Flick Power Study: Pre-Attentive Color Schemes to Enhance Customer Responsiveness to Time-of-Use Electric Rates

Ivy So, APTIM Environmental & Infrastructure
Mark Martinez, Southern California Edison
Andre Ramirez, Southern California Edison

ABSTRACT

The concept of Pre-Attentive Notification (PAN) exists all around us from commercials to music and is present in our awareness of the general environment. It is the subconscious accumulation of information without observers directly noticing. This concept is a form of indirect feedback which can be more conducive to long-term behavior change. As technological distractions surround us, sometimes the simplest methods work best to grab our attention.

This field-study research project at SCE assesses the efficacy of deploying color in homes and apartments to enhance customer response to time-based electric rate signals–providing PAN awareness for greater responsiveness to Time-Of-Use (TOU) pricing. The technology demonstration showcases how color from an unobtrusive light switch can be pre-attentively processed by TOU customers and how this can effectively change subconscious behavior to enable daily load shift.

From pilot deployment over 217 apartments, installations found 83% of residents reporting ‘increased customer awareness about their energy habits’, and 92% reporting ‘pleased that the technology can help them grow savings.’ According to a 2020 ACEEE Assessment of National and Metropolitan Energy Burden, median energy burden of low-income multifamily households is 2.3 times higher than that of others. Furthermore, energy-saving tools often don’t reach apartment residents because of split-incentive problems, older infrastructure, and lack of connectivity. By conducting an empirical study of color signaling, timed to peak demand and prompted at the inflection point of the light switch, this research expands understanding of how subtle environmental cues can empower climate-action behaviors and equitable savings for underserved communities.

Background

The rationale for implementing a Time-Of-Use (TOU) signaling device such as the Flick Power light switch is rooted in the need to bridge the gap in consumer understanding of electricity pricing throughout the day. As customers transition to TOU rates, which vary prices based on peak and off-peak hours, there is a significant challenge in conveying these dynamic rates effectively to residential users. The novel communicating light switch aims to address this challenge by providing clear, real-time visual signals that inform users about current electricity prices through color changes. This real-time feedback encourages consumers to adjust their energy usage habits, thereby promoting more efficient energy consumption patterns (Fischer 2008; Van Dam 2010).

In a broader context, such technologies are essential for enhancing grid stability and reducing peak demand pressures, ultimately contributing to a more sustainable and resilient energy system. The pilot study conducted in a student housing community in Irvine, California, illustrates the device's potential to foster greater awareness and proactive energy management among users, highlighting its importance in the evolving landscape of dynamic electricity pricing.

In 2023, Southern California Edison's Emerging Technologies Program (ETP) and Emerging Markets and Technology (EM&T) Program jointly initiated the pilot study to demonstrate the effectiveness of customer behavior change from a novel light switch technology that displays communicating signals to residential consumers about the price of electricity.

While Southern California Edison (SCE) customers have recently been transitioned to Time-Of-Use (TOU) rates, many do not know the hours that electricity is most expensive. The gap in understanding is apparent as California's lower income customers consistently have ~30% lower levels of awareness about TOU signals and energy programs, according to the 2020 Assessment of National and Metropolitan Energy Burden across the United States.

Colored light signals have been proven to change behavior but in-home display devices that sit on a counter have typically been set aside after initial months. The implementation of novel residential Demand Response (DR) feedback mechanisms, such as the Flick Power light switch, represents advancement in the field of energy management.

Prior investigation and literature have explored various DR feedback devices and their effectiveness in influencing consumer behavior and promoting energy efficiency. Notably, two EPRI economists, Faruqui and Sergici, surveyed evidence across four TOU experiments and "enabling technology emerged as the main driver of the load reductions especially on peak event days and for the high consumption customers." Their cross-experimental assessment found promising evidence that households do respond to higher prices by lowering usage from aggregated mean impact estimates indicating that TOU programs supported with enabling technologies reduce peak usage by 26 percent and a 95 confidence interval ranges from 21 to 30 percent (2010, 45–46).

