LBNL-2512E

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Wireless Demand Response Controls for HVAC Systems

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August 2007

DISCLAIMER

Acknowledgments

The work described in this report was conducted with technical support from the Demand Response Research Center (Girish Ghatikar) and Akuacom (Padmaja Pradhan and Dan Hennage). This work described in this report was coordinated by the Demand Response Research Center and funded by the California Energy Commission, Public Interest Energy Research Program, and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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Abstract

The objectives of this scoping study were to develop and test control software and wireless hardware that could enable closed-loop, zone-temperature-based demand response in buildings that have either pneumatic controls or legacy digital controls that cannot be used as part of a demand response automation system. We designed a SOAP client that is compatible with the Demand Response Automation Server (DRAS) being used by the IOUs in California for their CPP program, design the DR control software, investigated the use of cellular routers for connecting to the DRAS, and tested the wireless DR system with an emulator running a calibrated model of a working building. The results show that the wireless DR system can shed approximately 1.5 Watts per design CFM on the design day in a hot, inland climate in California while keeping temperatures within the limits of ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy.

Key Words: control, demand response, HVAC, wireless

Executive Summary

Introduction

Commercial air-conditioning is one of the largest contributors to the California Independent System Operator's (Cal ISO's) peak load. On the hottest days, approximately 15% of the load managed by the Cal ISO is commercial air-conditioning. One of the most effective ways to shed commercial air-conditioning load in response to a demand response signal is through the use of a global zone temperature setup. Global zone temperature setup involves raising the cooling setpoint of each and every zone in response to a demand response (DR) signal, then lowering it to the non-DR level after the DR event has ended. Global zone temperature setup requires direct digital control (DDC) at the zone (thermostat) level. Most commercial buildings do not have zone-level DDC, and many buildings that do have zone-level DDC cannot implement a global temperature setup because older DDC systems were not always designed to be freely programmable (i.e., setpoints must be changed manually, one by one). Wireless controls offer a way to achieve the demand response advantages of global zone temperature setup in buildings that do not have the zone-level DDC controls that can implement a global zone temperature setup. Wireless temperature sensors can be easily deployed in a building to measure zone temperatures. These temperature readings are transmitted back to a supervisory controller that adjusts the speed of the heating, ventilating, and air-conditioning (HVAC) system fans so that zone temperatures are allowed to float up to, but not exceed, a pre-determined setpoint that may be a function of the demand response price signal. The cost effectiveness of wireless demand response can be enhanced by adding the DR capability to an existing wireless control system that has been designed for energy efficiency.

Project Tasks

The project was divided into the following four tasks: 1) Develop DR software for Federspiel Advanced Control System (FACS), 2) Procure and test cellular routers, 3) Modify emulator for DR testing, and 4) Emulator testing. For Task 1, we wrote communications software so that FACS can communicate with the DRAS, which is a real-time price server originally designed by Lawrence Berkeley National Laboratory (LBNL) and now being used by the investor-owned utilities (IOUs) in California We also wrote the application software that enables DR capability integrated with other FACS applications. For Task 2 we procured and tested two cellular routers from two different manufacturers. Each cellular router was provisioned on a different carrier's cellular Evolution Data Optimized (EVDO) network. For Task 3, we configured our existing emulator to model one of the test air-handling units (AHU-B) and associated building mass at the Energy Resource Station (ERS) in Ankeny, Iowa. The emulator was configured to used weather data from California Climate Zone (CCZ) 12, which includes Sacramento and Livermore. For Task 4, the DRAS was configured to serve a price ratio of 1.0 prior to noon. The price ratio increased to 3.0 at noon. Between noon to 3pm the price ratio remained at 3.0. At 3pm the price ratio changed to 5.0. Between 3pm and 6pm the DR price ratio remained at 5.0. At 6pm the DR price ratio changed to 1.0 and remained at 1.0 for the remainder of the day. Zone temperature setpoints were 76 degF when the DR price ratio was 3.0, and 79 degF when the DR price ratio was 5.0. When the price ratio was 1.0, the zone temperature setpoint was undefined because the DR object was not instantiated; the DART object was running instead.

Project Outcomes

The project had five significant outcomes, which are as follows: 1) the DRAS could not always detect that our client was connected, 2) Some mobile broadband networks may not accept a DR server application, and some routers have features that could make operating a server its private side easier, 3) Cellular connections are not “always on”, 4) Wireless DR can provide large load sheds, and 5) Cost savings of DR is significant.

The first outcome may have been fixed by a recent upgrade to the DRAS software. The second and third outcomes are important for installations that cannot use an existing local area network (LAN) for the demand response client. The third outcome, in particular, would be important if the design of the DRAS server switched to a push system, which would have the advantage of reducing network traffic. For the fourth outcome, we show that wireless DR, when configured with a setpoint of 76 degF at the medium-price level (price ratio of 3) and 79 degF at the high-price level (price ratio of 5), can yield a load shed of 1.5 Watts per design cubic foot per minute (CFM), on average. The instantaneous amount of shed load varies through the demand response event from 1.1 to 1.9 Watts per design CFM. For the fifth outcome, we used the results from Outcome 4 and existing utility rates(E-19 and E-CPP in the PG&E service territory) e economic impact of wireless DR. For customers on E-19 and E-CPP, wireless DR has an economic benefit of ~$0.095 per square foot. This figure does not account for any benefit of switching to the E-19 alone to E-19 with E-CPP.

