AB970

Small Commercial
Demand-Responsiveness
Pilot Program

PROGRAM IMPACT EVALUATION OF THE 2004
SCE Energy$mart Thermostat^{SM} Program
Final Report

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Prepared for:

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Preface

The 2004 AB970 SCE Energy$mart Thermostat^{SM} Program impact evaluation was performed on behalf of Southern California Edison Company, under the direction of Mark S. Martinez, manager of load control programs. RLW would like to thank Mark for his contributions and commitment to the success of the evaluation. For further information on this report please contact Mark using the information provided below.

Dr. Roger Wright of RLW Analytics, Inc. directed the evaluation, Stacia Okura was acting project manager, and April Garcia assisted in the reporting and analysis tasks.

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Executive Summary

Background

This is the final report of the 2004 Program Impact Evaluation of the AB970 SCE Energy$mart Thermostat^{SM} Program. The study was conducted by RLW Analytics, Inc. (RLW) on behalf of the Southern California Edison Company (SCE), administrator of the program. This pilot program was implemented under the direction of the California Public Utilities Commission (CPUC) through Decision 01.03.073 dated March 27, 2001 (Decision) to test the viability of a new approach to small (under 200 kW) commercial/industrial customer demand-responsiveness in hot and rural areas.

The SCE Energy$mart Thermostat^{SM} (E$T) program provides small commercial/industrial customers in SCE's service territory with two-way programmable thermostats at no cost. SCE uses a software program to remotely curtail the HVAC load of the participants during critical periods by sending out a paging radio signal. The curtailments are scheduled on a test basis, to coincide with a system wide hot day.

When the curtailment is activated, the thermostat raises the cooling set point by a specified number of degrees, called the temperature offset, thereby reducing the cooling load. This is designed to reduce the AC load without affecting customer comfort. The thermostat sends a radio signal back to SCE indicating it has received the signal and has implemented the temperature rollback and/or any local overrides of the curtailment by the participant.

Most of the participants in 2004 had been enrolled during 2002 marketing efforts and at the start of the summer there were 4,600 thermostats installed. In 2004, SCE offered customers a $150 annual incentive per thermostat for participating in the program, payable at the end of the year. The participant was penalized $10 each time they chose to override a curtailment by reducing the temperature back to the normal setpoint.

SCE could schedule up to 12 curtailments during the summer and in actuality conducted a total of 12 tests. The program was in effect from May 1st through October 31st 2004 and had a goal of 4 MW in peak demand reduction.

Evaluation Objectives

The objectives of this summer 2004 impact evaluation were to assess the customer responsiveness to demand response curtailments, model the effects of time of event and daily temperature on the HVAC load reductions, and verify the gross peak demand reduction of the E$T program. These goals were addressed by examining program data collected by SCE during the summer and fall of 2004, including:

- Information characterizing the date, time and temperature offset of each of 12 curtailments during 2004,
- Information about the number of installed units (over 4,600 units), verified units and overrides occurring in each curtailment,
- Program tracking data, describing the thermostats and controlled air conditioners including the size in rated cooling tonnage,
- Hourly thermostat run time data available from the thermostats, collected for the entire summer of 2004.

- Whole Premise metering: 5-minute-interval load data for a statistically representative sample of 145 customer locations,
- End Use metering: 5-minute interval load and run time data for 100 controlled air conditioners at a statistically representative sub-sample of 55 sites,
- Hourly measurements of exterior temperature by zip code in the Southern California area, collected throughout the summer and fall of 2004.

Using these data resources, the following analyses have been carried out:

- Assessment of the SCE program tracking data to assess the total number of controlled air conditioners and their total size in tons,
- Initial estimate of the program-wide impact of curtailment based on the end use meter results,
- Summarization of the operating load of participating air conditioners in order to convert the thermostat run time data into estimated load, and
- Conversion of the thermostat run time data to energy to verify the program-wide impact of curtailments.

Total Participation Assessment

For the summer of 2004, SCE had 4,600 thermostats in the AB970 E$T program. The number of participants has slightly fluctuated over the last two years since there has been participant attrition due to the closing of service accounts and the transfer of some customers into other test programs. The original goal and funding authorization was 5,000. The 4,600 AB970 thermostats that were available for analysis at the start of the summer are estimated to control roughly 19,700 tons of air conditioning.

Estimating the Operating Load

The actual air conditioning load under control by SCE is dependent on the operation of the air conditioner, or the “run time” of the compressor system. HVAC units operate in an “on-off” cycling mode, and the run time of the compressors is monitored by the thermostats and recorded on an hourly basis. This information is downloaded by SCE via two-way paging and is used in the impact analysis.

In order to convert the thermostat run time information into AC unit energy consumption, it was necessary to know the peak operating load (kW) of each unit during operation. The rated value of the air conditioner from the SCE tracking data gives a maximum connected load value, but the actual operating load can vary widely. Fortunately, there were one hundred air conditioners that were metered individually and 5 minute load data were collected as part of the program that provided detailed operating load information during different temperature days.

Using the 5-minute end use meter load data, statistical models were developed that estimated the operating load per ton of small (< 7 tons) and large (>= 7 tons) air conditioners as a simple linear function of exterior temperature. The end use meter data show that the operating load is a function of the size of the unit, in tons, as well as the exterior temperature. The resulting hourly load data were developed for all units in the program with run time data, nearly 3,600 of the participating air conditioners.

Impact Estimation from the End Use Meter Data

There were a total of twelve curtailment days during 2004, and the end use meter data collected from the sample of one hundred air conditioners in the program were sufficient to perform complete analyses on eight of these curtailment days. On five of the eight days, SCE called a 4-degree, 2-hour curtailment between 2 PM and 4 PM on a hot summer weekday. Two other curtailments were 4-degree, 2-hour events, one from 3 PM to 5 PM and an instantaneous event from 4:10 PM to 6:10 PM. On the final day, SCE called two back-to-back, 4-degree, 2-hour curtailments.

As an example, Figure ES-1 is included to show the weighted sample average impact of the curtailment that was called on September 7, 2004 from 2 PM to 4 PM. The graph shows a direct comparison of the averaged load/ton of the end use metered units on September 7 (blue line) to the averaged load/ton for non-controlled comparison days (red line). The high on September 7 was 94.0 degrees, and the average high on the control days was 92.4 degrees. The peak load reduction was over 0.51 kW per rated AC tonnage.

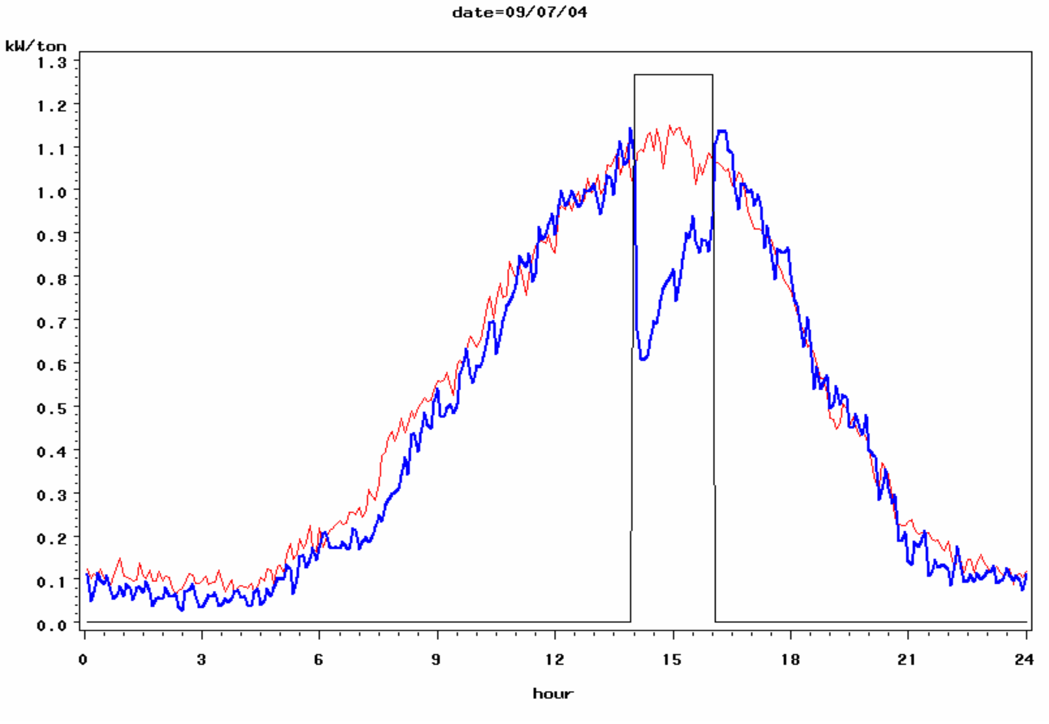

Figure ES-1: E$T kW/Ton Impact on September 7

By defining the effective curtailment duration to be the number of minutes during which the load reduction was at least half as large as the maximum initial load reduction, the average effective duration for the seven 2-hour, 4-degree curtailments was 86 minutes. The analysis of the data suggested little or no snapback following the curtailment period.

Averaging all eight curtailments, the maximum kW reduction in each curtailment was 0.49 kW per rated ton of the AC unit. The average kWh savings was 0.33 kWh per ton during the first hour of the curtailment and 0.21 kWh per ton during the second hour of the curtailment.

	Per Sample Ton	***Program Total***
Maximum kW Reduction	0.49	8,974
kWh Savings in Hour 1	0.33	6,021
kWh Savings in Hour 2	0.21	3,932

Figure ES-2: Estimated Program-Wide Impact from the End Use Metering

Assuming a total controlled tonnage of 18,322 tons (derated for signal communication losses), we have estimated that the average first hour energy savings due to the curtailments in 2004 were about 6.0 MWh, and the total energy savings in the second hour was about 3.9 MWh. The initial (15 minute) program peak demand reduction was about 9.0 MW.

Impact Estimation from Run time Data

The sample of 3,600 thermostats that provided hourly run time data via two-way paging were stratified by size and weighted to represent all units in the program and the estimated average hourly load was calculated on a kWh per ton basis. These data were available for eight of the twelve curtailment days. The first-hour and second-hour impact of each of these events was assessed using the run time data from the 3,600 units.

Averaging these eight curtailments, the average kWh savings was 0.33 kWh per ton during the first hour of the curtailment and about 0.17 kWh per ton during the second hour of the curtailment, almost identical to the results from the end use metered data analysis from the small sample.

	Run Time Data	
	Per Sample Ton	**Program Total**
kWh Savings in Hour 1	0.33	6,024
kWh Savings in Hour 2	0.17	3,184

Figure ES-3: Estimated Program-Wide Impact from the Run Time Data

Based upon our estimate of the controlled population cooling capacity of 18,322 tons, we extrapolated the savings results from the sample to all installed units, and estimated that the total first hour energy savings due to the curtailment was about 6.0 MWh, and the total energy savings in the second hour was about 3.2 MWh. Since the run time data were hourly, there was no estimate of initial peak demand reduction during the first 15 minutes.

Overall Program Impact – Summer 2004

The results from the hourly run time data confirm the estimates from the end use meter data analysis from the sample of end use metered units. The hourly impact estimates from the run times are almost identical to the metered data. Another confirmation of the comparability of the run time and end use meter results is how close they are to the results from the 2003 SCE E$T Program Impact Evaluation[1].

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[1] Both the run time and the EUM data analyses from the 2003 SCE E$T Program Impact Evaluation indicated that the total program first hour savings due to a 4-degree curtailment were between 6 and 7 MWh, and the total savings in the second hour were about 3 MWh.

The impact estimates for this report are quantified on a kW and kWh per ton basis. This was done to value the connected tonnage of the HVAC unit under curtailment since there is a positive correlation between the size of the load and the savings achieved when the load is curtailed.

The AB970 pilot did record substantial savings in 2004. Together, both the run time and the logger data analyses indicate that for a program population of 4,600 thermostats and a 4-degree positive adjustment in interior temperature, the following was achieved:

- First hour energy savings between 6 and 7 MWh
- Instantaneous demand reduction of 9 MW

The original AB970 pilot design in 2001 estimated a 4MW load reduction for a population of 5,000 thermostats. The results from the end use metering and run time data for 2004 are consistent with previous studies, and exceed the AB970 program goal by 125% with only 4,600 thermostats and a relatively mild summer.

1 Methodology

1.1 General Approach to the Evaluation

This section describes the general approach used to verify energy savings and peak demand reductions produced by this pilot program. The analysis will be described in much greater detail later in this report.

The impact evaluation was designed to address each of the key objectives and requirements of the Decision as summarized in the preceding section. In particular, the impact evaluation addressed the following questions:

1. Technical potential - What is the technical potential demand reduction of the 2004 pilot program?
2. Reliability - How much is the technical potential degraded by technical failures such as failure to detect override signals and other communication problems?

The approach to the evaluation built on the experience gained in the 2002 impact evaluation. The 2004 evaluation was based on the following data collected by SCE and its contractors during the summer and fall of 2004:

- Curtailment event summaries characterizing the date, time and temperature offset of each of 12 curtailments during 2004,
- Information about the number of installed units (over 4,600 units), verified units and overrides occurring in each curtailment, collected from the installed thermostats,
- Program tracking data, describing the thermostats and controlled air conditioners, including the size in tons recorded for over 4,200 controlled air conditioners,
- Hourly thermostat run time data available from almost 3,600 thermostats, collected for the entire summer of 2004 and including all of the curtailment days,
- Whole Premise metering (WPM) 5-minute interval load data for a statistically representative sample of 145 sites,
- End Use meter (EUM) 5-minute interval load and run time data for 100 controlled air conditioners at a statistically representative sub-sample of 55 sites, collected during all of the curtailment events, and
- Hourly measurements of exterior temperature from representative SCE-area weather stations in each climate zone collected throughout the summer and fall of 2004.

1.2 Experimental Plan

Our general approach has been to use the 5-minute end use meter data, the thermostat run time data and the information about the size of the controlled HVAC units collected for most of the participants to estimate the potential program load reduction impact. Our goal has been to estimate the maximum kW load reduction, the effective duration of the load reduction, the kWh reduction during each hour of the curtailment period, and the change in kWh during the first hour following the curtailment period.

1.3 Experimental Groups

SCE contracted with MeterSmart to install whole-premise meters and end use meters using a sampling plan developed by RLW. A total of 145 whole premise meters and 100 end use meters were installed during 2003 and 2004. The whole premise meters recorded 5-minute data measuring the total kW load at each site. The end use meters were installed at sites with whole-premise meters and recorded 5-minute data measuring the kW load for the HVAC units with smart thermostats installed. The end use meters also recorded the operating run time of the HVAC system during each 5-minute interval.

In the fall of 2002, RLW initially stratified the sampling frame according to those sites with predominately single-stage units and those sites with predominately multistage units. To do this RLW classified each site to be in class 1 if the average size per unit was less than 7 tons, and in class 2 if the average size per unit was at least 7 tons. Most of air conditioners at the sites in class 1 were single-stage units, whereas most of the air conditioners at the sites in class 2 were multistage units.

Model-based statistical sampling methods were used to develop the sample design for each class. RLW stratified each class by the number of tons of air conditioning at the site. Five strata were constructed in each of the two classes. Figure 4 shows the resulting sample design. Across all ten strata, the sample design called for the collection of whole premise load data at 145 sites participating in the program, and end use load data at a subset of 75 sites. A total of 118 whole premise meters and 105 end use meters were installed by the summer of 2003.

Class	***Stra-tum***	***Number of Sites***	***Max Tons***	***Total Tons***	***Units per Site***	***Tons per Site***	***Whole Premise Load***	***End Use Loads***
1	1	509	4	1,596	1.0	3.1	20	10
1	2	372	5	1,722	1.1	4.6	20	10
1	3	283	9	1,852	1.8	6.5	20	10
1	4	184	15	2,055	2.6	11.2	20	10
1	5	97	114	2,472	5.7	25.5	20	10
Subtotal		1,445		9,697			100	50
2	6	21	8	161	1.0	7.7	10	5
2	7	18	13	172	1.0	9.6	10	5
2	8	12	18	184	1.8	15.3	10	5
2	9	9	24	208	2.3	23.1	9	5
2	10	6	60	232	4.0	38.7	6	5
Subtotal		66		957			45	25
Total		1,511		10,654			145	75

Figure 4: Recommended Sample Design

In the spring of 2004, a second sample was planned to target the WPM sites by stratifying the population by annual kWh. This stratification ensured that the weights calculated for the WPM sites adequately represented the size of the site (using kWh as a proxy for size). In order to determine which size sites to include in the new WPM sample recruitment, RLW post-stratified the existing WPM sites with valid data in the sample by kWh using the population of customers in the tracking data. Then RLW determined the number of sites that would be needed in each stratum in order to balance the number of sites in the each stratum. Figure 5 shows the WPM sample design.

Stratum	Min*	Max*	Total*	Population	Sample
1	486	62,466	39,250,556	1,246	39
2	62,482	133,792	48,116,968	519	27
3	133,793	230,101	54,396,422	313	28
4	230,169	458,607	61,562,006	193	28
5	461,608	2,117,521	74,067,450	99	28
Overall	** 3/2002 to 4/2004 annual kWh*			**2,370**	**150**

Figure 5: Metering Sample Design

There are 150 whole premise meters and 100 end use meters that are currently providing valid data. The load data from these meters were used in this impact evaluation.

1.4 Methodology for the Statistical Analysis

The average 5-minute end use load of the 100 monitored AC units together with the hourly measurements of exterior temperature were used to estimate the program load impact of curtailments called on ten different days during the summer and fall of 2004. To simplify the analysis, the average load of the 100 units was converted to kW per ton in each 5-minute interval. The average load and tons were calculated by first stratifying the units in the sample and program population by size in tons, then developing kW/ton for each stratified group.

We also prepared hourly weather data from each of six weather stations that were representative of the six climate regions in the program. An average hourly temperature was calculated as a weighted average of the hourly temperatures in the six regions, weighted by the total cooling tons of the HVAC units in each region.

The differential impact of each of the ten curtailment events was developed by comparing the average 5-minute kW load per ton on each curtailment day to the load on one or more non-curtailment days that were selected to be similar to the curtailment day with respect to the hourly temperature.

The approach estimated the maximum kW load reduction per ton, and the effective duration of the load reduction - defined to be the number of minutes during the curtailment period in which the load reduction was greater than one-half of the maximum load reduction. We also estimated the kWh reduction during each hour of the curtailment period and the possible snapback - the change in kWh during the first hour following the curtailment period.

SCE and its subcontractors used the thermostat communications software to also collect hourly run time data for all of the participating thermostats for the entire summer of 2004. These data are stored in the thermostats on a five day limited memory, and downloaded via two-way paging upon request from the software, either manually or on a daily basis, to an FTP secure site. SCE and its contractors can then access the data.

The 5-minute end use meter data from each of the 100 sample AC units was used to develop two statistical regression models that estimated the operating kW load of each unit as a function of its size in tons and the exterior temperature. We developed one model for the small units (less than 7 tons) and another for the large units in order to capture the two-stages of compressor operation of the large units. We used this model to convert the end use hourly run times into estimates of the hourly kWh load of each of these 100 units.

We then used the run time data collected from the thermostats together with the SCE customer tracking information about the size of each unit to estimate the average hourly kWh load per ton of all participating units on the days in which the run time data had been collected. We used these data to provide an independent estimate of the hourly kWh impact per ton among all program participants when run time was collected on the curtailment days. Finally, we extrapolated the results by multiplying the impact per ton by the estimated total tonnage of all controlled units.

2 Findings from the Tracking Data

In this section we will present the detailed results of the preliminary analysis primarily developed from the SCE program tracking data, along with other data sources, that were used to support the impact analysis.

2.1 Number and Size of Installed Units

The SCE program tracking system is an ACCESS based database system and provides customer and program – related data for each of the thermostats that have been installed in the program. At the time of review, the SCE database provided records for 5,824 installed thermostats, which included AB970 participants, closed accounts, and other pilot program participants (not part of AB970). The ID of each unit includes an alphabetical designation (A – H) that identifies the regions and climate zones where the thermostats are installed, as shown in Figure 6.

Zone	Weather Zone	Name	Description
A	6	Coastal	Santa Barbara and Los Angeles coast.
B	8	OC	Orange County inland.
C	9	Central Valley	Burbank, Hollywood, and Pasadena area.
D	10	Inland Empire	San Bernardino and Riverside area.
F	14	Coachella Valley	Southern deserts.
G	15	Northern Deserts	Southeast deserts.
H	16	Mountains	Mountains - Sierra Nevada.

Figure 6: Climate Zones

The zones are mapped into the SCE customer tracking software, as well as the third-party communications and control software that operates the thermostats, enabling SCE to curtail the thermostats either as a complete group, or by zone. The Weather Zones are based on the California Energy Commission climate zones[2]. Zones A, B, C, D and F are progressively “hotter” climate areas with increased AC usage. The Name indicates the general area in Southern California.

Zones G and H are outlying rural areas with limited radio coverage and very small commercial populations, and Zone H has recently been cancelled, as it no longer has any customers. Zone E (not listed) is not a weather zone, but a special group that includes SCE test sites for engineering verification.

A map of all of the 16 California climate zones is presented below in Figure 7. Many of them are not in SCE’s territory, and some are shared with other utilities. Although SCE territory includes climate zone 13, customers here have not been included in the AB970 pilot program due to the lack of two-way paging coverage in this rural area.

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[2] http://www.energy.ca.gov/

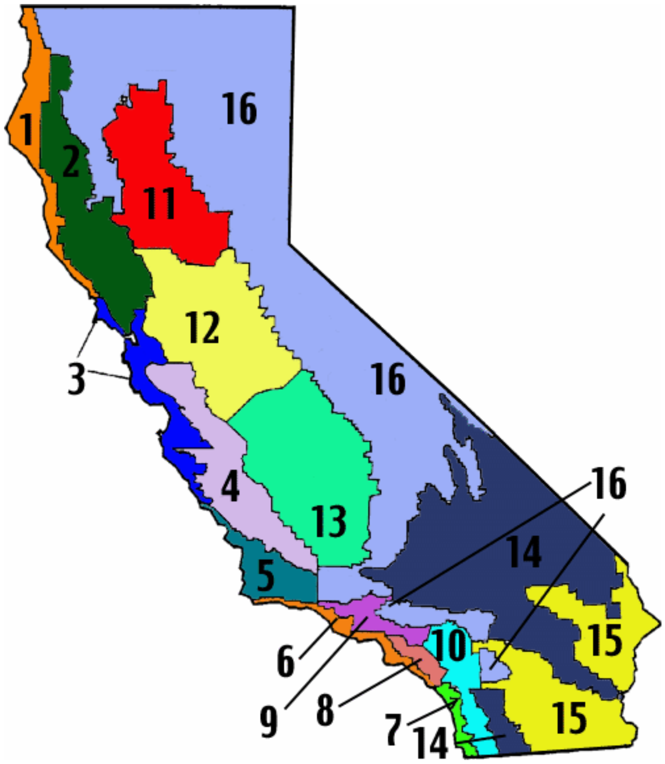

Figure 7: California Climate Zone Map

Knowing the rated AC tonnage of every air conditioner with a smart thermostat was very critical to the load impact analysis. SCE's installation plan required the contract thermostat installers to report the tonnage of each controlled air conditioning unit and to record other site and customer information. However, in many instances the installation contractor could not locate the tonnage on the nameplate or neglected to record the information. After identifying the missing site data, RLW worked on a field inspection project during early 2004 to collect the remaining tonnage information data that were not in the database.

