Online Smart Meter Analysis Achieves Sustained Energy Reductions: Results from Five Communities

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ABSTRACT

Hourly electric smart meter data combined with daily gas smart meter data provide the information necessary to perform an intelligent disaggregation of residential energy use. Proprietary, cloud-based analysis software from High Energy Audits (HEA) automatically separates a year's worth of energy use into seven categories and presents this information to homeowners through a 15-minute interactive online audit. This level of analysis provides sufficient information for homeowners to independently make effective, low-cost changes resulting in reduced electric use in 66% of the homes participating. This method was utilized in five San Francisco Bay Area towns commencing in April 2011 and ending in April 2012 with over 200 households registering to participate in the free program throughout the year. A total savings of 105,293 kWh was observed when compared to energy consumption in the previous year, or an average of 634 kWh per home across all participants completing the audit.[1]

Impetus for Developing an Automated Home Energy Profile

Most energy consumers do not know how energy is actually used in their homes (Darby 2006). They receive and pay a monthly bill that fluctuates to some extent, but has continued to increase over the years (AEP 2012). Equally mysterious to them is how they can reduce their energy consumption since the only data they have to act upon is a single number at the end of the month. Generalized recommendations about raising or lowering thermostats and replacing incandescent lighting are promoted by organizations including utilities, non-profit green organizations, municipalities and other government organizations, but these generalized suggestions don't apply equally to all homes, are not customized, and represent varying levels of effort to implement. How do energy consumers know which measures are most appropriate for their situation? Which categories of energy consumption represent their biggest opportunities for savings? Where should they focus their efforts? A focus on providing useful information about actual energy consumption was the design principle behind the development of the High Energy Audits (HEA) software. This development would not have been possible without the propitious convergence of government policy and technology that occurred in 2009.

In 2006 the California Legislature passed and Governor Schwarzenegger signed AB 32, the Global Warming Solutions Act of 2006, which set the 2020 greenhouse gas (GHG) emissions reduction goal into law (ARB 2012). As a result, communities all over California have begun to explore ways to meet the mandate. Communities with little or no commercial development must focus on reducing residential energy use to achieve their GHG reduction targets. Then in 2009 the American Reinvestment and Recovery Act designated $3.2 billion to support energy

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[1] These figures will change slightly until the final report is submitted to the California Energy Commission in July 2012. The complete report will be available upon request after submission.

efficiency through Energy Efficiency and Conservation Block Grants (EECBG). Towns with populations under 35,000 could apply to the California Energy Commission (CEC) to receive funding (CEC 2009) to support approved programs in their towns. The governing bodies of five small, primarily residential towns — Atherton, Los Altos Hills, Monte Sereno, Portola Valley and Woodside — voted to pool their EECBG funds to create a residential energy efficiency program specific to the climate and demographics of their communities.

Early Experiments and Research. Starting in 2008 two members of the Los Altos Hills Environmental Committee, Steve Schmidt and Peter Evans, spent several months using devices such as the Blue Line Whole House Monitor, HOBO loggers, and Kill-a-Watt meters to measure energy consumption in their homes and the homes of friends and neighbors. Based on the requirements of AB 32, the Environmental Committee was exploring ways to reduce home energy use. Through their analysis and conversations with local residents it had become apparent that home upgrades were not appealing because of the high cost but also, and perhaps even more importantly, because many of the homes with high energy consumption were new or newly remodeled to Title 24 standards and already met high envelope and HVAC requirements for energy efficiency.

**Figure 1: Preliminary Home Energy Profile Showing Total Energy Use
(both electricity and natural gas)**
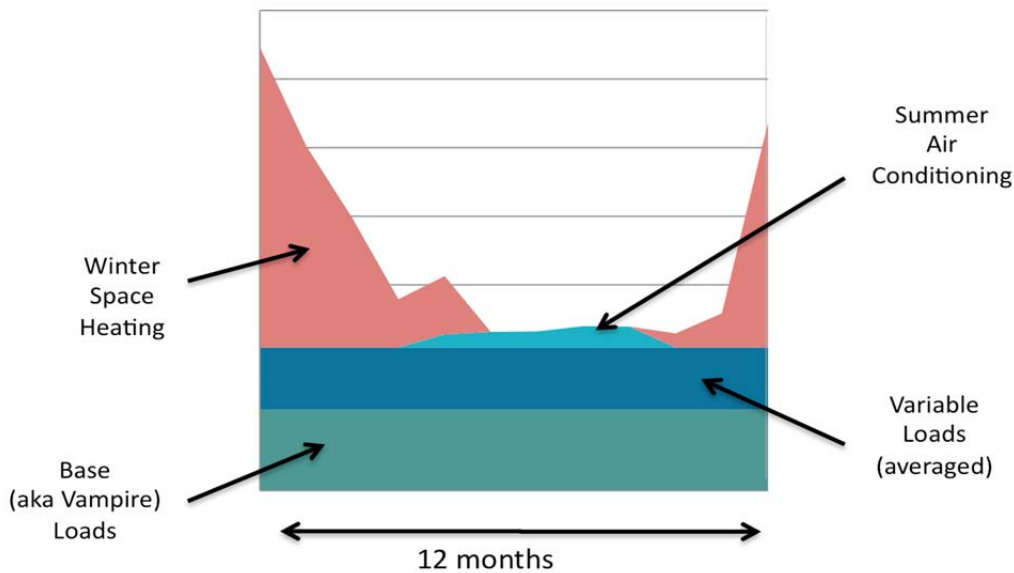
Source: In-home audits in Los Altos Hills, 2008-2009

