Expanding the Value of AMI Data for Energy Efficiency Savings Estimation in California

Jarred Metoyer and The Work Order 46 Team, DNV GL
Mona Dzvova, California Public Utilities Commission

ABSTRACT

Combining account-level automated metering infrastructure (AMI) data for residential and small commercial buildings with detailed engineering, statistical, and building modeling methods enables estimation of HVAC loads with a high degree of precision at a much lower cost than conventional end-use metering approaches. This paper presents the innovative methods used to expand the value of AMI data for a variety of energy efficiency evaluation purposes and presents preliminary study results.

The California Public Utilities Commission's current evaluation of a Whole House Retrofit program began using AMI data as a supplement to traditional evaluation based on billing analysis. This study begins the conversation of using hourly whole premise consumption data for energy efficiency program savings analysis. The analysis could be pre- and post-retrofit, treatment and comparison group type analysis, or a combination of both. Illustrative examples present two initial approaches used to develop comparisons between traditional monthly billing analyses and AMI analyses.

Although preliminary, the evaluation team initially discovered savings from AMI investigations more consistent with the expectations of the measures in the program compared to the monthly analyses. The program measures (e.g. insulation, air sealing, duct sealing) would tend to reduce the sensitivity of cooling consumption to temperature. Notably the comparison group approach shows a sharper response to temperature compared to participants. The pre-post results show summer savings consistent with comparison group profiles.

Introduction

This paper describes the initial use of automated metering infrastructure (AMI) interval data to help gain a deeper understanding of results of a traditional monthly billing analysis. Analysis of monthly energy bills underpins many evaluations of energy efficiency programs and projects. From program-level analyses to site-specific simulation calibration, monthly consumption data allows evaluators to estimate impacts of energy efficiency interventions, consistently, for decades. New evaluation techniques are needed as programs expand into non-extreme climates and include technologically-advanced measures. In California, the adoption of interval utility meters promises new opportunities for energy efficiency and heralds the strategic use of the new data.

The California Public Utilities Commission's current evaluation of a Whole House Retrofit program began using AMI data as a supplement to traditional evaluation based on billing analysis. The paper describes the program participants, monthly data analysis and initial results, followed by visualization of the AMI data being used to further investigate and interpret the original findings. Unlike the monthly data, AMI data can be used to examine demand savings around peak conditions. The demand analyses and final billing analyses is ongoing and the analyses presented here are considered exploratory investigations for this paper.

The Program and Initial Evaluation

DNV GL conducted the first phase of the impact evaluation of the California investor-owned utilities' (IOU) Residential Whole Building Retrofit Program 2010-2012. The IOU programs offered packages of prescriptive measures (Basic Upgrade Package) and performance-based incentives (Advanced Upgrade Package). The evaluation focused on the Advanced path which comprised a majority of participation and estimated savings. The incentives were scaled based on percent savings estimated for electric and gas measures. Examples included an incentive of $1,500 for 15% estimated savings to $4,000 for 40% estimated savings. The program contractors who completed retrofits used standard simulation software to estimate the savings.

The savings for many of the measures depend on climate conditions including adding insulation, air sealing, duct sealing, and installing high efficiency heating and cooling equipment. The evaluation plan selected a multi-phased billing analysis since the expected savings should be a significant proportion of total consumption and the program is based around a package of measures. The evaluation first explored the geographical distribution of participants followed by the consumption based on monthly utility bills.

Geographical Distribution of Program Participants

This section describes the geographical distribution of the program participants. The California Climate Zones climate zones with the most program participants as a percent of each utility's participants were:

- 46% of PG&E program participants (1,775) are in Climate Zone 12 (warm to hot)
- 51% of SCE program participants (1,128) are in Climate Zone 9 (mild to warm)
- 75% of SDG&E program participants (542) are in Climate Zone 7 (mild)

The distribution by climate zone shows that the first phase of the program concentrated on areas near the Pacific coast with mild and temperate climates. The following figures show the geographical distribution of program participants by zip code in IOU service territories. The maps focus on participation and may not show complete service territories. Shades of green represent one to three participants in a zip code, shades of yellow represent four to 20, orange represents 21 to 40, and red represents 41 or more participants in the same zip code.

The following figure shows the geographical distribution of program participants by zip code in the PG&E service territory as an example. Participation concentrated in areas near the coast with some low concentrations in some of the hottest locations. Note that climate zone twelve had concentrations in two parts: one near Sacramento that does not have PG&E electric service and another around the East Bay area that is in PG&E territory. The other IOU program participation concentrated near the coasts as well.

