

The Hawthorne effect and energy awareness

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The feeling of being observed or merely participating in an experiment can affect individuals' behavior. Referred to as the Hawthorne effect, this inconsistently observed phenomenon can both provide insight into individuals' behavior and confound the interpretation of experimental manipulations. Here, we pursue both topics in examining how the Hawthorne effect emerges in a large field experiment focused on residential consumers' electricity use. These consumers received five postcards notifying, and then reminding, them of their participation in a study of household electricity use. We found evidence for a Hawthorne (study participation) effect, seen in a reduction of their electricity use—even though they received no information, instruction, or incentives to change. Responses to a follow-up survey suggested that the effect reflected heightened awareness of energy consumption. Consistent with that interpretation, the treatment effect vanished when the intervention ended.

environmental decision making | energy conservation | electricity consumption | behavioral decision research

How to substitute human responsibility for futile strife and hatred—this is one of the most important researches of our time.

Elton Mayo, in Roethlisberger and Dickson (1)

Beginning in 1924, the Western Electric Company Hawthorne plant was the site of some of the most influential studies in the formative years of the social sciences: the illumination experiments, examining the effects of artificial lights on worker behavior. Although workers seemed to increase their productivity when lighting regimes changed, the researchers eventually concluded that those changes actually reflected psychological factors, such as workers' responses to receiving special attention or being aware of the experiment. Subsequent studies at Hawthorne reached similar conclusions (1). Such changes came to be called Hawthorne effects (2, 3), although, ironically, secondary analyses concluded that there was no effect in the original studies or, more precisely, that the studies' design was too flawed to establish whether the effect was, in fact, observed there (4–7).

The mythical status of the initial observation notwithstanding, the Hawthorne effect is a fundamental concern for scientists studying any program designed to change human behavior, who must distinguish the effects of the program from the effects of being in the study. As a result, the Hawthorne effect has been examined in many areas, including worker performance (8), education (9, 10), health (11), and voting (12). The evidence from these studies is mixed. Some of the variability in their results may reflect differences in how they operationalized the concept of “being in a study.” At one extreme lie such minimal manipulations as telling people no more than that they are in a study. At the other extreme lie treatments known to have their own effects, such as directly monitoring specific behaviors (13), providing performance feedback (14), inadvertently communicating research hypotheses (15), and providing new resources or instruction (16). Here, we add to the relatively small set of experiments that have examined the effects of study participation per se, with a field experiment examining electricity use of several thousand consumers. Our results reveal evidence of a pure Hawthorne effect, the psychological mechanisms shaping its size, and its implications for field studies of policy interventions.

In addition to its obvious economic and environmental importance, household electricity consumption offers several attractive features as a research domain. It is routinely measured for many households. It is such a small part of most Americans' budgets that it typically receives little attention, meaning that participating in a study might be enough to make it salient. Finally, most people know how to save electricity—even if they do not always know which ways are most effective (17, 18). Thus, if participating in a study increases the salience of electricity consumption, people should know what to do without further instruction—which could confound the pure participation manipulation.

Although there are many studies of interventions seeking to affect energy consumption, few have assessed the impact of Hawthorne (study participation) effects on their results (19). Among those few, some used an opt-in design eliciting a commitment to participate (hence confounded the mere-participation manipulation), had small samples, used weak manipulations, or omitted essential details in the research report, making it hard to tell what they did and found (20–22). As a measure of the importance of even small changes in energy consumption, states have set goals ranging from 0.1% to 2.25% annual savings (23).

Our experiment sent five weekly postcards to a random sample of electricity customers, notifying them about their participation in a study about household electricity use. Monthly electricity use was collected before, during, and after the experimental period for the treatment group and for a similarly selected control group. One month after the last postcard was sent, we surveyed a random sample of participants, asking about their response to the study.

Experimental Design

Participants were randomly selected from residential customers of a mid-Atlantic electricity utility to be in treatment or control groups. Households in the treatment group received their first notification a few days before the start date through a postcard stating that they had been selected to be in a 1-mo study about electricity use in their home and that no action was required on their part. They then received four additional weekly postcard reminders about the study. Thus, the study's sole stated goal was measuring electricity consumption. The control group received nothing. The observation period approximately spanned the interval between successive monthly readings. Table 1 summarizes household characteristics for the treatment and control groups. A subsample received a survey 1 mo after the end of the study period. *Methods* provides details on the postcards, survey, sampling, and data structure.

Results

The main dependent variable was households' electricity use. Although meter readings are scheduled for monthly intervals, there is some variability in when they are actually performed. To

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Table 1. Household characteristics for control and treatment groups

Characteristics	Control mean	Treatment mean	t	P value
Household size*	2.8	2.8	-0.72	0.47
% households renting*	13.7	13.9	-0.27	0.79
% households with electric heating [†]	33.1	33.3	-0.27	0.78
No. of rooms [†]	6.5	6.5	-1.71	0.09
Household income (thousands of dollars) [†]	101.7	102.0	-0.32	0.75
% households with low payment history [‡]	12.1	12.5	-0.50	0.62
% households with low income subsidy [‡]	1.6	1.9	-1.01	0.31
% Whites*	47.2	47.4	-0.25	0.81
% Blacks*	31.1	31.0	0.08	0.94
% Asians*	13.5	13.1	0.90	0.37
% Hispanics*	11.5	11.7	-0.83	0.40
Summer 2010 electricity use [‡] , kW-h/d	42.0	41.8	0.36	0.72
Fall 2010 electricity use [‡] , kW-h/d	28.5	28.8	-0.74	0.46
Winter 2011 electricity use [‡] , kW-h/d	40.9	41.9	-1.19	0.23
Spring 2011 electricity use [‡] , kW-h/d	29.9	30.0	-0.32	0.75

*Source: 2010 Census data (block-level information).