If the energy was not being used for heating and cooling, as was the assumption given the age and structural attributes of many of the homes initially tested, the first goal was to measure how the energy was actually being used. Complex Excel spreadsheets were used to record measurements of periodic energy consumption and correlate it to billing data, but it quickly became apparent the data needed to be categorized and presented in a manner that would make it easier to recognize how energy was being used. Figure 1 is an example of an early Home Energy Profile (HEP) built by manually measuring and calculating energy use into four categories: winter space heating, summer air conditioning, base loads and variable loads.

The y-axis indicates the combined monthly cost of electricity and natural gas, and it is easy to discern from this chart, based on the area of each colored region, that base and variable loads represent the majority of energy use for this home, a condition common in many of the early homes audited. Base loads consist of all the devices in the home continuously drawing power, even when they have been switched "off". Examples include: game consoles, desktop computers in sleep mode, VCRs, DVD players, fax machines and other electronics. Variable loads consist of appliance loads that occur intermittently throughout the day: lights, washing machine, dishwasher, the TV when being used, etc. Knowing the relative scale of different categories of energy use proved valuable in determining where to focus energy reduction efforts. In this example, reducing base loads provides the best opportunity for significant and cost effective energy savings.

Disaggregating energy in this manner proved valuable to the limited number of residents involved in the experiment. The hand-generated HEP solved one important problem: it presented energy use in a format that accurately reflected the total energy used in the home. However, the time and cost of making the detailed measurements necessary to build the HEP were very high and required specialized knowledge related to both top-down and bottom-up residential load analysis. Generating these HEPs on a large scale would be prohibitively time-consuming and costly.

Fortuitously, while these experiments were underway, PG&E was preparing to install electric and gas smart meters capable of reporting hourly and daily use respectively throughout their service territory. This wealth of energy use data would make it possible to automate the generation of the HEP. Automating the HEP would significantly reduce the cost and provide a more complete home energy analysis to large numbers of residents without the intervention and high initial cost of a home visit by an energy specialist.

Automating the Home Energy Profile. The original method for building HEPs involved entering a large amount of hand-measured data into an Excel spreadsheet and then using proprietary algorithms and sophisticated knowledge of home energy use to create the data for analysis and charts. Translating this labor-intensive process into an accurate, easy-to-use system that is available and understandable to homeowners required developers skilled in secure cloud computing, database development, algorithm development and Web 2.0 techniques.

The HEA software system requirements included:

- secure accounts for each resident on a scalable computing platform;
- a mechanism to automatically and regularly retrieve electricity and gas usage data from the resident's PG&E account;
- a method for creating a HEP which is both engaging and self-explanatory;
- a flexible technical platform to allow continuous improvements of the user interaction and disaggregation algorithms; and
- the ability to provide personalized, periodic energy consumption updates to each participant.

On April 22 2011, residents from all five towns were given the opportunity to use the software free of charge until April 23, 2012 by participating in the High Energy Homes program, administered by local non-profit Acterra. The requirements to participate included having a

PG&E account with a SmartMeter™ installed and having a year's worth of recorded energy consumption data. Over the year 166[2] residents created a HEP and achieved a measured total reduction of 105,293 kWh/yr in electricity consumption. The average home size of participants was 3,706 square feet. The program had an original goal of 1,000 participants with target savings of 167,000 kWh/yr. The participation rate was below expectations (less than 20%), but nonetheless 63% of the projected savings were achieved.