While the demand response impacts of that dataset are encouraging, the economists cautioned that the results were constrained due to the small number of observations and most likely also captured impacts due to central air conditioning (CAC) ownership. A three fourths majority of the implementations with enabling technologies were tested on customers with CAC ownership. Furthermore, across a range of time-varying rate increases, non-CAC customers (those without central AC) were consistently the least responsive group, while customers owning central air conditioning were the most responsive. Therefore, for this technology deployment study, the Flick Power Study intentionally evaluated customer willingness to enact other means of behavioral response beyond the adjustment of air conditioning, to further include powering off electronics, shifting large appliance usage, and many more.

Early devices like in-home display units and smart meters provided detailed energy consumption data but faced challenges in sustaining user engagement over time (Darby, 2006). Underlying those challenges and potentially more problematic, a 2015 qualitative analysis of consumers' self-reported experiences using in-home-displays (IHDs) found the success of IHDs in reducing energy consumption depends entirely on user engagement (Buchanan 2015). The researchers leading the analysis called for new IHDs to be developed and evaluated with user engagement in mind. As such, this pilot's visual and ambient feedback device was specifically devised to encourage energy savings by increasing user awareness of TOU periods and prompting immediate behavioral adjustments right upon entry into the living area.

This approach of using visual, color-changing light signals, attempts to addresses these issues by offering a more immediate and less intrusive means of communicating dynamic electricity prices, potentially maintaining user engagement more effectively. Through a field deployment of a smart light switch and color changing face representing time-based prices via internet, the Flick Power Study seeks to evaluate present-day impact of DR-enabling technology by focusing on the customer perception of the signaling light switch. By targeting a unique sector of residential units, this research aims to deepen our understanding of the behavioral shifts induced by these visual signals, such as load shifting and curtailment. The study's design, which includes surveys on customer motivating factors, offers valuable insights into the broader applicability and effectiveness of DR feedback technologies in achieving energy efficiency goals.

This evaluation will address key research questions relating to TOU response with a relatively under-researched customer group and the incremental impact of customer load shifting above and beyond what behavior change customers normally provide on a dynamic pricing program or rate. Study surveys sought to glean insight into inherent levels of customer interest regarding their energy consumption and characterization of motivating factors to energy use. Ensuring that various types of units all be proportionally represented in treatment and control, the experimental design allocates for a similar number of top floor, bottom floor, one-bedroom, and two-bedroom units be included in both treatment and control groups.

Methodology & Approach

The case study is locally sited in the Vista Del Campo Norte student housing apartment community of Irvine, California. The student housing facility was a mixture of suite-style living and individual dormitories, however the majority were suites comprised of 2 – 4 single bedrooms attached to a central living space and kitchen. 216 residential units had the signaling device installed, at random, to serve as the test group, with the remaining 344 units in the community serving as a comparative control group.

