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Public Interest Energy Research (PIER) Energy Savings through Smart Controls in Multifamily Housing Study:
Impact Analysis

Final

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March 2014

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This document is part of the fulfillment of deliverable *3.2.2 for Contract #: 500-10-019.* The work effort took place under sub-contract to the Benningfield Group under the direction of Garth Torvestad.

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1. Executive Summary

The Benningfield Group secured a contract with the California Energy Commission (CEC) Public Interest Energy Research (PIER) program to investigate Energy Savings through Smart Controls in Multifamily Housing (Contract #500-10-019). This contract includes several facets of research of which this document reports on only part. Opinion Dynamics Corporation, through a subcontract with the Benningfield Group, served as technical support for the impact analysis. This document provides results from the impact analysis only.

The overarching goal of this study is to test, demonstrate, and quantify the benefits of smart controls and smart meter technologies in multifamily buildings. The last several years have seen a proliferation of utility-side smart grid and smart meter projects, but consumer-facing extensions of these projects are just now being refined, including new in-home energy monitoring and control devices. These devices can work from within the home and community to achieve energy efficiency and energy cost benefits that are available from the user side of the meter.

The Benningfield study focuses on these in-home energy monitoring, display, and smart thermostat devices, collectively referred to as "smart controls". The study builds upon and complements the 2011 Residential Information and Controls Study sponsored by the Demand Response Research Center at Lawrence Berkeley National Laboratory and the Sacramento Municipal Utility District (SMUD) and managed by Herter Energy Research Solutions. While the prior study focused solely on single-family applications, this study uniquely addresses the effective application of these technologies in the multifamily market. Because of the strong participation by SMUD, all multifamily dwellings within this study reside in the SMUD service territory.

This study focuses on consumer choice, information, and changes in response to price and energy use information. A key component of these new displays and thermostats is the ability to relay real-time price signals from the utility to the consumer, to more accurately reflect the time-dependent cost of wholesale electricity, and help shift demand to periods of greater supply. Although Time of Use (TOU) and Critical Peak Period (CPP) pricing is not widely offered by today's utilities, those rates are likely to become commonplace, if not universal, within the next decade. The Benningfield Group therefore incorporated those rates into the study.

Through this research, we:

- Quantify the energy and demand savings potential of In-Home Displays (IHDs) and smart thermostats in multifamily buildings. (The data presented within this document)
- Determine whether the CEC should consider requiring smart thermostats or displays as part of the building energy efficiency standards that apply to multifamily buildings, or if the CEC should consider these technologies as a compliance option, provided there is adequate savings justification (provided as a part of the overall reporting by Benningfield Group).
- Identify practical, technical or building code barriers to adoption of smart controls for multifamily energy code (also provided as a part of the overall reporting by Benningfield Group).

There were three distinct interventions in this study, each hypothesized to create a progressively larger impact: 1) TOU/CPP rate only, 2) TOU/CPP rate plus an IHD, and 3) TOU/CPP rate plus an IHD and a smart thermostat. The energy impact results from each intervention apply to the pilot participants, but cannot extend to the general population of multifamily residences because the sample of buildings is non-random (convenience sample)[1]. The estimates in this report serve to estimate the size, if not the actual amount, of the savings and demand reduction that we expect if SMUD offers this program to their entire multifamily customer population.

Overall, the energy and demand analysis compared customers with the intervention from a set of customers living in the same buildings who continued to have a flat rate and no IHD or smart thermostat within a pre/post evaluation design. The summer of 2012 is the pre-period for both treatment and comparison group. Treatment intervention occurred prior to June 2013, so summer (June, July, August, and September) 2013 is the post-period. Results show:

- Peak demand savings[2] accrue for all interventions ranging from 8% to 29% of overall demand. While showing slightly different point estimates, the IHD does not provide any incremental savings over the rate-only intervention (3% and 9% respectively). Inclusion of the thermostat bumped up the peak savings to 29% of overall demand within the peak period.
- Specifically for the 12 CPP event days that took place in the summer of 2013, there are no incremental peak demand savings for the rate-only and IHD interventions. Thermostats do make a difference during CPP event days, bringing up savings another 6% over the non-CPP peak periods (for an absolute savings value of 35%).
- The evaluation team expected energy savings to be small. Analysis showed savings of 5% of use within the summer period for the TOU/CPP group and 5.8% for those with both the rate and an IHD. Energy savings for customers with all three interventions (TOU/CPP, IHD, and smart thermostat) are 7.3% of their summer energy use.

[1] The sample of participants is also non-random, although the implementation team randomly assigned customers who participated to a specific intervention using a recruit and deny method.

[2] Peak period covers hours ending 4 PM to 7 PM on non-holiday weekdays in June, July, August, and September. Values here do not include Critical Peak Pricing event days.

2. Pilot Study Introduction

The Benningfield Group secured a contract with the California Energy Commission (CEC) Public Interest Energy Research (PIER) program to investigate Energy Savings through Smart Controls in Multifamily Housing (Contract #500-10-019). This contract includes several facets of research of which this document reports on only part. Opinion Dynamics Corporation, through a subcontract with the Benningfield Group, served as technical support for the impact analysis. We performed the power analyses for the impact assessment prior to implementation and completed the statistical analysis of results. To implement the pilot, the Benningfield Group partnered with the Sacramento Municipal Utility District (SMUD). As such, this study complements other studies planned for summer 2013 as part of SMUD's SmartSacramento program.

The goal of this study is to test, demonstrate, and quantify the benefits of smart controls and smart meter technologies in multifamily buildings. The last several years have seen a proliferation of utility-side smart grid and smart meter projects, but consumer-facing extensions of these projects are just now being refined, including new in-home energy monitoring and control devices. These devices can work from within the home and community to achieve energy efficiency and energy cost benefits that are available from the user side of the meter. The study includes these in-home energy monitoring, display, and smart thermostat devices, which we collectively refer to as "smart controls". The project builds upon and complements SMUD's 2011-2012 Residential Information and Controls Study sponsored by the Demand Response Research Center at Lawrence Berkeley National Laboratory and SMUD and managed by Herter Energy Research Solutions. While the prior study focused solely on single-family applications, this study uniquely addresses the effective application of these technologies in the multifamily market.