Over 1,400 HVAC units were inspected by RLW in an attempt to collect the missing data. Despite visiting over 90% of the units with missing data, not all of the information could be collected or calculated from model numbers, so in some instances, it was either estimated as a range (i.e. 2-4 tons) for a group rating, or left blank. There are currently a total of 476 thermostats in the database without associated tonnage data. These missing tonnages not critical to the analysis, as the inspections and resulting addition of "lost tonnages" did not substantially increase or decrease the average tonnage of the population. Missing tonnages remaining are due to a lack of access to the site or thermostats that were installed after the tonnage collection project occurred.

The SCE database provided the tonnage rating for 4,250 of the units used in our analysis. These units varied in size from 1 to 24 tons. The second column of Figure 8 shows the detailed distribution of size in the population of units with known size. The third column of Figure 8 shows the distribution of the tons in the population of units with known size.

Tons	***Installed Thermostats***	***Known Tons***
1 to 1.9	0.5%	0.2%
2 to 2.9	11.8%	6%
3 to 3.9	24.5%	18%
4 to 4.9	24.4%	23%
5 to 5.9	32.3%	39%
6 to 6.9	0.9%	1%
7 to 7.9	1.8%	3%
8 to 8.9	1.5%	3%
9 to 9.9	0.1%	0.2%
10 to 10.9	1.3%	3%
> = 11	1%	3%
Total	**4,250**	**17,749**

Figure 8: Participant Population with Known Tons

Figure 9 shows the distribution of the participating units and tonnages by climate zone. The majority of the units are from climate zones 9 and 10 (warmer zones in rural areas).

Size	***Climate Zone***	***Units***	***Tons***
Small	A	7%	7%
	B	20%	18%
	C	31%	28%
	D	29%	28%
	F	3%	3%
	G	4%	4%
Large	A	0%	1%
	B	1%	3%
	C	1%	3%
	D	2%	4%
	F	0%	0%
	G	0%	1%

Figure 9: Small vs. Large Units by Climate Zone

We noted earlier that the large units, i.e. 7 tons or larger, were all multi-stage units. These presence of these units was of concern to the impact analysis because the thermostat run time data were not designed to describe the operation of multi-stage units. Fortunately, there are relatively fewer units greater than 7 tons distributed among the climate zones.

2.2 Signal Reception

The thermostat communications system sends out a radio page for controlling and communicating with the thermostats, and has the ability to track a “handshake” signal received from each of the thermostats after curtailment commands. The thermostat has a 2-way pager built into its system, and can verify that a command has been received. For a period of time after a command to curtail has been transmitted by the system, the thermostats send back a confirmation signal that they have “acknowledged” the command. Since there are nearly 5,000 thermostats in the SCE system, these acknowledgements are programmed in each thermostat to occur randomly over a 2 hour period after the command has been sent, to prevent the server incoming “mailbox” form being overloaded.

The communications software server also conducts a weekly communication test every Sunday, called a heartbeat test, with each thermostat. It tracks which thermostats respond to the test, and when the latest response to the test was received.

According to SCE, communication problems with thermostats can be broken down into two functional categories of non-responding devices:

1. Those that do not respond to a curtailment event (Non-Respondents), and
2. Those that do not send a weekly heartbeat response (Deadbeats).

SCE asserts that “Non-Respondents” may receive the curtailment requests, and act accordingly by reducing load, but their response for some reason is not registered by the server. Investigation into the non-respondents by SCE revealed that some devices do receive the curtailment signal and reduce load, but do not respond back, thereby indicating a false non-operational status. The two-way thermostat in effect becomes a one-way device, still operational in adjusting the setpoint, but not able to be “heard” by the paging system and confirmed[3].

True Deadbeats, on the other hand, fail to communicate on a weekly basis, do not respond to any signals and do not respond to curtailment events. True Deadbeats can arise from a defective radio, no radio reception, an unused or defective HVAC system, or the fact that the thermostat has been replaced. SCE defines a Deadbeat as a thermostat that has not responded to a heartbeat signal after 3 weeks. Deadbeats tend to grow in numbers before and after the summer ends, indicating that many customers turn off their air conditioners (and power to the thermostats).

Figure 10 presents the percentage of the average number of devices that failed to respond to the curtailments by month. This percentage includes the non-respondents during each curtailment event, and the deadbeats during that month.

Month	***% of Devices***
July	16%
August	14%
September	15%
October	21%

Figure 10: Non-Respondent and Deadbeat Thermostats

The review of the heartbeat tests from the paging server indicates that, on average, 5% to 7% of the installed units during the curtailments fall into the deadbeat category. In order to provide a conservative estimate of the total impact of the program, we have reduced our estimate of the total tonnage of all controlled units by 7%, i.e., from over 19,000 tons to 18,322 tons. Accordingly, subsequent analysis assumes that the total size of the controlled air conditioners is 18,322 tons.

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[3] The pager system in the thermostat is limited by FCC regulations to one Watt, and the signal can be masked by other radio frequency traffic in an attempt to reach the local paging receiver towers

2.3 Frequency of Customer Override

This section presents information on the number of thermostats that confirmed receipt of the curtailment notice, and the percentage of thermostats that were overridden by customers. An override is defined as a manual operation of the thermostat by the customer during a curtailment event (such as raising or lowering the setpoint) which effectively ends the curtailment event.

All non-responsive thermostats are excluded from the analyses in this section. The thermostat control software database collected these data during each curtailment event. Figure 11 presents the number of confirmed thermostats, the override rate, and the number of curtailments by degree-setback by month. The highest override rate occurred in July, with 21% of the thermostats being overridden.

Month	***Confirmed Thermostats***	***% Overrides***	***Total Curtailments***
July	3,900	21%	4
August	3,546	19%	2
September	3,868	19%	4
October	4,949	18%	2

Figure 11: Participation Rates and Curtailments by Month and Degree Setback

2.4 Dates and Times of Curtailment

During the summer of 2004, SCE issued 12 curtailments. Curtailments were called at a variety of times and weather conditions. SCE attempted to call curtailments in the middle of a heat period, in order to simulate the same conditions that would cause an ISO event. SCE also tried to match the timing of the curtailments during the day to the ISO peak load.

The selection of the dates of curtailment during the summer of 2004 by SCE was based upon weather forecasts for Los Angeles and Ontario and the CAL ISO web site[4]. The SCE program manager considered the type of day and week, such as holiday weekends and warming trends, the peak temperature of the predicted peak day, pre-heating trends, day of the peak, and the potential for peak energy usage. The manager also tried to include an assortment of business day types so that business operation trends could be assessed. The CAL ISO web site was used to establish the timing of the event by obtaining data on peak day usage for the system.

The E$T program tracking system provides detailed information about each curtailment event called in the summer of 2004. Figure 12 summarizes the curtailment events. The first column lists 13 events[5]. The table shows the ID assigned to the event by Carrier, the date of the event, the start and end times, and the setback.

Due to problems with the thermostat communications software system, thermostat run time data were only partially available for the events in July. As a consequence, only the eight curtailment events that took place from August 9 onward (due to the completeness of all data) were used in all of the impact analyses for this report.

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[4] *http://www.wunderground.com/US/CA/Ontario.html* and *http://www.caiso.com/EIS/weatherbank.html*

[5] The event on October 14th counts as one event for customer overrides, as it was a continuous reduction over 4 hours.

Event ID	***Month***	***Date***	***Start time***	***End time***
157	July	7/15/2004	2:00 PM	4:00 PM
160	July	7/22/2004	1:00 PM	6:00 PM
164	July	7/26/2004	3:00 PM	5:00 PM
166	July	7/27/2004	3:00 PM	5:00 PM
171	August	8/9/2004	3:00 PM	5:00 PM
174	August	8/10/2004	2:00 PM	4:00 PM
181	September	9/1/2004	2:00 PM	4:00 PM
183	September	9/7/2004	2:00 PM	4:00 PM
187	September	9/8/2004	4:10 PM	6:10 PM
191	September	9/23/2004	2:00 PM	4:00 PM
192	October	10/7/2004	2:00 PM	4:00 PM
193	October	10/14/2004	2:00 PM	4:00 PM
194	October	10/14/2004	4:00 PM	6:00 PM

Figure 12: Dates and Times of Curtailment

There were two events that occurred on 10/14, events 193 and 194. Event 193 was a 2-hour, 4-degree curtailment from 2 PM to 4 PM. At 4 PM the SCE Program Manager called another 4-degree setback for 2 hours. The manager wanted to understand what the load impact would be like if two curtailments were called continuously.

2.5 Weather on Curtailment Days

We will start by examining the exterior temperature in the SCE service area during the summer of 2004. The weather data used in this project were obtained from MeterSmart who had access to weather data by zip code in the Southern California area. Figure 13 shows the entire list of weather stations that are associated with each of the climate zones.

Zone	Station	Tons
A	KLAX	68
A	KSLI	589
A	KTOA	63
B	KCNO	178
B	KCQT	405
B	KFUL	425
B	KHHR	156
B	KLGB	499
B	KSLI	249
B	KSNA	1,581
C	KEMT	2,998
C	KFUL	327
C	KNTD	959
C	KONT	107
C	KPOC	950
C	KVNY	568
D	KCNO	1,830
D	KFUL	534
D	KNFG	546
D	KONT	1,680
D	KRAL	1,597
D	KRIV	1,668
F	KPMD	68
F	KRIV	197
F	KWJF	587
G	KPSP	1,466
H	KRAL	13
H	KRIV	113

Figure 13: Weather Stations

The total tonnage of the participating units in each of the weather zones was used to calculate a weighted average of the temperature across the program in each hour.

Figure 14 shows the daily high temperatures for each weekday. The curtailment days of special interest to us are highlighted in bold.

We will use this type of information to select baseline days that are comparable to the curtailment days to be analyzed.

Date	Day of Week	High
8/2/2004	Mon	82.4
8/3/2004	Tue	83.9
8/4/2004	Wed	82.1
8/5/2004	Thurs	83.5
8/6/2004	Fri	86.7
8/9/2004	***Mon***	***92.2***
8/10/2004	***Tue***	***94.1***
8/11/2004	Wed	89.5
8/12/2004	Thurs	85.1
8/13/2004	Fri	84.3
8/16/2004	Mon	84.6
8/17/2004	Tue	84.9
8/18/2004	Wed	83.6
8/19/2004	Thurs	85.3
8/20/2004	Fri	81.6
8/23/2004	Mon	79.4
8/24/2004	Tue	80.2
8/25/2004	Wed	83.0
8/26/2004	Thurs	81.6
8/27/2004	Fri	84.6
8/30/2004	Mon	89.1
8/31/2004	Tue	92.4
9/1/2004	***Wed***	***93.3***
9/2/2004	Thurs	90.9
9/3/2004	Fri	79.8
9/6/2004	Mon	92.4
9/7/2004	***Tue***	***94.0***
9/8/2004	***Wed***	***90.6***
9/9/2004	Thurs	90.5
9/10/2004	Fri	92.7
9/13/2004	Mon	83.0
9/14/2004	Tue	80.9
9/15/2004	Wed	82.5
9/16/2004	Thurs	84.5
9/17/2004	Fri	83.9
9/20/2004	Mon	75.4
9/21/2004	Tue	87.6
9/22/2004	Wed	90.1
9/23/2004	***Thurs***	***88.6***
9/24/2004	Fri	88.9
9/27/2004	Mon	83.6
9/28/2004	Tue	76.8
9/29/2004	Wed	73.8
9/30/2004	Thurs	71.4
10/1/2004	Fri	77.1
10/4/2004	Mon	78.4
10/5/2004	Tue	81.7
10/6/2004	Wed	83.6
10/7/2004	***Thurs***	***84.0***
10/8/2004	Fri	88.8
10/11/2004	Mon	78.2
10/12/2004	Tue	84.2
10/13/2004	Wed	80.6
10/14/2004	***Thurs***	***87.7***

Figure 14: Daily Weather Statistics

3 Analysis of the End Use Meter Data

The end use meter data provide 5-minute kWh measurements of the one hundred HVAC units that were selected for end use metering. These data were used to estimate the average kW and kWh impact per ton on each of eight curtailment days.

3.1 Method of Analysis

In this section we will summarize our methodology for using the end use meter data to estimate impacts. Our analysis followed these steps:

1. Use interactive data visualization software to review the 5-minute load data of each unit,
2. Develop case weights for each HVAC unit with end use meter data to represent the size distribution of all units installed in the program,
3. Using the case weights, calculate the average 5-minute load per ton of all one hundred HVAC units to provide a single analysis variable,
4. Use the temperature data to identify one or more days that are comparable to each curtailment day,
5. Use the 5-minute load data for the average HVAC unit to calculate the baseline load per ton for the curtailment day, and
6. Calculate the kW load reduction per ton as the difference between the actual load per ton and the baseline load per ton.

The average load per ton was obtained by post-stratifying the sample units as shown in Figure 16. Each unit was given a case weight equal to the population size divided by the sample size in the corresponding stratum. Then the case weights were used to calculate the average load, measured as kWh per ton, of the sample units in each 5-minute interval.

Once the savings were calculated, the estimated savings per ton was multiplied by the estimated total tons of all participating units to estimate the total kW and kWh savings of all participating units.

3.2 End Use Metered Sites

The end use metered data involved one hundred thermostats that controlled HVAC units in the program. MeterSmart collected 5-minute end use meter data for each unit from the beginning of August through October. The data typically include the kWh usage of each HVAC unit and the run time of the unit, both measured and recorded continuously every five minutes. The data were transferred to RLW after being screened and verified as correct.

Logger	Tons	Pin	Weight
A0101_1	4	1296644	59.17
A0330_1	4	1342046	59.17
A0330_2	4	1342681	59.17
B0142_1	8	1295719	8.67
B0243_1	4	1342462	59.17
B0243_2	3	1327320	60.35
B0243_3	3	1342099	60.35
B0243_4	5	1327791	61.59
B0633_1	10	1342183	14.89
B0950_1	4	1342594	59.17
B1085_1	4	1457120	59.17
B2036_1	5	1457116	61.59
B2298_1	3	1485938	60.35
B2333_1	4	1487072	59.17
B2333_2	4	1486714	59.17
B2521_1	10	1839227	14.89
B2956_1	5	1839157	61.59
B2970_1	4	1839166	59.17
B3335_1	24	1295639	14.89
C0258_1	5	1508523	61.59
C0258_2	3	1327216	60.35
C0444_1	10	1835022	14.89
C0444_2	5	1341112	61.59
C0676_1	4	1295725	59.17
C0676_2	4	1296285	59.17
C0705_1	3	1456987	60.35
C0705_2	3	1457037	60.35
C0842_1	8	1457644	8.67
C1042_1	5	1296372	61.59
C1042_2	5	1296183	61.59
C1936_1	5	1090857	61.59
C1936_2	5	1511751	61.59
C1936_3	5	1079958	61.59
C2373_1	7	1296266	8.67
C2373_2	7	1296227	8.67
C2373_3	3	1296271	60.35
C2814_1	4	1486701	59.17
C2814_2	4	1486699	59.17
C2977_1	5	1532901	61.59
C2977_2	3	1486820	60.35
C2977_3	3	1456943	60.35
C2977_4	5	1486513	61.59
C3029_1	5	1295568	61.59
C3029_2	5	1487053	61.59
C3029_3	5	1295666	61.59
C3029_4	5	1295670	61.59
C3225_1	2	1839595	60.35
D0075_1	3	1090505	60.35
D0129_1	3	1817919	60.35
D0300_1	8	1457181	8.67
D0300_2	8	1457288	8.67
D0300_3	8	1457998	8.67
D0403_1	8	1342218	8.67
D0403_2	15	1457046	14.89
D0403_3	15	1341875	14.89
D0403_4	8	1341902	8.67
D0471_1	3	6262097	60.35
D0471_2	3	6044145	60.35
D0812_1	5	1457372	61.59
D0812_2	5	1457364	61.59
D1013_1	3	1079790	60.35
D1013_2	4	1079840	59.17
D1013_3	5	1079791	61.59
D1013_4	3	1079800	60.35
D1317_1	2	1296539	60.35
D1379_1	3.5	1342627	59.17
D1379_2	4	1457616	59.17
D1573_1	8	1296589	8.67
D1648_1	5	6261966	61.59
D1831_1	2	1296186	60.35
D1831_2	2	1296445	60.35
D1831_3	2	1296446	60.35
D1831_4	2	1817945	60.35
D2018_1	5	1295960	61.59
D2099_1	7	1485265	8.67
D2099_2	7	1485592	8.67
D2200_1	5	1486939	61.59
D2428_1	2	1485257	60.35
D2428_2	6	1485587	24.52
D2428_3	6	1485588	24.52
D3034_1	8	6043985	8.67
D3034_2	8	6262134	8.67
D3034_3	3	6262097	60.35
D3034_4	8	6262083	8.67
D3618_1	4	6043939	59.17
D3714_1	5	1486712	61.59
D3714_2	5	1487049	61.59
D3714_3	4	1485926	59.17
D6010_1	8	1327654	8.67
F0379_1	2	1296407	60.35
F0379_2	3	1296410	60.35
F0379_3	4	1342824	59.17
F1633_1	3	1327337	60.35
F2389_1	4	6262060	59.17
G0007_1	5	1457373	61.59
G0336_1	10	1342520	14.89
G3999_1	8	1487065	8.67
G3999_2	8	1486674	8.67
G3999_3	4	6043189	59.17
G4130_1	3	6044137	60.35

Figure 15: HVAC Units in the End Use Metered Sample

There were one hundred units included in our analysis. The data provide a spot measurement of the kWh usage of each unit every five minutes from August through October. There are small units, less than 7-tons, and large units, 7-tons or greater, in the program. The smaller units sometimes have an independent fan load that is usually less than 1 kW and is not controlled by the thermostat. The large units are of concern to us for the analysis because they are often multi-stage units and the thermostat run time data were not designed to accurately describe the operation of these units.

Fortunately, after review of the end use data, it appears that the temperature-offset curtailment strategy appears to affect large, multistage units in essentially the same way as small one-stage units, ensuring a correlation of tonnage to load reduction.

3.3 Case Weights

The small commercial sites included in the end use metering sample were initially designed to be a representative sample of program participants. We developed case weights to ensure our analysis of the end use metered sample units located at these sites reflected the size distribution of all air conditioners installed in the program. We developed the six ex-post strata shown in Figure 16. The column named Weight shows the case weight used to calculate the average load per ton of the sample units.

Class	*Stratum*	*Max Size*	*Total Tons*	*Population*	*Sample*	*Weight*
Small	1	3	3,979	1,508	27	60.35
Small	2	4	4,281	1,114	21	59.17
Small	3	5	4,459	943	25	61.59
Small	4	6.5	4,523	895	2	24.52
Subtotal				4,461	75	
Large	1	9	1,169	153	18	8.67
Large	2	24	1,290	108	7	14.89
Subtotal				260	25	
Total			19,702	4,721	100	

Figure 16: Post Stratification of the HVAC Units with End Use Meter Data

3.4 Load of HVAC Units with End Use Meter Data

We now utilize the average load of the sample units with end use meter data to assess the impact of the eight curtailment days from August 9 onward. We will analyze the curtailment days in chronological order.

Event 171 - August 9, 2004

The August 9 curtailment was a 4-degree setback from 2 to 4 PM. The first step in the analysis of this event was to choose a comparison day to provide a baseline for calculating the true load impact of the curtailment. Instead of selecting one comparison day we decided to use an average of 3 comparison days (8/11, 8/31, 9/2). We first directly compared the average load of the sample units on the curtailment day to the average load on the three averaged comparison days. The temperatures were slightly different between the three comparison days and the curtailment day, therefore we chose to adjust the averaged baseline load to better reflect the load of a true baseline day by multiplying the baseline load by a fixed factor. We calculated the adjustment factor as the ratio between the average load during the two hours corresponding to the curtailment on the three baseline days, divided by the average load during the two hours prior to the actual curtailment on August 9.

After applying this true-up adjustment, we produced the graph shown in Figure 17. The blue line is the actual load on August 9 and the red line is the average load of the three baseline days. The area between the red and blue lines shows the estimated impact of the curtailment. In the first hour of the curtailment the load relief is the greatest, after which the load relief becomes smaller, a result of some of the HVAC units beginning to operate again.

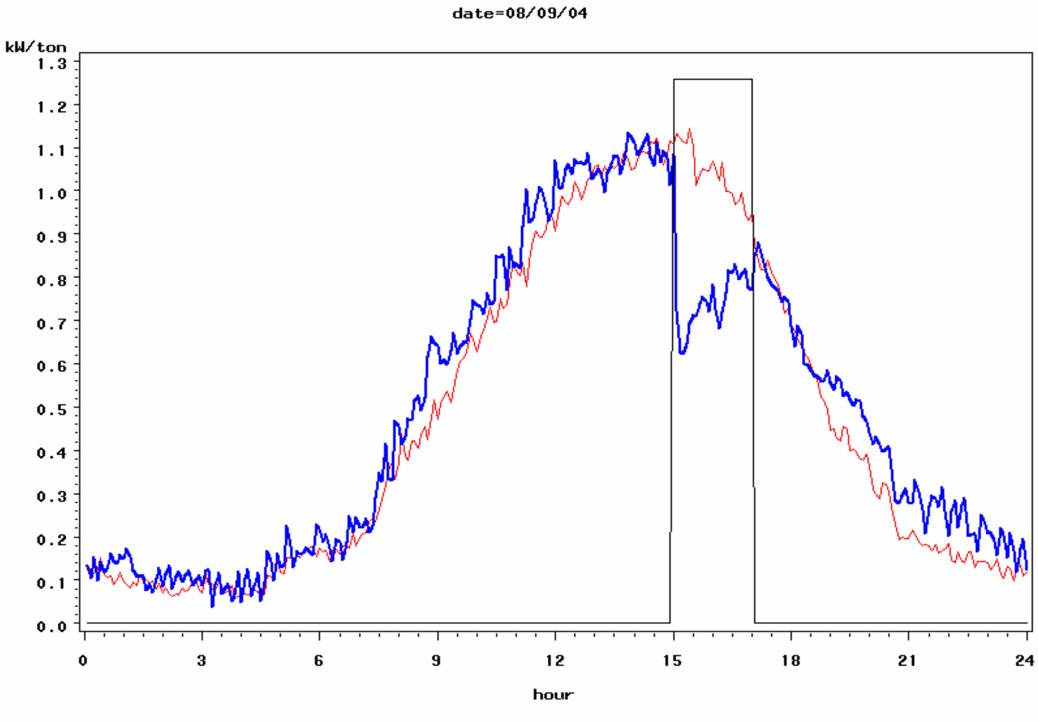

Figure 17: Estimating the Impact on August 9

Figure 18 summarizes the characteristics of the event. The summary shows the date and time of the curtailment and the temperature offset. The table also shows the high temperature on the day of curtailment, taken from Figure 14, as well as the override rate. The override rate is the number of units in the population that overrode the curtailment as a percentage of the units that confirmed the call. This statistic is taken from the event tracking data maintained by the thermostat communications server.

