Technology Evaluation of Programmable Communicating Thermostats with Radio Broadcast Data System Communications

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Disclaimer

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Abstract

Programmable Communicating Thermostats are thermostats that can be programmed by the user to respond to signals indicating a grid-level system emergency or pricing event. The California Energy Commission is considering standards that would include a requirement for Programmable Communicating Thermostats in residential and small commercial applications. The current specification for Programmable Communicating Thermostats requires Radio Data System communications to Programmable Communicating Thermostats.

This study tested the signal strength and reliability of Radio Data System signals at 40 customer sites within the Sacramento Municipal Utility District, which is serviced by 17 radio stations that already transmit Radio Data System signals. The study also tested the functionality of a commercially available Programmable Communicating Thermostat for compliance with California Energy Commission design standards.

Test results demonstrated that Radio Data System is capable of reliably sending price and emergency signals. This study also provides evidence that existing Programmable Communicating Thermostats, on receiving a Radio Data System pricing or event signal, are capable of automatically increasing setpoints to a customer-determined or utility-determined level, thus providing air-conditioning demand response within seconds or just a few (less than 5) minutes.

Keywords: demand response, programmable communicating thermostat, PCT, Radio Data System, RDS, radio broadcast data system, RBDS

Executive Summary

Introduction

Programmable Communicating Thermostats are thermostats that can be programmed by the user to respond to signals indicating an electrical emergency or pricing event. In 2007, the California Energy Commission (Energy Commission) considered in its 2008 energy efficiency building standards (Title 24) including a requirement for Programmable Communicating Thermostats in residential and small commercial applications. The goal of such a requirement would be to provide customers with technology that would enable them to respond to future dynamic pricing tariffs, which are expected to be offered by electric utilities as advanced metering technologies become more widespread in California.

However, due to public concern regarding the requirement of the Programmable Communicating Thermostat, the Energy Commission's Efficiency Committee directed that Programmable Communicating Thermostats be removed from the proposed 2008 energy efficiency building standards. The Committee also asked that the value and concerns related to the potential application of Programmable Communicating Thermostats be considered with other demand response technologies in the Energy Commission's Load Management proceeding (Docket # 08-DR-1). Moving the evaluation of the Programmable Communicating Thermostat to the Load Management proceeding provides a venue for a broader discussion on the Programmable Communicating Thermostat technology and how it could be used with future utility tariff and rate programs. It also provides an opportunity for a full examination by consumers, utilities, and manufacturers regarding the benefits and consumer choice options for demand response technologies.

The Energy Commission had proposed that all Programmable Communicating Thermostats contain an embedded one-way Radio Data System communications module that can receive and decode utility price and system reliability messages. This system is intended as a low-cost statewide default messaging system that will precede but eventually co-exist with other utility communications options. To encourage interoperability, the reference design includes expansion ports that will allow the addition of communications modules, which can be used to establish links to other devices. Several thermostat manufacturers are currently developing prototype thermostats based on draft reference designs.

Project Objective

The objective of this study is to evaluate whether Radio Data System is capable of supporting a reliable electric demand response network, and whether available Programmable Communicating Thermostat technology can provide automated air-conditioning response to the Radio Data System signal.

Project Outcomes

Based on a probability analysis, all 40 sites tested for this study would receive commands and messages sent through Radio Data System greater than 95 percent of the time by broadcasting on two of the existing Radio Data System enabled radio stations. Further reliability could be built into the system by adding a third radio station and/or repeating the command broadcast several more times.

The Programmable Communicating Thermostat tested for this study is a fully functional multi-zone thermostat with automated response to demand response events sent using a Radio Data System signal from a local FM station. The thermostat responds to both price and emergency events as required by current Energy Commission design specifications.

Conclusions

This study demonstrates that:

- For the 40 sites in the Sacramento Municipal Utility District service area, Radio Data System is sufficiently reliable to support an electric demand response network.
- The prototype Programmable Communicating Thermostat tested for this study successfully provided automated air-conditioning response to the Radio Data System signal.

Recommendations

A more detailed study of Radio Data System coverage may be warranted in individual utility service areas to address geographic and other broadcast/reception differences. Weather, valleys, distance from Radio Data System transmitters, the proximity of other buildings, and building materials could all impact Radio Data System signal reception.

Benefits to California

This study provides California State policymakers assurance that Radio Data System can be used to reliably broadcast information to devices in small buildings, both residential and commercial. In particular, this information informs California State energy agencies that it is possible to use this communications technology to reliably broadcast electricity prices and electric system alerts to the mass market. The usefulness of the system is not limited to electricity information, however. The FM-based communications system could also be used to provide public service messages, such as severe weather warnings or instructions following disaster events.

This study also provides evidence that existing Programmable Communicating Thermostats, on receiving a Radio Data System pricing or event signal, are capable of automatically increasing setpoints to a customer-determined or utility-determined level, thus providing air-conditioning demand response within seconds or just a few (less than 5) minutes.

1.0 Introduction

Programmable communicating thermostats or "PCTs" are thermostats that can be programmed by the user to respond to signals indicating a change in the price of electricity or an event such as a system emergency. The Energy Commission had considered a standard that would require the installation of PCTs in new residential and small commercial construction and developed a non-priority reference design1 for manufacturers to use when developing compliant devices (Gunther 2007a). The goal of such a requirement would be to provide customers with technology that would enable them to respond to future dynamic pricing tariffs, which will be offered by electric utilities as advanced metering technologies become more widespread in California.

PCTs developed under the Energy Commission's proposed draft reference design (Gunther 2007a) are just now becoming commercially available. The current communications specification for PCTs requires Radio Data System (RDS), also referred to in the United States as Radio Broadcast Data System (RBDS). Although RDS is commonly used to send digital signals containing radio programming information to automobiles, it has not been used for demand response (DR) controls in residential or small commercial buildings. In this study, the research team evaluated a specific PCT configuration to determine if RDS is capable of reliably providing the price and reliability signals included in the PCT reference design.

This study was conducted in two parts. The first part characterizes RDS signal reliability across a geographically diverse sample of residences and small businesses in the Sacramento Municipal Utility District (SMUD) service territory. In the second part of the study the research team examined the only existing PCT known to use RDS communications, documenting receipt of the signal, proper response and other basic functionality specified by the current Energy Commission design criteria. A full statewide rollout of RDS would require a more detailed statistical analysis of statewide RDS coverage than is presented in this work.

Thus the goals of this study are:

1. Provide evidence that RDS is or is not capable of supporting a reliable electric demand response network.
2. Provide evidence that available PCT technology can or cannot provide automated air-conditioning response to the RDS signal.

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[1] The purpose of developing the reference design was to provide a platform that would enable load reduction from a broad array of end uses, of which the thermostat would be the most complex.

2.0 Background

The California Public Resource Code (Sections 25402 and 25402.1) assigns the Energy Commission with the responsibility of developing and maintaining standards for energy efficiency and load management. PCTs could potentially enable new buildings with automated load management capabilities and serve as part of California's strategy to develop a statewide demand response system that can be used to encourage a more informed and empowered customer base. In time, such a system is expected to reduce system costs and prevent system disruptions. Other North American states and provinces are closely watching the California initiative with interest in adopting similar programs.

The Energy Commission had proposed that all PCTs contain an embedded one-way RDS communications module that can receive and decode messages. This communications system is intended as a low-cost statewide default messaging system that will precede but eventually co-exist with the more expensive (and less common) home automation systems that many utilities anticipate offering to customers in the future. To encourage interoperability with these and other systems, it was proposed that PCTs have expansion ports to allow the addition of communications modules that can be used to establish links to other devices (Gunther 2007a). Several thermostat manufacturers are currently developing prototype PCT devices based on draft specifications.

The Energy Commission's PCT reference design focuses on residential and small commercial air-conditioning (AC) for many reasons including:

- AC load management has long been considered a viable demand response option
- Residential and small commercial AC makes up about 30% of the California system peak load
- For most homes and businesses, over 30 years of program testing have shown that an increase of a few degrees for a limited number of hours does not significantly impact customer comfort
- Small changes in peak AC use could have a significant impact on utility resource requirements
- The diverse population of AC units throughout California provide capability to target price and reliability signals to geographically specific load and congestion problem areas

The development of a reference design standard is expected to reduce PCT costs, which will improve the cost effectiveness of future utility pricing, efficiency, and demand response options. In addition, PCTs that incorporate RDS can provide a new source of messaging capabilities from utility companies and other public agencies to communicate electric outage, customer service response, disaster or other emergency notification.

PCTs provide residential and small commercial customer with the capability to automate their response to utility price and reliability signals. Automating the customer response can lower system peak load, improve system reliability and help mitigate wholesale system costs.

Following are descriptions of the main functions that PCTs are expected to provide:

- **Pricing.** Under time-of-use (TOU) rates, customers are provided with pricing incentives to program the PCT to shift load from more expensive to less expensive time periods every day. Under critical-peak pricing (CPP) or real-time pricing (RTP) tariffs, pricing signals sent to the PCT can automatically initiate price-event control strategies as programmed by the customer – or, customers may choose not to respond to price events at all. This functionality is generally referred to as "price" or "economic" response.
- **Reliability.** During emergencies, PCTs can provide the option for electric service providers to exercise control over air conditioning (AC) loads in all non-exempt customer facilities as a last resort to avoid full rotating outages. This functionality is generally referred to a "reliability" or "emergency" response.
- **Messaging.** The PCT with RDS can function as a default display to provide customers with emergency and other non-emergency messages. Notifying customers of electric emergencies and the status of outage restoration work would have value to both the utility and customer. PCT messaging capability could also be used to support limited natural disaster and other public service or emergency announcements.

3.0 Radio Data System Signal Reception Testing

RDS is the recommended communications technology for the statewide demand response signaling standard.[2] This technology has been used extensively in automotive applications in Europe for two decades. In the U.S., RDS is widely used in mobile devices that receive real-time music and traffic information; however, there have been no evaluations of its performance within buildings.

For this study, the research team evaluated RDS communication performance in 40 residential and small commercial buildings in the Sacramento area using RDS monitoring systems. At each site, the number of complete RDS groups received every 10 seconds was recorded over a 2-minute interval for each of 17 RDS-capable FM stations in Sacramento. This data was used to estimate the probability of receiving a full demand response message (consisting of four RDS groups) at each site. The results show that all 40 test sites would receive a demand response message with near 100 percent probability using just one FM station.

3.1. Communications Infrastructure

Radio Data System, or RDS, is a European Broadcasting Union standard for sending small amounts of digital information using conventional FM radio broadcasts. The RDS system was originally designed to send data related to musical broadcasts, including song, artist, and station identification. RDS has been standard in Europe and Latin America since the early 1990s. The U.S. version of RDS is officially called Radio Broadcast Data System or RBDS, but RDS is also used (Figure 1).

