Evaluating Energy Use Feedback Devices

Experience shows that occupant behavior can make all the difference when it comes to saving energy in homes.

by Danny Parker, David Hoak, and Jamie Cummings

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Free standing display of The Energy Detective (TED) shows that the house is drawing 0.4 kW.

Most homes currently have no means to judge household energy use other than their monthly utility bill. Does more information help home occupants save energy?

It is a truism in the home performance field today that occupant behavior has a very large impact on residential energy use. Experience would suggest that this impact is much larger than the impact of intrinsic differences in building materials, or in energy-consuming appliances. Two studies, among many others, support this assertion.

The first of these studies measured energy use in ten identical Habitat for Humanity all-electric homes built the year before monitoring in Homestead, Florida. Even though all homes had two or more occupants, with identical appliances and equipment, energy use varied by 2.6:1 from the highest to the lowest consumer (see Figure 1). Detailed measurement of the end uses in the homes revealed that while electrical consumption of appliances such as refrigerators hardly varied at all, consumption for other uses, such as air conditioning, varied by 5:1 from highest to lowest. Evaluation of interior temperature, and of the operation of the air conditioners showed that much of that difference was due to differences in the way occupants used the thermostats.

The second study examined 11 very similar solar homes built in Sacramento, California, under the Sacramento Utility District (SMUD) Solar Homes program. This study evaluated the utility bills of these homes against those of nonsolar homes in the same community. The variation in annual energy use in the solar homes was tremendous (see Figure 2). The most frugal home had a negative utility cost (that is, it produced more solar electricity than it used), while the highest-consuming solar home used nearly twice as much electricity as the average nonsolar home.

Both studies—undertaken in very different part of the United States—suggest that motivating changes to occupant behavior can go a long way toward reducing energy use. This seems to be particularly true in the case of more efficient homes with

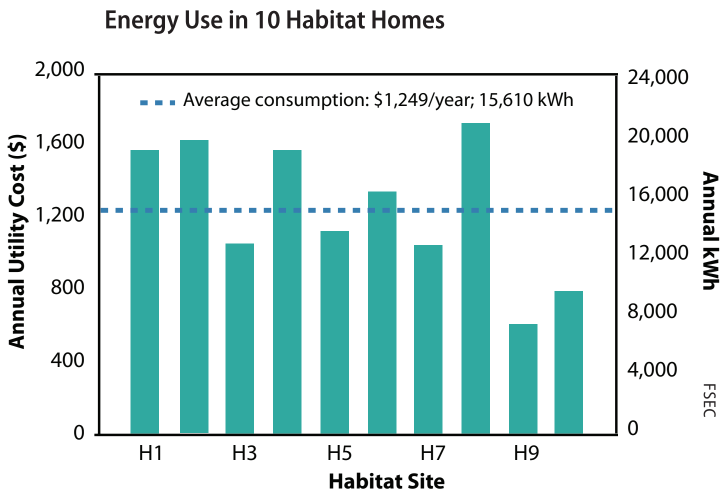

Figure 1. Even though all homes had two or more occupants, with identical appliances and equipment, energy use varied by 2.6:1 from the highest to the lowest consumer

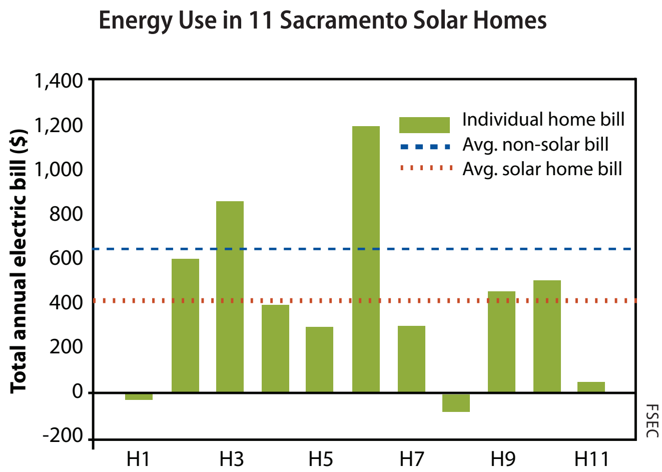

Figure 2. The most frugal home had a negative utility cost (that is, it produced more solar electricity than it used), while the highest- consuming solar home used nearly twice as much electricity as the average nonsolar home.

renewable energy features. Thus it is useful to examine ways in which providing more information to occupants on their immediate energy use might help them to save energy.

