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Executive Summary

The U.S. Energy Information Administration (2001)[1] estimated that total electricity consumption in 2001 was 1140 Billion kWh (with average consumption of 10,656 kWh per household), which amounts to $100.34 billion U.S. This estimate is 10% higher than estimates for 1997 (1037 kWh, with average consumption of 10,656 kWh per household) and is predicted to increase in the future.

Because of these enormous, growing energy demands and shortages, residential home owners are turning to energy conservation measures and smart home energy management devices to help them reduce energy costs and live more sustainably.

In this context, the Honeywell team researched, developed, and tested the Context Aware Smart Home Energy Manager (CASHEM) as a trusted advisor for home energy management. The project focused on connecting multiple devices in a home through a uniform user interface. The design of the user interface was an important feature of the project it provided a single place for the homeowner to control all devices and was also where they received coaching. CASHEM then used data collected from homes to identify the contexts that affect operation of home appliances. CASHEM's goal was to reduce energy consumption while keeping the user's key needs satisfied. Thus, CASHEM was intended to find the opportunities to minimize energy consumption in a way that fit the user's lifestyle.

In its two years of DOE-funded development, Honeywell conducted early stage research focused understanding technologies and interaction with user needs. The project activities included defining requirements, designing an integrated home energy management system, developing a lab prototype, designing a field study, hardening the lab prototype for field test robustness, and executing the field study.

This final report focuses on the execution and results of the field study. Detailed documentation on the requirements, system design, and field test plan were documented in the following deliverables to DOE:

- Context Aware Smart Home Energy Manager Project Requirements (November 2010)
- Context Aware Smart Home Energy Manager Design Documentation (January 2012)
- CASHEM Pilot Demonstration (Field Study) Plan (May 2012)

The CASHEM field study was executed over the summer of 2012 in homes located in Minnesota. The field study followed an A-B-A design, where the homeowners actively engaged with the CASHEM system only during the B phase of the design. The first phase, *pre-installation*, took place over one month. In this phase, the primary measure was user experience measured with subjective questionnaires, face-to-face interviews, and homeowners' utility bills.

The second phase, *installation*, took place over two and half months. In this phase, the primary measures were user interactions with CASHEM and user experience measured with subjective questionnaires, face-to-face interviews, and homeowners' utility bills.

[1] http://www.eia.gov/emeu/recs/byfuels/2001/byfuel_el.pdf

The *final* phase, after CASHEM was uninstalled, occurred over one month. In this phase, the primary measure was user experience, which was measured with subjective questionnaires, face-to-face interviews, and the users' utility bills. This phase was included in the field study to measure whether CASHEM-induced behaviors were maintained after de-installation.

During the *installation* phase of the pilot, users received energy conservation recommendations based on the data collected from their homes. All interaction with recommendations and the connected devices occurred through a web-based interface implemented on a mobile device. Recommendations were delivered bi-weekly and cycled through the devices in the home along with more generic recommendations. The CASHEM team tracked user response to their recommendations both through qualitative feedback and device data.

There were four main research questions in the CASHEM field experiment:

1. Does the presence of CASHEM lead to better cost/energy savings?

   The answer to this question is, yes.

2. Does the presence of CASHEM lead to more effective behavior and usage of appliances?

   The answer to this question is, yes. For example, homeowners started using the scheduling function in their thermostats, started showing a decline in the base loads, programmed their pool pumps to function more efficiently, had more conversations with their families on how to manage energy more efficiently, and became generally more aware of energy management in their homes.

3. Does the presence of CASHEM lead to better subjective ratings (on satisfaction, motivation to save energy, etc.) compared with the prior system?

   The answer to this question is, yes. As indicated by the survey responses, the homeowners were more motivated to save energy, were more knowledgeable of their energy usage, and wanted to even recommend the CASHEM system to their friends and family. In addition, when CASHEM was taken out of their homes, all homeowners *missed* the tips.

4. Based on subjective experience and ratings, do users reflect the same behavioral patterns post CASHEM (i.e., do they still represent CASHEM-like behavior)?

   The answer to this question is, partly yes. Homeowners were generally aware of how to save energy, and what the behaviors were that led to more efficient management of energy. However, they explicitly mentioned that they would like to continue receiving tips to make sure that they were doing the right things. In other words, they were taking the effort, however, with additional feedback they could continue to do even better.

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1 Introduction

The Honeywell team researched, developed, and tested the Context Aware Smart Home Energy Manager (CASHEM) as a trusted advisor. In its two years of DOE-funded development, Honeywell conducted early stage research focused on gaining understanding of technologies and interaction with user needs.

CASHEM was designed to help home owners reduce waste in the least painful way—by using automation to help them understand how they use energy in their homes. The project focused on connecting multiple devices in a home through a uniform user interface. The design of the user interface was an important feature of the project it provided a single place for the homeowner to control all devices and was also where they received coaching.

Team members supplied a communicating pool pump (Pentair) and refrigerator (Bosch), and Honeywell integrated these appliances with the thermostat and detailed energy information in the home. All of these communicating devices share their information, making it possible for CASHEM to watch how devices are being used. CASHEM begins to understand the homeowner's lifestyle and as a result, can provide tailored coaching.

Key elements that make CASHEM a trusted advisor include:

- User in control
- Motivation for change in user behaviors
- Enhanced information visualization and decision support
- Intuitive user interfaces and reliable automation
- Emotional and aesthetically superior interface design

To systematically determine the effectiveness of the CASHEM system, the Honeywell research team conducted a field study with homeowners in Minnesota during the summer of 2012. This report summarizes the purpose, methods used, experimental design, and results from the field study. Future directions for CASHEM and similar technologies are also discussed.

2 Project Objective and Background

The objective of Honeywell's CASHEM project was to create a system that adjusted the use of major home appliances according to conditions and homeowner convenience preferences, monitored and analyzed energy consumption, recommended further energy saving actions, and motivated the homeowner to adopt those recommendations.

CASHEM used data collected from homes to identify the contexts that affect operation of home appliances. CASHEM's goal was to reduce energy consumption while keeping the user's key needs satisfied. Thus, CASHEM was intended to find the opportunities to minimize energy consumption in a way that fit the user's lifestyle.

The system monitored energy use behaviors under different activity or occupancy conditions and suggested adjustments to HVAC and appliance use. CASHEM monitored inputs from multiple sources to create a hypothesis of the current state and to build patterns. The monitored inputs include HVAC and appliance activity and whole house electrical consumption as well as time of day. The connected systems in the CASHEM project included whole home energy along with operational parameters from HVAC systems, pool pump, and refrigerator. Note that the value of CASHEM increases exponentially as more context information becomes available and as more connected appliances are installed.

2.1 Activities Preceding Pilot

The CASHEM project was designed to create a communicating home system to support monitoring, interaction and recommendation generation. The team developed requirements to develop a prototype system that could be used in a field test, defined the information required to identify equipment context, defined critical parameters for convenience of service, developed a decision support system to analyze the collected data, prototyped that system in the lab, hardened that system for field deployment and ran a field test. The following sections provide a brief summary of the activities leading up to deploying the field test and analyzing results. The bulk of the final report focuses on the field test and results. Additional details on prior tasks are documented in previous deliverables.

2.1.1 Defining Requirements

The project began by analyzing the requirements for the home system and the system's interaction with user goals. The team defined overall system architecture requirements for the communications and physical systems needed to support a full home system for field testing. This included a communications architecture centered on a gateway, user interaction needs, energy data collection and energy management, requirements on algorithms to support delivering recommendations to homeowners. The CASHEM architecture was designed to overcome the challenge of communicating with varied link layer communication protocols and data formats (application layer protocols).

We also documented requirements on individual elements of the *load eco-system* (e.g., thermostat, appliances, pool pump). The load eco-system is a collection of appliances and equipment that consume energy and provide an opportunity for CASHEM to optimize energy usage. The requirements document also defined the needs for a context eco-system. A *context eco-system* is a collection of information such as weather, DR, occupancy, energy, etc. that provide the context in the home, so that CASHEM can optimize according to that context. The context eco-system included information that was not essential for control of the load, but provided information to help the end user in managing their energy consumption and/or provided information to help understand the usage patterns in the home. A high level design for the pilot was also defined in the requirements document. The requirements are documented in the deliverable titled "Context Aware Smart Home Energy Manager Project Requirements," submitted to DOE in November 2010.

2.1.2 Designing the CASHEM System

Once the requirements were in place, the team focused on developing a design to support the pilot. The following critical design principles were used to guide design decisions made to address the requirements. The first principle was *ease of use in capturing home energy management preferences*. CASHEM is intended to allow users to make decisions about their home energy management based on analysis of their energy usage patterns, occupancy, and ambient conditions. The customization of energy management guidance to each household is a key design parameter.

The second principle was *ease of use in communicating usage information and savings tips*. For the CASHEM system, the primary method for managing energy is through interaction with the user. The capability to sending information and savings tips that are tailored for an individual houseful was crucial to the success of CASHEM.

The third principle was *integrating appliance and HVAC controls*. To provide tips and local control of devices, CASHEM needed integrated systems that afford user interaction as well as data collection.

To address the requirements, we focused on understanding key context information for appliance management, how to define critical parameters for convenience of service, understanding how to incorporate the requirements into a decision support system, and how to design a human computer interface to support the requirements. This analysis led to the following design areas:

- *Appliance connectivity*. CASHEM connects to multiple devices through a local gateway that serves as a translator between different protocols and messages. The gateway normalizes the messages to and from devices, as well as providing access to the devices within the household, and sending data from devices to central storage.
- *Data analytics, context identification and energy analysis.* To support the delivery of customized tips and recommendations to each household, CASHEM includes data collection and analysis. Data from multiple devices along with energy measurements is collected from each home and stored in a central location for analysis. Analysis on the collected data has two primary functions. First, CASHEM uses collected data to identify operational contexts, such as occupancy and ambient conditions. All other data is interpreted within these contexts. Second, CASHEM uses data collected from multiple devices to analyze energy usage patterns in the home. Combined with the context, the analysis provided customized recommendations to the household.

- *Human Factors: intuitive, easy-to-use system design*. User interaction with the devices is provided in a uniform interface. Users can set parameters on each device using a familiar interaction paradigm. The user interface is designed to be simple, allowing the user to understand and use without training; flexible, so that user preferences can be supported; and intelligent, allowing CASHEM to get hints on the user's preferences through their usage of the system.

Appliance Connectivity

For appliance connectivity, we developed an architecture design that centered on a gateway for translation of protocols to a common schema based language. The intent of the design was to standardize the information extracted from and the control information transmitted to all devices. We designed an input and output schema for individual devices using as many common elements as possible. The gateway also provided continuous transmission of data to cloud storage so that analytics could be performance against the stored data. The gateway was designed to support a web-based interface to all connected systems in the home. Through the gateway, all key functions of connected devices could be accessed.

Algorithm Design

Algorithms were designed to use data transmitted from the connected devices. We designed algorithms for Base Load Analysis, Occupancy Detection, Thermostat Schedule and What-If analysis, Load Disaggregation, Monthly Energy and Cost Analysis, and Energy Benchmarking. Each of these algorithms used a combination of data available from the CASHEM eco-systems and provided the basis for understanding how the home and the appliances are being used. The output from these algorithms provides the foundation for the generation of recommendations to the homeowner.

User Interface Design

For the user interface design, we used the requirements to define a set of high-level use cases. These use cases included viewing energy usage, viewing recommendations, controlling energy usage, viewing and controlling home comfort/control settings, and viewing weather information. We defined a set of user personas that included Comfort Seekers, Money Minders, and Tree Huggers. We then defined a set of usage scenarios and usability metrics for each usage scenario. The user interface for the CASHEM system was designed with this set of usage scenarios.

We designed the user interface so that when the user enters the CASHEM system, he/she is presented with a series of tiles. These tiles represent access to information or control options for devices. The set of tiles acts as a top level dashboard; touching a tile displays a device status summary along with an image representing the device/function. When the user selects the tile, a control panel opens showing the overall device status and means to control the specific device. For example, the thermostat control panel shows the actual temperature, the programmed temperature, allows the user to put the thermostat into a hold state, and allows the user to change the system from heating to cooling or off. Each of the control panels also includes recommendations specific to that device. . The CASHEM design is documented in the deliverable titled "Context Aware Smart Home Energy Manager Design Documentation," submitted to DOE in January 2012.

2.1.3 Prototyping and Alpha Testing

With the design in place, the next step was to build a prototype system and alpha test in the laboratory. The lab system was built using the same equipment that would be installed in each home, including a pool pump, communicating thermostat, whole house electric meter and refrigerator. The prototyping required interfacing to each of the communication protocols supported by the individual devices. This included building a protocol converter for the pool pump, so that we could use standard Wi-Fi communication. For the thermostat, we built an interface to a web API, and for the refrigerator we connected to a wired protocol accessing the internal communications to the refrigerator touchpad. The whole house electric meter also had a standard Wi-Fi interface and API. With the translations in place for all devices, we built a user interface using the tile designs and running on the gateway web server. We used a combination of test data from our lab and existing home data collection to implement and test all algorithms.

Prior to running the pilot, we demonstrated the entire system in the laboratory. The demonstration covered all user interface elements, all connectivity, and data transmission to cloud storage. It also included transmission of recommendations to the user interface and gathering feedback from users as they reacted to the recommendations.

The design of the pilot study described in this report was also submitted as a project deliverable title “CASHEM Pilot Demonstration (Field Study) Plan” submitted in May 2012.

The remainder of this report focuses on the design and execution of the pilot and lessons learned from the pilot. The following sections review the experimental design, describe the participants, describe the process of field installation and updates, and discuss the results of the experiment. Additional details on the user interface implementation are also included, providing detail that goes beyond what was provided in the design document deliverable. We also discuss data processing during the experiment, lessons learned, and recommendations for future directions.

3 Field Study: Method

With the tasks of defining requirements, designing the hardware and user interface, implementing a prototyping and demonstrating a field ready system in place, CASHEM was ready for the field test portion of the project. The primary purpose of the Context Aware Smart Home Energy Manager (CASHEM) field study was to gather user input from homeowners regarding their preferences, opinions, satisfaction ratings, and related feedback on their experience interacting with the CASHEM system. The actual behavioral pattern of the homeowners and the energy usage in their homes were also measured and monitored. The following research questions were addressed in the study; each question is discussed in detail in the following sections:

1. Does the presence of CASHEM lead to better cost/energy savings?
2. Does the presence of CASHEM lead to more effective behavior and usage of appliances?
3. Does the presence of CASHEM lead to better subjective ratings (on satisfaction, motivation to save energy, etc.) when compared with the prior system?
4. Based on subjective experience and ratings, do users reflect the same behavioral patterns after the CASHEM study (i.e., do they still represent CASHEM-like behavior)?

As a part of the field study, the CASHEM system was installed in five homes in Minnesota. The following sections describe participant selection and the methods used to design, install, and monitor CASHEM use.

3.1 Participants

The project team initially contacted homeowners to gauge interest in participating in a field study. Interested homeowners received a brief explanation of the whole study including the remuneration, expected tasks, and timeline. After the homeowners expressed interest and commitment, a detailed survey was administered to gather the details about their demographics, home, lifestyle, interests, and preferences for technology, etc. To maintain a degree of control in the field study, the research team tried to meet the following requirements before finalizing which homes to study:

- Relatively newer homes (built after 1985 if possible)
- Similar family size (4-5)
- Should have a pool in their homes with a Pentair pool-pump
- Should be comfortable with technology use in general (e.g., smart phone users)
- Should show willingness to participate and continue in the study
- Preferable same zip code or all homes should be in close proximity to each other (was not a mandatory requirement)

Figure 1 through Figure 4 give detailed information from the five homeowners.