This study focuses on consumer choice, information, and changes in response to price and energy use information. A key component of these new displays and thermostats is the ability to relay real-time price signals from the utility to the consumer, to more accurately reflect the time-dependent cost of wholesale electricity, and help shift demand to periods of greater supply. Although Time of Use (TOU) and Critical Peak Period (CPP) pricing is not widely offered by today's utilities, those rates are likely to become commonplace, if not universal, within the next decade. We therefore incorporated those rates into our study.

There were three distinct interventions in this study, each hypothesized to create a progressively larger impact: 1) TOU/CPP rate only, 2) TOU/CPP rate plus an IHD, and 3) TOU/CPP rate plus an IHD and a smart thermostat. Additionally, each intervention (treatment) group includes two cohorts – low-income and non-low-income.

2.1.1 Research Hypotheses

The study includes three hypotheses each for energy and demand impacts.

Energy Savings Impact:

H1a: The treatment groups on a TOU/CPP rate (with and without IHDs and Price-Responsive Thermostats) will show significant savings between the summers of 2012 and 2013 compared to an equivalent group of customers on a conventional rate.

H1b: The treatment group on a TOU/CPP rate with an IHD will show significant savings between the summers of 2012 and 2013 compared to a group on a TOU/CPP rate and compared to a group on a conventional rate.

H1c: The treatment group on a TOU/CPP rate with a Price-Responsive Thermostat and an IHD will show significant savings between the summers of 2012 and 2013 compared to a group with IHD on a TOU/CPP rate, a group on a TOU/CPP rate, and a group on a conventional rate.

Demand Reduction Impact:

H2a: The treatment groups on a TOU/CPP rate (with and without IHDs and Price-Responsive Thermostats) will show significant reductions in daily and event peak energy between the summers of 2012 and 2013 compared to an equivalent group of customers on a conventional rate.

H2b: The treatment group on a TOU/CPP rate with an IHD will show significant reductions in daily and event peak energy between the summers of 2012 and 2013 compared to a group on a TOU/CPP rate and compared to a group on a conventional rate.

H2c: The treatment group on a TOU/CPP rate with a Price-Responsive Thermostat and an IHD will show significant reductions in daily and event peak energy between the summers of 2012 and 2013 compared to a group with an IHD on a TOU/CPP rate, a group on a TOU/CPP rate, and a group on a conventional rate.

To answer these research questions, we deployed a pre/post impact design with both a treatment and comparison group. We used statistical analyses to compare the savings between the comparison group and each treatment group as well as determine the incremental impacts of each intervention.

2.1.2 Structure of Report

We structure the remainder of the report to provide progressively more information as the reader moves through the report. Results are first for those interested in the bottom line. We then move into statistical methods deployed in the impact analysis along with our sample design. For those readers who want to know the details of the data used within the analyses, we provide this information after the method section. Lastly, we provide a very short summary of results.

3. Impact Results

This section details the impact analysis for the study.

3.1 Demand Savings

The results show a substantial and statistically significant peak-period demand reduction for all treated groups. Additionally, there are incremental savings during event days for the thermostat treatment group. Table 1 shows the peak savings for the in-home display treatment group is only slightly higher than the peak savings for the rate -only group, while the peak savings for the thermostat treatment group is more than double that of the other two treatment groups.

Table 1. Average Hourly Peak-period demand savings by treatment group (kWh/hr)

Treatment Group	N	Weekday Time Period	Savings (kWh/hr)	SE Hourly	95% Confidence Interval		Reference Load	Percentage Peak Savings	Treatment Incremental Savings
Rate only	85	Peak	0.10	0.04	0.03	0.17	1.14	8%	-
Rate + IHD	81	Peak	0.18	0.03	0.11	0.25	1.14	16%	7% – but not statistically different from Rate Only
Rate + IHD + Thermostat	74	Peak	0.33	0.04	0.23	0.42	1.14	29%	20%

Note: Peak period covers hours ending 4 PM to 7 PM on non-holiday weekdays in June, July, August, and September. The savings includes non-CPP event days only.

Table 2 shows the event-period demand savings[3]. For all three groups there was significant savings, but only an additional 6% when compared to the usual peak-period usage for the group.

Table 2. Average Hourly Event-period demand savings by treatment group (kWh/hr)