[†]Source: 2010 Census Data (tract-level information).

[‡]Source: data provided by utility company (household-level information).

accommodate this variability, we adjusted each household's electricity use by the number of days that fell during the postcard treatment period. We used this as our estimator of the intervention's impact, comparing electricity use in treatment and control households, before and after the treatment period (Eq. 1):

$$y_{it} = \alpha + \beta_1 \cdot X_{it} + \gamma \cdot \text{treatment_group}_i + \delta_1 \cdot \text{treatment_period}_t + \lambda_1 \cdot \text{CDD}_{it} + \lambda_2 \cdot \text{HDD}_{it} + \eta_i + e_{it}, \quad [1]$$

where y_{it} is the log of average daily electricity consumption for household i in month (billing period) t , treatment_group_i indicates whether household i is in the treatment (1) or the control group (0), and $\text{treatment_period}_t$ is the fraction of days in the treatment period included in monthly electricity use for t . X_{it} is the interaction between these two terms, equal to the fraction of days in the treatment period for month t for households in the treatment group and 0 for households in the control group. Because most of the variation in electricity use in this region reflects demand for heating and air conditioning, our statistical model included heating and cooling degree days in each billing period: CDD_{it} and HDD_{it} are the average cooling and heating degrees days for month t , respectively, using the weather station closest to household i . Several household characteristics (e.g., household size and electric heating) were included in the regression and are denoted as η_i (see [Supporting Information](#) for details). The error term is e_{it} . β_1 is the average treatment effect of the intervention.

We calculated the average treatment effect estimators for the posttreatment period in the same way. We used two posttreatment periods, for the month after the intervention (Eq. 2) and for the following month (Eq. 3), to estimate carry-over effects, perhaps reflecting energy-saving habits that people formed during the intervention, and then maintained afterward.

$$y_{it} = \alpha + \beta_1 \cdot X_{it} + \beta_2 \cdot Y_{it} + \gamma \cdot \text{treatment_group}_i + \delta_1 \cdot \text{treatment_period}_t + \delta_2 \cdot \text{first-month-after_period}_t + \lambda_1 \cdot \text{CDD}_{it} + \lambda_2 \cdot \text{HDD}_{it} + \eta_i + e_{it}, \quad [2]$$

$$y_{it} = \alpha + \beta_1 \cdot X_{it} + \beta_2 \cdot Y_{it} + \beta_3 \cdot Z_{it} + \gamma \cdot \text{treatment_group}_i + \delta_1 \cdot \text{treatment_period}_t + \delta_2 \cdot \text{first-month-after_period}_t + \delta_3 \cdot \text{second-month-after_period}_t + \lambda_1 \cdot \text{CDD}_{it} + \lambda_2 \cdot \text{HDD}_{it} + \eta_i + e_{it}, \quad [3]$$

where the new interaction terms, Y_{it} and Z_{it} , are equal to the fraction of days in the first and second months, respectively, after the intervention ended for households in the treatment group and 0 for households in the control group. β_2 and β_3 are the average treatment effect for the first and second month after the intervention, respectively. As in Eq. 1, $\text{first-month-after_period}_t$ and $\text{second-month-after_period}_t$ indicate use changes, that hold for both control and treatment groups, in each posttreatment period for t .

Table 2 presents ordinary least-squares (OLS) analyses, using robust SEs clustered by household. Models I, II, and III represent the treatment and posttreatment effects specified above, in Eqs. 1, 2, and 3, respectively. The table shows that the average household in the treatment group used 2.7% less electricity during the month of the study (model I, $\beta_1 = -0.027$, $P = 0.03$), compared with the control group. These results are essentially the same when adjusted for observed days within the treatment month, as would be expected given the 97.9% overlap in the periods. As shown in models II and III, there was no posttreatment effect in either the month after the last postcard (model II, $\beta_2 = -0.007$, $P = 0.45$) or in the second month after that (model III, $\beta_3 = -0.005$, $P = 0.55$). [Supporting Information](#) shows that these results are highly robust to changes in model specification and that including temperature data and household characteristics markedly improve the fit of the regressions (24).

Survey

The survey was conducted a month after the field intervention ended. It followed the tailored design method (25). The analysis focuses on treatment group respondents able to answer questions about the intervention. Most treatment group respondents (68.1%) reported remembering at least one postcard out of the five, with a mean of 3.0 (SD = 1.3). Respondents who could not remember a single postcard may simply have forgotten in the month since the study ended. Or, they may not be the person who got the card—although most did say that they were the person who usually picks up the mail. When asked an open-ended question about the purpose of the study, 30.2% of these respondents cited variants of “save, learn, or be more aware about electricity,” 29.6% offered variants of “study electricity usage” (as stated in the postcards); 20.4% said that they did not know. When asked how the study had affected them, 22.2% agreed or strongly agreed with the statement “the study made me reduce my electricity usage,” where 1 = “Strongly disagree” and 5 = “Strongly agree.” In addition, 36.4% thought that the study

Table 2. OLS regressions and average treatment effects, indicating the percentage change (savings) in the treatment group compared with the control group