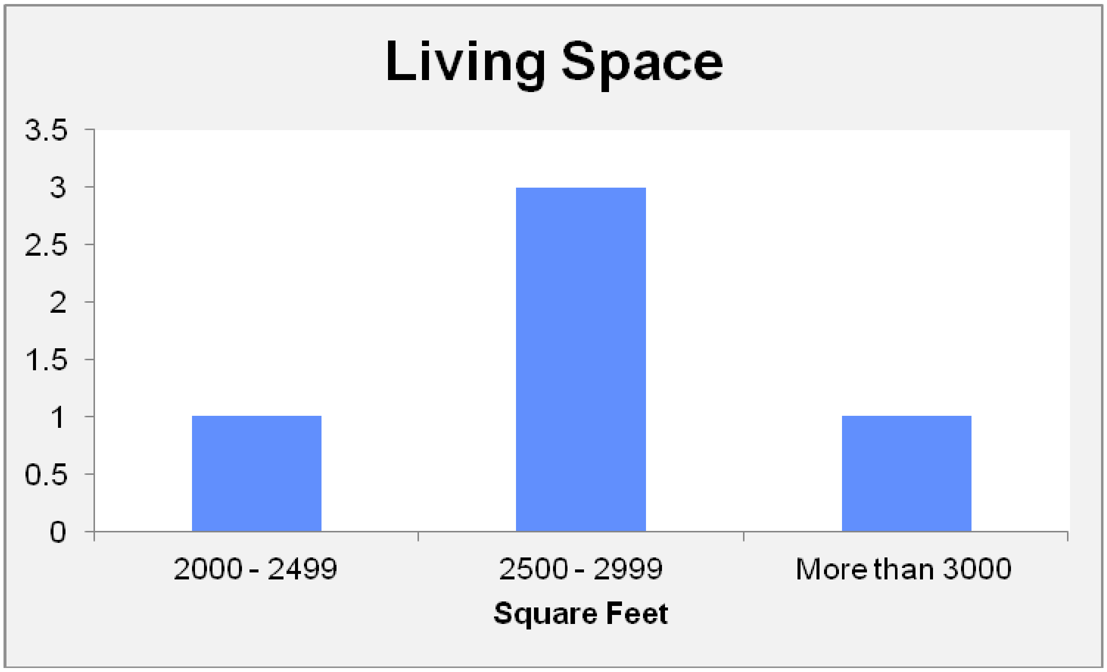


Figure 1. Size of Living Space

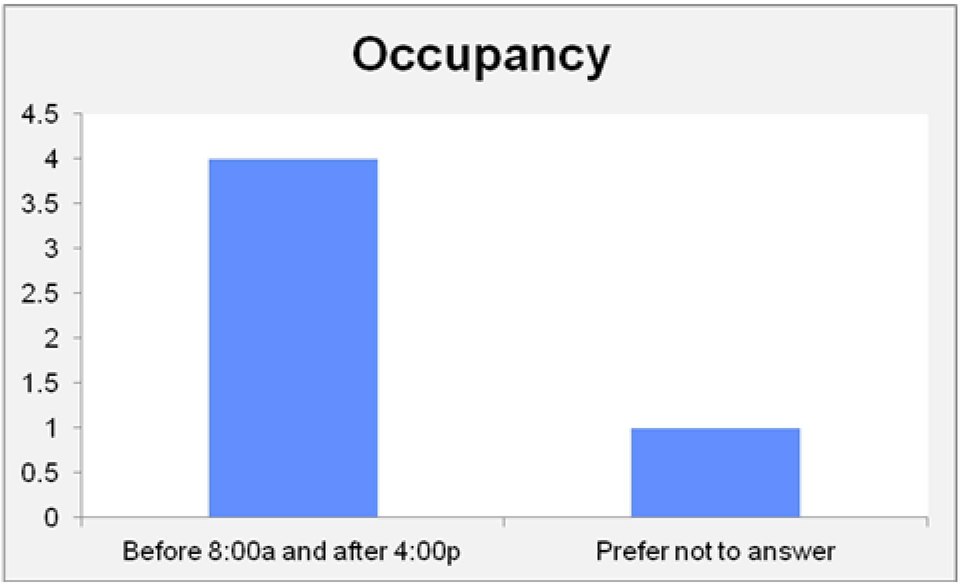


Figure 2. Hours of Occupancy

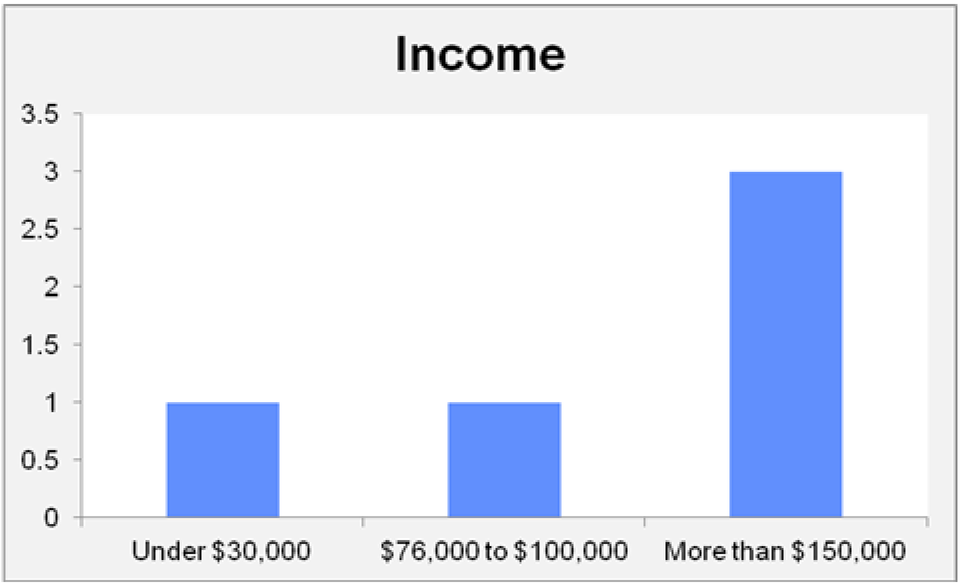


Figure 3. Income Range

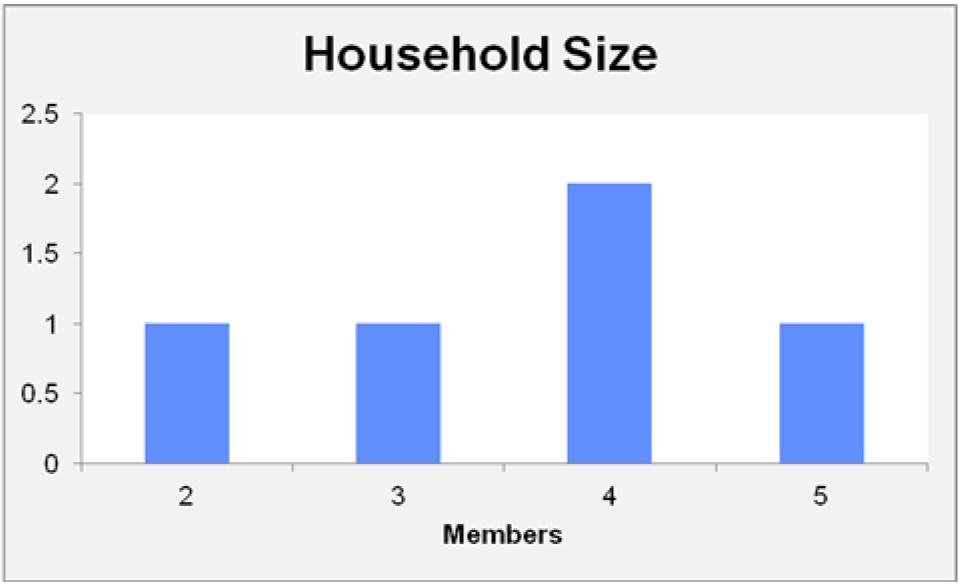


Figure 4. Household Size

3.2 Experiment Design

We used an ABA experimental design, as shown in Figure 5. The A "phases" represent baseline conditions of pre- and post-CASHEM installation. The B phase represents conditions during actual CASHEM usage.

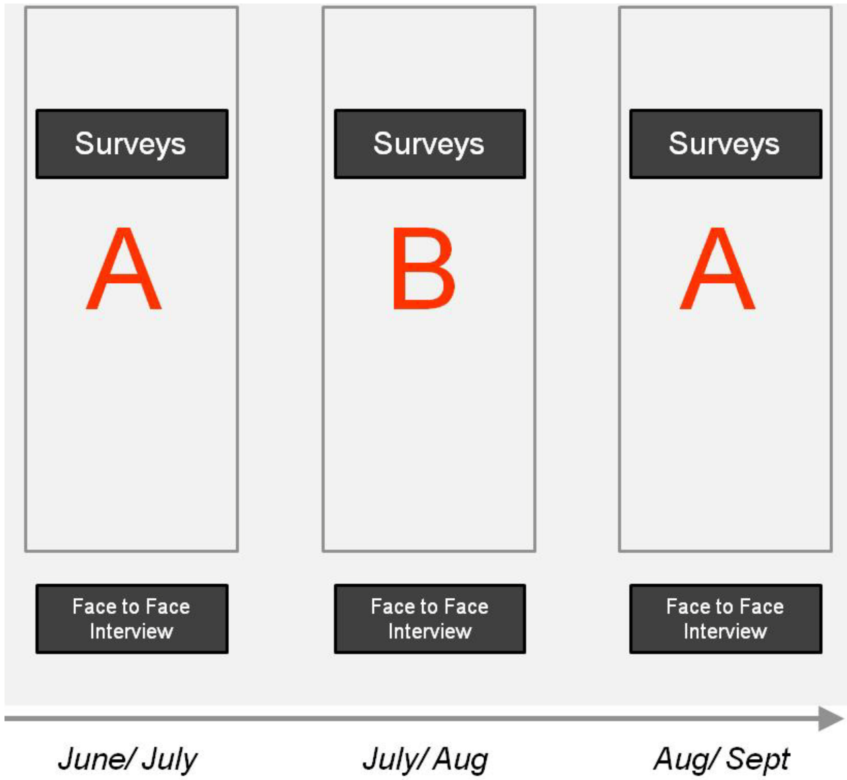


Figure 5. Experimental Design

1. A-preinstallation phase took place over one month. In this phase, the primary measure was user experience measured with subjective questionnaires, face-to-face interviews, and homeowners' utility bills.
2. B-installation phase took place over two and half months. In this phase, the primary measures were user interactions with CASHEM and user experience measured with subjective questionnaires, face-to-face interviews, and homeowners' utility bills.
3. A-final phase, after CASHEM was uninstalled, occurred over one month. In this phase, the primary measure was user experience measured with subjective questionnaires, face-to-face interviews, and their utility bills. This phase was included in the field study to measure whether CASHEM-induced behaviors were maintained after de-installation.

3.3 User Interface Design Methodology

This section describes how we designed the field ready CASHEM user interface and the procedures we followed to test and validate it.

In designing the CASHEM user interface (UI), we worked in three phases:

<u>User requirements elicitation</u>: The research team conducted surveys to understand the homeowners' current energy management motivations, behaviors, and energy saving strategies. They also identified the tools homeowner's used to manage their comfort, convenience, and home energy usage. As a follow on, the team conducted journaling activity and in-home interviews and observation sessions to comprehensively understand

users' energy management goals, needs, and motivations. Six homeowners participated in this exercise. Not all the homeowners who participated in this exercise participated in the final field study.

Concept generation: Ideation workshops were conducted to generate concepts for the CASHEM UI and to generate a tips repository.

User testing: Concepts and tips were tested with representative users in a lab setting to evaluate the usability and likeability of the information presented.

3.3.1 User Research

CASHEM leveraged existing user research conducted by an internally-funded research project. To understand the lifestyle, goals, and needs of the potential users of a Home Energy Management device, the team conducted user research with homeowners using surveys (29 participants) and focus groups (2 focus groups with 12 participants each).

In the follow-on user research activities, the CASHEM DOE project team recruited homeowners that have swimming pools, space conditioning, and refrigerators to be in tandem with the requirements of a CASHEM system that can control a pool pump, HVAC equipment, and a refrigerator apart from other household electrical appliances.

Since it is not common for homes to have swimming pools, the team worked with a local electric utility to identify home owners with swimming pools to conduct user research.

The team gave the home owners a journaling activity to complete before participating in a face-to-face interview. This activity required the participants to journal their current experiences on using, monitoring, controlling, and managing their energy consuming devices. Journaling allowed the research team to prime the participant in the context of home energy management prior to the face-to-face interview, which minimized the participant ramp-up time and allowed them to readily talk through various scenarios in their lifestyle leading to their energy management strategies, goals and needs.

After the journaling activity was complete, the team conducted face-to-face interviews with the home owners in their homes while observing them perform certain tasks such as controlling the pool pump, reviewing their home energy bills, etc.

Finally, the team synthesized and analyzed the data to identify patterns and generate design criteria for the CASHEM user interface.

The team used the data analysis from the surveys, focus groups, and the face-to-face interview sessions to categorize users into three broad categories based on their motivations for using a home energy management device. These categories are 1) penny pincher – one who can sacrifice comfort in return for savings on their energy bill; 2) comfort seeker – one who would like to seek comfort and convenience through automation and technology; and 3) tree hugger – one who is environment-friendly and is self-motivated to save energy for the planet. These categories allowed the team to gain an understanding of the heterogeneity within the population particularly in personal definitions/benchmarks of comfort and convenience. Figure 6 is a summary of the demographic that took part in the journaling activity and face-to-face interview sessions which is representative of the final list of participants recruited for the pilot study.

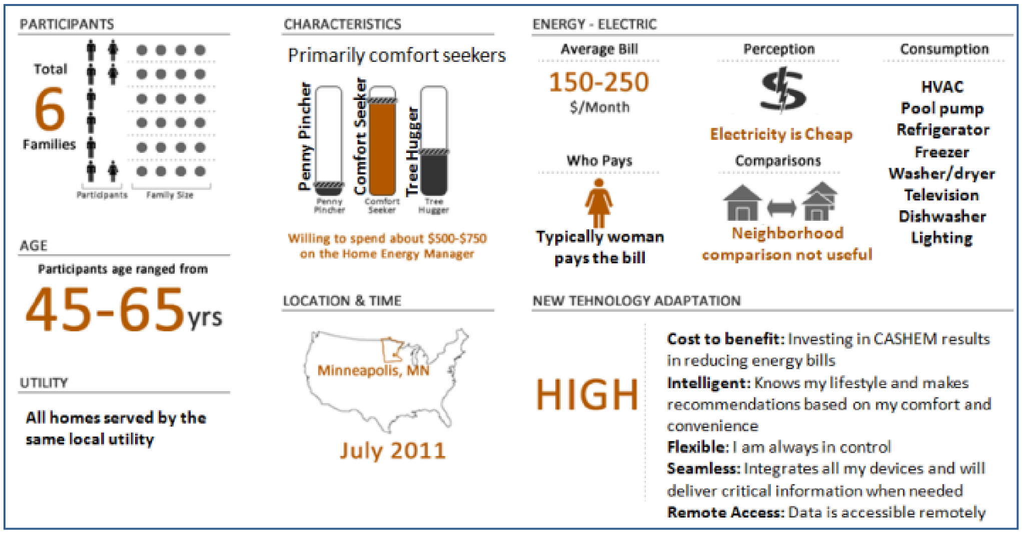


Figure 6. Demographics of Participants in the Face-to-Face Sessions

3.3.2 Concept Generation

To generate the conceptual design of the user interface for a home energy manager, the team generated design criteria by conducting pattern analysis of the user research data. The team also analyzed the best-in-class user interfaces and practices in the industry. The team aimed for a flexible, modular user interface concept that will work on the web and mobile platforms. In other words, the interface needed to allow seamlessly addition of new equipment/electrical loads without disrupting the user interface paradigm.

Idea generation workshops were conducted using the described criteria, leading to the development of a next generation flexible user interface for Home Energy Management. The selected concept, using "Tiles," is shown in Figure 7.

Figure 7. User Interface (Home Screen)

3.3.3 User Testing

The CASHEM UI concept was tested with representative users. The users were asked to perform typical home energy management tasks using a high-fidelity prototype and were given a subjective questionnaire at the end of the session to provide ratings on the usability and overall experience with the UI. The feedback thus generated was used to further enhance the user interaction. For example, on the earlier version of the UI, the dynamic piece of information presented on the pool pump tile displayed the operation mode – such as ECO mode (energy saving) or Manual mode. However, from the user testing, it became apparent that knowing if the pool pump is running or not is more useful to the users than knowing its operational mode. Similar patterns were drawn from the user testing data to identify the most meaningful and important information to be displayed on the tiles and their corresponding control panels along with identifying usability enhancements to the overall interaction and navigation paradigm.

3.3.4 Tip Generation

In accordance with the goals of the CASHEM project one of the primary objectives of CASHEM project is to provide users with energy conservation tips. From the in-home sessions during user research, we understood that the home owners prefer tips that are specific to their home conditions and usage patterns. Home owners do not always see value in tips that are generic.

One of the unique capabilities of CASHEM system is to collect data on the home owner's lifestyle based on the energy usage profile. CASHEM generates tips based on the home energy usage profile data and provides what specific actions can be taken to save energy and reduce the electricity bill. The energy usage profile includes data from individual devices in conjunction with the overall home energy to create a detailed profile of where, when, and how the home is consuming energy.

The CASHEM team conducted workshops to generate a tip library that is data-driven. The research team further conducted an affinity mapping exercise to group tips into two categories: 1) passive and informational and 2) those that require action from the users. The tips were grouped by function:

- Thermostat/HVAC
- Refrigerator
- Pool Pump
- Base Load
- Monthly Bill
- Monthly Target/Budget
- Comparison with similar homes
- Equipment programming based on occupancy

Finally, these tips were evaluated by eliciting feedback from representative users indicating if they would like, dislike, or ignore specific tips.

3.4 Tasks and Activities

During the preinstallation phase A (i.e., without CASHEM), we measured how homeowners managed and used energy at home before they were exposed to the CASHEM. Hence, during this phase, we monitored the energy usage in the homes without providing any feedback to homeowners.

During phase B (with CASHEM), the homeowners were given feedback on their energy use and management. The feedback was provided in the form of tips that could help homeowners make appropriate decisions to improve or change their energy management behavior. In addition, the tips were organized around the major devices in homes (e.g., refrigerator, pool pump, HVAC systems and base loads).

The tips were designed in a systematic way to provide homeowners typically with the following pieces of information (1) information about the context (2) insight to their energy usage for a specific time period (3) how they were doing relative to the other homes participating in the study and (4) recommendations on how to improve their behavior and usage patterns. Examples of specific tips include:

- Your pool pump is responsible for only 15% of the total energy consumption for this month. However, your pool pump did not operate as expected in past week. In this setup, it is switched off most of the time and your pool is not getting cleaned. Is this an intentional setting? If not please contact the Pentair representatives.
- Currently you are spending $50/month on loads that are ON 24 hours per day, and you had spent $65 in the last month. The lowest consumption reported was 0.18Watt/ft^2 and your consumption is relatively high compared to the average. Here is what other CASHEM homes are spending on baseload: $54. You can save money by checking for devices that can be shut off or unplugged until you are ready to use them. Computers and game consoles usually have settings to minimize power. Are all of your devices in a minimum power mode?
- Your refrigerator's energy cost for the past month was approximately $4.30, which is 5% more than for average CASHEM home owners. Your ice maker is ON about 97% of the time, which is responsible for the increase in energy consumption. If you had set ECO mode for this past month you would have spent about $3.05. ECO mode consumes the least energy. Keeping refrigerator and freezer doors OPEN increases energy consumption. CASHEM analysis shows that the overall door open time for your refrigerator is rather high. Recent studies show that poor open/close habits cost 10%–24% more energy.

4 Field Installation and Updates

This section describes process of installing the physical systems to the pilot homes, configuring systems for each home, maintaining the overall system during the pilot period and configuration of the final user interface for the field test.

4.1 Pre-installation Procedure

The CASHEM team developed a list of requirements describing the homes that would be qualified to participate in the study as described in Section 3.1. These requirements included a swimming pool with a filtration system that uses a pool pump. The local electric utility—our project partner—used these requirements to provide the team with a list of candidate homes. We then conducted pre-installation site visits.

One goal of the pre-installation visits was to determine the suitability of the homes for the project by talking with the homeowners and to find out their willingness to participate. We described the project goals, the data to be collected, how the data would be protected, and how it would be used. Another goal was to gather data for the installers so they could come prepared with the tools and equipment to conduct efficient and successful installations. We also recorded the types of thermostats, heating and cooling systems for HVAC installers.

The primary hardware requirement for homeowners was that they have 24/7 Internet connection and a Wi-Fi router. It was also helpful for the users to understand how to browse the Internet and be familiar with the iPad. The home router location was not a major concern, but it needed to be close enough to the gateway computer to ensure sufficient Wi-Fi signal strength for good, reliable communications. All of the homes we visited had good communications between gateway computer located near the refrigerator and the Wi-Fi router.

The location of the pool pump was another concern. The Wi-Fi signal strength between the gateway computer and the pool pump module needed to be strong enough for reliable communications. In some of homes, signal strength was a major issue that was solved by using Wi-Fi extender modules. We found that the type of siding on the house could cause attenuation of the signal strength; aluminum or steel blocked the Wi-Fi signals and communications could happen only if the signal came through the windows. The only way to get connectivity was to install Wi-Fi extension modules and place them in the windows facing the pool pumps. If the home had aluminum siding and did not have windows on the pool side of the house, installation would be very difficult. The pool pumps that were used in the project had to be connected to 240 volt power, which is common, but we needed to add power in two homes.

In each of the homes we installed a power monitoring system called The Energy Detective or TED. To connect the TED's Internet gateway, we needed an outlet located near the load panel. In some cases, we had to install this outlet. We determined the location of these outlets during home visits.

Figure 8 illustrates the basic CASHEM system components.

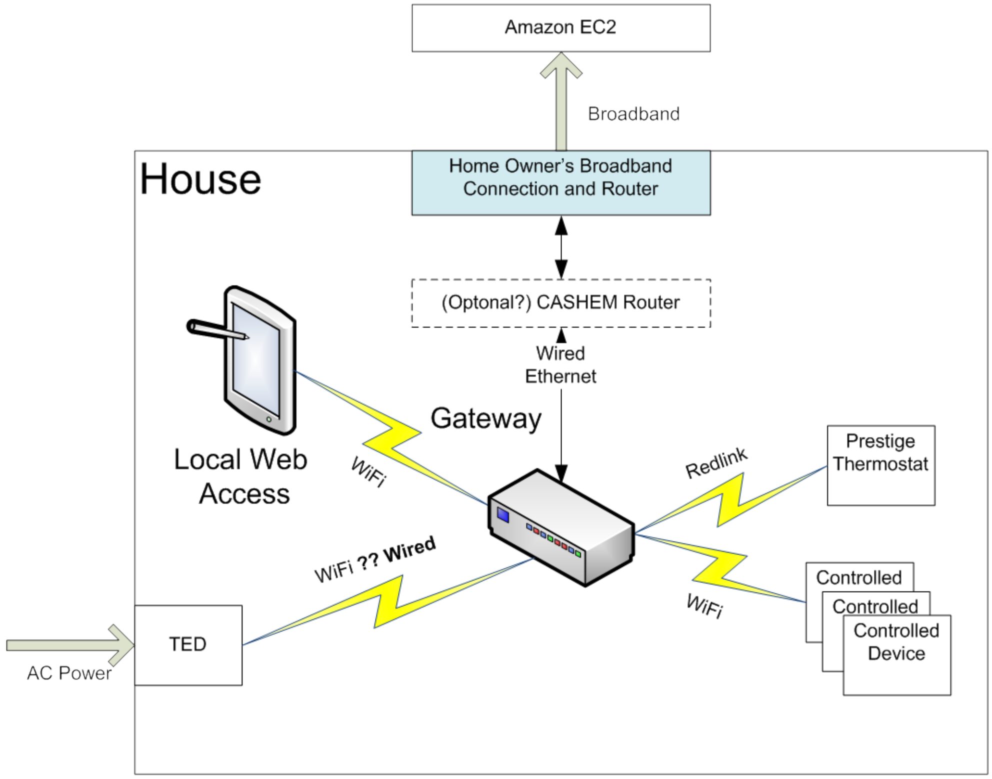


Figure 8. CASHEM system diagram

4.2 Equipment Installation

The CASHEM team installed five pieces of equipment in each of five pilot homes: a gateway computer, a Honeywell Prestige thermostat, a Bosch refrigerator, a pool pump Wi-Fi module, and a TED power meter. In one home, we had to load panels, so two TEDs where installed.

