Behavior vs. Automation: The Impacts of "Set It and Forget It" in the Multifamily Sector

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ABSTRACT

Numerous studies have demonstrated the savings potential of providing real-time energy information, dynamic rates, and/or direct load control of air conditioning and other end uses to single-family homeowners. Little is known, however, about how multifamily building construction and tenant behaviors differ from single-family home construction and homeowner behaviors with respect to energy savings. Even less is known about energy and load savings when multifamily customers automate their thermostats to respond to their comfort preferences and real-time changes in the price of electricity.

To fill this gap in knowledge and to explore the potential for codification of energy management systems in multifamily buildings, an electric utility, a consulting group and a governmental agency partnered to study a customer-controlled time-of-use and energy management program during summer 2013. This study compared electricity use and electricity using behaviors of a control group with 1) customers on a time-of-use/critical peak rate, 2) customers with the rate plus an in-home electricity display, and 3) customers with the rate, the display and a communicating thermostat they were assisted in setting to automatically respond to rate variations and comfort preferences.

Findings indicate that in the multifamily sector, information alone has no additional impact on energy and demand over a TOU-CPP rate, but that a TOU-CPP rate results in 5%-7% energy savings, 9%-16% weekday peak savings (TOU effect), and 15%-21% event peak savings (CPP effect). The addition of automation does not improve energy savings, but doubles weekday and event peak savings to 29% and 35% respectively.

Introduction and Background

The focus of most research on impacts of residential energy efficiency and demand response programs, both nationally and in California, has been in the single-family sector. The reasons for this are many. Multifamily programs suffer from the well-known split-incentive problem whereby the costs of efficiency improvements are borne by landlords while the benefits accrue to tenants. Also, in all but the dense urban areas multifamily dwelling units comprise a smaller proportion of the housing stock than single-family, and so account for a smaller portion of energy use. Finally, the units themselves are smaller and share common walls, floors and ceilings, making them intrinsically more energy-efficient.

The result of this historical focus on the single-family residential sector is a lack of multifamily programs and energy codes that effectively address many of the unique attributes of multifamily buildings and tenants. Despite this lack of information, assessments indicate considerable demand response and energy efficiency potential in multifamily buildings. (ACEEE 2009, GEP 2008, GEP 2010)

Although single-family homes dominated California's new construction market from1990 through 2010, in the last four years new multifamily construction has exceeded single-family home construction on a unit-by-unit basis. (CDF 2013) To address the lack of information regarding multifamily buildings in a now-burgeoning market, Benningfield Group secured a contract with the California Energy Commission (CEC) Public Interest Energy Research (PIER) program to investigate Unique Multifamily Code-Relevant Measures. This contract included several facets of research of which this study, called Multifamily Summer Solutions, is only one part. To implement the study, Benningfield Group partnered with Sacramento Municipal Utility District (SMUD) and subcontracted with Opinion Dynamics for impact and survey analyses.

The goal of this study was to test, demonstrate, and quantify the benefits of smart information and control technologies in multifamily buildings in order to inform energy efficiency and demand response programs and codes. The last several years have seen a proliferation of utility-side smart grid and smart meter related technologies and applications, but customer-facing devices and applications, such as displays, monitors, thermostats and smart chargers, are still being refined. A key component of these new devices is the ability to relay real-time price signals and other information from the utility to the consumer to more accurately reflect the time-dependent cost of wholesale electricity, and help lower demand in periods of short supply. Although time-of-use (TOU) and critical-peak-period (CPP) pricing that reflects the time-dependent cost of electricity is not widely offered by today's utilities, SMUD plans to place all residential customers on a default TOU rate by 2018, and to possibly offer a CPP rate adder as well. (SMUD 2013)

A great many studies have been conducted to date testing the electricity impacts of energy information and time-dependent or dynamic pricing (ACEEE 2012, Darby 2006, Delmas 2013, EPRI 2009, Faruqui 2009, Faruqui 2013, Fischer 2008, Vine 2013). The questions are no longer whether energy information and dynamic pricing reduce energy and demand, but to what extent the reductions observed are a function of behavioral changes in response to social or financial incentives, and to what extent they are a function of automation technology (customer- or utility-controlled devices). A follow-up question is whether there is a role for both kinds of catalysts in insuring reliable, grid-integrated demand-side resource.

