

Pacific Gas & Electric's SmartAC 2008 Load Impact Evaluation

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Abstract

SmartAC™ started in 2007. It is a demand response program that targets central air conditioners in the residential and small commercial sectors. In the first two years of operation, residential customers represent over 99% of all program participants, and thus this evaluation focused only on residential program participants.

The program's goal is to achieve about 300 MW of load relief by 2011.

There are two control technologies available: remotely controlled switches and programmable communicating thermostats (PCTs) with temperature set back capability.

The broad goals of the impact evaluation are to:

- a. Estimate 2008 ex post load impact, for the program as a whole and for each of the two technologies, including snapback
- b. Estimate ex ante load impacts with two sets of weather conditions
- c. Compare two different methods of thermostat control (temperature set back vs. 50% straight cycle)

The load impact evaluation conducted in 2007 concluded that the load impacts from switches were larger than those from thermostats. PG&E looked to increase PCT performance by changing its control strategy in 2008. This evaluation confirmed that the new control strategy increased PCT impacts, but that these impacts continued to be lower than those for switches.

The sample was stratified based on technology type, size of the air conditioner and presence of more than one unit, climate zone, and a proxy for building vintage.

We evaluated the performance for 19 control events (18 of which were for the M&E sample only) that spanned 79 hours during the summer of 2008. Only a single program-wide event (test event) and zero actual events were called during the season. This evaluation was conducted the new California Demand Response Load Impact Protocols established under California Public Utilities Commission (CPUC) Decision D.08-04-050. This evaluation utilized a model to estimate load in the absence of a control event, fit individually to each sample participant. Rather than generically modeling load in relation to weather and time of day, the analysis explicitly took into account the ways air conditioners and each type of control device work. The different control devices and strategies result in different patterns of use during and after a control event. Understanding these differences is important to projecting future impacts for planning and operations.

Introduction

PG&E's SmartAC Program is a direct load control (DLC) program that uses commercial paging signals to communicate with control devices which reduce the energy consumption of participants' air conditioners during Demand Response events. The air conditioners are controlled either by a programmable communicating thermostat (PCTs) or a switch that the Program installs at the participant's residence or small business. The switch employs a technology feature that enhances the devices' control of air conditioners based on prior air conditioning behavior¹. PCTs have the capability to change the indoor

¹ Switches are equipped with technology (True Cycle™) that "learns" the behavior of air conditioning loads over time in

temperature settings at which the air conditioner operates, or to simply cycle the AC units². Except for extreme power emergencies i.e. rotating outages, SmartAC participants can override a control event by going online or calling the SmartAC customer service center.

Launched in spring 2007, the Program began recruiting customers in San Joaquin County (the city of Stockton and its surrounding areas), and has now expanded to other areas of the PG&E service territory. The enrollment reached about 79,000 customers (mostly residential) at the end of the 2008 cooling season. At the time of system peak in 2008, there were about 64,000 customers with installed devices, of who 23 percent were PCT customers.

In 2008, as in 2007, there were no power emergencies and thus no actual program events were called. Had a program event been called, the switches would have reduced air conditioner use to 50% of that observed on learning days, and the PCTs would have shut down the air conditioners 15 minutes out of every half hour.

The load impact evaluation of the Program has three primary goals:

- a. Estimate 2008 ex post load impact, for the program as a whole and for each of the two technologies, including snapback
- b. Estimate ex ante load impacts with two sets of weather conditions (normal & extraordinary)
- c. Compare two different methods of PCT control (setback vs. 50% straight cycle)

Load Impact Evaluation Methodology

KEMA selected a sample of 578 homes with 670 AC units for the metering sample. The sample was stratified by the two control technologies, climate zone, size (cooling tons for sites with one unit, or presence of more than one unit), and home vintage.

Regression models were developed to estimate AC unit-specific baselines for load and duty cycle, which were compared to event-day values.

As in 2007, the 2008 evaluation took place at a time of daily, and substantial, increases in the number of SmartAC participants. Participation increased from 47,000 at the time of the first 2008 SmartAC event in May to 78,000 at the time of the last one in October. The weights utilized for the analysis varied accordingly - for each event, they were based on the composition of the sample and the population on that day.

The 2008 SmartAC load impact evaluation included nineteen events. Eighteen of these events were conducted only for the purposes of evaluation and affected sample participants only. One was conducted for the entire population of SmartAC participants, for the purposes of testing the system. We evaluated the performance of 19 control events that spanned 79 hours during the summer of 2008.

A brief summary of the steps utilized to estimate ex post impacts is the following:

- 1) A *cooling load* submodel was fit to each air conditioner in the sample, to estimate load in the absence of a control event. This submodel captures the relationships between air conditioner load and temperature and other variables, such as schedules. The cooling load submodel is described in more detail below.

order to achieve more load reduction on over sized air conditioning units. The learning algorithm predicts how much the customer's air conditioner would have run during the control period if it were uncontrolled, so that demand response is more effective.

2 For example, "50% straight cycle" refers to letting the air conditioner run 50% of the time, and turning it off the other 50%.