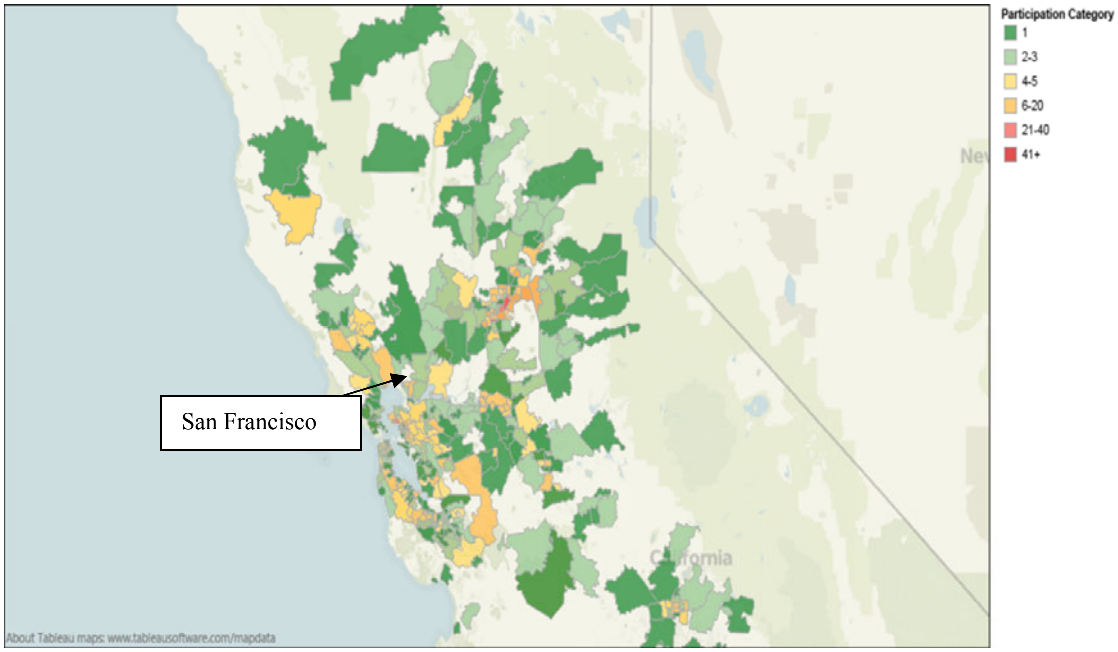

Figure 1. Distribution of 2010-2012 program participants in the PG&E service territory. *Source*: CPUC 2013.

Example of Comparison of Electric Consumption by Climate Zone

The plot in Figure 2 shows one comparison between 2011 to 2013 monthly electricity use in program participants in climate zones twelve, the two largest one in terms of PG&E program participation. The plot includes monthly electric consumption of program participants before and after retrofit. These comparisons identify differences in energy use between customers in the program and highlight overall variability in consumption from year to year and from pre to post. In particular, data were plotted to determine whether the energy use of all program participants decreases significantly after all retrofits are complete (2013) and to review the distribution of consumption for each month.

The next plot shows climate zone 12 is variably weather sensitive. Unlike climate zone 3, this climate zone does experience a slight increase in average consumption in the summer months that is distinguishable from the winter months, but the variability is also greater with some very high and some very low users in the same month. The large area and various microclimates are one factor and personal preferences within the microclimates likely leads to the larger distributions. The features used in the box and whisker plots displayed in this section represent the following:

Group Summary Statistic	Feature of Box-and Whisker Plot
Top/bottom 1% of records displayed	Circles
99th percentile	Endpoint of right whisker
Third quartile (75th percentile)	Right edge of box
Median (50th percentile)	Line inside box
Mean	Color change in box
First quartile (25th percentile)	Left edge of box
Minimum	Endpoint of left whisker