Usually the enabling technologies deployed in these studies provided electricity use and cost information and/or automated response to price signals, but only a few studies were designed to test the impacts of the technologies deployed separate from the impacts of the dynamic rates. The results of these studies indicate that while both information and automation increase load savings, automation has the greater impacts.[1]

SMUD's Single-Family Summer Solutions Study

[1] Three pilots (AmerenEU, BGE and OGE) directly compared a rate plus display information (orb, in-home, web) with the same rate, display information and automation (programmable thermostat, automatic setback, AC controller), and in all cases the addition of automation improved load savings. AmerenEU compared a three-tier TOU-CPP rate alone with the same rate plus a thermostat that automatically raised temperature settings during critical events. Adding automatic temperature control increased peak savings from 13% to 29%. (RLW 2004 and Voytas 2006) BGE compared a dynamic rate alone (TOU-CPP or two levels of PTR-CPP) with the rate plus display and with the rate plus display and an AC cycling switch. This study found that adding an energy orb to a dynamic rate increased load savings from 20% to 25%, while adding a utility-controlled AC switch at 50% cycling increased savings to 33%. (Faruqui 2009) OGE compared both a Variable Peak Price-Critical Price (VPP-CP) and a TOU-CP with different technology options: a web display, an IHD, a PCT and all three. Savings were achieved in all cases, but the PCT increased average on-peak savings by approximately one-third, and doubled maximum peak savings, depending upon the treatment group. (GEP 2012)

The Multifamily Summer Solutions study followed from and complemented SMUD's Residential Single-family Summer Solutions study conducted by Herter Energy Research Solutions. (HERS 2014) This study examined the effects of different levels of energy information and different rate and automation offerings on energy, demand and bill savings. Customers were offered a choice of two rates: SMUD's standard rate and the same TOU-CPP rate that was offered to Multifamily Summer Solutions participants. Irrespective of which rate they chose, customers could also participate in the Automatic Temperature Control (ATC) option, which allowed SMUD to automatically increase their smart thermostat set point during CPP events (SMUD calls these events "Conservation Days").

Participants were randomly pre-assigned to three different information treatment groups: 1) a group who could only view their whole-house 24-hour-old electricity use on SMUD's website (Baseline); 2) a group who could also view near real-time whole-house electricity use and cost information on their smart thermostat and on a local network website (Home); and 3) a group who could view real-time electricity use and cost information both for their whole house and by major appliance (HVAC, pool pump, refrigerator, electric dryer, entertainment center, etc.), both on their thermostat and on their local website (Appliance).

All participants were provided with smart thermostats, which they were assisted in setting at the time of installation. Participants who chose the ATC option allowed SMUD to automatically increase their thermostat setting by 4°F during peak hours on Conservation Days; these participants could only override once in 12 events during each summer. Participants who did not elect the ATC option could choose to automate their thermostats to any desired increase in set point between 1°F and 6°F during peak hours on Conservation Days regardless of their chosen rate, and 91% did so; these participants could override at any time.

Participants also all received considerable education and educational materials including installer guidance and demonstration on how to program their thermostat. Customers on the TOU-CPP rate received a refrigerator magnet with a graphical display of the rate. Participants were also encouraged throughout the summers to receive a free Home Energy Assessment from a trained technician. Finally, customer support was provided by a dedicated team via phone, email, and site visits if necessary, and email notifications were sent prior to each of 12 events providing energy-saving strategies for the Conservation Day.

Summer hourly loads were analyzed using a three-level (hours, days, participants) mixed effects model that normalized for weather effects. Impacts were estimated using a difference-in-difference estimate between baseline year 2010 and treatment years 2011and 2012 summers, and treatment groups and a recruit-and-delay control group to correct for exogenous effects. Although the model normalized for weather differences between control and treatment years, actual weather differences were minimal.