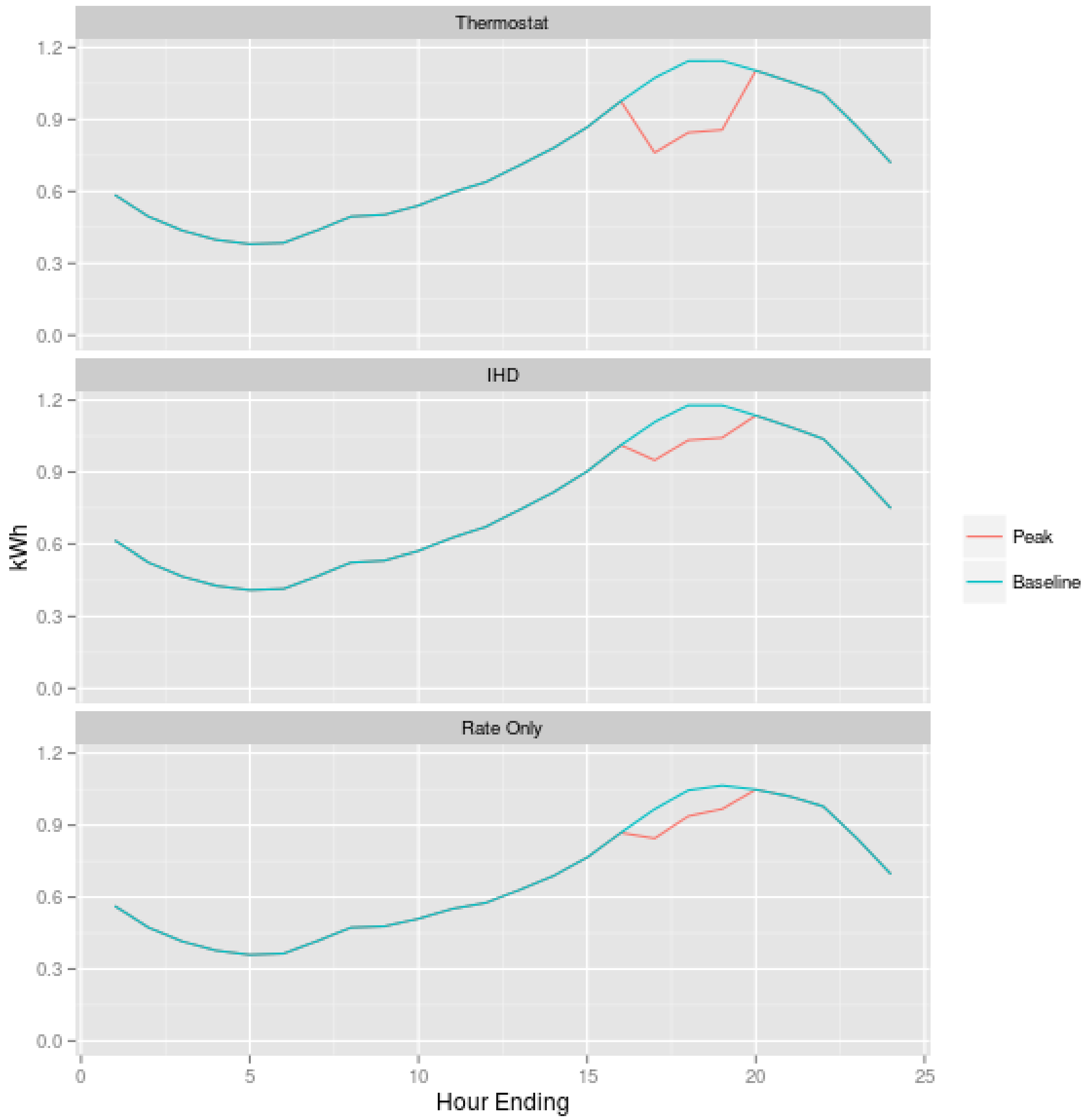
Treatment Group	N	Weekday Time Period	Savings (kWh/hr)	SE Hourly	95% Confidence Interval		Reference Load	Peak + Event Savings	Treatment Incremental Savings
Rate only	85	Event	0.17	0.04	0.08	0.25	1.14	15%	-
Rate + IHD	81	Event	0.24	0.04	0.16	0.31	1.14	21%	6% – but not statistically different from Rate Only
Rate + IHD + Thermostat	74	Event	0.40	0.05	0.28	0.52	1.14	35%	21%

Figure 1 shows the 2013 (treatment period) weekday mean kWh/h demand for the three treatment groups as compared to 2012 (pre-treatment period). The baseline line on this graph represents the hourly 2013 weather-

[3] There were 12 events called by SMUD in the summer of 2013.

corrected treatment group baseline usage, while the peak line represents the load for the treatment groups with their treatments applied on non-event days. There is a clear peak demand reduction in the thermostat treatment group, while demand reductions are lower for the in-home device and rate-only treatment groups.

Figure 1. 2013 Weekday Mean kWh/hr Demand for Treatment Groups



3.2 Energy Savings

The per-household energy savings from the program is small, ranging from 0.86 kWh per day for the rate-only treatment group to 1.27 kWh per day for the thermostat treatment group. The difference between the energy savings of the rate-only treatment group and that of the in-home device or thermostat treatment group is not statistically significant. The only statistically significant savings is the overall average program savings of 1.03 kWh per day. The hourly savings column is included for comparison to demand savings.

Table 3. Daily Energy savings by treatment group (kWh)

	N	Daily Savings (kWh)	Std. Err.	95% Confidence Interval		Modeled Daily Usage	Percent Savings	Incremental Savings	Hourly Savings (kWh/hr)
Comparison	202								
Rate only	85	0.86	0.45	-0.02	1.74	17.37	5.0%	5.0%	0.04
IHD	81	1.00	0.60	-0.17	2.18	17.37	5.8%	0.8%	0.04
Thermostat	74	1.27	0.76	-0.23	2.76	17.37	7.3%	2.3%	0.05
All Treated	240	1.03	0.43	0.19	1.87	17.37	6.0%		0.04
Total	442								

Therefore, our analysis shows that three of the six research hypotheses are true, while three are false. There is not a statistically significant difference between the IHD and rate-only treatment groups in either the overall energy savings or the peak demand savings. There is not a significant difference in overall energy savings between the thermostat and IHD or rate-only groups.