The software is constantly evolving and the system has changed since the initial release; however, the basic concept of the HEP has withstood the scrutiny of more than 600 participants[3]. Over the course of the past year several substantial improvements have been made based on customer feedback:

- new energy charts have been added and descriptions enhanced
- the disaggregation algorithms have been improved
- additional recommendations for reducing energy waste have been added
- the email communication capability has expanded
- the interactive, intelligent survey has been improved in numerous ways
- support has been added for a wide variety of unusual residential energy situations

Modeling vs. Analyzing

There are at least two important reasons to build a detailed profile of the energy use in an existing home: to determine the expected energy efficiency of the building and the HVAC components (also known as an asset analysis), and to determine what measures residents can easily and cost-effectively take to reduce their energy consumption.

The Home Energy Score (DOE 2012) from the Department of Energy is an example of an asset analysis. There is value in being able to compare the performance to other buildings similar to the value an MPG rating has for comparing the relative efficiency of vehicles. An asset score is particularly valuable when the home transfers owners, or is used as collateral for a loan. The Home Energy Score, like many other home energy rating standards, relies primarily on building models to rate the expected efficiency. There has been considerable discussion over the accuracy of these models (Holladay 2012 and Mills 2012) and given the attention the issue is receiving it seems likely that the accuracy will continue to improve. However improving the accuracy of these models will not necessarily make them any more appropriate for helping consumers easily and cost-effectively reduce energy use. An energy score intentionally does not take into account the behavioral aspects of energy efficiency, nor the specific set of plug loads in a home. This is appropriate if the goal is to rate a building.

But if the goal is to help residents make informed decisions about how to reduce their particular energy consumption, asset analysis will not identify many of the easiest and most cost-effective opportunities. A whole range of measures from changing thermostats and taking shorter showers to installing smart strips and timers have been lumped together as temporary or behavioral, and are intentionally discounted when doing an asset rating based on the justification that these changes are not permanent. However, our results indicate that many of these measures

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[2] These numbers will continue to change until July 2012 when the final report is presented to the CEC
[3] In addition to the program described in this paper, another EECBG-funded program is continuing through 2012 in Mountain View, and the non-profit GreenTown Los Altos has funded participation for 50 residents of Los Altos.

have lasting affects since once they are implemented existing residents are unlikely to undo them. On average, residents have reduced their annual electric use by 634 kWh and lowered their Idle Mode (definition follows) by 63 watts. Duration in the program ranged from a minimum of 1 month to over 12 months with an average 5.8 months. Unlike most asset changes, these measures are easy to perform and can generally be paid for in recouped energy costs in a few months. For homeowners looking to quickly and inexpensively reduce energy costs, these measures are an attractive solution.

Analysis of actual energy use is important because energy savings recommendations need to apply specifically to the homeowner's situation so that changes result in measurable reductions. Our analysis of over 600 homes has shown that there are very few "typical" homes. Each family, each home, and each HEP is unique and, while some generalizations about energy consumption can be made, specific information is required so the energy consumer can make smart decisions on how to approach energy reduction in their particular residence. Figure 2 illustrates some of the differences between the HEPs from a variety of homes.

Figure 2: Comparison of HEPs of Different Homes
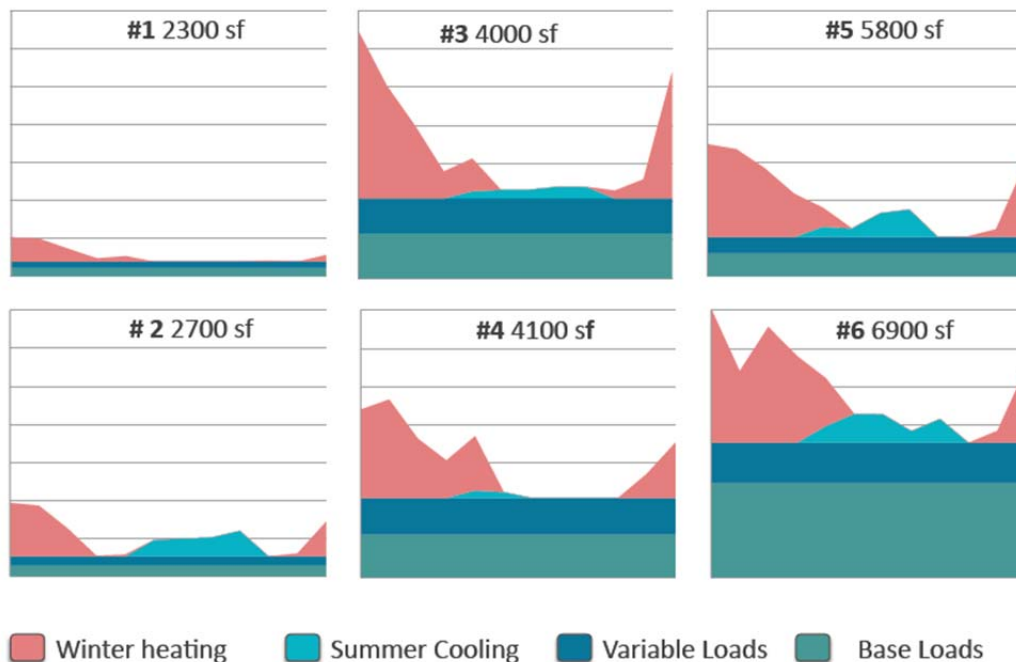
Source: High Energy Audits