Figure 1 shows the impacts of information treatments, and Figure 2 shows the impacts of rate and automation options.[2] The addition of real-time home information over baseline and appliance over home information during peaks had significant but small effects (~3%). (An unexplained anomaly is the 3% improvement in energy savings of the home-level information over appliance-level information.) If the addition of energy information contributed a relatively small amount to energy and peak savings, what then was primarily responsible for the overall 17% reduction in weekday peak and 41% reduction in event peak demand?

[2] All impacts are statistically significant at $p \leq 0.05$. Bolded values indicate significance beyond baseline, and underlined values indicate significance beyond both baseline and other treatments.

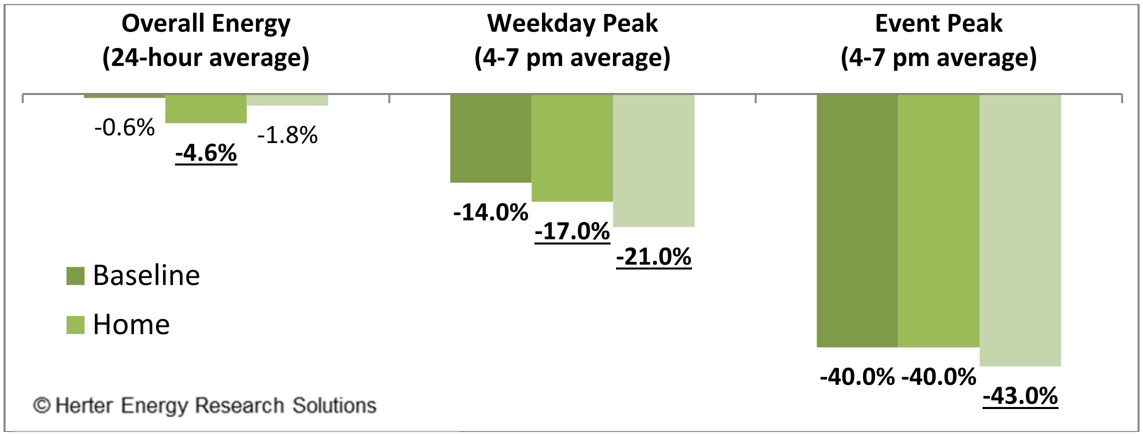

Figure 1. Single-family energy and load impacts by information treatment *Source:* Herter 2014.

When looked at by rate and automation treatment it becomes clear that the TOU-CPP rate accounts for nearly all the savings overall and on weekday and event peaks. Furthermore, the TOU-CPP rate doubles the savings over the standard rate with utility control during events. This suggests that half of the savings is accounted for by automation of air conditioning, and half by manual control of other end uses.

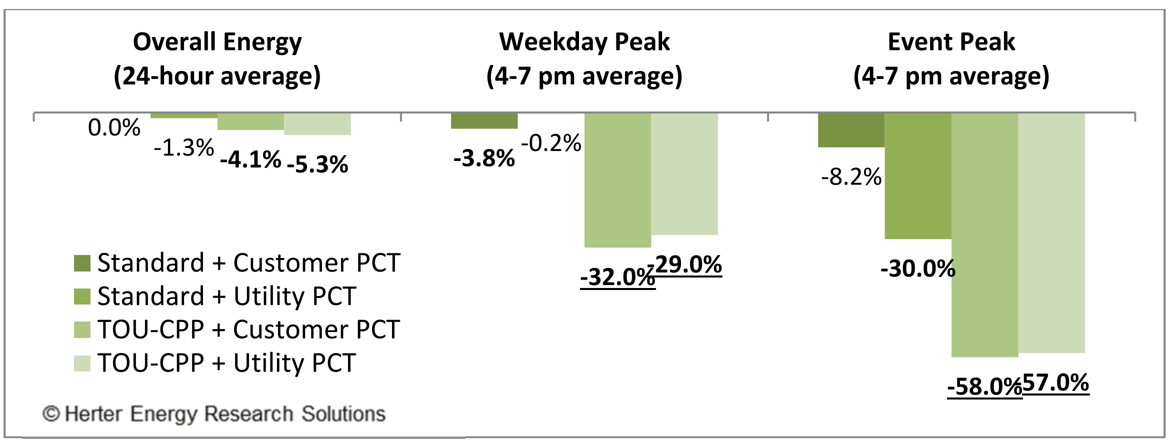

Figure 2. Single-family energy and load impacts by rate and automation. *Source:* Herter 2014.