Table 4. Answers to Research Hypotheses

Research Hypotheses			Results
Energy Impacts	H1a:	The treatment groups on a TOU/CPP rate (with and without IHDs and Price-Responsive Thermostats) will show significant savings between the summers of 2012 and 2013 compared to an equivalent group of customers on a conventional rate.	True
	H1b:	The treatment group on a TOU/CPP rate with an IHD will show significant savings between the summers of 2012 and 2013 compared to a group on a TOU/CPP rate and compared to a group on a conventional rate.	False
	H1c:	The treatment group on a TOU/CPP rate with a Price-Responsive Thermostat and an IHD will show significant savings between the summers of 2012 and 2013 compared to a group with IHD on a TOU/CPP rate, a group on a TOU/CPP rate, and a group on a conventional rate.	False
Demand Impacts	H2a:	The treatment groups on a TOU/CPP rate (with and without IHDs and Price-Responsive Thermostats) will show significant reductions in daily and event peak energy between the summers of 2012 and 2013 compared to an equivalent group of customers on a conventional rate.	True
	H2b:	The treatment group on a TOU/CPP rate with an IHD will show significant reductions in daily and event peak energy between the summers of 2012 and 2013 compared to a group on a TOU/CPP rate and compared to a group on a conventional rate.	False
	H2c:	The treatment group on a TOU/CPP rate with Price-Responsive Thermostat and an IHD will show significant reductions in daily and event peak energy between the summers of 2012 and 2013 compared to a group with an IHD on a TOU/CPP rate, a group on a TOU/CPP rate, and a group on a conventional rate.	True

4. Impact Methods

Opinion Dynamics estimated the impacts for peak-period kW demand (excluding event days), event-period kW demand and overall kWh savings using fixed-effects panel models. These linear regression models adjust for all time-invariant household-specific properties by calculating a separate adjustment term for each household. In this way, these models are able to adjust for the substantial differences between households, for all the characteristics (e.g. square footage, type and efficiency of cooling unit, other envelope characteristics, occupancy) of the households that do not change over the entire period of the experiment. The comparison group is included in the models to correct for all influences that affect everyone in the population (e.g. macro-economic situation, climate, etc.) Even though there is a household-specific intercept in the model, the model includes an overall mean intercept term that can be used when predicting savings for out of sample or future participants.

When implementation of a study randomly chooses the participants and comparison groups from the entire population of interest, analysts can extrapolate the model results to the full population of interest[4]. In this pilot however, because of the nature of multifamily building management and the need to contain costs, the buildings were a self-selected sample of multifamily buildings with more than 75 units. The implementation team recruited all tenants within a multifamily site and later denied some tenants participation when there were sufficient treatment sample sizes. As such, the results of this pilot cannot be directly extrapolated to estimates of the kW and kWh savings for the full population. The results can, however, be used as a guide for the expected size of kW and kWh savings.

We use the results of the model to estimate the energy use changes that occurred because of the program, corrected for both household-specific time-invariant influences and population-wide changes.

4.1 Sample Design

Once the implementation team chose multifamily buildings for inclusion in the pilot, there were attempts to contact all of the residents. The team assigned those residents who responded first into one of the three treatment groups. When the treatment quota was met, the remaining respondents who asked to participate in the program were assigned to the comparison group. The team further extended the comparison group by adding in those participants whose residence was not appropriate for the technology because the meter was too far away for the wireless connection. The evaluation team performed a power analysis prior to the study to assure a sufficient sample size, given certain parameters and effect sizes. Appendix A provides the specifics of that effort. After the power analyses, the implementation team chose to add in a low-income cohort for each treatment group and a low-income group within the comparison. This choice increased the comparison group, but did not change the overall numbers within the treatment cohorts. We performed the analysis by treatment group, including low-income customers in each treatment group. The actual coefficient of variation of participant energy usage for the participants in the treatment period is 0.55. The coefficient of variation for all participants for just the peak hours of 4-7 pm is 0.60.

4.1.1 Treatment and Comparison Group Counts

Table 5. Planned and actual participant counts for the treatment and comparison groups

Treatment Number	Treatment	Planned Treatment Group (n)	Planned Comparison Group (n)	Actual Treatment Group (n)	Actual Comparison Group (n)
1	**TOU/CPP rate only.** No equipment supplied by research team. The tenant uses whatever thermostat is currently installed in the unit.	100	100 (Customers who enrolled after the close of recruitment or those who were too far from the meter to receive the wireless signal. No TOU/CPP rate or equipment provided.)	85	202
2	**TOU/CPP rate + IHD.** The tenant uses whatever thermostat is currently installed in the unit.	100		81	
3	**TOU/CPP rate + IHD + Smart Thermostat.** In addition to an IHD, the tenant receives a thermostat capable of receiving price signals from the utility and adjusting set points in response to price and user preferences.	100		74	
	Total	300	100	240	202

4.2 Treatment and Comparison Group Comparison

It is best practice to check for any obvious bias that could arise from sampling. When the treatment and comparison groups both have similar characteristics in energy usage, demographics, and housing characteristics, then we expect the results of the models to have little or no bias[5]. However, there may still be some opt-in bias (i.e., differences between the treatment and comparison groups due to some unseen differences between people who chose to participate and those that did not) that affects savings.[6]

We checked for bias through comparing the pre-treatment period (summer of 2012) median hourly usage for each of the three treatment groups further divided into their normal and low-income cohorts and the comparison group (Figure 2).[7] It is clear from Figure 2 that the thermostat and in-home device treatment groups are not well matched because they have substantially higher peak usage than the comparison group.[8] This difference in peak usage between the treatment and comparison groups may result in bias in the peak demand savings estimates because the comparison group acts as a baseline comparison. However, we added

[5] Bias means there is a systematic difference that could affect savings. These differences could cause the modeled results to be higher or lower than the "true" results. Often the level of bias is unknown.