The remaining statistics in Figure 18 reflect our analysis of the average load of the sample units with end use meter data. During the two-hour curtailment, the average load per unit dropped by a maximum of 0.50 kW per ton. The minimum reduction was 0.13 kW per ton during the period, indicating that the full savings did not persist through the full period. The energy savings during the entire curtailment period was estimated to be 0.59 kWh per ton.

We also calculated the kWh savings during each hour of the curtailment, as well as during the first hour following the curtailment period. During the first hour of the curtailment the savings were 0.38 kWh per ton. From the first hour to the second hour of the curtailment period, the energy savings fell from 0.38 kWh to 0.22 kWh per ton. This is consistent with the estimated effective duration of the curtailment. In the hour following the curtailment period, there was little change in energy consumption. This suggests that there was little or no snapback. The summary characteristics shown in Figure 18 are consistent with the graphical description of the results shown in Figure 17.

Curtailment Date	8/9/2004
Start Time	3:00 PM
End Time	5:00 PM
Offset	4
Curtailment Day High	92.2
Override Rate	19%
Confirmed Units	3487
Baseline Days	8/11/04, 8/31/04, 9/2/04
Baseline Days Average High	92.1
Maximum Reduction	0.50
Minimum Reduction	0.13
Energy Savings	0.59
Minutes Duration	75
kWh Savings in Hour 1	0.38
kWh Savings in Hour 2	0.22
Hour Following	0.00

Figure 18: Summary Report for August 9

We will follow a similar approach for each of the remaining curtailment days of interest. Our commentary will be brief since the format of the results will be similar. After developing the results for each of the eight curtailment days, we will provide an analysis of the results and findings across all eight days.

Event 174 - August 10, 2004

As shown in Figure 19, the August 10 curtailment was a 4-degree setback from 2 to 4 PM. The chosen baseline days for August 10 were August 11, August 31, and September 2. Figure 19 shows the results graphically, and Figure 20 provides the summary report.

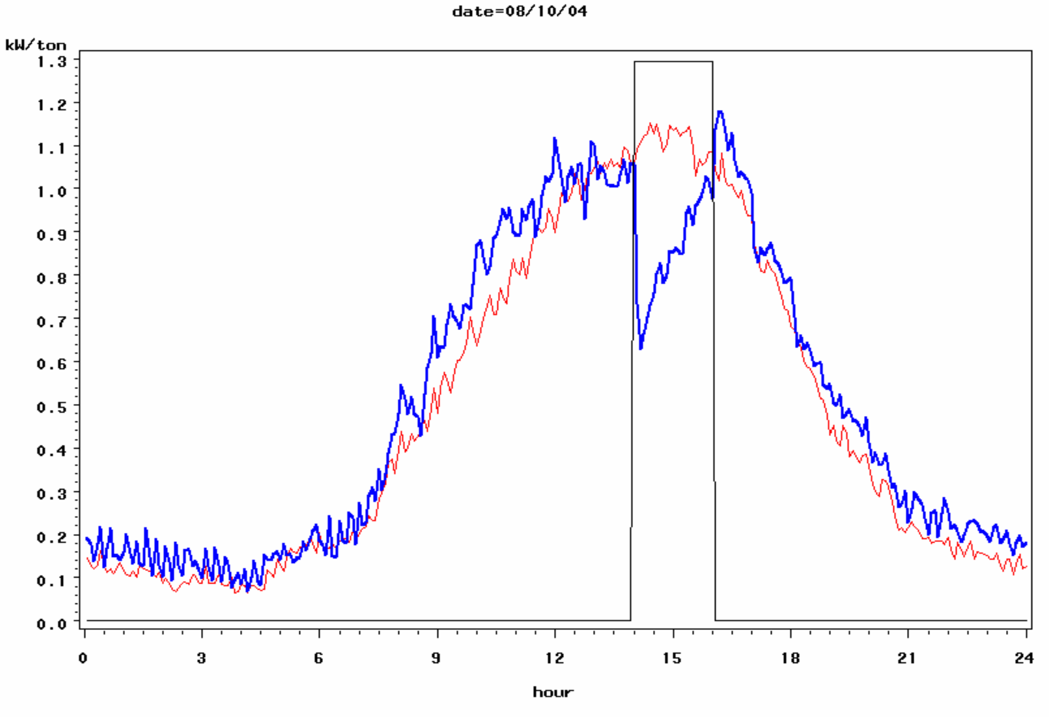

Figure 19: Estimating the Impact on August 10

Curtailment Date	8/10/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4
Curtailment Day High	94.1
Override Rate	19%
Confirmed Units	3605
Baseline Days	8/31/04, 8/11/04, 9/2/04
Baseline Days Average High	92.1
Maximum Reduction	0.48
Minimum Reduction	0.04
Energy Savings	0.51
Minutes Duration	75
kWh Savings in Hour 1	0.36
kWh Savings in Hour 2	0.15
kWh Savings in Hour 3	0.0
kWh Savings in Hour 4	0.0
Hour Following	-0.09

Figure 20: Summary Report for August 10

Event 181 - September 1, 2004

The September 1 curtailment was a 4-degree setback from 2 to 4 PM. As baseline days for September 1, we chose August 30, August 31, and September 2. The average high temperature on these days fell in a range from 90.1 to 94.4 degrees. Figure 21 shows the results graphically, and Figure 22 provides the summary report.

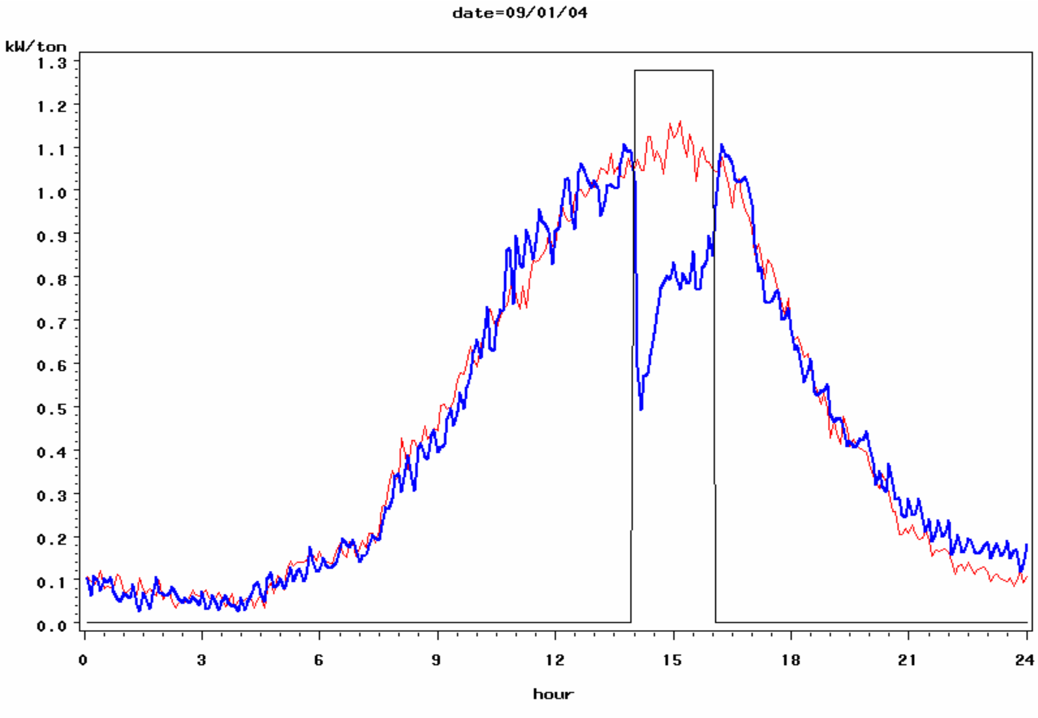

Figure 21: Estimating the Impact on September 1

Curtailment Date	9/1/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4
Curtailment Day High	93.3
Override Rate	21%
Confirmed Units	3633
Baseline Days	8/30/04, 8/31/04, 9/2/2004
Baseline Days Average High	91.9
Maximum Reduction	0.55
Minimum Reduction	0.17
Energy Savings	0.68
Minutes Duration	90
kWh Savings in Hour 1	0.40
kWh Savings in Hour 2	0.28
Hour Following	-0.03

Figure 22: Summary Report for September 1

Event 183 - September 7, 2004

The September 7 curtailment was a 4-degree setback from 2 to 4 PM. As shown in Figure 14, it was a hot 94 degrees that day. August 31, September 2, and September 9 were selected as comparison days because of their respective similar high temperatures of 93.5, 92.0, and 91.6.

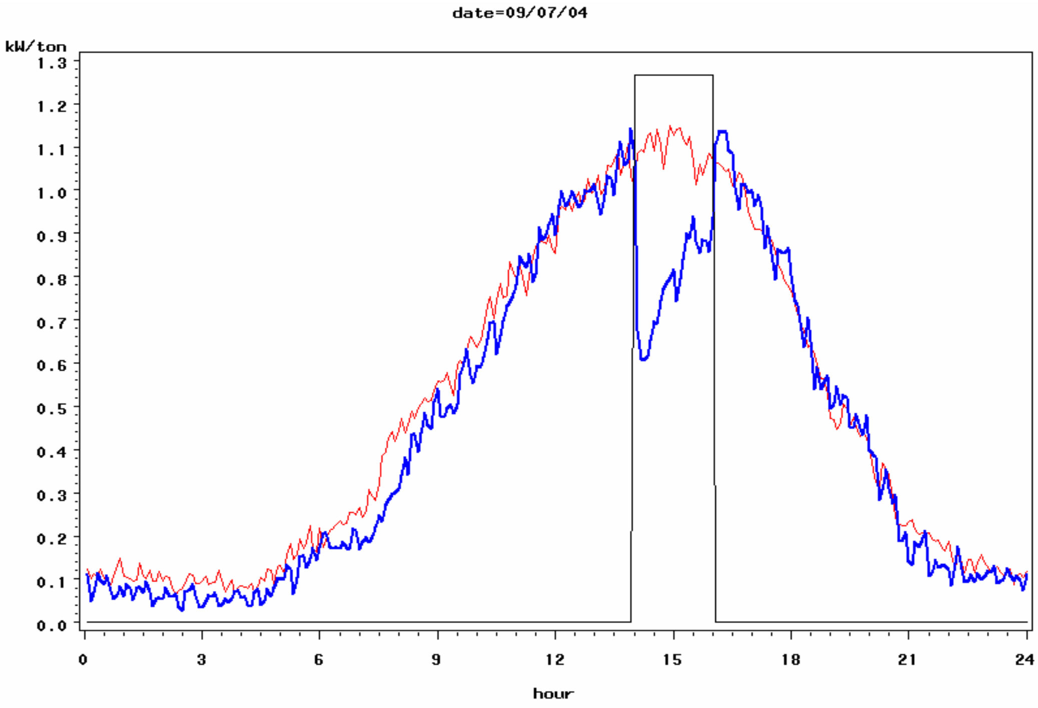

Figure 23: Estimating the Impact on September 7

Curtailment Date	9/7/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4
Curtailment Day High	94.0
Override Rate	21%
Confirmed Units	3760
Baseline Days	8/31/04, 9/2/04, 9/9/04
Baseline Days Average High	92.4
Maximum Reduction	0.51
Minimum Reduction	0.13
Energy Savings	0.62
Minutes Duration	75
kWh Savings in Hour 1	0.40
kWh Savings in Hour 2	0.22
Hour Following	-0.04

Figure 24: Summary Report for September 7

Event 187 - September 8, 2004

The September 8 curtailment was a 4-degree setback from 4:10 to 6:10 PM. The September 8 event occurred on a day with a high of 90.6 degrees. The days with comparable temperatures used as baseline for this day were August 31, September 2, and September 9, which had an average high of 92.4. The results are shown in Figure 25 and summarized in Figure 26. The maximum reduction on September 8 was 0.41 kW per ton. The estimated effective duration was 95 minutes.

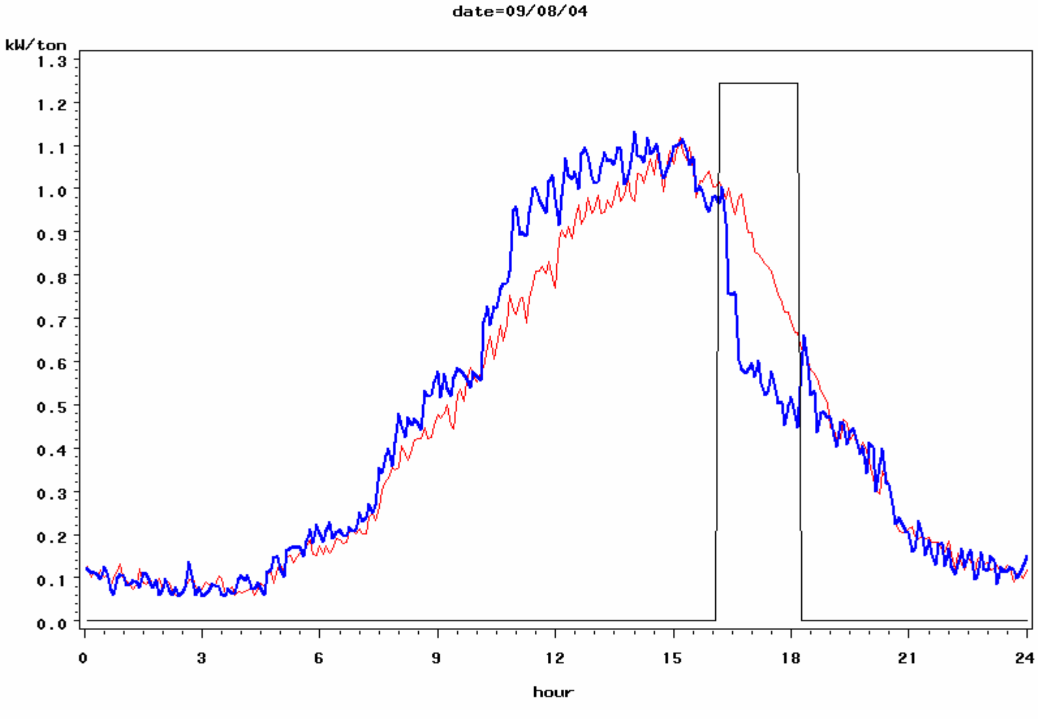

Figure 25: Estimating the Impact on Sept 8

Curtailment Date	9/8/2004
Start Time	4:10 PM
End Time	6:10 PM
Offset	4
Curtailment Day High	90.6
Override Rate	11%
Confirmed Units	3855
Baseline Days	8/31/04, 9/2/04, 9/9/04
Baseline Days Average High	92.4
Maximum Reduction	0.41
Minimum Reduction	0.00
Energy Savings	0.49
Minutes Duration	95
kWh Savings in Hour 1	0.25
kWh Savings in Hour 2	0.24
Hour Following	0.03

Figure 26: Summary Report for Sept 8

Event 191 - September 23, 2004

The September 23 curtailment was a 4-degree setback from 2 to 4 PM. The baseline for this curtailment was based on the load for the days of September 21, September 22, and September 27. As shown in Figure 14, on September 23, a Thursday, the maximum temperature was 88.6 degrees. The baseline days were chosen because of their similar average high temperature of 87.5.

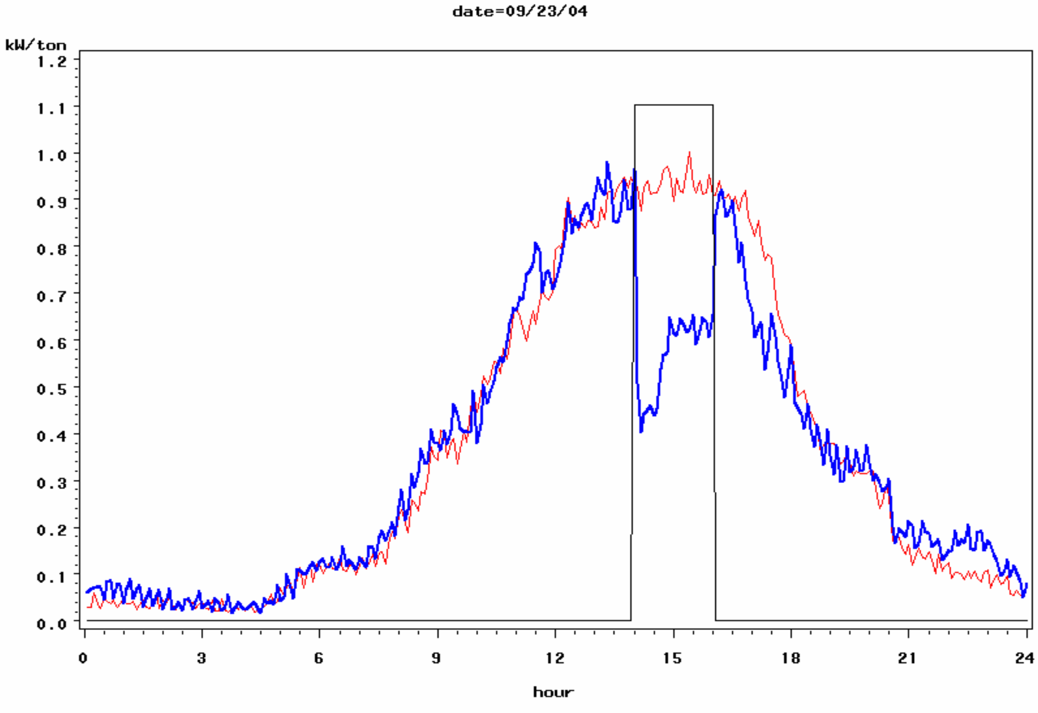

Figure 27: Impact of Curtailment on Average Load for September 23

Curtailment Date	9/23/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4
Curtailment Day High	88.6
Override Rate	20%
Confirmed Units	4222
Baseline Days	9/21/04, 9/22/04, 9/27/04
Baseline Days Average High	87.5
Maximum Reduction	0.49
Minimum Reduction	0.26
Energy Savings	0.73
Minutes Duration	120
kWh Savings in Hour 1	0.42
kWh Savings in Hour 2	0.31
Hour Following	0.08

Figure 28: Summary Report for Sep 23

Event 192 - October 7, 2004

The October 7 curtailment was a 4-degree setback from 2 to 4 PM. The baseline for the October 7 curtailment was based on the load for the days of September 27, October 6, and October 12. These days were chosen because their average high temperature was 84.9 degrees, which is the same as the high temperature on October 7.

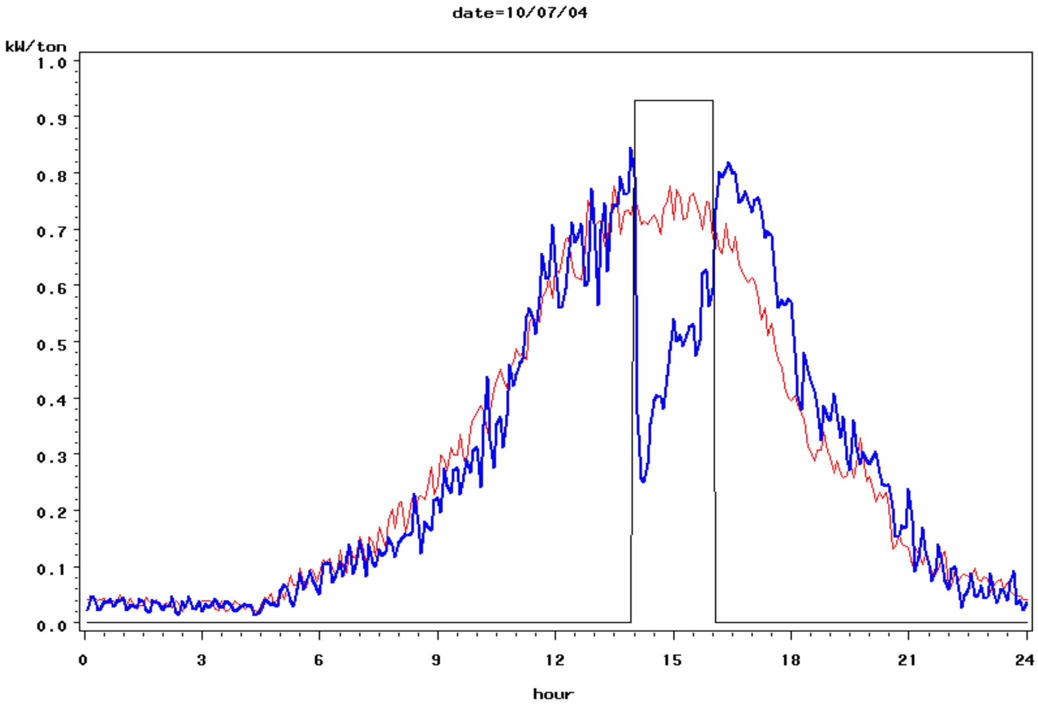

Figure 29: Impact of Curtailment on Average Load for Oct 7 Event

Curtailment Date	10/7/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4
Curtailment Day High	84.0
Override Rate	20%
Confirmed Units	4804
Baseline Days	9/27/04, 10/6/04, 10/12/04
Baseline Days Average High	84.9
Maximum Reduction	0.47
Minimum Reduction	0.08
Energy Savings	0.54
Minutes Duration	70
kWh Savings in Hour 1	0.35
kWh Savings in Hour 2	0.20
Hour Following	-0.12

Figure 30: Summary Report for Oct 7

Event 193 - October 14, 2004

There were two separate curtailment events called on October 14. The first was a 4-degree setback from 2 to 4 PM and the second was a 4-degree setback from 4 to 6 PM. The baseline for the October 14 curtailment was based on the averaged load on September 21, September 22, and October 12. These days were chosen because they were weekdays with an average high temperature of 87.6 degrees.