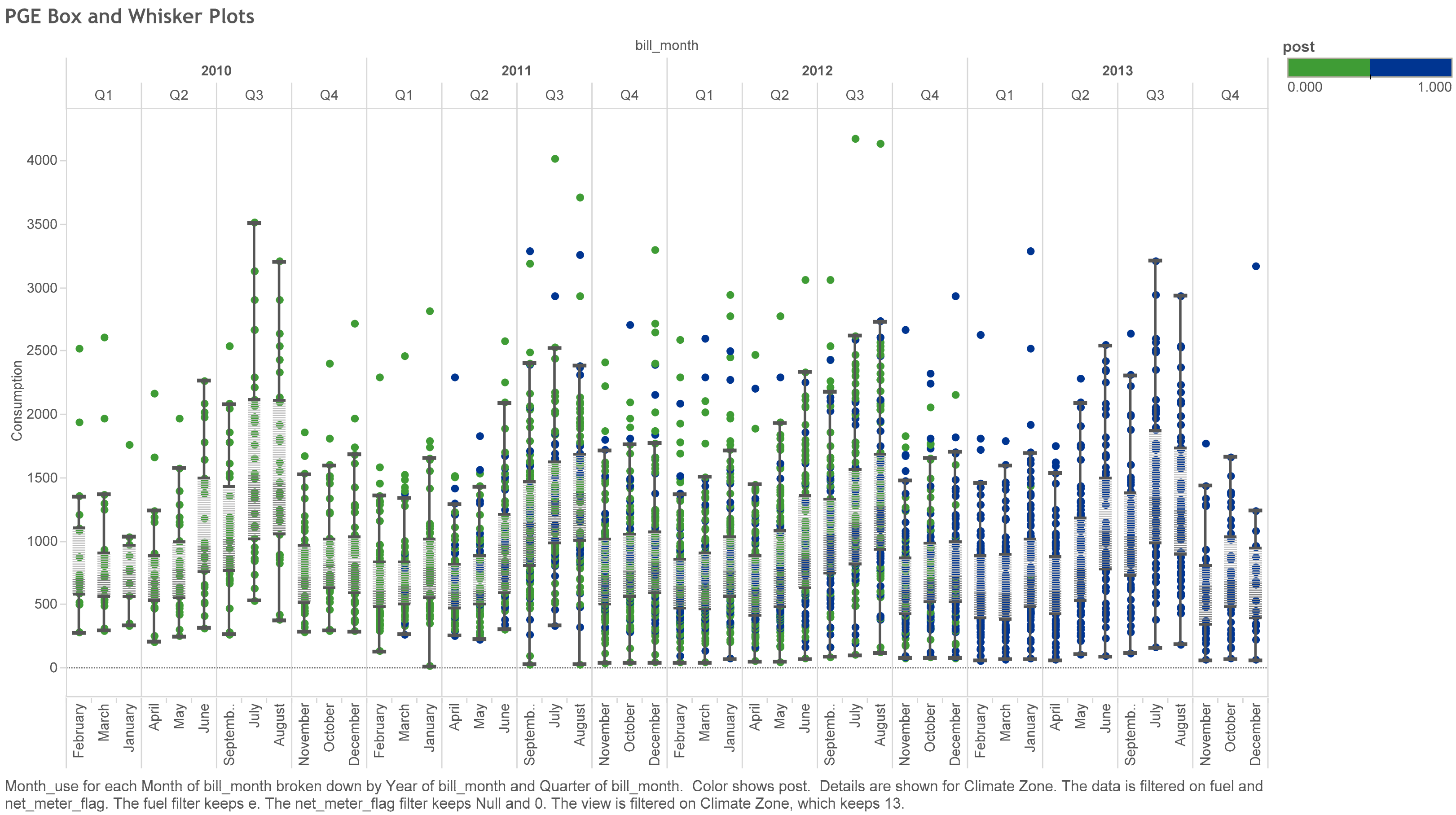

Figure 2. Climate zone twelve (Sacramento / Concord) electric consumption of whole house program participants. *Source*: CPUC 2013.

Initial Savings Analysis Using Monthly Bills

The evaluation includes analysis of gas savings and net electric savings, but this paper focuses on gross electric energy savings in order to compare to hourly electric AMI data. The gross savings analysis is based on an approach tailored to the current state of the program: no prior cycle program activity, participation started during the middle of the 2010-2012 program cycle, and the program worked in conjunction with ARRA funded efforts until mid-2012. The billing analysis approach used in this evaluation is described in more detail in the CPUC Work Order 46 Evaluation Plan[1]. This section presents some of the specifics of the model for this preliminary evaluation.