In the next section we will introduce more details about the HEP including additional categories and specific measurements, but a relative comparison of the homes in figure 2 is useful in highlighting the benefits of using energy consumption analysis. As a base line, home 1 is very energy efficient showing no discernable summer cooling and low winter heating, variable and base loads. Home 2 is also efficient but shows a profile of a home in a much warmer climate (Austin, Texas) hence the increase in the summer cooling load. Homes 3 and 4 are similar in size and profile but use much more energy than homes 1 and 2, even when taking into account their larger size. Home 3 has slightly higher heating use but both homes use a majority of their energy for base and variable loads so focusing on reducing them would be more cost-effective than a

retrofit. Home 5 is a fairly efficient home for its size. The HVAC and variable loads are less than those of smaller homes 3 and 4. Improving the efficiency of the home envelope would probably not be a cost-effective endeavor. Variable loads are also small indicating the residents have probably already invested in efficient appliances and are conscientious about general energy use. For this family to reduce their energy consumption they should focus on reducing their base load.

Most residents in homes like number 5 are unaware that base loads represent such a significant portion of their energy use. Home 6 has high energy consumption and the HEP shows that a large portion of the energy consumed in this home is the base load. Sometimes it requires considerable research to determine all the systems contributing to base loads, but in this particular case it was largely due to a whole house lighting system that consumed 1000 Watts continuously, even when all lights were off. But even in cases where the cause of high base loads are harder to diagnose, it is at least clear from the HEP that even if the owner chose to do an extensive asset upgrade, they would achieve relatively modest energy reductions because most of the energy is not being consumed by heating and cooling. If the first step in reducing energy consumption in this home had been to perform an extensive retrofit, more than likely the residents would be disappointed with the outcome because even reducing the asset energy consumption by 50% would only result in a 10% to 15% overall energy reduction.

The Home Energy Profile

The intent of the HEP is to provide energy use information in a way consumers can easily understand and act on, so both the format and the manner in which the information is presented are critical. The original hand0-generated HEP shown in figures 1 and 2 had proven useful so the development work for the automated HEP proceeded based on the prototype. Figure 3 shows an updated version of the automated HEP.

Figure 3: Home Energy Profile Automatically Generated from PG&E SmartMeter Data
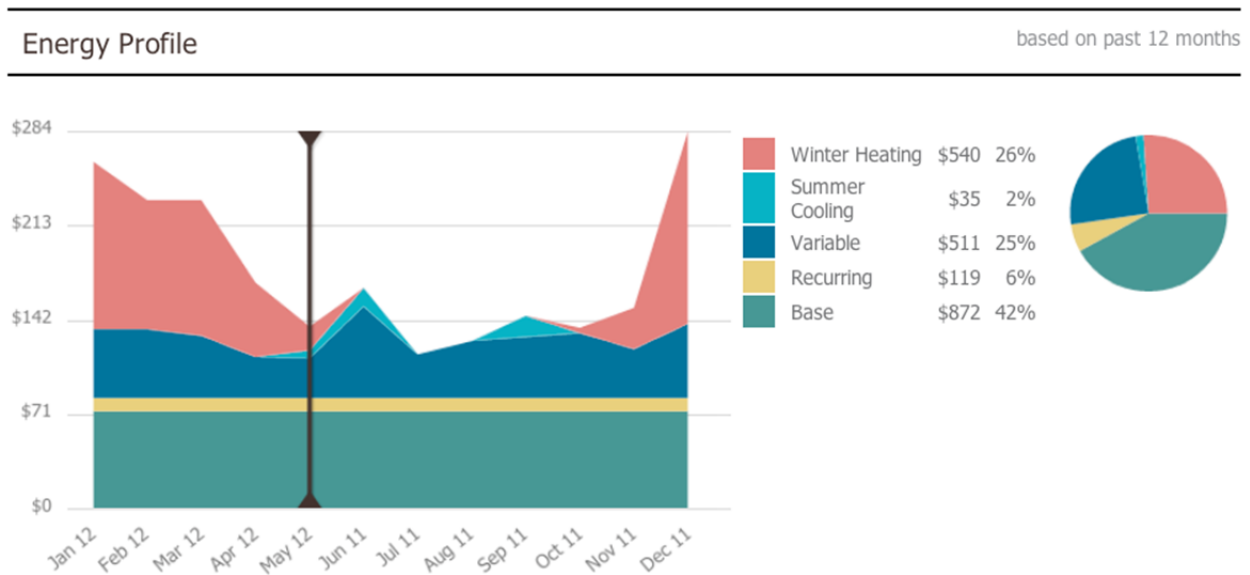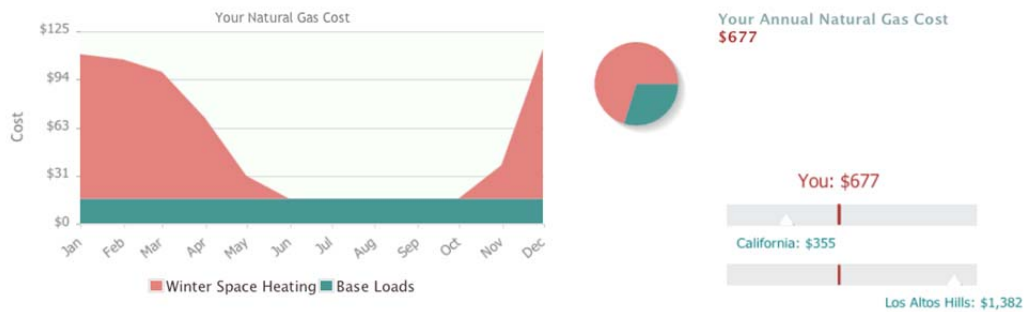