Figure 1. The RDS Logo
Source: RDS Forum (http://www.rds.org.uk/)

RDS uses a 57 kilohertz subcarrier to transmit data at over 1,000 bits per second. Data is transmitted in "groups" of four "blocks" – each containing 26 bits. RDS utilizes error correction that detects all single and double bit errors in a block, any single error burst spanning 10 bits or less, and about 99.8 percent of bursts spanning 11 bits and about 99.9 percent of all longer bursts. RDS does not cause interference or inter-modulation with FM stereo signals (NRSC 2005).

[2] California Title 24 Programmable Communicating Thermostat Wide Area Network One-Way Interface Recommendation, UC Berkeley PCT Research Team, 25 April 2006, Version 1.0.

3.2. Study Area

This study made use of test sites within the SMUD territory, a local utility that is collaborating on a related DR research pilot with HMG and the DRRC.[3]

SMUD was established in 1946 and is currently the nation's sixth largest community-owned electric utility. SMUD serves over half a million customers in Sacramento County, spanning 900 square miles. Peak demand for the SMUD system, measured on July 24, 2006, was 3.3 gigawatts.

Figure 2 shows the location of the SMUD service territory – forecast climate zone 6 – in relation to the state of California.

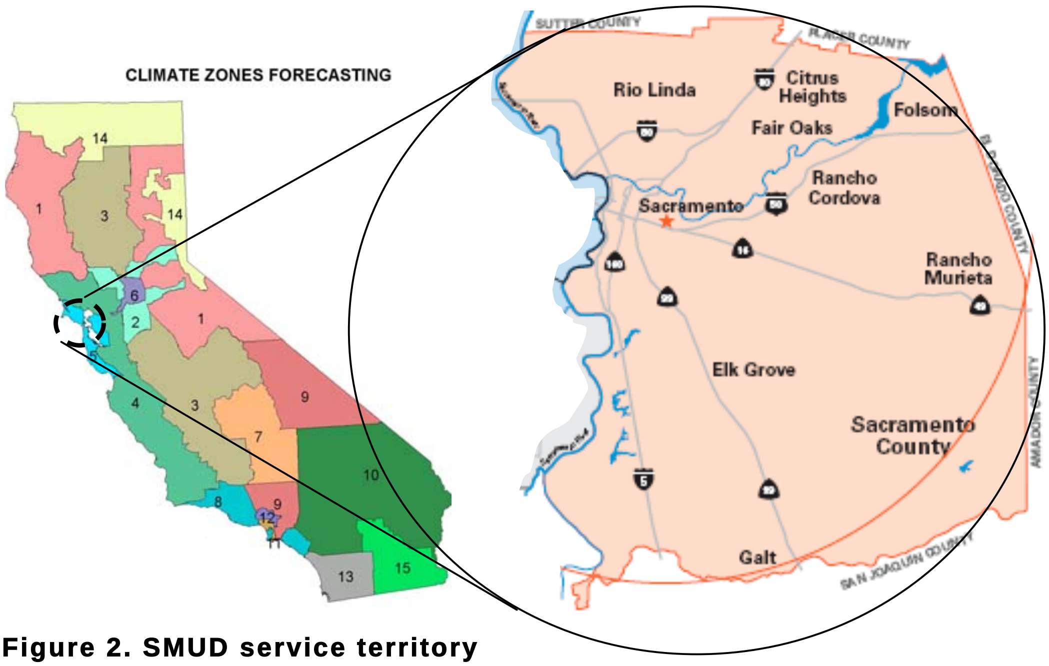

Figure 2. SMUD service territory

Source: SMUD service territory map - Sacramento Municipal Utility District; Forecast Climate Zones map - California Energy Commission

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[3] Incentives and Control Strategies for Successful DR Programs in the Small-Commercial Sector is expected to be completed in December of 2008.

Of the 39 FM radio stations in Sacramento, 17 use RDS to broadcast station, artist and song information. These 17 RDS-capable stations are listed in Figure 3 along with city, location coordinates, and estimated radio transmission power (ERP).

Sacramento Stations	Location	Latitude	Longitude	ERP (kW)
KXJZ 90.9 FM	Sacramento, CA	38° 42' 38" N	121° 28' 54" W	50
KREL 92.1 FM	Placerville, CA	38° 38' 10.50" N	120° 38' 14" W	6
KGBY 92.5 FM	Sacramento, CA	38° 42' 26" N	121° 28' 33" W	50
KQJK 93.7 FM	Sacramento, CA	38° 44' 22" N	121° 12' 50" W	25
KSSJ 94.7 FM	Roseville, CA	38° 40' 22" N	121° 19' 52" W	25
KYMX 96.1 FM	Sacramento, CA	38° 38' 9 " N	121° 33' 11" W	50
KSEG 96.9 FM	Sacramento, CA	38° 38' 53" N	121° 28' 38" W	50
KRXQ 98.5 FM	Sacramento, CA	38° 38' 53" N	121° 05' 51" W	50
KZZO 100.5 FM	Sacramento, CA	38° 38' 30" N	121° 05' 25" W	115
KHYL 101.1 FM	Sacramento, CA	38° 51' 28" N	121° 01' 39" W	36
KSFM 102.5 FM	Sacramento, CA	38° 35' 20" N	121° 43' 30" W	50
KBMB 103.5 FM	Sacramento, CA	38° 33' 59" N	121° 28' 47" W	6
KXCL 103.9 FM	Yuba City, CA	38° 52' 33" N	121° 7' 30" W	6
KNCI 105.1 FM	Sacramento, CA	38° 38' 31" N	121° 05' 25" W	50
KKFS 105.5 FM	Dunnigan, CA	38° 47' 17" N	122° 06' 52" W	3
KWOD 106.5 FM	Sacramento, CA	38° 38' 30" N	121° 05' 25" W	50
KDND 107.9 FM	Sacramento, CA	38° 42' 38" N	121° 28' 54" W	50

Figure 3. FM Stations in Sacramento with RDS capability

Source: Available reception as measured by Heschong Mahone Group; Federal Communications Commission

Figure 4 shows the “local” signal coverage for each of the 17 RDS stations listed in Figure 3, where “local” contours indicate a predicted field strength of 60 dBu (unloaded decibels). Within these contours, reception should be moderately good to very good on almost any radio.

Figure 4. Local signal coverage for FM Stations sending RDS signals. Signal coverage data from the Federal Communications Commission.
Source: Signal contours – Federal Communications Commission; Map - Google Maps

3.3. RDS Monitoring System

The RDS monitoring system used in this study was developed by a research team at University of California at Berkeley. The system consists of one or more RDS receivers and a base station, which is connected to a portable computer (Figure 5).

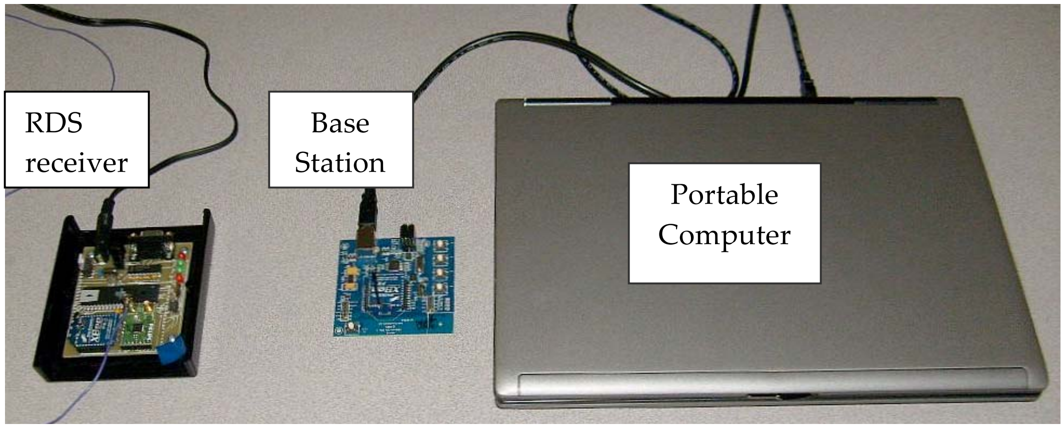

Figure 5. RDS Monitoring System Components
Source: Photo taken by Heschong Mahone Group

The computer runs control software that allows the research team to set parameters, such as a central list of FM frequencies to scan. Using the wireless link, the laptop sends a specified FM frequency command via the base station to the RDS receiver or receivers.

Each RDS receiver is comprised of an FM receiver chip coupled with a micro-controller and a wireless data link. The micro-controller is used to manage the FM receiver – for example, changing tuning frequency – and collect data samples. Each receiver tunes to the specified station and reports reception statistics back to the base station over the wireless link until instructed with a new command. The base station then feeds the data stream to the portable computer, where it is validated and recorded into a local database.

3.4. Data Collection

To test for RDS signal reception, one residential or small commercial site was chosen for each of 40 geographically diverse zip codes within the SMUD service territory. Figure 6 shows each of the test sites as a balloon labeled with its test site number. Also shown and labeled are the FM towers located within the map area.

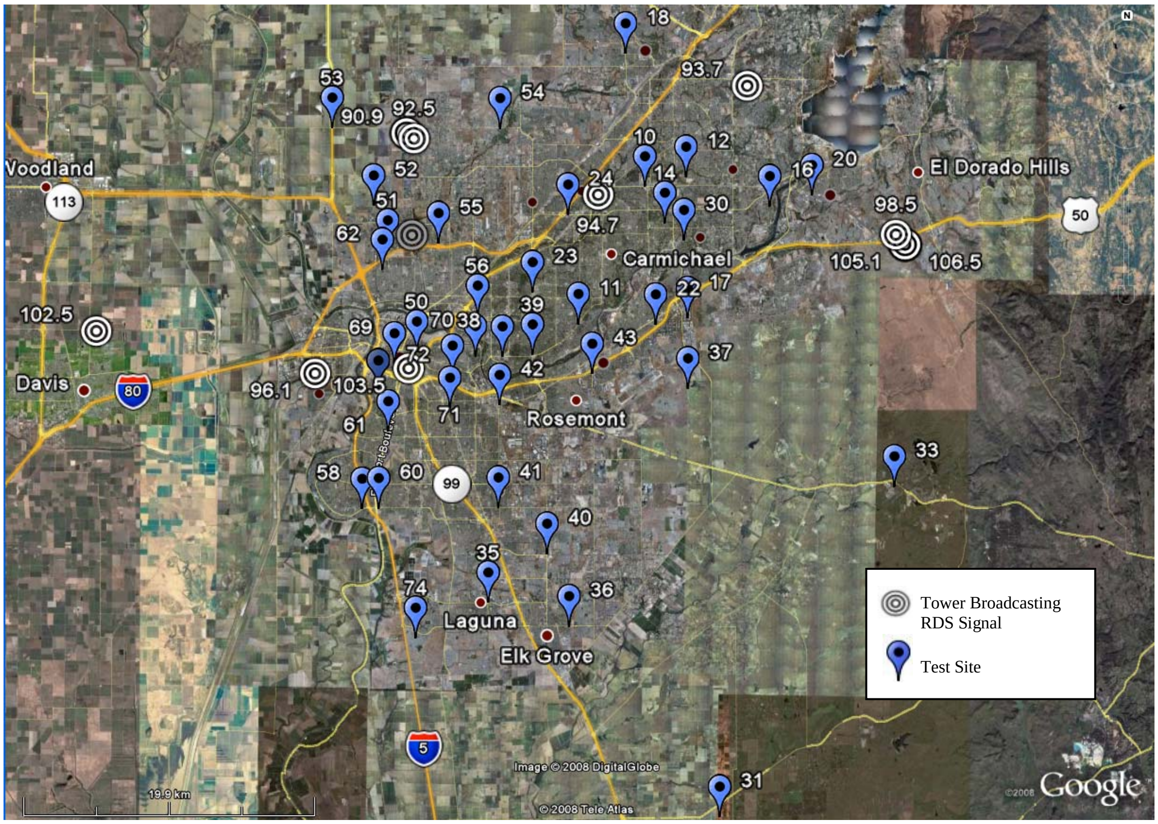

Figure 6. RDS test sites and Broadcast Tower Locations

Source: Test site locations – Heschong Mahone Group; Broadcast Tower locations – Federal Communication Commission; Background Map – Google Maps