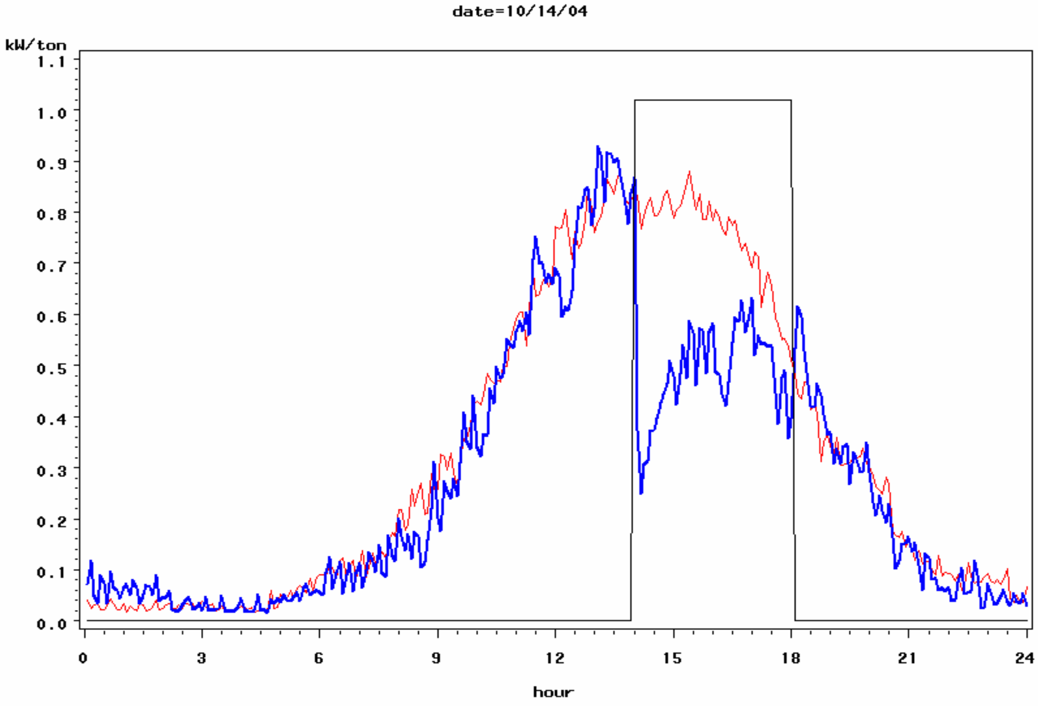

Figure 31: Impact of Curtailment on Average Load for Oct 14 Event

Curtailment Date	10/14/2004
Start Time	2:00 PM
End Time	6:00 PM
Offset	4
Curtailment Day High	87.7
Override Rate	19%
Confirmed Units	3628
Baseline Days	9/21/04, 9/22/04, 10/12/04
Baseline Days Average High	87.6
Maximum Reduction	0.52
Minimum Reduction	0.06
Energy Savings	1.07
Minutes Duration	130
kWh Savings in Hour 1	0.42
kWh Savings in Hour 2	0.29
kWh Savings in Hour 3	0.22
kWh Savings in Hour 4	0.13
Hour Following	-0.06

Figure 32: Summary Report for Oct 14

3.5 Summary of All Eight Curtailment Days with End Use Meter Data and Program Impact Estimate

Figure 33 provides the information from the summary reports for each of these eight curtailment events. Although these events differed in some respects, we believe they can be analyzed as a group.

We will start by noting the average characteristics of the eight curtailments shown in Figure 33. Based on a simple numerical average, the ‘typical’ event can be described as follows:

- The maximum reduction was 0.49 kW per ton,
- The savings in the first hour was 0.33 kWh per ton,
- The savings in the second hour was 0.22 kWh per ton,
- The effective duration was 86 minutes, measured as the ‘half-life’ of the savings,
- There was little or no snapback following the curtailment period.

Based on these results from the end use meter data sample, we can estimate the total program-wide impact of a 4-degree curtailment. In Figure 16 we estimated that the 4,700 participating units have a total size of 19,701 tons. As discussed previously, after discounting for 7% non-responsive thermostats (deadbeats), we estimated that the total controlled tonnage was 18,322 tons. Using this information together with the preceding results, we can estimate the total program impact as shown in Figure 34.

Curtailment Date	8/9/2004	8/10/2004	9/1/2004	9/7/2004	9/8/2004	9/23/2004	10/7/2004	10/14/2004
Start Time	3:00 PM	2:00 PM	2:00 PM	2:00 PM	4:10 PM	2:00 PM	2:00 PM	2:00 PM
End Time	5:00 PM	4:00 PM	4:00 PM	4:00 PM	6:10 PM	4:00 PM	4:00 PM	6:00 PM
Offset	4	4	4	4	4	4	4	4
Curtailment Day High	92.2	94.1	93.3	94.0	90.6	88.6	84.0	87.7
Override Rate	19%	19%	21%	21%	11%	20%	20%	19%
Confirmed Units	3487	3605	3633	3760	3855	4222	4804	3628
Baseline Days	8/11/04, 8/31/04, 9/2/04	8/31/04, 8/11/04, 9/2/04	8/30/04, 8/31/04, 9/2/2004	8/31/04, 9/2/04, 9/9/04	8/31/04, 9/2/04, 9/9/04	9/21/04, 9/22/04, 9/27/04	9/27/04, 10/6/04, 10/12/04	9/21/04, 9/22/04, 10/12/04
Baseline Days Average High	92.1	92.1	91.9	92.4	92.4	87.5	84.9	87.6
Maximum Reduction	0.50	0.48	0.55	0.51	0.41	0.49	0.47	0.52
Minimum Reduction	0.13	0.04	0.17	0.13	0.00	0.26	0.08	0.06
Energy Savings	0.59	0.51	0.68	0.62	0.49	0.73	0.54	1.07
Minutes Duration	75	75	90	75	95	120	70	130
kWh Savings in Hour 1	0.38	0.36	0.40	0.40	0.25	0.42	0.35	0.42
kWh Savings in Hour 2	0.22	0.15	0.28	0.22	0.24	0.31	0.20	0.29
Hour Following	0.00	-0.09	-0.03	-0.04	0.03	0.08	-0.12	-0.06

Figure 33: Summary of 4-Degree Curtailments

	Per Sample Ton	***Program Total***
Maximum kW Reduction	0.49	8,974
kWh Savings in Hour 1	0.33	6,021
kWh Savings in Hour 2	0.21	3,932

Figure 34: Estimated Program-Wide Impact from the End Use Metering Results

From this analysis which developed a kW per ton estimate of the demand reduction for the AB970 pilot, we can now extrapolate to the AB970 population. We estimate that among all 4,723 participating units during the summer of 2004, a 4-degree, two-hour curtailment will yield on average a maximum initial kW reduction of approximately 9.0 MW, first hour energy savings of about 6.0 MWh, and second hour energy savings of about 3.9 MWh.

3.6 Precision

Figure 35 again shows the estimates of the kWh savings for each curtailment event measured in kWh per ton of controlled air conditioning that were presented in Figure 33. The last row of Figure 35 shows the average results across the curtailments. Considering all eight curtailments taken together, the savings were 0.329 kWh per ton in the first hour and 0.215 kWh per ton in the second hour, for a total savings of 0.543 kWh per ton in the first two hours of the curtailment. The average value of the maximum impact across the eight curtailments was 0.49 kW per ton. In calculating the average duration, we have excluded the one 4-hour curtailment (event 193). Among the seven 2-hour curtailments the average duration was 86 minutes. In the hour following the curtailment, the average snapback was 0.023 kWh per ton.

		Savings in Hour				Total	Maximum	Minutes	Hour
Date	Event	1	2	3	4	Savings	Impact	Duration	Folowing
8/9/04	171	0.376	0.215	na	na	0.591	0.50	75	0.001
8/10/04	174	0.361	0.152	na	na	0.513	0.48	75	-0.086
9/1/04	181	0.405	0.278	na	na	0.683	0.55	90	-0.035
9/7/04	183	0.405	0.220	na	na	0.624	0.51	75	-0.036
9/8/04	187	0.249	0.242	na	na	0.491	0.41	95	0.032
9/23/04	191	0.420	0.307	na	na	0.727	0.49	120	0.078
10/7/04	192	0.346	0.199	na	na	0.545	0.47	70	-0.120
10/14/04	193	0.418	0.295	0.221	0.131	1.065	0.52	130	-0.059
Average, all Events		0.329	0.215	na	na	0.543	0.49	86	-0.023

Figure 35: Measures of Impact from End Use Metering

Figure 36 shows the relative precision of the kWh savings reported in Figure 35, calculated at the 90% level of confidence. For example, the first-hour savings of all eight curtailments taken together had a relative precision of ± 21% at the 90% level of confidence. So the 90% confidence interval for the first-hour savings of all eight curtailments taken together can be calculated as 0.329 ± (0.21)(0.329), or 0.329 ± 0.069 kWh per ton. Similarly, the 90% confidence interval for the total savings over the two hours of the curtailment period is 0.543 ± 0.147 kWh per ton.

		Relative Precision in Hour				Total Savings
Event	Date	1	2	3	4	
171	8/9/04	0.28	0.35	0.00	0.00	0.28
174	8/10/04	0.31	0.63	0.00	0.00	0.36
181	9/1/04	0.26	0.33	0.00	0.00	0.26
183	9/7/04	0.30	0.47	0.00	0.00	0.33
187	9/8/04	0.30	0.36	0.00	0.00	0.30
191	9/23/04	0.25	0.36	0.00	0.00	0.26
192	10/7/04	0.31	0.46	0.00	0.00	0.33
193	10/14/04	0.32	0.33	0.33	na	0.31
Average, all Events		0.21	0.27	0.34	na	0.22

Figure 36: Relative Precision of Savings from End Use Metering

Figure 37 shows the error ratios associated with the kWh savings. The error ratios are a measure of site to site variability for stratified ratio estimation, and can be used to help plan the sample sizes for future studies. Considering the average savings of all events, the error ratio was found to be 1.2 for the first-hour savings, and 1.5 for the second-hour savings. The increase in the error ratio from the first hour to the second hour suggests greater variability in the savings in the second hour compared to the first hour, reflecting site to site differences in the persistence of the savings. The error ratio was 1.2 for the total savings in the two hours of the curtailment.

The error ratios for the average of all events are always smaller than the error ratios for the individual events. This reflects the reduction in site to site variation in the average savings of each site across several events compared to the site to site variation in the savings of the individual events. However, the reduction in the error ratio from averaging eight events is less than would be the case if the savings were statistically independent from event to event within a given site. Thus the variability is more strongly affected by the number of sites in the sample than by the number of curtailments per sample site.

		Error Ratio in Hour				Total Savings
Event	Date	1	2	3	4	
171	8/9/04	1.4	1.8	0.0	0.0	1.4
174	8/10/04	1.5	3.2	0.0	0.0	1.8
181	9/1/04	1.2	1.6	0.0	0.0	1.2
183	9/7/04	1.4	2.3	0.0	0.0	1.6
187	9/8/04	1.5	1.8	0.0	0.0	1.5
191	9/23/04	1.1	1.5	0.0	0.0	1.2
192	10/7/04	1.6	2.1	0.0	0.0	1.6
193	10/14/04	1.4	1.4	1.4	na	1.4
Average, all Events		1.2	1.5	0.0	na	1.2

Figure 37: Error Ratio of Savings from End Use Metering

We will now take a more detailed look at the eight events. We will explore the following questions:

- Is there a time trend in the kW and kWh impacts or override rate?
- Were overrides more common on hot days than relatively cooler days?

- Was the maximum kW reduction related to the override rate?
- Was the maximum kW reduction greater on hot days than relatively cooler days?
- Was the first-hour kWh savings greater on hot days than relatively cooler days?
- Was the effective duration of the savings greater on hot days than relatively cooler days?

We start by looking for a time trend. Our purpose is to look for changes that might be happening over time. However, we must be cautious about interpreting the following graphs since many characteristics of the curtailment event are different from one day to another.

Figure 38 shows the maximum kW reduction plotted by the date of curtailment. There is little or no trend in the maximum kW reduction.

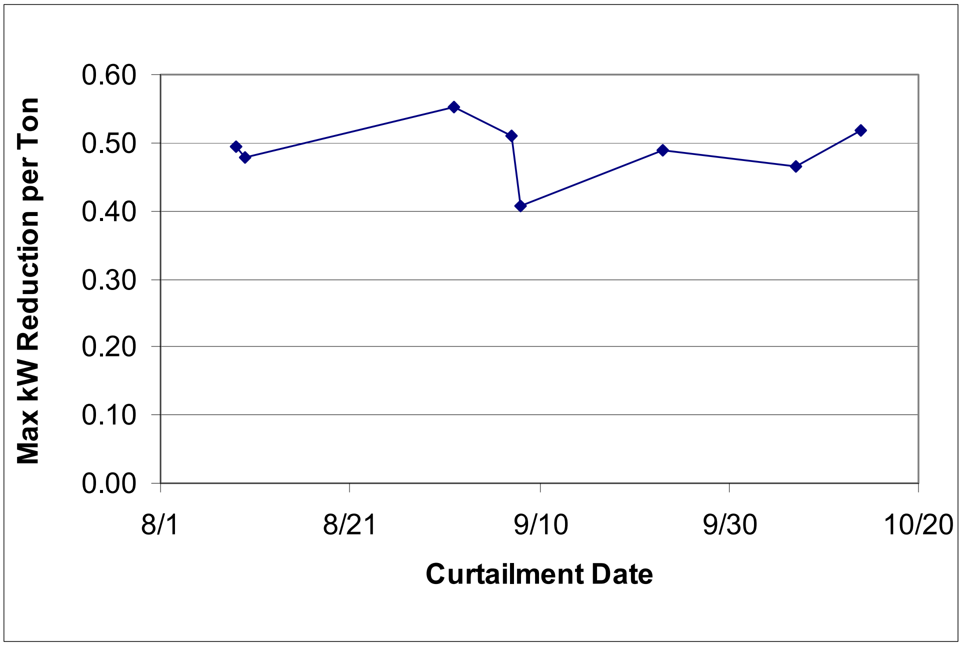

Figure 38: Maximum kW Reduction by Date of Curtailment

Figure 39 shows the savings in the first hour of the curtailment, plotted by the date of curtailment. There does not appear to be a trend in the first hour savings.

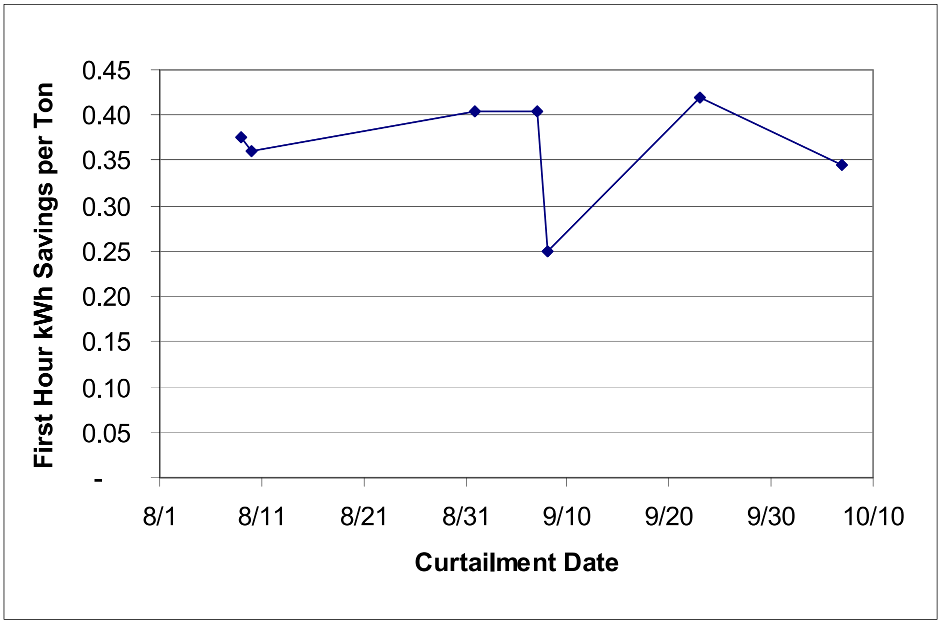

Figure 39: First Hour kWh Savings by Date of Curtailment

Figure 40 shows the override rate plotted by the date of curtailment. The graph shows that the average override rate hovers at approximately 20% with the exception of the curtailment event on September 8 where the override rate dropped to 11%. This anomaly has not been explained, but the fact that this event was the only one of the series that started at 4pm (others started at 2pm) may be part of the cause.

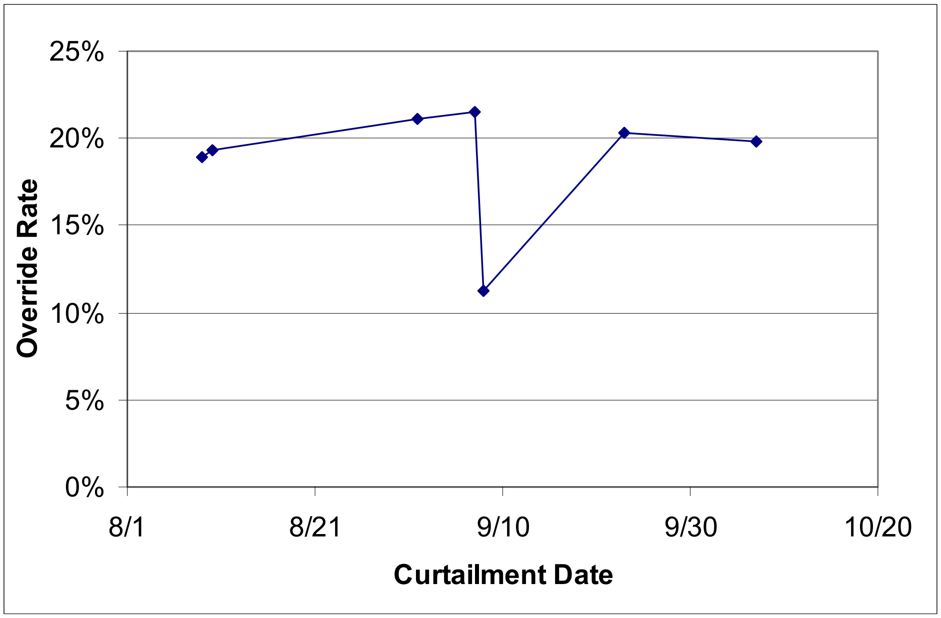

Figure 40: Override Rate by Date of Curtailment

Figure 41 shows a scatter plot relating the override rate of the 4-degree curtailments to the high temperature on the day of the curtailment. The graph shows that the override rate averages at 20% while slightly increasing with the increased temperature. Our expectation was the override rates would significantly increase when the temperatures increased. However, the scatter plot does not lend support to this assumption. Neglecting the September 8th event which started at a later time, the plot suggests override rates do not increase due to higher temperatures.

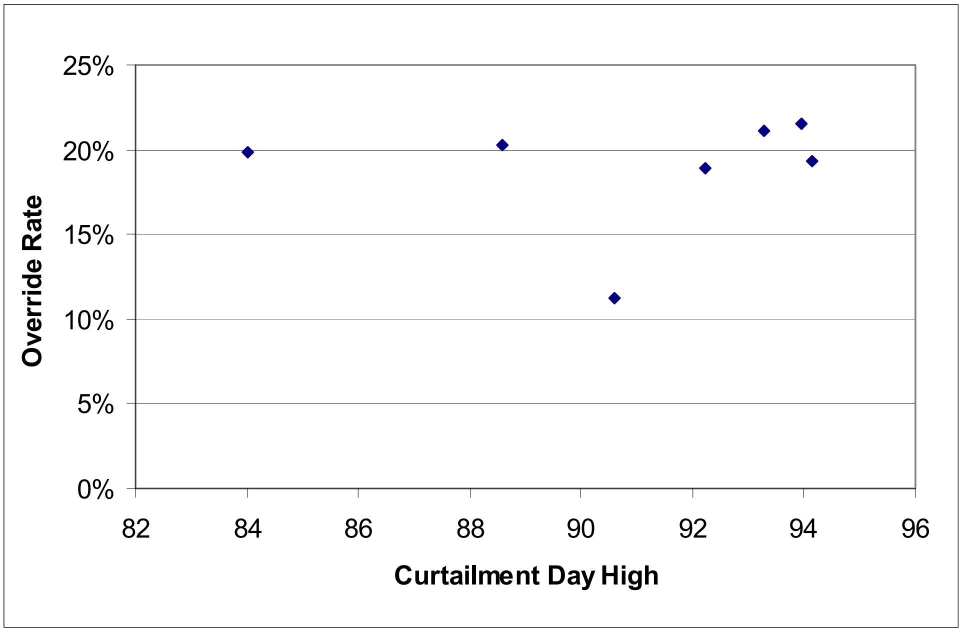

Figure 41: Override Rate vs. High Temperature on Curtailment Day

Figure 42 shows a scatter plot relating the maximum kW reduction per ton to the override rate. Since the override rates did not vary significantly (except for the one 4-hour event), Figure 42 does not show any significant relationship between the override rate and maximum kW reduction.

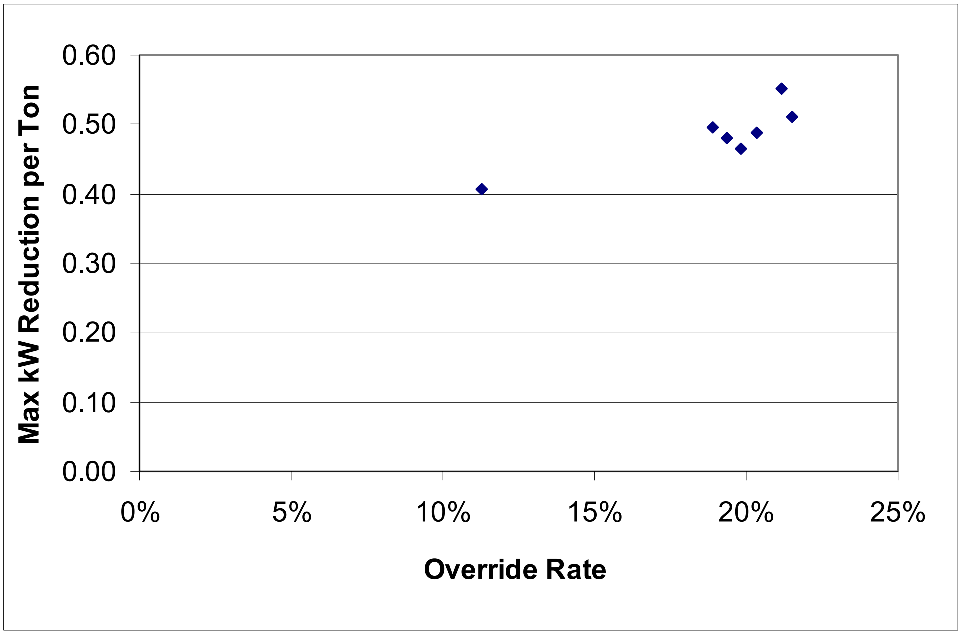

Figure 42: Maximum kW Reduction per Ton vs. Override Rate

Figure 43 shows a scatter plot relating the effective duration to the override rate. Recall that the effective duration was defined to be the number of minutes during the curtailment period in which the estimated load reduction was at least one half of the maximum reduction. Our expectation was that the effective duration would be shorter when the override rate was higher. Again, there is a lack of range of overrides to substantiate a significant relationship.