Source: High Energy Audits

Both electricity and natural gas use are combined in this chart to give homeowners a complete picture of their home's energy use. The vertical axis shows monthly cost and the horizontal axis a complete year's worth of energy use. To avoid confusion, the chart always begins with January and ends with December with the vertical black line indicating the date of the most recent bill data. The automated HEP added a new category to the disaggregation, called recurring loads (definition follows). The pie chart to the right summarizes the percentage of energy used for each category. This entire chart, when viewed online, can also show energy units as opposed to dollars spent. Given the large price discrepancy between electricity and gas (for PG&E customers, electricity can cost ten times the price of gas per BTU), winter heating dominates many HEPs when energy units are displayed instead of dollars. The user can also choose to display only natural gas or only electric use.

The energy categories identified in the disaggregation process are summarized in table 1. The "Gas" and "Electricity" columns indicate whether this energy would normally be a component of the category, and the "Consists of…" column contains examples of appliances or electronics typically found in the category.

Table 1: Disaggregation Energy Categories

Energy Category	Gas	Electricity	Consists of…
Winter Heating	√	√	Energy use that correlates with lower temperatures, including gas furnaces, electric space heaters, heated floors, electric blankets, etc.
Summer Cooling		√	Energy use that correlates with higher temperatures, including fans, air conditioning, etc.
Variable		√	Appliances that come on intermittently during the day: lights, washing machines, dishwashers, microwaves, stoves, cook tops, entertainment systems when they are on, computers when they are turned during a portion of the day, etc.
Recurring		√	Appliances that go on and off at the same time every day: pool or spa pumps, outdoor lighting, coffee pots on timers, etc. These loads can be controlled by timers but can also reflect behavioral patterns easily recognized by the residents.
Base	√	√	Devices continuously drawing power in a predictable manner: refrigerators, water heating, desktop computers in sleep mode, game consoles in sleep mode, DVRs, whole house audio systems in standby, surround sound systems, routers, wifi routers, powered phones, etc.

Figure 4: Gas Only HEP Information

Source: High Energy Audits

In addition to the HEP shown in figure 3, the user is also presented with a chart showing only gas use, breaking the use into two categories – winter heating and year-round – as shown in figure 4. Winter heating is exactly as expected: the gas used to operate the furnace for space heating (or boiler for radiant heating). Year-round gas use consists of loads including hot water heating, cooking and clothes drying.

Interactively building the HEP. Just as important as the categories is the method used to introduce the HEP. Most of our participants had no awareness of home energy disaggregation, so an important part of the process is education. Presenting the chart in figure 3 with no explanation would cause confusion and might cause users to assume the information is too difficult to use. Also, presenting a single written explanation is not optimal because it is tedious to read, especially when there is little visual information to reinforce the text. To avoid both of these conditions, HEA took the approach of building the HEP chart by adding each category as the user moves through the analysis. Each layer represents an energy use category and each category is explained as it is added to the chart. The user steps through this process by viewing a series of web pages containing graphics, specific information about their home, and additional help information. The user can stop at any time and start up again at the place they left off. From website usage logs we know that users spend anywhere from 5 to 40 minutes building their HEP. At the end of the entire process, users are asked to take a short survey; to date they have rated the time required to finish the process at 3.95 out of 5, with 5 being the highest rating possible.