Given the design of the experiment and the fact that almost all participants automated their air conditioning during events or allowed SMUD to automate it, there is no way to distinguish the effect of automation from the effect of the rate on participant behavior from this study. It also appears to be immaterial whether the utility or the customer is in control, as long as air conditioning response is automated. The sheer magnitude of the savings during event peaks where both automation and behavior are operating gives rise to the notion that the best approach would be an intervention that encourages and facilitates customers to set their communicating thermostats to respond to price events, and then to manually manage appliances that do not yet support automation.

Multifamily Summer Solutions Study

It was the desire to more clearly delineate the effects of the TOU-CPP rate from the effects of real-time information and the effects of automation of air conditioning price response that drove the design of the Multifamily Summer Solutions study. To measure the separate effects of the rate, information and automation, the research design had three distinct interventions, each hypothesized to create a progressively larger impact. Invited participants were randomly assigned to one of three treatment groups (interventions): 1) a time-of-use, critical peak period (TOU-CPP) rate; or 2) the TOU-CPP rate plus an in-home display (IHD) showing real-time energy use, cost information, conservation tips, and conservation messaging; or 3) the TOU-CPP rate and the IHD, plus a programmable communicating thermostat (PCT) that can be set to automatically respond to the TOU rate and CPP events.

These three treatment groups were also compared to a baseline of comparable customers on the standard rate to distinguish the effects of the TOU-CPP rate alone. Customers who signed up after treatment quotas were reached or who signed up and changed their minds prior to the start of the study were used as the comparison group in order to both control for exogenous effects and to act as a baseline comparison group of customers on a standard rate.[3]

In SMUD's service territory, most residents in multifamily complexes are renters (82%), and most of these (72%) are participants in SMUD's Energy Assistance Program Rate, a rate targeted and available to low-income customers. These customers may have particular motivation to use technologies already in their dwellings to save electricity and money on their electric bill. There is some evidence that this is the case: participant pre-survey and installer survey questions reveal that 21% of participants in Multifamily Summer Solutions programmed their thermostats prior to the study compared to 1% in the Single-family Summer Solutions study.

TOU-CPP Rate

The dynamic rate used for both the single-family and multifamily studies is a hybrid of SMUD's standard two-tiered flat rate and a typical TOU-CPP rate in that it incorporates the consumption tiers of the standard rate in the off-peak period. The reason for this is that one-third of all residential customers and almost two-thirds of multifamily customers remain below the first consumption tier. If the consumption tiers were not incorporated into the TOU-CPP rate, few multifamily customers would be able benefit on the rate over the standard rate, even by changing their behavior. SMUD is moving toward eliminating the consumption tiers by 2018 and placing all its residential customers on a TOU rate by default. (SMUD 2013)

Because this same rate was used in other SMUD pilots, there have been exactly 12 CPP events called each summer from 2011 through 2013. Graphics showing the standard and low-income (Energy assistance Program Rate, or EAPR) TOU-CPP rates in effect during the study are shown in Figure 3.[4]

[3] This was a modified form of a Randomized Encouragement Design (RED). See Cappers 2013 for an in-depth discussion of experimental designs for consumer behavior studies.
[4] Note that the EAPR rate has three consumption tiers compared to the two consumption tiers of the standard rate.