Unfortunately, most homes currently have no means to judge household energy use other than their monthly utility bill. However, this bill does not tell them much about how or where the energy is being used. This is especially true when the bill comes in long after the occupants have forgotten exactly what they did that month.

The Technology

Due to advances in microelectronics and computing, energy feedback systems for home use are now commercially available. These systems typically consist of a small wall- or desk-mounted display that communicates the second-by-second electric power demand of the household. Most accumulate the data to show expected monthly utility costs or time-related energy cost data. Some systems cost as little as $140. More detailed (and expensive) systems can report on disaggregated end uses.

The question remains as to whether the additional information provided by these home-monitoring systems is a benefit or liability. Is it simply excess information, or does it provide valuable insights? Commercially available home-monitoring systems vary in terms of capability. The two most popular devices as of this writing are the PowerCost Monitor (see "Engineering the Customer into the Solution," *HE* May/June '08, p. 14), and The Energy Detective, or TED. Both systems simplify installation by avoiding costly hard wiring. TED sends the energy demand signal over household wiring, while the PowerCost Monitor uses a radio signal from the sending unit. However, TED does have two important advantages: (1) it has a resolution of 10 watts versus 100 watts for the PowerCost Monitor, which makes it better for evaluating the energy use of small appliances, lighting, and standby power; and (2) it provides more frequent real-time updates—every second, versus every 30 seconds for the PowerCost Monitor.

Table 1. Energy Use Pre and Post Installation of Demand Feedback Monitors

Home	Before Installation	After Installation	Reduction	Normalized Savings
C1	49.9 kWh	52.1 kWh	-4.4%	-2.9 kWh (-5.9%)
C2	41.3 kWh	41.3 kWh	-0.2%	-0.6 kWh (-1.4%)
C3	39.9 kWh	38.1 kWh	4.4%	1.2 kWh (3.1%)
F1	51.4 kWh	50.0 kWh	2.6%	0.6 kWh (1.2%)
F2	113.3 kWh	92.2 kWh	18.6%	19.5 kWh (17.5%)
H1	39.7 kWh	37.9 kWh	-0.2%	-0.4 kWh (-1.1%)
H2	30.2 kWh	27.1 kWh	10.3%	2.7 kWh (9.1%)
H3	40.8 kWh	36.7 kWh	10.0%	3.6 kWh (8.9%)
H4	76.0 KWh	66.4 kWh	12.6%	8.2 kWh (10.9%)
K1	43.8 kWh	44.3 kWh	-1.2%	-2.3 kWh (-5.4%)
M1	18.3 kWh	19.1 kWh	-4.5%	-1.1 kWh (-5.9%)
M2	32.8 kWh	31.2 kWh	5.0%	0.8 kWh (2.4%)
M3	45.6 kWh	38.3 kWh	16.1%	6.7 kWh (15.0%)
S1	26.0 kWh	27.4 kWh	-5.6%	-2.4 kWh (-9.5%)
S2	31.8 kWh	28.9 kWh	8.9%	2.4 kWh (7.7%)
T1	138.4 kWh	114.1 kWh	17.5%	19.3 kWh (14.5%)
V1	38.8 kWh	32.7 kWh	15.7%	5.6 kWh (14.5%)
Overall	**50.4 kWh**	**45.8 kWh**	**9.1%**	**3.7 kWh (7.4%)**

Energy Feedback Monitor

In a two-year pilot evaluation of TED, we installed the system in 22 case study homes in Florida. The study consisted of an opportunity sample of households with the participants self-selected based on interest. Although TED sells for $140, study participants received the system and installation at no cost.

The original sample of 22 was reduced to 17 when the results were analyzed. This was done for several reasons. One home could not obtain utility bill data for the period prior to the installation of the device. Another home experienced interference from home electronics that prevented the device from working (a problem that has since been largely eliminated by the manufacturer). Two other homes did not yet have 12 months of post data when the analysis was complete. Finally, one home belonged to one of the authors and was eliminated from the evaluation to reduce potential bias. This left a total of 17 participants in the final analysis group. This group had a full year of pre and a full year of post data. Matching data periods within the large utility sample comprised the control.

TED is a 3 1/2 inch x 5 inch display unit that plugs into the wall and receives power line carrier signals from a sending unit installed in the central breaker panel. Output is available on a digital display (see photo, p. 36). The system has the following attributes:

- It computes true power every second (in kW) with a resolution of 10 watts. Energy use of the system itself was measured at 0.8 watts.

