Evaluation of automated residential demand response with flat and dynamic pricing

Joel Swisher, Kitty Wang and Stewart Stewart
Rocky Mountain Institute
1739 Snowmass Creek Road
Snowmass, CO 81654 USA
jswisher@rmi.org

Keywords
demand response, load management, program evaluation, time-of-use tariff, critical peak pricing

Abstract
This paper reviews the performance of two recent automated load management programs for residential customers of electric utilities in two American states. Both pilot programs have been run with about 200 participant houses each, and both programs have control populations of similar customers without the technology or program treatment. In both cases, the technology used in the pilot is GoodWatts, an advanced, two-way, real-time, comprehensive home energy management system. The purpose of each pilot is to determine the household kW reduction in coincident peak electric load from the energy management technology.

Nevada Power has conducted a pilot program for Air-Conditioning Load Management (ACLM), in which customers are sent an electronic curtailment signal for three-hour intervals during times of maximum peak demand. The participating customers receive an annual incentive payment, but otherwise they are on a conventional utility tariff. In California, three major utilities are jointly conducting a pilot demonstration of an Automated Demand Response System (ADRS). Customers are on a time-of-use (ToU) tariff, which includes a critical peak pricing (CPP) element. During times of maximum peak demand, customers are sent an electronic price signal that is three times higher than the normal on-peak price.

Houses with the automated GoodWatts technology reduced their demand in both the ACLM and the ADRS programs by about 50% consistently across the summer curtailment or super peak events, relative to homes without the technology or any load management program or tariff in place. The absolute savings were greater in the ACLM program, due to the higher baseline air conditioning loads in the hotter Las Vegas climate. The results suggest that either automated technology or dynamic pricing can deliver significant demand response in low-consumption houses. However, for high-consumption houses, automated technology can reduce load by a greater absolute kWh difference. Targeting programs to such customers can improve the economics of residential demand response.

Introduction
This paper reviews the performance of two automated load management programs for residential customers of electric utilities in two American states. The programs, which are summarized in turn below, are the Nevada Power Two-Way Air-Conditioning Load Management (ACLM) program and the California Automated Demand Response System (ADRS) program, which is being conducted by the three investor-owned electric utilities in California.

Both pilot programs have been run with about 200 participant houses each, and both programs have control populations of similar customers without the technology or program treatment. In both cases, the technology used in the pilot is GoodWatts, an advanced, two-way, real-time, comprehensive home energy management system. The purpose of each pilot is to determine the household kW reduction in coincident peak electric load from the energy management technology. While the Nevada program applies automated technology without any change to the customer tariff, the California program also uses time-dynamic critical peak pricing (CPP) to elicit load reductions.

Technology Description

All treatment homes in both pilots received a GoodWatts home energy management system provided by Invensys Intelligent Home Controls. GoodWatts is an always on, advanced climate control system with web-based programming of user control preferences. Via the Internet, homeowners with GoodWatts can view whole-house or end-use specific demand in real time and display trends in historical consumption. Participants can also set climate control and spa or pool pump runtime preferences and view these settings at any time both locally and remotely. For utilities implementing price responsive demand control, as in California, GoodWatts allows users to view at all times the current electricity price on-line or via the thermostat, and program desired thermostat and pool/spa responses to changes in electricity prices. GoodWatts can also be used to control electric water heaters, although these are uncommon in both Nevada and California.

The energy management technology includes the following components:

- Two-way communicating whole-house meter capable of recording and storing consumption data in 15-minute intervals
- Wireless Internet gateway and cable modem
- Programmable smart thermostats for air-condition (or heating)
- Load control and monitoring (LCM) device to manage selected loads (e.g. pool pump)
- Web-enabled user interface and data management software

Thus for pilot homes with pools and spas, supplemental LCMs are installed to garner additional demand reduction during utility triggered curtailment events.

Data Collection

The interval meters installed in the treatment homes collected 15-minute load data for the duration of the pilot peak air-conditioning period from June through September 2004. Homeowners, utility personnel, and analysts can access load data via a secure, password-protected web site. Interval load data for control group homes are collected via interval whole-house meters, accessible six to eight weeks following the completion of each month's billing period.

Hourly outdoor temperature data are also collected via weather subscription service. Postal codes of treatment and control homes were collected for locating each home's appropriate temperature data.

Consumption data availability was greater than 99 percent for both pilots. Nevertheless, utility meter data were also collected and used to validate the data from the load management system meters, with no discrepancies reported.

Nevada Power Two-Way ACLM Pilot

Nevada Power Company (NPC) is an investor-owned electric utility headquartered in Las Vegas, Nevada. NPC's existing Air-Conditioning Load Management (ACLM) program involves simple direct-load-control technology. Utility personnel send a signal directly to the air conditioning units of participating households to cycle off during several hours of the day during the summer when the system is close to its seasonal peak and power market prices are high. To complement and extend this program, NPC is investigating the merits of advanced load control technologies for use in its existing ACLM program.

Nevada Power's Two Way Air-Conditioning Load Management (ACLM) Pilot uses GoodWatts, an advanced, two-way, real-time, comprehensive home energy management system provided by Invensys Home Control Systems. The purpose of the evaluation is to determine the reduction in household coincident peak electric load. The energy impact and economic results from the pilot, currently planning for its third year of operation, will be utilized by Nevada Power to design a full-scale deployment.