Once at the test site, researchers made an attempt to place the RDS receiver in a location similar to that which an actual thermostat would be placed. The researcher then tested each frequency (channel) for 2 minutes at each site, recording among other things signal strength and the number of complete data groups received every 10 seconds (max 114.18). Over the course of a week, the research team collected data for each of the 40 sites identified.

3.5. Signal Strength and Group Reception

Figure 7 shows that the number of valid groups received on a particular frequency at any of the sites increases with the signal strength. Thus, as expected, a high signal strength increases the likelihood that the RDS information is received, while a low signal strength increases the likelihood that the RDS information is not received.

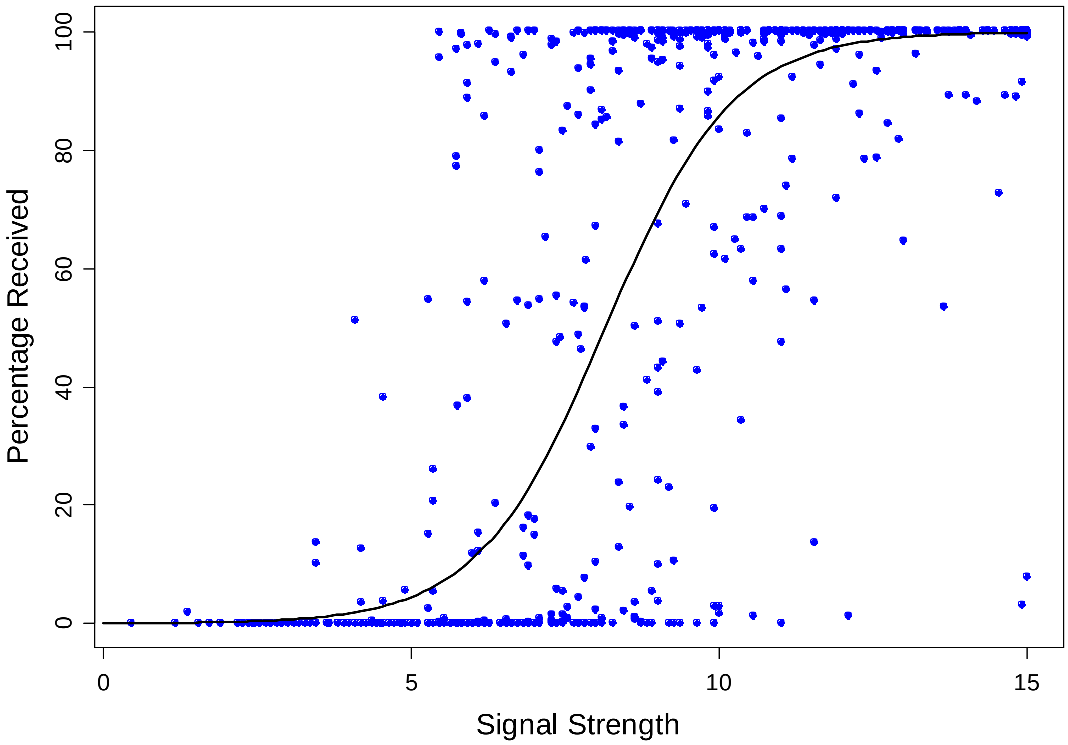

Figure 7. Signal Strength and Percentage of Groups Received, with Trend Line
Source: Heschong Mahone Group

3.6. Probability of Message Reception

The ultimate goal of documenting the percentage of RDS groups received at each test site was to estimate the likelihood of receiving a demand response signal. Since a demand response signal is comprised of multiple groups, this estimation required a probability analysis based on the number of groups required for each signal. A longer message is less likely to be received successfully by a PCT or other demand response device because all of the groups are required before action can be taken. The RDS decoder designed for the PCT tested in Section 4.0 below can receive groups in any order.

The likelihood that the PCT will successfully receive the entire message increases with repeated broadcasts of the message. The probability *P(Success)* that a particular message - of length l repeated n times with group reception probability p - will be successfully received is shown in Formula 1.

$$P(Success) = (1 - (1 - p)^n)^l$$

Equation 1. Message reception probability

Figure 8 shows the probability of successfully receiving messages comprised of four groups when the message is repeated between 1 and 10 times. When the probability of reception of a single group is greater than 80 percent, repeating the message at least three times provides a probability of message reception near 100 percent. Thus repeating the transmission of the groups comprising the demand response message disproportionately increases the probability that the entire message will be received.

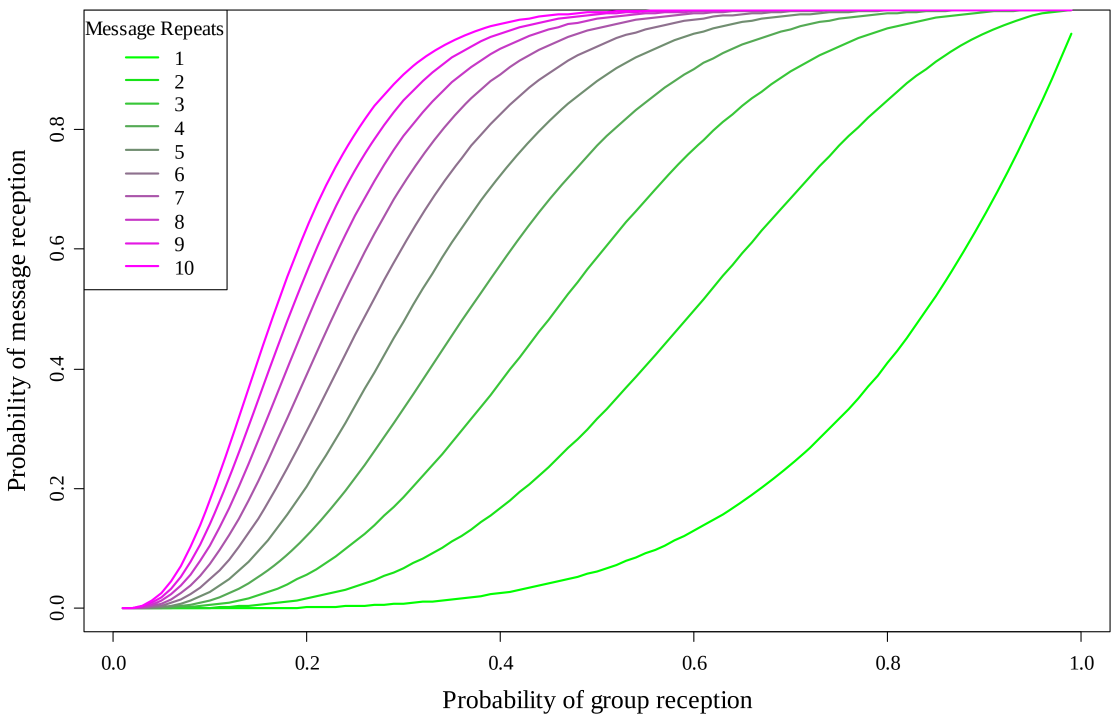

Figure 8. Probability of message receipt as a function of signal repeat
Source: Heschong Mahone Group

Demand response applications have marginal effects on FM transmitting station capacity: on the order of one to two percent of total average data capacity. For this low level of utilization, the FM station contract costs for RDS transmission capability run in the hundreds of dollars per month. Signal repetition within the contracted capacity can be done at no extra cost. The other obvious way to increase the probability of signal reception is to install DR signal transmission capability at additional FM stations, which would require capital investments of thousands of dollars per station and ongoing maintenance costs. Where feasible, signal repetition is clearly a more cost-effective method of increasing reliability.

After collecting data from all 40 sites, Equation 1 was used to calculate the probability of a message being accurately received at each site on a particular frequency (station). RDS sends 114.18 groups every 10 seconds. For each frequency, the research team recorded the number of complete groups for eleven 10-second intervals, so the maximum number of groups received during the two-minute period was 1254.

For example, if only 800 complete groups were received in the two-minute interval, the probability of receiving a four-group message sent just once would be 17 percent. If this same message were sent five times (rather than once) within the 2-minute interval, the message reception probability would jump to 98 percent.

Figure 9 shows the probability that sites successfully received the message sent once via the RDS signal. The vertical y-axis indicates the individual frequencies while the horizontal x-axis shows each of the 39 test sites for which complete data was obtained.[4] The length of the bar of a particular color represents the probability that a message is received for that station and site. A bar that extends entirely from the bottom to the top of the band for that particular frequency would have a 100 percent probability of receiving a message sent just once on that frequency. Figure 9 shows that if a message were broadcast just one time on 90.9, 96.9 and 100.5, all but one of the sites (site 58) would receive the message with near 100 percent probability. Even at this one site with poor reception, however, there is greater than 50 percent chance of receiving a message – from station 100.5.