Recommendations

Given the large load shedding potential demonstrated by this scoping study, we recommend a second-phase project aimed at demonstrating the wireless DR system in working buildings. The best candidate buildings would be located in hot or transition climates, and would have pneumatic or legacy DDC terminal controls. The project would need to be initiated soon to ensure that the controls would be in place for the 2008 cooling season.

Introduction

In California, air-conditioning is one of the largest contributors to peak electrical load. Figure 1, taken from Rosenfeld (2004), shows that commercial air-conditioning contributes about half of the difference between the winter baseline load and the summer peak load. On the hottest days of the cooling season, commercial air-conditioning accounts for approximately 15% of the Cal ISO daily peak load.

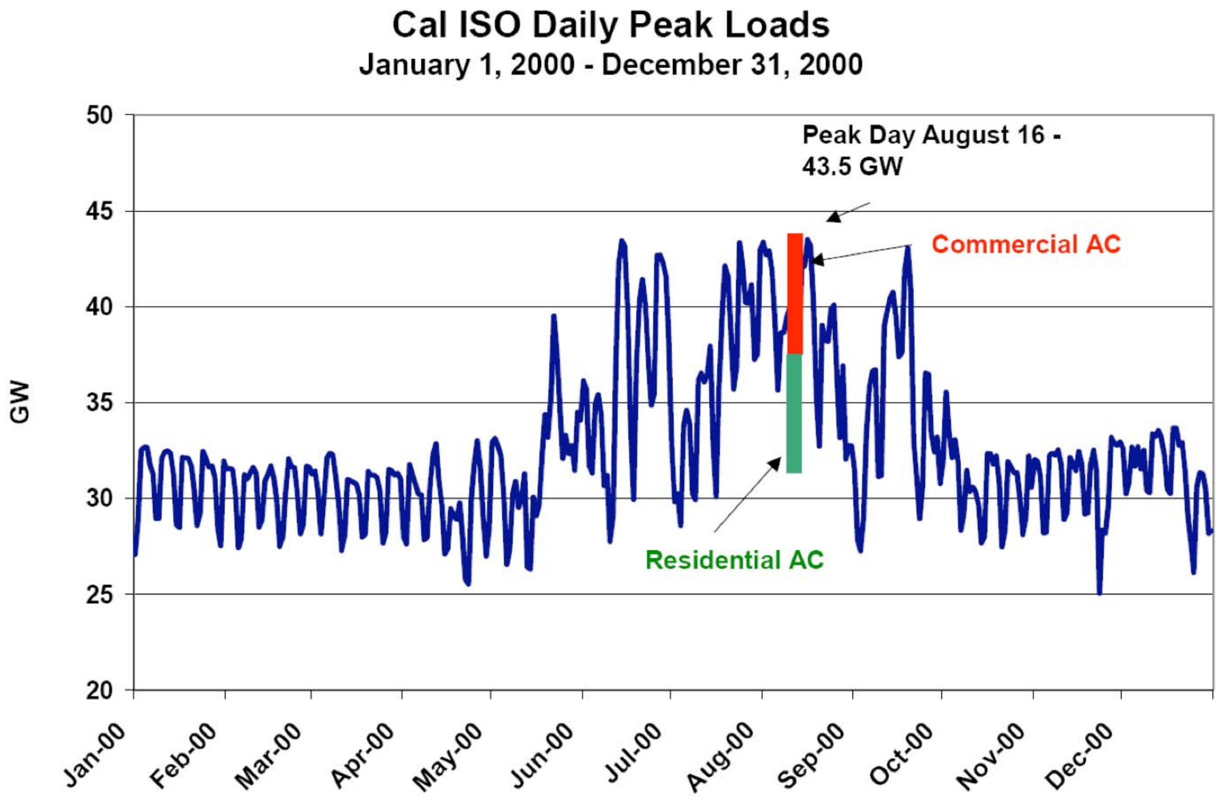

Figure 1: California peak loads, showing the contribution of air-conditioning.

Recent research on ways to automatically or semi-automatically shed HVAC load on peak summer days has demonstrated that a global zone temperature setup is the preferable way to shed load in response to a DR event [Killicote and Piette, 2005; Piette et al., 2005]. Global zone temperature setup involves raising the cooling setpoint of each and every zone in response to a DR signal, then lowering it to the non-DR level after the DR event has ended. In comparison to other DR control strategies for HVAC, global zone temperature setup has the following advantages: 1) it is a closed-loop strategy, so thermal discomfort can be minimized, and 2) it does not cause system interactions that increase loads on other components or cause system imbalances and discomfort, as do strategies such as raising the supply air temperature (which results in increased fan energy use for VAV systems). A disadvantage of global zone temperature setup is that it can only be implemented with state-of-the-art (SOA) direct digital control (DDC) systems that have zone-level DDC. Most commercial buildings either do not have zone-level DDC or have a DDC system that cannot be programmed for a global zone temperature setup.

In some buildings, internet access for a DR system may be difficult to get. Some information technology (IT) departments will not allow HVAC controls to reside on the organization's data network. Even if the HVAC controls can use the organization's local area network (LAN), most organizations run a firewall between internet and the organization's LAN. The problem is less acute for a DR client application seeking access to an internet server via web services, but in the event that the HVAC controls cannot use the LAN, it may be necessary to install another means of accessing the internet. A wireless broadband (cellular) connection is one possible solution.