Fixed Effects Model

DNV GL conducted billing analysis using a Fixed Effects model to estimate program savings. For each IOU, all monthly consumption data (both pre and post-installation) of eligible participants are included in a single model with the following specification:

$$E_{im} = \mu_i + \beta_1 Post_{im} + \beta_2 CDD70_{im} + \beta_3 HDD60_{im} + \beta_4 PostCDD70_{im} + \beta_5 PostHDD60_{im} + \theta_m + \varepsilon_{im}$$

Where:

E_{im}	Average electric (or gas) consumption per day for participant *i* during billing period *m*
μ_i	Fixed effect (or specific intercept) for participant *i*
$Post_{im}$	Post-retrofit period indicator (1 for post-installation and 0 for pre-installation period)
$CDD70_{im}$	Average daily cooling degree days (CDD) at 70^{0}F for participant *i* during billing period *m* *(not included in gas model)*
$HDD60_{im}$	Average daily healing degree days (HDD) at 60^{0}F for participant *i* during billing period *m*
$PostCDD70_{im}$	Interaction term between post indicator and CDD70 *(not included in gas model)*
$PostHDD60_{im}$	Interaction term between post indicator and HDD60
θ_m	Monthly binary variables for each billing month
β_1	Change in energy consumption during post-installation period
β_2	Effect of cooling on energy consumption during pre-installation period
β_3	Effect of heating on energy consumption during pre-installation period
β_4	Change in the effect of cooling on energy consumption during post-installation period
β_5	Change in the effect of heating on energy consumption during post-installation period

[1] Impact Evaluation Research Plan. WO 046—Residential Whole Building Retrofit.
California Public Utilities Commission, Energy Division. Proposal Reference Number 09PS5863B
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Weather-normalized savings are calculated as:

$$Average\ Normalized\ Daily\ Savings = \beta_1 + (\beta_4 \times \overline{CDD70}_{norm}) + (\beta_5 \times \overline{HDD60}_{norm})$$

Where:

$\overline{\beta_1}, \overline{\beta_4}, \overline{\beta_5}$	Coefficients determined by the fixed effects model
$\overline{CDD70}_{norm}$	Average daily CDD calculated using temperature data from TMY3 or CTZ2 of the participants *(not included when estimating gas savings)*
$\overline{HDD60}_{norm}$	Average daily HDD calculated using temperature data from TMY3 or CTZ2 of the participants

Monthly Analysis Results

Table **1** summarizes the average annual electric and gas consumption during the pre- and post-installation periods, the weather-adjusted energy use for the same two periods, the weather-adjusted program impacts estimated with the billing analysis, and the Ex Ante savings as a percent of annual consumption before installation. Table **1** illustrates the following:

- Actual consumption (not weather normalized) is the energy use average of the 12 months before and 12 months after participation in the program. These two figures cannot be directly compared because weather, the most influential variable in energy use, varies from one year to the next.
- Weather-Adjusted Consumption is the weather-normalized energy use average of the 12 months before and 12 months after participation in the program, obtained from the PRISM estimates. These estimates may show an increase or decrease in use compared to the prior year, which is not adjusted for program effects, and thus cannot be used directly to estimate savings. For example, if program participants are already reducing their energy use prior to implementing the program measures for reasons that are independent of the program, post-retrofit weather-normal energy use may be lower, but such change cannot be attributed to the program.
- Estimated Program Savings are the changes in pre-/post- retrofit weather-normalized consumption attributed to the program. These savings estimates are calculated from the Fixed Effects model that controls for site-specific characteristics that do not change over time and for the overall consumption trend that is not program-related.

Table 1. Energy use and program savings estimates by IOU for 2010-2011 participants with 12 months of pre- and post-retrofit data

Consumption/Savings	Annual Electric (kWh)		
	PG&E	SCE	SDG&E
No. of sites	389	483	137
Actual Consumption Per Site (**not** weather-normalized)			
Avg Annual Usage Before Installation	8,428	9,894	7,096
Avg Annual Usage After Installation	8,149	9,834	6,780
Weather-Adjusted Consumption Per Site (Using TMY3)			
Avg Annual Usage Before Installation	8,498	10,076	6,990
Avg Annual Usage After Installation	8,143	9,588	6,645
% Change in Energy Use	-4%	-5%	-5%
Estimated Program Savings			
Normalized annual savings using TMY3			
Annual savings estimate	5.6 ^{ns}	290.2 ^{ns}	366.2
Standard error	184.9	224.7	212.1
Percent savings	0.1%	3%	5%
Ex Ante Software savings as percent of total annual usage	35%	11%	27%
Ex Ante claimed savings as percent of total annual usage	21%	6%	18%