TWO-WAY ACLM PILOT DESCRIPTION

During the pilot's first year of operation in the summer of 2003, NPC gained familiarity and understanding of the features and capabilities of the GoodWatts system, tested homeowner and utility employee user acceptance, and estimated the potential for the technology to reduce utility system peak load. The goals of the pilot's second year of operation during the summer (June-September) of 2004 were to address a number of design deficiencies during the previous year, primarily the statistical validity of the results based on a small sample of participant homes, and to move from a technology test to program test.

On days with extreme forecasted system-wide peak demand, NPC sends a curtailment signal to the Two-Way ACLM participants. The signal increases customers' thermostat temperature setpoints and interrupts power to pool pumps. During the summer 2004 pilot period, NPC completed a total of twelve curtailment events in July, August and September. The events covered a range of temperature regimes to test demand response and customer behaviour, including the frequency of signal overrides. The majority of curtailment events called for 4°F (2.2°C) offsets in air-conditioning setpoint, though 2°F (1.1°C) and zero degree (placebo) events were also called. All events were triggered at 4 p.m. on non-holiday weekdays for a duration of three hours. Relative consumption between participant and control group homes were compared during event and non-event days, and during the peak (4 p.m. – 7 p.m.) and off-peak periods to test the effectiveness of GoodWatts technology for demand response.

TWO-WAY ACLM PILOT DESIGN

A total of 202 homeowners were recruited at random across the Las Vegas valley. Participation is voluntary, or on an "opt-in" basis. Although this sample is not fully representative of a random population, it is representative of customers who would join a fully-scale program, which will also be "opt-in." Eligibility is limited to single-family homes with central air conditioning, located in areas served by the cable television provider Cox Communications, a partner in the ACLM pilot. Because of the additional capability of Goodwatts technology to manage pool pump loads, homes with pools were desirable but those without pools were not excluded from participation. In order to monitor impacts of demand reductions at both the meter and distribution network levels, recruitment concentrated on three specific postal codes in established neighborhoods with mixed income levels and population demographics.

A broad recruiting effort was made to include a diverse group of homes that closely represents the distribution of single-family domiciles in NPC's service territory. Participating homes were assigned to one of five consumption strata defined by NPC, based on the average monthly energy usage from the past 12-months' billing data. Table 1 delineates the ranges of the five consumption strata and Figure 1 provides the distribution of the sample population by stratum compared to the actual NPC single-family population. Given that only 4 homes were recruited into stratum 5, analysis and results for this stratum are not statistically significant and are omitted.

In addition to pilot participants, 223 homes were randomly selected from within the utility's Load Research Group (LRG) for use as a control population. LRG homes were initially screened for comparability against the pilot or treatment group—single-family domiciles with central air conditioning. The control homes were also segmented into the five consumption strata based on average historical monthly consumption. The control population is weighted to make the distribution by consumption stratum agree with the participant population.

Table 1. Stratum Classifications of ACLM Pilot Populations.

Stratum	Minimum monthly consumption (kWh)	Maximum monthly consumption (kWh)
1	0	799
2	800	1 249
3	1 250	1 749
4	1 750	3 499
5	3 500	

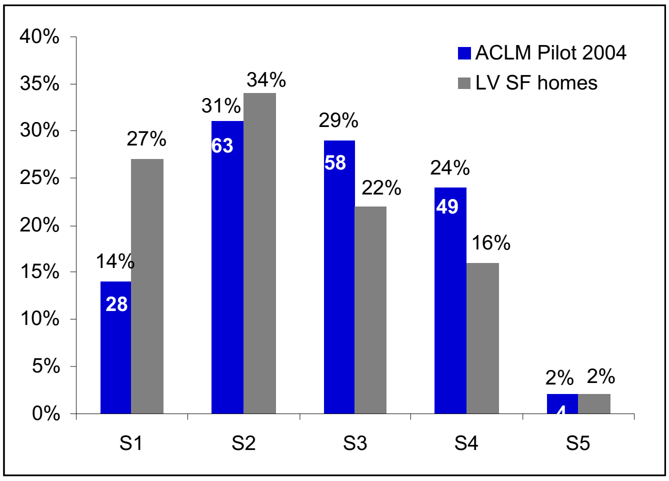

Figure 1. *Distribution of pilot sample by consumption stratum compared to that of single-family homes in Nevada Power's service territory.*

TWO-WAY ACLM ANALYSIS METHODOLOGY

The 15-minute interval load data are used to construct average daily load profiles for both treatment and control groups for both curtailment and non-curtailment days by stratum. Participant homes are compared directly to control homes on non-curtailment days to assess change in consumption behaviour attributed to technology.