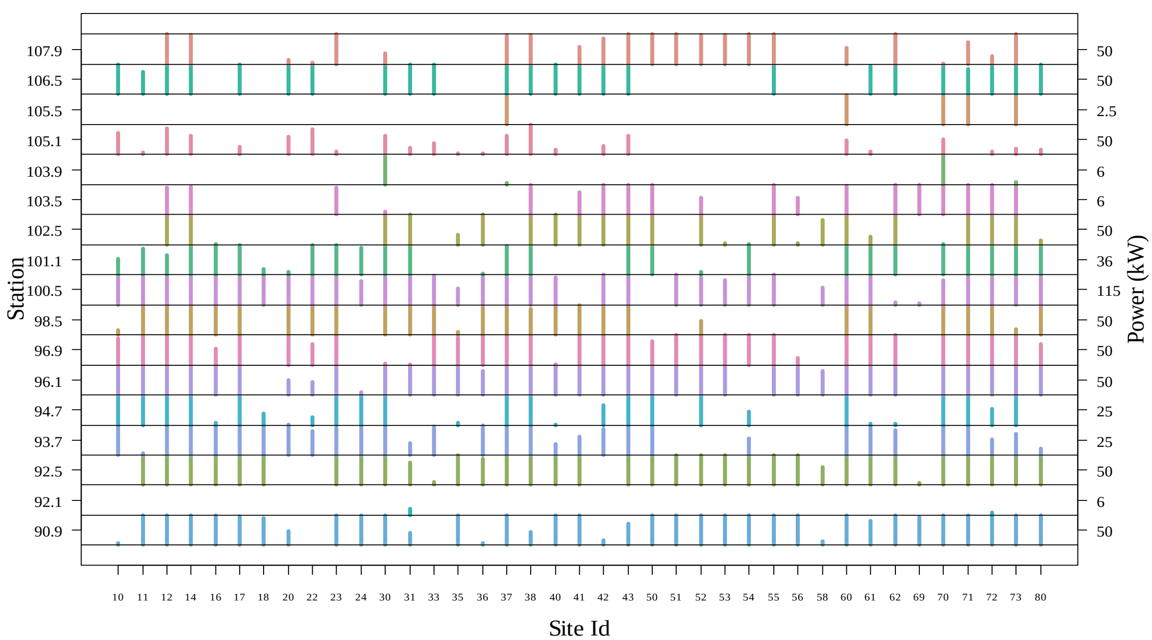

Figure 9. Probability of receiving a message sent once
Source: Heschong Mahone Group

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4. Note that results for Site 39 are not reported due to limited data collected at this site.

Figure 10 shows that if the message were repeated five times, the likelihood of receiving the message increases considerably. Under this scenario, just two stations (90.9 and 100.5) would provide near 100 percent probability of reception at all 40 sites. This is important because the cost of adding to the number of stations that broadcast the demand response message is much greater than the repeat transmission cost, which is negligible.

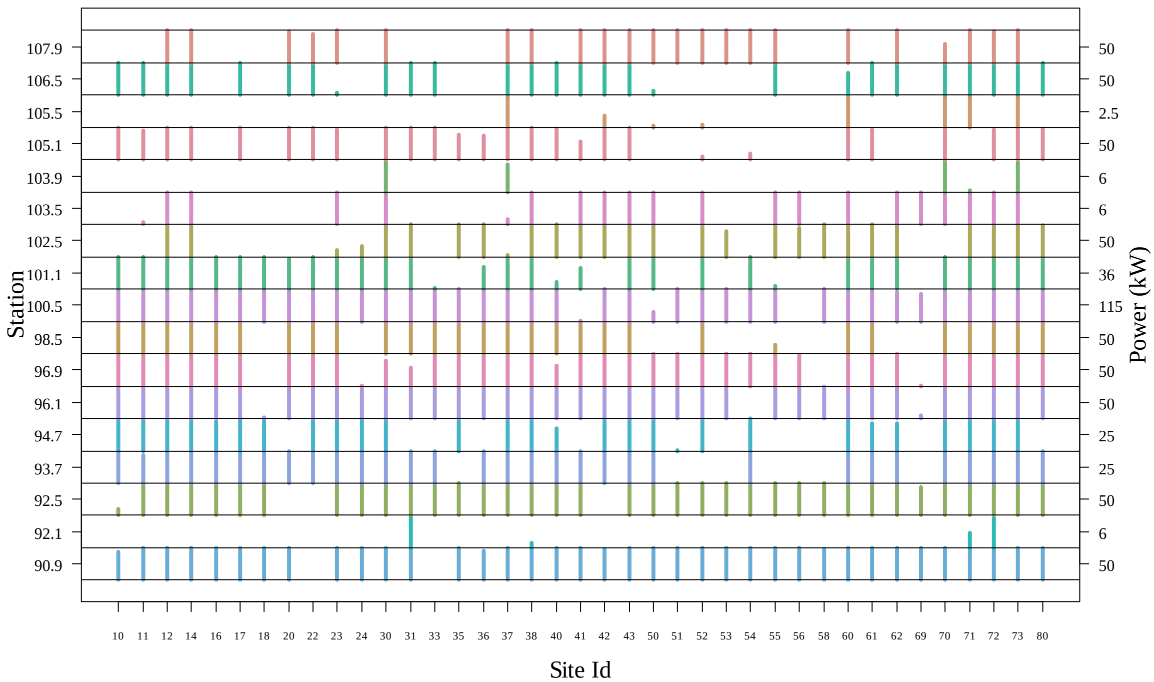

Figure 10. Probability of receiving a message sent five times
Source: Heschong Mahone Group

Figure 11 shows the probability of message reception at each site where the message is repeated 100 times. Of particular interest is that 90.9 FM, the one station in Sacramento that is currently set up with the hardware required for broadcasting demand response signals – provides coverage for all test sites. In fact, further analysis indicates that it would require 55 repeats of a message via 90.9 FM to reach all sites with at least 95 percent probability of message reception. Given that the current RDS system at 90.9 FM sends one group per second, repeating a four-group demand response signal 55 times would take less than four minutes.

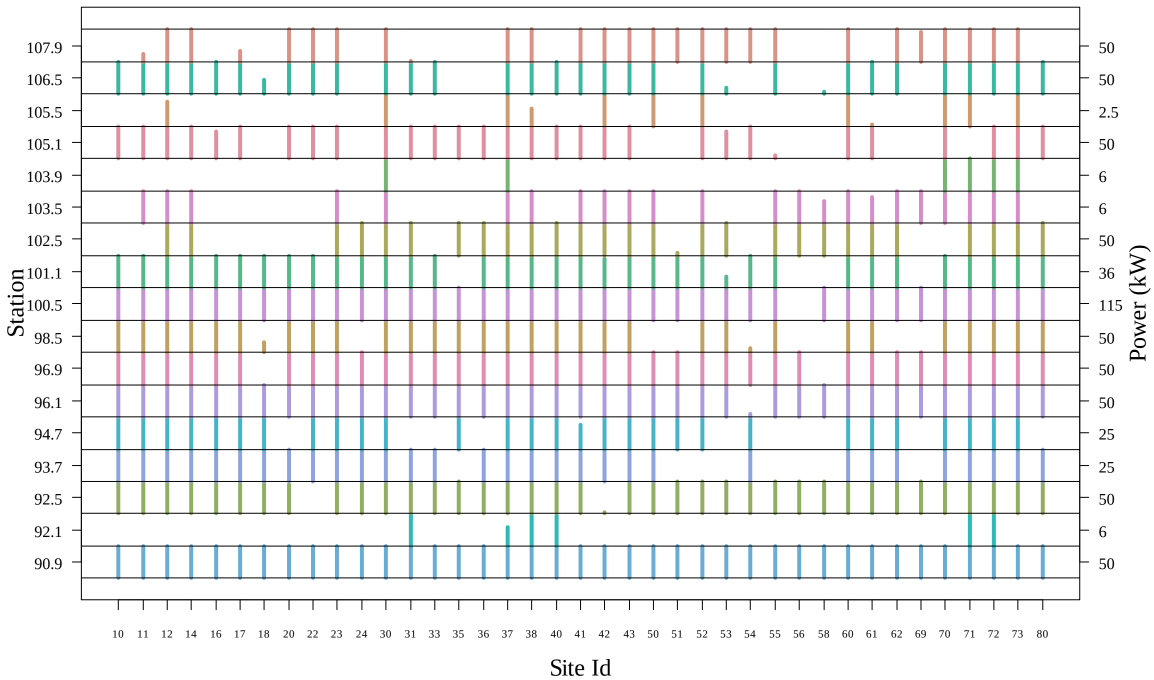

Figure 11. Probability of receiving a message repeated 100 times
Source: Heschong Mahone Group

Based on this analysis, the research team concludes that RDS can be considered a reliable communications infrastructure for demand response signaling, and that as few as one FM station can be used to provide excellent coverage of an area at least the size of the SMUD service territory (about 900 square miles), assuming similar terrain.

4.0 PCT Functionality Testing

The goal of the PCT functionality testing was to provide evidence that available PCT technology, based on the Energy Commission reference design, can or cannot provide automated air-conditioning response to the RDS signal.

At the beginning of this study, PCTs were being designed by Residential Control Systems, Inc. (RCS), located in Rancho Cordova, California – and two other large thermostat vendors. When PCT testing began in March of 2008, only RCS was close enough to a completed product to allow testing. By the end of this study (June 2008), one of the two large vendors indicated that their PCT was also ready to be tested. In the interest of timely completion of this product, only the RCS PCT test results are presented here.

Communications to the PCT began at an Internet-based program interface used to schedule the parameters for events. These parameter values were then sent to the FM radio station via the Internet, and broadcast via RDS to the PCTs. Note that when no event signals are being sent, the RDS signal continuously carries information including the current time, so the PCT time is always synchronized with the RDS signal. The RDS signal can also be set up to carry real-time electricity pricing; however, there was no need to do this for this study.

The following sections describe each of the pieces of technology required for this process in more detail.

4.1. Energy Commission Proposed Requirements for PCTs

The Energy Commission's draft PCT Specification provides the language originally proposed for inclusion in the 2008 Title 24 standards and subsequently considered in the Load Management proceedings that began in 2008. The original proposal specified that thermostats in new buildings (1) have RDS communications, (2) voluntarily respond to price signals, and (3) respond to emergency signals without possibility of override by the occupant ("customer"). This final requirement (number 3) is the topic of much controversy. If PCTs are eventually required through Load Management Standards, it is likely that customers will have the option to override the emergency signal if they so choose.

The proposed language also requires the following features, which were not considered for this study:

- at least one industry standard expansion/communication port
- user information regarding communications system connection and event status
- standardize terminal mapping and 24-volt power supply
- randomization of the time at which the PCT returns to the programmed setpoint
- addressability at the substation level or finer

4.2. Communications

The research team worked with eRadio USA, Inc., and local radio station KXJZ (90.9 FM) to provide the RDS transmission, which required (a) installation of new servers at the KXJZ headquarters and transmission tower, and (b) a web-based software interface from which DR event parameters could be set.