The HEP differs from other web-based energy analysis tools in that it requires very little input from the user. Nearly all the data has been gathered prior to the user interacting with the system. The energy use data comes directly from their PG&E account, which they explicitly give permission to access when registering. Other supporting information is gathered from various public sources available on the web. Users can choose to spend time learning about all the energy categories or they can click quickly through the 20 or so screens. The HEP is built using smart survey technology so the specific number of screens varies based on the user's situation. A typical flow for a new user is:

1. Log into their secure HEA account;
2. Verify that they give permission to access their PG&E SmartMeter data;
3. Verify their PG&E account information;
4. Indicate how many people live at the residence;
5. Verify the size and age of their residence; and

6.   Indicate if they have pool, spa or other water feature.

At this point all the data necessary to create the HEP has been gathered and there have only been a handful of questions requiring a response from the user. All of the questions are simple and most users know the answers without having to refer to anything else: do you have a pool, how many people live in your house, is this the correct size of your home, etc.

Next they are lead through a process of building up their specific HEP component by component. Figure 5 shows an example screen. All the screens are laid out in a similar manner including: a header, "next" and "prev" buttons, the HEP with certain information highlighted, a pie chart showing the percentage of energy use represented by the category being described on that page, related information, and additional charts if helpful. Excluded from the figure is an area to the right side of the charts containing more help information and information on specific energy leaks found in this house.

Figure 5: Screen Showing Information Presented During HEP Creation
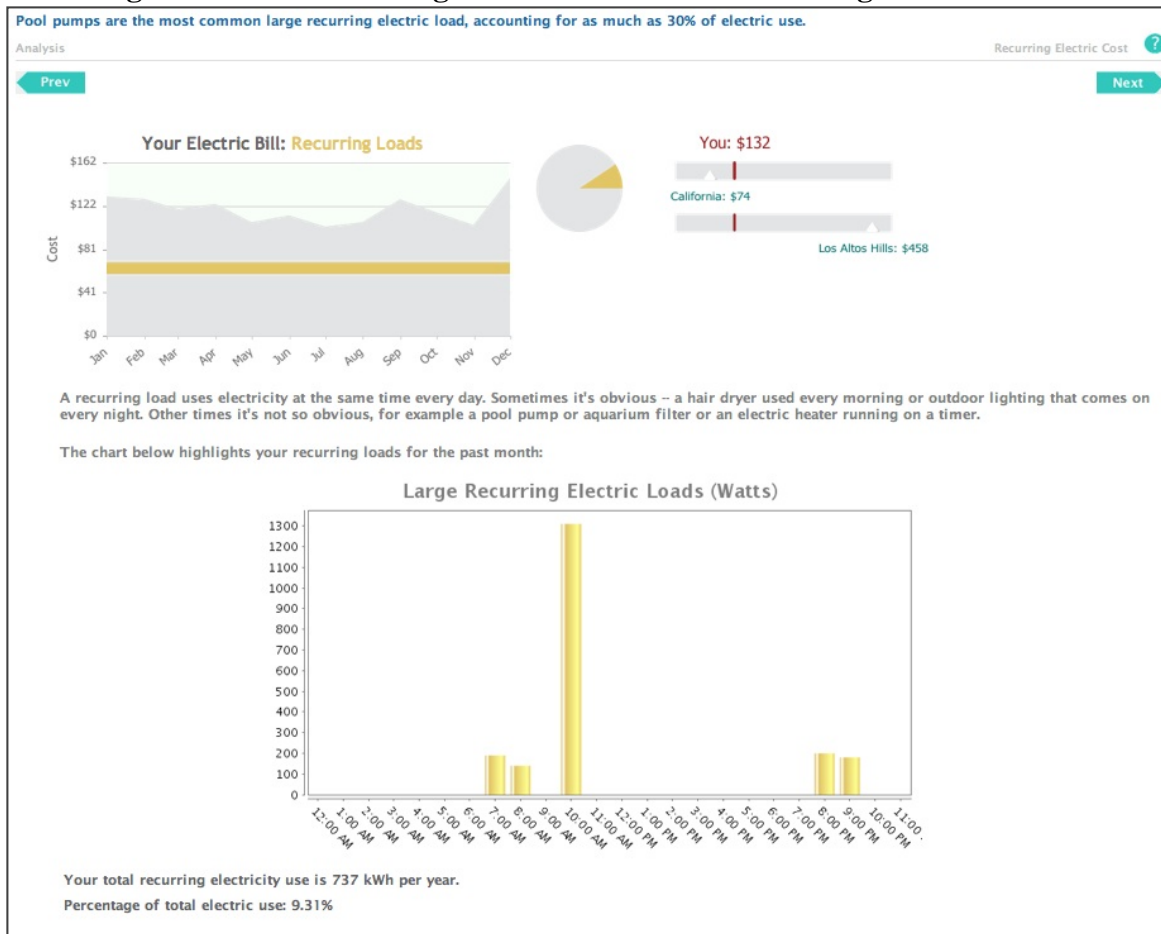
Source: High Energy Audits