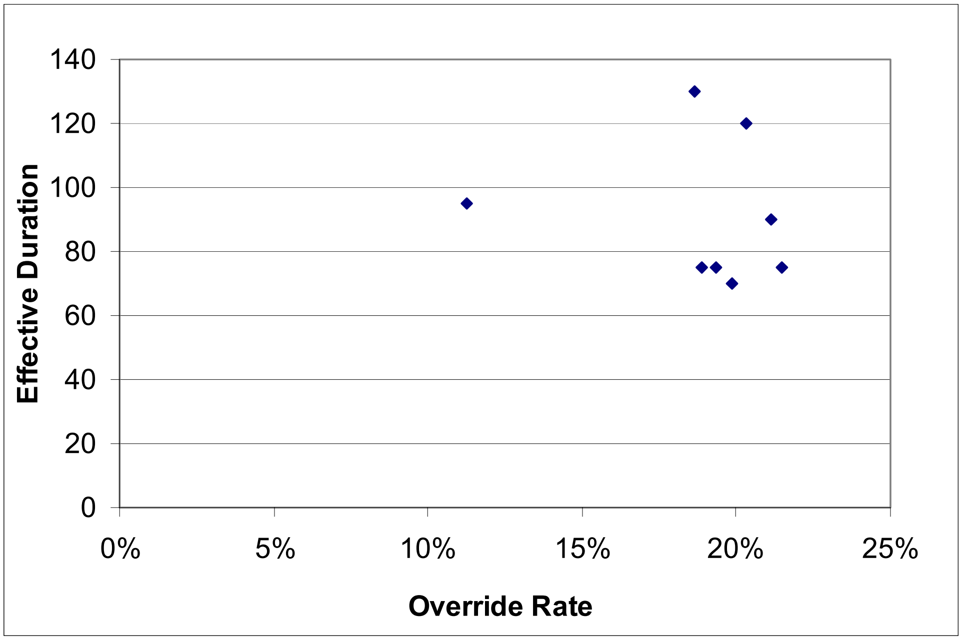

Figure 43: Effective Duration vs. Override Rate

Figure 44 shows a scatter plot relating the maximum kW reduction per ton to the high temperature on the day of the curtailment. Our expectation was that the maximum kW reduction would be greater on the hotter days. However, Figure 44 does not show any significant relationship between the maximum kW reduction and the high temperature on the day of the curtailment. We also looked at the first hour kWh savings and did not see a relationship between the first hour kWh savings and the high temperature on the day of the curtailment.

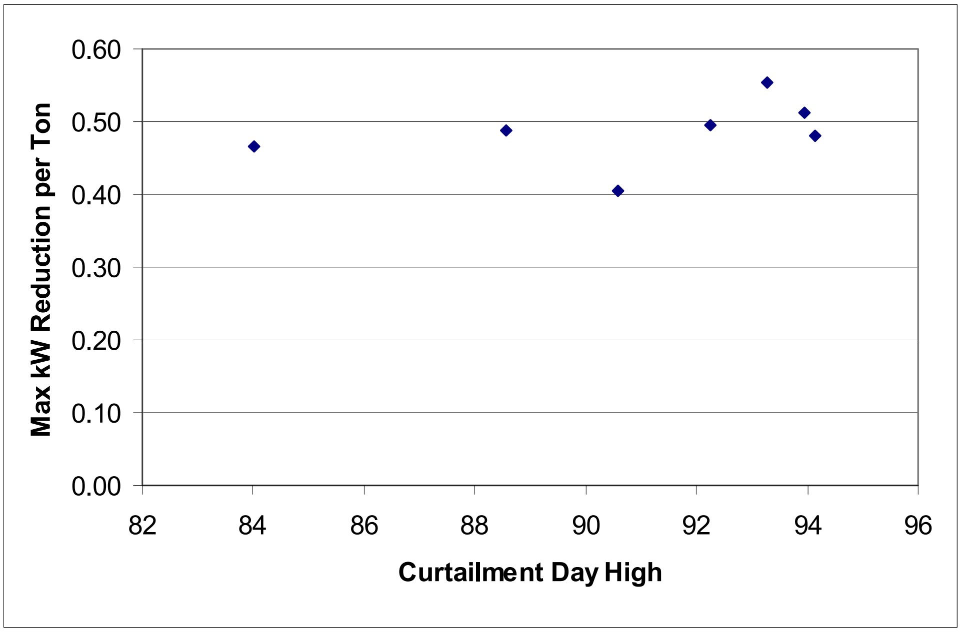

Figure 44: Maximum kW Reduction vs. Curtailment-Day High Temperature

Figure 45 shows a scatter plot relating the effective duration of the curtailment to the high temperature on the day of the curtailment. Our expectation was that the effective duration would be shorter on hotter days. Figure 45 does not lend support to this assumption for the entire duration of the curtailment.

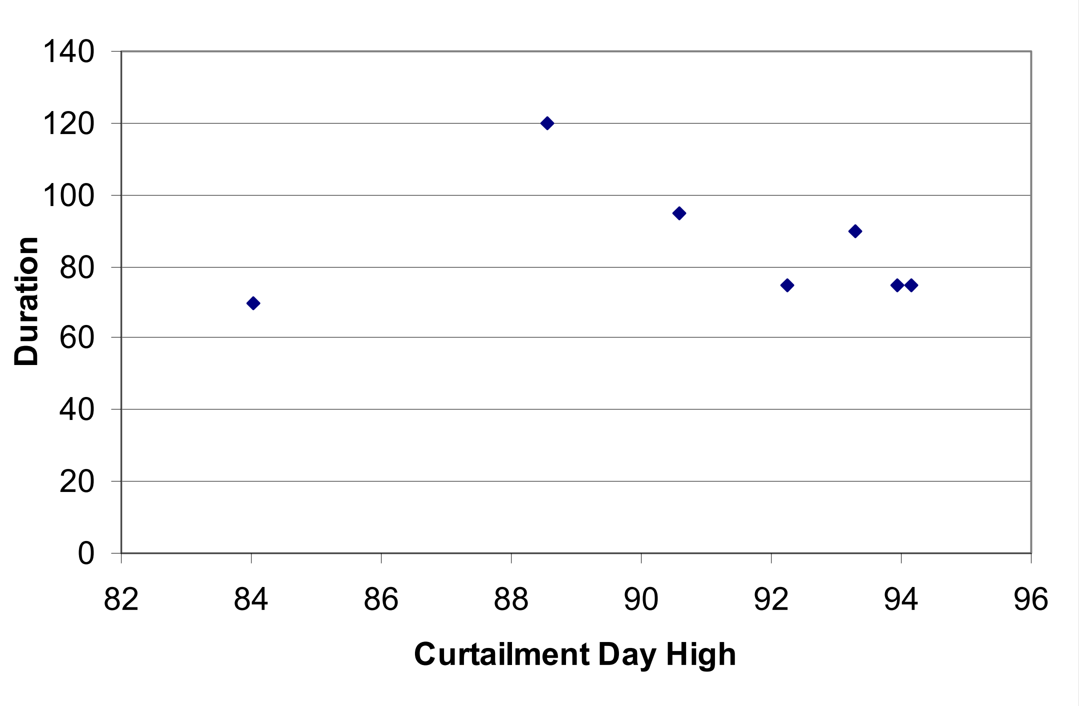

Figure 45: Effective Duration vs. High Temperature on Curtailment Day

4 Analysis of the Whole Premise Meter Data

This section summarizes the results from our analysis of five-minute metered load data collected at the whole-premise level for a sample of sites[6]. Our goal is to assess the impact of each curtailment on the total energy and demand of the sites participating in the program. We regard these results to be the net impact after factoring in any interactions with other loads at the sites.

For example, if a site has auxiliary electrical equipment in addition to the curtailed HVAC unit, the auxiliary equipment might either add or subtract from the load of the curtailed unit thereby increasing or reducing the net impact. Although unlikely in the present program, other loads such as lighting might be curtailed at the site in addition to the directly controlled HVAC units. The whole-premise analysis would reveal any added savings due to secondary curtailments.

4.1 Methodology

In the research plan developed to support the 2003 analysis, a whole-premise metering sample was selected using a sample design that was stratified by the cooling capacity of controlled HVAC units at each site in the program. This sample design did not work as desired since there were a few sample sites with a small amount of cooling but with very large whole-premise loads. These sites were given large case weights under the sample design. When the large whole-premise loads were combined with the large case weights, these small sites dominated the remaining sample sites so that the results were statistically unreliable.

To remedy the problem, in the spring of 2004 we developed a new sample design for the whole-premise metering based on stratification by total annual energy consumption. To develop the sample design, we used billing data to calculate the annual kWh use for each of the 2,370 customer sites in the tracking system at the time (representing over 4,600 thermostats). Then we categorized the whole-premise metered sites into the strata and supplemented the sample as necessary. This increased the whole-premise metered sample to 145 sites divided among five strata based on the annual kWh consumption of each site. See Figure 46.

Stratum	***Max kWh***	***Population***	***Sample***	***Weight***
1	31,233	1,246	35	35.6
2	66,896	519	23	22.6
3	115,050	313	30	10.4
4	229,303	193	27	7.1
5	1,058,760	99	30	3.3
Total		2,370	145	

Figure 46: Sample Design for Whole Premise Meter Sample

For example, stratum 1 consisted of all sites with annual use up to 31,233 kWh and our sampling frame contained 1,246 E$T sites in this stratum. Our augmented whole-premise metered sample contained 35 such sites. We calculated a case weight for each

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[6] The metered data was collected from a parallel meter installed by MeterSmart contractors via phone line – the existing SCE meter at the site was not removed or replaced.

of these sites as the number in the population divided by the number in the sample, in this case, 1,246 / 36 = 35.6.

For each sample site and each curtailment event, we calculated the impact of the curtailment from the whole-premise metered data using the same technique as we used to analyze the end use metered data, reported in the previous section. We calculated the average 5-minute load profile of the site on the three baseline days, trued-up the profile to have the same consumption as the site's load profile on the curtailment day, and then calculated the difference between the trued-up baseline load and the actual load on the curtailment day. We used this difference to calculate the following statistics for each sample site:

- ☐ Total energy savings during the curtailment,
- ☐ Savings during each individual hour of the curtailment,
- ☐ Snapback during the hour following the curtailment,

Then case weights and the site-specific savings were used to extrapolate the results to the population. We used stratified ratio estimation, with the y-variable taken to be the measure of savings and the x-variable to be the cooling tonnage of the controlled HVAC units at each sample site. These results gave us an estimate of the average savings per ton for all sites in the program, together with the statistical precision of the estimates, and the error ratios to be used for planning future studies.

In addition we extrapolated the 5-minute load profiles and trued-up baselines themselves in order to get the average savings per ton in each 5-minute interval during the curtailment period. We used the resulting savings profile to estimate the maximum impact and the duration of the impact.

4.2 Findings

This section summarizes the findings from the analysis of the whole-premise metered sample. Figure 47 through Figure 54 show graphs of the estimated program-wide impact of each of the curtailments, estimated from the whole-premise metered data. The vertical axis shows the load of the participating sites, measured in kW per ton of controlled cooling. The vertical lines indicate the curtailment period, from hour 15 (3 pm) to hour 17 (5 pm) in the case of Figure 47. The heavy blue line is the actual load profile on the curtailment day, and the light red line is the baseline profile, i.e., the trued-up average load profile on the three selected comparison days. The difference between the blue and red lines during the curtailment is our estimate of the impact of the curtailment, based on the extrapolation to the program participants using the results for all 145 sites in the whole-premise metered sample.

Figure 47 to Figure 50 are remarkably similar. In each of these curtailments, the graph shows that the load dropped almost immediately but slowly recovered over the two-hour period of the curtailment. On these days, there was no noticeable snapback following the curtailment.

Figure 51 looks somewhat different. This curtailment started later in the afternoon, after the load had started to fall. The initial impact was smaller but the impact did not seem to decrease as rapidly. Figure 52 and Figure 53 were also somewhat different. In the case of Figure 52, the savings seemed to persist more strongly than usual. In the case of Figure 53, there seem to be some snapback following the curtailment period.

Finally, Figure 54 shows the one four-hour curtailment. Recall that in this case the initial curtailment was for two hours, followed immediately by a second call for another two-hour curtailment. The graph indicates that there was a moderate drop in load half way into the four-hour period. This probably reflects the effect of re-curtailing some of the units that overrode the initial curtailment.