* Statistically significant at 10% level
** Statistically significant at 5% level
^{ns} Not statistically significant

Overall, we found that the program generated statistically significant reductions in electricity consumption for SDG&E using TMY3 normal weather. Reductions in electricity consumption were not significant for PG&E and SCE using normal weather. For SDG&E, the average estimated savings are 366 kWh per year[2], or about 5% of weather-normalized annual consumption. In contrast, all gas utilities showed statistically significant gas savings. For PG&E, the average estimated savings are 63.2 therms per year, or about 11% of weather-normalized annual consumption. For SDG&E, the same 63.2 therms per year amount to 15% of weather-normalized annual consumption.

The results raised concerns given the expected total percent savings were not being realized and while there were gas savings (though less than expected), the electric savings appeared to be very small and within the margin of error. As illustrated prior to the analysis the variability in consumption between participants in relatively similar climates varied the most under hotter conditions. The evaluation team hypothesized that the driving factor for the results were milder microclimates within climate zones and cooling setpoint assumptions that did not capture the program variability.

Fortunately the study transitioned to a second phase and that task refines the phase one monthly analysis and adds additional hourly analyses. The evaluation team approached the initial

[2] Using TMY3 weather

analysis in an exploratory fashion. We anticipate this analysis to be a conversation starter with several other relevant options that were not chosen to be tested on this problem.

Savings with AMI Data

The evaluation team took on the primary challenge of adapting proven techniques for energy efficiency and demand response evaluations into this analysis. The results from the previous monthly billing analysis led us to prioritize use of the electric AMI data as the subject for comparison since the monthly gas data was already showing significant savings across climates. The added granularity of hourly electric data only adds more variability, which would not seem to help the problem. We performed an initial exploration using a simplified pre and post model that was similar to the pooled fixed-effect monthly analysis, as well as a simplified treatment and comparison group approach. The final combined approach remains under development to incorporate an improved comparison group specification.

Change in Consumption "Pre-Post"

The exploratory analyses visualized the data and analysis results to make an initial comparison to the monthly analyses. Figure 5 illustrates the savings from the retrofit program based on hourly electric data and knowledge of the timing of retrofits. The graph shows energy savings for retrofit customers in black and losses for retrofit customers in dark blue. The graph indicates areas with no savings or losses in light blue. The procedure to construct the graphs was as follows:

1. Draw a random sample of 200 customers from each of the three electric IOUs.
2. Pull the hourly electricity use for each member of the sample from 2011 through 2013.
3. Categorize the hourly data into three period:
    - Pre—30 or more days before the retrofit
    - Blackout—within 30 days of the retrofit
    - Post—30 or more days after the retrofit
4. Compute the average energy use for the post and pre periods by hour, day, and IOU.
5. Compute difference in energy use between the pre and post group by hour, day, and IOU.
6. Graph the differences where there is a mix of pre and post retrofit customers. The figure only graphs differences where the customer mix contains are least 20% of the pre and at least 20% of the post retrofit customers.

Customers begin in the pre group and end in the post. Since the retrofit activity took place in 2011 through 2012, the pre and post customer pools constantly change through the analysis period. At these early stages of the analysis there are still periods of missing data. Unfortunately the late ramp-up in participation for SDG&E is missing from the figure. Despite the data limitations, the initial results show savings for PG&E and SCE that may have been masked in the monthly analyses. The later PG&E participants seem to add smaller saving sites and perhaps some consumption increases which diminishes savings seen as significant from early participants. The SCE loadshape appears to be trending toward increased savings at the point where the data is cut off due to lack of reliable estimates.