4.2.1. KXJZ 90.9 FM

KXJZ 90.9 FM is a public radio station broadcasting in the Sacramento area. Their antenna is located a few miles north of downtown Sacramento – at Latitude 38° 42' 38" N, Lon 121° 28' 54" W.

Broadcasting at 50 kilowatts, KXJZ is a very typical radio station in terms of broadcast power. Note that more than half of the RDS stations listed in Figure 3 broadcast at 50 kW, while only one (100.5 FM) broadcasting at a higher power rating.

Figure 12 is the signal coverage map for KXJZ. At this level, local reception for KXJZ reaches to Yuba City on the north, and to Vacaville in the South, while distant and fringe reception include Grass Valley, Vacaville, Lodi, Napa, Vallejo, and Stockton.

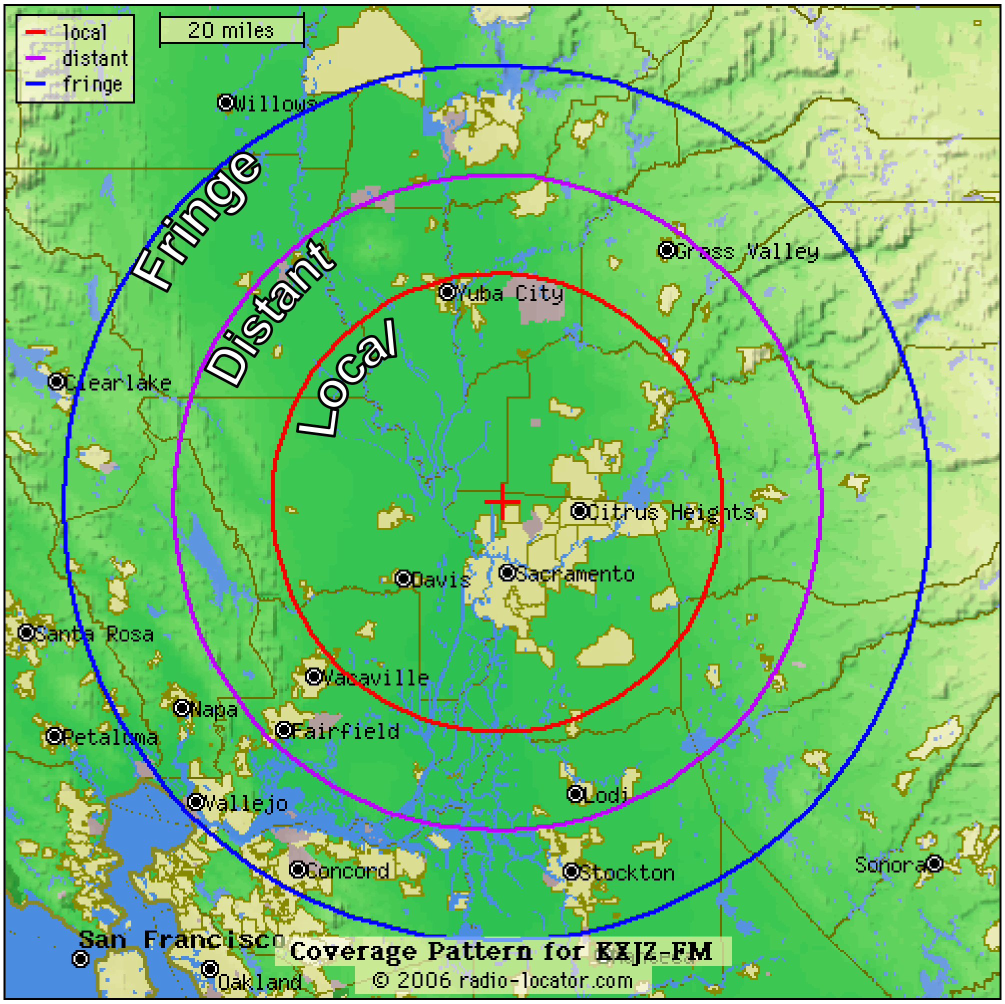

Figure 12. Local (inner), distant (middle) and fringe (outer) signal coverage for KXJZ 90.9 FM Sacramento.
Source: Source: Radio-Locator (www.radio-locator.com)

Within the Local Coverage contour at 60 dBu, reception should be moderately good to very good on any radio. Within the Distant Coverage contour at 50 dBu, reception may be weak on a substandard radio or antenna. Within the Fringe Coverage contour at 40 dBu, reception of the signal will only be possible with a very good radio with a good antenna.

4.2.2. Software Interface

The research team sent data streams to the thermostats through a web interface custom designed by eRadio USA. Screenshots of a sample of the user interfaces are provided in Figure 13 through Figure 15.

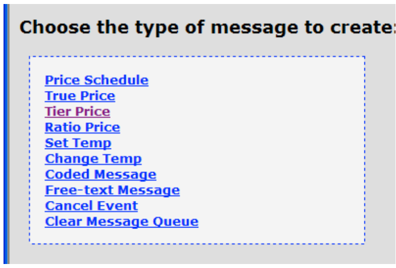

Figure 13. Main user interface for PCT testing
Source: Heschong Mahone Group

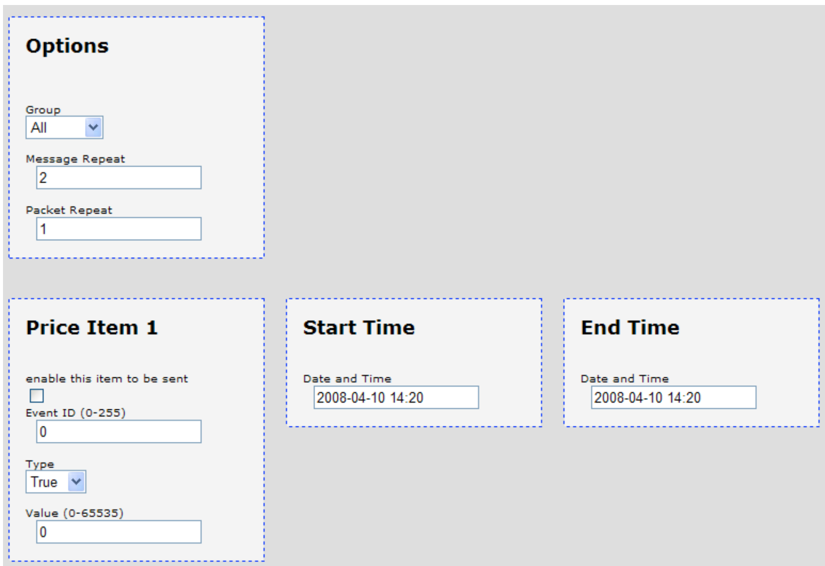

Figure 14. Price event interface for PCT testing
Source: Heschong Mahone Group

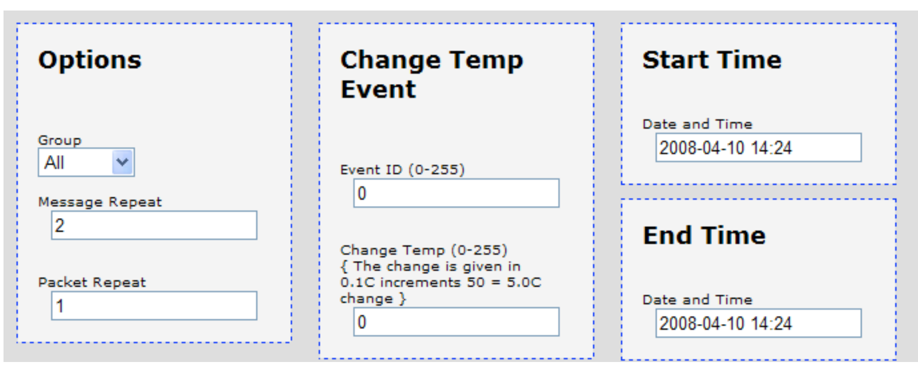

Figure 15. Emergency event interface for PCT testing
Source: Heschong Mahone Group

The current interface provides the following options.

- Signal type – events and messages
- Start time – date and time the event will start
- Stop time – date and time the event will stop
- Group – what PCT group(s) will receive the information
- Message – allows a free-text message of 32 or fewer characters
- Tier – for a price event, the price tier (1-4), where 4 is a critical event
- Offset – for a temperature control event, the number of degrees offset

4.2.3. RDS Messaging Structure

Figure 16 lists the number of groups required for each type of demand response message tested for this study.

Message Type	Number of groups
Price Event	4
Change Temperature	4
Set Temperature	4
Cancel Event	2
Free Text	4 + 1 for every 3 characters

Figure 16. Length of Messages sent via RDS
Source: Heschong Mahone Group

4.3. Thermostats

Residential Control Systems, a vendor of thermostats and other home controls systems, designed and manufactured the communicating thermostats for use in this pilot. The communicating thermostat used in this pilot is based on the TR40, an RCS thermostat currently available in the retail market. RCS added an RDS receiver (supplied by eRadio USA), a logger (for experimental purposes) and some additional translation logic to the TR40 to create the TR40-PCT.

The TR40-PCT has a graphical LCD display capable of both text and graphics on multiple display screens. The main screen is shown in Figure 17. Other standard screens include: Messages, Schedules, User Settings, and Thermostat Info.

Figure 17. Residential Control System's TR40 display unit
Source: Heschong Mahone Group

The controller for the TR40 (Figure 18) is separate from the display. It can be connected to the thermostat wire at any point between the air-conditioning unit and the display.

Figure 18. TR40-PCT controller
Source: Heschong Mahone Group

The controller unit is attached the logger via an Ethernet cable, and the RDS receiver is connected to the logger with an Ethernet cable (see Figure 19).

Figure 19. TR40-PCT logger and RDS receiver
Source: Heschong Mahone Group

4.4. PCT Functionality Results

The current version of the TR40-PCT includes all of the functionality of the TR40 plus:

- Continuous time update via RDS
- Menu option for pricing event offset
- Menu option for precooling – a 4°F setpoint decrease that commences 4 hours before the onset of an event

The current version of the password-protected Web interface developed for this project includes options for:

- Event – a message, price or temperature change event
- Group – which PCT group(s) will receive the information
- Message – freeform of max 44 characters per transmission
- PriceTier – the price tier; a maximum of 4 tiers are currently available
- TempChange – number of degrees offset from the existing setpoint
- Start – date and time the event will start
- Stop – date and time the event will stop

The research team successfully created simultaneous events for multiple groups involving a combination of Tier Price and Temperature Change events. In addition to basic event settings, a "Message Repeat" field is available, allowing the user to increase the number of times that the message is broadcast. Higher values increase the probability that the signal is received by the thermostat and the amount of time required to send the repeated message.