For SmartAC for residential customers, this was done for periods of 15 minutes of running time and 15 minutes of no running time. In this situation, there are demand response impacts only if the unit would naturally run more than 50% of the time during the event. Otherwise, this control method results in synchronizing the air conditioner to the timing of the demand response event, and does not generate real demand response savings.

- 2) A *connected load* submodel was also fit to each of the air conditioners in the sample. Connected load is the instantaneous kW draw of the unit when the compressor is running. Prior studies including KEMA's work have found a consistent linear trend of connected load increasing with ambient temperature. This submodel becomes the upper limit of the kW draw of each unit. This upper limit is especially useful to model situations where temperatures observed during an event are higher than any of the temperatures observed in the absence of events. In these situations (where a model of cooling load is used to predict load at temperatures that are higher than observed in the data that was used to fit the model), there is a possibility that the forecasted load is higher than the connected load (the physical capability) of the unit. The connected load submodel provides an upper limit to the cooling load model, while at the same time acknowledging that connected load does vary with temperature.
- 3) Each air conditioner unit is modeled with the two submodels described above. These submodels are used to estimate the reference load on event days. The load impact of each AC unit is the difference between the estimated reference load and the observed event day load. Program impacts are estimated by applying sample weights to the individual load impact estimates.

Connected Load Submodel

Connected load is the instantaneous kW draw of the unit when the compressor is running. Connected load is often assumed to be constant, taken from nameplate specifications or a single spot kW reading. Prior studies including KEMA's work have demonstrated a consistent linear trend of increasing connected load with ambient temperature, 1 to 2% increase per degree F, depending on the unit (Neal & O'Neal, 1992).

The instantaneous 1-minute kW readings are either 0, if the compressor is not running, or the connected load, if it is running. Thus, each non-zero reading is a direct observation of the connected load. We model these non-zero observations as functions of current ambient temperature and relative humidity.

Figure 1 **Error! Reference source not found.** is an example for a typical unit. It shows that:

- The linear relationship between connected load and ambient temperature is very well determined.
- A very small fraction (less than 0.04 %) of instantaneous readings is over the cloud of connected load data. Thus, this fitted line can be treated as an effective upper bound to the

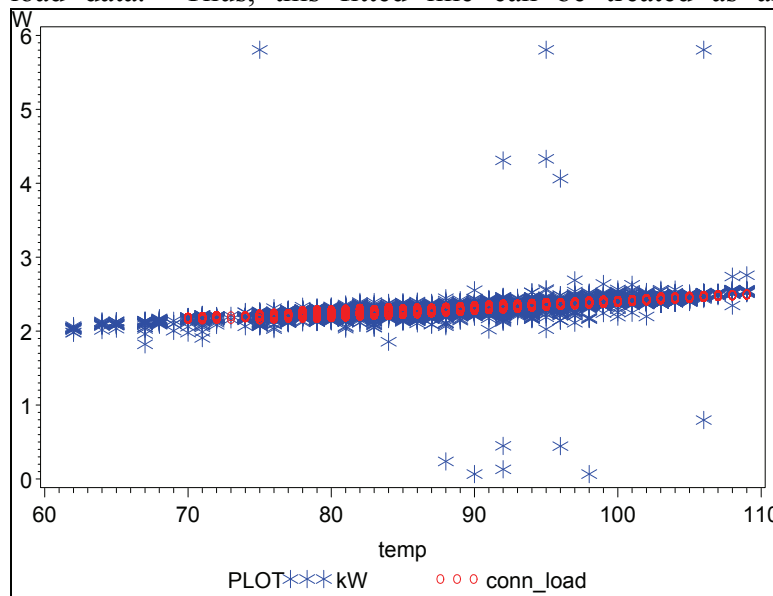


Figure 1 Connected Load (kW) Vs Ambient Temperature (degrees Fahrenheit)

demand at a point in time or averaged over an interval.

Cooling Load Submodel

From the 1-minute instantaneous kW readings, we calculate hourly averages. For a given interval, this average reflects both the kW drawn when the unit is running (i.e., the connected load for the interval), and the fraction of time the unit runs during the interval (the duty cycle, indicated by the fraction of 1-minute observations that are nonzero).

The hourly average demand is estimated using a 2-breakpoint model. The first breakpoint is the home's base or reference temperature (the outside temperature above which air conditioning is required.) This breakpoint is estimated for each unit as part of the model fit. We model hourly average kW as a function of cooling degree-days with respect to this reference temperature, and other terms.

The second breakpoint is the point above which the unit runs at 100% duty cycle, meaning that the average demand over an interval is equal to the connected load. This second breakpoint is estimated implicitly, by setting the model estimate equal to the minimum of the unconstrained estimate and the estimated connected load.

The overall load model is illustrated schematically in Figure 2 below.