According to the most recent CBECS survey (EIA, 2003) only 24% of the commercial building floor space is served by buildings with an energy management control system (EMCS). Only a fraction of that 24% is capable of implementing global zone temperature setup, either because there is no zone-level DDC, or because the EMCS cannot be programmed to perform a global setup. Retrofitting a building with a SOA EMCS system with zone-level DDC so that a global zone temperature setup can be performed is not cost effective. An SOA EMCS with zone-level DDC typically costs $4/SF in California [Killicote and Piette, 2005]. Furthermore, the retrofit is disruptive to the building occupants and the business activities in the building. If the owner saves ~0.10/SF/yr from the global zone temperature setup, then the simple payback period is ~40 years, not counting the cost of the business disruption caused by the retrofit.

In a previous PIER-funded research project, Federspiel Controls demonstrated the use of a control system that converted constant air volume (CAV) HVAC systems to VAV using wireless discharge air temperature sensors, such as the one shown in Figure 2 [Federspiel, 2006]. The demonstration was conducted at the Iowa Energy Center's Energy Resource Station (ERS). The control application is called Discharge Air Regulation Technique (DART). DART can be installed quickly (the system at the ERS was installed in two hours) and at low cost (typical payback period of less than two years), and it provides comparable energy savings to a conventional CAV to VAV retrofit.

Figure 2: Wireless discharge air temperature sensor used for DART demonstration.

In a related PIER-funded research project, Federspiel Controls used computer simulations to assess the performance of DART under a variety of operating conditions, including common HVAC system fault conditions [Federspiel, 2007]. The project also involved the development of an emulator based on the computer simulations. The emulator is a real-tiime simulation running on a computer with analog input and output cards (data acquisition cards). The emulator is used for hardware in the loop testing of the wireless control hardware and software.

The recent development of wireless sensor network technology offers an opportunity to design a DR control system for existing buildings that either do not have an EMCS or that have a legacy EMCS that cannot be programmed to perform a global temperature setup. Wireless, battery-powered zone temperature sensors can be added to any building at relatively low cost and without disrupting the occupants or the activities in the building. The signals from these sensors are checked by a controller that reduces the HVAC system output and allows the zone temperature readings to rise during a DR event until one or more reach a setpoint that is a function of the DR signal. When the maximum zone temperature reaches the setpoint, the controller regulates the maximum zone temperature by modulating the HVAC system output until the DR signal changes. Such a system could open up the possibility of getting closed-loop zone-level DR response from the overwhelming majority of buildings that cannot respond to DR signals today.

DART is now one of the control applications of the Federspiel Advanced Control System (FACS™), which is a web-based energy management system that utilizes wireless mesh network technology. FACS hardware includes a Federspiel Supervisory Controller (FSC), a Web-to-Wireless Gateway (WWG), Wireless Sensor Modules (WSMs), and Wireless Control Modules (WCMs). Each FSC has a driver for one or more WWGs, a SQL database, a web server, and one or more control applications such as DART. FACS utilizes the Time Synchronized Mesh Protocol (TSMP™) technology from Dust Networks. TSMP uses time division multiple access (TDMA) combined with frequency hopping. Time division allows for a very low duty cycle, which makes it possible to run all network nodes on AA batteries for years and still have all network nodes be mesh routing nodes. Frequency hopping helps the system avoid interference, and it also improves wireless security. TSMP has additional security features including 128 bit encryption. FACS radios operate in the 902-928 Industrial, Scientific, and Medical (ISM) band, which is unlicensed in North America. The 900 MHz ISM band is better for penetrating building materials than the 2.4 GHz ISM band, and has a longer line-of-sight range for the same radiated power.

To improve the DR value proposition, the DR application would be deployed as a FACS application in conjunction with an energy efficiency application such as DART so that much of the wireless control hardware infrastructure could be reused. This dual EE and DR system design would reduce the incremental cost of DR and should make the DR application cost effective for many commercial operations.

Project Objectives

The project objectives were as follows:

- Develop DR application for the Federspiel Advanced Control System (FACS™),
- Investigate the use of cellular internet connections for DR,
- Demonstrate the performance of wireless DR using an emulator.

Project Approach

The technical work was divided into four tasks.

1. Develop DR software for FACS

We wrote communications software so that FACS can communicate with the DRAS [Piette et al., 2007], and we wrote the application software that enables DR capability integrated with other FACS applications. The DRAS is a real-time price server designed by LBNL. It is now being used by the investor-owned utilities (IOUs) in California for their critical peak pricing (CPP) demand response programs.

For the AutoDR client software, we used gSOAP. The gSOAP web services development toolkit is an open-source project that provides an XML to C/C++ language binding to ease the development of SOAP/XML web services in C and C/C++. gSOAP provides a transparent SOAP API through the use of proven compiler technologies that utilize strong typing to map XML schemas to C/C++ definitions. Strong typing provides a greater assurance on content validation of both WSDL schemas and SOAP/XML messages. The gSOAP compiler generates efficient XML serializers for native and user-defined C and C++ data types. More information about gSOAP can be found at http://gsoap2.sourceforge.net/. We selected gSOAP because it is open-source software and because it is compatible with C/C++. FACS software is written in C/C++ (as opposed to Java or .NET) because C/C++ results in smaller, faster executables which can be deployed on an embedded computer.

The DRAS API requires that the client request the price at least once every five minutes, but no faster than once every 50 seconds. Once every 60 seconds is recommended. We programmed our client to request the price once every 60 seconds.

The DRAS provides clients with future price change events. Our client doesn't use information about future price changes. This is because our DART application cannot pre-cool. DART only controls the air-handling unit. Attempts to pre-cool (e.g., by lowering the supply air temperature) would be defeated by the terminal controls. The heating would have to be shut off to pre-cool. In a dual-duct system this would have to be done by closing the hot deck.