DV: ln(kW/h/d)	Model I			Model II			Model III		
	Coefficient	SE	t	Coefficient	SE	t	Coefficient	SE	t
Treatment effect	-0.027**	0.012	-2.159	-0.026**	0.012	-2.151	-0.026**	0.012	-2.153
First-month-after effect	—	—	—	-0.007	0.010	-0.751	-0.007	0.010	-0.697
Second-month-after effect	—	—	—	—	—	—	-0.005	0.009	-0.592
Treatment group (= 1; 0 if not)	0.006	0.014	0.47	0.007	0.014	0.48	0.007	0.014	0.488
Treatment period	-0.038***	0.008	-4.95	-0.038***	0.008	-4.966	-0.038***	0.008	-4.945
First-month-after period	—	—	—	0.033***	0.006	5.231	0.032***	0.006	5.075
Second-month-after period	—	—	—	—	—	—	-0.032***	0.006	-5.393
Cooling degree days	0.056***	0.001	107.622	0.056***	0.001	104.229	0.056***	0.001	103.964
Heating degree days	0.014***	<0.001	54.985	0.014***	<0.001	54.458	0.014***	<0.001	54.418
Constant	1.439***	0.054	26.484	1.460***	0.054	27.026	1.473***	0.054	27.38
Household characteristics		Yes			Yes			Yes	
Adjusted R ²		0.220			0.216			0.218	
Households		5,598			5,598			5,598	
Observations		113,624			119,087			124,578	

Dependent variable (DV) is the log of household's average daily electricity use. * $P < 0.10$, ** $P < 0.05$, *** $P < 0.01$. A log transformation of average daily use produced residuals closer to a normal distribution than did analyses using actual use, suggesting more robust results and inference. Without the transformation, the average treatment effect was -0.998 kW/h/d ($P = 0.04$), or 2.2% based on the control group's average daily use of 44.5 kW/h/d during the treatment period.

had made them more aware of their electricity use and 30.2% that they had learned more about what things use electricity.

As seen in Table 3, treatment group respondents were more likely to report that they had reduced their electricity consumption when they saw themselves as doing more than their neighbors to save electricity (model 1; $\beta = 0.386$, $P < 0.01$), and when they perceived the study as having heightened their awareness of electricity use (model 3; $\beta = 0.669$, $P < 0.01$). Whether they reported reducing their consumption was not related to whether they expressed concern about privacy with new metering devices that would constantly track their use, which could be seen as another form of awareness. Finally, even though perceived reductions were related to believing that the study was about reducing, learning, or being aware of electricity use (model 2; $\beta = 0.545$, $P < 0.01$), that effect disappeared when reported electricity awareness was added to the model (model 3). Thus, perceived reductions reflect heightened awareness of electricity use as a result of participating, rather than beliefs about the study's purpose. Additional regression analyses found no relationship between actual use and these survey questions (See *Supporting Information* for details). However, only 162 respondents reported remembering at least one postcard, limiting the statistical power of this test.

When asked how often they had performed nine energy-saving actions (with "never" = 1 and "always" = 5), treatment group respondents who reported reducing their electricity consumption were also more likely to report turning off their air conditioning, unplugging devices when not in use, and using electrical devices less, compared with respondents in the control group ($P = 0.07$, $P = 0.01$, and $P < 0.01$, respectively). There were no differences in reports of the other six actions, whether routine (e.g., turning off computers and lights) or sustained (e.g., buying energy-efficient light bulbs or appliances). Comparing all actions reported by treatment group respondents who reported not reducing their electricity use with respondents in the control group revealed only one significant difference: Control group respondents reported using electrical devices less ($P < 0.01$).

Discussion

We find evidence for a "pure" (study participation) Hawthorne effect in electricity use. Residential consumers who received weekly postcards informing them that they were in a study reduced their monthly use by 2.7%—an amount greater than the annual conservation goal currently mandated by any state. A follow-up survey found that participants who reported having responded more to the study also reported greater awareness of

Table 3. Survey measures associated with reported-use electricity reduction

DV: perceived electricity reduction caused by the study	Model 1			Model 2			Model 3		
	Coefficient	SE	t	Coefficient	SE	t	Coefficient	SE	t
Do more than neighbors to save electricity	0.386***	0.100	3.857	0.306***	0.101	3.023	0.120*	0.070	1.71
Concern about being observed with new metering devices	0.139	0.089	1.565	0.132	0.087	1.528	0.027	0.060	0.446
Study's perceived purpose to save, learn, or be more aware about electricity (= 1; 0 if not)	—	—	—	0.545***	0.188	2.893	0.186	0.131	1.420
Became more aware of their electricity use because of the study	—	—	—	—	—	—	0.669***	0.054	12.425
Constant	0.901**	0.446	2.018	1.024**	0.437	2.347	0.055	0.307	0.179
Adjusted R ²		0.097			0.145			0.604	
No. of observations		136			136			136	

Of the 162 treatment group respondents who reported remembering at least one postcard, hence could answer questions about the study, 136 answered all of the questions used in this analysis. Unstandardized coefficients. Unless otherwise noted, for all scales 1 = "Strongly disagree" to 5 = "Strongly agree." * $P < 0.10$, ** $P < 0.05$, *** $P < 0.01$.

their electricity consumption and saw themselves as already doing more than their neighbors. These results suggest that the Hawthorne effect occurred here because participation in the study increased the saliency of the focal behavior—an interpretation supported by the fact that the treatment effect vanished when the intervention ended.