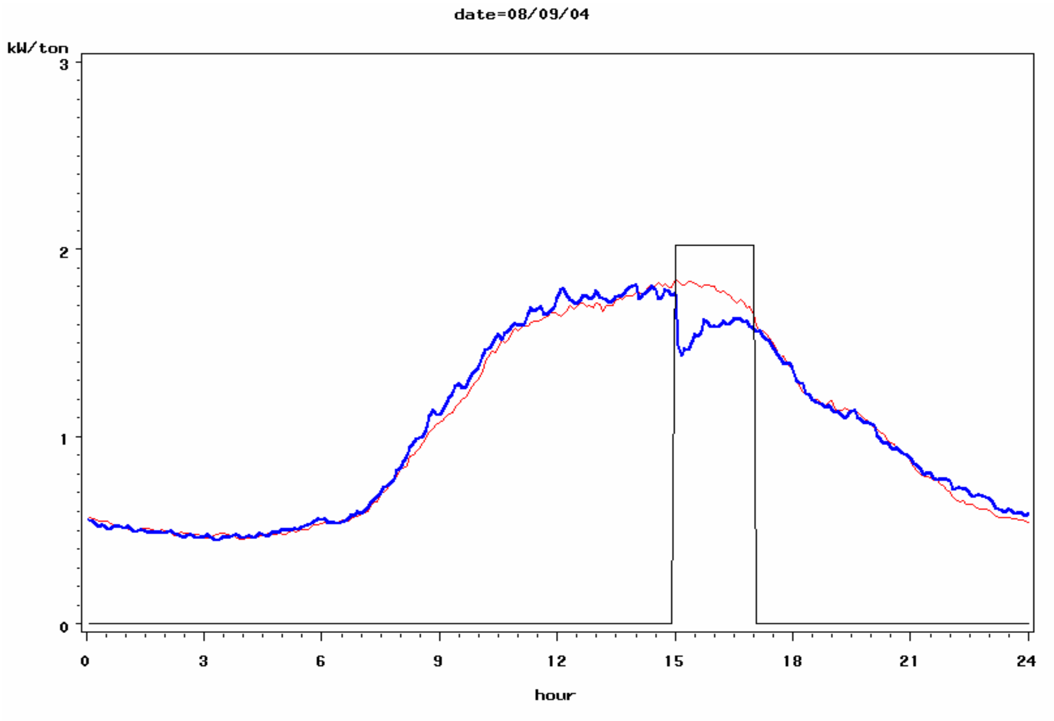

Figure 47: Impact of the Curtailment on August 9

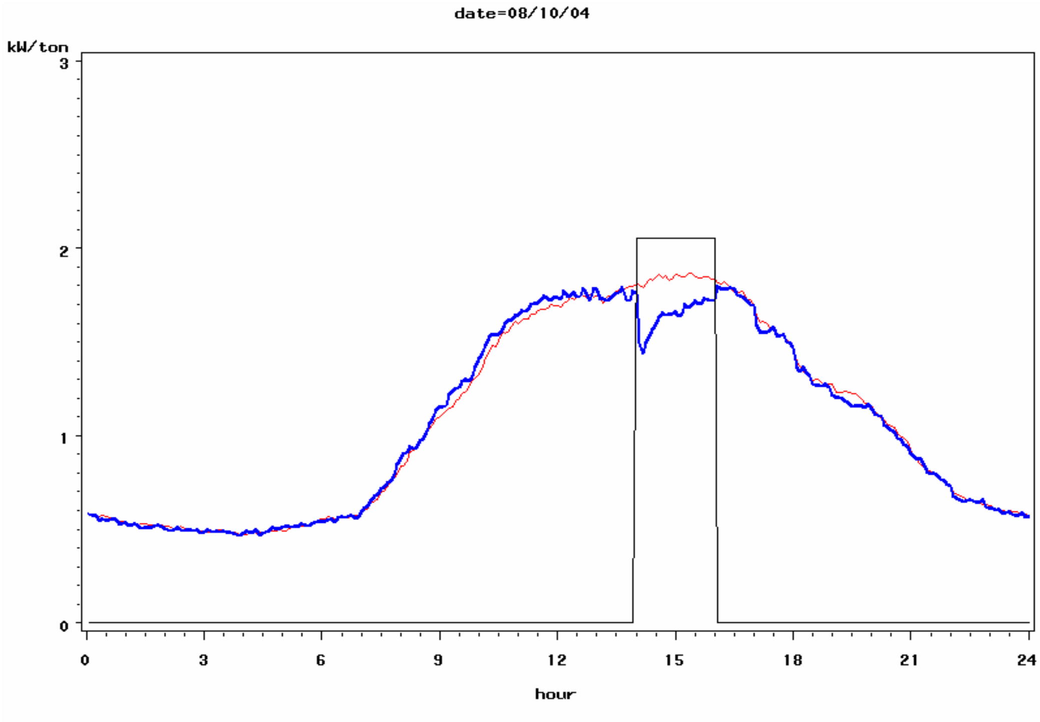

Figure 48: Impact of the Curtailment on August 10

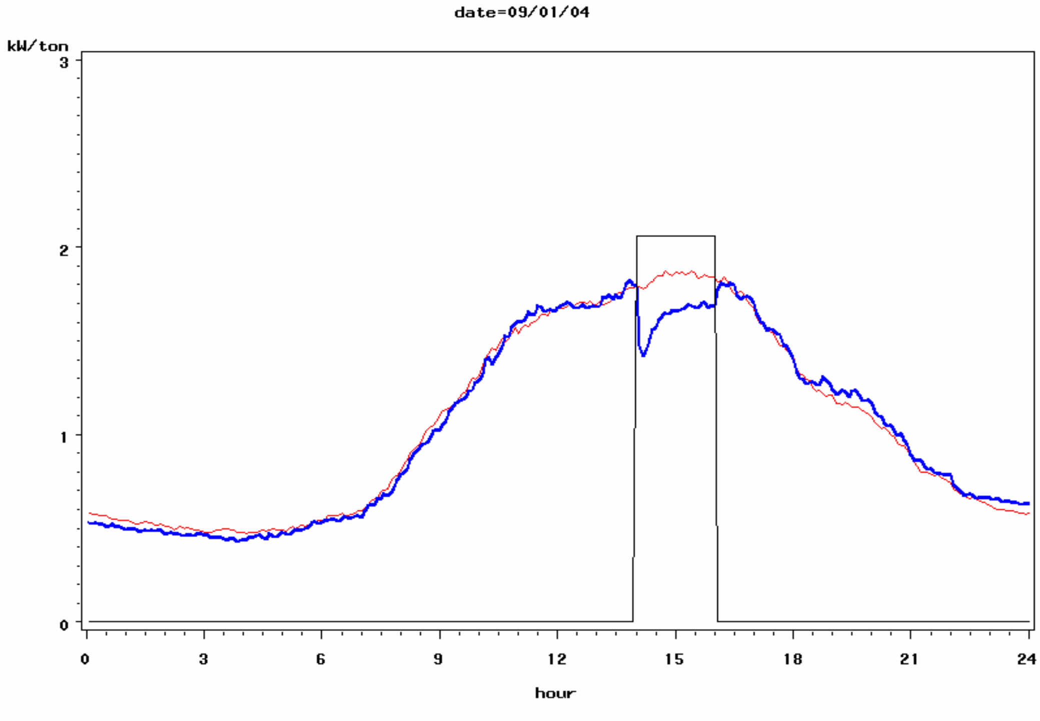

Figure 49: Impact of the Curtailment on September 1

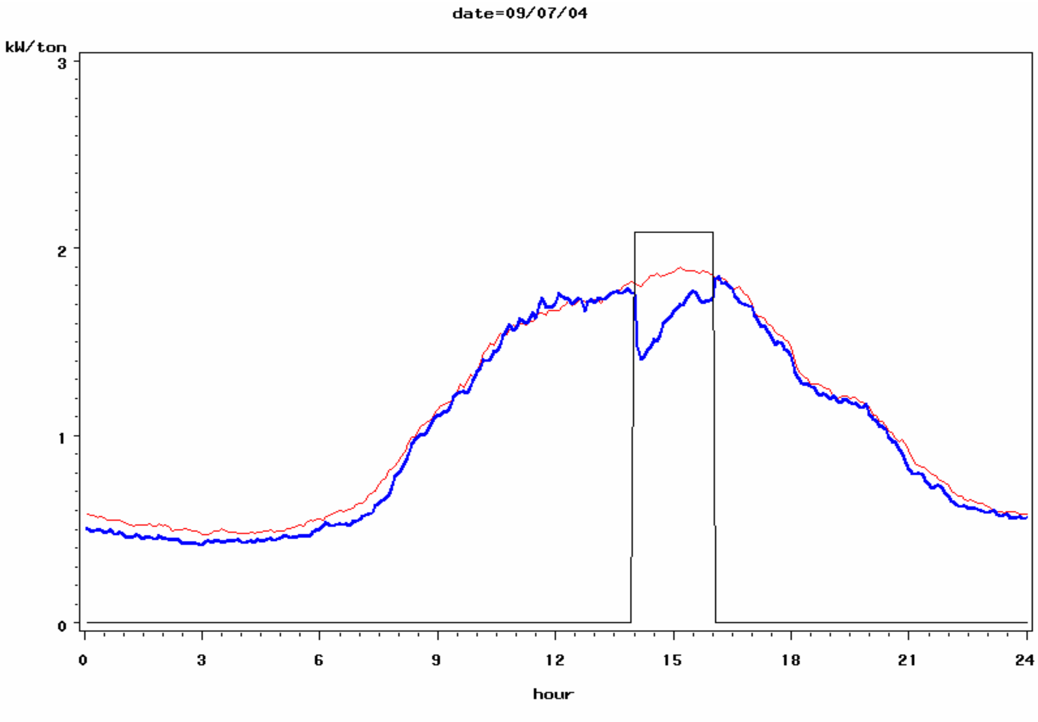

Figure 50: Impact of the Curtailment on September 7

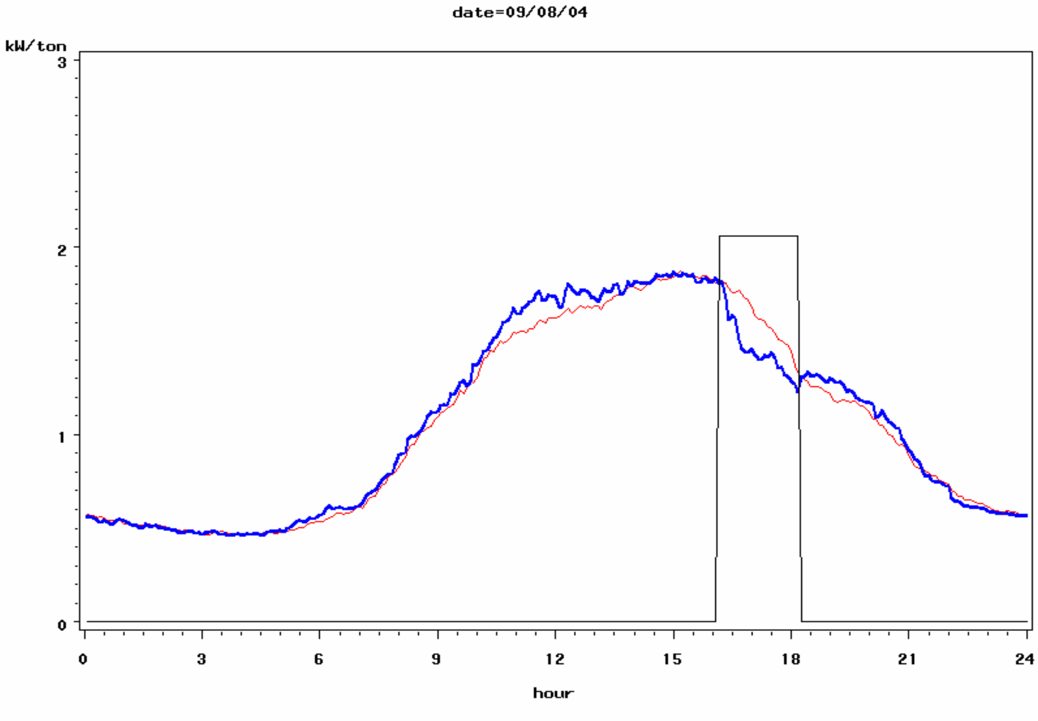

Figure 51: Impact of the Curtailment on September 8

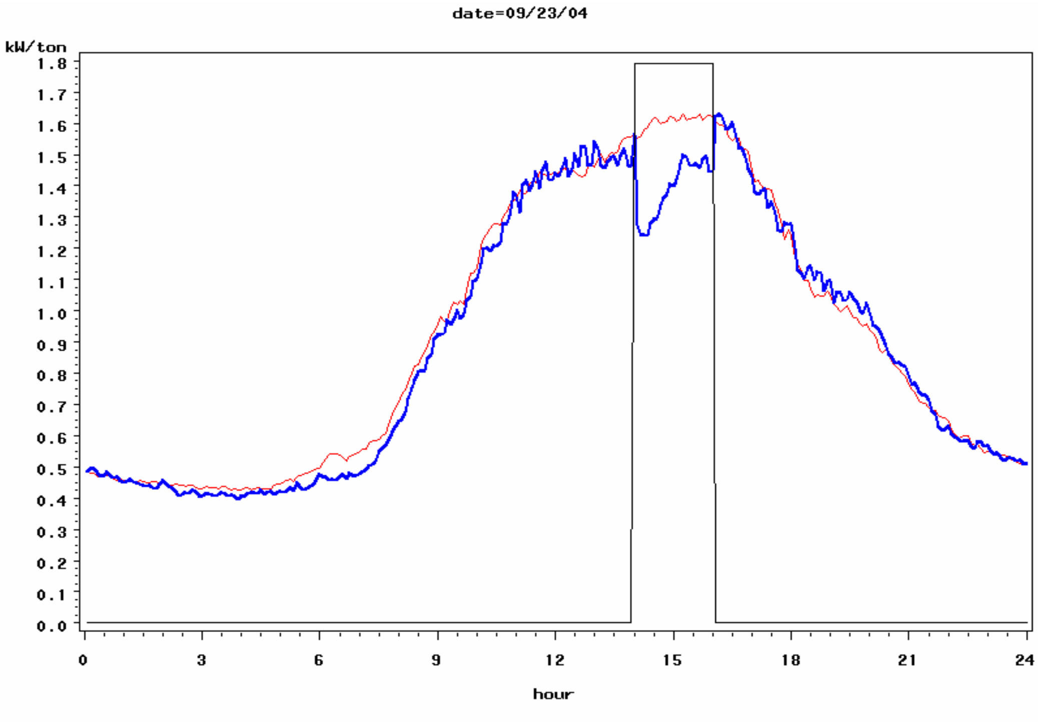

Figure 52: Impact of the Curtailment on September 23

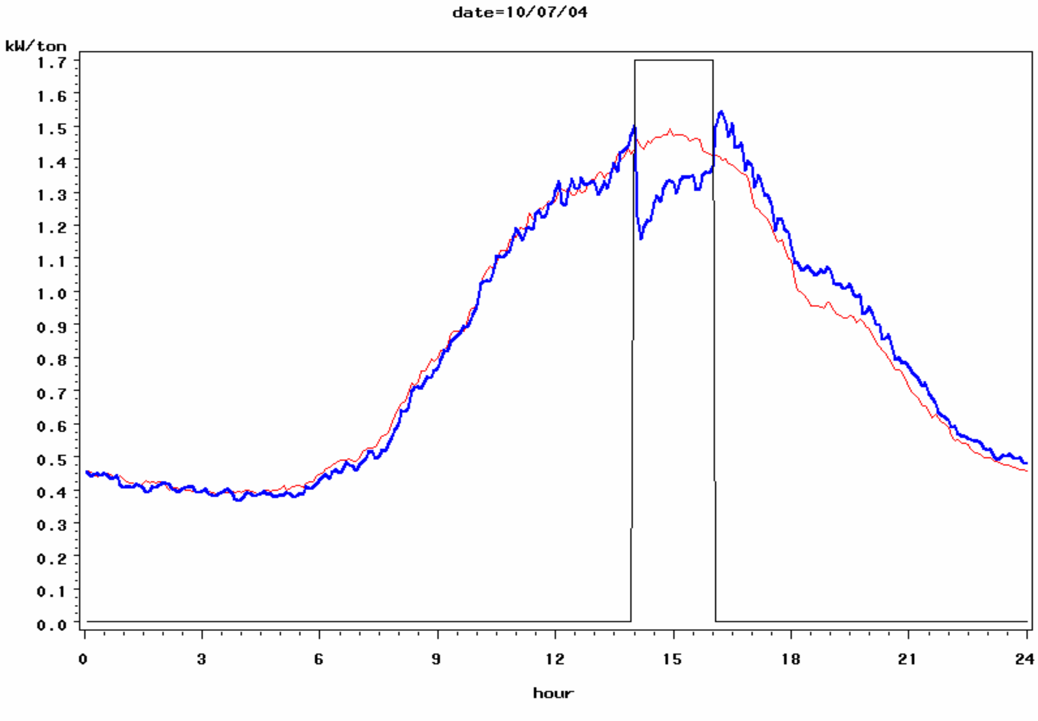

Figure 53: Impact of the Curtailment on October 7

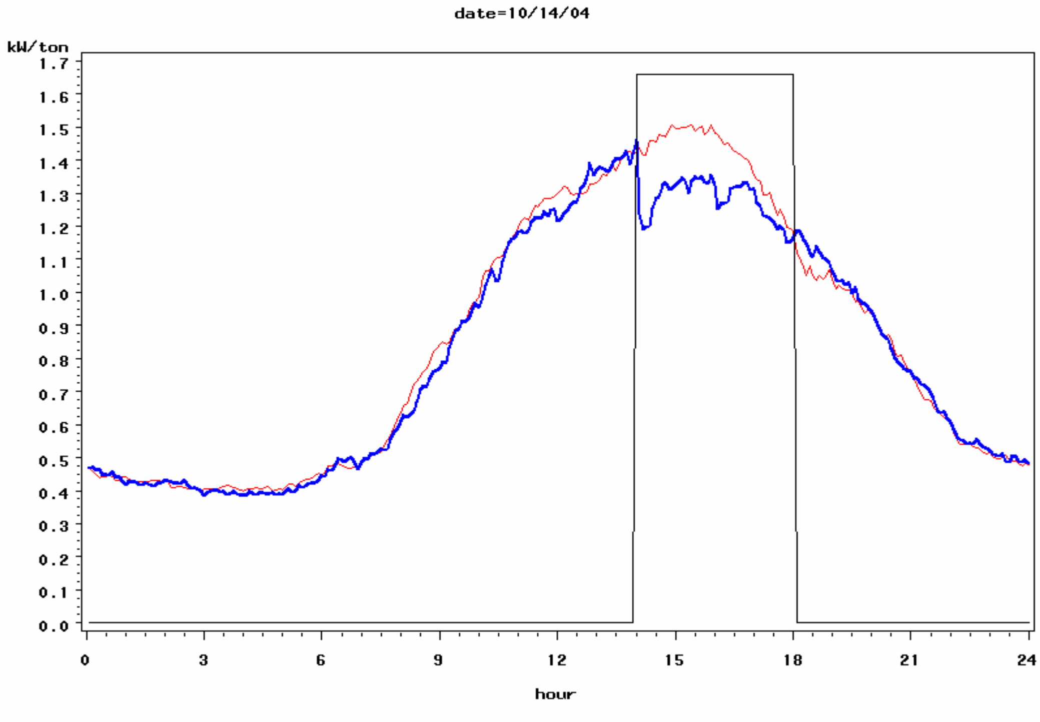

Figure 54: Impact of the Curtailment on October 14

Figure 55 shows the estimates of the kWh savings for each curtailment event. The results are measured in kWh per ton of controlled cooling capacity. For example, Event 171 on August 9, 2004 yielded an estimated savings of 0.28 kWh per ton in the first hour of the curtailment, 0.12 kWh per ton in the second hour of the curtailment, for a total savings of 0.40 kWh per ton in the two hours combined.

The next column shows the maximum impact in any five-minute period, measured in kW per ton. The column labeled 'Minutes Duration' shows the length of the savings, calculated as the number of minutes during which the kW reduction was at least half of the maximum kW reduction. These results indicate that the 4-hour event on October 14, 2004 had a substantially longer duration than the 2-hour events, probably because the second call midway through the period re-curtailed units that had been overridden during the first two hours.

The final column shows the change in kWh energy use during the first hour after the end of the curtailment period. A negative value would indicate a snapback, i.e., an increase in consumption following the curtailment. The numerical results suggest a moderate snapback on October 7, 2004 and a smaller snapback on September 8, 2004 and October 14, 2004.

The last row of Figure 55 shows the average results across the curtailments. Considering all eight curtailments taken together, the savings were 0.245 kWh per ton in the first hour and 0.149 kWh per ton in the second hour, for a total savings of 0.394 kWh per ton during the first two hours of the curtailment. The average value of the maximum impact across the eight curtailments was 0.33 kW per ton. In calculating the average duration, we have excluded the one 4-hour curtailment. Among the seven 2-hour curtailments the average duration was 73 minutes. In the hour following the curtailment, the average snapback was 0.025 kWh per ton.

		kWh per Ton Savings in Hour				Total	Maximum	Minutes	Hour
Event	Date	1	2	3	4	Savings	Impact	Duration	Folowing
171	8/9/04	0.280	0.124	na	na	0.404	0.38	60	0.013
174	8/10/04	0.249	0.150	na	na	0.398	0.35	70	0.014
181	9/1/04	0.259	0.170	na	na	0.429	0.36	80	0.002
183	9/7/04	0.316	0.151	na	na	0.467	0.39	70	0.028
187	9/8/04	0.191	0.152	na	na	0.343	0.30	80	-0.055
191	9/23/04	0.280	0.151	na	na	0.431	0.34	75	-0.004
192	10/7/04	0.201	0.110	na	na	0.311	0.28	75	-0.088
193	10/14/04	0.192	0.160	0.123	0.055	0.530	0.26	140	-0.064
Average, all Events		0.245	0.149	na	na	0.394	0.33	73	-0.025

Figure 55: Measures of Impact from Whole Premise Metering

Figure 56 shows the relative precision of the kWh savings reported in Figure 55, calculated at the 90% level of confidence. For example, the first-hour savings of all eight curtailments taken together had a relative precision of ± 16% at the 90% level of confidence. So the 90% confidence interval for the first-hour savings of all eight curtailments taken together can be calculated as 0.245 ± (0.16)(0.245), or 0.245 kWh per ton ± 0.039 kWh per ton. Similarly, the 90% confidence interval for the total savings over the two hours of the curtailment period is 0.394 kWh per ton ± 0.071 kWh per ton.

		Relative Precision in Hour				Total
Event	Date	1	2	3	4	Savings
171	8/9/04	0.22	0.46	na	na	0.26
174	8/10/04	0.23	0.35	na	na	0.24
181	9/1/04	0.25	0.37	na	na	0.27
183	9/7/04	0.19	0.36	na	na	0.22
187	9/8/04	0.24	0.39	na	na	0.26
191	9/23/04	0.24	0.55	na	na	0.33
192	10/7/04	0.26	0.47	na	na	0.30
193	10/14/04	0.30	0.30	0.44	0.96	0.31
Average of All Events		0.16	0.24	na	na	0.18

Figure 56: Relative Precision of Savings from Whole Premise Metering

Figure 57 shows the error ratios associated with the kWh savings. The error ratios are a measure of site to site variability for stratified ratio estimation, and can be used to help plan the sample sizes for future studies. Considering the average savings of all events, the error ratio was found to be 1.3 for the first-hour savings, and 1.9 for the second-hour savings. The increase in the error ratio from the first hour to the second hour suggests greater variability in the savings in the second hour compared to the first hour, reflecting site to site differences in the persistence of the savings. The error ratio was 1.5 for the total savings in the two hours of the curtailment.

The error ratios for the average of all events are always smaller than the error ratios for the individual events. This reflects the reduction in site to site variation in the average savings of each site across several events compared to the site to site variation in the savings of the individual events. However, the reduction in the error ratio from averaging eight events is less than would be the case if the savings were statistically independent from event to event within a given site. Thus the variability is more strongly affected by the number of sites in the sample than by the number of curtailments per sample site.

		Error Ratio in Hour				Total
Event	Date	1	2	3	4	Savings
171	8/9/04	1.6	3.4	0.0	0.0	1.9
174	8/10/04	1.8	2.7	0.0	0.0	1.9
181	9/1/04	1.9	3.0	0.0	0.0	2.1
183	9/7/04	1.5	3.0	0.0	0.0	1.8
187	9/8/04	1.8	2.8	0.0	0.0	1.9
191	9/23/04	1.8	4.2	0.0	0.0	2.5
192	10/7/04	1.9	3.6	0.0	0.0	2.3
193	10/14/04	2.2	2.3	3.2	7.2	2.3
Average of All Events		1.3	1.9	na	na	1.5

Figure 57: Error Ratio of Savings from Whole Premise Metering

4.3 Whole Premise Metered (WPM) versus End Use Metered (EUM) Results

As indicated in the introduction to this chapter, we can interpret the preceding results to be the net impact after factoring in any interactions with other loads at the sites. In this section, we compare the results of the whole-premise and end use metered analysis in order to investigate the extent of interactions between the controlled air conditioners and other loads at the site.

Figure 58 shows the key measures of impact by event for both the EUM and WPM. The data clearly shows that the EUM impact is greater than that of the WPM. One hypothesis was that some customers may notice the curtailment and then curtail other loads at their location. If that were the case then we would observe the WPM perhaps being larger than the EUM. Clearly, this is not occurring.

	8/9/04		8/10/04		9/1/04		9/7/04		9/8/04		9/23/04		10/7/04		10/14/04		Average	
Method	WPM	EUM	WPM	EUM	WPM	EUM	WPM	EUM	WPM	EUM	WPM	EUM	WPM	EUM	WPM	EUM	WPM	EUM
kWh Savings per Ton in Hour 1	0.28	0.38	0.25	0.36	0.26	0.40	0.32	0.40	0.19	0.25	0.28	0.42	0.20	0.35	0.19	0.42	0.25	0.33
kWh Savings per Ton in Hour 2	0.12	0.22	0.15	0.15	0.17	0.28	0.15	0.22	0.15	0.24	0.15	0.31	0.11	0.20	0.16	0.29	0.15	0.21
Total Savings	0.40	0.59	0.40	0.51	0.43	0.68	0.47	0.62	0.34	0.49	0.44	0.73	0.31	0.54	0.53	1.07	0.39	0.57
Maximum Reduction	0.38	0.50	0.35	0.48	0.36	0.55	0.40	0.51	0.29	0.41	0.35	0.49	0.28	0.47	0.26	0.52	0.33	0.49

Figure 58: Measures of Impact from EUM and WPM

Figure 59 shows the estimate of difference between the two measurement approaches. The data presented in this table are calculated as the difference between the EUM and WPM measures in Figure 58.

Difference EUM - WPM	8/9/04	8/10/04	9/1/04	9/7/04	9/8/04	9/23/04	10/7/04	10/14/04	Average
kWh Savings per Ton in Hour 1	0.10	0.11	0.15	0.08	0.06	0.13	0.14	0.23	0.08
kWh Savings per Ton in Hour 2	0.09	0.00	0.11	0.07	0.09	0.16	0.09	0.14	0.07
Total Savings	0.19	0.12	0.25	0.15	0.15	0.29	0.23	0.54	0.18
Maximum Reduction	0.12	0.13	0.19	0.11	0.12	0.14	0.19	0.26	0.16

Figure 59: Difference between EUM and WPM for Measures of Impact

For some reason the difference in the EUM and WPM kWh savings per ton measurements in the first hour seems to increase over time, which does not correlate to any program parameter that can be correlated. More investigation of these results is needed before we can certify the WPM impacts as being significant to the analysis – this work is pending.

5 Analysis of the Thermostat Run time Data

A key element of our analysis strategy is the hourly HVAC run time data that can be retrieved from each of the thermostats via the communications software. The thermostat manufacturer has described the run time data collected by these thermostats as follows:

- What it does:
  - Each hour, the thermostat monitors and records the HVAC equipment run time for each hour in minutes, average room temperature, and thermostat temperature set points.
  - The thermostat can store the hourly data for 7 days, then it starts to write over its own records.
  - The run time data can be transmitted via two way pager on request to a server maintained by another contractor, which then stores the data and can later retrieve it for analysis upon request.

There is also a means to collect a real time “Snapshot” of the run time available from the thermostat on an as-requested basis during a curtailment. Figure 60 illustrates a “snapshot” of the run time data that is collected during a curtailment. The figure shows that just prior to the curtailment, the set point was 72° F, but this was raised to 76° F for four hours. The current temperature shows the average temperature at the thermostat during each hour during the curtailment. At the Start of the curtailment, the temperature was 72 degrees. By Hour 3 this had risen to 76 degrees.

	Start	Hour 1	Hour 2	Hour 3	Hour 4	End
Current Temp	72	74	75	76	76	76
Cool Setpoint	72	76	76	76	76	72
Mode	Cool	Cool	Cool	Cool	Cool	Cool
Fan	Auto	Auto	Auto	Auto	Auto	Auto
Hold	Off	Off	Off	Off	Off	Off
Run Time	-	0	0	17	45	-
Number of Starts	-	0	0	1	2	-

Figure 60: Sample Snapshot Data

The run time shows that in this example the air conditioner was idle during the first two hours and ran only 17 minutes during the third hour. In the third hour the AC was started once. We can infer from this that the effective duration of the curtailment was at least 2 hours and probably about 2 hours and 43 minutes. In the fourth hour, the AC had two starts and a total run time of 45 minutes. By this time we can infer that the AC was cycling normally at the higher set point. So these data provide a rather complete picture of the curtailment event for this particular air conditioner.

If the run time data are coupled with estimates of the operating kW of each HVAC unit, these data can be used to estimate the hourly kWh load of each installed unit. These data can also be used to estimate the hourly load reduction during each curtailment.

5.1 Available data

During 2004, SCE attempted to collect hourly thermostat run time data from all installed thermostats throughout the program on as many days as possible from July through October. The data are available on a flat file format, and the fields are: Account Number, PIN, Local Time Stamp, Run Time, Starts, and Temperature, where the PIN identifies each unique thermostat.

Over that period, SCE managed to collect hourly thermostat run time data from almost 3,600 thermostats for 47 days including 8 of the 12 curtailment days. The great advantage of the run time data is that it is available from such a large number of thermostats, almost as a census. Moreover, the run time data can be collected at relatively low cost because the thermostats themselves generate these data, and no additional equipment is required.

The disadvantage of this approach for determining load impacts with the run time data is that the thermostats do not provide kW itself, only the number of minutes of HVAC unit operation in each hour. The run time data have to be converted using information about the kW load of the units when they are operating. Moreover, the hourly data do not provide the fine resolution of the 5-minute end use meter data. In particular, the hourly run time data are not very useful in assessing the impact of a curtailment that begins on a half-hour, such as a curtailment from 2:30 to 4:30.

In the 2002 impact evaluation study, the run time data from the thermostats were compared to run times calculated from 5-minute end use metered data. These results showed that the average thermostat run time data is quite accurate within 99% as a means of estimating program load impacts. This type of validation of the thermostat run time data will not be repeated in this report.

5.2 Estimating the Operating Load

In this section we address the following problem – how to best estimate the hourly kW loads of each HVAC unit from the run time reported by the thermostat. The operating load of each unit is the key to converting the thermostat run time data into an estimate of the kW load of each unit. The operating load of an air conditioner is defined to be its kW demand when the compressor is operating. In the 2002 study, we demonstrated that the operating load is related to the cooling capacity (tons) of the unit, as might be expected, but the operating load is also related to the exterior temperature. We have used regression analysis to determine the effect of both factors: cooling capacity and temperature.

In particular, we have analyzed the 5-minute end use metered data as follows:

1. For each of the one hundred units with end use data, identify and select all 5-minute intervals in which the unit was operating throughout the interval, i.e. the recorded operating time was equal to 5 minutes, and calculate the operating kW load per ton of the unit during each interval. To ensure that the analysis was representative of hours in which a curtailment was most likely, the analysis was

restricted to the 5-minutes intervals during the 2 pm through 5 pm hours of each day.

2. For each unit and each selected interval, identify the outside temperature during the associated hour in the climate zone in which the unit was located.
3. Prepare and review scatter plots for each of the end use metered units relating the operating load per ton to the temperature. Exclude the unit from further analysis if there were very few intervals with meaningful data. Also, identify filters for each unit to exclude spurious measures such as any operating loads associated with fan-only operation.
4. Use the resulting operating load per ton and temperature data to estimate a simple linear regression model for each unit relating the operating load per ton to the temperature.
5. Save and plot the studentized[7] residuals from each of the preceding regression models, and drop intervals in which the studentized residual is greater than three in absolute value.
6. Re-estimate the simple linear regression models for each unit relating the operating load per ton to the temperature after dropping the intervals identified in the preceding step.
7. Calculate the average value of the intercept and slope for the small and large units.

From this analysis, we arrived at the following two simple predictive equations:

$$\text{kW per Ton} = 0.5977 + 0.00851 * \text{Temp} : \text{if tons} < 7, \text{and}$$

$$\text{kW per Ton} = 0.5438 + 0.00649 * \text{Temp} : \text{if tons} >= 7$$

Where Temp is the exterior temperature in the climate zone, measured in degrees Fahrenheit.

Figure 61 and Figure 62 summarizes the results of this analysis. The table shows our estimate of the operating load of an HVAC unit versus the exterior temperature. The operating load is measured in kW per tons. The exterior temperature is measured in degrees Fahrenheit. As an example, a two-ton unit would be expected to have an operating load of about 2.72 kW on a 90-degree afternoon.

Figure 62 shows that throughout the temperature range, larger units tend to be more efficient in terms of kW/ton than small units. Large units are also just slightly less temperature sensitive since their operating load increases about 0.0065 kW per degree per ton whereas the operating load of small units increases slightly more, about 0.0085 kW per degree per ton.

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[7] The result of standardizing the residual with an independent estimate of sigma^2.