The DR application software is object-oriented code written in C++. The DR application runs queries against the FACS database, searching for recent values with a "zone temperature" profile associated with the air-handling unit under control. It computes the maximum zone temperature, and provides that value as feedback to a proportional-integral-derivative (PID) control object. The output of the PID object is sent over the air to the control module(s) associated with the AHU under control so that they can change the speed command to the variable frequency drive(s) (VFDs). The application includes feedforward compensation for fast response to sudden DR price changes, and bumpless transfer to and from energy efficiency applications such as DART. The feedforward compensation reduces the fan speed by the ratio of the outdoor air temperature minus the DR setpoint divided by the outdoor air temperature minus the average zone temperature. Bumpless transfer means that the energy efficiency (e.g., DART) output and DR output coincide at the point of switching. The DR application is designed to run as a service in Windows XP.

2. Procure and test cellular routers

We procured and tested two cellular routers. The first is a Linksys WRT54G3G-ST Wireless G router for mobile broadband. This router includes a 4-port switch, a wireless G access point (802.11g), and a standard PC Card slot for a mobile broadband data card. The WRT54G3G-ST has the same features as other Linksys WRT54G routers. We tested the WRT54G3G-ST with a Merlin S720 data card from Novatel Wireless provisioned for the Sprint mobile broadband network. The second router is a Digi ConnectPort WAN provisioned for the Verizon Wireless mobile broadband network. Both of these cellular routers were provisioned with Evolution Data Optimized (EVDO) cellular radios. EVDO is a telecommunications standard for the wireless transmission of data through radio signals, typically for broadband Internet access. EVDO is standardized by 3rd Generation Partnership Project 2 (3GPP2) as part of the CDMA2000 family of standards and has been adopted by many mobile phone service providers around the world – particularly those previously employing CDMA networks, as opposed to GSM networks. EVDO is significantly faster than the Enhanced Data Rates for GSM Evolution (EDGE) used by GSM networks. It provides access to mobile devices with air interface speeds of up to up to 3.1 Mbit/s (with Rev. A). EVDO provides an IP based network.

We checked that we were able to access the DRAS from a computer located on the private side of the router. We also checked that we could access a web server on the private side of the router from the public side of the router, Additionally, we checked that the router had sufficient bandwidth to run the mesh network commissioning tool from a computer on the public side of the router against a network on the private side of the router.

3. Modify emulator for DR testing

Our emulator runs Matlab code that we call VirtualHVAC, which was developed at Federspiel Controls. This Matlab code can model the transient response of an HVAC system, including transient duct airflows, heat exchanger heat transfer, damper movement, building heat transfer, and local loop controls.

We configured the emulator to model one of the test air-handling units (AHU-B) and associated building mass at the Energy Resource Station (ERS) in Ankeny, Iowa. The ERS is a teaching and testing facility operated by the Iowa Energy Center. The emulator was configured to integrate the differential equations describing the transient heat and mass transfer of the ductwork, mechanical equipment, and building every 10 seconds. We used weather data from California Climate Zone (CCZ) 12, which includes Sacramento and Livermore. When testing the DR application, the emulator was started the previous day. The emulator was started by simulating the 24 hour period prior to starting the emulator three times repeatedly, using the terminal state each of these days as the initial condition for the next day.

We configured the I/O boards to report zone temperatures, discharge air temperatures, outdoor air temperature, fan power, and chiller power. They were also configured to accept voltages corresponding to the supply fan speed and return fan speed.

4. Emulator testing

Figure 3 shows the components of the emulator testing, which include the emulator (a PC with Matlab software modeling the ERS), the FACS wireless control system (sensor modules, control modules, gateway, and supervisory controller that runs the control application software), and the DRAS. The computer is a standard desktop PC. It has data acquisition cards that accept analog inputs from wireless control modules, and that provide analog outputs to wireless sensor modules. We used the Matlab data acquisition toolbox to interface the Matlab model to the data acquisition cards. The Matlab software integrates a set of differential equations that model the heat and mass transfer of the HVAC system and building. The HVAC and building components that make of the Matlab model of the building were developed by Federspiel Controls for another project. The emulator includes component models for heat exchangers, valves, dampers, ducts, fans, room air, building construction layers, and weather. The Matlab integrator is executed every 10 seconds, and each Matlab integration takes about one second. If FACS makes large control changes, then the integration steps take longer. It is possible, but unlikely, that integration steps will take longer than the integration period. If that happens, then the dynamic response of the emulator becomes skewed and inaccurate.