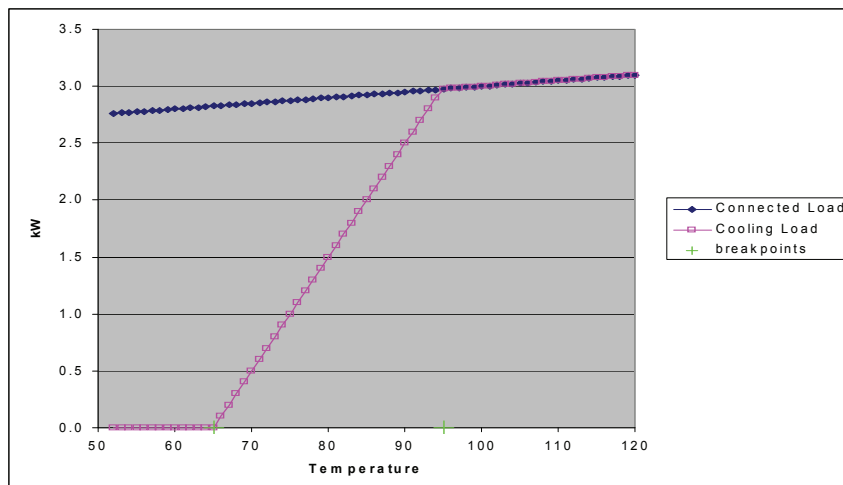


Figure 2 – Illustration of the two components of the load model: Connected Load and Cooling Load

Selected 2008 Ex Post Program Impact at Time of System Peak

As noted earlier, in 2008 there was only one program-wide event, in May. With the exception of the May event, “population” or “program-wide” results refer to estimates of impacts based on this evaluation’s results, had a program event been called on that day.

PG&E’s 2008 system peak occurred on July 8, at 4 PM (hour ending 5 PM), at a load of 20,385 MW. This section describes the load impact estimates on this day.

Ex Post impacts are reported at the unit level. Ex Ante estimates are reported at the participant level. There is an average of 1.1 units per participant.

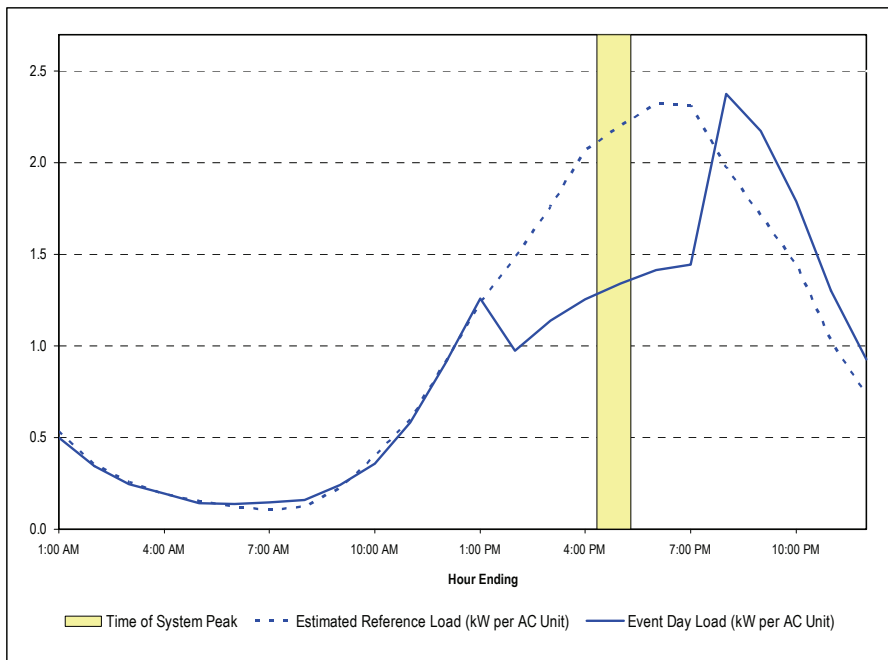


Figure 3 - SmartAC Ex Post Estimated Reference Load and Event Day Load at Time of System Peak (July 8, 2008)

Ex Post Overall Program Impact

On the system peak day, the event took place from hours ending 2 PM through 7 PM. During these hours, the average hourly load impact across sample units ranged from a low of 0.51 kW in the first hour to a high of 0.91 kW on the hour ending at 6 PM. The impact at time of system peak was 0.86 kW per device. The hours after the event indicate a snapback effect of up to 0.46 kW. However, it should be noted that higher impacts actually occurred on July 9th, the day after the system peak day.