4.2.1 Gateway Computer Installation

Figure 9. CASHEM gateway computer

The gateway computer for the CASHEM system was a small, Windows-based computer produced by Acer. One of the installation challenges was that the computer needed to be connected to the Bosh refrigerator with a USB cable, which is limited to about 15 feet in length. To overcome this challenge, we drilled a 1 in. hole into a cabinet adjoining the refrigerator, then threaded the serial cable and power into the cabinet. This solution worked well to connect the power and USB cable to the gateway computer. Some of the gateway computers where installed in lower cabinets, while others were installed in the cabinet above the refrigerator. Installing these devices in a closed cabinet does put thermal stress on the device, which may cause longevity problems. When the gateway computer was installed above the refrigerator, it was inconvenient to connect it to a monitor for troubleshooting and maintenance.

4.2.2 Thermostat Installation

At each home, Honeywell service technicians installed a new Prestige® thermostat system. The system comes with a RedLINK™ communications module and an outdoor temperature sensor. The Honeywell propriety RedLINK communications module communicates with the thermostat and the outside temperature sensor using RedLINK RF communications. The RedLINK module is also connected to the home owner's internet router, which interfaces with the cloud, (Amazon EC2).

Figure 10. Honeywell's Prestige Thermostat

4.2.3 Bosch Refrigerator Installation

The Bosh refrigerator is taller than standard refrigerators, so the installer needed to make some cabinet modifications. The refrigerators were installed by a Bosch technician and the connection to the ACER gateway computer by Honeywell. Both installers worked together to make sure the devices were working properly during the installation. During installation the serial cable and extension cord was routed through the opening into the cabinet and connected to the ACER gateway computer. The refrigerator was tested using an application provided by the manufacturer. After the refrigerators were installed, the electronics were accessible only by removing the freezer drawer.

4.2.4 Pool Pump Wi-Fi Module Installation

As part of the CASHEM project, Pentair installed IntelliFlo pool pumps at each home. The Pentair pool pumps were modified with a Wi-Fi module designed by Honeywell for the project. The module converted Wi-Fi to RS232 serial, then converted it to RS485, which was then connected to the pool pump. Once the module was designed and packaged, the modifications and installation to the pool pump was not difficult. Connecting power to the

Figure 11. Pool Pump Module

modules was accomplished by installing a 5 volt power supply to the 240 volts supplied to the pump. The pool pumps are typically located out of doors and a good distance away from the homes. As a result of the location, Wi-Fi communications to the computer presented some difficulties, and we used Wi-Fi extension modules to boost the signal. A waterproof box was used to protect the electronics. In one home, the pool pump was about 50 feet away from the house and behind some trees; here, the pool pump module was modified by adding an external antenna.

4.2.5 TED Installation

Each home CASHEM installation used a least one TED power meter. The TED uses current transformers that were installed into the home owner's load panel by an electrician. The TED uses power line carrier interface to communicate outside the load panel into the TED interface module. To ensure a clean signal and not to cause problems in the home an electrical filter was added. This filter was installed on the same wires that the interface module was plugged into. If it was possible a new receptacle was installed next to the load panel for the modules. Otherwise the module was plugged into a receptacle that was located near the load panel and the filter was added to those wires. The TED's interface module is a web server as well and it has an RJ45 internet connection on it. This device needed to be connected to the internet using an Ethernet cable. In some homes the internet router and cables where not close enough to the load panel to be directly connected with an Ethernet cable, so a Wi-Fi extender module with an Ethernet cable input was used.

Figure 12. TED (The Energy Detective)

4.3 Configuration

This section describes the configuration required to customize a CASHEM system to each home in the pilot.

4.3.1 Gateway Computer Configuration

Each home used a small, Windows based computer as the CASHEM gateway. As described in the design document, this gateway connected to all CASHEM devices and translated protocols to a common language. For each home, the gateway was configured with passwords and the correct IP addresses. They also required installation of some basic applications, including Microsoft Security Essentials to provide virus protection, an XAMPP Apache server, LogMeIn for remote access, and the Honeywell-developed CacheManager software.

Along with the computer system, a D-link Router provided a private wireless network in the home. Router configuration required an IP address, port forwarding, and passwords.

4.3.2 Pool Pump Configuration

Honeywell developed an application to easily configure and modify the pool pump Wi-Fi modules. They were all configured to the same SSID and IP addresses so they could be tested in the lab and installed without being individualized for each home.

4.3.3 Honeywell Prestige Thermostat Configuration

To configure the Honeywell Prestige® thermostat systems, the installer connected the RedLINK™ module to the internet so the CASHEM system could obtain HVAC data for home. For the CASHEM project, standard Prestige thermostats were replaced with modified Prestige thermostats that collect data and store it internally. Bosch Refrigerator Configuration

The Bosch refrigerator came with a USB interface and software application that was installed on the gateway computer. The refrigerator did not need to be configured. The computer was configured with the correct baud rate and software was developed to communicate with it.

4.3.4 TED Configuration

Each TED unit has an MTU (maximum transmission unit), a gateway, and a display. The MTU is installed inside the load panel. The gateway is plugged in near the load panel and hosts a webpage. To configure the system, a computer needed to be plugged into the TED unit and connected to its server. The TED's gateway was configured to communicate with the MTU and display by entering the serial numbers for the devices. The IP address for the gateway also needed to be changed, so it could be connected to the Internet and it could be accessed remotely.

LogMeIn software was installed on each computer to give us remote access to make software changes and monitor the systems.

4.4 Maintenance

The EC2 Client application (Figure 13) monitors the status of each house by reporting the last time the data was changed for the TED, pool pump, thermostat, and refrigerator. This process requires running the application, waiting for it to update, and manually scanning the list to determine whether all of the devices are reporting. For the CASHEM project, this process is manageable, but for a large set of homes, this application would be automated to send a notice when the data became older them a specified amount of time.

We prepared a troubleshooting guide for the Honeywell team to help isolate any problems when an error did occur.

The LogMeIn client on the gateway computers allowed Honeywell to operate the computers remotely, which was useful for analyzing any problems with the subsystems. One of the vulnerabilities of the system was the reliability of the homeowner's Internet. If the home lost connectivity, CASHEM did, too. When devices lost connectivity, they had to be reset.

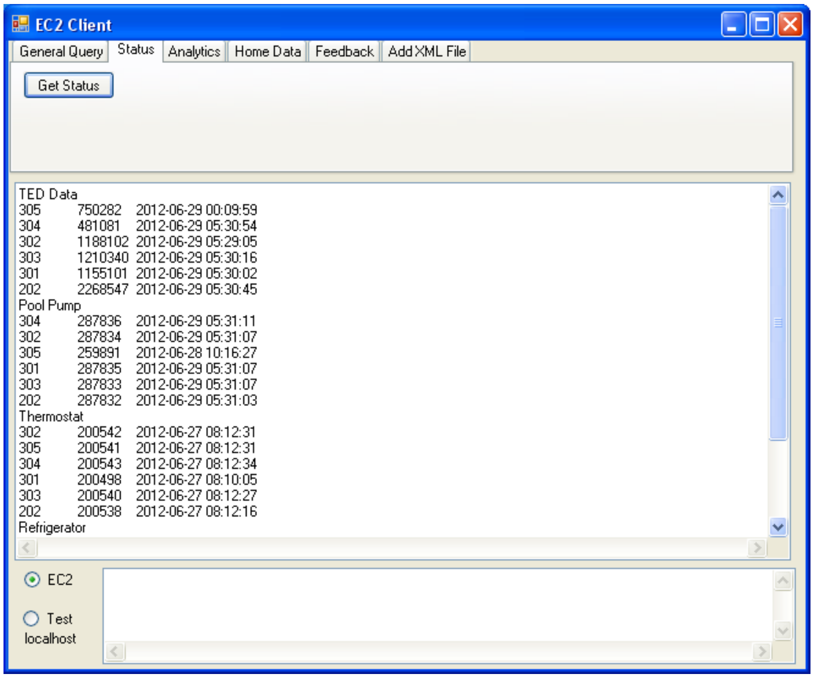


Figure 13. EC2 Client application

Occasionally, the homeowner had to cycle power on a device. If that did not fix the problem we would need to make a service call.

At one point, we needed to install a software update in the TEDs. Installation required a service call because the update reset the IP address, and we could not connect to it remotely.

Occasionally a pool pump would stop communicating, but we could use remote reset to get them back on track. One pool pump module just stopped working and had to be replaced.

4.5 User Interface Device and Design

After recruitment and installation of CASHEM equipment, participants were given a tablet computer to access the web-based CASHEM UI to control home energy use. The users also received a quick start guide (both paper-based and web-based—see Appendix A for a sample) that described the interface and its use.

4.5.1 Device Configuration

The user interface is completely web-based, using HTML, XML, CSS, and JavaScript. The user does not need to install, configure, or worry about “applications.” This design also means that the interface can be accessed through any web browser, on any device, (i.e., desktop, laptop, tablet, or cell phone) running any operating system. Thus, while the CASHEM team provided Kindle Fire tablets, they could also use any other compatible device.

Team members worked with homeowners to set up the Kindle Fire's browser to show how it connects to the CASHEM gateway in the home. This process is as simple as typing in the known URL, just like any other website. The Kindle Fire's main landing page has a quick-launch area that can maintain a direct link to the CASHEM homepage, providing easy access for the user to return to the interface at any time. This area is similar to a browser's "favorites" functionality.

Application architecture

The architecture of the user interface and underlying messaging structure was built to be easily extensible; allowing new devices to be added to the interface with little effort. Each device or status element requires its own html page, which contains specific details for that item; controllable devices have page elements that provide access to the devices' control capabilities; status items have unique page elements to produce effective and efficient visualizations for the information. Each item must also have its own data file, written as XML, to provide current parameter values. Aside from those unique requirements, much of the remaining infrastructure is simply re-used. The JavaScript that handles all the control requests uses the same functions for similar actions between devices, such as incrementing/decrementing button pushes, or committing changes to the gateway. Only the device's Friendly Name (a configuration parameter) is required to distinguish which device is requesting the changes.

4.5.2 User Interface Design

The team used a "tiles" concept, which is simple to use, intuitive, flexible, and intelligent. Each CASHEM function/device has its own control tile. The tile is identified by an intuitive icon and a descriptive label. Tiles have two sizes, thumbnail (small) and control panel (expanded). The collection of thumbnails that the user has chosen to view is a "top-level dashboard" for the home (Figure 14). When a thumbnail tile is selected, the screen displays an expanded control panel tile with status information for the device and the means to control it. When a tile is selected, the remaining tiles are pushed to the screen boundaries (Figure 15) and are still visible to allow navigation to other functions.

Figure 14. Dashboard View with Thumbnail Tiles

Figure 15. Expanded Tile and Remaining Thumbnails

The tiles on the UI correspond to the following general information categories:

- Thermostat for HVAC control
- Refrigerator
- Pool Pump
- Overall Energy Consumption
- Tips
- Weather

Figure 16 and Figure 17 display the control panel/expanded tile views for pool pump and energy features respectively.

Each thumbnail tile has three pieces of information: 1) Label 2) Icon and 3) Status. The status information is dynamic. For example, a thermostat tile displays the current inside temperature, and the energy tile displays the amount of energy consumed so far this month. This paradigm allows the user to get the status of the equipment “at a glance” without having to interact with the application. Further, the tile allows interaction (similar to an icon on an Apple™ iPhone®) to view more details, control the equipment parameters, and get tips related to that specific tile.

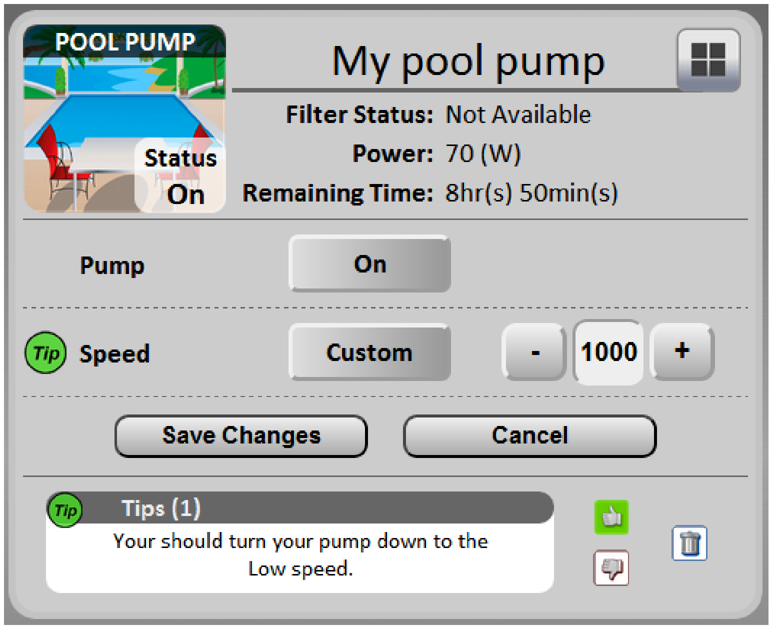


Figure 16. Detailed View/Control Panel of the Pool Pump

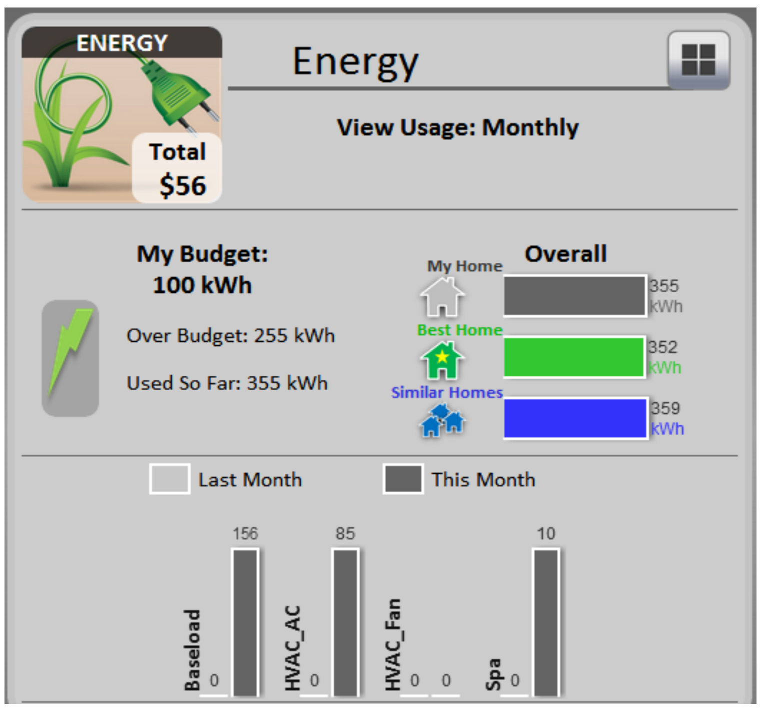


Figure 17. Detailed View of the Energy Usage

This interface concept made adding new equipment/features easy and intuitive, because we could just add a new tile corresponding to the feature without changing the user interaction paradigm.

4.5.3 User Interface Implementation

A Quick Start Guide helped users in acclimate to the Kindle Fire and the UI. “Starting CASHEM” is presented in a very simple flow on the first page to show how to find the homepage and recall it. The next page explains the Home Screen and the functions that can be initiated from there. The remaining pages cover the usage of the tiles for the controllable devices and other status-related tiles available in the pilot. See Appendix A for an excerpt of the guide.

The pilot began with basic functionalities available through tiles for the categories described above. Tips were available for appropriate categories to help users make efficient use of appliances. The tips were presented on Tuesday and Friday each week.

Tip Interaction: Each tip can be accessed from two different areas on the interface: (1) by activating the Tips tile, which displays the repository of old and new tips similar to the “Inbox” metaphor of a mail portal; (2) by activating the control panel for the equipment to which the tip relates. Users could like, dislike, or trash a tip using the CASHEM UI. The system uses this data in the following way:

- Like – System continues to present similar tips
- Dislike – System discontinues presenting similar tips
- Trash – System deletes that instance of the tip from the repository

This interaction paradigm keeps the user in control. The structure of each tip was as follows:

- Each tip has a title corresponding to its feature/equipment/information category such as refrigerator, thermostat, etc.
- The tip statement has four pieces of information: 1) CASHEM’s observations on the home’s energy usage, 2) comparison to the rest of the CASHEM homes, 3) what action the user can take, 4) savings that could result from the action. More details and examples of tips are provided later in this report.

4.5.4 UI Upgrades

Over the course of the pilot, users discovered some functionality limitations within the pool pump control panel. After working closely with Pentair and generating a more precise state-diagram, the pool pump UI was updated and well-received. The upgrade required the team to simply push webpage-related files to each home’s gateway and required no interaction with the user and no system downtime.

The other notable upgrade was for the Tips tile. After user feedback about the length and amount of detail presented in recommendations, the interface was updated to divide the recommendation into sections for the main text and the details. The majority of the recommendation text was hidden within a *Details* link that expands an area just below the main text and displays the details. This update required changes to the recommendation database schema, adding another element to the recommendation XML message and UI design. With close team coordination, the changes were made quickly and deployed to the CASHEM eco-system flawlessly, again without requiring any actions by the homeowners to enable the changes. Remote access to each home’s gateway was achieved through LogMeIn (as described in section 4.4) and all new UI files were transferred through this interface.

5 Survey Results

5.1 Surveys 1 and 2

At the end of each phase [pre-phase A (without CASHEM) and phase B (with CASHEM)], homeowners were requested to complete a survey to indicate their experience within that phase. Summary of the findings are listed below. Thereafter, graphical representations are laid out that provide a more detailed look in to each question of the survey.

1. The detailed and tailored tips provided by CASHEM was perceived to be extremely useful for managing energy consumption
2. Homeowners were better able to find the information they needed from the CASHEM system compared with the whet they received through their utility bills
3. The homeowners generally felt relatively better prepared to manage energy consumption using the CASHEM system
4. The tips provided by CASHEM were perceived to be much more easy to understand compared with the tips provided in their utility bills
5. The homeowners loved the CASHEM system so much that they wanted to recommend that to their friends, neighbors and family
6. There was a higher chance that homeowners would discontinue good energy management practices if they did not have the CASHEM system. This was not true with the utility bills.