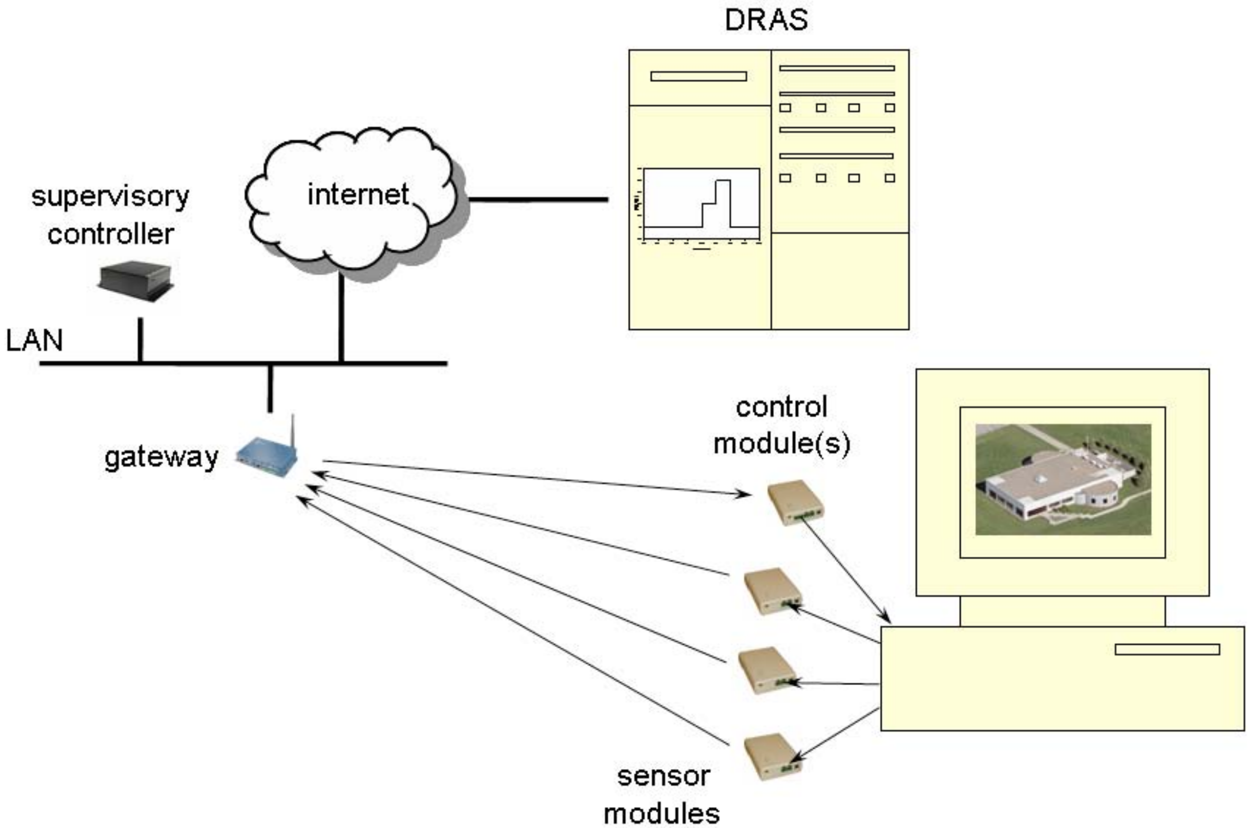

Figure 3: Components use for the emulator testing.

The DR test was conducted with a critical peak pricing (CPP) signal. The signal represents a price multiplier. Most of the time the signal is 1.0, indicating that no DR event is active. On the event day, the DR signal goes from a value of 1.0 to 3.0 at noon. Between noon to 3pm the DR signal remains at 3.0. At 3pm the DR signal goes from a value of 3.0 to a value of 5.0. Between 3pm and 6pm the DR signal remains at 5.0. At 6pm the DR signal goes from a value of 5.0 to a value of 1.0 and remains at 1.0 for the remainder of the day. Figure 4 shows the DR signal on the event day.

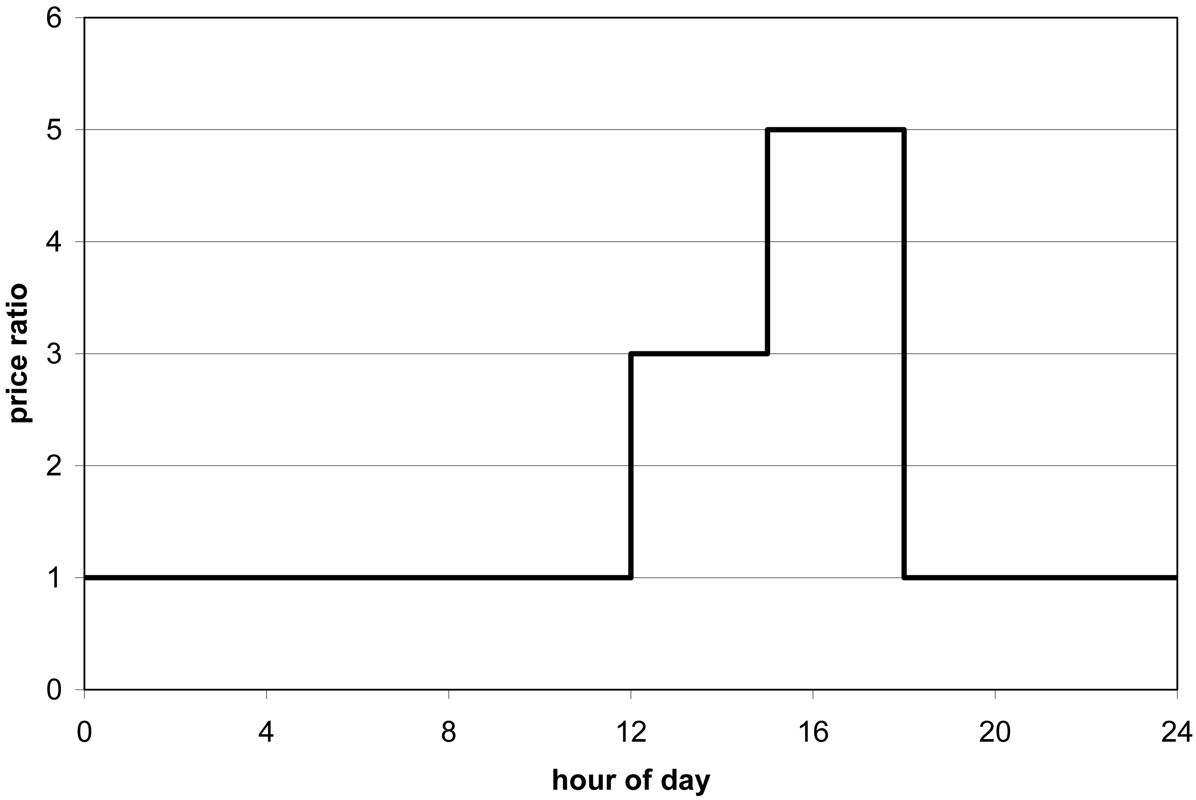

Figure 4: Price signal used for emulator tests.