The field study contributes to our understanding of the Hawthorne effect by addressing methodological limitations of previous studies. Namely, our design isolates the effect of participation in a study from potential confounds, such as providing information or feedback. The follow-up survey further clarifies the underlying mechanisms. Our results suggest that participation in a study can change behavior without providing feedback, resources, information, or direct observation. The results also suggest that participants' interpretation of the study's purpose was less relevant than their increased awareness of the study's topic, in a context where attention alone might change behavior—because people already know how to respond. As with any self-reports, these responses may not have reflected participants' actual behavior or perceptions. According to one well-known account, self-reports are more accurate when the stimulus is salient and the responses plausible (26). Those conditions should hold for our stimuli (postcards) and focal responses (energy-saving actions). According to another well-known account (27), retrospective self-reports are less valid than concurrent ones. Ours fall somewhere in between, with participants reporting on the actions that they remember having taken in response to the postcards. Still, it is possible that the relationships that we observed might have been obscured by cases in which participants failed to remember their own actions or succumbed to social desirability bias and reported actions that they had not actually taken. Further clarifying the mechanisms affecting Hawthorne responses is an important topic for future research. Another topic for future research is how the Hawthorne effect varies with the source of the observation or study (neighbors, utility company, a university, or a governmental agency) and how people view (e.g., trust) it.

The Hawthorne effect has long been known as a potential experimental artifact. The present results show the importance of assessing the impact of just being in an electricity-use study, before making inferences about the impact of experimental manipulations. Were people better informed about how best to save energy, then the energy saving might be larger. However, providing guidance regarding effective energy-saving actions (28) would have confounded our study of Hawthorne effects. These results also suggest how these behavioral changes come about: by heightening awareness of electricity use. That interpretation is consistent with the observation that the effects of sustained energy conservation programs seem to decay between quarterly use reports (29). Thus, any socially acceptable way of increasing awareness might reduce consumption for those motivated to do so, but only as long as the intervention continues, unless it creates sustained habits or prompts structural changes (e.g., buying efficient air conditioning or upgrading home insulation). We cannot know what effects a sustained Hawthorne intervention (e.g., a steady stream of postcards notifying consumers about new studies) would produce. It is possible that it would lose effect over time, as consumers habituate to the messages, or have increasing effect, as awareness becomes routine and energy-saving behaviors a matter of habit. However, if awareness alone can improve performance in contexts where people require no additional information, we might retire the “Hawthorne effect” in favor of a “Hawthorne strategy” (30) of reminding people about things that matter to them but can get neglected in the turmoil of everyday life.

Methods

Field Experiment Participants. Participants ($n = 6,350$) were randomly selected from a dataset of residential customers who live in one of the regions served

by a major mid-Atlantic electricity utility. Customers with scheduled meter reading dates close to July 20, 2011, and August 20, 2011, were eligible for the study. Other eligibility criteria were met by almost all customers: having an individual electricity meter and being a residential customer under a standard (i.e., flat-rate) price-scheme program. From the 45,509 eligible customers, 6,350 were randomly selected and divided between the treatment and control groups. This sample size was determined through statistical power analysis using 2010 electricity-use data, considering effect sizes of previous energy conservation programs and budget constraints.

Procedure. The intervention lasted from July 20, 2011, to August 20, 2011. Households in the treatment group received postcard notification of participation in the study a few days before its beginning. Then, at weekly intervals, they received three postcards reminding them of their participation and a final postcard notifying them that the study was ending. All material said that the households were participating in a study conducted by researchers at Carnegie Mellon University, but with no explicit goal other than measuring their electricity consumption: “You have been selected to be part of a one-month study of how much electricity you use in your home. This study will start on Wednesday July 20, 2011, close to the day of your meter reading this month. No action is needed on your part. We will send you a weekly reminder postcard about the study. Thank you. This study is being conducted by researchers at Carnegie Mellon University with help from your utility company.” Customers' names and addresses appeared as well, using the post office format. On the front of the postcard was a picture of a house with appliances connected to an electricity meter and the Carnegie Mellon University logo. The materials were pretested with a sample of people recruited from an online national subject pool, to assess their understanding and interpretations. Postcards were sent out on Fridays, so households would receive them the following Monday or Tuesday and be informed in a timely fashion about the beginning and end of the study. We sent postcards to two households of the study's service territory but not part of the study, who confirmed their arrival dates. The control group received no experimental material.

The field study used an opt-out design, in which customers (in the treatment group) could call a 1-800 toll-free number or visit a Web site to request not being part of the study and not receiving additional material. None of these communication channels provided more information than that shown on the postcards. Thirty-six (treatment group) participants (1.28%) elected to opt out. Although they received no additional postcards, they were included in the analyses of energy use for two reasons: (i) We had intended to treat them and (ii) receiving one or two postcards (and actively opting out) may have increased their energy awareness, distinguishing them from the control group. Excluding them did not affect our results.

Attrition. The sample was selected with 2010 data. By the start of the study (summer 2011), 9.7% of households in the treatment group and 9.3% in the control group had moved or closed their accounts and hence did not receive the materials. Between August and October 2011, an additional 2.1% of households in the treatment group and 2.6% in the control group had moved or closed their accounts. The postcards had a “sender request to be returned” stamp, and most returns indicated that customers had moved. As of October 2011, the final treatment and control groups had 2,802 and 2,796 participants, respectively. There was no significant difference between the treatment and control group in attrition rate [$\chi^2(1) = 0.04, P = 0.84$]. Although there are no data on electricity consumption for these households for the study period, there is information about some characteristics, revealing that they had lower baseline electricity consumption and were more likely to be renting than those who received the study materials ($P < 0.05$). Thus, participants in the study ($n = 5,598$) represented more “settled” households in the area.

Electricity Consumption Data. All participants had 2 y of prior monthly electricity use (133,545 observations), from November 2009 to October 2011. Of these, 6.7% had monthly electricity bills based on estimates, rather than actual consumption, as a result of scheduled meter readings not being performed, typically owing to weather conditions or meter inaccessibility. They were excluded, as were a few (<0.1%) with zero readings. These exclusions left 124,578 observations in the analysis.