It is not possible to review all the screens used in building the HEP but the screen shown in figure 5 provides an example of how providing users with the right level of information can be a powerful tool to identify wasted energy in their home. Recurring loads are electrical loads

occurring at the same time every day. The chart in the upper left hand corner shows recurring loads highlighted as part of the overall energy use for the year and laid out in the same format as the completed HEP. The pie chart in the upper center shows the percentage recurring loads represent in the overall electricity bill providing guidance for how important this category is when considering areas to focus on for energy reductions. The two "norming bars" in the upper right corner show how this recurring load compares to all of California and more specifically, the town in which the user lives. The bar chart at the bottom of the screen shows the time and magnitude of their specific recurring loads.
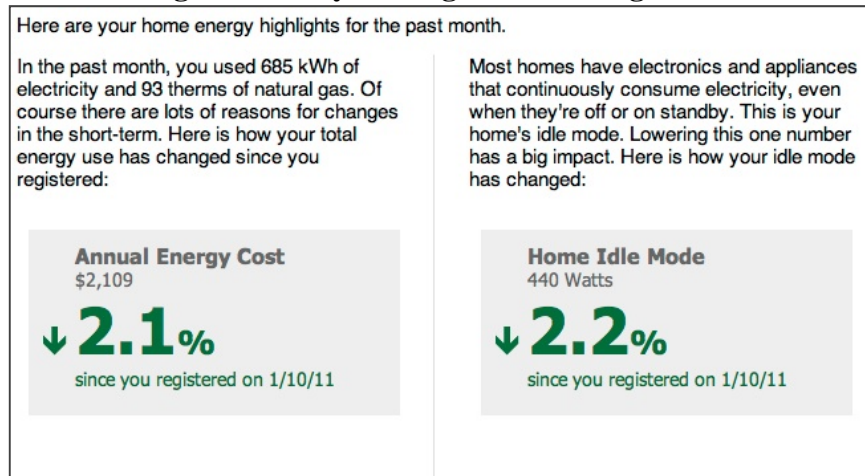
In this simple page the user has received valuable information that is also actionable. First, the percentage of overall electric use, as represented in the pie chart, is a good indicator of the level of effort that should be expended reducing this particular load. In this example, the recurring loads represent about 10% of the overall electricity costs. Even if this user completely eliminates their recurring loads they would only reduce their electric bill by 10%. Cutting their recurring loads in half would only save 5%. If these cuts are easily achieved the effort in making them may be cost-effective. But if the cost in time and money to reduce this category is high, the user would most likely benefit from focusing on finding ways to reduce other categories of energy use. (This is not to imply that recurring loads are consistently low: they can be quite high. We have seen numerous examples of this category consuming 30% or more of electric use.)

The norming bars provide some context for this energy category both locally and throughout a larger population, in this case the entire state. The category use in the community will more likely reflect the similar demographics and home styles; however, it is also interesting to keep in mind a broader context for each load category, especially in communities with higher energy use such as those in this program. The statewide averages were taken from the 2010 KEMA RASS report for the CEC, and the community averages are computed by HEA.

Finally, the hourly bar chart helps users pinpoint which appliances are generating the recurring loads. When the homeowner sees the amount of energy consumed tied to a specific time, they can usually identify the appliance (or activity) and they now have an excellent approximation of how much the device (or activity) is costing them in electricity. The two biggest categories of recurring loads include pumps for pools, spas and fountains, and outdoor lighting. Often, the durations of these loads are easy to adjust and can result in significant energy savings with little monetary investment or change of behavior.