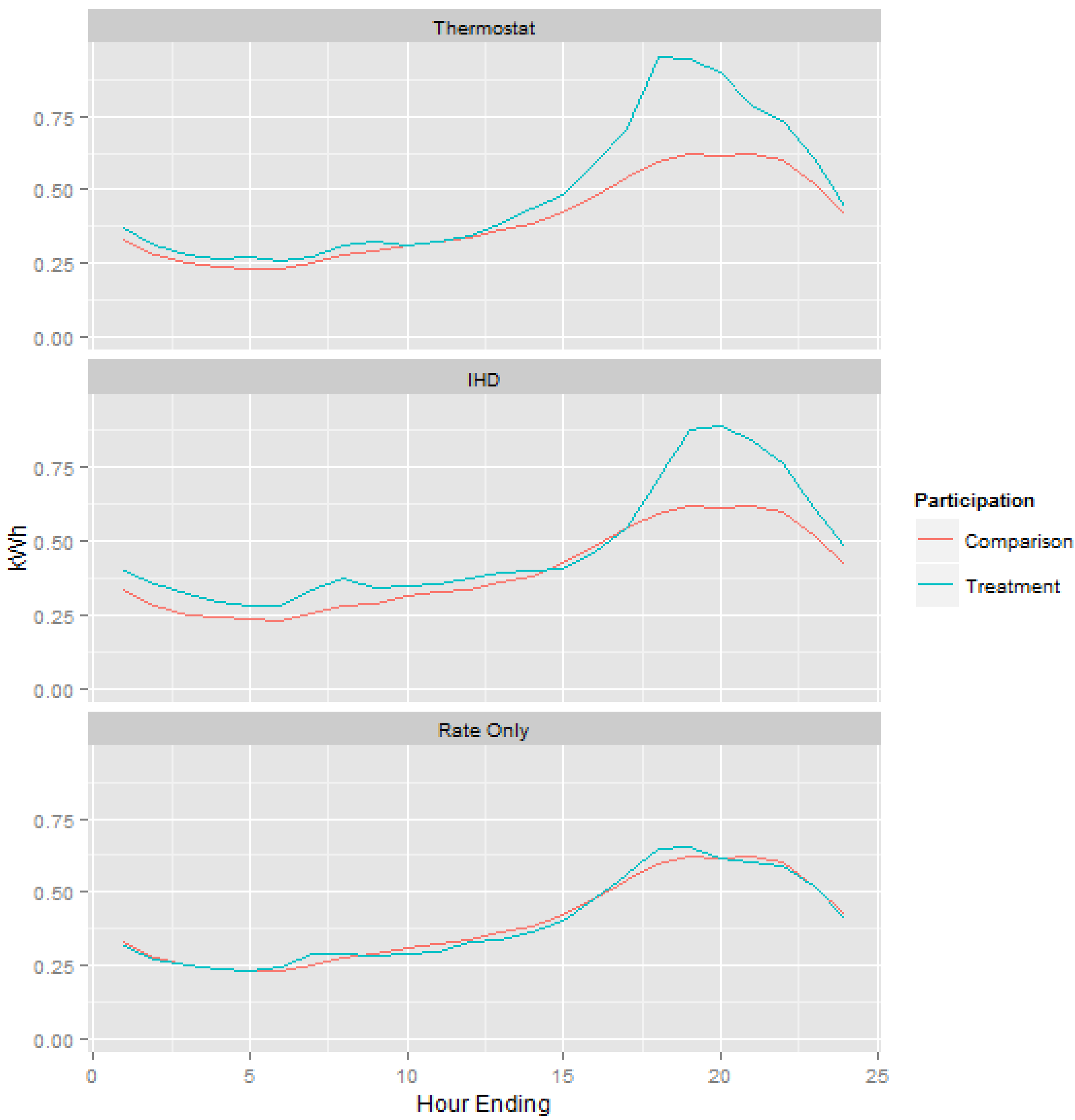
[6] We can estimate if there is potential for opt-in bias by looking at differences in the two parts of the comparison group. Because of how the implementation team brought customers into the pilot, one part of the comparison group made minimal effort to participate in the program (i.e., they refused initially) while another part of the comparison group asked to become participants, but they did not qualify because the program had already met the quota (i.e., recruit and deny).

[7] Median values (half above the value and half below) provide a better look at the cohort since outliers do not pull the value high or low as would occur within an average value.

[8] When the comparison group is not well matched to the treatment group, it is impossible to completely remove all sources of bias, as the groups might respond differently to factors such as weather, changing economic climate, or other unmeasured factors.

terms to the model to handle these differences as much as possible and as such, we believe this bias to be minimal within our models and not sufficient to change any choices made based on the results.

Figure 2. Median kWh/hour Consumption for the Three Treatment and Comparison Groups in Summer 2012



To provide further data on the cohorts, Table 6 includes descriptive statistics for the different treatment groups and the comparison group in peak and off-peak periods (the median values are shown in the figure above).

Table 6. Treatment and Comparison Weekday Hourly Usage

Treatment	Treatment Group	Peak	Median kWh/hr	Mean kWh/hr	Minimum kWh/hr	Maximum kWh/hr	Std. Dev. kWh/hr
Treated	Thermostat	Off-Peak	0.38	0.69	0.00	7.57	0.81
Treated	IHD	Off-Peak	0.43	0.71	0.01	9.56	0.81
Treated	Rate Only	Off-Peak	0.36	0.63	0.00	9.92	0.74
Treated	Thermostat	Peak	0.84	1.23	0.00	7.29	1.11
Treated	IHD	Peak	0.84	1.26	0.02	8.09	1.18
Treated	Rate Only	Peak	0.69	1.09	0.00	8.29	1.06
Comparison		Off-Peak	0.35	0.62	0.00	10.13	0.73
Comparison		Peak	0.65	1.10	0.00	10.02	1.06

Using the treatment and comparison groups shown above, we modeled both demand and energy savings, described next.

4.3 Demand Savings

Opinion Dynamics estimated peak-period and event-period demand reduction using a fixed-effects panel model on hourly data. Equation 1 shows the model.