Next, detailed graphical representations are provided for each question included in the survey. In each graphical representation, 1 indicates strong agreement and 7 indicates strong disagreement. The average ratings of all the homeowners were calculated for each question, without CASHEM and with CASHEM. It is important to note that the home energy management system that homeowners relied on during pre-phase A (without CASHEM) was their utility bill, which provided information on their current usage, how they were positioned relative to homeowners with similar profiles and mechanisms to improve energy management.

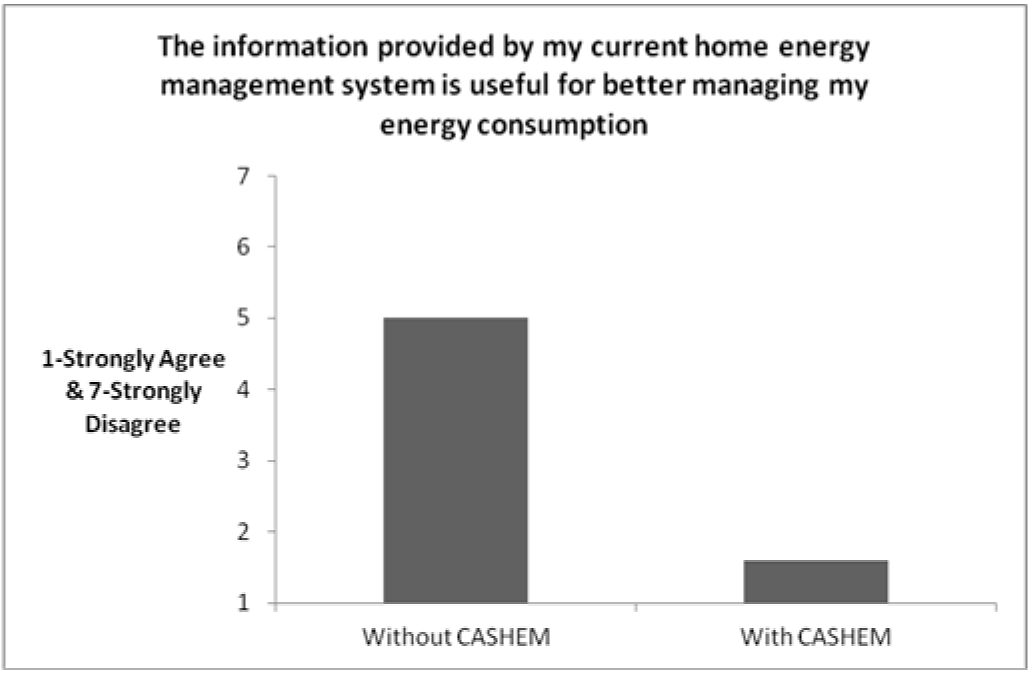


Figure 18. Response to Question on Usefulness of Information

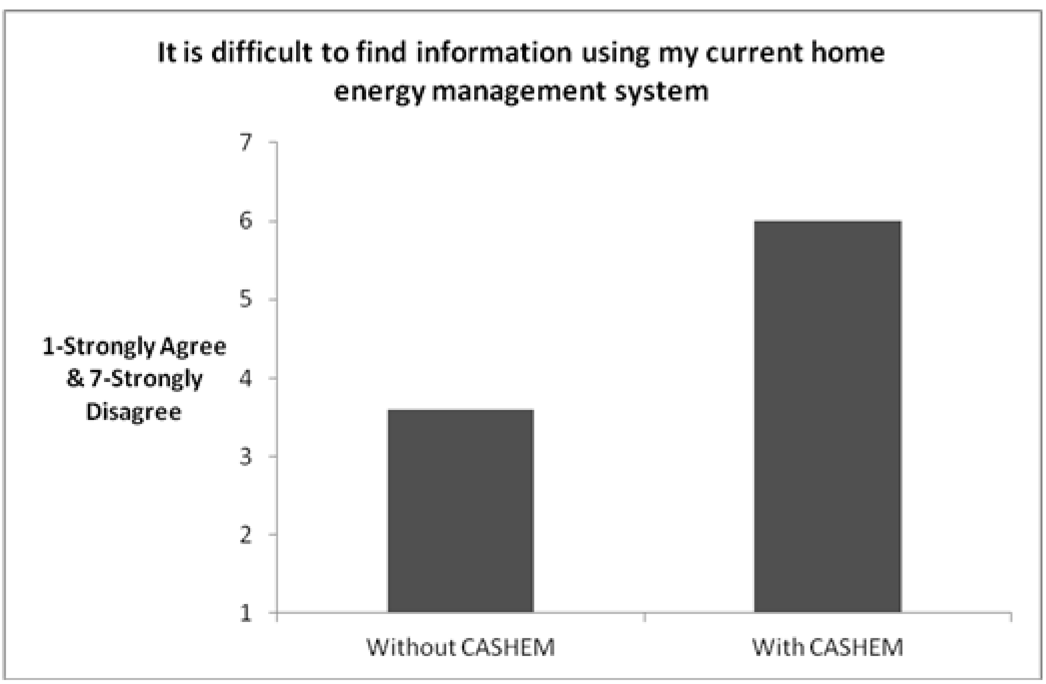


Figure 19. Response to Question on Difficulty of Finding Information

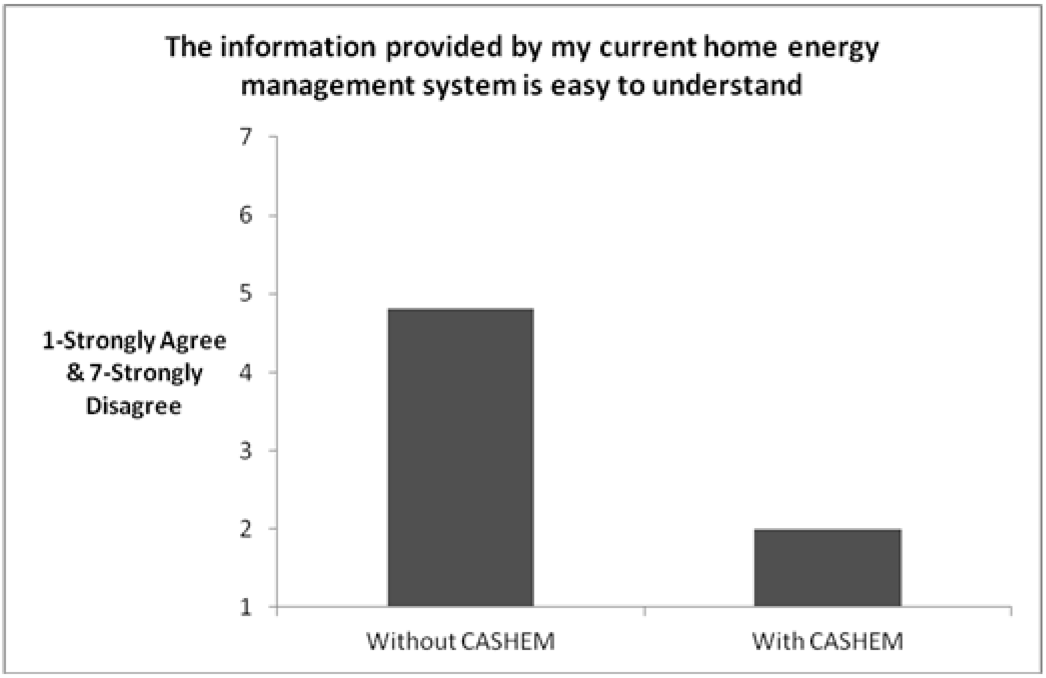


Figure 20. Response to Question on Easiness to Understand Information

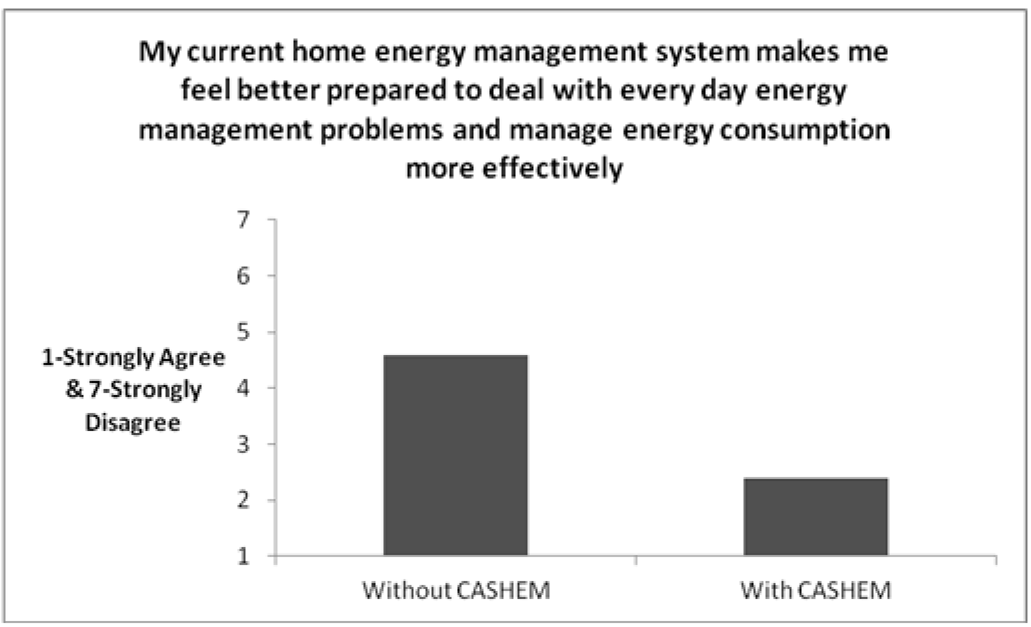


Figure 21. Response to Question on Preparing for Energy Management

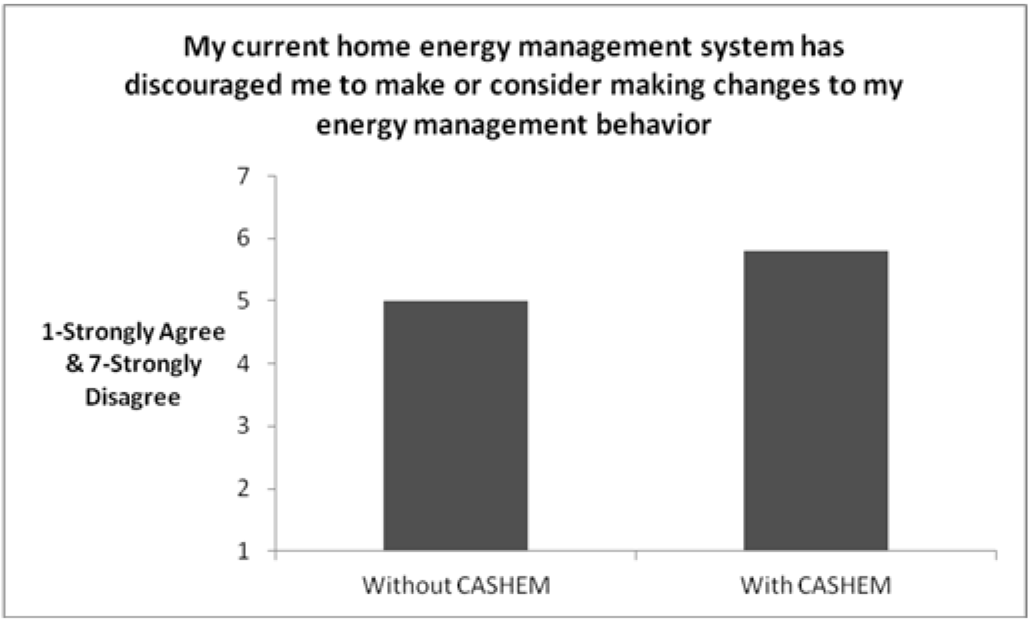


Figure 22. Response to Question on Making Changes to Energy Management

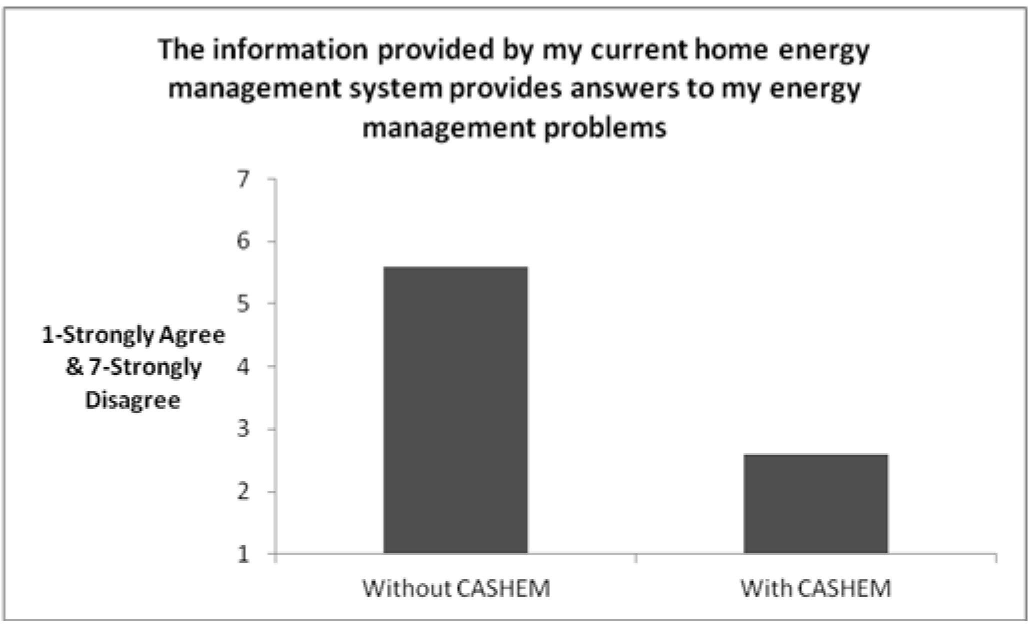


Figure 23. Response to Question on Information Provided

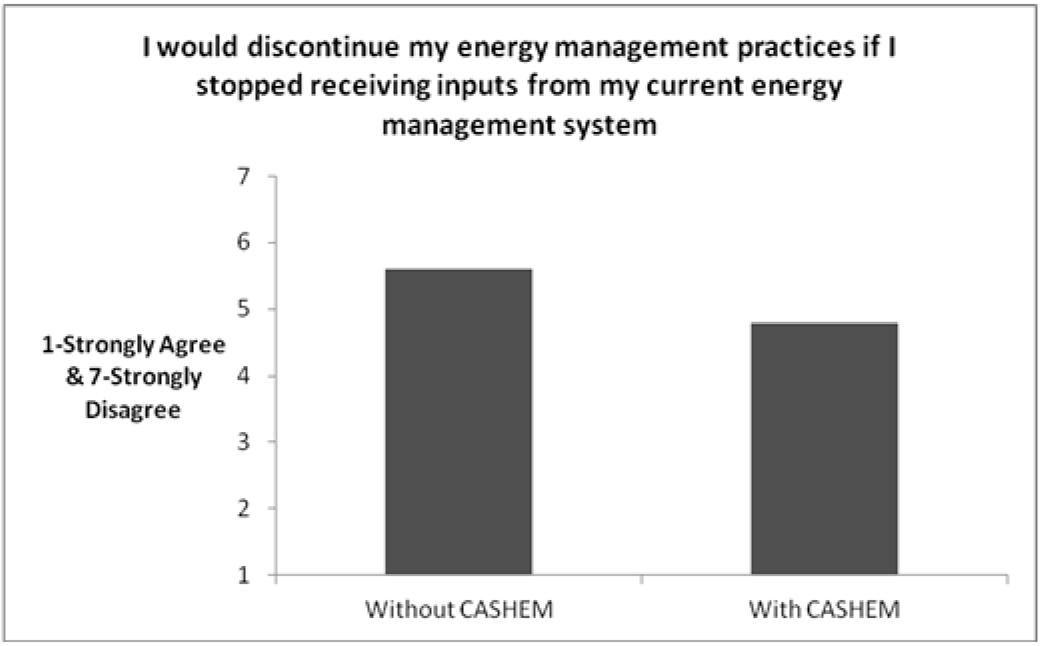


Figure 24. Response to Question on Importance of Inputs

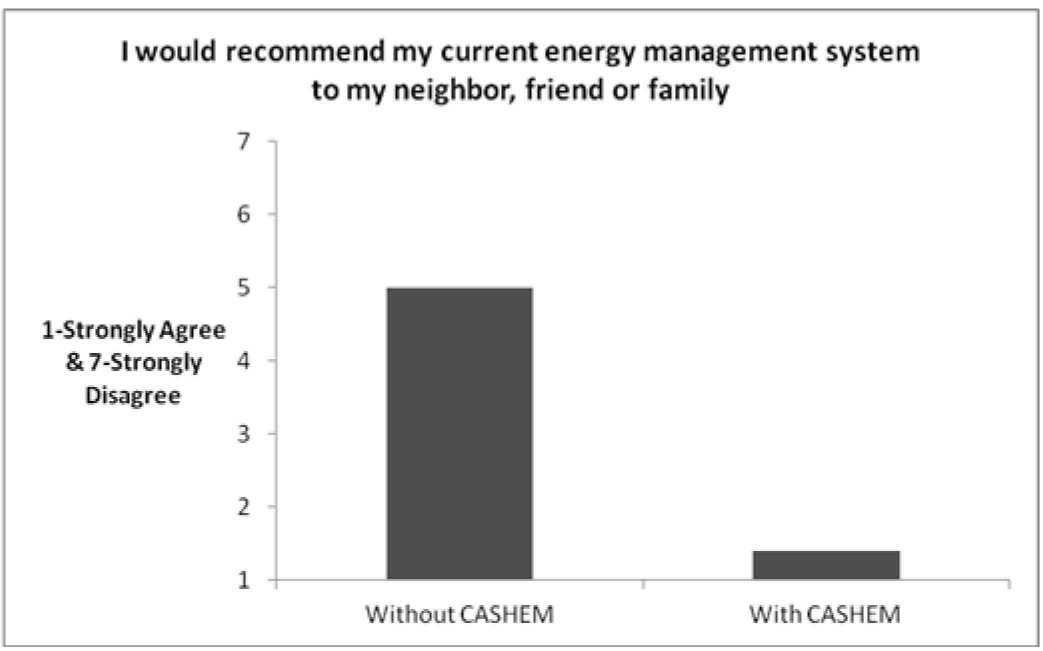


Figure 25. Response to Question on Recommending the Home Energy Manager

5.2 Survey 3

At the end of post-Phase A homeowners were requested to complete another survey to indicate their experience within that phase. In this phase, similar to pre-phase A, they received no feedback on their energy management behavior. The rationale for including this phase was to see if interaction with CASHEM in phase B leads to sustenance of good energy management practices. Summary of the findings from the survey are listed below. Thereafter, graphical representations are laid out that provide a more detailed look in to each question of the survey.

1. The conversations the homeowners used to have with family members on energy management behavior reduced significantly in this phase, compared with when they were receiving tips from CASHEM
2. The homeowners felt they were less aware of their energy management behavior in this phase
3. Homeowners felt like they did not become fully reliant on tips to manage energy better, but that they would do better with energy management if they continued to receive tips from CASHEM
4. The tips on heating and cooling patterns were missed the most by homeowners, followed by tips on base loads, refrigerator settings and then the pool pump
5. All homeowners were interested in continuing to receive tips on energy usage and behavior, even after the field study officially came to an end

Next, detailed graphical representations are provided for each question included in the survey. In each graphical representation, 1 indicates strong agreement, and 7 indicates strong disagreement. The ratings from all five homeowners who participated in the study are included.