Meter Reading Dates. Meter readings are not always performed on the scheduled day, meaning that the treatment period did not fully coincide with a single billing cycle of participants. Overall, there was a 97.9% overlap between participants' bill cycle and the month of the treatment period. For the months before and after the treatment, the overlap was 9.5% and 3.6%, respectively.

We adjusted our analyses to consider the days in the monthly billing cycle that overlapped with the study treatment and posttreatment periods.

Weather and Household Data. Cooling degree days in the billing period for each household were calculated as the sum of the average daily temperature over 65 °F, for a billing period, using the closest weather station to its ZIP code. Heating degree days were calculated similarly for average daily temperatures below 65 °F. Household data were obtained from utility company and 2010 Census data, for which we geo-referenced addresses to block and tract numbers. [Supporting Information](#) details all variables.

Survey Respondents. Participants from the treatment ($n = 600$) and control ($n = 370$) groups were mailed a survey. Given our interest in how the intervention affected treatment group members, they were oversampled, with the control group's survey responses used to compare self-reported energy-saving actions (See [Supporting Information](#) for details). Sixty-nine participants had moved or closed their accounts, hence did not receive the survey. From the 572 (treatment group) and 329 (control group) participants, the overall response rate was 42.5%, with no significant difference between groups ($P = 0.97$). This response rate is greater than the response rate normally reached by the utility company that serves these customers, which is around 10%. See [Supporting Information](#) for respondents' and non-respondents' characteristics, using Census and electricity-use information, with a few seemingly minor differences.

Procedure. Participants received a package containing a cover letter explaining the goal of the survey, a 5-min survey with questions about electricity, a \$2 bill, and a postage-paid envelope. One week later, all participants received a thank-you-and-reminder postcard. Participants had the option of answering the survey online. Two-thirds of participants were randomly offered participation in a raffle if they returned the survey before the end of September, as part of our ongoing study of how to increase participation rates (it made no difference.) [Supporting Information](#) details all questions included in the survey.

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Supporting Information

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Additional Tables

Table S1 details all household variables obtained from utility company and 2010 Census data.

Electricity Consumption. Table S2 provides results for the following models (S1, S2, and S3), using ordinary least-squares (OLS) analyses, with robust SEs clustered by household.

$$y_{it} = \alpha + \beta_1 \cdot X_{it} + \beta_2 \cdot Y_{it} + \beta_3 \cdot Z_{it} + \gamma \cdot \text{treatment_group}_i + \delta_1 \cdot \text{treatment_period}_t + \delta_2 \cdot \text{first-month-after_period}_t + \delta_3 \cdot \text{second-month-after_period}_t + e_{it} \quad [\text{S1}]$$

$$y_{it} = \alpha + \beta_1 \cdot X_{it} + \beta_2 \cdot Y_{it} + \beta_3 \cdot Z_{it} + \gamma \cdot \text{treatment_group}_i + \delta_1 \cdot \text{treatment_period}_t + \delta_2 \cdot \text{first-month-after_period}_t + \delta_3 \cdot \text{second-month-after_period}_t + \lambda_1 \cdot CDD_{it} + \lambda_2 \cdot HDD_{it} + e_{it} \quad [\text{S2}]$$

$$y_{it} = \alpha + \beta_1 \cdot X_{it} + \beta_2 \cdot Y_{it} + \beta_3 \cdot Z_{it} + \gamma \cdot \text{treatment_group}_i + \delta_1 \cdot \text{treatment_period}_t + \delta_2 \cdot \text{first-month-after_period}_t + \delta_3 \cdot \text{second-month-after_period}_t + \lambda_1 \cdot CDD_{it} + \lambda_2 \cdot HDD_{it} + \eta_i + e_{it} \quad [\text{S3}]$$

where:

y_{it} : log of the average daily electricity consumption for household i in month (billing period) t .

X_{it} : the fraction of days in the treatment period for month t for households in the treatment group and 0 for households in the control group.

Y_{it} : the fraction of days in the first month after the intervention ended for month t for households in the treatment group and 0 for households in the control group.

Z_{it} : the fraction of days in the second month after the intervention ended for month t for households in the treatment group and 0 for households in the control group.

treatment_group_i : whether household i is in the treatment (=1) or control group (= 0).

$\text{treatment_period}_t$: the fraction of days in the treatment period included in the monthly electricity use for t .

$\text{first-month-after_period}_t$: the fraction of days in the month after the intervention ended included in the monthly electricity use for t .

$\text{second-month-after_period}_t$: the fraction of days in the second month after the intervention ended included in the monthly electricity use for t .

CDD_{it} : cooling degree days for month t , using the weather station closest to household i .

HDD_{it} : heating degree days for month t , using the weather station closest to household i .

η_i : household's characteristics (e.g., household size or electric heating). Table S2 gives results for each characteristic. For the rest of the tables, as in the manuscript, we indicate that household characteristics have been included.

e_{it} : error term.

Table S3 applies model S3 using 3 and 4 y of data. Doing so increases the number of observations per household while reducing the number of households captured (e.g., as consumers move). All participants had electricity consumption data for the 2 y before the study, 97.2% for 3 y, and 87.9% for 4 y. As seen, the treatment and posttreatment effects are very similar with all three periods. We also conducted a model using 4 y of electricity usage, and excluding winter data. Treatment effect was a 2.6% reduction ($\beta_1 = -0.026$, $P = 0.02$).