Equation 1. Peak and Event Demand Savings Fixed-Effects Model

$$\begin{aligned} kW_{it} = \alpha_i &+ \beta_1 Peak_{it} + \beta_2 Event_{it} + \beta_3 CDH_{it} + \beta_4 CDH_{it-1} + \beta_{5-27} Hour_{it} + \beta_{28} Rate_{it} + \beta_{29} IHD_{it} \\ &+ \beta_{30} Thermostat_{it} + \beta_{31} Peak_{it} CDH_{it} + \beta_{32} Peak_{it} CDH_{it-1} + \beta_{33} Event_{it} CDH_{it} \\ &+ \beta_{34} Peak_{it} AHC_i + \beta_{35} Event_{it} AHC_i + \beta_{36} Peak_{it} AHC(Hour\ 17)_i \\ &+ \beta_{37} Event_{it} AHC(Hour\ 17)_i + \beta_{38-39} Peak_{it} Hour_{it} + \beta_{40-41} Event_{it} Hour_{it} \\ &+ \beta_{42} Peak_{it} IHD_{it} + \beta_{43} Event_{it} IHD_{it} + \beta_{44} Peak_{it} Thermostat_{it} + \beta_{45} Event_{it} Thermostat_{it} \\ &+ \beta_{46} Rate_{it} CDH_{it} + \beta_{47} IHD_{it} CDH_{it} + \beta_{48} Thermostat_{it} CDH_{it} + \beta_{49} Peak_{it} IHD_{it} CDH_{it} \\ &+ \beta_{50} Event_{it} IHD_{it} CDH_{it} + \beta_{51} Peak_{it} Thermostat_{it} CDH_{it} + \beta_{52} Event_{it} Thermostat_{it} CDH_{it} \\ &+ \varepsilon_{it} \end{aligned}$$

α_i = Customer-specific intercept

$Peak_{it}$ = indicator for peak hours (hours ending 17-19) during the 2013 treatment period for customer i at time t

CDH_{it} = Cooling degree hours (base 70) for customer i at time t

CDH_{it-1} = Cooling degree hours (base 70) for customer i at time t–1

$Hour_{it}$ = 23 indicators for hour of the day

$Rate_{it}$ = Indicator for TOU+CPP rate for customer i at time t (if the customer is receiving treatment, this is 1 for the entire summer of 2013)

IHD_{it} = Indicator for In-Home Display for customer i at time t (if the customer is receiving IHD treatment, this is 1 for the entire summer of 2013)

$Thermostat_{it}$ = Indicator for information display thermostat for customer i at time t (if the customer is receiving thermostat treatment, this is 1 for the entire summer of 2013)

AHC_i = Average summer 2012 hourly kWh consumption for customer i

$AHC(Hour\ 17)_i$ = Average summer 2012 hour ending 17 kWh consumption for customer i

We fit the model using hourly interval usage data from the summers of 2012 and 2013 (June, July, August, and September) combined with hourly weather data from the Sacramento Executive Airport. This is a two-step process whereby we calculate the modeled usage in the absence of the program by setting the Event, Peak, Rate, IHD, and Thermostat indicator variables to zero and calculating the usage prediction for all participants. After the modeled usage is determined, we then calculate peak savings by subtracting the modeled usage for those treated from the modeled usage in the absence of the program. We calculate the marginal event savings by subtracting the modeled event period usage for those treated from the modeled usage in the absence of the event.

For two of the cohorts (those with IHD and those with IHD and smart thermostat), the connection of the devices to the smart meter allows the treated customer to see the cost of their use. Without that connection and subsequent information, the customer may not react to changes in the same manner, which could affect savings. We had a single point in time (midnight) where we knew if the devices were connected or not. After choosing to set the day prior to the data point as connected or not, we included the variable in the model. As such, we fit the model with additional terms for daily connectivity (an indication of whether or not the participant was receiving reliable data from the meter) and an interaction term with connection times Peak. Neither of the coefficient estimates for these terms was statistically significant, so we removed connectivity from the demand model.

4.4 Energy Savings

Opinion Dynamics estimated kWh savings using a fixed-effects panel model on daily data. Equation 2 shows the model.

Equation 2. Energy Savings Fixed-Effects Model

$$kWh_{it} = \alpha_i + \beta_1 Rate_{it} + \beta_2 CDD_{it} + \beta_3 Post_{it} + \beta_4 IHD_{it} + \beta_5 Thermostat_{it} + \beta_6 Rate_{it} CDD_{it} + \beta_7 Post_{it} CDD_{it} + \beta_8 Thermostat_{it} CDD_{it} + \varepsilon_{it}$$

α_i = Customer-specific intercept

$Post_{it}$ = indicator for 2013 period for customer i at time t

CDD_{it} = Cooling degree days (base 70) for customer i at time t

$Rate_{it}$ = Indicator for TOU+CPP rate for customer i at time t (if the customer is receiving treatment, this is 1 for the entire summer of 2013)

IHD_{it} = Indicator for In-Home Display for customer i at time t (if the customer is receiving IHD treatment, this is 1 for the entire summer of 2013)

$Thermostat_{it}$ = Indicator for information display thermostat for customer i at time t (if the customer is receiving thermostat treatment, this is 1 for the entire summer of 2013)

Opinion Dynamics fit the model using daily usage data from the summers of 2012 and 2013 (June, July, August, and September) combined with daily weather data from the Sacramento Executive Airport.

As with demand savings, this is a two-step process whereby we calculate the modeled usage in the absence of the program by setting the Rate, IHD, and Thermostat indicator variables to zero and calculating the usage prediction for all treated participants. After the modeled usage is determined, we then calculate energy savings by subtracting the modeled usage for those treated from the modeled usage in the absence of the program.

Similar to the demand modeling, we also fit the model with additional terms for daily connectivity, and interaction terms with connection by IHD and connection by Thermostat. As with demand, neither of these coefficient estimates were statistically significant, so we did not include connectivity in the energy savings model.

5. Data

We used six sets of data within the analysis:

- Billing data (hourly load data for 2012 and 2013 for June, July, August, and September of each year)
- Daily weather data for Sacramento
- Dates of CPP conservation events
- Specific customers participating in each CPP event and how they were contacted (phone, text messaging, email)
- Customers divided into treatment and comparison groups, including variables of which treatment group each customer fell into
- Daily connectivity data for those with IHD or IHD and smart thermostat

SMUD provided us all this data except the weather data, which we obtained from the NOAA site. Also included was customer address and demographics for the treatment group. As shown in the equations above, we did not include customer specific information within our modeling.