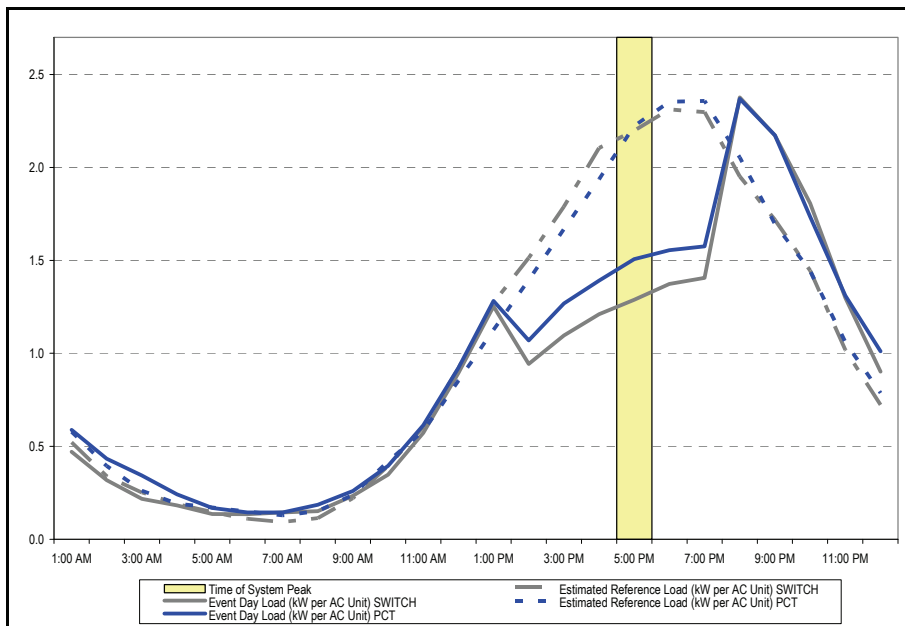


Figure 4 - SmartAC Ex Post Estimated Reference Load and Event Day Load (kW) at Time of System Peak by Device Type (July 8, 2008)

Ex Post Program Impact by Type of Device

Load impacts were calculated separately for each device type. At time of system peak, the average Switch produced a demand reduction of 0.91 kW, compared to 0.72 kW for PCTs. At hour ending 6 PM when the largest demand reductions of the day took place, it is estimated that Switches yielded average demand reductions of 0.94 kW, compared to 0.80 kW for PCTs. This is illustrated in Figure 4.

Because there are more installed Switches than PCTs, their program-wide impact at time of system peak would have been about 44.6 MW for Switches, and about 10.8 MW for PCTs.

Ex Post Program Impact by Load Control Area

Load impacts are calculated separately for each of the California ISO's Load Capacity Areas (LCA) where SmartAC was active in 2008. We estimated load impacts for the Greater Bay Area, Greater Fresno, and Stockton.

At time of 2008 system peak, the highest savings per unit were in the Greater Bay Area, at about 1 kW per unit. The savings in Stockton are estimated at 0.90 kW, and in Fresno, at 0.70 kW per unit, respectively. This is illustrated in Figure 5.

In general, the hottest of these three areas is Fresno, followed by Stockton and then the Bay Area. It is noteworthy that on the day of the system peak, the temperatures in the Greater Bay Area exceeded those in Stockton for the on-peak hours. At time of system peak, the weighted average temperature was actually higher in the Greater Bay Area than in Greater Fresno.

It is estimated that a program-wide event would have about 26 MW contributed from the Greater Bay Area, 12 MW from Greater Fresno, and 6 MW from Stockton.

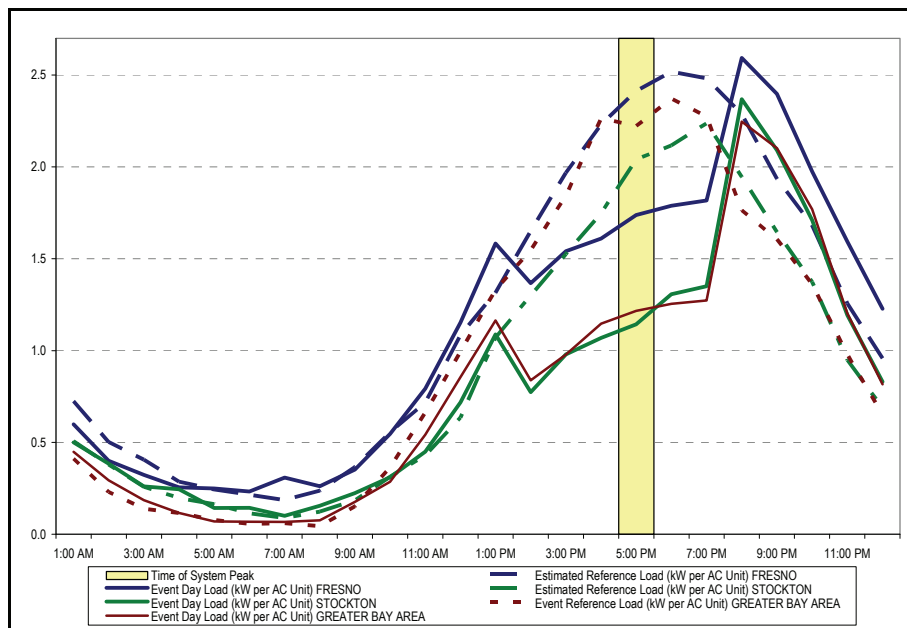


Figure 5 - SmartAC Ex Post Estimated Reference Load and Event Day Load (kW) at Time of System Peak by Load Capacity Area (July 8, 2008)

Selected Ex Ante Program Impacts

As dictated by the California Demand Response Protocols (CPUC Decision 08-04-050, April 24, 2008), ex ante load impacts were estimated for 1-in-2 and 1-in-10 weather conditions³.

³ PG&E selected 2004 to represent the 1-in-2 weather conditions, and 2003 to represent 1-in-10. Year 1-in-10 peak is in July

In addition, the ex ante load impacts at the participant level were combined with an enrollment forecast developed independently of this evaluation to produce Program-level ex ante impacts, which are also not part of this evaluation. The enrollment forecast and the ex ante Program-level estimates dictate that ex ante impacts be estimated differently than ex post estimates:

- As mentioned above, ex post impacts are reported at the AC unit level. Ex ante estimates are reported at the participant level. There is an average of 1.1 units per participant.