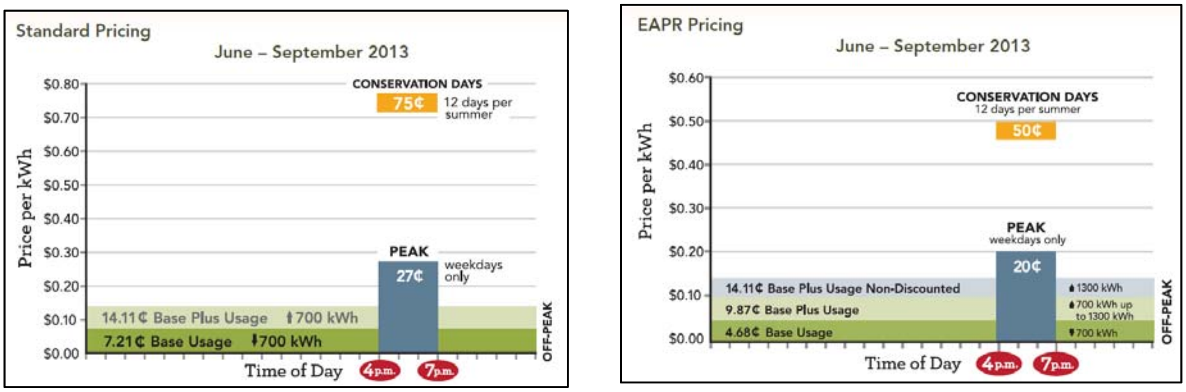

Figure 3. SMUD’s 2013 TOU-CPP standard and low-income rates.

Customer Recruitment and Education

Because the study involved the installation of PCTs in dwelling units, the sample was recruited in two stages: first property managers and owners of apartments with 50 or more units were recruited, and then all tenants in properties of participating managers/owners were recruited. Property managers/owners were mailed letters offering a $100 Visa gift card for participation and enclosing a Q&A sheet, and an agreement form with a return envelope. Shortly following the mailing, follow-up phone calls to the managers/owners were made.

Residents of condominium or townhome complexes were recruited directly at the same time that renters in participating apartment complexes were recruited. If condominium or townhome dwellers were renters, they were required to obtain their property owner’s permission to participate. Participants were sent letters, a tri-fold informational pamphlet and an application form and return envelope.

Like the Single-family Summer Solutions study, participants received substantial education and educational materials. Installers provided guidance on using the IHDs and PCTs, and participants were left with treatment-customized welcome booklets, with information about peak hours and Conservation Days, notifications, energy saving tips, the TOU-CPP rate, frequently asked questions and contact information. The PCT group received a SMUD-developed simplified Thermostat User’s Guide educating customers on how to set up automated temperature adjustments based on their needs and how the thermostat displayed real-time price changes through different light signals. Finally, customer support was again provided by a dedicated team via phone, email, and site visits if necessary. Email, text and phone notifications were sent the day before each of the12 Conservation Days.

Equipment and Training

The Multifamily Summer Solutions study leveraged SMUD’s recently deployed AMI and devices that had already been tested with SMUD’s wireless mesh system and were being used in other studies and pilots. The devices used were the Energate Pioneer Z 100 smart thermostat, the Energy Aware Power Tab IHD and the DIGI Xbee wireless range extender, shown in Figure 4. SMUD had installed ZigBee radios in all residential smart meters deployed over its 2011-2012 roll out, but the ZigBee standard is not without limitations. Because ZigBee is a low-energy wireless protocol, the range of the wireless signal is limited. This can cause connectivity problems in multifamily settings where typically meters are arrayed together on a building, and not usually near the units they serve. For this reason, range extenders were used to relay ZigBee radio signals. The range extenders used can be plugged into any AC outlet, and work by receiving and repeating the ZigBee wireless signal to shorten the effective distance between devices.

The IHD and PCT both displayed instantaneous energy use (kW) and the IHD displayed cumulative energy use (kWh) as well. The PCT offered participants the choice of how they would respond to daily and event peak prices through a feature called "Conservation Settings." Five different settings ranged from Maximum Savings to Maximum Comfort, and automatically set the temperature up from 0°F -6°F during peak periods, depending on the chosen setting and whether it was a daily or event peak. Both devices indicated upcoming price changes, Conservation Day events, and energy efficiency messaging tips.

Figure 4. Energy Aware Power Tab IHD, Energate Pioneer Z100 thermostat and DIGI Xbee wireless range extender used in the Multifamily Summer Solutions Study.

All three devices were installed by GoodCents, a professional installation contractor, whose employees were given day-long training on SMUD protocols, processes and procedures. Even though the IHD did not technically require professional installation, it was deemed the best way to avoid anticipated problems with obtaining and maintaining connectivity to SMUD's mesh network, as well as to avoid the low rate of activation seen when customers were mailed IHDs as in other SMUD pilots. Even with the use of range extenders and professional installers, the connectivity rate of IHDs proved to be problematic: 75% of IHDs had connectivity problems, 39% of them persistent, compared with 26% of PCTs, of which 14% were persistent.