To assess the relative load reductions on curtailment days, a two-part process is applied. Actual measured load of participant homes with technology is again compared against control homes without technology. Additionally, multivariate regression is used to construct a predicted baseline of participant consumption assuming the curtailment event has not been called that day. The regression equations are developed for each of six different hour periods (three hour duration of curtailment period and three hours for temperature recovery), and include outdoor temperature and average control homes' consumption during the time interval to predict participant homes consumption. The outdoor temperature term accounts for air-conditioning load. The control home consumption term of the regression accounts for non-air-conditioning load (e.g. lighting and appliances) in the participant homes, and to account for potential self-selection bias in the treatment group.

$$L_t = a*C + b*T + e$$

Where,

L_t = treatment group demand,
C = control group demand,
T = outdoor temperature,
a = control demand coefficient,
b = outdoor temperature coefficient, and
e = error term

TWO-WAY ACLM RESULTS

Load impact results are presented here for event (curtailment) weekdays and non-event weekdays from June through September. Figure 2 gives the average daily load profiles of participant and control groups for all *non-event* weekdays from June through September for all strata. The daily consumption profile of participant homes closely matches that of the control homes with the exception of the peak hours between 3 p.m. and 7 p.m., where participant homes consume more load than control homes. Notice however, that peak consumption for participant homes occurs about an hour later than control homes, or at 4:30 p.m. instead of 5:30 p.m. This is a direct result of participant homes using their GoodWatts technology to actively program their air conditioning schedules. This shift in time, however, does not result in a reduction of load during the peak hours, but rather a modest amount of conservation during the off-peak hours or about 0.13 kW.

On the other hand, the technology-enabled participant homes do cause a significant reduction in load during curtailment events. A total of twelve curtailment events were called from July through September, on days with tempera-

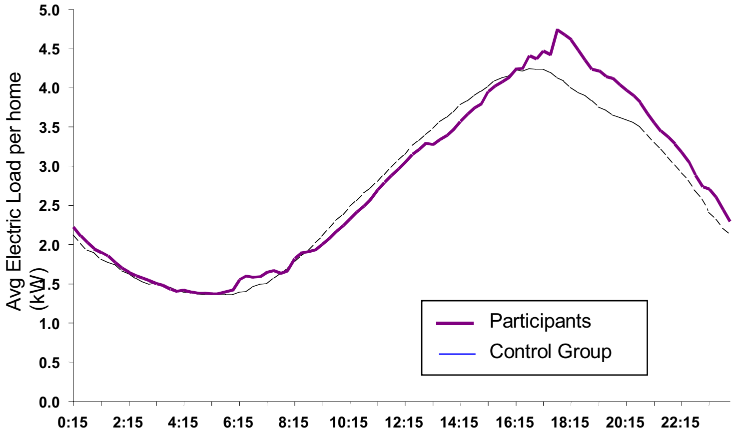

***Figure 2.** Average load profile of ACLM participant and control homes, non-event weekdays*

tures averaging 37.8ºC and above. Two of three events were called in September when outside temperature peaked at just 36.0ºC. The hottest event day was August 11th, when outside temperatures reached 43.9ºC. The twelve curtailment days were July 7, 21 22, 23 and 29; August 4, 9, 10 and 11; September 2, 7 and 16. The July 23 event was the only 2ºF (1.1ºC) curtailment event. Note that consecutive three days events were called in July and August to test customer response to a prolonged event.

The daily load profiles of participant and control homes averaged over the twelve curtailment event weekdays are shown in Figure 3. The participant demand in the absence of a curtailment event, as predicted by the regression equation, is also shown. Average load reduction per participant for all twelve event days across the three hour peak period was 7.3 kWh (2.4 kWh/hr). On a percentage basis, average reduction relative to predicted consumption was 45% across the three peak hours on 4ºF (2.2ºC) curtailment days and 23% on the July 23 2ºF (1.1ºC) curtailment day. At the start of the curtailment event, the utility sends a signal to the home, which automatically responds by adjusting the thermostat upward by a minimum of 4ºF (2.2ºC). This instantaneous response is evident in the sharp drop in load at the start of the curtailment period at 4 p.m. (average of 3.4 kW or a 61% reduction), followed by a gradual decline in load reduction as the indoor temperature of the participant homes rises across the three hour peak period (average of 1.7 kW or 31% reduction by 7 p.m.). There is also a rather sharp recovery effect at the end of the curtailment period at 7 p.m., as air conditioners work harder to cool the home back to its normal temperature setting.

Figure 4 shows that the average load reduction per participant home on each of the twelve curtailment event weekdays was 2.3 kW to 2.7 kW on the 4ºF (2.2ºC) offset days, with maximum load shed per home ranging from 2.9 kW to 4.0 kW. The result for the 2ºF (1.1ºC) offset July 23 event lagged those of the other curtailment days, with load shed per home averaging just 1.2 kW for the peak hours of 4 p.m. – 7 p.m.

Load reduction results by stratum on each of the curtailment days were comparable in July when outdoor temperatures were highest, although stratum 3 reduced somewhat more than the other strata. While higher consumption homes did not shed more load than lower consumption homes in July, during the months of August (shown in Figure 5) and September, outside temperatures were slightly lower on curtailment event days, and differences in load reduction by consumption stratum became more pronounced. In August and September, higher consumption homes in strata 3 and 4 performed better than smaller homes in strata 1 and 2.

