs might be attributed to non-ADR components. It is interesting to note that since PG&E already provides smart meter capability for its customers, the DR automation costs for these projects do not incur telemetry related expenses.

Table A2 summarizes the DR automation cost for another 14 projects (PG&E 12-25) implemented at PG&E customer sites. These projects are listed separately from those in Table A1, because project details are not available to break down project costs into the categories discussed earlier. Project implementation occurred between 2012 and 2013. Enablement cost covered an even wider range than those shown in Table A1, primarily because of the low project cost of "PG&E 12" - $8 per kW, and high project cost for "PG&E 25" - $3,250 per kW. The latter was partially due to the addition of a wireless pneumatic thermostat system and zone-level thermostat network as part of the new system.

Table A2 - ADR Cost for Other PG&E Projects

Customer	Project Year	Total Shed (kW)	Jan 2015 $ / kW
PG&E 12	2013	100	$8
PG&E 13	2012	155	$80
PG&E 14	2013	91	$100
PG&E 15	2013	74	$180
PG&E 16	2013	106	$360
PG&E 17	2012	2003	$370
PG&E 18	2012	69	$400
PG&E 19	2013	221	$500
PG&E 20	2013	49	$530
PG&E 21	2013	216	$760
PG&E 22	2013	29	$910
PG&E 23	2012	32	$1,080
PG&E 24	2013	86	$1,250
PG&E 25	2012	155	$3,250

Table A3 summarized the DR automation costs for four NYSERDA projects in January 2015 dollars. The enablement cost ranged from $70 to $740 per kW. In addition to the cost categories listed in Table A1, two of the four NYSERDA projects also incurred telemetry equipment and labor costs. As discussed in the main text of the report, “NYSERDA 4” was an educational building, and because facility managers were never able to perform the planned load shed due to classroom schedules and academic activities, the project cost was therefore matched with a low load shed, resulting in a relative high $/ kW. For “NYSERDA 1”, the relative low $/ kW was potentially achieved by an economy of scale, where equipment and labor costs were distributed across a larger load shed.

Table A3 - ADR Cost for NYSERDA Projects

	NYSERDA 1	NYSERDA 2	NYSERDA 3	NYSERDA 4
Project Year	2012	2012	2012	2012
Cost Year	Jan, 2015	Jan, 2015	Jan, 2015	Jan, 2015
Total Cost ($)	$46,200	$46,400	$44,900	$42,100
Total Shed (kW)	652	151	137	57
$/kW	$70	$310	$330	$740
Breakdown ($/kW)				
Communications Equipment	$6	$30	$35	$58
Communications Labor	$34	$103	$163	$350
Controls Equipment	$12	$22	$31	$100
Controls Labor	$19	$116	$57	$230
Telemetry Equipment		$11	$12	
Telemetry Labor		$27	$29	

Table A4 summarized PG&E 2007 projects in January 2015 dollars. The total cost includes technical coordination (TC) and installation cost. The cost ranges from $9/kW to $236/kW. The total load shed has a wide range, from 24 kW for "PG&E (07')-04" to 10000 kW for PG&E (07')-12". Two customers that achieved largest load shed ("PG&E (07')-12" and "PG&E (07')-13") are both new industrial customers, and the relatively low cost indicates that they have achieved economy of scale, whereas the third largest load ("PG&E (07')-14") is associated with the highest unit cost ($236/kW).

Table A4 - ADR Cost for 2007 PG&E Projects

Customer	Total Shed (kW)	Total Cost ($)	Cost in Year 2015($/kW)
PG&E(07')-01	74	13624	208
PG&E(07')-02	346	60907	198
PG&E(07')-03	203	2685	15
PG&E(07')-04	24	4750	223
PG&E(07')-05	34	3600	119
PG&E(07')-06	172	8220	54
PG&E(07')-07	112	5690	57
PG&E(07')-08	217	12030	63
PG&E(07')-09	100	800	9
PG&E(07')-10	136	3312	27
PG&E(07')-11	800	99596	140
PG&E(07')-12	10000	706883	80
PG&E(07')-13	5175	61844	13
PG&E(07')-14	2874	602690	236
PG&E(07')-15	274	8064	33
PG&E(07')-16	488	21166	49
PG&E(07')-17	496	5075	12
PG&E(07')-18	306	33976	125
PG&E(07')-19	276	18253	75
PG&E(07')-20	309	31854	116
PG&E(07')-21	76	15448	229
PG&E(07')-22	76	13674	203
PG&E(07')-23	74	13176	201

Table A5 summarized Bonneville Power Admin- Seattle City Light 2009 projects in January 2015 dollars. The data is collected from five commercial buildings, with two Target stores ("BPA 03") combined. Only cost data for summer DR events are included, ranging from $11/kW to $293/kW. Target achieved the largest load shed with lowest unit cost. The major strategies they used were turning off 50% of sales area lights, turning off two out of 12 rooftop units and global temperature adjustment. Customer "BPA 04" is the Seattle University, which used similar strategies, including pre-cooling and global temperature adjustment of HVAC systems, but the unit cost is higher than other three customers ($293/kW).