Ongoing energy analysis. Similar information is displayed on separate screens for the other energy categories as the user steps through the process, ending with the completed HEP as seen in figure 3. After going through this learning process the user understands the significance of each category for their home and the HEP becomes a valuable tool for prioritizing energy reduction actions. But the HEP is a live document that changes as new energy data becomes available. So not only does it provide information prior to energy reduction measures, it is also the means for tracking how well those measures work. The user can log into their secure account at any time to view their HEP and view each energy category individually. In addition, they receive automated monthly emails tracking their progress to help serve as reinforcement for positive progress and a reminder if their energy usage starts increasing, as shown in figure 6.

Figure 6: Body of Progress Tracking Email

Here are your home energy highlights for the past month.

In the past month, you used 685 kWh of electricity and 93 therms of natural gas. Of course there are lots of reasons for changes in the short-term. Here is how your total energy use has changed since you registered:

Most homes have electronics and appliances that continuously consume electricity, even when they're off or on standby. This is your home's idle mode. Lowering this one number has a big impact. Here is how your idle mode has changed:

Annual Energy Cost
$2,109

↓ **2.1**%

since you registered on 1/10/11

Home Idle Mode
440 Watts

↓ **2.2**%

since you registered on 1/10/11

Source: High Energy Audits

The email is kept deliberately simple to make it easy to read and, perhaps after reading the detailed explanation once, the gist of the information can be discerned in a glance by reading the numbers and noting their colors: energy use is decreasing if the numbers are green and the arrows are pointing down; if the numbers are red and the arrows are pointing up, energy use is increasing.

The "Annual Energy Cost" is self-explanatory: it is the comparison between the most recent twelve-month's worth of energy use and the baseline year (the year prior to registering with the HEA service). Once the user registers, the HEA system analyzes the prior year's worth of energy consumption and uses it as the baseline for comparing all use categories.

The "Idle Mode" (IM) is a new but powerful concept in energy disaggregation. IM[4] is the energy being consumed constantly, 24 hours a day, 365 days a year and is usually invisible to residents. In many cases, the IM represents mostly pure waste – energy consumed but providing no benefit to the homeowners, like a car left idling in the garage. Reducing it by even a small amount can have a big effect on overall energy consumption. Home idle modes vary widely from as low as 30 Watts to over 4,000 Watts. Both of these extremes come from single-family homes within 15 miles of each other. There is a weak correlation between the size of the home and the IM: some very large homes have a low IM and some modest-sized homes have a very high IM. The IM is usually an indicator of the number of consumer electronics plugged in. The waste represented by the IM can often be reduced through simple smart strips and timers. By presenting users with their IM each month they can easily track the benefit of installing such devices or making other simple changes. Additionally, they will quickly see the otherwise hidden cost of purchasing a gaming desktop computer and leaving it in sleep mode: quite a few high-end electronics have very high standby loads (over 100W).

Periodic communication with personalized information is an important component of the HEA service and we expect the information provided to users will continue to evolve based on user feedback.

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[4] The IM is a measure of base load in watts; the base load is the cumulative idle mode in kWhs.

Energy Savings Results from Five Communities

High Energy Audits software was made available to the towns of Atherton, Los Altos Hills, Monte Sereno, Portola Valley and Woodside on April 22, 2011. Residents of the towns were eligible to participate in the town-sponsored program if they had lived in their home for more than a year and had a PG&E SmartMeter installed. Residents with solar PV systems installed were the largest group ineligible to participate because they currently do not have PG&E SmartMeters and therefore no hourly energy use data to analyze[5]. As of May 16, 2012, 166 households from these towns were participating. Most participants created their HEA account and build the HEP with no additional support. Users spend anywhere from 5 minutes to 1 hour creating their HEP and reviewing the results. A brief satisfaction survey asks users for feedback and to date we have achieved an average score of 15 out of a possible 20 for user satisfaction.

A more complete analysis of the results are available upon request. The final report will be submitted to the CEC in July 2012, after the deadline for this paper. The following results are preliminary and may change.

Table 2: Summary of Energy Savings

Number of participants	Average months in program	Total square footage analyzed	Total kWh per year saved	Total IM reductions in Watts
166	5.8	615,235	105,293	11,050

Conclusions

Automatically analyzing actual home energy use is now possible because of the growing availability of hourly electric and daily gas use data due to the deployment of smart meters. This level of energy use granularity is sufficient to disaggregate consumption into 7 unique categories. By presenting the energy consumption categories in an easy-to-understand format, reinforced with monthly energy consumption emails, energy consumers have reduced their energy use through low-cost and easily implemented measures such as smart strips and timers and simple behavior modifications. Based on our study over 12 months, these energy use reductions continue and residents do not return to a higher energy use level.

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[5] Similar energy disaggregation could be done on homes with solar PV as long as the hourly energy generation and use data is captured. We believe it would be a valuable analysis because most PV installations do not cover all the electrical use in a home.

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