The sample of ACLM participants included 78 homes that had swimming pools. The GoodWatts home energy management technology includes the ability to separately control pool pump operation and schedules. Load control monitors (LCMs) were installed for homes with pools, and

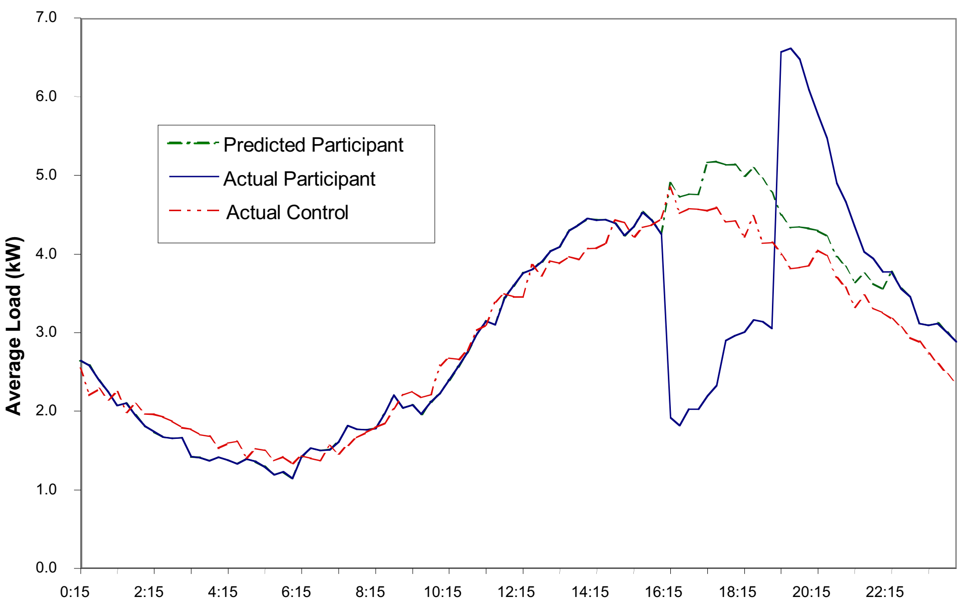

***Figure 3.** Average load profile of ACLM participant and control homes, curtailment event weekdays.*

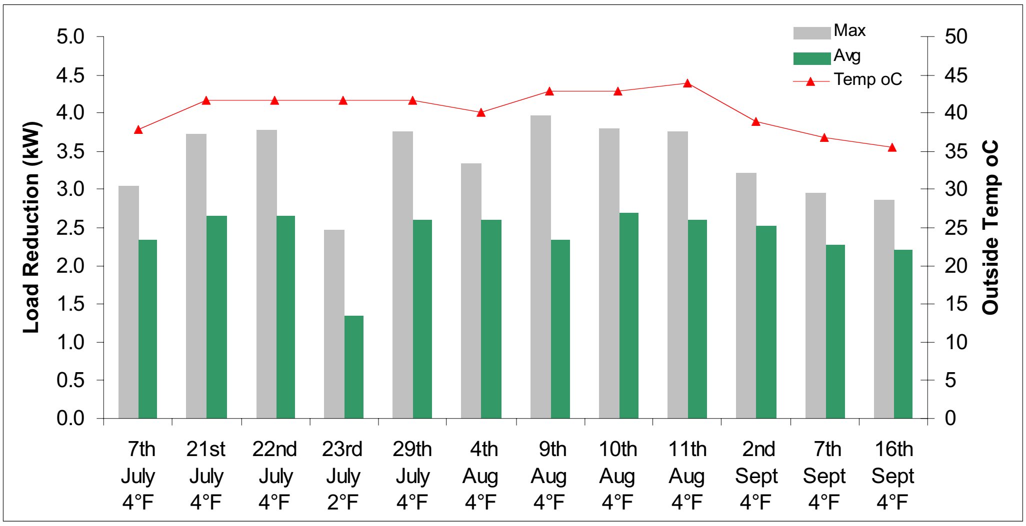

Figure 4. *Maximum and average load reduction of pilot homes for the twelve curtailment events*

their consumption was measured separately. While the average load of individual pool pumps is approximately 2 kW, the average pool pump load is less because at any point in time, only a fraction of the total population of pools are operating. The diversity of pool pump operating schedules among the sample population causes the average sample pool load to be lower than the average load of individual pools in the sample. Homeowners were able to successfully shut off their pool pump operation on curtailment event weekdays, with an average reduction per home of approximately 0.6 kW across the three-hour peak period.

California ADRS Pilot

The Automated Demand Response System (ADRS) program is an additional and parallel pilot alongside the Statewide Pricing Pilot (SPP), in which the potential for residential demand response is being evaluated. These pilot programs involve California's three major electric utilities, Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E).

While the entire statewide pilot addresses a range of dynamic pricing strategies, including time-of-use (ToU) tariffs and critical peak pricing (CPP) tariffs, ADRS focuses on the further impact of energy management technology on residential customers, together with time-differentiated tariffs experienced under the SPP's critical peak pricing programs. Thus, the California ADRS program is a test of automated price response, in contrast to the load response program design used by Nevada Power.