Table S4 shows analyses with a specification using a household-level standard fixed-effect estimator, capturing all time-invariant household characteristics (which were partially represented using Census information). Results are very similar to the ones already presented, with savings owing to the treatment of 2.5%.

Table S5 uses the previous model to examine the heterogeneity of the treatment effect. It finds that the treatment effect was larger for smaller households and those with higher income, although the latter effect moderates with household income above \$130,000.

Survey. Treatment group respondents remembered having received more postcards when they had lived in their homes longer [$r(222) = 0.16$, $P = 0.03$] and when they lived with fewer people [$r(226) = -0.15$, $P = 0.02$].

Table S6 indicates respondents' and nonrespondents' characteristics. Table S7 details all questions included in the survey. Tables S8 and S9 detail the energy-saving actions performed by respondents who reported reducing their electricity use during the study. The actions that they reported performing were mainly related to not wasting electricity with unused appliances. A smaller fraction reported actions related to air conditioning. Table S10 shows the relationship of actual use with survey questions, based on the 136 respondents who answered all survey questions among 162 who reported remembering at least one postcard.

Table S2. OLS regressions and average treatment effects

DV: , ln(kW-h/d)	Model S1			Model S2			Model S3		
	Coefficient	SE	t	Coefficient	SE	t	Coefficient	SE	t
Treatment effect	-0.022*	0.012	-1.87	-0.025**	0.012	-2.037	-0.026**	0.012	-2.153
First-month-after effect	-0.006	0.01	-0.652	-0.007	0.01	-0.695	-0.007	0.01	-0.697
Second-month-after effect	-0.005	0.009	-0.534	-0.004	0.009	-0.501	-0.005	0.009	-0.592
Treatment group (=1; 0 if not)	0.017	0.015	1.121	0.017	0.015	1.096	0.007	0.014	0.488
Treatment period	0.395***	0.008	47.348	-0.047***	0.008	-5.942	-0.038***	0.008	-4.945
First-month-after period	-0.047***	0.007	-6.783	0.024***	0.006	3.877	0.032***	0.006	5.075
Second-month-after period	-0.264***	0.006	-43.165	-0.034***	0.006	-5.706	-0.032***	0.006	-5.393
Cooling degree days	—	—	—	0.056***	0.001	103.18	0.056***	0.001	103.964
Heating degree days	—	—	—	0.013***	<0.001	50.747	0.014***	<0.001	54.418
% rent	—	—	—	—	—	—	-0.001***	<0.001	-2.682
Average household size	—	—	—	—	—	—	0.069***	0.013	5.466
% race (= "Black")	—	—	—	—	—	—	0.001***	<0.001	4.51
Number of rooms	—	—	—	—	—	—	0.145***	0.01	14.521
Electric heating	—	—	—	—	—	—	0.005***	<0.001	15.113
Household income	—	—	—	—	—	—	0.001**	<0.001	2.496
Low payment history	—	—	—	—	—	—	0.165***	0.017	9.484
Constant	3.290***	0.011	300.086	2.905***	0.011	260.368	1.473***	0.054	27.38
Adjusted R ²		0.02			0.091			0.218	
No. of households		5,598			5,598			5,598	
No. of observations		124,578			124,578			124,578	

Dependent variable (DV) is the log of household average daily electricity use. Household characteristics at Census block and tract level, as indicated in Table S1. *P < 0.10, **P < 0.05, ***P < 0.01.

Table S3. OLS regressions and average treatment effects

DV: ln(kW-h/d)	Model S4 (2 y)			Model S5 (3 y)			Model S6 (4 y)		
	Coefficient	SE	t	Coefficient	SE	t	Coefficient	SE	t
Treatment effect	-0.026**	0.012	-2.153	-0.029**	0.013	-2.323	-0.028**	0.013	-2.138
First-month-after effect	-0.007	0.01	-0.697	-0.009	0.01	-0.872	-0.004	0.011	-0.365
Second-month-after effect	-0.005	0.009	-0.592	-0.007	0.009	-0.784	-0.004	0.01	-0.422
Treatment group (=1; 0 if not)	0.007	0.014	0.488	0.006	0.014	0.453	0.004	0.014	0.301
Treatment period	-0.038***	0.008	-4.945	-0.046***	0.008	-5.641	-0.052***	0.009	-5.98
First-month-after period	0.032***	0.006	5.075	0.029***	0.007	4.389	0.018**	0.007	2.493
Second-month-after period	-0.032***	0.006	-5.393	-0.035***	0.006	-5.587	-0.047***	0.007	-6.99
Cooling degree days	0.056***	0.001	103.964	0.057***	0.001	103.273	0.057***	0.001	94.438
Heating degree days	0.014***	<0.001	54.418	0.015***	<0.001	57.366	0.015***	<0.001	55.779
Constant	1.473***	0.054	27.38	1.468***	0.055	26.57	1.571***	0.059	26.571
Household characteristics		Yes			Yes			Yes	
Adjusted R ²		0.218			0.204			0.192	
No. of households		5,598			5,440			4,920	
No. of observations		124,578			183,094			218,058	

These models include households with 2, 3, and 4 y of electricity use. Dependent variable (DV) is the log of household average daily electricity use. *P < 0.10, **P < 0.05, ***P < 0.01.