We configured our DR client to poll the DRAS once per minute to get the price signal. We configured the wireless sensor modules connected to the emulator to report their values every 30 seconds. We tested the DR application running in sequence with our DART application. A DART object was instantiated and used to control the fans of AHU-B when the price signal was 1.0. When the price signal became higher than 1.0 the DART object was destroyed (memory freed), and a DR object was instantiated and initialized. The DR object operated the fans until the price signal dropped back to 1.0, at which point a new DART object was instantiated and used to control the fans.

Zone temperature setpoints were 76 degF when the DR price ratio was 3.0, and 79 degF when the DR price ratio was 5.0. When the price ratio was 1.0, the zone temperature setpoint was undefined because the DR object was not instantiated then. Instead a DART object was instantiated when the price ratio was 1.0. Test were conducted on the design day using California Climate Zone 12 weather data (Livermore) and a price signal that went from 1.0 to 3.0 at noon, from 3.0 to 5.0 at 3pm, and dropped from 5.0 to 1.0 at 6pm. For our purposes, we define the design day as the day in the CCZ 12 weather file with the highest peak dry bulb outdoor air temperature. That day is July 24. The HVAC system was operated 24/7 to demonstrate the thermal recovery period after the DR event ended.

Project Outcomes

Outcome 1: The DRAS could not always detect that our client was connected.

The DRAS has a web-based human-machine interface (HMI) that allows the system administrator to see which clients are connected. The DRAS API requires that the client return the previous price to the server. The DRAS compares the returned price to the current price (not the previous price). When there is a mismatch, the DRAS HMI does not update the connection status. This behavior prevents the HMI from showing a connected client until the second time that a client requests a price. Since it compares the returned price with the current price, it also prevents the HMI from updating the connection status immediately after a change in price. Not realizing that this would happen, we wrote our client software such that its SOAP object was created then destroyed every time we requested a price. This prevented the HMI from showing that our client was connected. When we modified our software such that the SOAP object was static, then the DRAS showed our client as connected after the second price was requested, and after the second request following a price change.

Outcome 2: Some mobile broadband networks may not accept a DR server application, and some routers have features that could make operating a server its private side easier

It was much easier to get a mobile broadband plan working with Sprint than with Verizon. We could sign up for a Sprint plan online, whereas we had to go through a dealer and fill out several pages of paperwork for Verizon. Also, Verizon has stricter rules about using their network. Both companies' contracts state that a server cannot be deployed on the private side of the connection, but Verizon polices their policy. Users have been cut off abruptly for using excessive bandwidth. These policies are not a problem for a DR client running on the private side of the router.

The Linksys router was easier to use than the Digi router. However, the Digi router had more features. A useful feature of the Digi router is port mapping. The mobile broadband networks block port 80 (the default HTML port), but the Digi router could be configured to map another port on the public side of the router to port 80 on the private side. This is particularly useful for devices with embedded web servers because it is not always possible to change the port used by the embedded web server.

Outcome 3: Cellular connections are not "always on"

To conserve network bandwidth, the mobile broadband routers are designed to terminate the internet connection if there has been no activity for a period of time. This period can be configured, but has a limit (e.g., one day). If the router closes the connection, then a person or process on the public side can no longer access anything on the private side. For private-side clients polling a public-side server periodically (as was the case for this scoping study), this is not a problem. If the connection is terminated, it will automatically re-connect when a private-side client tries to access the internet. However, if the router were used in a system where the server pushes price changes to subscribed clients (this architecture would reduce network traffic on the server), then it would be necessary for the private-side client to keep the cellular connection active by accessing the public side of the router more frequently than the disconnect period.

Outcome 4: Wireless DR can provide large load sheds

Figure 5 shows the total power consumption of the two fans (supply and return) and the chiller power associated with AHU-B on the design day with and without a DR event. We computed the chiller power from the cooling coil heat transfer rate and an assumed chiller efficiency of 1.0 kW/ton (one ton is 12,000 Btu/hr). The system was operated 24/7 for this event and its comparison no-event day to show the thermal recovery. The small difference at the start of the day (shortly after midnight and during the mid-day ramp-up are caused by differences in the start time of the emulator the prior day; on the no-event day the building has a little more accumulated heat because it was started two hours later the previous day.