Ex ante estimates are estimated at the climate zone level.

Figures 6, 7 and 8 illustrate the differences between 1-in-2 and 1-in-10 load impacts in the three climate zones⁴.

- Climate zone R displays the smallest of these differences. The maximum load impact is reached in August for year 1-in-2, and in July for year 1-in-10. There is an average difference of about 7% in the load impacts for these two years. The reference loads are very similar for each of the years in this climate zone. This is reasonable considering that this climate zone experiences hot weather consistently.
- Both climate zones S and X experience less consistent hot weather, which creates larger differences between the load impacts in hotter years and in milder years.
- In climate zone S the forecasted load impact in 1-in-10 (June) is twice as much as that in 1-in-2 (August).
- In climate zone X the difference between 1-in-10 (July) and 1-in-2 (September) is about 35% - not quite as high as with climate zone S, but still much higher than with climate zone R.

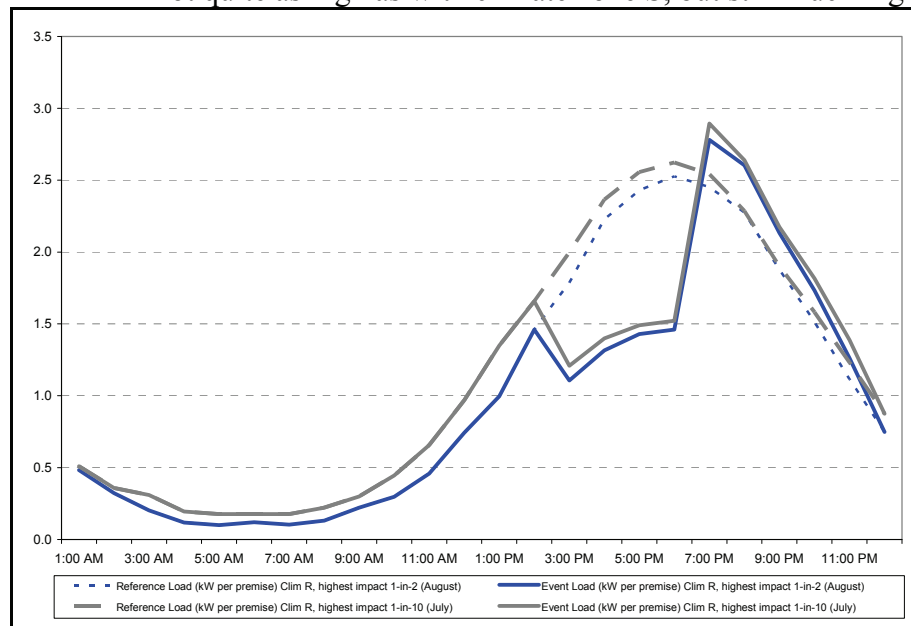


Figure 6 - Ex Ante Estimates (kW) for Climate Zone R

for climate zone R and in June for climate zone S. Year 1-in-2 peak is in August for climate zones R and S and in September for climate zone X.

The timing of the maximum load impact is roughly consistent with the California Independent System Operator's (CAISO) reported system peaks, on July 17, 2003 (1-in-10) and September 8, 2004 (1-in-2). From 1998 to 2007, 2004 was the only year that the CAISO peaked in September. All other CAISO peaks occurred in July and August.

4 PG&E has four large climate zones (R, S, X, and T, listed from hottest to mildest), which are defined according to the baseline territories used in PG&E's tariffs. Ex ante impacts were calculated for climate zone T, but are not discussed in this document.