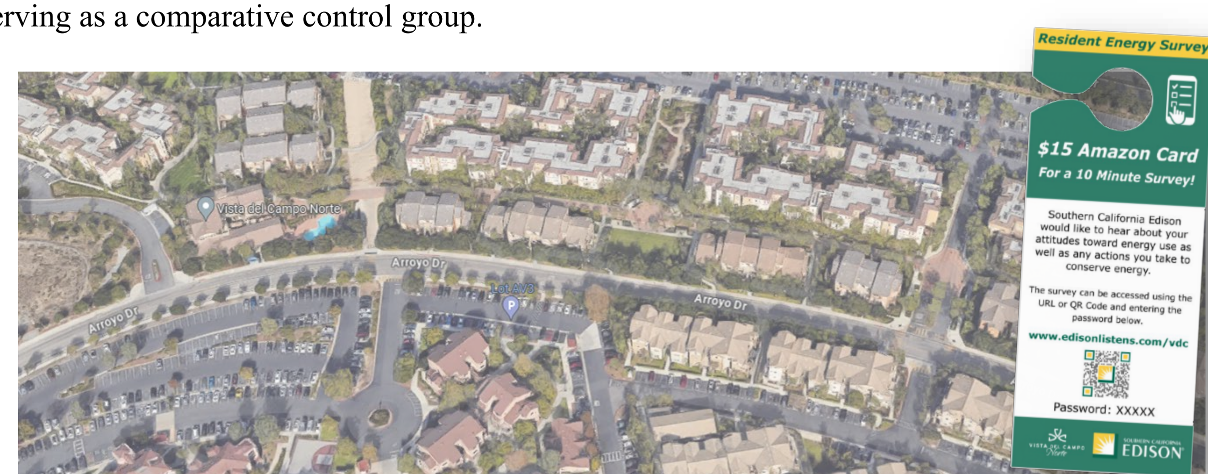

Figure 1. Energy survey invitations delivered via doorhangers provided to 560 individual apartments & overhead view of the Vista Del Campo Norte community

The Flick Power light switch devices were pre-installed by an electrician. The utility and customers' rates are programmed into the switch and its indicator displays colored light signals to show the price of electricity: green (lowest price), blue (moderate), and red (most expensive). One test hypothesis was whether the device facilitates consumers to think more about energy use, if they better understand when the peak hours are, and try to take more actions to reduce and shift their electricity consumption.

The test/control pilot design initially composed for two components – one component to compare attitudinal, awareness, and behavioral differences between the test and control apartments with the promise of a $15 gift card to all respondents. The other component is to compare differences in load across the 216 test apartments and the 334 control apartments.

Pre- and Post- survey instruments were self-administered, and web based. Door hanger flyers prompted participants to take the survey via a QR code on their smartphone, tablet, or personal computer. The Pre-Pilot questionnaire assessed attitudes and behaviors such as the following:

- Level of interest in lowering their energy bill
- Self-assessment about how much they think about electricity usage
- Awareness of being transitioned to TOU rate
- Knowledge of current rate
- Understanding of how TOU works
- Understanding of peak hours
- Actions taken to shift/reduce including:
    - Reducing usage of air conditioning or adjusting to pre-cool for afternoons
    - Avoided running of the dishwasher
    - Turning off entertainment systems

To address the research question if customers with Flick demonstrate any conservation or ongoing energy efficiency from lower average usage versus customers without a Flick device, treatment and control groups are invited to a similar post-survey to measure effects in their awareness and behavior.

To capture the incremental effects on a TOU rate, it is optimal to have pre-treatment data from the prior year (same customer and same premise) in order to allow for a difference-in-differences calculation. Therefore, an initial survey was delivered to 560 housing units to establish the usage and characterize existing user attitudes of the Vista del Campo Norte community members.

This Flick Power Study scope of work intended for the following technical evaluation task list:

1. Data Cleaning and Validation
    a. Ensure proper and complete data was received
    b. Validate treatment assignment
        i. Validate pre-treatment load data is similar between treatment and control group (for TOU) and validate load is similar between the treatment and control group on non-event days (for Emergency Load Reduction Program (ELRP))
        ii. Develop analysis dataset combining treatment assignment data, load data, and event data for ELRP and synthetic event days.
2. Load Analysis
    a. TOU: Conduct difference-in-differences calculation via regression model (if pre-treatment data is available) or straight differences via regression model (if pre-treatment data is not available). Regression models are used to obtain standard

errors in order to determine if the impacts are statistically significantly different from zero.
    b. ELRP: Conduct difference-in-differences calculation via regression model. Regression models are used to obtain standard errors in order to determine if the impacts are statistically significantly different from zero.
3. Reporting/Deliverables
    a. Develop an emerging technologies report with specified contents including description of pilot, summary statistics for pilot population, brief high-level methodology, and findings.