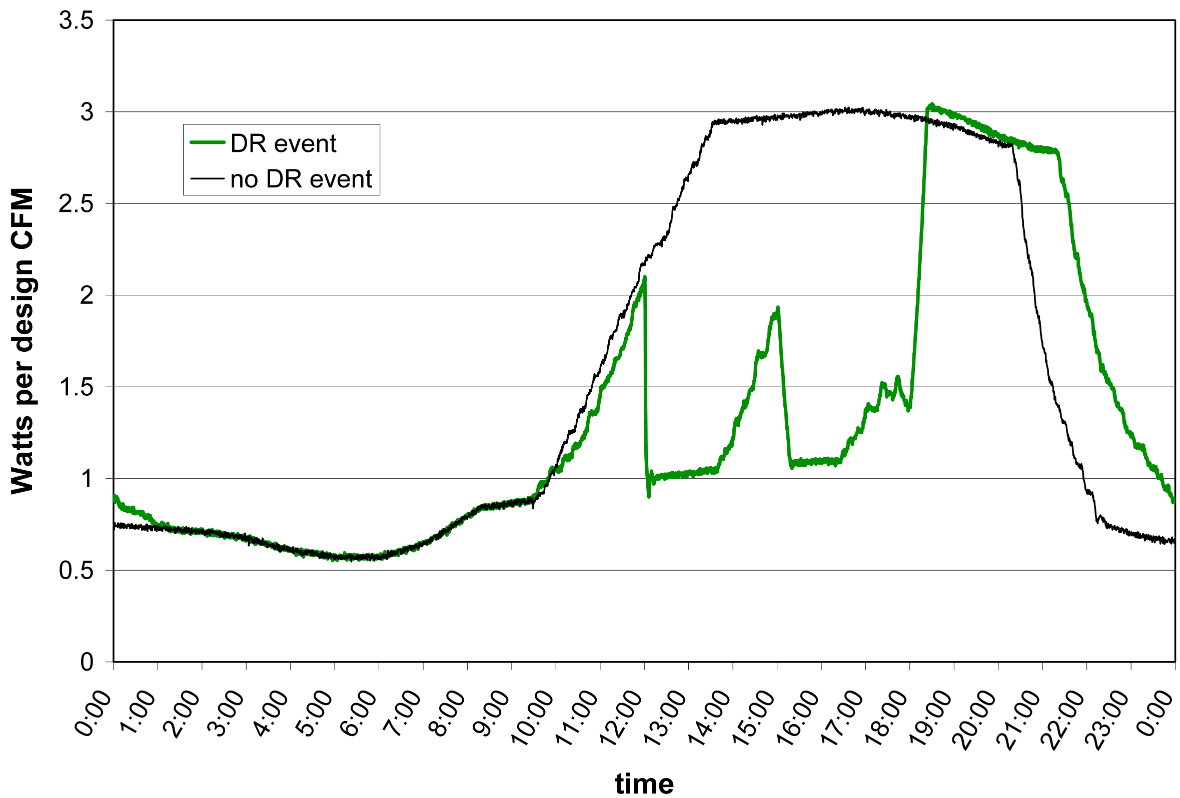

Figure 5: Specific HVAC electric power consumption with and without a DR event.

Figure 6 shows the difference between the kW demand on the no-event day and the kW demand on the event day. Under these conditions, the DR application reduces the kW demand by 1.5 W/CFM on average. However, the load shed is not a perfect square wave; the shed load varies from 1.08 W/CFM to 1.9 W/CFM. During the recovery period, the HVAC system fans are running at full speed until after 21:00. This sudden increase in energy consumption at the end of the DR event could cause grid consumption problems. It could be mitigated by limiting the fan speed during the recovery period. In many buildings the fans would shut off at 18:00, in which case the recovery would be avoided by the fan schedule. The magnitude of the area under the curve during the recovery period is significantly less than the area under the curve during the shedding period, demonstrating that the load shedding conserves energy in addition to reducing the demand during the event interval.