ADRS PILOT DESCRIPTION

The summer of 2004 was the first application of the ADRS program. The goals of the pilot were to evaluate the load reductions achieved by the combined technology-rate package, compare them to reductions from technology-only and

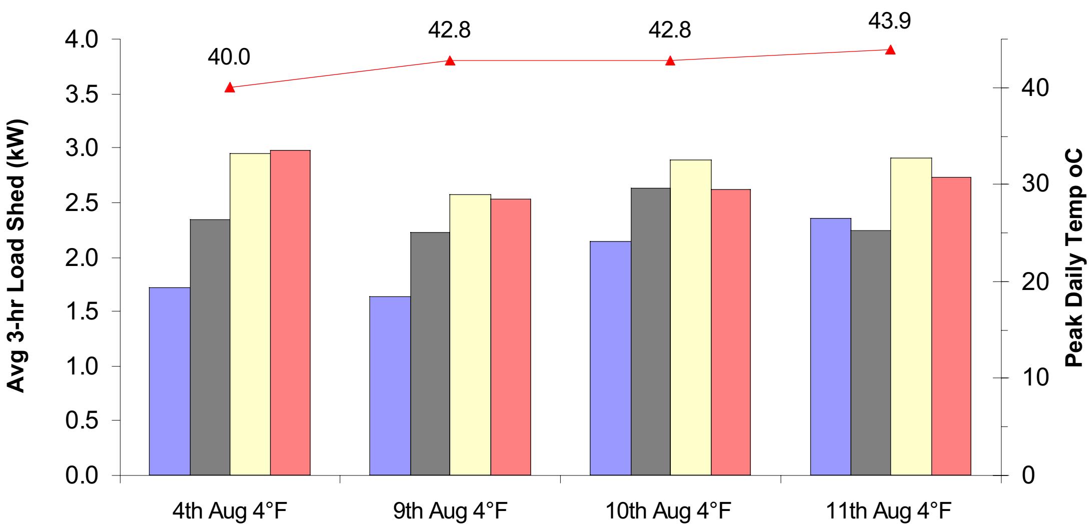

Figure 5. *Average load reduction of pilot homes on August curtailment events by stratum, and outside temperature of the curtailment events.*

rate-only programs, and evaluate the cost-effectiveness of the program if deployed at full scale statewide. The ADRS pilot installed full-scale system technology, capable of automatically controlling the electrical load of multiple appliances in a limited number of residential customers across the three participating utilities.

Participants in the ADRS pilot have the same critical peak pricing fixed (CPP-F) tariff as many of the SPP participants. This is an aggressive variant of ToU pricing, in which customers receive different on-peak rates during normal (non-event) weekdays and "Super Peak" event days. The normal on-peak rates are about triple the off-peak rates. Furthermore, the super-peak rates are almost triple the normal on-peak rates, or about eight times the off-peak rates. This rate structure is programmed into the GoodWatts technology, along with the customers' chosen strategy to respond to the changing rates by resetting the air-conditioning thermostat or curtailing other loads.

On normal weekdays, the utilities send the on-peak pricing signal to ADRS participants. The signal triggers a pre-programmed change, via the GoodWatts system, in the customers' thermostat setpoints and interrupts power to pool pumps. On days with extreme forecasted system-wide peak demand, the utilities send a super-peak pricing signal to ADRS participants. Based on the programming of the GoodWatts system, the signal triggers a further change in the thermostat setpoints.

During the summer 2004 pilot period, the utilities completed a total of twelve curtailment events in July, August and September. The events mostly occurred when the average high temperatures were around 35°C, and they included multi-day events to test customer response under prolonged hot spells with high prices. Because the customers' chosen response strategies are pre-programmed into the GoodWatts system, there are no utility-chosen temperature offsets, nor are there explicit customer overrides. All events were triggered at 2 p.m. on non-holiday weekdays for a duration of five hours (two hours longer than the peak period in the Nevada project). Relative consumption between participant and control group homes were compared during event and non-event days, and during the peak (2 p.m. – 7 p.m.) and off-peak periods.

ADRS PILOT DESIGN

ADRS targeted 175 participants in the three major California utility territories: 75 for SCE, 75 for PG&E, and 25 for SDG&E. ADRS participants were recruited only from a single (warm) inland climate zone and were required to have central air conditioning and be located in areas served by a participating cable television provider. Homes with pools were included but they were not required for participation. Recruitment concentrated on several specific postal codes in established neighbourhoods with mixed income levels and population demographics.

As in Nevada, both participant and control homes were stratified into consumption strata. However, in California there were only two strata, with the boundary between them set at average summer usage of 24 kWh/day. Houses in the lower stratum (20% of the total), with less than 24 kWh/day usage, have relatively low baseline air conditioning loads. All other homes (80% of the total), those with summer usage above 24 kWh, fell into the high stratum.

For the ADRS pilot, the control population is comprised of homes that are on a standard, non-time-differentiated tariff, do not have the ADRS technology, and are unaware of their role as a control group. This group is designated A03 in the SPP. The control population was filtered to only single-family homes in the same climate zone as the ADRS homes, in order to assess the total ADRS impact from the GoodWatts technology and the CPP-F tariff.