Table A5 - ADR Cost for 2009 BPA/SCL Projects

Customer	Project Year	Total Shed (kW)	Total Cost ($)	Cost in Year 2015 ($/kW)
BPA 01	2009	40	4200	114
BPA 02	2009	181	8330	50
BPA 03	2009	285	2850	11
BPA 04	2009	35	9432	293

In order to have a more realistic assessment of the DR cost, we put together all the 56 data points from PG&E, BPA and NYSERDA projects, and then trimmed the outliers in two ways. In the first case, the outliers are defined as five highest $/kW and five lowest $/kW. In the second case, the outliers are defined as four highest $/kW and four largest kW. Figure A1 and Figure A2 show the graph with trimmed data. The descriptive statistics of cost before and after the trimming are shown as below in Table A6.

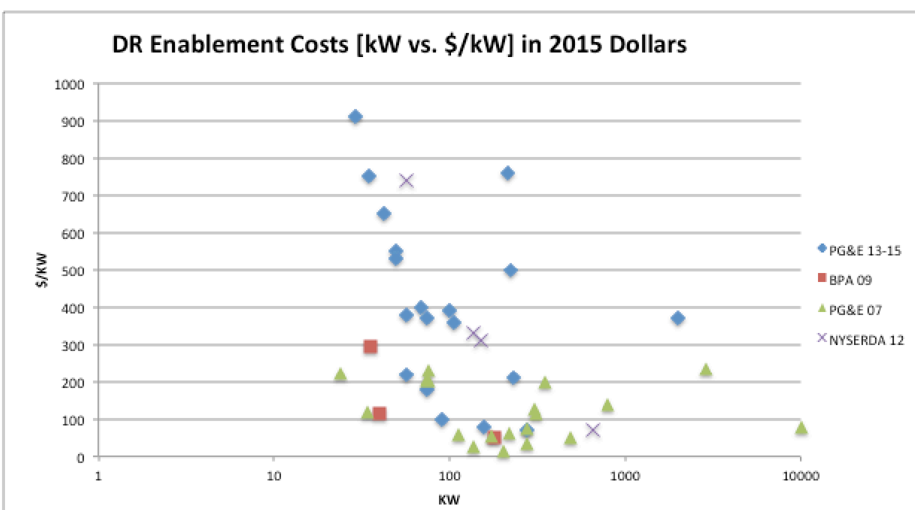


Figure A1 Comparison of costs for Auto DR systems from 2007 to present from PG&E, NYSERDA, and BPA programs (46 customers)

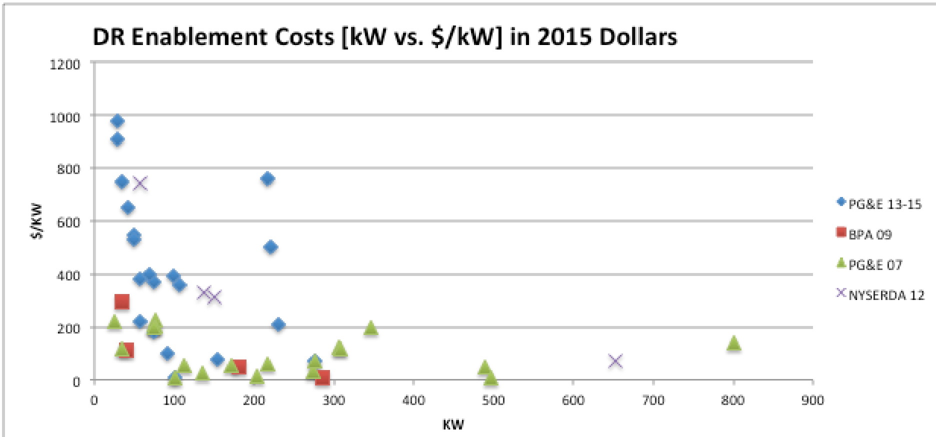


Figure A2 Comparison of costs for Auto DR systems from 2007 to present from PG&E, NYSERDA, and BPA programs (48 customers)

	Untrimmed	Trimmed1	Trimmed2
Number of Observations	56	46	48
Average	355	264	260
Minimum	8	15	8
Maximum	3250	910	980
Standard Deviation	511	226	254
Median	203	205	200

Table A6 Descriptive Statistics of Trimmed and Untrimmed Sites (Unit: $/kW)

The average cost reduced from $355/kW to around $260/kW after trimming the outliers in both ways. There's still a wide range within the data, but the standard deviation is almost reduced by half. The median value of DR cost is similar in all cases.