FEEDBACK SYSTEMS IN HIGH EFFICIENCY SOLAR HOMES: FOSTERING ENERGY-EFFICIENT OCCUPANTS

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ABSTRACT

One of the main research objectives of the Building America Program (BAP) is to determine how to build cost effective, energy efficient residential homes. The results of this research program to date have been very impressive. New energy efficient homes can be built today that are very close in price and size to traditional homes yet use 50% less energy. The research presented here is complementary to the BAP goals of reducing energy consumption in homes. The focus of this study is on how consumers use their energy efficient homes. Specifically, we want to understand the potential of real-time energy feedback systems and consumer education on energy use in new, energy efficient residences.

1. INTRODUCTION

The goal of the U.S. Department of Energy's Building America Program (BAP) is to reduce energy use in new residential construction. To accomplish this goal, the BAP has focused on building Zero Energy Homes (ZEH). ZEHs are not truly "energy neutral" but use a combination of better building techniques and technologies along with solar power to reduce the energy demands of the home. To date, the BAP program has been very successful. The Zero Energy Homes that have been built as a result of the BAP program have cut electricity costs by as much as 50% or more and, as a result, are viewed as desirable among certain consumer segments.

However, these new energy efficient homes have highlighted other issues that can impact residential energy use. Research has shown that consumer behavior can have a major impact on how much energy is used in a ZEH. The goals of this study are to better understand how consumers impact home energy use and to determine how real-time energy feedback systems and energy conservation education can affect behavior and energy use in ZEHs.

2. CONSUMER BEHAVIOR ISSUES IN RESIDENTIAL ENERGY USE

There are at least three major issues related to consumer behavior and home energy use. The first of these involves the number and type of appliances that consumers have in their homes (e.g., number and age of refrigerators, type and number of TVs, age of washer and dryer, number and type of lights, age of air conditioner, age of heater, type of water heater, etc.). It is quite possible for homes of a similar size to have very different numbers of appliances and other energy using devices. A second issue is how consumers interact with their home in terms of their daily behavior. For example, consumers make decisions every day about the temperature in their homes, whether they leave lights, TVs and computers on or off, and which windows and doors to leave open. Finally, the number of people in a home can have a large impact on the amount of energy a home uses. More people mean more cooking, more TV watching, more showers, etc.

The extent to which these variables impact home energy use was quite apparent in research done on 95 ZEHs in a community called Premier Homes in Sacramento, CA (see Figure 1). A study of these homes by ConSol and the Sacramento Municipal Utility District (SMUD) showed substantial variation in electrical loads (and costs) associated with nearly identical homes in the Cresleigh development, which was used as a control in this study. As can be seen from the electrical bills for these homes in July

2006, (see Figure 2), the average electric bill for the Premier homes was $67.05. This bill compares very favorably with the non-solar (Cresleigh Homes) that had an average July electricity cost of $133.62. It is also very impressive in light of the average electricity bill for all SMUD residences of $123.67.

What was surprising in these results was the substantial amount of variability in home electricity costs within each subdivision. The Cresleigh home electricity bills ranged from a low of about $30 per month to over $340. The Premier home electricity costs were below $0 for some homeowners, but others with very similar homes had bills over $235. While the variability in the ZEH energy costs was not as great as for the Cresleigh homes, it was still very substantial.

Fig. 1: BAP 95-home solar community (courtesy of SMUD).