Message Event

When a message event is chosen, the interface prompts for a message to send. The message is displayed on the PCTs belonging to the chosen group during the time specified or until any button is pressed. Figure 20 shows the entries made during a test message event. The message "text message test" was transmitted two times to increase the probability of successful receipt by the PCT, and set to appear 17 April 2008 at 16:03 and clear 17 April 2008 at 16:04. Figure 221 shows the PCT displaying the message.

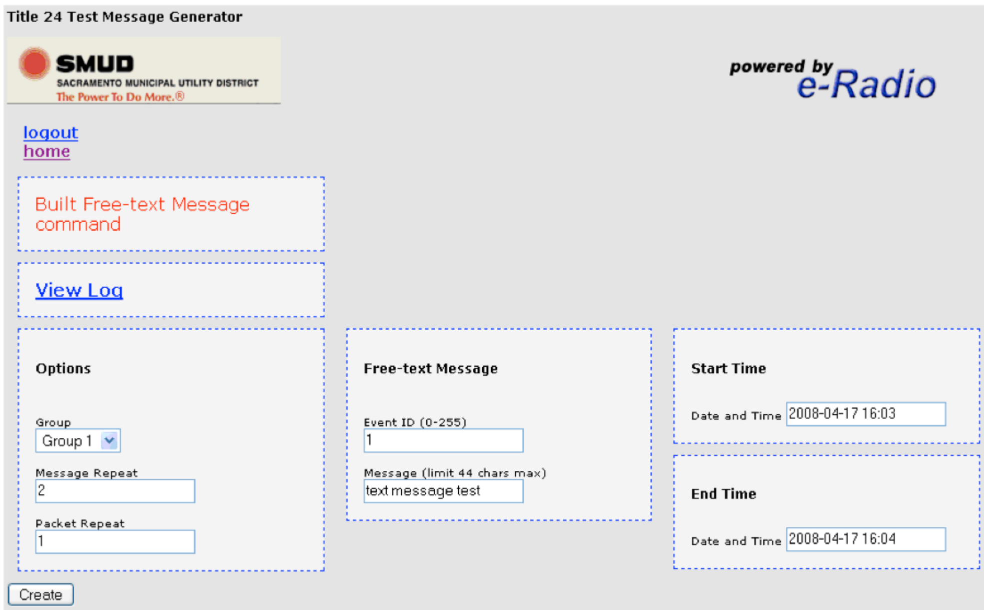

Figure 20. Website interface for a message event
Source: Heschong Mahone Group

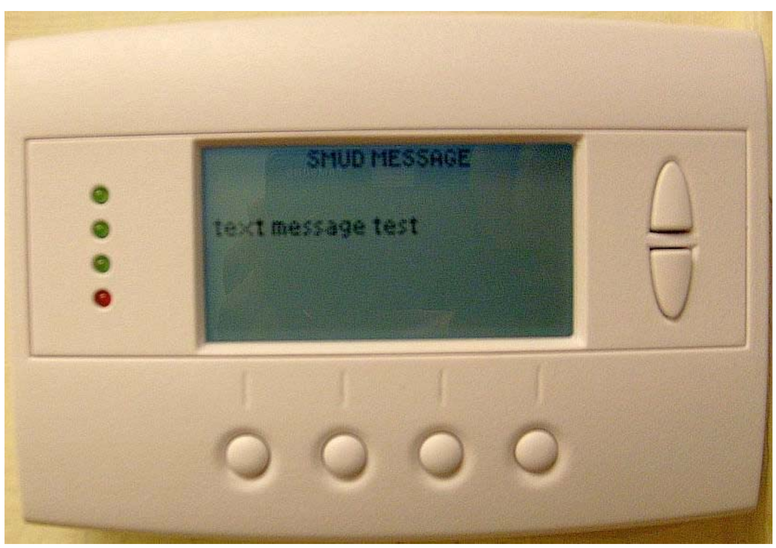

Figure 21. PCT displaying a message
Source: Heschong Mahone Group

The transmission of the RDS signal was recorded by the eRadio server at the transmission tower site. The message "text message test" was 10 groups (shown in the log as packets) long and repeated twice for a total length of 20 groups. The log for this event shows that the signal transmission started at 16:01:19 and ended at 16:01:39, a total time of 20 seconds.

```
event_id:1  command_type:MessageFree      total_packets:20    start_time:2008-04-17 16:01:19          end_time:2008-04-17 16:01:39
```

The reception of the RDS signal was recorded by the RDS logger which is connected to the PCT. This log shows that the signal was received at 16:01:30[5] and that the message was displayed on the PCT from 16:03:01 to 16:04:01.

```
04/17/2008 16:01:30> DL485: Added Message 1: text message test

04/17/2008 16:01:30> DL485: - Start: 04/17/2008 16:03:00

04/17/2008 16:01:30> DL485: - Stop: 04/17/2008 16:04:00

04/17/2008 16:03:01> DL485: Message 1 Activated

04/17/2008 16:04:01> DL485: Removed Message 1
```

5. Testing immediately prior to these results showed that the time on the receiver log was eight seconds different than the time on the eRadio server log. The times in the receiver logs have been modified to reflect this.

4.4.1. Price Event

When a price event is chosen, the interface prompts for a price tier. The current system allows for price tiers 1 through 4, but could easily be programmed to accommodate more. Electricity prices corresponding to each tier must be set by utilities in advance. For this project, when Tiers 1-3 are selected, the PCTs will simply display the current price. For Tier 4, PCTs will (a) immediately warn customers of the impending price event, (b) initiate a pre-cooling strategy (if any) on the morning of the event, and (c) initiate the response strategy (if any) at the onset of the event. Customers will also be notified when the event ends. Figure 22 shows the entries made during a test price event. The critical peak (Tier 4) event was transmitted two times to increase the probability of successful receipt by the PCT, and set to start 17 April 2008 at 16:12 and end 17 April 2008 at 16:16.

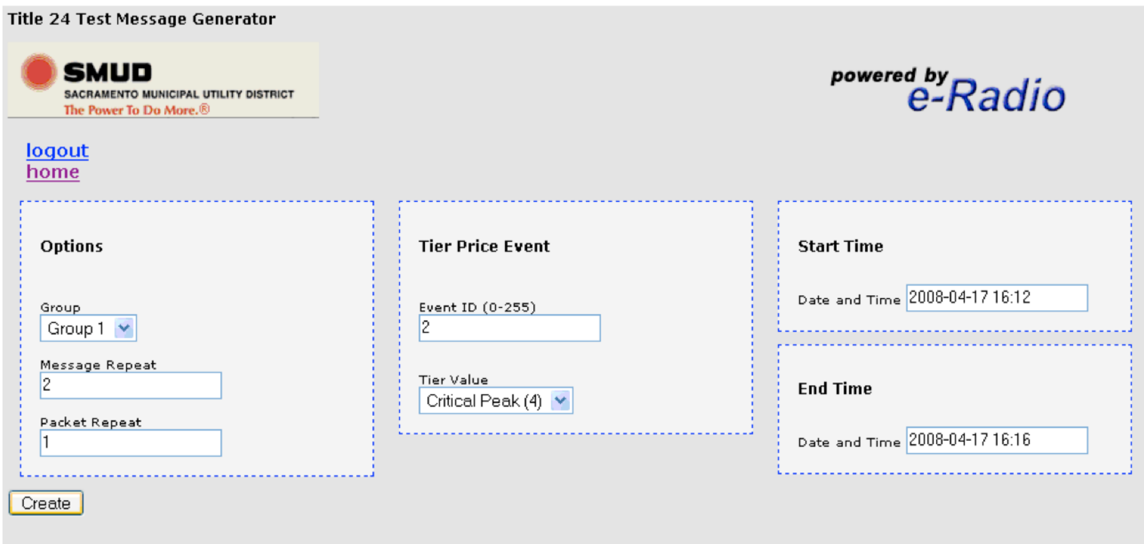

Figure 22. Website interface for a price event

Source: Heschong Mahone Group

When the Tier = 4, the flashing notice shown in Figure 23 is displayed until any button is pressed.

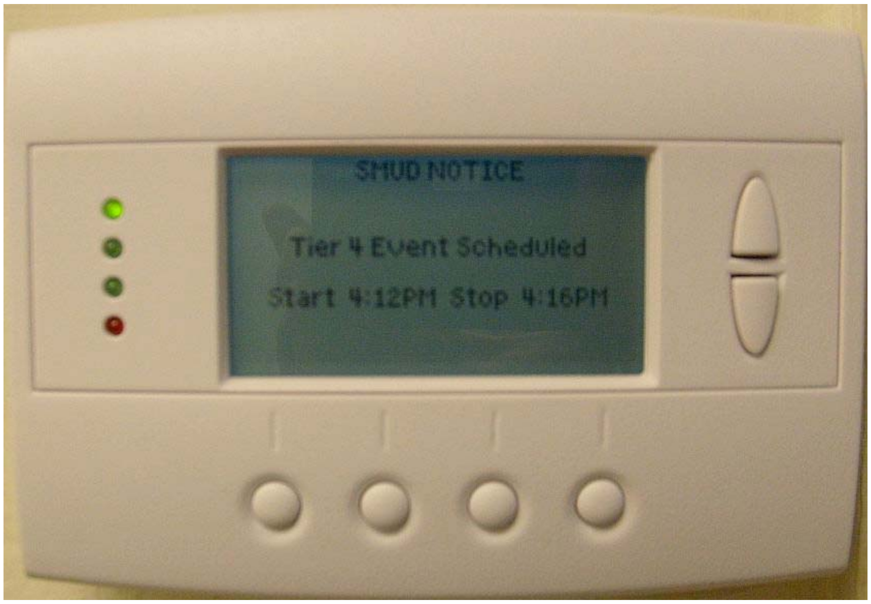

Figure 23. PCT displaying Tier 4 notice
Source: Heschong Mahone Group

After a button is pressed to acknowledge the event, the current settings are displayed as shown in Figure 24. The cooling set point, shown on the right side of the display, is 76°F and the thermostat is in RUN mode–the AC unit is on.