ADRS ANALYSIS METHODOLOGY

As in Nevada, the 15-minute interval load data are used to construct average daily load profiles for both participant and control groups for both curtailment and non-curtailment days by stratum. Participant homes are compared directly to control homes on both normal days and super peak event days to assess change in consumption behaviour attributed to the combination of the time-dynamic tariff and the technology. Unlike in Nevada, it was not possible to use regression analysis to project participant customer usage during peak hours (hypothetically) without the technology in place. The reason that this approach would not work with ADRS data was that participants responded to on-peak pricing on both normal and super-peak days, so there were no off-peak weekday afternoons to calibrate the regression model.

The results are reported in terms of 5-hour averages (2 p.m.–7 p.m. on normal peak and super peak periods) and hour-by-hour reductions, and they are reported statewide for all three utilities' customers. The sample average is weighted according to the distribution of participants by utility for each customer stratum. The control home data are weighted according to the distribution of the ADRS population (by utility and consumption strata) so as to permit direct comparison among populations which vary by geography, weather, and baseline consumption.

ADRS RESULTS

ADRS load impact results are presented here for super-peak event weekdays and non-event weekdays from June through September. Figure 6 gives the average daily load profiles of participant and control groups for all *non-event* weekdays from June through September for both strata. The daily consumption profile of participant homes closely matches that of the A03 control homes with the exception of the peak hours between 2 p.m. and 7 p.m., where participant homes use less than control homes. ADRS participants use an average of 3.7 kWh (0.74 kWh/hour), or 34% less than the control group during the on-peak hours. This is a direct result of participant homes using their GoodWatts technology to actively program their air conditioning schedules in response to normal on-peak rates, without the super-peak price signal. The ADRS participants load profile is somewhat flatter than that of the control sample in the hours preceding the peak period, suggesting that participants are programming GoodWatts to anticipate the higher rates, but this effect is not significant enough for us to be confident of this interpretation.

At the start of the peak period, the utility sends a signal to the home, which automatically responds by adjusting the thermostat according to the ADRS system programming.

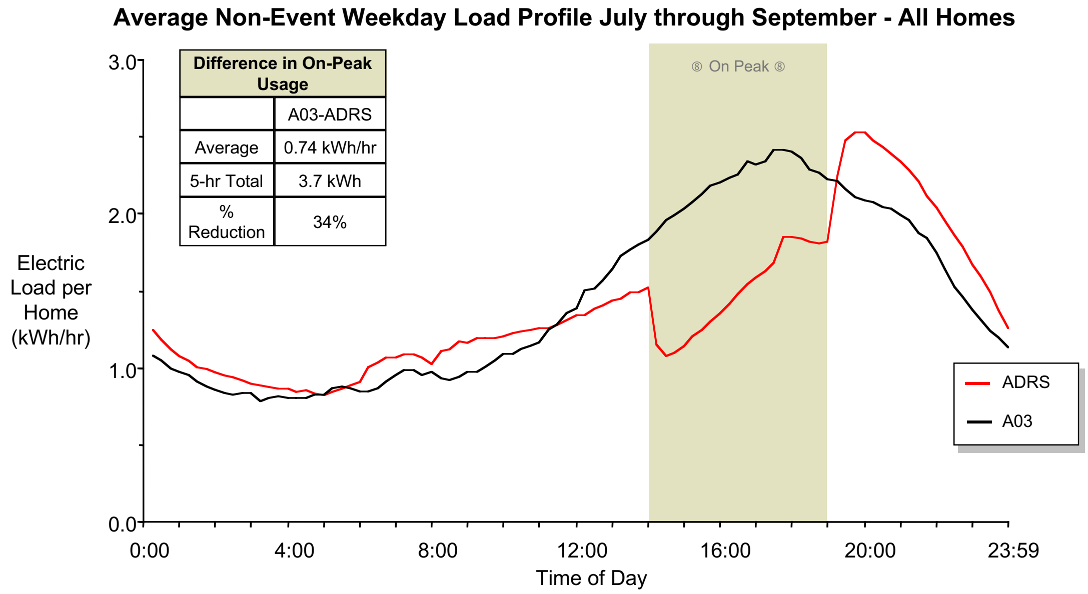

Figure 6. *Average load profile of ADRS participant and A03 control homes, non-event weekdays.*