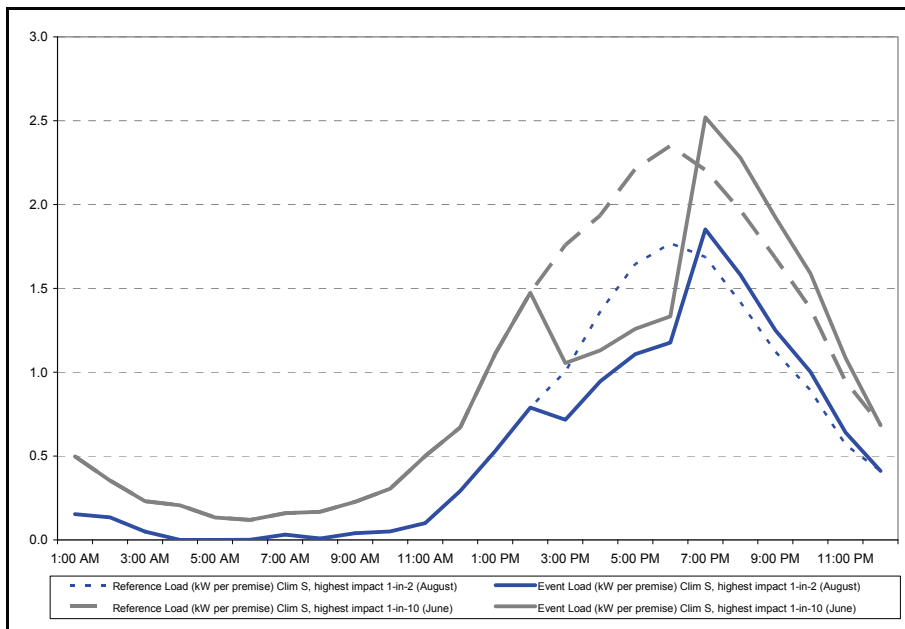


Figure 7 - Ex Ante Estimates (kW) for Climate Zone S

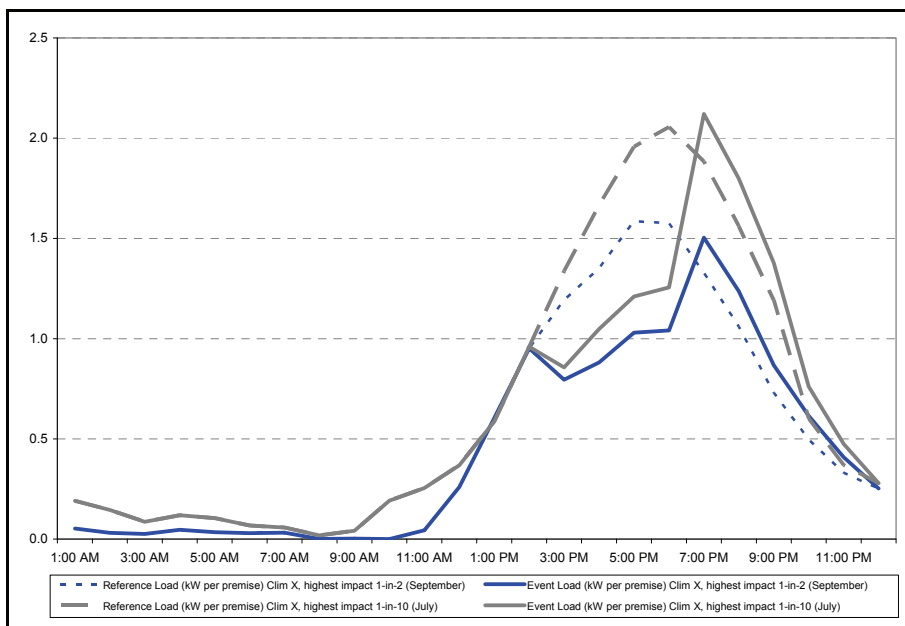


Figure 8 - Ex Ante Estimates (kW) for Climate Zone X

Differences between PCT Set Back and a 50% Cycling Strategy

In 2007, the SmartAC program chose a ramping strategy for program PCT participants in the event of full program activations. Once the program was deployed the ultimate strategy chosen imposed an increase of 1°F at the beginning of the first, third, and fifth hours of the event⁵.

⁵ The 2007 report refers to this strategy as the “gradual” strategy. For the purpose of testing the ramping strategy concept, PG&E identified a second, more aggressive ramping strategy to be tested only on the M&E sample which was referred to as the “steep” strategy. The steep strategy increased the set-point 1°F at the beginning of each of the first four hours.

Seeking to improve PCT's lower-than-expected impacts found in 2007, in 2008 the SmartAC program changed its program-wide PCT control strategy to legacy switch-style cycling. The PCTs deployed in 2007 & 2008 do not have the learning capabilities that enable switches to provide more effective cycling, but can be operated as a 50% straight cycle control.

In 2008, the M&E sample tested a third set-point control strategy—a “2-1-1 ramp.” The 2-1-1 ramp increased the set-point 2°F at the beginning of the first hour, and 1°F each at the beginning of the second and third hours.

The ex post results for the 2008 ramped PCT (2-1-1) show higher nominal savings at certain dates and hours than those for 50% straight cycle, and even the adaptive cycle. This result led us to investigate whether this control strategy may be able to deliver higher load impacts for SmartAC PCTs than the 50% straight cycle.

Based on our review of the results of the 2-1-1 PCT ramping strategy and some illustrative theoretical analysis, it appears unlikely that the PCTs that were evaluated in 2008 can outperform the 50% duty cycle control at high temperatures using temperature setbacks within the limits of the current tariff⁶. In 2009 the SmartAC program will introduce a new model of PCT that can utilize learning algorithms for direct load control. This upgraded PCT is expected to improve the load impacts delivered by those of the older model.

Temperature increases and duty cycle reductions produce impacts in different ways. While the two are frequently compared (i.e. “a 4 degree setback is equal to 50 percent cycling”), any realistic comparison should, at a minimum, consider the following variables: outdoor temperature, indoor rate of temperature gains, set point, and AC sizing.

PCT impacts are a combination of two factors: (1) complete elimination of AC operation during the float period, while the house rises to the new set point and the AC starts running again, and (2) the lower duty cycle required to maintain the house temperature at the higher set point.

To investigate the differences between the three control strategies tested in 2008 (switches, PCTs utilizing the 2-1-1 temperature setback, and PCTs utilizing the 50% straight cycle), we mapped out the theoretical behavior of the control technologies, and developed a Ramp vs. Duty Cycle worksheet tool (KEMA 2008c) to illustrate these relationships. The figures below show the average impact over a 4-hour control period for three different control strategies, calculated using the tool. For each scenario illustrated, we discuss the underlying key qualitative relationships considered.