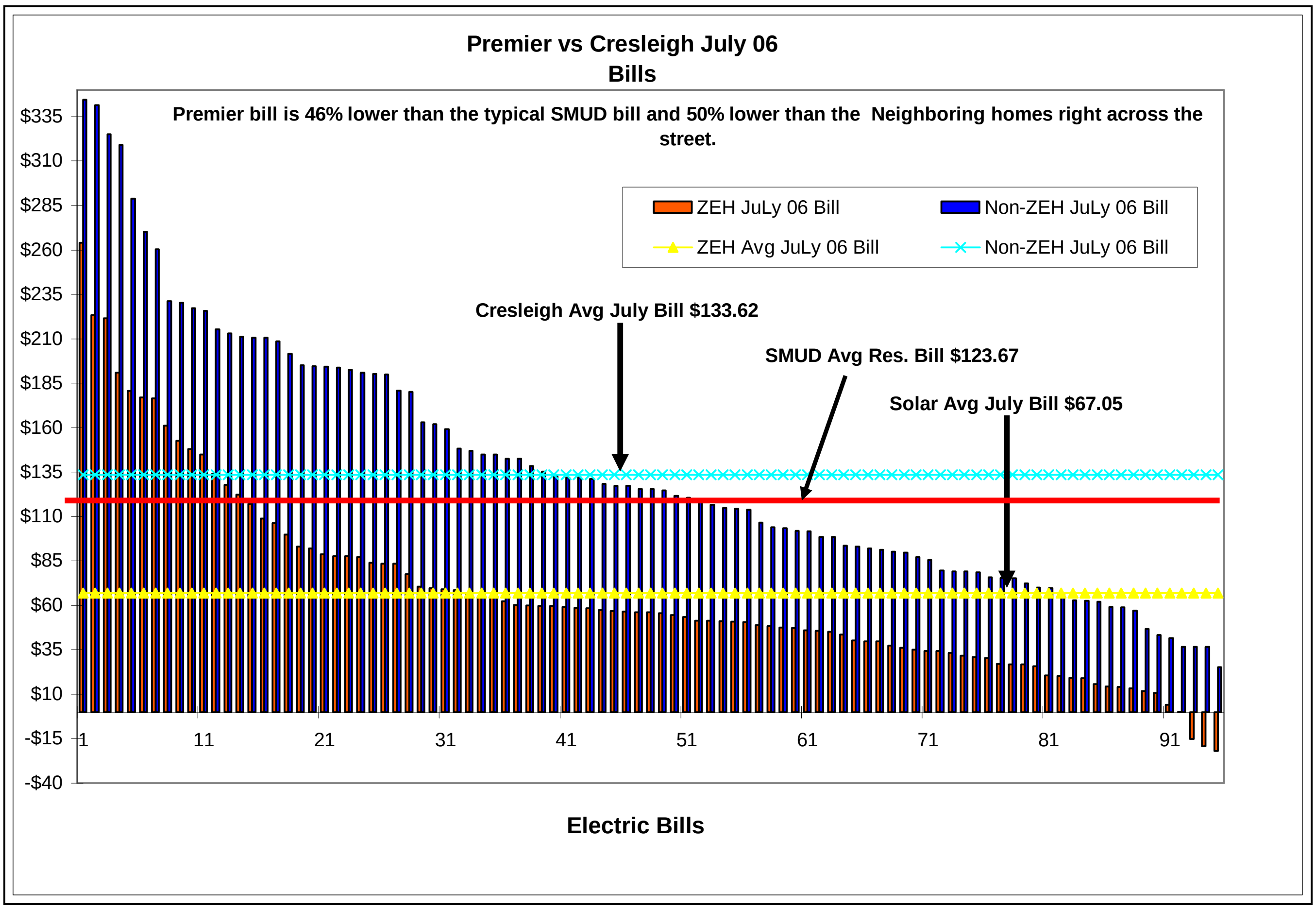

Fig. 2: Bills from Premier and Cresleigh Homes displaying average energy use and energy use variability (courtesy of SMUD).

Based on this study it is clear that providing consumers with energy efficient homes can potentially decrease their utility bills, but much of the savings still depends on how the homeowner uses their residences.

An important question raised by these study results is why the differences in bills are so great in similar types of homes. In addition, it is critical to understand the best way to help consumers, even those who buy ZEHs, use their homes in the most efficient way. Most utility companies offer sufficient educational material to help consumers make these decisions, but this approach alone may not be sufficient to change consumer behavior.

3. REAL-TIME ENERGY USE FEEDBACK SYSTEMS

In addition to educating consumers about how to use their homes more efficiently, some utility districts have explored "real-time energy use" feedback systems. There are a number of these devices available in the market today that show how much energy the home is using at a particular point in time. These devices allow the homeowner to unplug appliances, and even light bulbs, to see the impact of the appliances on energy use. They can also use the real-time meters to experiment with different home temperature settings and other behaviors that can impact overall home energy use.