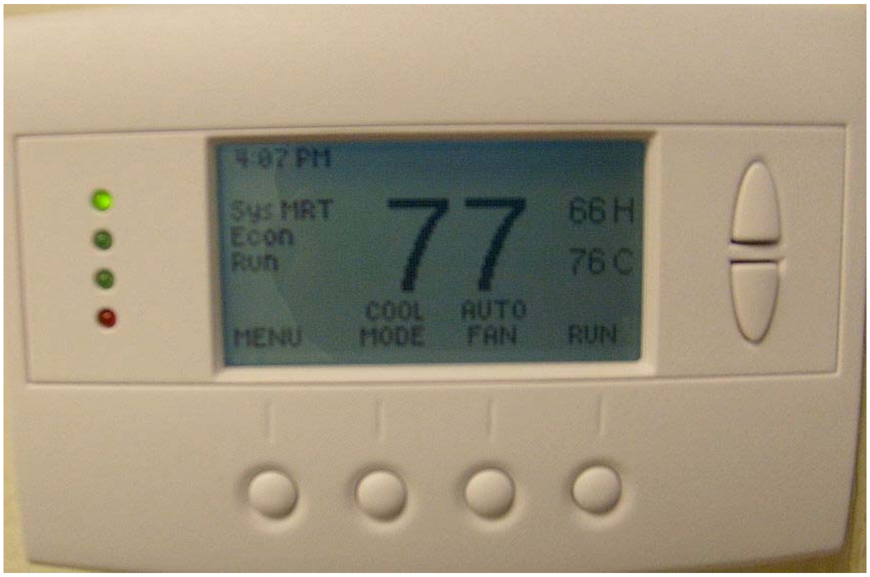

Figure 24. PCT showing current settings before Tier 4 event
Source: Heschong Mahone Group

At the beginning of the event the PCT displays a flashing screen as shown in Figure 25 until any button is pressed.

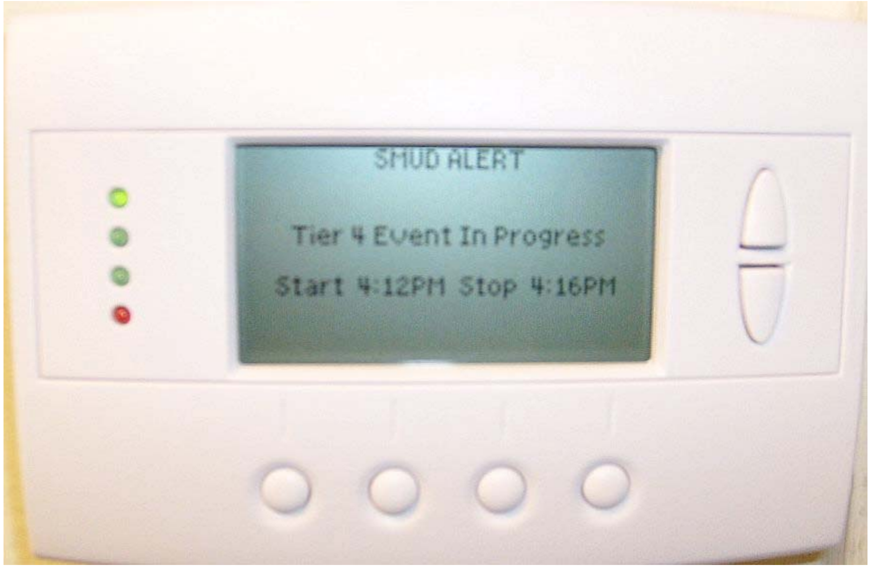

Figure 25. PCT displaying Tier 4 event in progress
Source: Heschong Mahone Group

This particular thermostat is programmed to respond to a Tier 4 price event with a 4 degree temperature offset. Note that the cooling temperature set point in Figure 26 has changed from 76°F to 80°F and the thermostat has changed from RUN to HOLD mode–the AC unit is off.

Figure 26. PCT showing current settings during a Tier 4 price event
Source: Heschong Mahone Group

At the end of the event, the PCT returns to normal programming and displays the flashing screen shown in Figure 27 until any button is pressed.

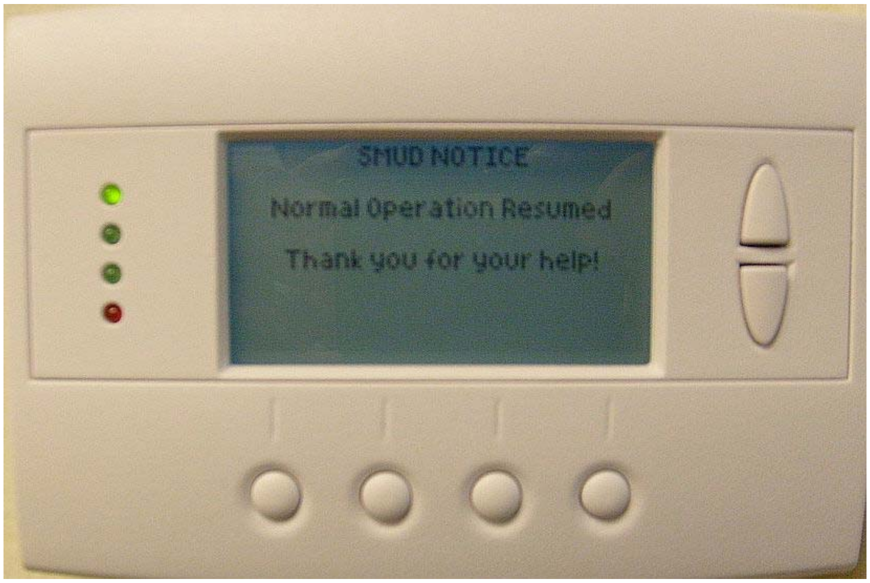

Figure 27. PCT displaying end of price event message

Source: Heschong Mahone Group

The transmission of the RDS signal was recorded by the eRadio server at the transmission tower site. The price event signal required 4 groups (shown in the log as packets) and was repeated twice for a total length of 8 groups. The log for this event shows that the signal transmission started at 16:07:55 and ended at 16:08:03, for a total transmission time of 8 seconds.

```
event_id:2  command_type:PriceEvent total_packets:8

start_time:2008-04-17 16:07:55            end_time:2008-04-17 16:08:03
```

The reception of the RDS signal was recorded by the RDS logger which is connected to the PCT. This log shows that the signal was received at 16:08:00 and that the event lasted from 16:12:02 to 16:16:02.

```
04/17/2008 16:08:00> DL485: Added Event 2: Price, Tier:4.000000

04/17/2008 16:08:00> DL485: - Start: 04/17/2008 16:12:00

04/17/2008 16:08:00> DL485: - Stop: 04/17/2008 16:16:00

04/17/2008 16:12:02> DL485: Event 2 Activated

04/17/2008 16:16:02> DL485: Removed Event 2
```

4.4.2. Temperature Change Event

When a Temperature Change event is chosen, the interface prompts for an offset. On receiving the signal, PCTs (a) immediately warn customers of the impending curtailment event, (b) initiate the pre-cooling strategy (if any) on the morning of the event, and (c) initiate the response strategy at the onset of the event. Customers are also notified when the event ends.

Figure 28 shows the entries made during a test temperature change event. The message was repeated twice to increase the probability of successful receipt by the PCT. The event was set to start on 17 April 2008 at 16:22 and end on 17 April 2008 at 16:26 with a temperature offset of 5°F.

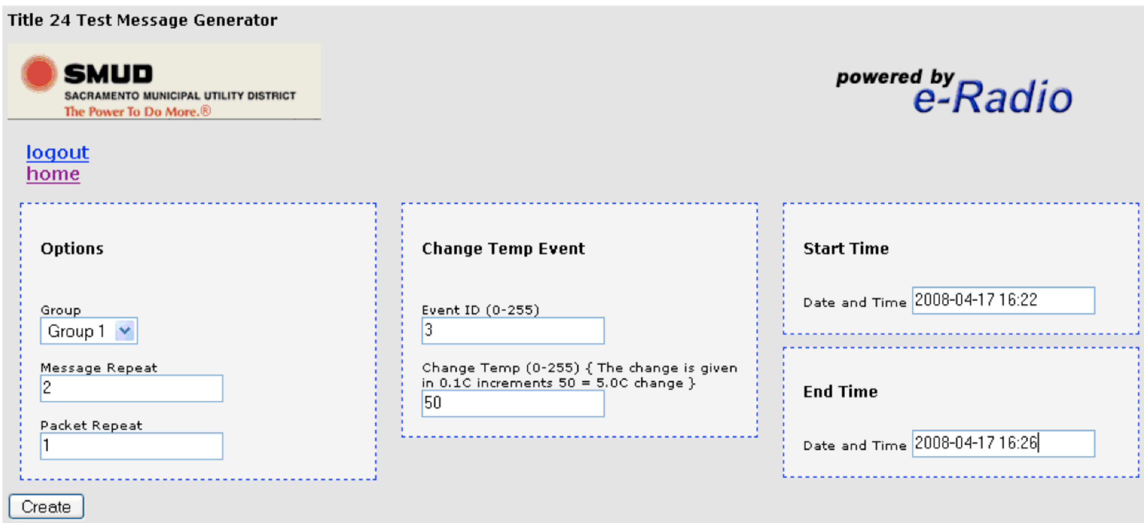

Figure 28. Website interface for a temperature change event
Source: Heschong Mahone Group

When the Temperature Change notice is received, the PCT displays a flashing notice as shown in Figure 29 until any button is pressed.

Figure 29. PCT displaying temperature change notice
Source: Heschong Mahone Group

After a button is pressed to acknowledge the event, the current settings are displayed as shown in Figure 30. The cooling set point is 76°F and the thermostat is in RUN mode–the AC unit is on.

Figure 30. PCT displaying current settings before temperature event
Source: Heschong Mahone Group

When the event begins, the PCT displays a curtailment alert as shown in Figure 31 and changes the setpoint temperature according to the instructions received.

Figure 31. PCT displaying temperature event in progress notice
Source: Heschong Mahone Group

After a button is pressed to acknowledge the event, the new settings are displayed as shown in Figure 32. Note that the cooling set point has increased from 76°F to 81°F, the thermostat has changed from RUN to HOLD mode, and the AC unit is off.

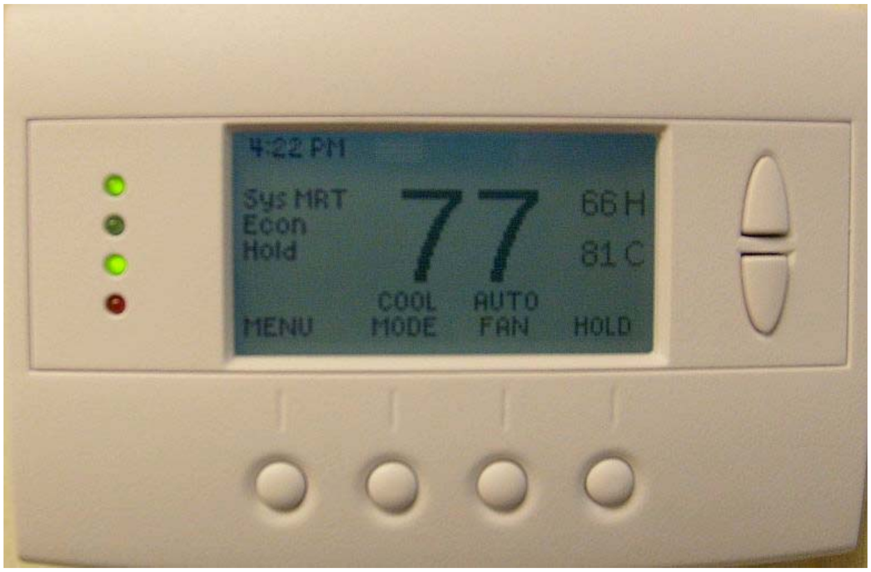

Figure 32. PCT displaying current settings during temperature event
Source: Heschong Mahone Group

At the end of the event, the PCT returns to normal programming and displays a flashing notice as shown in Figure 33 until any button is pressed.