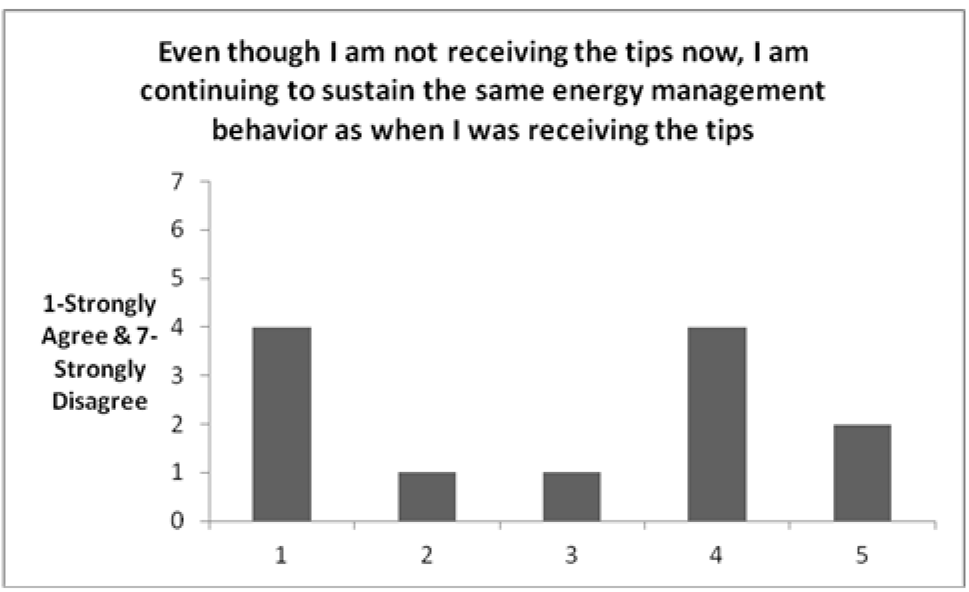


Figure 26. Response to Question on Sustaining Energy Management Behavior

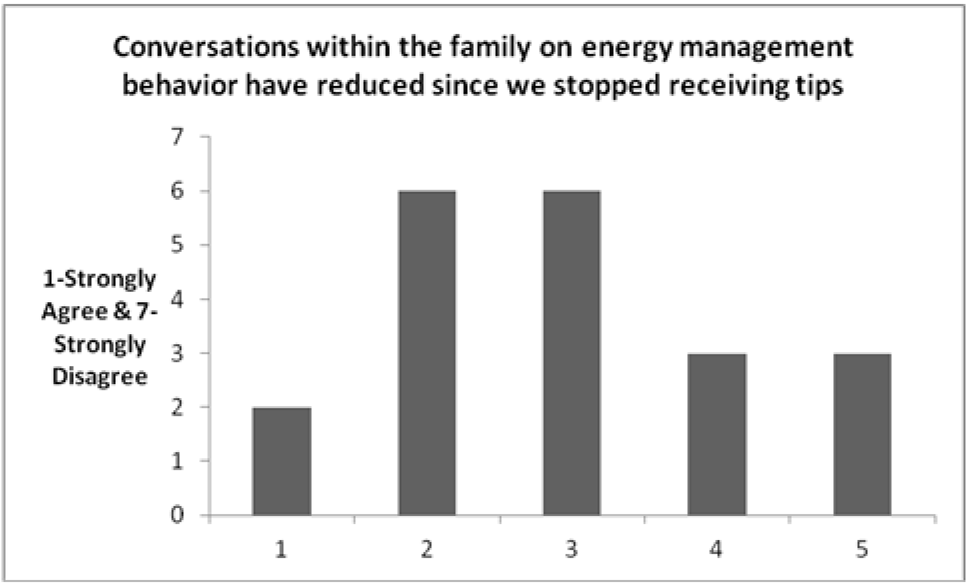


Figure 27. Response to Question on Conversations with Family on Energy Management

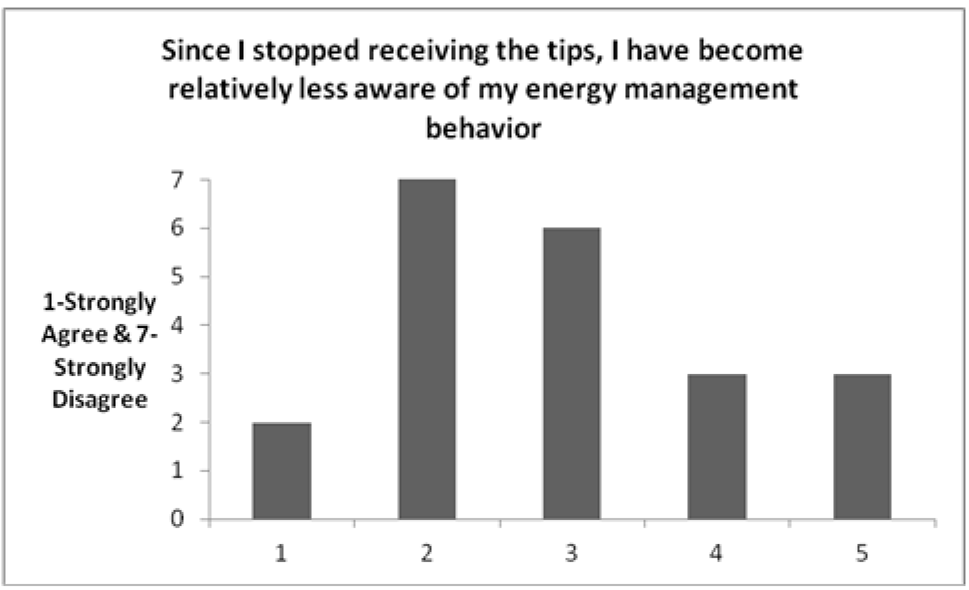


Figure 28. Response to Question on Awareness of Energy Management Behavior

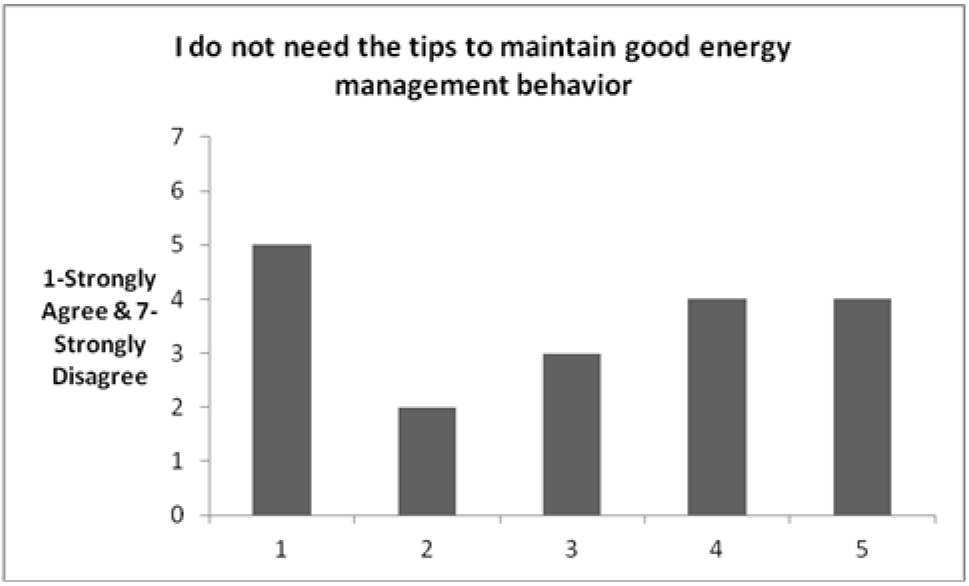


Figure 29. Response to Question on Need for Tips

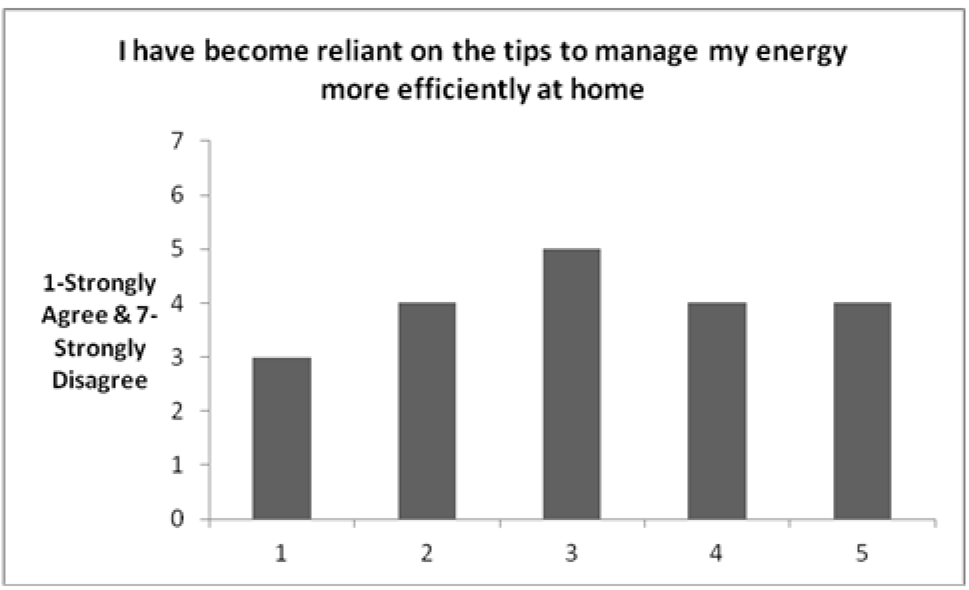


Figure 30. Response to Question on Reliance on Tips

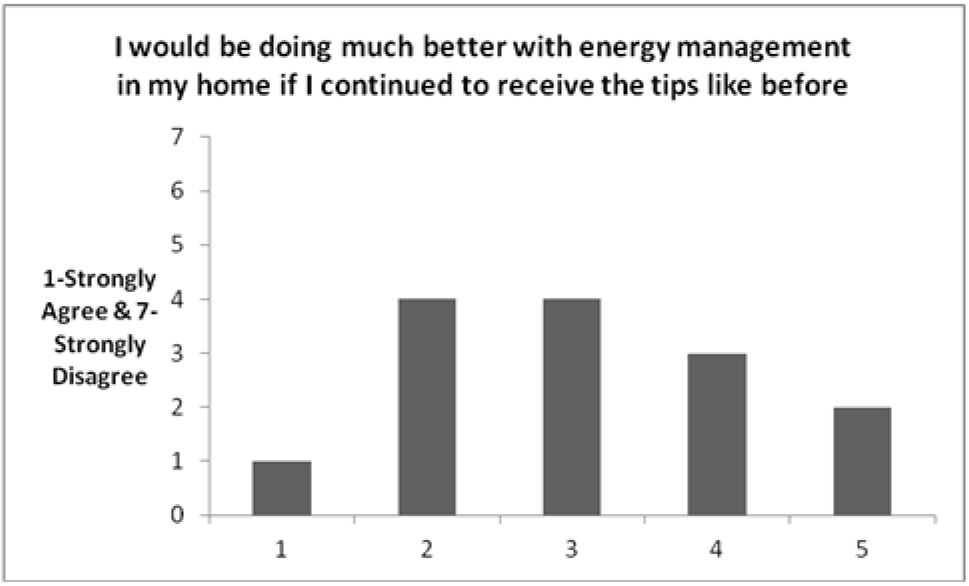


Figure 31. Response to Question on Importance of Tips

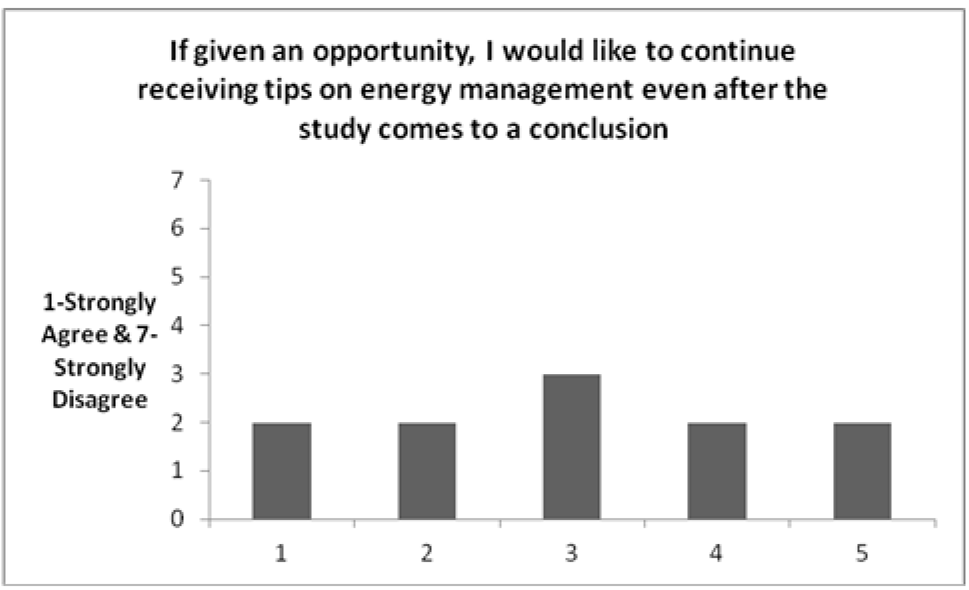


Figure 32. Response to Question on Continuing to Receive Tips

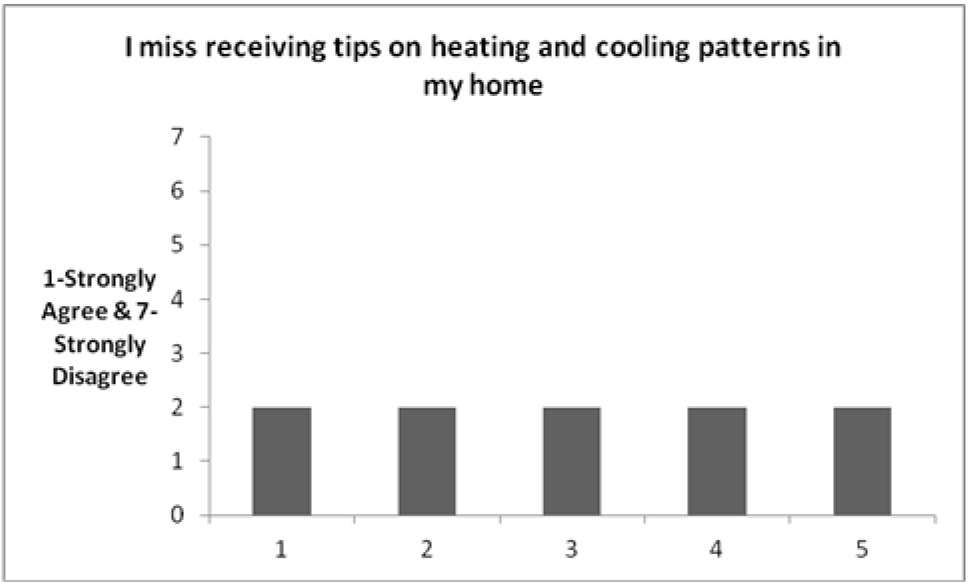


Figure 33. Response to Question on How Much Tips on Heating and Cooling are Missed

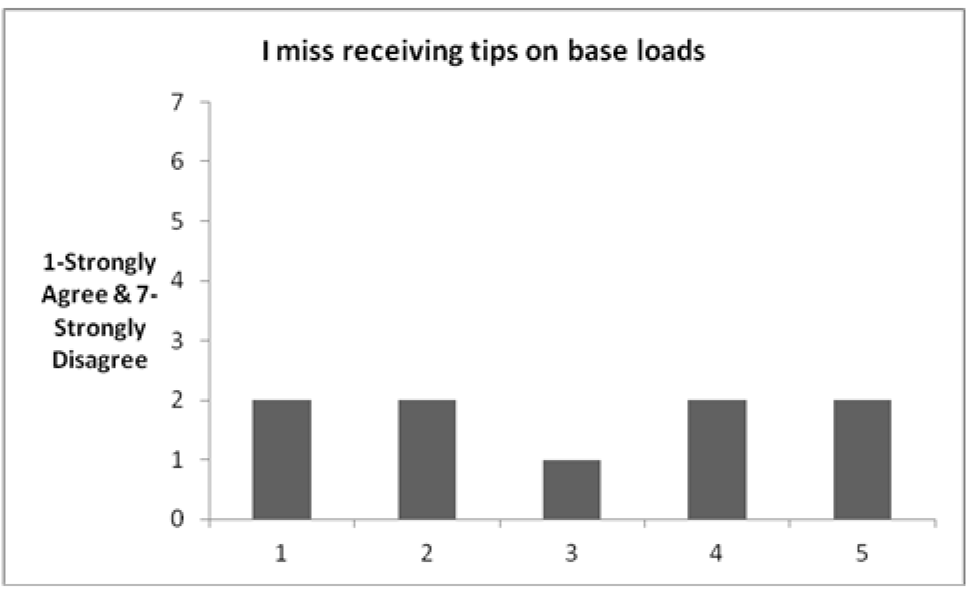


Figure 34. Response to Question on How Much Tips on Base Loads are Missed

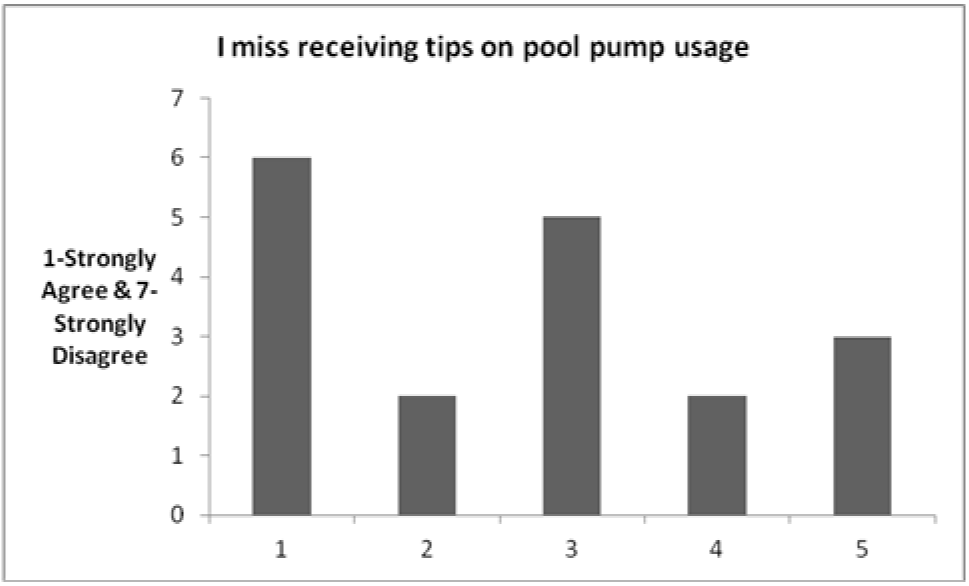


Figure 35. Response to Question on How Much Tips on Pool Pump Usage are Missed

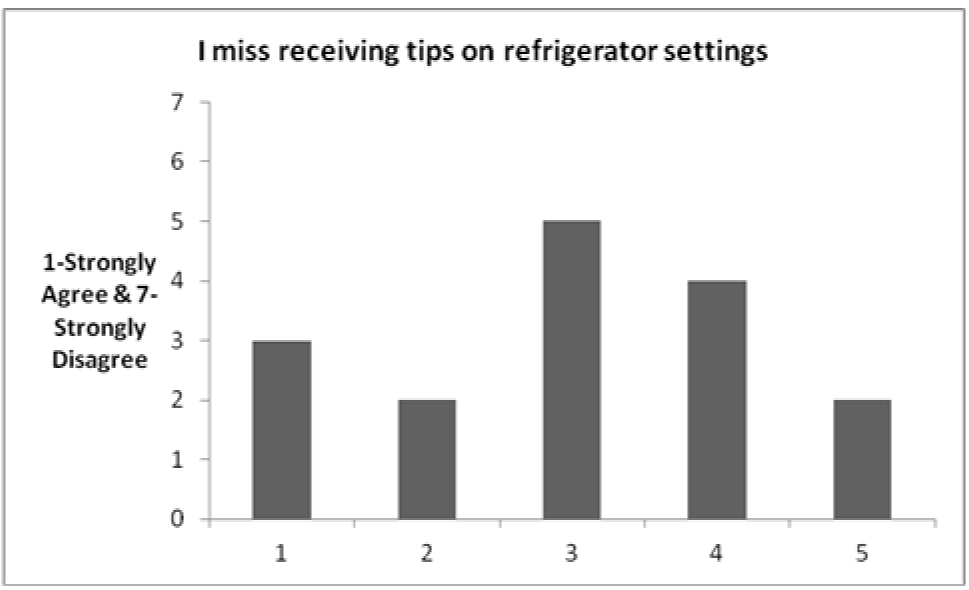


Figure 36. Response to Question on How Much Tips on Refrigerator Settings are Missed

5.3 One-on-One Sessions

At the end of each major phase (A, B and A), the project team held one-on-one sessions with each homeowner to further discuss their experience within each phase. All homeowners were also given the opportunity to blog about their experiences on a daily basis or record their experiences in a notebook. One of the objectives of the one-on-one sessions was to get in to more in-depth discussions on their blogs, notes from the notebook and responses to the surveys. A summary of the inputs from the homeowners has been listed below.