Table S4. OLS regressions and average treatment using a household-level standard fixed-effect estimator

DV: ln(kW-h/d)	Model S7		
	Coefficient	SE	t
Treatment effect	-0.025**	0.012	-2.099
First-month-after effect	-0.006	0.01	-0.639
Second-month-after effect	-0.007	0.008	-0.823
Treatment period	-0.039***	0.007	-5.352
First-month-after period	0.037***	0.006	6.079
Second-month-after period	-0.029***	0.006	-5.116
Cooling degree days	0.057***	0.001	112.189
Heating degree days	0.015***	<0.001	60.557
Constant	2.891***	0.004	731.462
Household-level fixed effects		Yes	
R ²		0.090	
No. of households		5,598	
No. of observations		124,578	

Dependent variable (DV) is the log of household average daily electricity use. *P < 0.10, **P < 0.05, ***P < 0.01.

Table S5. OLS regressions and average treatment effects by household characteristics

DV: ln(kW-h/d)	Model S8		
	Coefficient	SE	t
Treatment effect × household size	0.050356**	0.022	2.263
Treatment effect × income	-0.004338**	0.002	-2.200
Treatment effect × income ²	0.000016*	<0.001	1.943
Treatment effect	0.083472	0.120	0.697
Treatment period × household size	-0.025902*	0.016	-1.600
Treatment period × income	0.005898***	0.001	4.215
Treatment period × income ²	-0.000028***	<0.001	-4.700
Treatment period	-0.237678***	0.083	-2.800
Cooling degree days	0.057134***	<0.001	110.000
Heating degree days	0.015243***	<0.001	60.000
Constant	2.887660***	0.004	710.000
Household-level fixed effects		Yes	
R ²		0.089	
No. of households		5,598	
No. of observations		113,624	

Dependent variable is the log of household average daily electricity use. *P < 0.10, **P < 0.05, ***P < 0.01.

Table S6. Survey respondent and nonrespondent characteristics

Characteristics	Respondent mean	Nonrespondent mean	t	P value
Household size*	2.8	2.8	-1.13	0.26
% households renting*	14.4	13.8	-0.56	0.58
% households with electric heating [†]	32.1	33.3	1.09	0.27
No. of rooms [†]	6.5	6.5	-0.53	0.60
Household income (in thousands of dollars) [†]	106.0	101.6	-2.17	0.03
% households with low payment history [‡]	6.8	12.7	3.38	0.00
% households with low income subsidy [‡]	1.8	1.7	-0.13	0.89
% Whites*	51.7	47.0	-2.84	0.00
% Blacks*	25.4	31.4	3.28	0.00
% Asians*	14.0	13.2	-0.98	0.33
% Hispanics*	12.1	11.6	-0.82	0.41
Summer 2010 electricity use, [‡] kW-h/d	42.3	41.8	-0.47	0.64
Fall 2010 electricity use, [‡] kW-h/d	28.4	28.7	0.34	0.74
Winter 2011 electricity use, [‡] kW-h/d	39.6	41.6	1.10	0.27
Spring 2011 electricity use, [‡] kW-h/d	29.7	30.0	0.29	0.77

*Source: 2010 Census data (block-level information).

[†]Source: 2010 Census data (tract-level information).

[‡]Source: data provided by utility company (household-level information).

Table S7. Survey questions

Question
Study ID (previously inserted)
What is your sex?
What is your age?
Who is primarily responsible for paying your monthly electricity bill? (I am, Another adult (spouse, roommate, family member, etc.), My landlord, Other)
How do you receive your monthly bill? (Online—I log in to view it, In the mail—I receive a paper bill, I don't get one—an automatic payment is deducted from my bank account, Other)
Who generally picks up the mail at your home? (I do, Another adult (spouse, roommate, family member, etc.), Other)
How many people live in your home?
How long have you lived in your current home?
How many of these postcards do you remember having seen? [a picture of a postcard was inserted next to this question]*
If you did not see all five postcards, why do you think that happened? (I wasn't at home throughout the study (vacation, moving, living somewhere else, etc.), I might have thrown a postcard away without noticing it, Someone else might have picked up a postcard, Other)*
What do you think was the purpose of the Smart Electricity Study?*
Are you aware of having done anything different after receiving the postcards?*
Please tell us how much you agree with the following statements about the study. I think the study ... [1: Strongly disagree to 5: Strongly agree]*
Made me more aware of my electricity use
Made me reduce my electricity use
Made me learn more about what things use electricity in my home
Had no effect on me at all
How often did you do each of these things, during the month of the study? During the study ... [1: Much less than usual to 5: Much more than usual; 6: Doesn't apply]*
I turned off my air conditioner (AC)
I set my AC thermostat higher
I turned off lights when not in use
I turned off computers and TVs when not in use
I unplugged appliances when not in use
I used electrical devices less
I replaced incandescent light bulbs with CFLs
I bought an energy-efficient appliance
If you changed any other aspect of your electricity use during the month of the study, please describe the change.
Please indicate how often you do these things to save electricity, in general. In general, to save electricity ... [1: Never to 5: Always; 6: Doesn't apply]
I turned off my air conditioner (AC)
I set my AC thermostat higher
I turned off lights when not in use
I turned off computers and TVs when not in use
I unplugged appliances when not in use
I used electrical devices less
I replaced incandescent light bulbs with CFLs
I bought an energy-efficient appliance
I use an electricity tracking device (e.g., in-home display)
I insulate my home
If you do other actions to save electricity (not listed in the previous table), please describe them.
How much do you agree with the following statements? Compared with the average household in my city ... [1: Strongly disagree to 5: Strongly agree]
My household uses more electricity
My household has done more to reduce its electricity consumption
My household cares more about the environment
About how much was your last monthly electricity bill?
About how many kilowatt hours (kWhs) did you use on your last monthly bill?
At what temperature do you usually keep your AC thermostat in summer?
How many of each of these appliances do you have? Please write a number in each space. Several appliances were listed (e.g., Central air conditioner, TV, and dishwasher)
Do you have a smart meter in your home? (A smart meter sends your electricity use to the power company continuously, rather than just once a month). (Yes, No, I don't know)
How much do you agree with the following statements. Smart meters can ... [1: Strongly disagree to 5: Strongly agree]
Make electricity more expensive
Violate your privacy
Let the electric company control your electricity use
What is your current employment status? (Used full time, Used part time, Unemployed, Looking for work, Student, Homemaker, Retired)
What is the highest level of education that you have completed? (Less than high school, High school/GED, Some college, 2 y college degree (Associates) 4 y college degree (BA, BS), Masters, PhD, MD, JD, etc.)
What is your annual household income(\$)? (0–15k, 16k–30k, 31–50k, 51–75k, 76–100k, 101–125k, 126–150k, 151–175k, 176k+, Prefer not to answer)