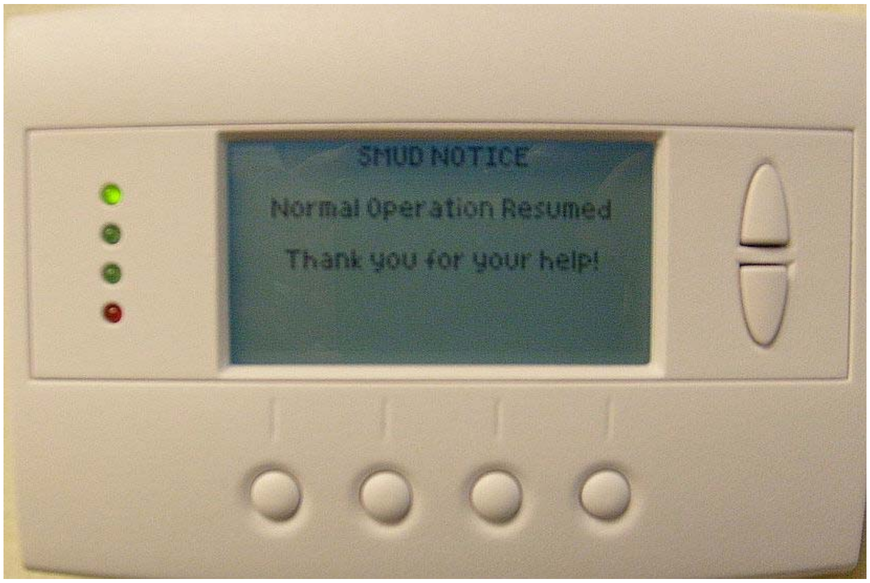

Figure 33. PCT displaying end of temperature event notice
Source: Heschong Mahone Group

The transmission of the RDS signal was recorded by the eRadio server at the transmission tower site. The temperature change event signal was four groups (shown in the log as packets) long and repeated twice for a total length of eight groups. The log for this event shows that the signal transmission started at 16:19:33 and ended at 16:19:41, for a total transmission time of 8 seconds.

```
event_id:3  command_type:ChangeTemp total_packets:8

start_time:2008-04-17 16:19:33            end_time:2008-04-17 16:19:41
```

The reception of the RDS signal was recorded by the RDS logger which is connected to the PCT. This log shows that the signal was received at 16:19:38 and that the event lasted from 16:22:02 to 16:26:02.

```
04/17/2008 16:19:38> DL485: Added Event 3: Change Temp 5.000000

04/17/2008 16:19:38> DL485: - Start: 04/17/2008 16:22:00

04/17/2008 16:19:38> DL485: - Stop: 04/17/2008 16:26:00

04/17/2008 16:22:02> DL485: Event 3 Activated

04/17/2008 16:26:02> DL485: Removed Event 3
```

5.0 Summary and Discussion

The two parts of this study demonstrate:

1. For the 40 test sites in the greater Sacramento area, RDS communication is capable of supporting a reliable electric demand response network.
2. The PCT from Residential Control Systems can provide automated air-conditioning response to the RDS signal.

Commands and messages sent through RDS to the 40 sites would be received with greater than 95 percent probability by broadcasting on one RDS enabled radio stations. Further reliability could be built into the system by adding a third radio station and/or repeating the command broadcast several more times. Outside the SMUD service area, more stations might be necessary to reliably service customer more varied geographic condition.

A more detailed study of RDS coverage, which should occur before a statewide rollout of RDS controlled PCTs, would include different, geographically diverse locations in California, and also an investigation of RDS receiver placement within buildings. Weather, valleys, distance from RDS transmitters, the proximity of other buildings, and building materials could all have a substantial effect on RDS signal reception.

The PCT tested for this study is a fully functional multi-zone thermostat with automated response to demand response events sent using an RDS signal from a local FM station. The PCT responds to both price and temperature change events as required by current Energy Commission design specifications (Gunther 2007a). Future PCT research should include testing of methods for addressability and security.

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Appendix A. Literature Review

Since the California energy crisis in 2000 and 2001, the Energy Commission has been investigating the feasibility of using Programmable Communicating Thermostats or "PCTs" to enable automated load management capabilities in new buildings. PCTs are thermostats that can be programmed by the user to respond to RDS (radio data system) signals indicating electrical emergency or pricing events. This appendix provides a review of the limited literature available on both RDS and PCTs as of April 2008.

RBDS Specification

The "NRSC-4-A, United States RBDS Standard Specification of the Radio Broadcast Data System (RBDS)" was produced by the Radio Broadcast Data System (RBDS) Subcommittee of the National Radio Systems Committee (NRSC) based on input from "broadcasters, receiver manufacturers, users and potential users of radio data system services." This Standard is a voluntary standard. Recommended Standards and Publications are adopted by the NRSC in accordance with the American National Standards Institute (ANSI) patent policy. The National Radio Systems Committee is jointly sponsored by the Consumer Electronics Association (CEA) and the National Association of Broadcasters (NAB).

According to the Specification, RDS is a VHF/FM broadcast between 87.5 and 108.0 MHZ. Its main objective is to "enable improved functionality for FM receivers and to make them more user-friendly by using features such as Program Identification, Program Service name display and where applicable, automatic tuning for portable and car radios..." The Specification provides major sections describing the physical layer, data-link layer, and message format (addressing and coding), which are essential to understanding the engineering details of the technology. There are also 21 appendices (Annexes A-U). Interestingly, one of the appendices (Annex Q) includes a specification for an open data application for the U.S. Emergency Alert System.

California Title 24 PCT Specification

The Energy Commission's Title 24 PCT Specification provides the language proposed for inclusion in the 2008 Title 24 standards. The proposed standard would require that thermostats in new buildings (1) have RDS communications, (2) can voluntarily respond to price signals, and (3) must respond to emergency signals without possibility of override by the occupant ("customer"). This final requirement (number 3) is currently the topic of much controversy. It is likely that the emergency signal will remain, but that customers will have the option to override the signal if they so choose.

The proposed language also requires the following features, which were not considered for this study:

- at least one industry standard expansion/communication port
- user information regarding communications system connection and event status
- standardize terminal mapping of terminal numbers 1-9 with 24-volt power supply

- the capability to randomize the time at which the thermostat returns to the programmed setpoint
- addressability at the substation level or finer

UC Berkeley Technical Review of PCTs

The *Technical Review of Residential Programmable Communicating Thermostat Implementation for Title 24-2008* documents the results of a study funded by PIER and managed by the Energy Commission. The goals of the study were to (a) determine the feasibility of the Energy Commission's PCT vision, (b) document and resolve technical issues that arose, and (c) examine the system impact of PCT controls.

The research team investigated PCT interfaces and an economically feasible bill of materials, and demonstrated RDS communications with a PCT as further proof-of-concept. They also describe an RDS monitoring system that they developed to test RDS signal reception.

Results include a minimum-functionality PCT with a total bill of materials estimated to be $20.20. The team's recommended communication method was RDS for a one-way PCT. The overall conclusion was that a minimum-functionality Title-24-compliant PCT could be developed at under $100 per unit before April 2009, thus providing evidence for the feasibility of the Energy Commission's vision for PCTs.

PCT Design

EnerNex Corporation was contracted by the Energy Commission to write two related technical documents on PCTs: *PCT Technical Specifications, Joint Appendix 5* [4] and *PCT Reference Design, v.15* [5]. Both of these documents define the function and design requirements for PCTs for the 2008 Title 24 Standards, with the former being a joint appendix to the Title 24 PCT language. In addition to basic requirements for all PCTs, the document details four specific interfaces that must be supported: (1) HVAC system interface, (2) expansion interface, (3) communications interface, and (4) human-machine interface. The Reference Design gives special emphasis to an overview of security options related to PCT system design. Annex A of the Technical Specifications clarifies many of the terms defined in the document by examining likely cases of PCT use.

California Demand Response Update

The *Energy Central* article "Statewide Demand Response Network Update from California" is considered the first widespread public vetting of the proposed PCT standards. The article described the California Energy Commission's vision for the PCT and the technology that would make it possible.

Public Response to Proposed Standard

On January 11, 2008, the *New York Times* published an article entitled "California Seeks Thermostat Control," featuring a photograph of the Energy Commission's Commissioner Arthur Rosenfeld and describing the proposed standard [7]. The next day, the *San Francisco*

Chronicle published “Critics cool to 'smart thermostat' proposal.” The article announced the Energy Commission’s decision to allow customers to override emergency signals, in an effort to placate “critics worried about Big Brother dictating home temperatures…” [8]. On January 17, the *North County Times* ran an article announcing the Energy Commission’s removal of proposed mandate altogether, on the heels of increase public and political pressure [9]. An analysis of what went wrong and what the Energy Commission plans to do to fix it can be found in an interview with Commissioner Pfannenstiel in the April issue of *Public Utilities Fortnightly* [10]. In it, the Commissioner describes the Commission’s plans to reconsider the PCT in load management standards with an emphasis on the benefits to customers of the pricing functionality.

Appendix B. RDS Test Protocol

RDS data collection requires an RDS receiver, RDS base station and a properly configured laptop.

To record data during a site visit:

1. Go to C:\Documents and Settings and open the text file "logger.properties"
2. Go down to "mysql.siteID" and enter the two-digit site id number.
3. Save the file and close.
4. Place the logger at an appropriate location in the building, plug it in, and orient the purple antenna vertically.
5. Plug the RDS board into the bottom USB port (i.e., COM5).
6. Open the Command Prompt; do this by going to Start → Run, and enter "`cmd`".
7. "C:\Documents and Settings>" should be at the top of the screen. If you don't see this, enter "`cd C:\Documents and Settings`"
8. To run the program, enter the following text (be sure to include the spaces shown): "`java -jar PCT.jar logger.properties`"
9. Allow the program to cycle through all the radio frequencies (90.9, 92.1, 92.5, 93.7, 94.7, 96.1, 96.9, 98.5, 100.5, 101.1, 102.5, 103.5, 103.9, 105.1, 105.5, 106.5, 107.9). The frequencies that appear while the program is running will be long numbers, but with a decimal point in the proper place, they should round to the numbers in the list above.
10. After about 35 minutes, the program will repeat the cycle automatically; stop this by pressing Ctrl-c.
11. Close all windows and repeat the above procedure at the next site.