A number of experiments have been run on homes equipped with energy use feedback devices. According to a Florida Solar Energy Center (FSEC) publication, "A compilation of available data on real-time feedback studies suggests an average of 10-15% reduction in overall energy."[1] Another study done by Hydro One, released after the FSEC publication, installed meters in 435 homes in Canada and found that each home reduced total energy consumption by 7-10%.[2]

These studies reveal that energy use feedback mechanisms can provide substantial reductions in overall electricity use that benefit the consumer, electrical utilities and the environment. However, these studies do not identify: (1) why and how ZEH owners react to the meter; and (2) when the behaviors take place (e.g., during peak vs. non-peak energy use times). The purpose of our study is to do a field experiment to answer these questions. The study will use the same Premier Garden residents that were involved in the ConSol-SMUD study discussed above.

4. EXPERIMENTAL TEAM

The Building America Program is a public/private partnership aimed at partnering with building industry stakeholders to reduce energy consumption in homes and increase adoption of on-site renewable energy. The Building Industry Research Alliance (BIRA), led by ConSol, is a diverse group of industry leaders working with BAP to promote their goals. ConSol is working with its BIRA partners, including SMUD, GE, California State University Chico, FSEC, and the National Renewable Energy Center (NREL) to research, design, and execute this experiment. SMUD is involved in parallel research funded by the California Energy Commission (CEC) PIER Program. This SMUD-PIER project will directly benefit from a number of aspects of our real-time feedback research. Because of this, SMUD is working to ensure that these two research projects will be comparable and complimentary.

5. EXPERIMENTAL DESIGN

For the past three years, SMUD and ConSol have been working on a BAP project that involves monitoring energy use for homes in Premier Gardens in the Sacramento, California area. The 95 homes in Premier Gardens contain highly energy-efficient ZEH homes with solar-electric systems. The original field experiment compared the gas and electricity use of these homes to more traditionally built homes in a similar development called Cresleigh Homes. In addition to monthly gas and electricity bills for all homes in this study, SMUD and ConSol also evaluated the 15-minute electricity consumption and PV production data at 18 homes within the Premier community.

We are using the same Premier homes in this study. This will provide us with multiple years of data for each home before installing the real-time energy (electrical energy only) units in the homes. This existing data will provide the control against which electricity consumption patterns can be compared after the installation of the feedback system. The statistical efficiency of a paired approach (pre/post) for evaluating technology impacts in this application is superior to side-by-side testing.[3] A paired (pre/post) experimental approach is approximately 467% more efficient than side-by-side testing, which means that it will be easier to determine the real impact of the feedback device on energy use.[4]

GE's new Solar Electric Power Meter (see Figure 3) will be installed in the Premier Gardens community homes. The meter displays both solar electric (PV) production and whole house kW consumption graphically and numerically. It also provides the residents with energy production information measured as a percentage of total energy consumption. When the energy meters are installed, the

[1] Hoak, David and Parker, Danny, "How Much Energy Are We Using? Potential of Residential Energy Demand Feedback Devices," Florida Solar Energy Center
[2] Hamilton, Tyler, "Monitors cut Energy Usage, Study Finds," Technology Reporter, 17 Dec. 2005

[3] Cochran, William G. and Snedecor, George W., Statistical Methods, Sixth Edition, Iowa State University Press, Ames, Iowa, 1968
[4] Parker, Danny, Internal Building America document, Florida Solar Energy Center

occupants will be instructed on how to read the meters and will be encouraged through educational materials to use the meters to reduce electricity use and thereby lower their bills (initial results from multiple small-scale studies suggest displaying PV production and consumption is a powerful incentive to reduce electricity use[5]). Study participants will also get information about how much CO_2 is emitted per unit of electrical use.

Fig. 3: GE Solar Electric Power Metering System (courtesy of GE).

In addition to monitoring monthly (and 15 minute) energy use, study participants will also provide information about their knowledge, beliefs, attitudes and behavior regarding sustainability issues in general as well as more specific information about their energy use at home. The more general sustainability information will help us profile the respondents based on their knowledge about sustainability issues. The more "home specific" consumer behavior information will help us determine the present behavior of the respondents as well as provide an inventory of the number and type of appliances in the home. This, along with demographic information about each household, will give us valuable insight into the "why" question associated with changes (or lack thereof) in behavior.