Figure 9 illustrates some general relationships:

- At moderate temperatures, the PCT is capable of providing impacts that compare favorably to those from both duty cycle control strategies.
- At extremely hot temperatures, the PCT set point adjustment will have no effect. That is, once the temperature is 4 degrees or more above the point where the unit is maxed out, the unit will continue to run at 100% if the set-point is raised by up to 4 degrees. Oversized units may never reach conditions where this takes place, but properly sized units may reach this point within the range of realistic temperatures.

For the case illustrated in Figure 9, the avoided use while the home floats to the higher setpoint provides the majority of the PCT savings. Figure 9 assumes 36 minutes of float time for each 2 degree set point increase. Some houses may take more time, others less. As outside temperatures increase, float time decreases.

⁶ The SmartAC tariff in effect in 2007 and 2008 allows for a maximum temperature setback of 4°F.

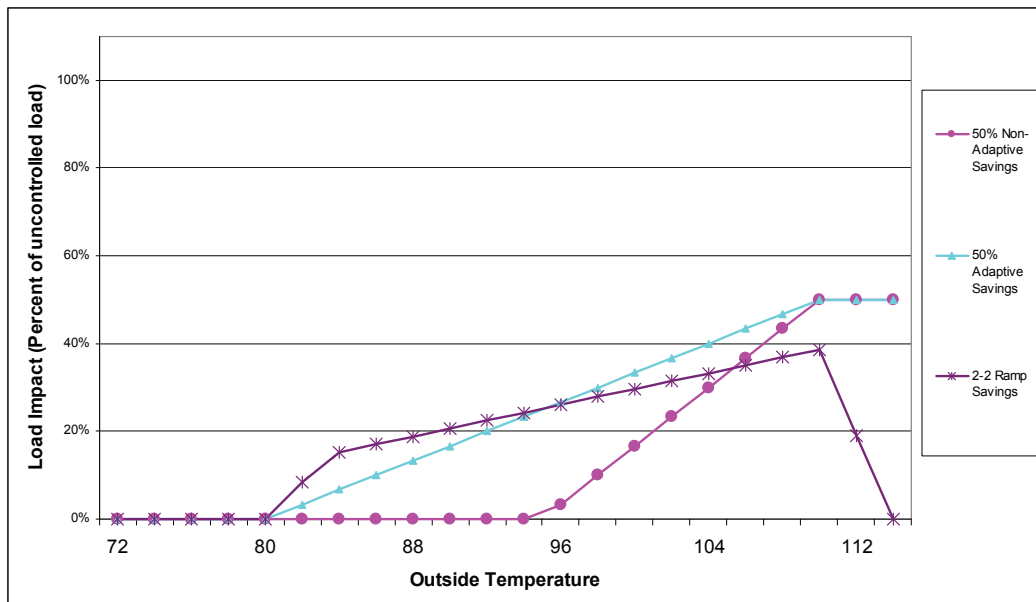


Figure 9 - Illustrative comparison of average impacts for different 4-hour control strategies
Outdoor temperature at which the AC operates = 80°F
Temperature at which unit reaches 100% duty cycle = 110°F
Float= 60% (36 minutes each of first two hours)

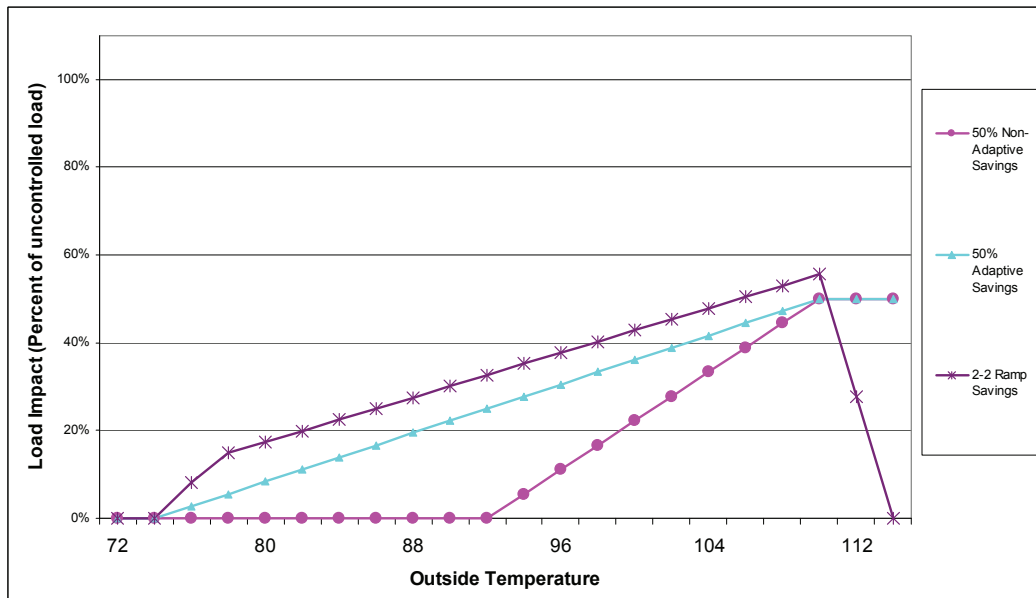


Figure 10 - Illustrative comparison of average impacts for different 4-hour control strategies - lower reference temperature, longer float
Outdoor temperature at which the AC operates = 74°F
Temperature at which unit reaches 100% duty cycle = 110°F
Float= 100% (60 minutes each of first two hours)