Surveys

Three separate surveys were developed and administered throughout the study period.

- An installer survey asking questions regarding building and dwelling unit characteristics (number of stories, square footage, number of bedrooms and bathrooms, story of unit, cooling equipment, type and location of thermostat, appliances and end uses, orientation, window space, etc.)
- A pre-study participant survey asking questions regarding study expectations, degree of knowledge about time-based prices, typical appliance usage and costs, thermostat use and settings and demographics

- A detailed post-study participant survey regarding motivations, comfort and satisfaction with the various study elements, such as the rate, the IHD, the PCT, customer support, and installation

The installer and pre-study participant surveys were completed onsite during installation of the IHDs and PCTs, and by mail and phone follow-up for the rate only treatment group. The post-study participant survey was mailed with phone follow-up. Opinion Dynamics conducted the telephone survey follow-up, database development and survey analysis.

Impact Methodology and Hypotheses

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. In this pilot however, because of the nature of multi-family building management and the need to obtain permission to install thermostats, the sample was effectively a single-stage self-selected cluster sample of multi-family buildings with more than 50 units. All tenants within a participating multi-family site were recruited. Respondents were placed into their treatment groups until sufficient sizes were obtained, and late-comers were denied participation and placed in the comparison group. The comparison group was further extended by adding those participants who initially agreed to participate but later declined. As such, the results of this study 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.

A power analysis using average summer monthly billing kWh for the sampling frame was conducted prior to the study to assure sufficient sample sizes given certain parameters and effect sizes. Table 1 shows the planned (per the power analysis) and actual participant counts for the treatment and comparison groups. The actual coefficient of variation of participant energy use 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.

Table 1. Treatment and comparison group counts

Treatment	Planned Treatment Group (n)	Planned Comparison Group (n)	Actual Treatment Group (n)	Actual Comparison Group (n)
Rate Only (Baseline)	100	100	94	246
Rate + IHD (Information)	100		88	
Rate + IHD + PCT (Automation)	100		75	
Total	**300**	**100**	**257**	**246**

Opinion Dynamics estimated the impacts for weekday peak-period kW demand (excluding event days), event-period kW demand and overall kWh savings using fixed-effects panel models. (ODC 2014) 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.

The study included a hypothesis for each treatment group for each impact estimate (energy, weekday peak and event peak).

- Ha: The treatment groups on a TOU-CPP rate (with and without IHDs and PCTs) will show significant savings between the summers of 2012 and 2013 and reductions in weekday and event peak energy compared to an equivalent group of customers on a conventional rate.
- Hb: The treatment group on a TOU-CPP rate with an IHD will show significant savings between the summers of 2012 and 2013 and reductions in weekday and event peak energy compared to a group on a TOU-CPP rate alone and compared to a group on a conventional rate.
- Hc: The treatment group on a TOU-CPP rate with an IHD and a PCT will show significant savings between the summers of 2012 and 2013 and reductions in weekday and event peak energy compared to a group with IHD on a TOU-CPP rate, a group on a TOU-CPP rate alone, and a group on a conventional rate.

In addition to the impact analysis, Opinion Dynamics also conducted correlation analysis between the demand savings results found in the impact analysis and survey responses. It was not possible to use the modeled savings developed for the impact evaluation, so the absolute difference as an uncorrected savings estimate was used instead.

Findings

The results show substantial energy and peak-period demand reductions of the TOU-CPP rate over the standard rate for all treated groups. Additionally, there are substantial peak-period incremental savings for the PCT treatment group over the rate-only and IHD treatment groups. Figure 5 shows that the peak savings, both weekday and event, for the automated PCT treatment group is double that of the other two treatment groups, at 29% savings during weekday peak and 35% savings during event peak.[5]

The per-household energy savings from the rate overall averages 6%. In terms of energy savings, there are no differences among treatment groups. In fact, there are no statistically significant differences between the rate-only and the IHD treatment groups for any of the estimates[6], indicating that the addition of information over a dynamic rate has little or no impact on energy and demand.