5.1 Treatment and Comparison Group by City

Drawing from nine different cities within the SMUD service territory (with 70% coming from Sacramento), this study includes data from 547 participating households. Of those, 442 had complete usage data; we dropped the 106 participants with partial usage data from the analysis. Table 7 shows the number of customers (both treatment and comparison group) in each city and the percentage within each city designated to comparison or treatment.

Table 7. Number of participants by city

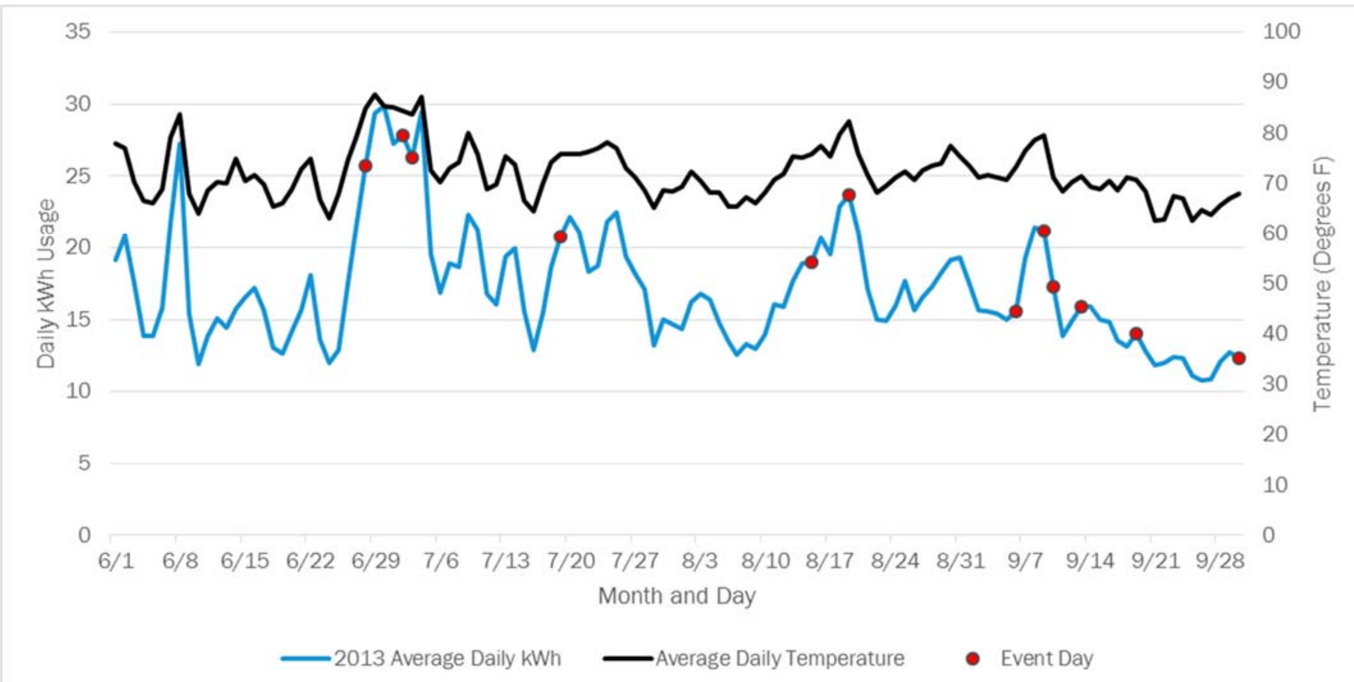
City	Comparison Group	Treatment Group	Total
Antelope	46%	54%	24
Carmichael	58%	42%	26
Citrus Heights	58%	42%	26
Elk Grove	55%	45%	33
Fair Oaks	56%	44%	18
Folsom	27%	73%	15
North Highlands	33%	67%	3
Rancho Cordova	63%	37%	19
Sacramento	52%	48%	383
Total	52%	48%	547

5.2 Interval Meter Data, Weather Data, and Event Days

As stated earlier, SMUD provided hourly usage data for 547 participant customers for the four months from June through September in both 2012 and 2013. The data were complete for all participants and there was no missing or duplicate data. Opinion Dynamics downloaded Sacramento Executive Airport (SAC) hourly weather for 2012 and 2013 from the NOAA website.

Figure 3 shows that there is a relatively strong relationship between mean kWh consumption for the participants and mean temperature in the Sacramento area. The models include weather correction to help account for this strong relationship.

Figure 3. 2013 Overall Mean Daily kWh Consumption and Weather for the Treatment and Comparison Groups
(Summer Months)



There were 12 CPP events called in 2013 (as shown in the figure above and in Table 8 below) All events had a critical peak period that coincides with the peak period, 4-7pm, of the time of use rate.

Table 8. Event dates

Event Number	Date	Maximum Temperature
1	6/28/2013	103
2	7/2/2013	101
3	7/3/2013	104
4	7/19/2013	98
5	8/15/2013	94
6	8/19/2013	104
7	9/6/2013	93
8	9/9/2013	101

Event Number	Date	Maximum Temperature
9	9/10/2013	85
10	9/13/2013	90
11	9/19/2013	90
12	9/30/2013	78

5.2.1 Connectivity

Opinion Dynamics received logs of electric meter to information display connection for the two treatment groups who received real-time energy information from in-home devices or thermostats from SMUD. These logs showed the once-daily meter connection diagnostics performed by the information displays. When the information display to meter connection was unavailable for some reason at midnight, the diagnostic log recorded that event. It is possible that the device reestablished the meter connection sometime during the day, but these logs serve as a proxy for finding the treated households where the connection may have been unreliable.