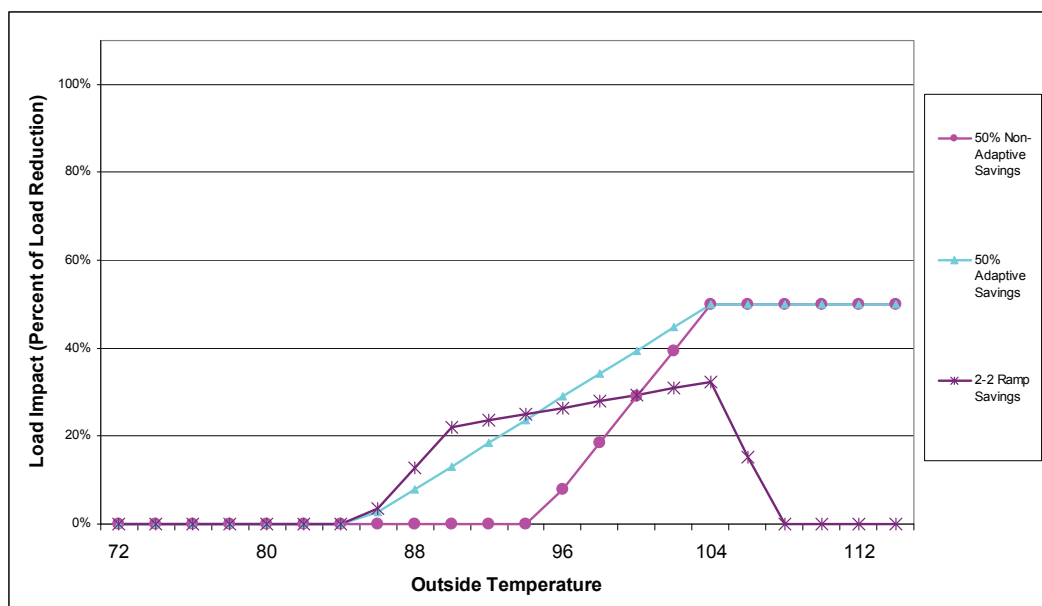


Figure 11 - Illustrative comparison of average impacts for different 4-hour control strategies - higher reference temperature, shorter float

Outdoor temperature at which the AC operates = 85°F

Temperature at which unit reaches 100% duty cycle = 104°F

Float= 33% (20 minutes each of first two hours)

Ramped PCTs can provide better impacts than adaptive switches at high temperatures for houses with certain conditions. Figure 10 illustrates a house that is kept at a very low temperature and the temperature increases very slowly. Under these conditions, the 2/2 ramp would effectively turn the unit off for two hours or more. Across a wide range of temperatures, the ramp impact is above that of the adaptive switch. At a very high temperature (in this example, 114°F) the PCT impact again goes to zero.

Last, Figure 11 illustrates a likely scenario where an air conditioner kicks in when the outdoor temperature reaches 85 degrees, it runs at 100% duty cycle when it reaches 104 degrees, and it can float for 20 minutes after it reaches the temperature dictated by the PCT. As with the first example:

- At temperatures just above the home's reference temperature, the PCT yields the highest impacts of the three technologies;
- At higher temperatures, PCT ramping outperforms a fixed 50% cycling switch but not the adaptive switch, and
- At very high temperatures the PCT ramp provides no savings.

Conclusions

The learning algorithm employed by the switches is effective. The switches used by the SmartAC program employ learning algorithms that aim to reduce air conditioner load compared to its own load observed in the past, rather than restricting its run time to a pre-determined number of minutes per hour. In the absence of enough data to inform the algorithm, the switches revert to a fixed 50% cycle. This evaluation demonstrated that the learning algorithm is effective at increasing load impacts compared to fixed cycling.

The learning algorithm employed by the switches is not fully utilized yet. This study produced evidence (included in the full report) that the switch performance is roughly midway between that of "ideal" control and the fixed 50% control. Further, the performance moves closer to ideal behavior at higher

temperature. At higher temperatures, switches produce load impacts that are effectively a combination of about 60% “learned”, 40% fixed cycle control. Increasing the percent of units utilizing the algorithm can improve load impacts. In 2009 an updated algorithm (TrueCycle2) will be employed which will further refine the cycling and will be evaluated as part of the 2009 load impact evaluation.

In 2008 Switches produced higher load impacts than PCTs. On average, switches produced higher load impacts than PCTs utilizing a 50% fixed cycle and a 2-1-1 setback algorithm.

Different control devices and strategies result in different patterns of use during and after a control event. Understanding these differences is important to projecting future impacts for planning and operations.

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