Table S7. Cont.

Question

Would you describe yourself as: (American Indian/Native American, Black/African American, Asian, Hispanic/Latino, White/Caucasian, Other, Prefer not to answer)

Do you consider yourself to be: (Democrat, Republican, Independent, Other, Prefer not to answer)

*Only households in the treatment group.

Table S8. Energy-saving actions reported by survey respondents

Action performed more than usual during the study	% of respondents
I turned off lights when not in use	69.6%
I turned off computers and TVs when not in use	60.4%
I turned off my air conditioner (AC)	45.8%
I unplugged appliances when not in use	45.8%
I replaced incandescent light bulbs with CFLs	43.5%
I set my AC thermostat higher	38.3%
I used electrical devices less	28.3%
I bought an energy-efficient appliance	26.1%

Only responders who reported taking actions in response to the study.

Table S9. Energy-saving actions reported by respondents who did and did not report reducing their use in response to the study and those in the control group

Action	Mean		
	Treatment: reported reduction (i)	Control (ii)	Treatment: didn't report reduction (iii)
I turned off my air conditioner (AC)*	3.13	2.81	2.96
I set my AC thermostat higher	3.43	3.52	3.31
I turned off lights when not in use	4.37	4.42	4.41
I turned off computers and TVs when not in use	4.24	4.13	4.09
I unplugged appliances when not in use**	3.23	2.66	2.67
I used electrical devices less***	3.25	2.64	2.25
I replaced incandescent light bulbs with CFLs	3.24	3.46	3.38
I bought an energy-efficient appliance	3.78	3.97	3.99
I insulate my home	3.38	3.73	3.65

Respondents used a scale anchored at 1 = "Never" and 5 = "Always." We also asked for the use of in-home displays (but only a very small number of respondents used (or know) these devices. There were no significant difference between (ii) and (iii), except for using electrical devices less. * $P < 0.10$, ** $P < 0.05$, *** $P < 0.01$, when comparing (i) vs. (ii).

Table S10. OLS regressions and average treatment effects, using survey questions

DV: ln(kW-h/d)	Coefficient (t statistic)				
	Remembered postcards	Perceived reduction	Model S9	Model S10	Model S11
Treatment effect	-0.026** (-2.051)	-0.026** (-2.051)	-0.026** (-2.051)	-0.026** (-2.051)	-0.026** (-2.051)
Treatment group (=1; 0 if not)	0.007 (0.473)	0.007 (0.473)	0.007 (0.472)	0.007 (0.472)	0.007 (0.472)
Treatment period	-0.042*** (-5.219)	-0.042*** (-5.221)	-0.042*** (-5.230)	-0.042*** (-5.231)	-0.042*** (-5.231)
Effect of remembering at least one postcard	0.104 (1.166)	—	—	—	—
Effect of perceived electricity reduction caused by the study (1 = "Strongly disagree" to 5 = "Strongly agree")	—	-0.029 (-0.879)	—	—	—
Effect of doing (reported) more than neighbors to save electricity (1 = "Strongly disagree" to 5 = "Strongly agree")	—	—	0.005 (0.071)	0.009 (0.132)	-0.004 (-0.062)
Effect of concern (reported) about being observed with new metering devices (1 = "Strongly disagree" to 5 = "Strongly agree")	—	—	0.037 (0.679)	0.035 (0.637)	0.030 (0.542)
Effect of interpreting the study's purpose to save, learn, or be more aware about electricity (= 1; 0 if not)	—	—	—	-0.025 (-0.294)	-0.039 (-0.463)
Effect of becoming more aware of their electricity use because of the study (1 = "Strongly disagree" to 5 = "Strongly agree")	—	—	—	—	0.035 (0.916)
Cooling degree days	0.056*** (107.665)	0.056*** (107.665)	0.056*** (107.604)	0.056*** (107.608)	0.056*** (107.607)
Heating degree days	0.014*** (54.991)	0.014*** (54.994)	0.014*** (54.977)	0.014*** (54.98)	0.014*** (54.98)
Constant	1.438*** (26.434)	1.438*** (26.433)	1.437*** (26.421)	1.437*** (26.422)	1.437*** (26.422)
Control for answering survey (and interactions with group and period)	Yes	Yes	Yes	Yes	Yes
Control for answering survey question (and interactions with group and period)	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes
Adjusted R ²	0.220	0.220	0.221	0.221	0.221
No. of households	5,598	5,598	5,598	5,598	5,598
No. of observations	113,624	113,624	113,624	113,624	113,624

Note that 136 respondents answered all survey questions, among 162 who reported remembering at least one postcard. Dependent variable (DV) is the log of household average daily electricity use. **P* < 0.10, ***P* < 0.05, ****P* < 0.01.