Collaboration & Partners

Provisioned with funds from SCE ETP and EM&T, this project lies in both the "Market Assessments" and the "Technology Assessments" investment categories, as there are elements of both research goals in this study. The Market Assessments category is designed to create a better understanding of the emerging innovation and developments of new consumer markets for DR-enabling technologies and an awareness of consumer trends for smart devices. The Technology Assessments category assesses and reviews the performance of DR-enabling technologies through lab and field tests and demonstrations designed to verify or enable DR technical capabilities.

To implement the research study, SCE executed a service contract with Flick Power as the technology provider and primary partner providing technology, installation, and communication support with the pilot participants, electricians, and building managers. The Flick Power research team is also in collaboration with SeeChange Institute (SCI) and together have developed the lines of inquiry, study design, and messaging campaign.

SCI supports the design of outreach and evaluation materials for this pilot. Activities are determined in consultation with Flick Power & SCE, including advising content and door hanger design, drafting content for resident email correspondence, and developing other strategies to engage pilot residents.

Furthermore, this project engages APEX Analytics for work on the load impact study design & emerging technology report. As part of the project team, they facilitate load change measurements and calculate impacts via regression models, with SCE presiding as an active reviewer of the work in progress.

To synthesize findings for tech transfer to project stakeholders, relevant forums, and interested utility partners, SCE engages APTIM Environmental & Infrastructure for support and communications coordination. They are also designated to support project reporting and providing progress development updates to meet broader program compliance.

Device & Customer Communications

Residents were welcomed with a static cling to educate them about the three varying color signals and informed of steps they can take to reduce or shift their energy consumption e.g. delaying a load of laundry or precooling air conditioning usage.

The device has the following tech specs: Rated current:15A, Rated voltage: AC110V~ 125V/ 50-60Hz, Rated power:1 Gang (1800W), Working frequency:2.412~2.484GHz, Safety: WEP/WPA-PSK/WPA2-PSK, Static power loss: ≤0.5W, Working temp:-20 C°~75 C°, Humidity: <95%, and 2-year extendable warranty.