- It sends signals on instantaneous electric power use over house wiring by power line carrier, so that the display unit can be located in any room and simply plugged into the wall. This significantly simplifies installation and setup. (We found that the entire system could be easily installed in 30 minutes.)

- It shows both instantaneous and cumulative electric power use for the month. It also records daily and monthly peak electrical demand.

It maintains its programming and cumulative data in nonvolatile memory. Thus no programming or data are lost if the power is interrupted.

Two-Million-Home Control Group

Within the study we had 17 monitors with a full year of data to analyze. Understanding the need to establish a control group with which to compare our limited-opportunity sample, we asked Florida Power and Light Company (FPL) if we could obtain long-term billing histories for all single-family customers who were not seasonal residents. The utility agreed to help, providing five-year-average data on energy use in the over two million single-family homes in its service territory. These homes represent roughly 2% of the entire U.S. residential building stock and a third of all residential dwelling units of all types in the state of Florida.

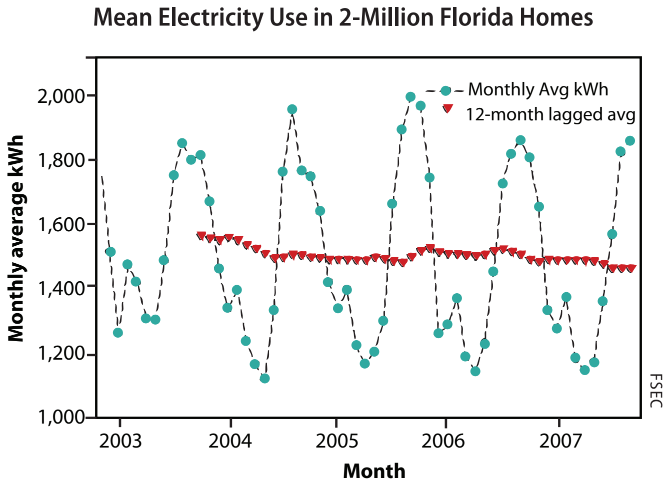

Figure 3. The arithmetic mean, shown as yellow triangles, shows that electricity use in single-family residences occupied year-round slowly declined over the measurement period.

The advantage of using these data was that doing so would provide a control group for both the pre and post periods for each participant—a control group that would adjust for natural changes due to appliance saturation and behavior, as well as responses to monthly weather conditions. Figure 3 shows the average electricity use of the two million customers over the five-year period September 2002 to August 2007. One can see on the data the superposition of a moving 12-month average of electrical consumption that takes out the seasonal variation in energy use. This arithmetic mean, shown as yellow triangles, shows that electricity use in single-family residences occupied year-round slowly declined over the measurement period.

Annual consumption averaged 18,948 kWh in the first year, slowly declining to 17,688 kWh in the last year. Analysis of the data when compared to weather data from West Palm Beach (approximately the geographic account-weighted center of the FPL service territory) revealed that most of the decline in consumption came from a slow decline in heating degree-days (HDDs) during Florida's mild winters over the five-year period. A simple multiple-regression model including HDDs and CDDs for the current and previous month and a dummy variable for Christmas explained 88% of the variation in measured average electricity consumption.

All coefficients were statistically significant at a better than 99% level. Note that holiday lighting is very evident both in the graphic presentation of the data and in the statistical model, being estimated at approximately 160 kWh for the month of December. Note also the relatively larger coefficients for HDDs than for CDDs. This difference is probably attributable to the fact that many Florida homes are heated with electric-resistance heat, whereas air conditioners that meet excessive CDDs have an efficiency greater than unity. We did try adding a variable to see if energy consumption was changing over time after controlling for weather and holidays. However, even though the added variable (elapsed months) was slightly negative, it was not statistically significant, indicating that most of the change in electricity consumption was weather related.

The advantage of using this very large data source was that we could use it as the control group. We compared the two groups' consumption over the specific pre and post period for each home in the sample. Generally, most homes saw a natural, weather-related reduction from the pre and post period (the variation was -4.0% to + 2.5%) with an average drop of 1.9% for the entire sample.