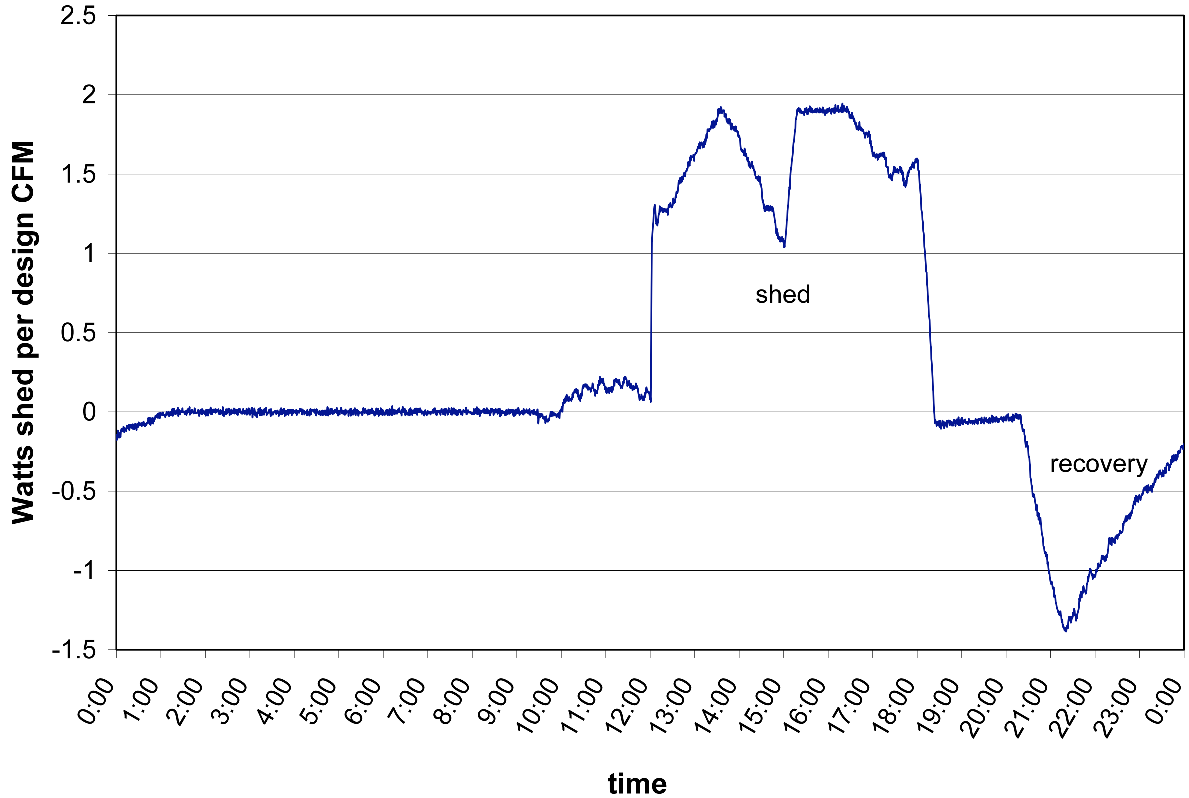

Figure 6: Load shed on the DR event day.

Outcome 5: Cost savings of DR is significant

Though not originally part of the scoping study, we performed a simple analysis of the financial benefit of wireless DR. We assessed the financial benefit of this load shedding capability with some simple assumptions. We assumed that a customer is on the E-19 rate from PG&E [PG&E, 2007a], and on the E-CPP rate from PG&E [PG&E 2007b]. For this analysis, we compute the economic difference between shedding HVAC load and not shedding HVAC load. This analysis does not consider the economics of the E-CPP tariff itself. Under the assumptions in Table 1, wireless DR capability could save an end user ~$0.095/SF/yr. In Table 1, row 1 is the average watts per design CFM that we demonstrated could be shed on a design day in Sacramento. Row 2 is the design CFM per square foot; this is typical for hotter, inland climates

Table 1: Assumptions for finacial analysis

1	average W/dCFM shed	1.5
2	design CFM/SF	1.5
3	# events/yr	12
4	hrs/event	6
5	kWh shed to kWh recovery ratio	3
6	on-peak $/kWh	0.14445
7	on-peak credit	0.03167
8	part-peak $/kWh	0.10576
9	part-peak credit	0.00897
10	moderate price charge, $/kWh	0.16457
11	high price charge, $/kWh	0.56128
12	on-peak demand charge, $/kW	15.02
13	part-peak demand charge, $/kW	3.57
14	coincidence ratio	0.73
15	**$/SF/yr saved**	**0.095**

in California. Row 3 is the number of DR events per year; this is the maximum allowed by E-CPP. Row 4 is noon to 6pm, which is the entire on-peak period of the E-19 rate. Row 5 is the energy shed during the DR event divided by the extra energy for recovery; the ratio is based on these scoping study results. Rows 6-13 are from the E-19 and E-CPP rate tariffs available from PG&E. Row 14 is the fraction of load shedding (row 1) that decreases the monthly peak demand used for bill calculation; the assumption is that DR events occur on days that would contribute to the peak demand. Row 15 (the result) is energy charges avoided on-peak (E-19 plus E-CPP) minus energy charges incurred during part-peak (for recovery) plus avoided on-peak demand charges (just E-19) minus incurred part-peak demand charges (for recovery).

Battery life for the wireless sensor network is 3-10 years on a pair of AA lithium batteries. Assuming the worst case battery life, 1000 square feet per sensor, 15 minutes labor per battery pack, $50/hr for labor, and $2.50 per battery for two batteries, the annual cost of battery maintenance is $0.006/sf/yr.

Costs for a cellular router are $350 for a Sprint WRT54G3G-ST and $850 for a Digi ConnectPort WAN. The Sprint service costs $60/month for a two-year contract, and the Verizon service costs the same. For a 100,000 square foot building, the recurring cost of the cellular connection is just $0.007/sf/yr.

Recommendations

Given the large load shedding potential demonstrated by this scoping study, we recommend a second-phase project aimed at demonstrating the wireless DR system in working buildings. The best candidate buildings would be located in hot or transition climates, and would have pneumatic or legacy DDC terminal controls. The demonstration should be conducted in buildings that do not have unusual or critical processes. An office building, college campus building containing offices and/or classrooms, or a hotel would be good candidates. Poor candidates would include datacenters or laboratories. The site should be available for load shedding of the entire conditioned space so that there is no risk of transferring the shed load to a section of the building that is not shedding load. The project would need to be initiated soon to ensure that the controls would be in place for the 2008 cooling season.

Additionally, we recommend that the DRAS software be upgraded so that a mismatch between the current price and the returned price is not confounded with connection status. The server should provide authentication time and date, time and date of last price request (if different from authentication time and date), and a logical variable indicating whether or not the price comparison failed or succeeded. The server should also compare the returned price with the previous price served, not with the current price.

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Glossary

3GPP2: 3rd Generation Partnership Project 2
AHU: Air-handling unit
ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers
Btu: British thermal unit
CAV: constant air volume
CCZ: California climate zone
CDMA: Code Division Multiple Access
CFM: cubic feet per minute
CPP: critical peak pricing
DART: discharge air regulation technique
DDC: direct digital control
DR: demand response
EDGE: Enhanced Data Rates for GSM Evolution
EMCS: energy management control system
ERS: Energy Resource Station
EVDO: Evolution data optimized
FACS: Federspiel Advanced Control System
GSM: Global System for Mobile communication
HTML: hypertext markup language

HVAC: heating, ventilating, and air-conditioning
IOU: investor-owned utility
IP: internet protocol
LAN: local-area network
PID: proportional-integral-derivative
PIER: Public Interest Energy Research
SOA: state-of-the-art
VAV: variable-air-volume
VFD: variable frequency drive