5.3.1 One-on-one session after pre-phase A

- On overall experience
  - Not really aware of our energy usage
  - We want to do more, but would like to know how to do so
  - A common energy management technique used is energy efficient bulbs
- On tips
  - The only energy management tips that homeowners had at that point were from their utility bills. In the utility bill, there was information about how the homeowner did in comparison to similar homes. However, the homeowners complained that such information seemed too generic, and was not useful. Hence, they hardly relied on that information.
  - Homeowners mentioned that they were ready to embrace an effective energy management tool that is tailored to their homes and needs

5.3.2 One-on-one session after phase B

- On overall experience
  - Learned a lot from CASHEM
  - Tips were very informative
  - Really liked the touch screen user interface on the tablet
  - It was good to see all energy components on one interface
  - A game-based approach wherein we were ranked against other participating homes was motivating for us to strive for more energy efficient behavior
  - We will recommend CASHEM to friends and neighbors
  - Set up logistics had a few pain points
  - The manuals for the pool pump were quite hard to understand
- On tips
  - Baseload tips were very informative
  - The language used in the tips was very easy to understand
  - A/C tips to increase set point during HOT summer was not accepted
  - A good frequency for providing tips would be twice a week. It was difficult to keep up with the tips when it was sent once every day
- On the User Interface
  - It is not difficult to find the information using the tablet UI
  - Everything has been pretty user friendly and self-explanatory and never had to use the quick start guide.
- On Trust
  - There is no reason not to trust CASHEM recommendations
  - It seems to be actual factual data based off of actual consumption. It is real-time data
- On Behavior Change
  - CASHEM brought a change (positive) to our lifestyle and energy management

- We altered our actual usage / habits
- One of the home owners mentioned the energy bill has gone down by approximately $50 for the month stating - “My bill for last month was $216 and is usually between $250 and $290”

- On missing CASHEM
  - Like any convenience, grown used to it
  - The biggest incentive with CASHEM is the tips and having feedback on energy consumption and to get reminded periodically that these settings are really helping with your energy consumption.

5.3.3 One-on-one session after post-phase A

- On overall experience
  - Was OK, but we became less aware of our energy management and usage
  - It would be good to have this in the winter months too
- On (lack) of tips
  - We missed the tips; they were so informative
  - We want to continue receiving tips

6 Decision Support System

This section describes the deployment of the algorithms developed to analyze data collected from the HVAC, pool, appliance and metering devices in each home. The section begins with a brief overview of the analytics and a description of the data collected. This description is followed by an overview of the daily energy analysis process, generation of candidate recommendations, and a set of example recommendations generated from the data. The section concludes with an analysis of the user feedback on recommendations collected during the pilot and assessment of recommendation adoption based on the system data.

6.1 Analytics Deployment Overview

Algorithms to process meter data, device consumption data, device history, and external context information provide the intelligence for home energy management. Compact and efficient algorithms, such as the embedded controller on a programmable thermostat, must be developed to fit a relatively light computation footprint. The algorithms that are key to CASHEM had to function with sparse, and potentially asynchronous, data from connected devices.

Algorithm context is derived from disparate data sources and validated from multiple sources. For example, detecting occupancy status was an important CASHEM algorithm derived from multiple sources, including whole building meter data, cues from individual connected devices (such as door openings) that confirm occupancy, thermostat settings, and potentially other sources.

A set of algorithms may infer the opportunity for energy savings after analyzing the acquired data. For example, an active feedback on base load consumption can help the user to uncover appliances/equipment that constantly consume power and suggest ways to reduce usage. In another instance, a specific algorithm can highlight an anomaly between actual HVAC usage and user-programmed settings and assist in taking appropriate actions/recommendations for saving energy. Another example is a load scheduler that considers user preferences, ambient conditions, electricity price information, and appliance/equipment constraints and then deduces a set of schedules for "optimal" home energy performance.

A set of algorithms can provide the feedback explaining ways to limit the energy expenditure to a user-specified monthly limit. In yet another instance, an algorithm can provide the best schedule and operational setpoint for high-energy consuming equipment such as HVAC, pool pump, water heater, etc. The best possible times for running non-essential and schedulable loads are also provided by this module.

6.1.1 Deployed Algorithms

1: Baseload analysis

Base load is the minimum average electrical load over a given period of time present in a home. A high base load indicates energy inefficiency for the building. The analysis of the base load reveals various loopholes in the thermal design of the house and unnecessary loads and provides an opportunity to improve the energy performance of house. The base load estimation and reporting, together with the loads that are responsible for base load, provide an opportunity for the home owner to control unnecessary consumption/wastage of energy. The CASHEM base load is designed to answer the following important questions:

- How much is the base load (day/night)?
- Is it within acceptable limits?
- What caused higher baseload, or how did I reduce the baseload?
- What appliances/loads are operating continuously? What are the most common reasons for higher baseload?
- What is the total base load consumed for the month and associated cost.
- How can I reduce the baseload?

2: Occupancy detection

Energy signature based occupancy detection adds immense value to the CASHEM program; accurate information of home occupancy can be a strong driver for energy conservation. The home occupancy has direct bearing on major loads such as HVAC, water heater and pool-pump. Hence, accurate estimation of occupancy is critical in CASHEM. Additional sensors can be embedded with the CASHEM controller for detecting occupancy; however, we employed a different approach and analyzed the energy signature to detect occupancy. In the algorithm, we attempt successive removal of non-informative load consumption from the whole house energy and then analyze the residual signature for occupancy detection. The typical inferences deduced from this algorithm include:

- Anomalies in user occupancy and thermostat setting
- Energy and dollars wasted due to an anomaly in the thermostat setting and user occupancy
- Expert advice on best thermostat for the user
- Load advice when AWAY and in vacation mode

3: Thermostat analysis

Programmable thermostats facilitate personalization of individual lifestyle and space heating/ cooling needs. They have potential for energy conservation, since they can condition the home or building, only as required. In other words, the space need not be conditioned 24 x 7 and the user can control the operation of the HVAC system for daily routines. A report from McKinsey [Cho09] shows that, while programmable thermostats can achieve a savings of 20% of consumed energy for heating and cooling, improper use of programmable thermostats can reduce or completely eliminate savings. An easy-to-use system can recoup savings and enhance the savings by optimizing programmed schedules to the actual family schedule. Some of the pertinent questions that are relevant for energy conservation are:

- **Is my thermostat schedule OK?** Are thermostats are used daily/routinely to program ‘WAKE,’ ‘AWAY,’’RETURN,’ and ’SLEEP’ modes? Are thermostats used efficiently during business day, weekend, holidays, and vacations?

- **Should I change my set-points to save money? What is the impact of changing set-points? T**hermostat temperature and humidity set points are programmed to energy conservation norms stipulated in ASHRAE standards. Are external weather conditions used optimally for energy conservation?
- How much money and energy could I save by changing my thermostat schedule?
- Is the HVAC usage high?
- Has the outside air used optimally for energy conservation?

The ‘Thermostat Analysis’ routines use a series of data mining and data analysis activities in arriving at the usage efficiency of the thermostat. The method considers many inputs from the thermostat data, including ‘time of day,’ ‘day of week,’ ‘holiday/business day,’ ‘heater set point,’ ‘ambient humidity,’ ‘ambient temperature,’ ‘space temperature,’ ‘space humidity,’ ‘heater temperature set-point,’ ‘cooler temperature set-point,’ ‘heater relay state/states,’ ‘cooler relay state/states.’ The system correlates the outside air conditions and space set points and estimates how to best include outside weather conditions. The system also provides the steps needed to ensure the best possible usage of the environmental conditions.

4: Monthly energy and cost analysis

Monthly energy and cost analysis contains a set of algorithms that interactively provide feedback to the user regarding their consumption. It is an information and advisory tool that provides valuable information regarding the whole house performance along with individual load information. There are many ways this information can be provided, two of them include:

4.1: Monthly energy & cost projection. The total energy spent for the month is critical information that is useful in controlling/limiting energy usage. Monthly energy usage information predicts the month-end power and energy bill.

4.2: Monthly budget planning. Monthly budget planning is closely associated with “monthly energy & cost analysis.” In this analysis, the user inputs a desired amount to spend on electrical energy, which becomes the benchmark for the system to track. The advantage of this approach is that, at any given point in time the user can compare performance with the predetermined dollar threshold. The method also uses the output of the other sub-systems in CASHEM and interactively provides the ways to control the loads to meet the energy and dollar goals.

5: Load disaggregation

Knowing the consumption of individual loads is crucial for conserving load, making it possible to plan the usage of individual loads and monthly budgets. Normally, sub-meters are connected at the load ends to measure the power profile of critical loads. However, additional meters result in higher cost and introduce integration complexity. Hence, innovative concepts and methods infer the individual load consumption based on available data in the house. CASHEM, as the integrator of multiple sources of information can observe many parameters corresponding to different loads along with whole house energy data. We exploit this situation to extract disaggregated information of different loads with lower estimation uncertainty.

6: Energy benchmarking

In CASHEM, Energy benchmarking is attempted at two levels.

> **6.1: Historical benchmarking**. Benchmarking is performed for base load, major loads such as HVAC, pool pump, water heater, etc., monthly energy, and dollars spent, among others. Benchmarking with respect to last month and last year same month are carried out. The user can compare the home's own energy performance and measure the improvement in energy efficiency over time.
>
> **6.2: Comparative benchmark**. This benchmark compares the home owner's energy performance with peers and recommends the energy conservation and dollar saving opportunities.

7: Simulation and what-if analysis engine

Simulation and what-if analysis engine has three requirements:

- To provide periodic detailed reports on "AS-IS" home energy performance.
- To develop models for high energy-consuming equipment/appliances that estimate:
  - Time to complete the scheduled task
  - Corresponding energy consumption
  - Corresponding energy cost
- To provide recommendations for optimal energy performance including appliance/equipment scheduling.

In one instance, the what-if engine deduces the AS-IS process for major equipment, which provides insight about the overall state of major loads. At the next level, the what-if engine provides the 'TO-BE' process, which involves not only the load schedules but also operational parameters such as temperature set points, flow rate, time-to-complete task, modes of operation, etc. This calculation is carried out through extensive home simulation, analyzing all plausible events, and choosing the best possible scenario while keeping in mind the home-owners comfort conditions and financial objectives.

6.2 Data Sources for CASHEM

The CASHEM system integrates the load and energy/source system to infer the "big picture" for the house. Hence, data collection, data synchronization, analysis, inference, and deduction of control actions are critical for algorithm development. Data collection and pre-processing are crucial and play an important role in overall efficacy of CASHEM in achieving its goals. We acquire data from multiple data sources, described below.

1-Whole house electrical data collected through energy meter

The energy meter measures the power consumption in the house (in Watts) with a configurable sampling time (ex: 1 sec). The table below provides the data container for a typical data collected from the energy meter. [Note: julDate = Julian date]

date	julDate	power	homeID
11:30:48 AM	7.350E+05	880	301
11:30:49 AM	7.350E+05	880	301

11:30:50 AM	7.350E+05	880	301
11:30:51 AM	7.350E+05	882	301
11:30:52 AM	7.350E+05	882	301
11:30:53 AM	7.350E+05	882	301
11:30:54 AM	7.350E+05	882	301
11:30:55 AM	7.350E+05	882	301
11:30:56 AM	7.350E+05	884	301
11:30:57 AM	7.350E+05	884	301

2-Diagnostic data set collected from Prestige thermostat installations

Prestige data is collected as a batch (ex: once in a week) for the analysis. This data is integrated with the data from other subsystems in the eco-system for deducing the contexts. The table below explains the relevant parameters obtained from the thermostat.

date	julDate	humAmb	humOAS	tAmb	tOAS	coolSp	heatSp	humSp
6/20/2012 17:54	735040.7	50	77	71.91	72.34	74	70	35
6/20/2012 17:54	735040.7	50	77	71.91	72.34	74	70	35
6/20/2012 17:54	735040.7	50	77	71.91	72.34	74	70	35
6/20/2012 17:55	735040.7	50	77	71.97	72.34	74	70	35
6/20/2012 17:55	735040.7	50	77	71.95	72.34	74	70	35
6/20/2012 17:55	735040.7	50	77	72.02	72.34	74	70	35
6/20/2012 17:56	735040.7	50	77	72	72.34	74	70	35
6/20/2012 17:56	735040.7	50	77	71.98	72.34	74	70	35
6/20/2012 17:56	735040.7	50	77	72.04	72.34	74	70	35
6/20/2012 17:57	735040.7	50	77	72.02	72.34	74	70	35

System Switch	RELAY_ HUM	RELAY_ DHUM	RELAY_ VENT	RELAY_ C1	RELAY _H1	RELAY_ F1	homeID
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301
3	0	0	0	0	0	0	301

The parameters in the table above:

humAmb = Humidity inside the home (in %)
humOAS = Humidity outside home
tAmb = Inside Home Temperature in deg F
tOAS = Outside Home Temperature in deg F
coolSp = Air conditioner temperature setpoint in deg F
heatSp = Heater temperature setpoint in deg F
humSp = Humidity setpoint
SystemSwitch = Mode of the system (Heater, Cooler, Fan)
RELAY_HUM = Humidifier Relay State (0,1)
RELAY_DEHUM= Dehumidifier Relay State (0,1)
RELAY_VENT = Relay State of Vent
RELAY_C1 = Relay State of Cooler (Stage 1)
RELAY_H1 = Relay State of Heater (Stage 1)
RELAY_F1 = Relay State of Fan (Stage 1)

3-Pool Pump Data

This data is collected with a sampling interval of 15 seconds and uploaded to the EC2 data repository.

date	julDate	homeID	Running_Status	Priming_Status	Output_Power
6/20/2012 7:43	735040.3	301	On	Prime_Prim	83
6/20/2012 7:43	735040.3	301	On	Prime_Prim	84
6/20/2012 7:43	735040.3	301	On	Prime_Prim	86
6/20/2012 7:44	735040.3	301	On	Prime_Prim	82
6/20/2012 7:44	735040.3	301	On	Prime_Prim	82
6/20/2012 7:44	735040.3	301	On	Prime_Prim	85
6/20/2012 7:44	735040.3	301	On	Prime_Prim	85
6/20/2012 7:45	735040.3	301	On	Prime_Prim	84
6/20/2012 7:45	735040.3	301	On	Prime_Prim	84
6/20/2012 7:45	735040.3	301	On	Prime_Prim	84

Actual_RPM	Actual_ Flow	Filter_Status	Alarm	Remaining_ Hours	Remaining_ Minutes
750	0	0	NONE	7	43
750	0	0	NONE	7	43
750	0	0	NONE	7	44
750	0	0	NONE	7	44
750	0	0	NONE	7	44
750	0	0	NONE	7	44
750	0	0	NONE	7	45
750	0	0	NONE	7	45
750	0	0	NONE	7	45
750	0	0	NONE	7	45

4-Refrigerator Data

Refrigerator data is collected at one minute intervals and uploaded to the database.
In the table below, the term “RC” = Refrigerator Compartment and “FC” = Freezer Compartment.