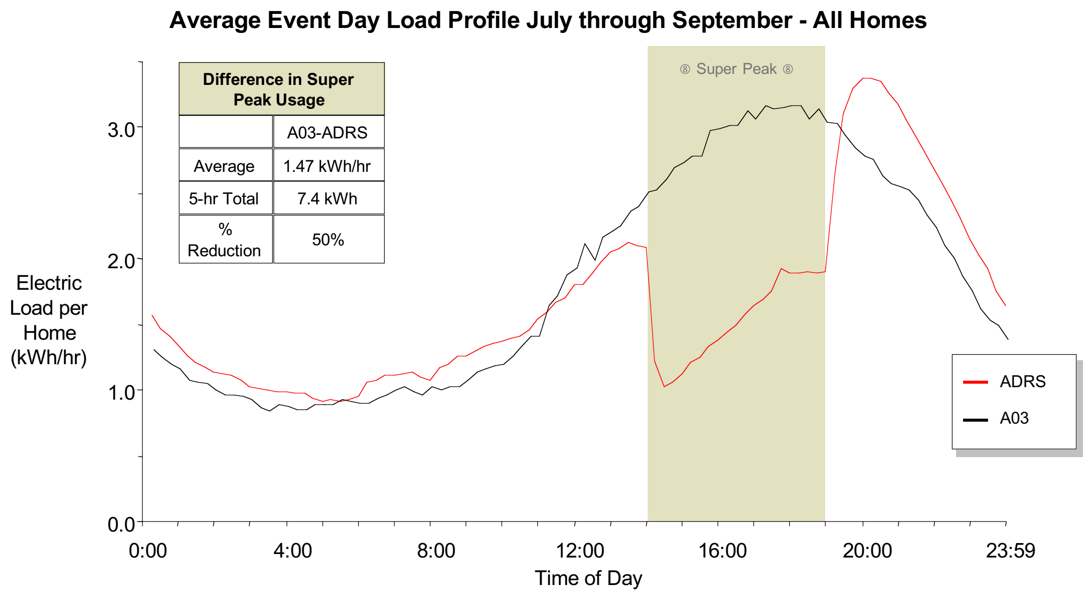

Figure 7. *Average load profile of ADRS participant and A03 control homes, super-peak event weekdays*

The instantaneous response is evident in the drop in load at the start of the peak period at 2 p.m., followed by a gradual decline in load reduction as the indoor temperature of the participant homes rises across the peak period. There is also a recovery effect at the end of the peak period at 7 p.m. Because of additional air-conditioning use during this recovery period, the ADRS houses' peak demand is about equal to that of the control homes, but it occurs two hours later, after the end of the on-peak period.

The ADRS technology-enabled participant homes reduce on-peak load by even more during super-peak events. A total of twelve curtailment events were called from July through September, mostly on days with average daily high temperatures averaging about 35°C (95°F). However, a few events were called when the average high temperature was in the range of 31-33°C (87-91°F). The twelve curtailment days were July 14, 22, 26 and 27; August 8, 9, 10, 11 and 27; September 8, 9 and 10. Note that consecutive three days events were called in August and September to test customer response to a prolonged event.

The daily load profiles of ADRS participant and control homes averaged over the twelve super-peak event weekdays are shown in Figure 7. Average load reduction per participant for all twelve event days across the five-hour peak period was 7.4 kWh (1.47 kWh/hr), or 50% compared to the control population. There is a steep drop in load at 2 p.m. (average of 1.5 kW or a 60% reduction), followed by a gradual decline in load reduction as the indoor temperature of the participant homes rises across the peak period (average of 1.2 kW or 40% reduction by 7 p.m.). The recovery period

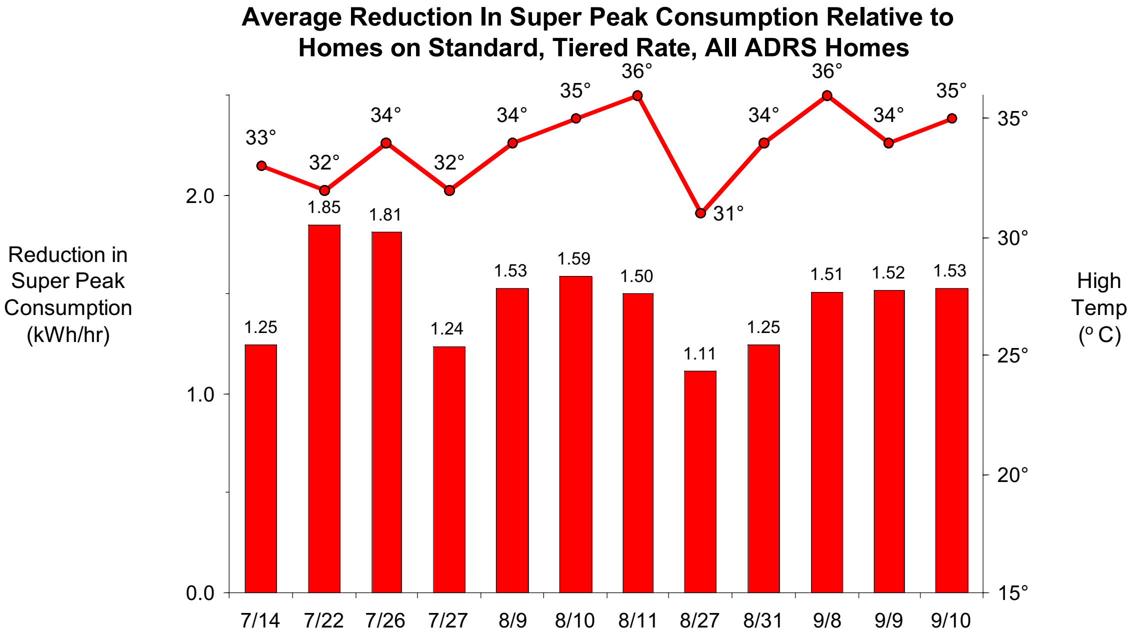

Figure 8. *Maximum and average load reduction of pilot homes for the twelve curtailment events.*

for the ADRS houses follows the same pattern as on non-event weekdays.