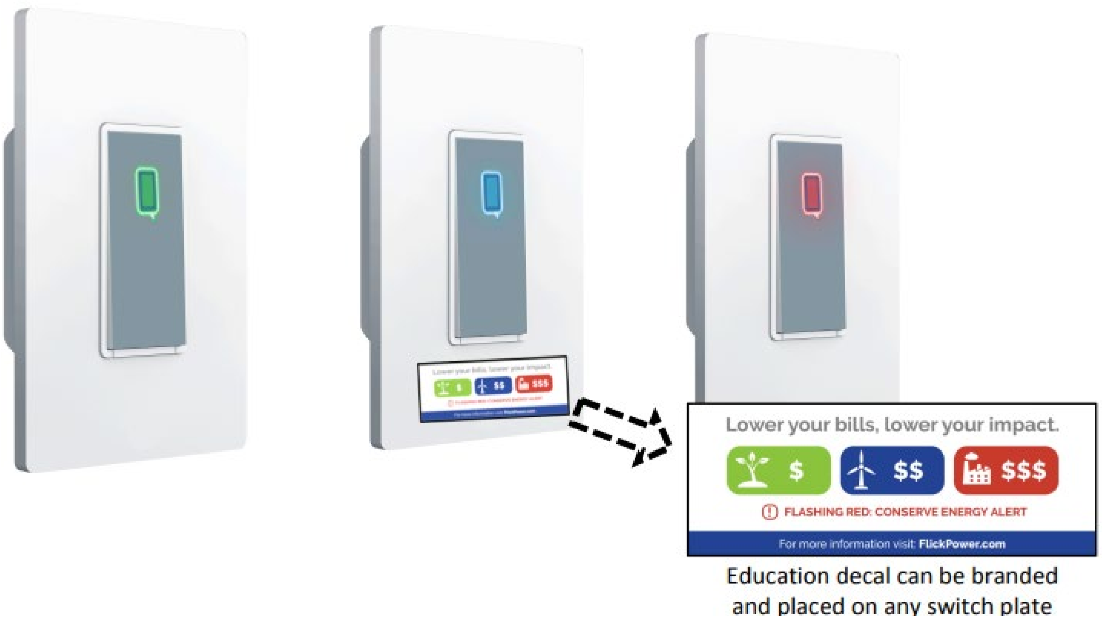

Figure 2. The light switch device with its three color-signaling display indicators and education decal provided to residents for color legend reference

Results & Findings

Educational materials were provided via door hangers to test site apartments in October 2023, with 216 devices installed in August 2021. These apartments received survey invitations in December 2023, with the project team anticipating a 15% response rate from control apartments and 20% from test apartments, to yield sample sizes of 50 for control and 43 for the test.

Surprisingly, an elevated and early response rate garnered substantially higher sample counts than were expected- up to 45% from the test group and control group each, which theoretically yields 100 Test and 150 Control responses.

Analysis of the early responses suggests that just over half of the test apartments acknowledge the devices. This means the near half who are not aware of the light switch device already installed could not be reputably expected to show any impact (and effectively, these can be added to/become part of the control responses). The higher response rates combined with the reassignment of some test responses to those of the control responses, would be expected to produce survey response cell sizes of 50 and 200 respectively.

While these sample sizes could be expected to provide a meaningful analysis, continuing the project's component of load analysis does not expect to be worthwhile. If half of residents in the test apartments are unaware that they have the device, no load changes should be expected. The project team elects to preserve budget for load analysis use in future demonstration testing.

Data collection was conducted on an ongoing basis throughout the 4th quarter of 2023. The preliminary findings across the sites reflect the following metrics. First, most students (71%) that were aware of the light switch device were also aware of the display's different color meanings.[1] To note, residential units that had the color-signaling devices installed are labeled "(not functional)" in Table 1 below, because of connectivity disruptions discovered after the survey results came in.

[1] Survey Question: Before today, were you aware of the meaning of the different colors?

Table 1. Responses of Device color awareness and Receipt of instructions

	Device Status: Currently Installed (Not Functional) (n=24)	Device Status: Device Never Installed (n=26)
Aware of Color Meaning		
Yes	71%	12%
No	25%	88%
Not Sure	4%	-
Received Instructions		
Yes	63%	8%
No	25%	88%
Not Sure	13%	4%

Of those that saw the display's colors change on the device, over half (54%) took action to reduce or shift their energy usage.[2] Self-reported actions taken are individually broken out below in Table 2.[3]

Table 2. Responses of Device color change and Actions taken post-signal recognition

	Device Status: Currently Installed (Not Functional) (n=24)	Device Status: Device Never Installed (n=26)
Seen Device Change Color		
Yes	38%	19%
No	54%	58%
Not Sure	8%	23%
Actions Taken		
Did not prompt me to take any specific action	**46%**	**54%**
NET: Took Action	**54%**	**46%**
Reduced using or adjusted the use of your home's air conditioning on warm afternoons and evenings	38%	19%
Avoided running the dishwasher	21%	19%
Turned off entertainment systems (TV, Xbox, PlayStation, etc.)	29%	27%
Turned off office equipment (computer, printer, etc.)	25%	23%
Pre-cooled the home by running air conditioning earlier in the day	8%	15%
Looked up the Flex Power switch instructions	8%	15%
Avoided doing laundry	8%	8%
Others	13%	-

Delineated in Table 3, nearly three out of four students think about their energy use at least once per week, and slightly more so for residents with installed devices versus without.

[2] Survey Question: Have you seen the Flick Power light switch changing color, indicating that you are or were in a peak period and energy rates and carbon emissions were higher?
[3] Survey Question: What actions did you or others in your apartment take after seeing the light switch change color?