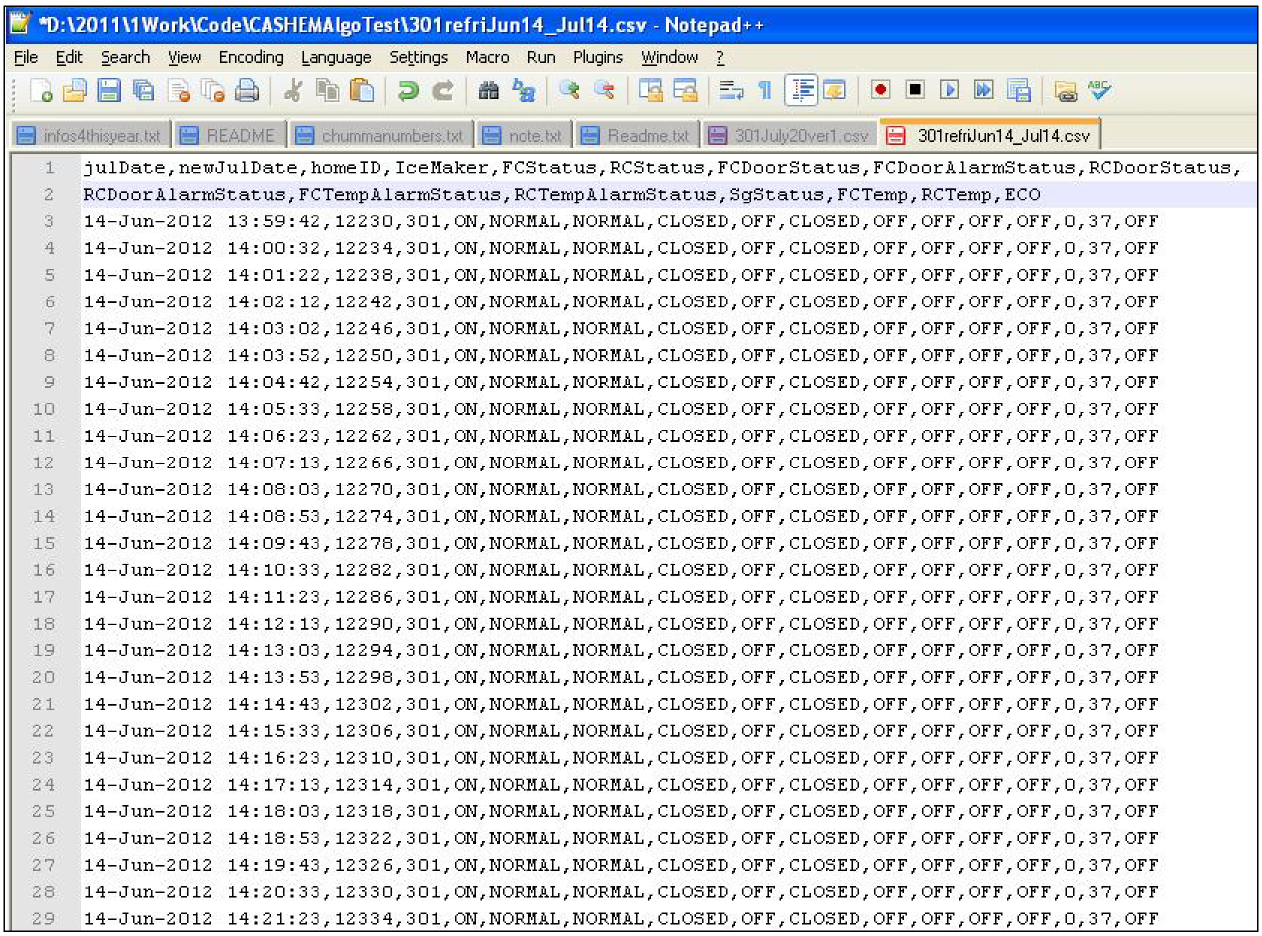
date	julDate	homeID	IceMaker	FCStatus	RCStatus	FCDoorStatus	FCDoorAlarmStatus
6/14/2012 13:59	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:00	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:01	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:02	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:03	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:03	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:04	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:05	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:06	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF
6/14/2012 14:07	735034.6	301	ON	NORMAL	NORMAL	CLOSED	OFF

RCDoorStatus	RCDoorAlarmStatus	FCTempAlarmStatus	RCTempAlarmStatus	SgStatus	FCTemp	RCTemp	ECO
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF
CLOSED	OFF	OFF	OFF	OFF	0	37	OFF

6.3 Recommendation Generation and Updating framework

Data preparation for the analysis

As mentioned earlier, the CASHEM system for each home acquires data from the energy meter, Prestige thermostat, pool pump, and refrigerator. Preparing the data container that best performs basic data mining tasks is critical for practical data analysis work. The input data is textual (a comma separated file), and automating the process of cleaning and transforming the textual information to an easy-to-handle data container is carried out. A snippet of the textual data dump from the Amazon EC2 server is shown in Figure 37.




```
julDate,newJulDate,homeID,IceMaker,FCStatus,RCStatus,FCDoorStatus,FCDoorAlarmStatus,RCDoorStatus,
RCDoorAlarmStatus,FCTempAlarmStatus,RCTempAlarmStatus,SgStatus,FCTemp,RCTemp,ECO
14-Jun-2012 13:59:42,12230,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:00:32,12234,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:01:22,12238,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:02:12,12242,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:03:02,12246,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:03:52,12250,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:04:42,12254,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:05:33,12258,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:06:23,12262,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:07:13,12266,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:08:03,12270,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:08:53,12274,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:09:43,12278,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:10:33,12282,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:11:23,12286,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:12:13,12290,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:13:03,12294,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:13:53,12298,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:14:43,12302,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:15:33,12306,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:16:23,12310,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:17:13,12314,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:18:03,12318,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:18:53,12322,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:19:43,12326,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:20:33,12330,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
14-Jun-2012 14:21:23,12334,301,ON,NORMAL,NORMAL,CLOSED,OFF,CLOSED,OFF,OFF,OFF,OFF,0,37,OFF
```

Figure 37. Raw Text data downloaded from EC2 server

The user needs to receive actionable intelligence to help save energy and dollars; data integration plays a critical role in this endeavor. To deliver actionable intelligence meant having the integrated data in one place, the ability to slice and dice data according to the access requirements, and the data in a format to define context and conditions. In other words, we needed data containers that can append the data streams as and when acquired and provide a unified data structure (or master data container) for further data indexing. In our approach, we maintain a master data container for each of sub-system in

CASHEM eco-system and use time novel indexing techniques to integrate the information as and when required. Some of the analytics routines necessitate synchronization of the data; we carry out this task as and when required.

After obtaining the data dump, we process, clean, and compress the data and index the data as per the ‘datetime’ class to make sure that data samples are not repeated in master data container. Also, we categorize/factorize the data as per ‘home identification’ and ‘asset identification,’ which will help us in arriving at contexts.

One issue faced in data cleaning was repetitive data samples in the text data dumps, which needs to be taken care during updation of the master data container. The overall steps in data cleaning and generating the master dataset are given below:

1. Scan the text file and initiate/define the data structure for the sub-system data (‘temp’ container)
2. Process each line of text and extract the data entries and continue till end of file
3. Process the date and insert ‘date-time’ entries and update data container with its numeric equivalent.
4. Process missing data and outliers and substitute with appropriate estimates.
5. Load master data set (last row) and index the ‘temp’ data container based on ‘datetime’ attribute.
6. Append the master data container with the new dataset.

These steps are repeated for all the test data dumps obtained from individual sub-systems and repeated once in a day. In other words, data downloading, cleaning and running of the analytics is done once in a day. However, there is one exception for thermostat data. Thermostat data is uploaded to the common share area by the home-owner at a frequency of once in a week. Hence, this data is processed weekly and thermostat master dataset is updated weekly.

6.3.1 High-level Overview of Daily Energy Analysis

As indicated in previous section, thermostat data is acquired once in a week and hence this analysis is performed as and when the data is acquired. The other datasets are continuously updated to EC2 database and hence, we undertake this analysis once a day. The master dataset stored in the local computer is used for the analysis routines. The high level steps involved in energy analytics is given below:

1. Load the virtual master datasets as memory mapped files (Memory Virtualization)
2. For a given day, index the necessary data and load TED energy meter, Prestige thermostat, and Pool pump and Refrigerator datasets to main memory.
3. Synchronize TED and thermostat data.
4. Synchronize Pool pump and TED data if possible (This step is optional)
5. Perform iterative visualization of the data and detect events and exceptions if any.
6. Execute baseload analysis algorithm
7. Execute load disaggregation methods and sequentially estimate the wattage and energy consumption of different loads

8. Obtain residual energy signal and detect the occupancy based on residual energy signal
9. Perform user set-point mining for thermostat data.
10. Correlate user occupancy with thermostat program and enumerate the thermostat programming efficiency.
11. Perform energy benchmarking and consumption prediction routines.
12. Run What-IF simulations as and when required
13. Generate recommendations based on the analytics and upload the recommendations as and when required.

6.3.2 Recommendations Generation and User Feedback Analysis

In this section we provide samples of the recommendations given to the home owners and list the analytics routines used to generate these recommendations. The recommendations were generally formulated as 'cause and effect,' wherein observations and inferences were listed with their effect on energy and dollar consumption along and the possible reduction in energy if the recommendations were followed. We list the unique recommendations sent to a user along with the home owner's response to those recommendations. Recommendations were given to five different homes and one Honeywell lab location. The Honeywell lab was used for testing the recommendation content and display in the Kindle device, which was provided to the home owners.

In total, CASHEM delivered 22 recommendations between 20 July 2012 and 14 September 2012. Generic recommendations were sent twice a week on Tuesdays and Fridays and the response of the home owner was analyzed.

We also conducted a second set of experiments wherein we benchmarked the base load of the user and ranked them using the benchmark and provided the information as a competition exercise. We studied the home owner's behavior change under this scenario. In this experiment, we provided three recommendations in a week (on Monday, Wednesday, and Friday). The content of the recommendations were similar, but the baseload numbers and the rankings were altered according to the home owner's performance. Some of the unique recommendations and users' feedback are provided below. At the end of this section, we describe the users' behavior change and the possible effect of the recommendation on daily energy management activities.

Recommendation Example 1 – Thermostat Data Analysis

Recommendation for July 20 2012

You can save as much as $16 on your energy bill if you follow energy star recommended thermostat temperature settings as suggested below:

"WAKE = 75F, AWAY = 85F, RETURN = 78F, SLEEP = 82F. "

"To minimize the energy wastage, I also recommend you to set the thermostat to AWAY mode, when home is unoccupied."

This is based on my following observations:

A. 98% of the time you have set your setpoint to 74 degree or less.

B. Currently HVAC is the biggest energy guzzler at your home.

C. Energy consumption for HVAC so far in this billing cycle was 705 KWH which translates to 46% of the total energy. The dollar equivalent of this energy is $80 (excluding the minimum charges of 9.5$ and state tax).

D. I am predicting that this month your electricity bill will be in the vicinity of $180 of which $85 may be spent on air conditioning.

It may be very difficult to balance the comfort and savings during this hot summer. So I am analyzing your thermostat program and will provide you my suggestions soon.

This recommendation was based on load disaggregation, HVAC setpoint mining, and ‘monthly energy prediction’ based algorithms. Home owners responded to the recommendations as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	20-Jul-12	Thermostat	LIKE	7/31/2012 17:40
302	20-Jul-12	Thermostat	DISLIKE	7/24/2012 22:30
303	20-Jul-12	Thermostat	NULL	NA
304	20-Jul-12	Thermostat	LIKE	7/21/2012 10:37
305	20-Jul-12	Thermostat	NULL	NA

Recommendation Example 2 – Thermostat Data Analysis

Recommendation for July 24 2012

You can minimize your spending on Air-conditioning when your home is unoccupied while not affecting your comfort by simply setting the thermostat to 'AWAY' mode.

I have attempted to estimate the total number of hours the home was kept in 'COMFORT' conditions and probably unoccupied. I have done this to explore the avenues for dollar saving without compromising on comfort level. I have made the following observations/analysis based on your energy usage pattern over the last 15 days.

(A) You have set your thermostat to operate at 74F irrespective of weekdays or weekends.

(B) My estimates show in the last 15 days, the house was unoccupied approximately for 30 hours. However, the air-conditioning was still running to cater to comfort conditions costing you more electricity that could have potentially been saved.

(C) In the last 15 days you have spent $26 on HVAC energy.

(D) My estimates show you could have saved $4 over 15 day period by setting the thermostat to 'AWAY' mode when the house was unoccupied.

As you may be aware, programming the thermostat as per actual schedule has large potential to save electrical energy. I am analyzing more patterns from your home and I will recommend the best thermostat schedule for you after analyzing them.

This recommendation was based on 'occupancy detection,' 'load disaggregation,' 'HVAC setpoint mining,' and 'monthly energy prediction' based algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	24-Jul-12	Thermostat	DISLIKE	2012-07-31 17:39:19
302	24-Jul-12	Thermostat	LIKE	2012-07-24 22:30:08
303	24-Jul-12	Thermostat	NULL	NA
304	24-Jul-12	Thermostat	NULL	NA
305	24-Jul-12	Thermostat	NULL	NA

Recommendation Example 3 – Baseload Analysis

Recommendation for July 27 2012

So far in July, you have spent $56 on loads that are 'ON' 24 hours per day; equivalent to 0.25 Watts/ft^2, which is relatively low among CASHEM homes. Here is what other CASHEM homes are spending on base loads:

$65, $113, $50, $65. Other CASHEM homes like yours spent $86 on baseload. So, you are doing relatively well.

You can save money by checking for devices that can be shut off or unplugged until you are ready to use them.

Computers and game consoles usually have settings to minimize power. Are all of your devices in a minimum power mode?

The above recommendation was based on 'baseload estimation,' 'load disaggregation,' and 'energy benchmarking' based algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	27-Jul-12	Baseload	LIKE	2012-07-31 17:39:05
302	27-Jul-12	Baseload	LIKE	2012-08-06 08:15:12
303	27-Jul-12	Baseload	LIKE	2012-08-14 08:29:52
304	27-Jul-12	Baseload	NULL	NA
305	27-Jul-12	Baseload	LIKE	2012-08-02 19:10:26

Recommendation Example 4 – "Refrigerator Data Analysis"

Recommendation for July 31 2012

Sample 1

Your refrigerator ice maker is ON continuously, which consumes as much as twice the energy required.

I have observed that your refrigerator has been on ECO mode from 20th July onwards. You are doing a good job by keeping your refrigerator on ECO mode, which conserves energy while retaining food quality.

Sample 2

I have observed a few anomalies in your refrigerator since July 25.

This month the refrigerator ice maker status was mostly ON, but for the past two days it has been OFF. When the ice maker is in ON mode, the refrigerator consumes as much as twice the energy required.

Your refrigerator is not using its full energy conservation capabilities. You can set it to ECO mode to conserve more energy while retaining the food quality.

Sample 3

Your refrigerator ice maker is ON continuously, which consumes as much as twice the energy required.

Your refrigerator has never been set to ECO mode. You can set it to ECO mode to conserve more energy while retaining the food quality.

The above recommendation was based on 'Refrigerator data analysis.' Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	31-Jul-12	Refrigerator	DISLIKE	2012-07-31 17:38:06
302	31-Jul-12	Refrigerator	NULL	NA
303	31-Jul-12	Refrigerator	LIKE	2012-08-14 08:23:49
304	31-Jul-12	Refrigerator	LIKE	2012-08-01 07:38:06
305	31-Jul-12	Refrigerator	LIKE	2012-08-02 19:10:35

Recommendation Example 5 – "Whole House Energy Analysis"

Recommendation for August 3 2012

Sample 1

You spent about 1700 KWh of energy between 19 June and 18 July. The corresponding KWH charge is $202.

Your total electricity bill, including the taxes is about $233. Similar CASHEM homes spent $339 this month.

You are doing relatively well!

Sample 2

You spent about 2876 KWh of energy between 26 June and 25 July. The corresponding KWH charge is $335.

Your total electricity bill, including the taxes, is about $386. Similar CASHEM homes spent $259 this month.

Your home energy consumption is relatively high.

The above recommendation was based on 'Monthly Energy Analysis,' and 'Energy Benchmarking'. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	3-Aug-12	Home Energy	LIKE	2012-08-09 07:10:48
302	3-Aug-12	Home Energy	LIKE	2012-08-03 19:04:18
303	3-Aug-12	Home Energy	LIKE	2012-08-14 08:24:18
304	3-Aug-12	Home Energy	LIKE	2012-08-06 21:55:46
305	3-Aug-12	Home Energy	LIKE	2012-08-07 20:25:37

Recommendation Example 6 – "WHAT-IF Simulation"

Recommendation for August 7 2012

Sample 1

I checked your thermostat schedule for a typical day in July.

You spent about $2.83 on cooling during a typical day this July. Your programmable thermostat is saving you about $66/month by adjusting the temperature throughout the day.

If you would like to save more, you can raise the temperature by 2 degrees and save an additional $26 per month.

Sample 2

I checked your thermostat schedule for a typical day in July.

You spent about 21 KWH on cooling during a typical day this July. If you would like to save more, you can raise the temperature by 2 degrees and save an additional 227KWH/month.

The above recommendation was based on 'What-If Analysis' and 'Load Disaggregation'. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	7-Aug-12	What-If Analysis	LIKE	2012-08-09 07:10:31
302	7-Aug-12	What-If Analysis	LIKE	2012-08-07 17:25:20
303	7-Aug-12	What-If Analysis	LIKE	2012-08-14 08:24:47
304	7-Aug-12	What-If Analysis	LIKE	2012-08-08 06:50:51
305	7-Aug-12	What-If Analysis	LIKE	2012-08-07 20:25:33

Recommendation Example 7 – Pool pump analysis

Recommendation for August 10 2012

Sample 1

I analyzed the performance of your pool pump for the past two weeks. Your pool pump is consuming 68% more energy compared to the energy it consumed at the beginning of August. Your filters may be dirty and may need a backwash.

Dirty filters can consume as much as double the energy compared to clean filters.

I also observed that in the beginning of this month, you adjusted your pool pump to run continuously throughout the day.

You have subscribed to off-peak period tariff and can save considerable dollars if you schedule the pool pump to operate during off-peak periods.

You have kept your flow rate to 43 Gallons/minute, which is sufficient to cycle 60000 Gallons of water/day. However, if you adjust the flow rate to the pool size, you can save more money. I recommend that you contact the local Pentair representative to program your pool pump more efficiently.

Sample 2

I checked your thermostat schedule for a typical day in July.

You spent about 21 KWH on cooling during a typical day this July. If you would like to save more, you can raise the temperature by 2 degrees and save an additional 227KWH/month.

The above recommendation was based on 'What-If Analysis' and 'Load Disaggregation.' Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	10-Aug-12	Pool pump	LIKE	2012-08-13 16:51:11
302	10-Aug-12	Pool pump	NULL	NA
303	10-Aug-12	Pool pump	LIKE	2012-08-14 08:22:34
304	10-Aug-12	Pool pump	NULL	NA
305	10-Aug-12	Pool pump	LIKE	2012-08-15 20:38:36

Recommendation Example 8 – "Refrigerator Recommendation"

Recommendation for August 14 2012

Sample 1

> Your refrigerator's energy cost was approximately $4.50 for the past month, which is 11% more than the average CASHEM home owner.
>
> Your ice maker is ON continuously, which is responsible for the relative increase in energy consumption. If you had set ECO mode for this past month, you would have spent about $3.05. ECO mode consumes the least energy.
>
> Keeping refrigerator and freezer doors open increases energy consumption.
>
> My analysis shows that you are doing a fairly good job of containing refrigerator energy costs. Recent studies show that poor open/close habits cost 10%–24% more energy.

Sample 2

> Your refrigerator's energy cost was approximately $3.20 for the past month. Compared to other CASHEM home owners, it consumed the least energy. Your ice maker is never switched ON, which may be a reason for lower energy consumption.
>
> If you had set ECO mode for this past month, you would have spent about $3.05. ECO mode consumes the least energy. Keeping refrigerator and freezer doors open increases energy consumption.
>
> My analysis shows that you are doing a fairly good job of containing refrigerator energy costs. Recent studies show that poor open/close habits cost 10%–24% more energy.

The above recommendation was based on 'Load Disaggregation' and 'Refrigerator Analysis.' Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	14-Aug-12	Pool pump	LIKE	2012-08-16 08:00:19
302	14-Aug-12	Pool pump	LIKE	2012-08-14 17:53:59
303	14-Aug-12	Pool pump	LIKE	2012-08-15 07:45:01
304	14-Aug-12	Pool pump	LIKE	2012-08-16 20:05:33
305	14-Aug-12	Pool pump	LIKE	2012-08-15 20:39:16

Recommendation Example 9 – "HVAC Usage Feedback"

Recommendation for August 17 2012

Sample 1

I observed that you adjusted your thermostat schedule from July 21 onwards to optimize HVAC energy consumption.

To understand the effect of your new settings, I compared the kWh spent to maintain comfort conditions when the outside temperature exceeded 75F. In the new setting, your HVAC system spent only 0.7 kWh compared to 1.5 kWh for a similar earlier period.

In this billing cycle (19 July to 18 August), the total HVAC energy consumption was about 400 kWh ($45), which comes to about 700 kWh ($79) for the last billing cycle. The reduction in ambient temperature and your current thermostat settings have definitely lowered HVAC energy consumption.

Sample 2

In this billing cycle (26 July to 25 August), your HVAC energy consumption for the first week was 158 KWH ($18).

The total HVAC energy consumption for the last billing cycle was 824 kWh ($94). I predict that this month's HVAC consumption will be about 450 kWh ($50). The lower HVAC energy consumption for this month can be attributed to lower ambient temperatures.

Sample 3

In this billing cycle (22 July to 21 August), your HVAC energy consumption for the first ten days was 190 kWh.

The total HVAC energy consumption for the last billing cycle was 653 kWh. I predict that this month's HVAC consumption will be about 400 kWh. The lower HVAC energy consumption for this month can be attributed to lower ambient temperatures.