We are still considering how to measure belief and attitudinal changes that occur as a result of using the feedback device. We plan to use multiple questionnaires over the 2 year study period, but they will not capture when these changes occurred. We may use diaries to collect this type of data. Consumer diaries have been used successfully to monitor purchasing and TV watching behavior. The major problem with consumer diaries is that people forget to fill them out. This is something we still need to address before the study begins.

The final part of the experimental design involves the use of conjoint analysis to capture the tradeoffs consumers are willing to make in terms of their energy use decisions in their homes. With conjoint analysis these tradeoffs can be presented to the consumers, and via their responses a utility value can be associated with the different attributes of consumer behavior leading to a more sustainable home (e.g., the temperature of the home, whether to use certain appliances, or whether to replace their old refrigerator). Since each of these attributes has a "cost" associated with it, we can determine at what cost home owners are willing to make sustainability decisions in their homes. We will use the conjoint survey twice during the study: once before the homeowners have the real-time energy device installed and again after they have used the device for at least a year.

A diagram of the experimental design is presented in Figure 4.

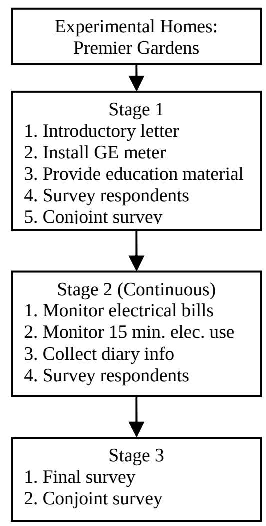

Fig. 4: Research stages.

6. RESEARCH OBJECTIVES

(1) Analyze impact of real-time energy use feedback system (PV generation and energy use) on whole-house electricity use in highly efficient solar electric homes
   a) Measures required: Monthly electricity use before (control) and after (treatment) inclusion of feedback device
   b) Results normalized based on: Demographic information, weather data, appliance and plug load considerations, and home size

(2) Analyze impact of real-time energy use feedback system (PV generation and energy use) on time-of-day

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[5] Curtain, Gerald and Parker, Danny, Personal Interviews, May-June 2007

whole-house electricity use in highly efficient solar electric homes

a) Measures required: Fifteen minute electricity use data before (control) and after (treatment) inclusion of feedback device, impact on peak electricity use, and impact on base/phantom loads through analysis of “quiescent” electricity use
b) Results normalized based on: Demographic information, weather data, appliance and plug load considerations, and home size

(3) Analyze impact of educating homeowners on energy use in the home and how the feedback device can be used to lower energy consumption and electrical bills
a) Measures required: Consumer feedback information gathered via pre/post surveys, interviews, and/or diaries

(4) Determine most effective education protocols to create electricity use reductions in line with future program goals (e.g., peak aversion, overall electricity reductions)
a) Measures required: Peak energy use, monthly energy use and consumer feedback via pre/post surveys, interviews, and/or diaries

(5) Determine how the feedback device impacts consumer beliefs, attitudes, and behavior that lead to reductions in electricity use
a) Measures required: Consumer feedback information gathered via pre/post surveys, interviews, and/or diaries

(6) Analyze tradeoffs consumers make in terms of energy reducing behavior in their homes
a) Measures required: Consumer feedback collected via conjoint analysis surveys

7. CONCLUSIONS

We believe that reducing residential home energy costs for consumers as well as peak load requirements for utilities will require both efficient homes (climate-specific envelope design, HVAC system, water heating, lighting, etc.) and significant changes in home energy use behavior.

BAP has made great advances in ZEH design, and even more efficient homes are being built and tested today. One of the major objectives of this study is to determine how the positive effects of the ZEHs can be enhanced by providing consumers with information on how best to use their homes. A second benefit of our research is that it will help us more clearly understand the tradeoffs consumers are willing to make in terms of sustainability and home energy use.

While the focus of this research is on ZEH consumer behavior, we believe that some of our findings can be generalized to consumers in non-ZEH homes. What we learn from our two year study should be helpful in providing information for all homeowners on how they can interact with their homes to reduce both their energy costs and the impact of their energy use on the environment.

8. REFERENCES

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(2) J. D. Muhs, “Design and Analysis of Hybrid Solar Lighting and Full-Spectrum Solar Energy Systems,” *Solar 2000, July 16-21, 2000*, American Solar Energy Society