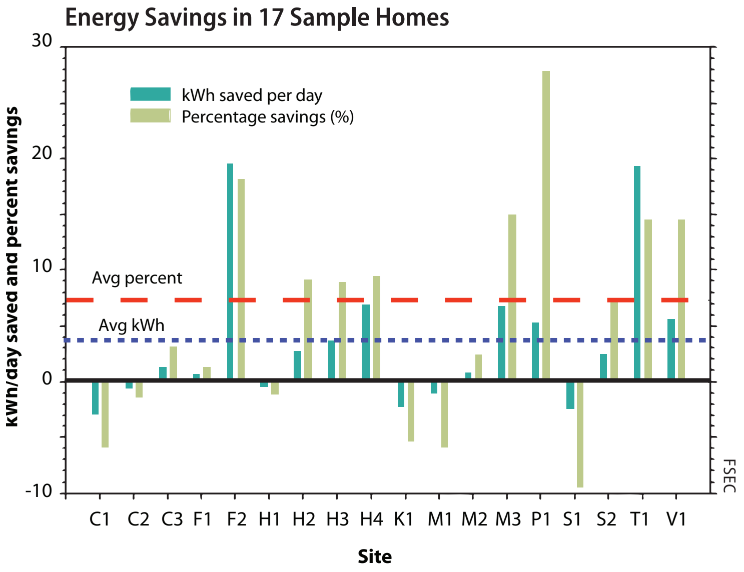

Figure 4. Eleven homes showed savings, while six homes showed increases. The absolute value of the weather-adjusted savings varied from -2.9 to 19.5 kWh per day.

Benefits of More Information?

The results of the study are summarized in Table 1. Note that preinstallation consumption averaged 18,396 kWh per year. This is virtually identical to the 18,201 kWh seen in FPL's two-million-home control group from May 2005 to April 2006.

Our analysis showed that average electricity use in the 17 sample homes declined in the year after the energy monitors were installed. However, as expected, the specific change varied substantially from one home to another. The average raw reduction was 9.1%, or 4.6 kWh per day.

When we corrected for the weather-related reductions in the post period for the control group, we saw an average savings from the energy feedback monitors of 3.7 kWh per day, or 7.4%. However, this varied considerably from one home to another, ranging from an energy increase of 9.5% to a savings of 27.9% (see Figure 4). Eleven homes showed savings, while six homes showed increases. The absolute value of the weather-adjusted savings varied from -2.9 to 19.5 kWh per day.

Generally, the homes with the largest consumption also experienced the largest savings. The two homes that used the most energy in the pre period achieved the largest savings in the post period. Based on exit interviews with the occupants, these two households paid close attention to the monitors and used what they learned to make changes in their use of household appliances, as well as in scheduling their use of some equipment. In one house, this included using less energy for household lighting, reducing pool pump hours, and replacing an aging A/C system. This may mean that energy feedback monitors would have special value for homes that run up high energy bills.

Findings from Survey

A one-page survey was sent to all 17 homeowners at the end of the study. Fourteen of these homeowners filled out and returned the survey.

We found that most homeowners placed the display unit in the kitchen, although the degree to which the household paid attention to it varied considerably. Several respondents said that they looked at the display unit several times a day, but others said that they seldom looked at it, and one considered the device an eyesore. Most respondents indicated that their primary reason for using the energy monitor was to save money; the second most common reason given was to help the environment.

Respondents were asked to rate their interest in using the monitor. Once again, responses varied, from "very interested and useful" to "total apathy." The respondents who were most interested in using the monitor all said that they made considerable changes to their energy-using equipment, or to their schedules. Not surprisingly, we found that these responses correlated strongly to observed energy savings in the second year. Of the five respondents who reported both considerable interest in using the monitor and considerable changes made in equipment or schedules, savings averaged 9.2 kWh per day, or 13.3%, versus a savings of 1 kWh per day, or 2.6%, for the other less interested and less motivated respondents.

Although ours was a very limited sample, this study seems to indicate that interest and motivation play a very large role in determining whether having an energy monitor actually lowers energy use. Thus consumers who are worried about high bills, or are otherwise really interested in lowering their energy use, could be the best candidates for using the technology. It is not clear from this study how the timing of the savings would affect utility peak demand, or the motivational factors that generate interest in the first place. One clue, however, is that the major motivation mentioned by participants was saving money—and that the ones who saved the most money and energy generally had the highest utility bills. He

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For more information:

For more information about the study that is the basis of this article, contact Danny Parker at dparker@fsec.ucf.edu.

For more on The Energy Detective (TED), go to www. theenergydetective.com.