Figure 8 shows that the average super peak load reduction per participant home on each of the twelve curtailment event weekdays was 1.1 kW to 1.85 kW (46% to 56%). The magnitude of load reductions remains consistent over the summer, with no falloff apparent in the September events. In fact, both the August and September events include three-day series of super peak days, during which the ADRS load reduction was nearly constant, with no sign of fatigue on the part of the participant homeowners. Daily maximum temperatures on event days ranged from 31°C (87°F) to 36°C (96°F).

The ADRS participants also achieved a modest degree of energy conservation, with all of the net savings taking place during on-peak hours. Total daily energy consumption of ADRS houses was 5% lower than that of the comparable control homes on non-event weekdays and 12% lower on super peak days.

Household level analysis reveals that the majority of ADRS homes (52%) actively experimented with the technology to control home energy use, while an additional 7% made minor adjustments. Furthermore, about 10% of the ADRS population are "Supersavers," reducing load at 2 p.m. by more than 30% consistently across the summer months. The Supersaver ADRS homes contributed about 20% of super peak reduction and about 25% of normal on-peak reduction across the summer months. About 3% showed no reduction on average.

Also, ADRS proved very useful to pool owners and to higher-consumption homes, and less so for homes with modest consumption. Where present, pool pumps make a significant contribution to reduction of peak load. Relative to a control group of pools, ADRS pools reduce on-peak consumption by 2.8 kWh per day. For the average ADRS home with a pool, this 2.8 kWh reduction is 48% of the 5.8 kWh total reduction on non-event weekdays and 29% of the 9.5 kWh expected on Super Peak days. As just 44 of the 175 ADRS have pools, reductions from pool loads comprise roughly 20% of total peak load reduction and 10% of the reduction in Super Peak consumption

Breaking down the population by energy-usage stratum, high-consumption customers reduced on-peak load by an average of 0.87 kWh/hr (35%) on normal weekdays and by an average of 1.7 kWh/hr (51%) on super peak days. Low-consumption customers reduced on-peak load by an average of 0.38 kWh/hr (28%) on normal weekdays and by an average of 0.81 kWh/hr (43%) on super peak days. Meanwhile, results from the broader SPP program suggest that much of the savings in these low-consumption houses are a behavioural response to price signals that occurs even without automated technology in place. Thus, technology appears to be an important driver in reducing load, especially super peak load, for high-consumption homes, while the price signal appears to be a stronger driver of reduction in low-consumption homes.

The small sample size in the low-consumption stratum limits the statistical quality of the results from this sample, but it also minimizes the influence of these results on the full-population averages discussed above. Nevertheless, low-consumption houses have lower loads and achieve about half as much absolute load reduction compared to high-consumption homes. Meanwhile, high-consumption, technology-enabled ADRS homes reduce load further than the overall population, and much of the difference appears to be due to the use of automated technology.

For the full sample, statistical variation in on-peak consumption is high for both participants and control homes. However, the variations among the ADRS participants and the control group are not independent; rather, they are correlated (i.e., relatively high or low value tend to occur at similar times in each population. The differences in on-peak consumption between the participant and control groups are statistically significant at a confidence level above 95%, for both super peak days and normal weekdays. The statistical quality improves further if we consider only the high-consumption homes. Although the results for low-consumption homes are less significant, they are also less interesting in terms of their relevance to the design of future programs using automated technology.

Discussion and Conclusion

Houses with the automated GoodWatts load management technology reduced their demand in both the ACLM and the ADRS programs by about 50% consistently across the summer curtailment or super peak events, relative to homes without the technology or any load management program or tariff in place. The absolute savings were greater in the ACLM program, due to the higher baseline air conditioning loads in the hotter Las Vegas climate.

Moreover, the demand reductions were consistent over the summer, even on consecutive three-day curtailment or super peak events. There was a small drop in the load reduction in the last hours of the on-peak periods, but most of the air conditioning temperature recovery occurred later, during off-peak hours. There was also a modest conservation effect, as total daily usage was reduced by about 5% during the summer months.

In the California ADRS program, some of the load reduction is attributable to the dynamic pricing tariff, and it appears that much of the observed savings in low-consumption houses was due to the tariff. However, technology appears to be an important driver in reducing load, especially super peak load, for high-consumption homes. In the Nevada ACLM program, where there was no change in the tariff, the peak load reductions were consistent across a wide range of energy-usage strata.

Thus, our initial finding from these programs suggest that either automated technology or dynamic pricing can deliver significant demand response in low-consumption houses, but that the combination of both technology or dynamic pricing might not be necessary. For high-consumption houses, technology-enabled homes can reduce load by a greater absolute kWh difference, and much of this difference appears to be due to the technology.

Since the cost-effectiveness of a demand response program depends most directly on the magnitude of the peak demand reduction achieved, these results suggest a strategy of targeting a technology-enabled residential demand response to higher-usage customers. Especially in the California ADRS program, with lower baseline usage and dynamic pricing in place, the benefit of peak load reduction attributable to the technology will be greater for these customers. This targeting strategy can thus be expected to improve the economic performance of automated residential demand response. Larger scale programs can benefit from using this strategy in program design.