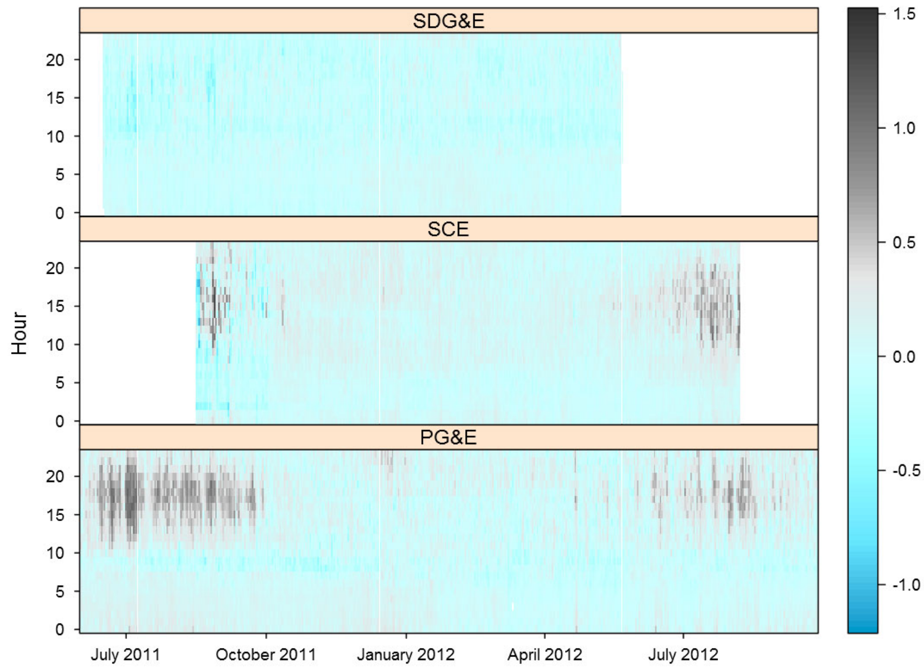

Figure 3. Electric energy savings loadshapes based on pre-post AMI analysis. *Source*: CPUC 2013.

Treatment and Control

The team analyzed the same data by developing a comparison group using the pre consumption of the nearby homes with similar consumption. The comparison group comprised participants prior to their retrofits. To best match household characteristics these prior participants served as the comparison as opposed to other matching and selection options. The analysis options were limited given the program did not have any participation prior to the 2010-12 program cycle.

Figures 6, 7, and 8 below agree with the initial findings from the pre-post analysis. Significant savings are shown in the average daily profiles for PG&E and SCE. The same limitations exist for SDG&E and SCE participants in late 2012 which reduce the savings shown in the average daily loadshapes.

The PG&E average daily profile shows late evening cooling as a driving factor of the whole house load shape. This aligns with the timing of savings in the pre-post analysis. The project team noticed that both analyses show clear patterns of savings while the monthly approach struggled with high variability. Notably the control group shows a sharper response to temperature. The program measures (e.g. insulation, air sealing, duct sealing) would tend to reduce the sensitivity of cooling consumption to temperature.

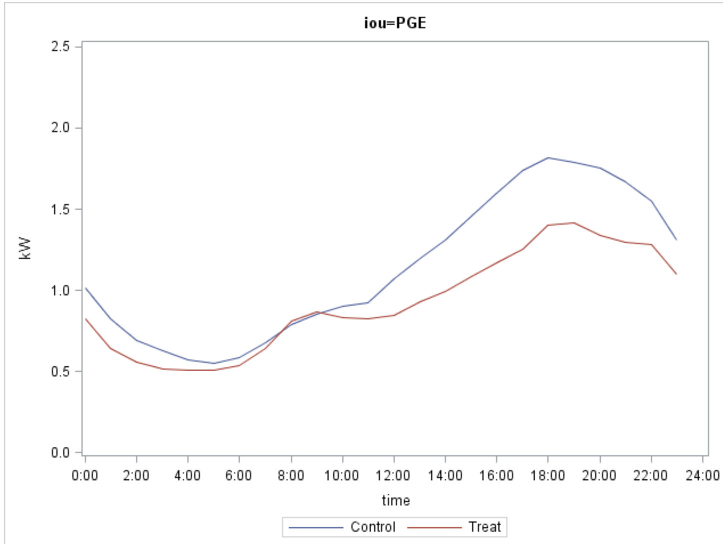

Figure 4. Electric energy savings average daily loadshapes based on comparison group AMI analysis. *Source*: CPUC 2013.

The SCE average daily profile shows early afternoon cooling as a driving factor of the whole house load shape. This aligns with the timing of savings in the pre-post analysis. Similar to PG&E, the project team noticed that both analyses show clear patterns of savings while the monthly approach struggled with high variability, and. notabl, the control group shows a sharper response to temperature. The program measures (e.g. insulation, air sealing, duct sealing) would tend to reduce the sensitivity of cooling consumption to temperature.