Both sets of data (shown below) around connectivity indicate that customers may have had relatively poor or unreliable connection. However, as stated above, because the logger provides data from a single point in time of the day, we have no insight into whether the actual information was available throughout the day. The logs only recorded at midnight, when the most important time of day from the standpoint of this program is the 4-7pm peak period. The inclusion of this data within our modeling did not change the results. As such, we believe this connectivity data is not useful for assessing either the validity of the modeling or the effect of the connectivity interruptions on the usefulness of the in-home displays or the thermostats.

Table 9 shows the overall number of days where treated participants had logged connection issues. Over a third of participant-days in the 2013 treatment period had connectivity issues logged.

Table 9. Overall number of days with connection issues

Treatment Group	Device Type	Mean Days with Bad Connectivity	Number of Days in Period	Percent of Days with Connection Issues
IHD	IHD	47.3	122	39%
IHD & Thermostat	IHD	46.4	122	38%
	Thermostat	15.7	122	13%

Table 10 shows the number of participants from the in-home display and thermostat treatment groups with logged connection issues.

Table 10. Counts of treated participants with connection problems

Treatment Group	Device Type	Connectivity	Number of Customers
IHD	IHD	Participant with no connectivity issues	20
		Participant with less than 30 days of connectivity issues	16
		Participant with 30 or more days of connectivity issues	45

Data

Treatment Group	Device Type	Connectivity	Number of Customers
Thermostat	IHD	Participant with no connectivity issues	15
		Participant with less than 30 days of connectivity issues	19
		Participant with 30 or more days of connectivity issues	40
	Thermostat	Participant with no connectivity issues	52
		Participant with less than 30 days of connectivity issues	10
		Participant with 30 or more days of connectivity issues	12

Next is an appendix that describes the original power analyses performed for this pilot.

6. Summary

This report provides the energy and demand impacts from a distinct set of multifamily housing sector interventions within SMUD's service territory. Specifically, during the summer of 2013[9], 281 individual multi-family dwelling units received one of three treatments: 1) TOU/CPP rate only, 2) TOU/CPP rate and IHD, and 3) TOU/CPP rate, IHD, and smart thermostat. For each intervention, the team estimated impacts for both peak-period kW demand and overall kWh savings using fixed-effects panel models. While we included a rate-only treatment group, the evaluation team designed the study to test the incremental savings from the two technologies, not the savings specific to the CPP/TOU rates.

Peak demand impacts are substantial and statistically significant, with the rate-only group showing 18% peak savings. There are no incremental savings from the addition of the IHD, but inclusion of the smart thermostat provides an additional 15% savings.

Energy savings for the summer period are not statistically significant (i.e., there was not enough information to determine that the true savings is different from zero). However, we still made best estimates of the savings based on the program results. The rate-only group had an estimated 5% savings, those with rate and an IHD had an estimated 5.8% savings, while those with the smart thermostat had an estimated savings of 7.3%.

[9] Analysis occurred for the summer months of June, July, August, and September only.

Appendix A. Power Analysis Prior to Study

We conducted multiple power analyses to determine if there were sufficient sample points to detect savings and demand effects, if the effects are present. All power analyses assumed use of daily consumption data (alternatives discussed below). For each power analyses, we considered multiple scenarios based on (a) the effect size (percent savings or demand reduction) and (b) the variance of energy usage (reflected in the coefficient of variation (CV) of monthly usage).[10] Each power analysis is designed to detect the given effect size with 80% statistical power at a 90% statistical confidence level. We assume a CV of 0.4 for one set of calculations, 0.6 for another, and 0.8 for a last calculation. Additionally, we assumed that the comparison group needed would be sized similarly to each treatment group.

First, we conducted power analyses for the study's ability to detect savings and demand effects between the Treatment and Comparison group overall. Then, we conducted similar power analyses to determine if there were sufficient sample points to detect savings differences between treatment groups. (Table 12).

As shown below, with a combined treatment group of 300 (100 in each group), if there is a small-to-medium effect size and moderate variation there will be sufficient sample points in our analysis to determine a difference between treatment and comparison groups. However, if the effect of the treatment is very small or the variation is larger, our study is underpowered to detect savings if they occur. The actual coefficient of variation for kWh usage of all participants for the treatment period is 0.55, and 0.60 for peak hours (4-7 pm.)

Table 11. Power Analysis: Sample Sizes Needed for Various Effect Sizes and Comparisons between the Treatment and Comparison Groups

		Difference Between Treatment and Comparison Percent Change		
CV	Group	Very Small Effect[a] 2%	Small Effect 5%	Medium Effect 8%
0.4	Treatment	1,109	177	69
	Comparison	554	89	35
0.6	Treatment	2,495	399	156
	Comparison	1,248	200	78
0.8	Treatment	4,436	710	277
	Comparison	2,218	355	139

[a]Effect Size (Average % Savings)
Blue box = sample size that meets the budget
Source of Sample Size Methodology: *Measurement and Verification Principles for Behavior-Based Efficiency Programs*. The Brattle Group. May 31, 2011.

[10] The coefficient of variation is a standard measure of variance in the data that is standardized by the associated mean of the measure of interest, calculated as the ratio of the sample standard deviation to the sample mean. A higher CV reflects more variation.

Table 12 shows the sample size required for each of the treatment groups. Since each of these groups were planned to be equal size, we do not show a group variable. As shown below, if there is a medium effect size and low variation, there may be sufficient sample points in our analysis. However, if the effect of the treatment is very small or small or there is larger variation, our study is underpowered to detect savings if they occur.

Table 12. Power Analysis: Sample Sizes Needed for Various Effect Sizes and Comparisons between Treatment Groups

CV	Difference Between any Two Treatment Groups (Percent Change)		
	Very Small Effect[a] 2%	Small Effect 5%	Medium Effect 8%
0.4	739	118	46
0.6	1,663	266	104
0.8	2,957	473	185

[a]Effect Size (Average % Savings)

Blue boxes = sample size that meets the budget

Source of Sample Size Methodology: *Measurement and Verification Principles for Behavior-Based Efficiency Programs*. The Brattle Group. May 31, 2011.

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