Table 3. Frequency of thinking about energy usage

Thoughts on Energy Use	Total Respondents (n=172)	Device Status: Currently Installed (Not Functional) (n=25)	Device Status: Device Never Installed (n=90)
Net: At least once a week	**72%**	**76%**	**71%**
At least daily	27%	16%	29%
Every few days	26%	20%	24%
Once a week	19%	40%	18%
Once a month	**14%**	**8%**	**14%**
Less often	**9%**	**8%**	**7%**
Never	**5%**	**8%**	**7%**
Not sure	**1%**	-	**1%**

For on-peak awareness and summarized in Table 4, students without the device installed demonstrate a marginally lower likelihood to identify correctly 4 – 9 pm peak hours. Interestingly, more students with device installed also incorrectly identify peak between the hours of 1 pm to 4 pm.[4]

Table 4. Recorded responses on peak hour awareness by 1-hour periods

Peak Hours	Total Respondents (n=172)	Device Status: Currently Installed (Not Functional) (n=25)	Device Status: Device Never Installed (n=90)
12:00 to 5:59 am	22%	4%	29%
6:00 to 11:59 am	44%	28%	47%
12 noon-12:59 pm	23%	32%	18%
1:00-1:59 pm	24%	40%	19%
2:00-2:59 pm	29%	48%	22%
3:00-3:59 pm	32%	48%	24%
4:00-4:59 pm	**37%**	**44%**	**32%**
5:00-5:59 pm	**38%**	**40%**	**37%**
6:00-6:59 pm	**34%**	**36%**	**32%**
7:00-7:59 pm	**31%**	**32%**	**32%**
8:00-8:59 pm	**29%**	**28%**	**29%**
9:00-9:59 pm	19%	12%	21%
10:00-10:59 pm	11%	8%	13%
11:00-11:59 pm	6%	8%	8%
Not sure	36%	28%	41%

[4] Survey Question: Peak hours are when the price of electricity is higher. On the Edison Time-of-Use rate plan, during what hours is electricity most expensive?

The majority of community residents (64%) at least sometimes consider the time of day when deciding when to use appliances as summarized in Table 5.[5]

Table 5. Respondent-selected motivating factors to lower energy use

Consider Time of Day	Total Respondents (n=172)	Device Status: Currently Installed (Not Functional) (n=25)	Device Status: Device Never Installed (n=90)
NET: Always/Almost Always/Sometimes	**64%**	**68%**	**61%**
Always	7%	4%	7%
Almost Always	17%	12%	20%
Sometimes	40%	52%	34%
Almost Never	19%	16%	20%
Never	17%	16%	19%
Not Sure	1%	-	-

Resident surveys and attitudinal characterization have been completed. Characterized by Table 6, notable findings based on those surveyed include:

1. The majority of students (64%) at least sometimes consider the time of day when deciding when to use appliances.
2. As expected, interest in energy consumption is relatively low among students who don't pay their energy bill (30%).
    a. Even though the students don't pay their own electric bill, the largest motivating factor to lower their energy use was to save money.[6]
    b. Students living in a housing unit with the Flick Power device installed were significantly more motivated by saving money than those without the device.

Table 6. Respondent-selected motivating factors to lower energy use

Motivating Factors (%8-10)	Total Respondents (n=172)	Device Status: Currently Installed (Not Functional) (n=25)	Device Status: Device Never Installed (n=90)
Save Money	67%	80%	61%
Reflect my concerns about climate change	38%	52%	36%
Act to protect the environment for future generations	37%	48%	34%
Lower my household's carbon footprint	32%	48%	31%
Lessen my home's load on the electricity grid	25%	44%	22%

[5] Survey Question: Typically, how often would you say you consider the time of day when deciding whether or not to run appliances such as your dishwasher, washer/dryer, air conditioning, etc.?
[6] Survey Question: How motivating might each of the following be for you to use less electricity in your household? A desire to...