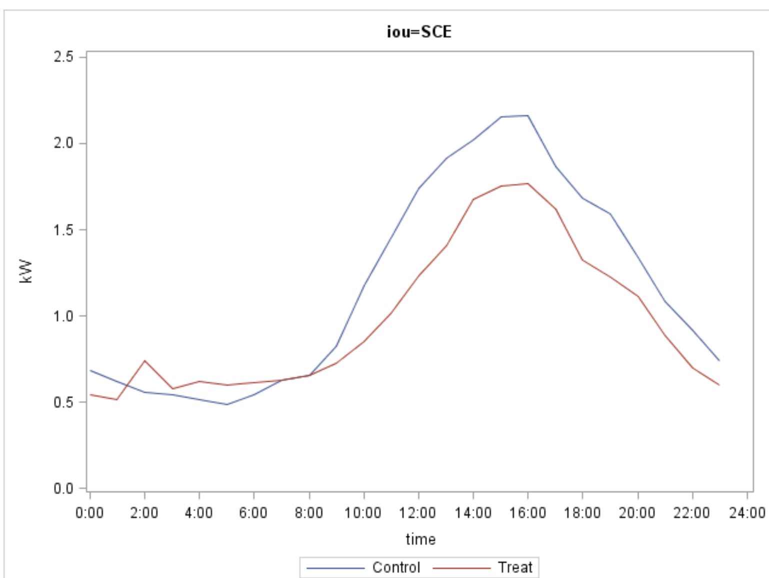

Figure 5. Electric energy savings average daily loadshapes based on comparison group AMI analysis. Source: CPUC 2013

The SDG&E average daily profile shows a relatively flat profile for the whole house load shape likely driven by a high percentage of coastal participants. The pre-post analysis proved inconclusive for SDG&E and so does the comparison group approach. The project team noticed that both AMI analyses did not show clear patterns of savings while the monthly approach showed statistically significant savings.

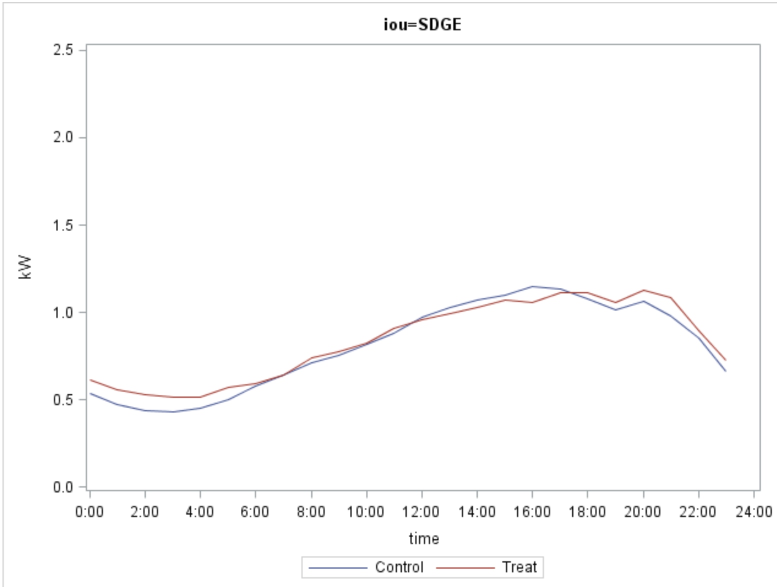

Figure 6. Electric energy savings average daily loadshapes based on comparison group AMI analysis. Source: CPUC 2013

Conclusions

The analysis of AMI data for whole house program participants created more questions than it answered. The results seemed to be the opposite of the monthly analyses as the utilities with low savings showed much more when changing from monthly to hourly data sources. The converse also proved true where a utility with statically significant savings from the monthly analysis had indistinguishable savings from the AMI analyses. The data gaps contributed to the latter case. The results, however, still raised questions as to why the monthly analysis and AMI investigations would be so different.

The evaluation team initially discovered savings from AMI investigations more consistent with the expectations of the measures in the program compared to the monthly analyses. The program measures (e.g. insulation, air sealing, duct sealing) would tend to reduce the sensitivity of cooling consumption to temperature. Notably the comparison group approach shows a sharper response to temperature compared to participants. The pre-post results show summer savings consistent with comparison group profiles.

The study now progresses to filling the initial data and methodological gaps and starting to quantify savings from the new approaches. The initial investigation allowed the evaluation team to see the potential of AMI analyses and the need for more development to ensure stable and defensible results. Additional analyses to determine the source of the differences in the monthly and hourly analyses continues given the initial results of lower than expected savings from the traditional billing analysis.

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