See: http://www.csc.fi/cschelp/sovellukset/stat/sas/sasdoc/sashtml/insight/chap39/sect54.htm

Exterior Temperature	***Operating Load***	
	Small (< 7 Tons)	***Large (>= 7 Tons)***
70	1.19	1.00
75	1.24	1.03
80	1.28	1.06
85	1.32	1.10
90	1.36	1.13
95	1.41	1.16
100	1.45	1.19

Figure 61: Operating Load per Ton for various Exterior Temperatures

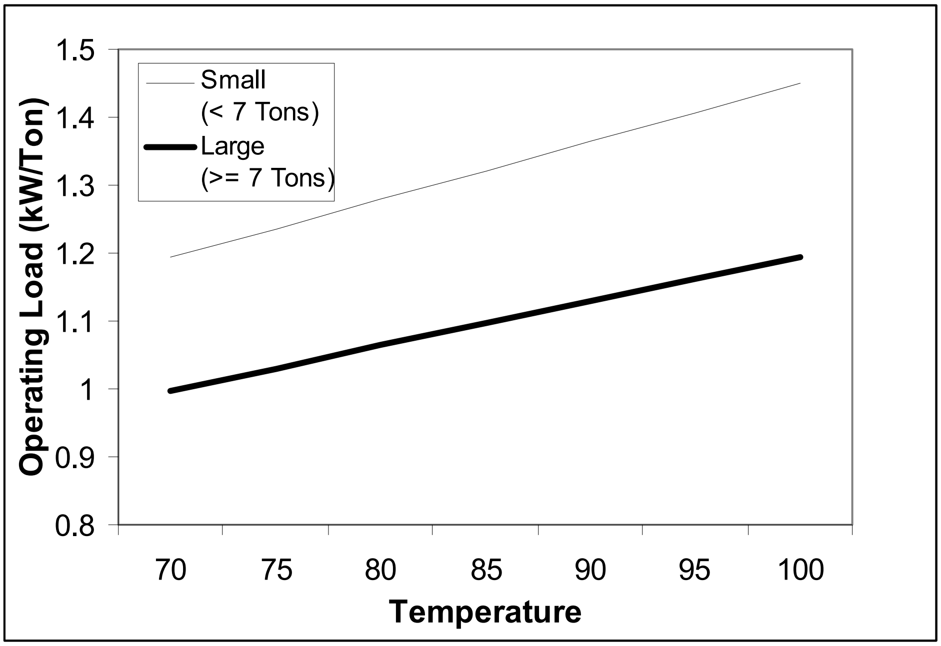


Figure 62: Operating Load per Ton vs. Exterior Temperature

5.3 Estimating Hourly kWh Consumption from Thermostat Run time Data

The next step was to use the operating load models described in the preceding section to estimate the hourly kWh consumption of each unit with thermostat run time data. We restricted this analysis to units with run time data for more than 30 days. In total, there was thermostat run time data for 4,003 thermostats, and 3,998 of these controlled air conditioners with known cooling capacities. Of these, 3,583 units had run time data for more than 30 days.

We calculated the kWh of each of these 3,583 units by hour using the following steps:

1. Identify the size of the unit in tons,
2. Identify the temperature of the hour in degrees Fahrenheit in the region that the unit is located,

3. Use either the small or large operating load model to calculate the operating load of the unit,
4. Multiply the operating load by the run time in the hour, measured as a fraction between 0 and 1.

Then we post-stratified the 3,583 units as if they were a sample, using the strata definitions given in Figure 16, and calculated case weights. Finally, we used the case weights to calculate the average hourly kWh per ton of all of the 3,583 units taken together.

5.4 Estimating Load Impacts using the Run time Data

In preceding sections we have estimated the total potential impact of the program by examining eight curtailments that were called during the summer of 2004 using the 5-minute load data for one hundred end use metered units. In order to extrapolate these results to the population of all participating units, we assumed that this sample of units were representative of the population of HVAC units in the program. This assumption is reasonable since the units that were end use metered were selected following a statistical sampling plan.

In this section we will report on our analysis of the run time data available for the summer of 2004. We hope that these results will reinforce the estimates of impact that we developed from the end use metered data.

Our work will follow the same general approach used to analyze the end use metered data. However, because these data are hourly, the results will not have the 5-minute time resolution of the end use metered results. For this reason we will not attempt to estimate the maximum impact of the curtailment, or the duration. Instead, we will focus on the impact in each hour during the curtailment event. Moreover, given the hourly resolution, we will not attempt to use these data to estimate the impact of a curtailment event starting on a half-hour.

Our work has followed these steps:

1. Merge the run time data with the tracking data characterizing the size of the controlled HVAC units and with the weather data giving the exterior temperature.
2. Describe the set of units included in the analysis.
3. Use the equation for the operating load that we have developed to convert the run time data for each of these units to estimated hourly kWh consumption and calculate the average hourly kWh consumption per unit of all units.
4. Estimate the hourly impact (kWh per unit) of each of the eight curtailments.
5. Compare the results to our prior analysis from the end use metering data.

Figure 63 shows the results of step 2. The table shows that there were a total of 3,998 units included in this analysis and that these units had an average size of 4.15 tons per unit. The smaller units comprise 95% of all units and 88% of the total tons.

Recall from Figure 8 that there were a total of 4,234 participating units with recorded tons in the tracking database and that these units have an average size of 4.22 tons per unit. Among these units, the smaller units comprise 95% of all units and 88% of the total tons. Therefore, the units included in the present analysis represent 95% of all installed units with recorded size. Moreover, the average size of these units is practically identical to the entire population.

Size in Tons	***Number***	***Percent***	***Total Tons***	***Percent***	***Tons per Unit***
6 or Smaller	3,779	95%	14,555	88%	3.85
7 or Larger	219	5%	2,047	12%	9.35
Total	3,998	100%	16,602	100%	4.15

Figure 63: Summary Statistics for the Units Included in the Run Time Analysis

We should also compare the units included in the present analysis with the units included in our prior analysis of the 5-minute end use metering data. The final eight curtailments shown in Figure 12 in Section 2.4 are the curtailment events that were analyzed in the end use meter data analysis and the run time data analysis. We had data for June through October 2004, however significant changes to the tracking data were in progress and the data was somewhat suspect. We now present the results for the eight curtailment days with run time data.

Event 171 - August 9, 2004

The August 9 curtailment was a 4-degree offset from 3 to 5 PM. The same days were chosen as a baseline for the run time analysis as the end use analysis. The average high temperature for the baseline was 92.1 degrees, which practically matched the actual high temperature on August 9 of 92.2 degrees.

Figure 64 displays the results of our new analysis using all available run time data for installed units. Figure 64 is based on the hourly run time data of about 3,500 units. Note that these series of graphs will differ significantly from the graphs generated from end use metered data, due to the “smoothing” effect and slower transitions of hourly run time data as opposed to the more detailed presentation of 5-minute metered data.

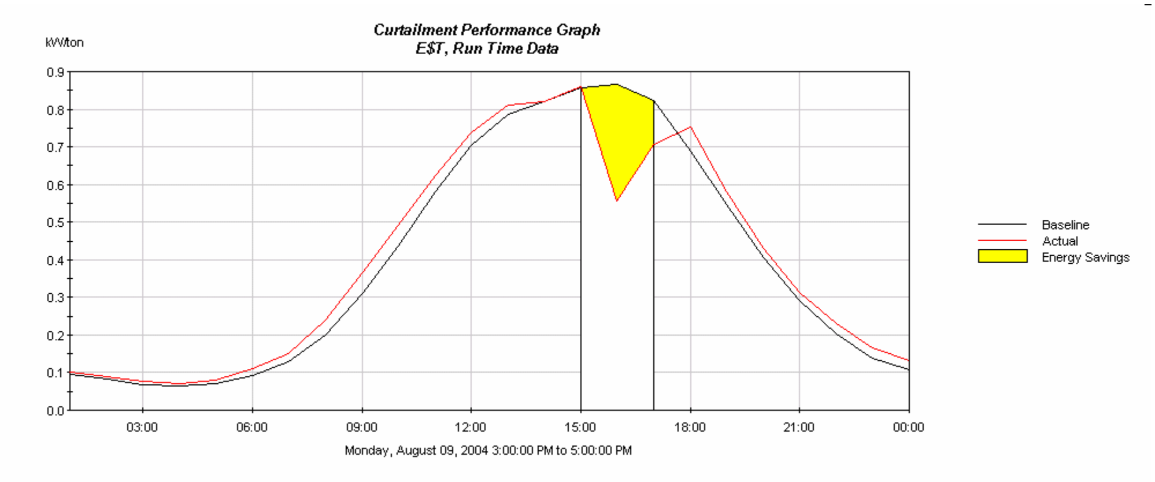


Figure 64: Estimating the Impact on August 9 using the Run time Data

Figure 65 summarizes the results of the new analysis. This table is similar to those developed from the 5-minute end use metering data, but some of the statistics have been deleted since the current results are based on hourly load. The statistic labeled Confirmed Units is new to this analysis; it reflects the number of units that confirmed the curtailment signal sent by SCE with a return signal of their own. However, this confirmation only indicates “messages received”; it does not indicate actual curtailment performance of the thermostat.

The Override Rate is also based on the number of units that indicated that the customer manually operated the thermostat during the curtailment period, and may have “overrode” the signal, resulting in a loss of curtailment. This rate indicates the total number of units that were operated during the duration of the curtailment period. The thermostat transmits the signal via a return page when it ends its curtailment, and sends a time stamp.

The table also shows the number of units included in the run time analysis of the event, in total and as a proportion of all confirmed units in the program group. The remaining characteristics reported in Figure 65 are equivalent to their use in the summary reports that have been presented using the end use metering data.

The first hour savings for the August 9, 2004 event are 0.31 kWh per ton, with second hour savings of 0.12 kWh per ton. This drop in savings in the second hour is expected, because some of the HVAC units are being curtailed and also begin to reach the new set point in the second hour.

Curtailment Date	8/9/2004
Start Time	3:00 PM
End Time	5:00 PM
Offset	4 Degrees
Curtailment Day High	92.2
Override Rate	19%
Confirmed Units	3,487
Baseline Day(s)	8/11/04, 8/31/04, 9/2/04
Baseline Day High	92.1
Trueup Adjustment	99.8%
kWh Savings in Hour 1	0.31
kWh Savings in Hour 2	0.12
Hour Following	-0.06

Figure 65: Summary Report for August 9 from the Run Time Analysis

Event 174 - August 10, 2004

The curtailment that took place on August 10, 2004 was a 4-degree offset from 2 PM to 4 PM. Once again August 31, August 11, and September 2 were used as baseline days because they had comparable daily high temperatures with August 10. Figure 66 displays the results of our analysis using all available run time data for installed units.

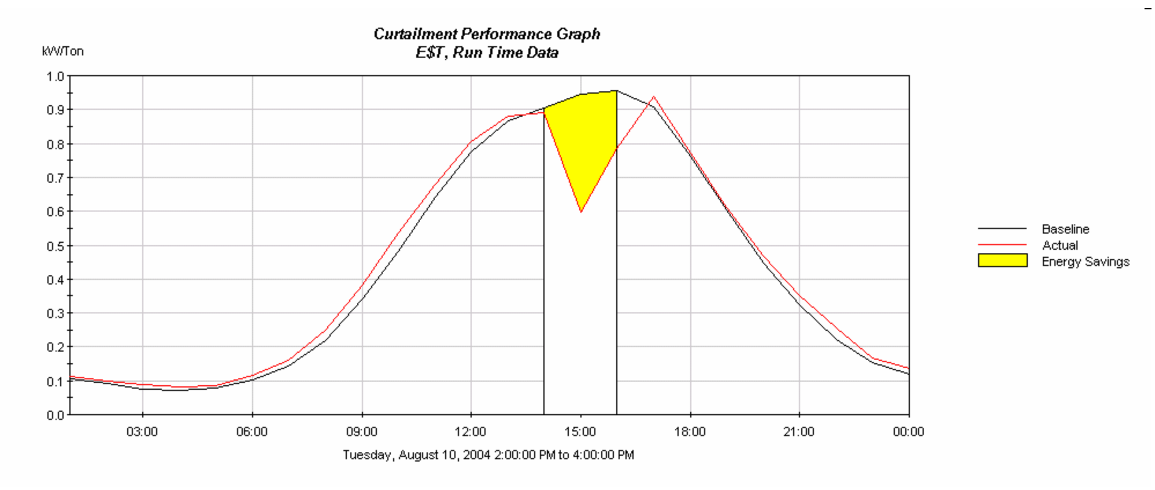


Figure 66: Estimating the Impact on August 10 using the Run time Data

Figure 67 summarizes the results of the run time analysis. The first hour savings were 0.35 kWh per ton and the second hour savings were 0.17 kWh savings per ton.

Curtailment Date	8/10/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4 Degrees
Curtailment Day High	94.1
Override Rate	19%
Confirmed Units	3,605
Baseline Day(s)	8/31/04, 8/11/04, 9/2/04
Baseline Day High	92.1
Trueup Adjustment	110.1%
kWh Savings in Hour 1	0.35
kWh Savings in Hour 2	0.17
Hour Following	-0.03

Figure 67: Summary Report for August 10 from the Run Time Analysis

Event 181 - September 1, 2004

The curtailment on September 1 was a 4-degree offset from 3 PM to 5 PM. August 30, August 31, and September 2 were chosen as the baseline for September 1 because of their comparable daily high temperatures.

Figure 68 displays the results of our analysis using all available run time data for installed units.

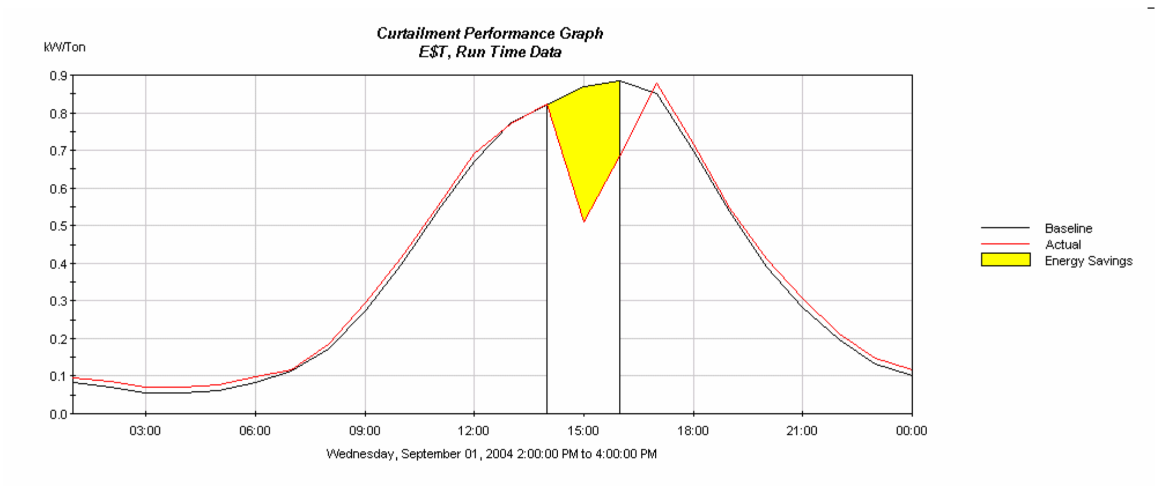


Figure 68: Estimating the Impact on September 1 using the Run time Data

Figure 69 summarizes the results of the run time analysis. The first hour savings were 0.36 kWh per ton and the second hour savings were 0.20 kWh savings per ton.

Curtailment Date	9/1/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	2 Degrees
Curtailment Day High	93.3
Override Rate	21%
Confirmed Units	3,633
Baseline Day(s)	8/30/04, 8/31/04, 9/2/2004
Baseline Day High	91.9
Trueup Adjustment	105.6%
kWh Savings in Hour 1	0.36
kWh Savings in Hour 2	0.20
Hour Following	-0.03

Figure 69: Summary Report for September 1 from the Run Time Analysis

Event 183 - September 7, 2004

The curtailment that occurred on September 7 was a 4-degree offset from 2 to 4 PM. The days chosen as the baseline for this day were August 31, September 2, and September 9 due to their similar daily high temperatures.

Figure 70 displays the results of our analysis using all available run time data for installed units.

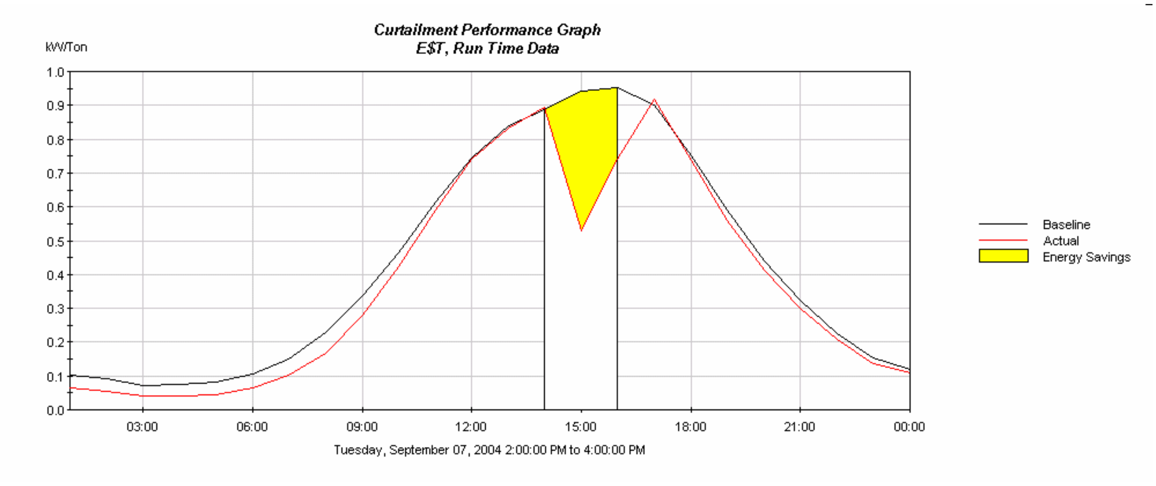


Figure 70: Estimating the Impact on September 7 using the Run time Data

Figure 71 summarizes the results of the run time analysis. The first hour savings were 0.41 kWh per ton and the second hour savings were 0.21 kWh savings per ton.

Curtailment Date	9/7/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4 Degrees
Curtailment Day High	94.0
Override Rate	21%
Confirmed Units	3,760
Baseline Day(s)	8/31/04, 9/2/04, 9/9/04
Baseline Day High	92.4
Trueup Adjustment	110.0%
kWh Savings in Hour 1	0.41
kWh Savings in Hour 2	0.21
Hour Following	-0.02

Figure 71: Summary Report for September 7 from the Run Time Analysis

Event 187 - September 8, 2004

The curtailment that took place on September 8 was a 4-degree offset from 4:10 to 6:10 PM. August 31, September 2, and September 9 were chosen as the baseline days for September 8 due to their similar daily high temperatures

Figure 72 displays the results of our analysis using all available run time data for installed units.

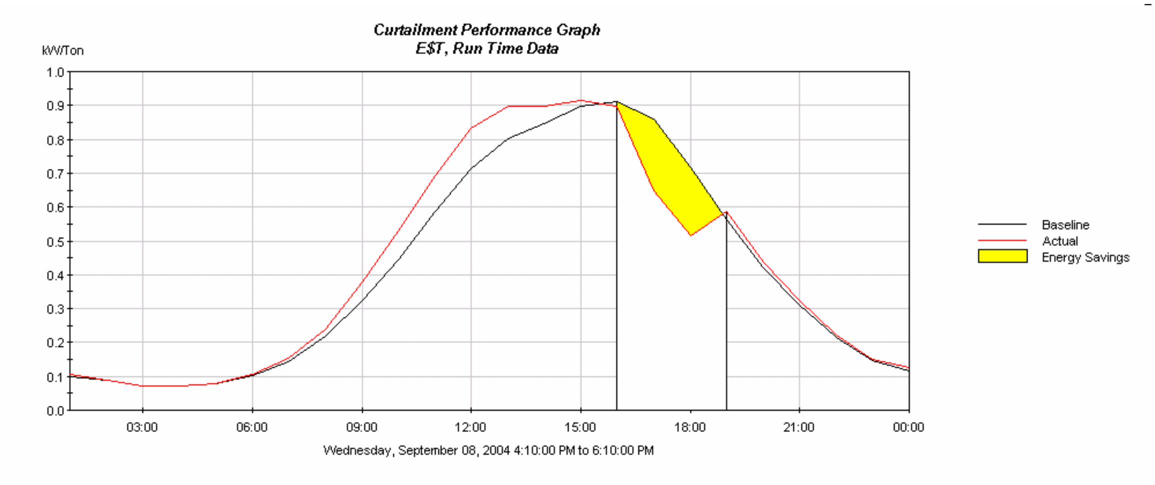


Figure 72: Estimating the Impact on September 8 using the Run time Data

Figure 73 summarizes the results of the run time analysis. The first hour savings were 0.18 kWh per ton and the second hour savings were 0.20 kWh savings per ton. The second hour of curtailment showed increased savings over the first hour because of the time chosen to curtail the thermostats, at 4pm. The first hour showed a much less dramatic drop than usual because the curtailment began at a time when cooling equipment usage is expected to lower naturally. The second hour showed continued savings because the later curtailment occurred at a time when exterior temperatures were dropping, which slowed the increase in internal temperature, thus preventing units from running for a longer period. Coincidentally, this later curtailment also led to a lower override rate.

Curtailment Date	9/8/2004
Start Time	4:10 PM
End Time	6:10 PM
Offset	4 Degrees
Curtailment Day High	90.6
Override Rate	11%
Confirmed Units	3,855
Baseline Day(s)	8/31/04, 9/2/04, 9/9/04
Baseline Day High	92.4
Trueup Adjustment	105.1%
kWh Savings in Hour 1	0.18
kWh Savings in Hour 2	0.20
Hour Following	-0.02

Figure 73: Summary Report for September 8 from the Run Time Analysis

Event 191 - September 23, 2004

The September 23 curtailment was a 4-degree offset that occurred from 2 to 4 PM. September 21, September 22, and September 27 had comparable daily high temperatures, and were therefore used as the baseline for September 23.

Figure 74 displays the results of our analysis using all available run time data for installed units.

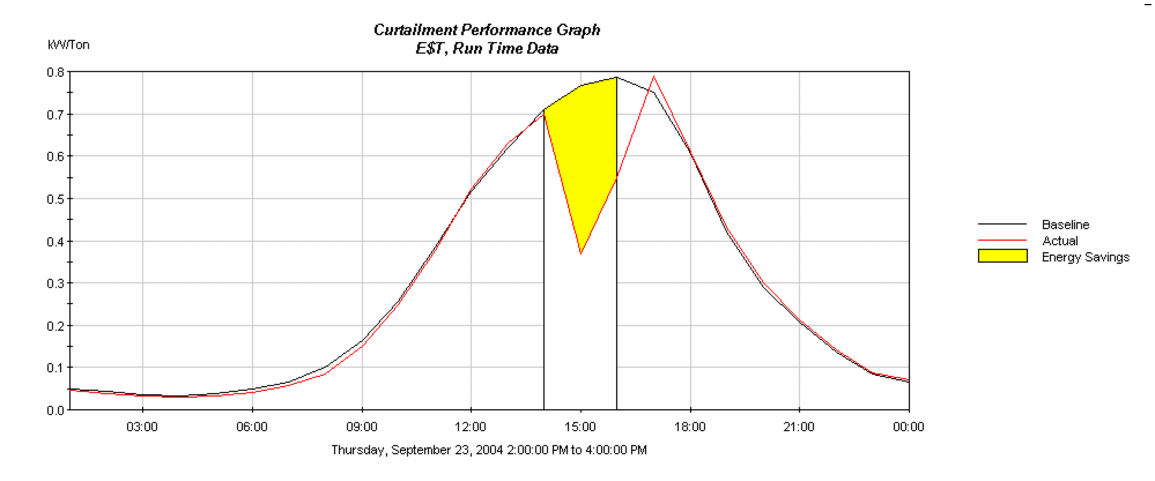


Figure 74: Estimating the Impact on September 23 using the Run time Data

Figure 75 summarizes the results of the new analysis. The first hour savings were 0.40 kWh per ton and the second hour savings were 0.24 kWh savings per ton.