Lessons Learned

The project team identified several factors that contributed to the low awareness of the first-generation device installed in Test group apartments which will be useful in the development and deployment of Generation II.

The device feedback report uncovered twenty-five devices that were found to be unable to access the internet due to a change of internet service provider (ISP) at some point. The hardwired light switch devices also had to be reset remotely by the vendor, which possibly caused connection disruptions. These two operational challenges prompt the need for devising improvements to the operational capability of the second-generation device as a closed loop system instead where the device manufacturer can manage all communications with the devices, gateways, and its servers.

Furthermore, during the time period when devices could not access the internet, the light switch device displays simply flashed white. Treatment group feedback in particular expressed interest to "know if the device is functioning properly or not." This obstacle and resulting verbatim points to the untapped benefit of including a "system live" status indicator for troubleshooting. The project team is addressing this need and incorporating an indicator for the next generation device to proactively communicate when it has been disconnected or is no longer functioning.

The lessons learned through this research project's work provide implementation guidance for deployment of these signaling devices in multi-family and affordable housing as well. A few such properties have expressed interest in the 2nd generation device deployment and evaluation study. The project team is exploring applicability for these communities and plans to educate in advance about the device and its potential value to property residents to improve affordability.

Conclusion

This study on the Flick Power signaling device demonstrates its potential to significantly enhance consumer engagement with Time-of-Use rates and dynamic pricing. By providing visual cues about electricity pricing, the device effectively prompted behavior changes such as load shifting and curtailment among users. The findings indicate a positive correlation between device awareness and energy-saving actions, with users demonstrating an increased understanding of peak hours and a greater motivation to reduce energy consumption. The study's results suggest that integrating such smart technologies can lead to more efficient energy usage patterns and higher consumer responsiveness to dynamic pricing. This research underscores the potential for broader implementation of innovative demand response technologies, informing future policies and the design of consumer-centric energy programs.

The next steps, including enhanced visual notifications and improved network connectivity, aim to further optimize these benefits and facilitate wider adoption in multi-residential settings, ultimately contributing to a more resilient and responsive energy grid. Development of the Flick Power light switch Generation II is underway with advanced communication features that may replace traditional in-home wireless systems. Informed by data gathered during the first phase of the pilot deployment, the project team is building a screen feature to display messaging to reinforce color signaling and drive more persistent savings compared to the first-generation light switch, which only utilizes color. The Flick team is developing a proposed scope of work to deploy the next phase of the technology.

References

Buchanan, K., R. Russo, and B. Anderson. 2015. "The Question of Energy Reduction: The Problem(s) with Feedback." *Energy Policy*, 77 (1): 89-96.

Darby, S. 2006. *The Effectiveness of Feedback on Energy Consumption: A Review for DEFRA of the Literature on Metering, Billing, and Direct Displays*. Oxford, UK: Environmental Change Institute, University of Oxford. www.researchgate.net/publication/238785702_The_Effectiveness_of_Feedback_on_Energy_Consumption.

Drehobl, A., L. Ross, and R. Ayala. 2020. *How High Are Household Energy Burdens? An Assessment of National and Metropolitan Energy Burdens across the U.S.* Washington, DC: American Council for an Energy-Efficient Economy. https://www.aceee.org/research-report/u2006.

Faruqui, A., and S. Sergici. 2010. "Household Response to Dynamic Pricing of Electricity: A Survey of the Empirical Evidence." *The Brattle Group*, February 12. www.smartgrid.gov/files/documents/ssrn_id1134132.pdf.

Fischer, C. 2008. "Feedback on Household Electricity Consumption: A Tool for Saving Energy?" *Energy Efficiency*, 1 (1): 79-104.

Van Dam, S., C. Bakker, and J. Van Hal. 2010. "Home Energy Monitors: Impact Over the Medium-Term." *Building Research & Information*, 38 (5): 458-469.