[5] Again, bolded values indicate significance at $p \leq 0.05$ beyond baseline, and underlined values indicate significance $p \leq 0.05$ beyond both baseline and other treatments.
[6] Although the differences between peak savings of the rate-only and the IHD treatment groups appear large, the sample was too small to detect any statistically significant differences, so the values for the two groups that appear on the graphs are essentially the same.

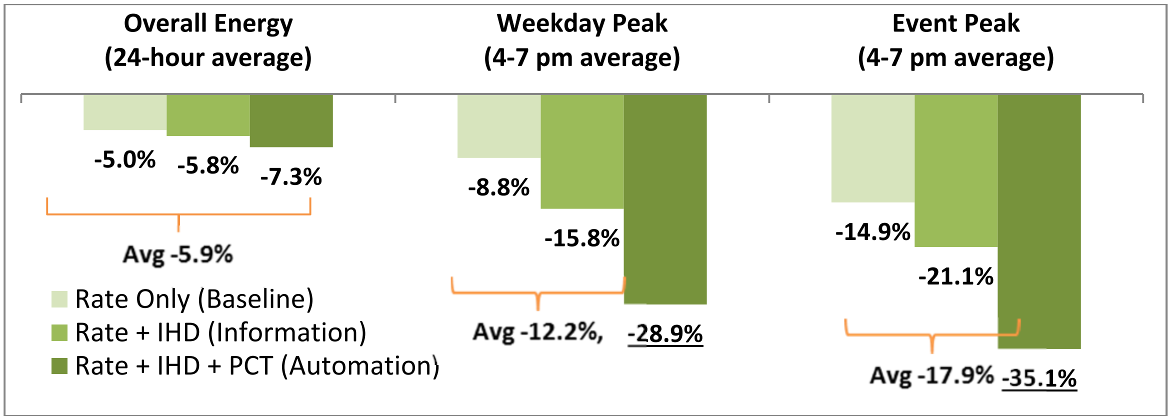

Figure 5. Multifamily energy and load impacts by rate, information and automation.

Correlation analysis revealed very few statistically significant correlations due in part to the low number of participants in each cell. One significant correlation, however, stood out, and that is that participants in the PCT treatment group who saved more energy said they paid less attention to their household's electricity use during the study period (2013) than before the study (2012). This is a surprising result and could reflect the belief that the PCT is managing energy use, both daily and during peaks, so they don't need to.

Conclusions and Recommendations

These findings corroborate what was suspected but not provable in the Single-family Summer Solutions study—that automation essentially doubles savings achieved from behavioral responses during peak periods, whether during the daily peak or an event peak. In addition, behavioral responses seem to be attributable to the rate and not information about energy use. However, these sample sizes were relatively small, and larger sample sizes may well reveal real differences due to energy information, as were seen for daily peak impacts in the single-family study. The lack of response to information may also be a reflection of the unreliability of IHD connection, which likely discouraged participants from paying attention to the IHDs. Survey responses revealed customers' frustration with continued loss of IHD connectivity. SMUD plans to repeat the multifamily research design in the single-family sector with larger sample sizes to be able to better distinguish rate, information and automation effects.

The policy implications for program planning and energy code modifications from these findings are obvious but likely to be difficult to implement in practice, due to the current state of communication protocols and smart grid enabled devices, problems with their application in multifamily housing, and most importantly, customers' current ability and willingness to program their thermostats. The answer to the question posed earlier, "Is there a role for both behavioral and automation catalysts in insuring reliable, grid-integrated demand-side resource?" is "Yes" until thermostats that set themselves to respond to price signals are ubiquitous. Until then, there is still a need for behavioral interventions that will result in customers programming their thermostats.

However difficult it is to implement the obvious policies, it is useful to articulate them, if only for a view into the future.

- Programs and codes that encourage the development and installation of reliable, interconnected and easy to use automation devices should be implemented.
- Time-based and dynamic rates that encourage the reduction of energy use during peak times, both daily and on critical days, should be developed and implemented.
- Interventions that encourage and facilitate customers to program their connected devices to save energy in response to time-based and dynamic rates should be developed, tested and implemented.

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