Curtailment Date	9/23/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4 Degrees
Curtailment Day High	88.6
Override Rate	20%
Confirmed Units	4,222
Baseline Day(s)	9/21/04, 9/22/04, 9/27/04
Baseline Day High	87.5
Trueup Adjustment	117.9%
kWh Savings in Hour 1	0.40
kWh Savings in Hour 2	0.24
Hour Following	-0.04

Figure 75: Summary Report for September 23 from the Run Time Analysis

Event 192 - October 7, 2004

The curtailment on October 7 was a 4-degree offset that occurred from 2 to 4 PM. In our analysis of this event, we selected September 27, October 6, and October 12 as the comparison days.

Figure 76 displays the results of our new analysis using all available run time data for installed units. This graph can be compared to Figure 29. While the two graphs are generally very similar, two differences should be noted:

- The baseline load in Figure 76 has a maximum of about 0.7 kW per ton, whereas the baseline load in Figure 29 has a maximum of about 0.8 kW per ton, and
- Figure 76 is based on the hourly run time data of about 4,800 units, whereas Figure 29 is based on 5-minute end use metered data from 100 units.

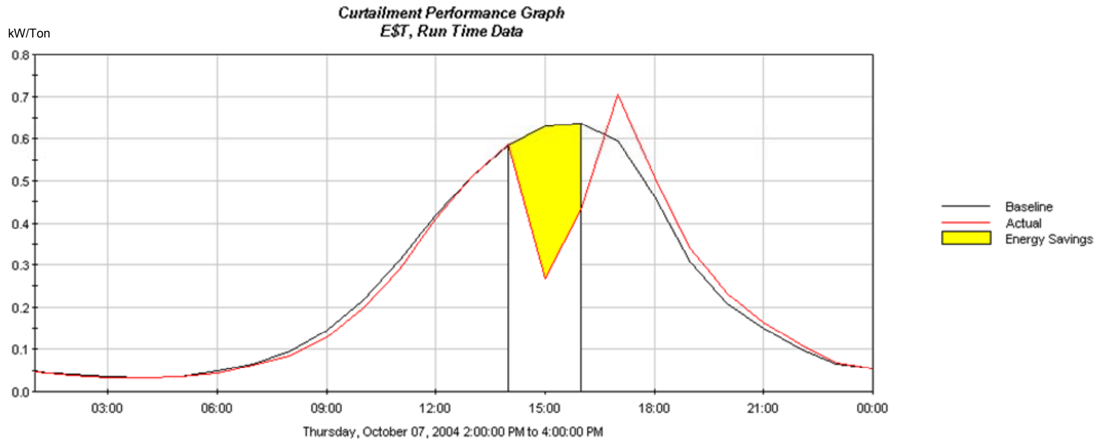


Figure 76: Estimating the Impact on October 7 using the Run time Data

Figure 77 summarizes the results of the new analysis. Figure 77 can be compared to Figure 30. Figure 77 shows that the run time analysis is based on 4,804 units, or 88% of all 5,447 confirmed units. By contrast, Figure 30 is based on the weighted results from the 100 units in the end use meter data. The savings in the first hour of the curtailment reported in Figure 77 are almost equal to the comparable statistics reported in Figure 30. However, the savings in the second hour of the curtailment are significantly higher from the data analysis using the end use metered data than the run time data.

Curtailment Date	10/7/2004
Start Time	2:00 PM
End Time	4:00 PM
Offset	4 Degrees
Curtailment Day High	84.0
Override Rate	20%
Confirmed Units	4,804
Baseline Day(s)	9/27/04, 10/6/04, 10/12/04
Baseline Day High	84.9
Trueup Adjustment	104.2%
kWh Savings in Hour 1	0.36
kWh Savings in Hour 2	0.20
Hour Following	-0.10

Figure 77: Summary Report for October 7 from the Run Time Analysis

Event 193 - October 14, 2004

On October 14 there were two separate 4-degree offsets that occurred back to back. The first curtailment was from 2 to 4PM, and the second curtailment was from 4 to 6 PM. We chose September 21, September 22, and October 12 as the baseline days for our analysis of the run time data and the end use metered data. Figure 78 describes our results. Figure 79 provides the summary report.

The savings shown in Figure 79 differ from the average savings reported in Figure 32. In the end use metered data analysis, the first, second, third, and fourth hours savings were 0.47, 0.35, 0.22, and 0.08 kWh per ton respectively, while in the run time data analysis the savings were 0.31, 0.17, 0.21, and 0.13 respectively. In the end use metered analysis the savings dropped each hour, whereas in the run time data analysis the savings dropped, then increased, then dropped again. Also, the magnitude of savings differed between the two.

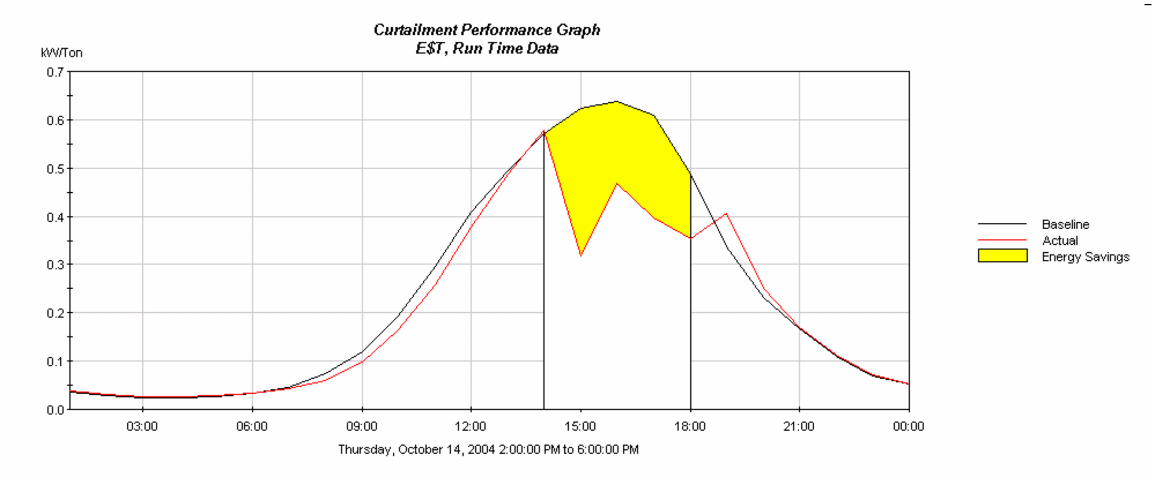


Figure 78: Estimating the Impact on October 14 using the Run time Data

Curtailment Date	10/14/2004
Start Time	2:00 PM
End Time	6:00 PM
Offset	4 Degrees
Curtailment Day High	87.7
Override Rate	16%
Confirmed Units	5,094
Baseline Day(s)	9/21/04, 9/22/04, 10/12/04
Baseline Day High	87.6
Trueup Adjustment	101.0%
kWh Savings in Hour 1	0.31
kWh Savings in Hour 2	0.17
kWh Savings in Hour 3	0.21
kWh Savings in Hour 4	0.13
Hour Following	-0.07

Figure 79: Summary Report for October 14 from the Run Time Analysis

5.5 Comparison of the End Use Metering and Run Time Results

Curtailment Date	8/9/2004		8/10/2004		9/1/2004		9/7/2004		9/8/2004		9/23/2004	
Method	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers
kWh Savings per Ton in Hour 1	0.31	0.38	0.35	0.36	0.36	0.40	0.41	0.40	0.18	0.25	0.40	0.42
kWh Savings per Ton in Hour 2	0.12	0.22	0.17	0.15	0.20	0.28	0.21	0.22	0.20	0.24	0.24	0.31
Hour Following	0.00	0.00	0.00	-0.09	-0.03	-0.03	0.00	-0.04	-0.02	0.03	-0.04	0.08

Figure 80 compares the results of the end use metering and run time analysis for the eight curtailment days with 4-degree offsets that were included in both analyses. These data are taken directly from Section 5.4, and the end use metered data analysis results.

The table shows that the two methods of analysis yielded remarkably similar estimates of savings per ton in the first and second hours of these two curtailment events.

The top portion of the table shows the average size of the units included in the two types of analysis, measured in tons per unit. The lower portion of the table restates the results in kWh savings per ton.

Curtailment Date	8/9/2004		8/10/2004		9/1/2004		9/7/2004		9/8/2004		9/23/2004		10/7/2004		10/14/2004	
Method	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers
kWh Savings per Ton in Hour 1	0.31	0.38	0.35	0.36	0.36	0.40	0.41	0.40	0.18	0.25	0.40	0.42	0.36	0.35	0.31	0.42
kWh Savings per Ton in Hour 2	0.12	0.22	0.17	0.15	0.20	0.28	0.21	0.22	0.20	0.24	0.24	0.31	0.20	0.20	0.17	0.29
Hour Following	0.00	0.00	0.00	-0.09	-0.03	-0.03	0.00	-0.04	-0.02	0.03	-0.04	0.08	-0.10	-0.12	0.21	-0.06

Figure 80: Summary of Savings per Ton for 4-Degree Curtailments

Figure 81 summarizes the characteristics of all units installed in the program. We can estimate the total impact of the program by multiplying the per ton impact shown in Figure 80 by the total tons of the installed units, 18,322. Figure 82 shows the results.

Curtailment Date	8/9/2004		8/10/2004		9/1/2004		9/7/2004		9/8/2004		9/23/2004	
Method	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers
kWh Savings per Ton in Hour 1	0.31	0.38	0.35	0.36	0.36	0.40	0.41	0.40	0.18	0.25	0.40	0.42
kWh Savings per Ton in Hour 2	0.12	0.22	0.17	0.15	0.20	0.28	0.21	0.22	0.20	0.24	0.24	0.31
Hour Following	0.00	0.00	0.00	-0.09	-0.03	-0.03	0.00	-0.04	-0.02	0.03	-0.04	0.08

Installed Units	4,721
Tons per Unit	3.9
Total Tons	18,322

Figure 81: Summary of Units Installed in Program

Curtailment Date	8/9/2004		8/10/2004		9/1/2004		9/7/2004		9/8/2004		9/23/2004		10/7/2004		10/14/2004	
Method	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers	RTD	Loggers
Total Tons in Program	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322	18,322
MWh Savings in Hour 1	5.7	6.9	6.4	6.6	6.6	7.4	7.5	7.4	3.3	4.6	7.3	7.7	6.6	6.3	5.7	7.7
MWh Savings in Hour 2	2.2	3.9	3.1	2.8	3.7	5.1	3.8	4.0	3.7	4.4	4.4	5.6	3.7	3.6	3.1	5.4
Hour Following	0.0	0.0	0.0	-1.6	-0.5	-0.6	0.0	-0.7	-0.4	0.6	-0.7	1.4	-1.8	-2.2	3.8	-1.1

Figure 82: Estimated Total Impact of Program-Wide 4-Degree Curtailment

The new results shown in Figure 82 are consistent with the total program impacts developed earlier in our analysis of the end use metering data.

We have also summarized the information from the run time analysis summary reports for each of the eight 4-degree curtailment events. Although these eight events differed in many respects, we believe that they can be analyzed as a group.

We will start by noting the average characteristics of the eight 4-degree curtailments shown in Figure 83. Based on a simple numerical average, the ‘typical’ 4-degree event can be described as follows:

- The savings in the first hour was 0.33 kWh per ton,
- The savings in the second hour was 0.17 kWh per ton,
- There was little or no snapback following the curtailment period.

Date	kWh Savings per Ton in Hour 1	kWh Savings per Ton in Hour 2	Hour Following
8/9/2004	0.31	0.12	-0.06
8/10/2004	0.35	0.17	-0.03
9/1/2004	0.36	0.20	-0.03
9/7/2004	0.41	0.21	-0.02
9/8/2004	0.18	0.20	-0.02
9/23/2004	0.31	0.12	0.00
10/7/2004	0.35	0.17	0.00
10/14/2004	0.36	0.20	-0.03
Average	**0.33**	**0.17**	**-0.02**

Figure 83: Average kWh Savings using Run Time Data

Based on these results we can estimate the total program-wide impact of a 4-degree curtailment. Recall that we estimated that the 4,700 participating units have a total size of 19,701 tons. That number was reduced by 7% due to the existence of deadbeats, resulting in a program total of 18,322 tons. Using this information together with the preceding results, we can estimate the average total program impact using the run time data as shown below. We estimate total savings of 6.0 MW in hour 1 and 3.2 MW savings in hour 2.

	Run Time Data	
	Per Sample Ton	Program Total
kWh Savings in Hour 1	0.33	6,024
kWh Savings in Hour 2	0.17	3,184

Figure 84: Estimated Program-Wide Impact Using Run time Results

Figure 85 summarizes the data presented in Figure 84 and Figure 34. Not surprisingly, we find that the average kWh savings in hour 1 are very similar for the two data sources, differing by only 0.04 kWh per ton. We also find that the average kWh savings in hour 2 are very similar for the two data sources, differing by only 0.08 kWh per ton.

	Run Time Data		End Use Meter Data	
	Per Sample	Program Total	Per Sample	Program Total
kWh Savings in Hour 1	0.33	6,024	0.33	6,021
kWh Savings in Hour 2	0.17	3,184	0.21	3,932

Figure 85: Comparison of Impact from Run Time and End Use Meter Data

From this run time data analysis, we estimate that among all 4,700 participating units, a 4-degree, two-hour curtailment will yield first hour energy savings of about 6.0 MWh, and second hour energy savings of about 3.2 MWh.

6 Factors Affecting the Duration of the Impact

This section looks at the factors that affect the persistence of the savings throughout the curtailment period. In this program, the thermostats curtail the load by increasing the temperature set point, thereby curtailing the air conditioner until the indoor temperature reaches the new set point. Conceptually, the greater the rate of indoor heat gain at the site, the more quickly the indoor temperature will move up to the new set point and the shorter the duration of the savings at the site.

This would suggest that the duration might be increased by reducing the heat gain, for example by shading south or west facing windows and reducing the heat generated by internal loads such as lighting by installing more efficient equipment.

As an initial test of this hypothesis, we have sought to identify a relationship between the duration of the savings at each site and the characteristics of the site. Because of the substantial variation in energy use from one 5-minute period to another, we were unable to define duration at the site level. Therefore, in this analysis we used the ratio of the savings in the second hour to the savings in the first hour as a proxy for the duration of the savings. We called this ratio the persistence of the savings.

The analysis was carried out in the following steps:

1. Start with the first and second hour savings of each site for each curtailment, determined from our analysis of the whole-premise metered load data. We excluded event 171 on August 9, 2004 and event 187 on September 8, 2004 because these curtailments occurred relatively late in the day and the air conditioning load appeared to have dropped significantly by the second hour of the curtailment.
2. Merge the savings data with the tracking data giving acknowledgement and overrides for each combination of site, curtailment and AC unit. For each site, eliminate the curtailment if any AC units at the site failed to acknowledge the curtailment or over-road the curtailment.
3. Calculate the total savings for the site in the first and second hours over all of the remaining curtailments. Calculate the ratio of the savings in the second hour divided by the first hour, provided that the first hour savings were greater than 0. If the resulting ratio was greater than 1 define the persistence to be 1. If the resulting ratio was less than 0 define the persistence to be 0. Otherwise define the persistence to be the ratio itself.
4. Merge the resulting site-level measure of persistence with the candidate explanatory variables measuring the characteristics of the site. This left a sample of 70 sites.
5. Develop a regression model relating the persistence to the candidate explanatory variables measuring the characteristics of the site.

The following candidate explanatory variables were used:

1. **ConvBusHrs** – an indicator variable taking the value of 1 if the site had conventional business hours, and 0 otherwise.
2. **Workers** – the number of workers per thousand square feet of space.

3. **LPD** – the lighting power density, calculated as the connected wattage of the lighting divided by the square footage of the space.
4. **EPD** – the equipment power density, calculated as the connected wattage of the non-lighting electrical equipment divided by the square footage of the space.
5. **South_Double** – 1 if the south windows are double paned, 0 otherwise,
6. **South_Tinted** – 1 if the south windows are tinted, 0 otherwise,
7. **South_Int_Shade** – 1 if the south windows are have internal shades, 0 otherwise,
8. **South_Ext_Shade** – 1 if the south windows have external shading, 0 otherwise,
9. **WindowArea_S** – the area of the south windows divided by the square footage of the building;
10. **WindowArea_Double_S** = South_Double * WindowArea_S,
11. **WindowArea_ Tinted _S** = South_ Tinted * WindowArea_S,
12. **WindowArea_ Int_Shade _S** = South_ Int_Shade * WindowArea_S,
13. **WindowArea_ Ext_Shade _S** = South_ Ext_Shade * WindowArea_S,
14. **West_Double** – 1 if the west windows are double paned, 0 otherwise,
15. **West_Tinted** – 1 if the west windows are tinted, 0 otherwise,
16. **West_Int_Shade** – 1 if the west windows are have internal shades, 0 otherwise,
17. **West_Ext_Shade** – 1 if the west windows have external shading, 0 otherwise,
18. **WindowArea_W** – the area of the west windows divided by the square footage of the building;
19. **WindowArea_Double_W** = West_Double * WindowArea_S,
20. **WindowArea_ Tinted _W** = West_ Tinted * WindowArea_S,
21. **WindowArea_ Int_Shade _W** = West_ Int_Shade * WindowArea_S,
22. **WindowArea_ Ext_Shade _W** = West_ Ext_Shade * WindowArea_S,

These candidate variables were identified based on the following hypotheses.

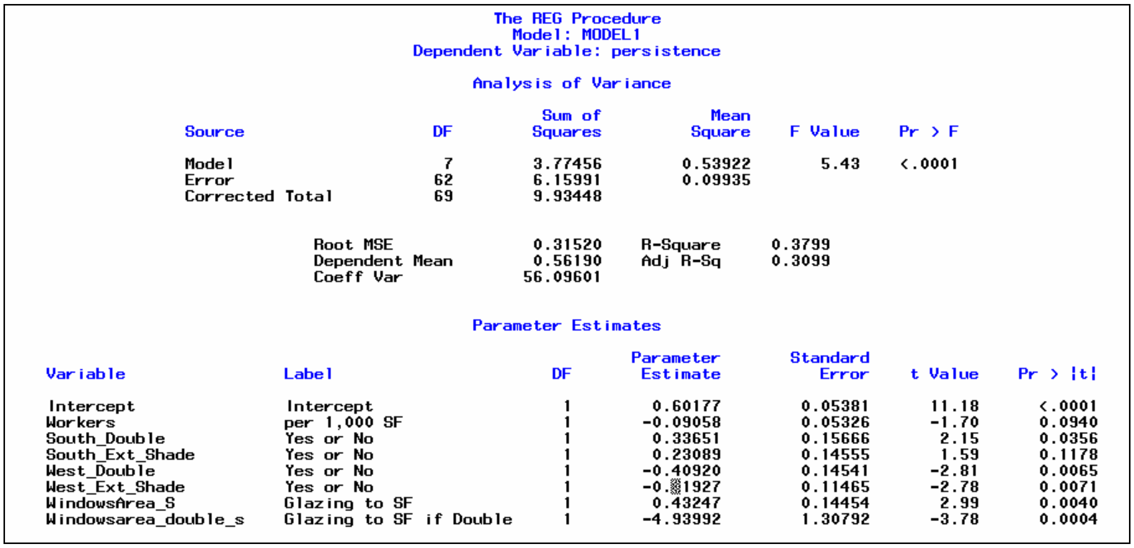
- ☐ Sites with conventional business hours would be expected to have higher persistence of savings than those with irregular business hours because of more consistent AC use throughout the business day.
- ☐ Sites with more workers per square foot might have lower persistence of savings due to internal heat gains associated with the activities of the workers.
- ☐ Sites with higher lighting power densities (LPD) and equipment power densities (EPD) would be expected to have lower persistence of savings due to internal heat gains associated with the lighting.
- ☐ Sites with more windows on the south and west walls would be expected to have lower persistence of savings due to external heat gains

associated with the windows. However, the heat gain would be smaller for double paned windows, tinted windows, and shaded windows.

Figure 86 shows the regression model that we obtained after some exploration of alternative models. The analysis of variance section of the output indicates that the model is highly significant, and has an unadjusted R-square of 37% and an adjusted R-square of 31%. In the initial model, the LPD variable had a positive but very insignificant coefficient to this variable and was dropped. The remaining variables have coefficients that are consistent with our expectations. However, the model itself is barely statistically significant, with a p-value of only 0.07. Moreover most of the explanatory variables have poor statistical significance so this model is certainly not definitive.

The parameter estimate section of the output shows the estimated regression coefficients (labeled parameter estimate) and the statistical significance of each coefficient, labeled Pr > |t|. The results indicate that most of the selected explanatory variables are highly significant. The South_Ext_Shade variable has a p-value of only 0.12 so it is only weakly significant. All of the remaining candidate variables have been dropped due to poor significance.

The results indicate that, as expected, the persistence is lower for buildings with more workers per square feet. The persistence is higher if the south windows are double paned or have external shading. The remaining coefficients of the model do not follow our expectation. The persistence is *lower* if the west windows are double paned or have external shading. Moreover the persistence is *higher* if there are more *single*-paned windows on the south, but *lower* if there are more *double*-paned windows on the south.



```
                                 The REG Procedure
                                  Model: MODEL1
                          Dependent Variable: persistence

                               Analysis of Variance

                                        Sum of          Mean
        Source               DF        Squares        Square    F Value    Pr > F

        Model                 7        3.77456       0.53922       5.43    <.0001
        Error                62        6.15991       0.09935
        Corrected Total      69        9.93448


                     Root MSE              0.31520    R-Square     0.3799
                     Dependent Mean        0.56190    Adj R-Sq     0.3099
                     Coeff Var            56.09601


                               Parameter Estimates

                                                      Parameter     Standard
Variable             Label                    DF      Estimate        Error    t Value    Pr > |t|

Intercept            Intercept                 1       0.60177      0.05381      11.18      <.0001
Workers              per 1,000 SF              1      -0.09058      0.05326      -1.70      0.0940
South_Double         Yes or No                 1       0.33651      0.15666       2.15      0.0356
South_Ext_Shade      Yes or No                 1       0.23089      0.14555       1.59      0.1178
West_Double          Yes or No                 1      -0.40920      0.14541      -2.81      0.0065
West_Ext_Shade       Yes or No                 1      -0.[illegible]1927      0.11465      -2.78      0.0071
WindowsArea_S        Glazing to SF             1       0.43247      0.14454       2.99      0.0040
Windowsarea_double_s Glazing to SF if Double   1      -4.93992      1.30792      -3.78      0.0004
```

Figure 86: Regression Model for Persistence

The fact that the regression model is highly significant is encouraging. But the fact that several of the estimated coefficients are different than expected suggests that there may be bias from the omission of important variables. Therefore, more work is needed to refine the data collection before these results can be regarded as convincing.