The above recommendation was based on 'HVAC Data Mining,' 'load disaggregation,' and 'monthly energy analytics' algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	17-Aug-12	HVAC	LIKE	2012-08-22 20:07:35
302	17-Aug-12	HVAC	LIKE	2012-08-17 17:29:34
303	17-Aug-12	HVAC	NULL	NA
304	17-Aug-12	HVAC	LIKE	2012-08-19 11:41:44
305	17-Aug-12	HVAC	NULL	NA

Recommendation Example 10 – "Baseload Benchmarking"

Recommendation for August 21 2012

Sample 1

You are spending $54/month on loads that are ON 24 hours per day, and you spent $56 last month.

You are spending 0.21 Watts/ ft^2— average consumption for other CASHEM homes is 0.28Watts/ ft^2.

The lowest reported consumption was 0.18Watt/ ft^2. Your home is performing close to that.

Other CASHEM homes are spending approximately $50, $91, $43, $79. You are doing relatively well.

You can save money by checking for devices that can be shut off or unplugged until you are ready to use them.

Computers and game consoles usually have settings to minimize power. Are all of your devices in a minimum power mode?

Sample 2

You are spending $43/month on loads that are ON 24 hours per day, and you spent $50 last month.

You are spending 0.18 Watts/ ft^2— average consumption for other CASHEM homes is 0.28Watts/ ft^2.

Your home is the most efficient CASHEM home, spending the minimum power/ft^2.

Other CASHEM homes are spending approximately $50, $91, $91, $79 on baseload and you are doing very well.

Sample 3

You are spending 0.37 Watts/ft^2 on loads that are ON 24 hours per day, and you spent 0.35 Watts/ft^2 last month.

The lowest consumption reported for a CASHEM home was 0.18Watt/ft^2 —your consumption is relatively higher than average.

You can save money by checking for devices that can be shut off or unplugged until you are ready to use them.

Computers and game consoles usually have settings to minimize power. Are all of your devices in a minimum power mode?

The above recommendation was based on 'Baseload Analysis' and 'Energy Benchmarking' algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	21-Aug-12	HVAC	LIKE	2012-08-22 20:07:56
302	21-Aug-12	HVAC	LIKE	2012-08-23 15:10:24
303	21-Aug-12	HVAC	NULL	NA
304	21-Aug-12	HVAC	LIKE	2012-08-21 21:17:42
305	21-Aug-12	HVAC	LIKE	2012-08-22 20:48:36

Recommendation Example 11 – "Occupancy Analysis & Thermostat Programming Analysis"

Recommendation for August 24 2012

Sample 1

I analyzed recent thermostat programming patterns for your home and observed the following:

- Overall, you are doing great and your air-conditioner energy consumption has been reduced by 43% compared to the previous month. In comparison with last month, you are saving more dollars by setting the thermostat in energy conservation mode.
- You are largely following one set of schedules for working days and another for non-working days and they are largely unaltered. I believe that you further conserve energy by keeping the thermostat in AWAY mode when house is not occupied.
- My analysis suggests that you were largely away from home on the weekends (5, 6, 7, 11, and 12 of August) and the air-conditioner was working hard to maintain the comfort conditions. Programming the thermostat to actual schedule is a good practice and has a large potential to save electrical energy.

Sample 2

I analyzed the recent thermostat programming patterns for your home and observed the following:

- Overall, you are doing a great job and your air conditioner energy consumption was reduced by 45% compared to the previous month. In comparison with last month, you are saving more dollars by setting the thermostat in energy conservation mode as prescribed by Energy Star.
- You followed the Energy Star recommended settings for the past two weeks, which has reduced HVAC energy consumption considerably. My analysis suggests that you have spent as little as $2 on air conditioning in the past two weeks.
- I also observed that you have been following a static schedule recently. Dynamic scheduling of thermostat based on the occupancy is a good practice and has a large potential to save electrical energy.

Sample 3

I analyzed recent thermostat programming patterns for your home and observed the following:

- Overall, you are doing great and your air conditioner energy consumption was reduced by 40% compared to the previous month. You are dynamically changing the thermostat schedule according to real occupancy.
- My analysis suggests that you were on vacation from August 17 to 19 and you set the thermostat on energy conservation mode. However, there was a constant base load of approximately 600 Watts while you were AWAY, which cost you $3.5. It is a good idea to detect loads that are ON 24x7.

Sample 4

I analyzed recent thermostat programming patterns for your home and observed the following:

- Overall, you are doing great and your air conditioner energy consumption was reduced by 67% compared to the previous month. You are dynamically changing the thermostat schedule according to real occupancy.
- For the past two weeks, you set the thermostat to 78F when AWAY from home. This is a good setting for energy conservation. My analysis suggests that you were on vacation from August 4 to 6 and you set the thermostat on energy conservation mode. However, there was a constant base load of approximately 1300 Watts while you were AWAY, which cost you 63 KWH (approximately $4).
- It is a good idea to detect the loads that are ON 24x7.

The above recommendation was based on 'Occupancy Analysis' and 'Thermostat Data Mining' algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	24-Aug-12	HVAC	LIKE	2012-08-27 06:40:26
302	24-Aug-12	HVAC	LIKE	2012-08-28 13:08:56
303	24-Aug-12	HVAC	NULL	NA
304	24-Aug-12	HVAC	NULL	NA
305	24-Aug-12	HVAC	NULL	NA

Generic Recommendations

We also provided generic tips to the home owner to help further minimize energy consumption. These tips are described in ‘Energy Conservation’ literature provided to the home owner keeping the CASHEM eco-system in mind. Some samples of these recommendations and the associated user feedback are listed below.

Example 12

Recommendation for August 31 2012

You can transform your efficient refrigerator into a green refrigerator!

- Based on refrigerator energy consumption, you have been ranked fifth amongst CASHEM home owners. Here are some tips that may help you minimize the energy consumption:
- Keep the door seals and coils clean.
- Raise the freezer temperature up to 3F (It is set to zero).
- Switch to ECO mode to minimize frost build-up.
- It is ideal to place the refrigerator in a cool place in the house. A refrigerator can consume 61% more energy in a 90 F environment than a 70F environment.

The above recommendation was based on ‘Occupancy Analysis’ and ‘Thermostat Data Mining’ algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	24-Aug-12	HVAC	LIKE	2012-08-27 06:40:26
302	24-Aug-12	HVAC	LIKE	2012-08-28 13:08:56
303	24-Aug-12	HVAC	NULL	NA
304	24-Aug-12	HVAC	NULL	NA
305	24-Aug-12	HVAC	NULL	NA

Example 13

> **Recommendation for September 4 2012**
>
> A whopping 90% of the energy used for washing clothes often gets used just to heat the water! You can save as much as $150 per year just by changing the laundry temperature settings.
>
> Your washing machine may have multiple wash-rinse cycles that consume different levels of energy.
>
> A comparative study revealed that a hot (wash)-warm (rinse) cycle consumes as much as 4.5 kWh per wash compared. A cold-cold cycle consumed an average of 0.3 kWh; a fifteen fold lower energy consumption. The other wash-rinse settings such as warm-warm, hot-cold and warm-cold consumed approximately 3.5 kWh, 2.8 kWh and 1.9 kWh respectively.
>
> Most washing machines leave far too much water in the clothes, making the dryer run much longer. You can use an additional spin cycle in the washer to extract water from your clothes before drying.

The above recommendation was based on 'Occupancy Analysis' and 'Thermostat Data Mining' algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	24-Aug-12	HVAC	LIKE	2012-08-27 06:40:26
302	24-Aug-12	HVAC	LIKE	2012-08-28 13:08:56
303	24-Aug-12	HVAC	NULL	NA
304	24-Aug-12	HVAC	NULL	NA
305	24-Aug-12	HVAC	NULL	NA

Example 14

> **Recommendation for September 4 2012**
>
> The dish washer is a dominant energy guzzler in your home. Here are tips to reduce its energy consumption.
>
> - It is better to scrape the dishes rather than rinsing, which will save water and the energy required to heat the water.
> - The dishwasher energy savings can be maximized when the dishwasher is full. It is expensive to run the dishwasher half-empty.
> - Your dishwasher may have energy saving features. Please use them. Try to avoid features like heat-dry, rinse-hold, and pre-rinse.

The above recommendation was based on 'Occupancy Analysis' and 'Thermostat Data Mining' algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	24-Aug-12	HVAC	LIKE	2012-08-27 06:40:26
302	24-Aug-12	HVAC	LIKE	2012-08-28 13:08:56
303	24-Aug-12	HVAC	NULL	NA
304	24-Aug-12	HVAC	NULL	NA
305	24-Aug-12	HVAC	NULL	NA

Example 15

Recommendation for September 4 2012

The traditional incandescent light bulbs waste 90% of its energy to create heat—only 10% is actually used to create light! This heat is also responsible for increased energy consumption of the air conditioner. Switch to compact fluorescent light (CFL) bulbs and save 75% of the energy you'd use.

LED holiday lights use up to 90% less energy than traditional incandescent bulbs to produce the same amount of holiday sparkle. Look for LED lights this holiday season and save energy while you celebrate!

Other easy ways to save money on lighting include putting lights on timers or motion sensors and just being more diligent about turning off lights you're not using. A single 100-watt bulb left on continuously will cost you $9 a month.

The above recommendation was based on 'Occupancy Analysis' and 'Thermostat Data Mining' algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	24-Aug-12	HVAC	LIKE	2012-08-27 06:40:26
302	24-Aug-12	HVAC	LIKE	2012-08-28 13:08:56
303	24-Aug-12	HVAC	NULL	NA
304	24-Aug-12	HVAC	NULL	NA
305	24-Aug-12	HVAC	NULL	NA

Example 16

> **Recommendation for September 4 2012**
>
> On behalf of the field study team, we would like to thank you for your participation in this study. This study would not have been possible without your help and support. In the next phase, starting from tomorrow, September 15th, you will not be receiving any tips on energy management. We will send you more details via email.
>
> The study will end on October 15th . Please expect a detailed energy report of your house in few days.

The above recommendation was based on 'Occupancy Analysis' and 'Thermostat Data Mining' algorithms.

Home ID	Reco Date	Reco Category	Like/Dislike	Feedback Time
301	24-Aug-12	HVAC	LIKE	2012-08-27 06:40:26
302	24-Aug-12	HVAC	LIKE	2012-08-28 13:08:56
303	24-Aug-12	HVAC	NULL	NA
304	24-Aug-12	HVAC	NULL	NA
305	24-Aug-12	HVAC	NULL	NA

Competition Based Recommendation

Near the end of recommendation exercise, we provided 'competition based recommendations' to encourage home owners to work further on energy conservation. We decided to use baseload consumption ranking and provided ways to reduce the baseload energy. This recommendation was provided three times a week on predetermined days of week, and user response was observed. A sample of such recommendation was provided here. We provided a total of six recommendations under this category; one sample is shown here.

Example 17

Recommendation for August 28 2012

We are nearing the completion of this experiment phase. You are ranked first among the homeowners participating in this exercise based on energy/ft^2 consumption, which is 0.32 KWH/ft^2. The immediate next contender is drawing 0.37 KWH/ft^2 and slowly catching up with you.

Your pool pump is responsible for only 15% of the total energy consumption for this month. However, your pool pump did not operate as expected for the past one week. It is mostly switched off and your pool is not getting cleaned in this set up. Is this an intentional setting? If not please contact the Pentair representatives.

You are spending 0.21 Watts/ft^2 on loads that are ON 24 Hours a day. This is one of the lowest and you are doing very well.

The only suggestion I have for you is to dynamically set the thermostat to AWAY mode, which may save further energy. Overall you are home is the greenest among the homes in the CASHEM experiment.

Sample 2

We are nearing the completion of this experiment phase. You are ranked five among the homeowners participating in this exercise based on energy/ft^2 consumption. Your consumption is 0.50 KWH/ft^2. The best home is consuming 0.32 KWH/ft^2, which is 36% lower.

Your pool pump is responsible for only 20% of the total energy consumption for this month, which is reasonably good.

You are spending 0.32 Watts/ft^2 on loads that are ON 24 Hours a day. This is relatively high and there is scope for optimization.

Typically lighting is the third largest energy guzzler in US homes. A single 100-watt bulb left on continuously will be responsible for $9 a month. Turn off lights when you are not using them, even for just few minutes. Use the lowest-wattage bulbs for lights that are always on. Use LED or CFL lamps instead of traditional incandescent lights.

You have been following a static thermostat schedule recently. Dynamic thermostat scheduling based on occupancy is a good practice and has large potential to save electrical energy.

In the next few days, I will provide generic tips that may help you to reduce energy consumption.

Sample 3

We are nearing the completion of this experiment phase, and overall you are ranked second among the homeowners participating in this exercise based on energy/ft^2 consumption. Your consumption is 0.37 KWH/ft^2; the best home is consuming 0.32 KWH/ft^2.

Your pool pump is responsible for a whopping 60% of your total energy consumption for this month, which is extremely high. If this is controlled, your home may soon become the greenest home among CASHEM home owners.

Typically, lighting is the third largest energy guzzler in US homes. A single 100-watt bulb left on continuously will be responsible for $9 a month.

Turn off lights when you are not using them, even for just few minutes. Use the lowest-wattage bulbs for lights that are always on. Use LED or CFL lamps instead of traditional incandescent lights.

In next few days, I will provide more tips that may help you to reduce energy consumption.

This recommendation was based on 'Occupancy Analysis' and 'Thermostat Data Mining' algorithms. Home owners responded to the recommendation as shown in the consolidated list below:

Home ID	Reco Date	Reco Category	Likes/Dislike/NULL	Feedback Time
301	24-Aug-12	HVAC	LIKE	2012-08-27 06:40:26
302	24-Aug-12	HVAC	LIKE	2012-08-28 13:08:56
303	24-Aug-12	HVAC	NULL	NA
304	24-Aug-12	HVAC	NULL	NA
305	24-Aug-12	HVAC	NULL	NA

6.4 Feedback Analysis

In this section, we summarize user interaction with the CASHEM eco-system. As a first step, we describe how individual users liked the recommendations. Later in the section, we give the details of the user responses to specific recommendations and the associated behavior change.

Home owner ‘301’ has interacted extensively with the CASHEM eco-system and responded to the recommendations positively. The parameter ‘TimeLagDays’ represent the elapsed time between the recommendation date and actual feedback provided by the user.

homeID	recoDate	recoType	feedback	feedbackTime	TimeLagDays
301	9/14/2012 0:00	energy	like	9/18/2012 17:37	4
301	9/14/2012 0:00	Energy	like	9/18/2012 17:37	4
301	9/12/2012 0:00	Energy	like	9/18/2012 17:37	6
301	9/11/2012 0:00	lighting	null	9/18/2012 17:37	7
301	9/10/2012 0:00	Energy	like	9/18/2012 17:37	8
301	9/7/2012 0:00	dishwasher	like	9/18/2012 17:38	11
301	9/7/2012 0:00	Energy	like	9/18/2012 17:38	11
301	9/5/2012 0:00	Energy	like	9/5/2012 17:31	0
301	9/4/2012 0:00	Energy	like	9/5/2012 17:31	1
301	8/31/2012 0:00	refrigerator	dislike	9/3/2012 7:36	3
301	8/28/2012 0:00	home	like	8/30/2012 18:39	2
301	8/24/2012 0:00	thermostat	like	8/27/2012 6:40	3
301	8/21/2012 0:00	baseload	like	8/22/2012 20:07	1
301	8/17/2012 0:00	Thermostat	like	8/22/2012 20:07	5
301	8/14/2012 0:00	refrigerator	like	8/16/2012 8:00	2
301	8/10/2012 0:00	My pool pump	like	8/13/2012 16:51	3
301	8/7/2012 0:00	thermostat	like	8/9/2012 7:10	2
301	8/3/2012 0:00	home	like	8/9/2012 7:10	6
301	7/31/2012 0:00	Refrigerator	dislike	7/31/2012 17:38	0
301	7/27/2012 0:00	baseload	like	7/31/2012 17:39	4
301	7/24/2012 0:00	thermostat	dislike	7/31/2012 17:39	7
301	7/20/2012 0:00	thermostat	like	7/31/2012 17:40	11
301	7/17/2012 0:00	home	like	7/20/2012 17:12	3

homeID	recoDate	recoType	feedback	feedbackTime	TimeLagDays
302	9/14/2012 0:00	Energy	like	9/18/2012 7:00	4
302	9/12/2012 0:00	Energy	null	9/12/2012 17:42	0
302	9/11/2012 0:00	lighting	like	9/11/2012 17:50	0
302	9/10/2012 0:00	Energy	like	9/11/2012 17:50	1
302	9/7/2012 0:00	dishwasher	like	9/10/2012 8:37	3
302	9/7/2012 0:00	Energy	like	9/10/2012 8:38	3
302	9/5/2012 0:00	Energy	like	9/10/2012 8:38	5
302	9/4/2012 0:00	Energy	like	9/4/2012 21:01	0
302	8/31/2012 0:00	refrigerator	like	9/4/2012 21:00	4
302	8/28/2012 0:00	home	like	8/29/2012 20:54	1
302	8/24/2012 0:00	thermostat	like	8/28/2012 13:08	4
302	8/21/2012 0:00	baseload	like	8/23/2012 15:10	2
302	8/17/2012 0:00	Thermostat	like	8/17/2012 17:29	0
302	8/14/2012 0:00	refrigerator	like	8/14/2012 17:53	0
302	8/7/2012 0:00	thermostat	like	8/7/2012 17:25	0
302	8/3/2012 0:00	home	like	8/3/2012 19:04	0
302	7/27/2012 0:00	baseload	like	8/6/2012 8:15	10
302	7/24/2012 0:00	thermostat	like	7/24/2012 22:30	0
302	7/20/2012 0:00	thermostat	dislike	7/24/2012 22:30	4

homeID	recoDate	recoType	feedback	feedbackTime	TimeLagDays
303	9/11/2012 0:00	lighting	like	9/12/2012 21:03	1
303	8/14/2012 0:00	refrigerator	like	8/15/2012 7:45	1
303	8/10/2012 0:00	pool pump	like	8/14/2012 8:22	4
303	8/7/2012 0:00	thermostat	like	8/14/2012 8:24	7
303	8/3/2012 0:00	home	like	8/14/2012 8:24	11
303	7/31/2012 0:00	Refrigerator	like	8/14/2012 8:23	14
303	7/27/2012 0:00	baseload	like	8/14/2012 8:29	18
303	7/17/2012 0:00	home	like	7/18/2012 22:42	1

homeID	recoDate	recoType	feedback	feedbackTime	TimeLagDays
304	9/14/2012 0:00	energy	like	9/15/2012 22:06	1
304	9/14/2012 0:00	Energy	like	9/15/2012 22:04	1
304	9/12/2012 0:00	Energy	like	9/14/2012 8:07	2
304	9/11/2012 0:00	lighting	null	9/14/2012 8:06	3
304	9/10/2012 0:00	Energy	like	9/10/2012 21:10	0
304	9/7/2012 0:00	dishwasher	like	9/10/2012 21:11	3
304	9/7/2012 0:00	Energy	like	9/7/2012 19:18	0

304	8/31/2012 0:00	refrigerator	like	9/4/2012 7:16	4
304	8/28/2012 0:00	home	like	8/31/2012 7:39	3
304	8/21/2012 0:00	baseload	like	8/21/2012 21:17	0
304	8/17/2012 0:00	Thermostat	like	8/19/2012 11:41	2
304	8/14/2012 0:00	refrigerator	like	8/16/2012 20:05	2
304	8/7/2012 0:00	thermostat	like	8/8/2012 6:50	1
304	8/3/2012 0:00	home	like	8/6/2012 21:55	3
304	7/31/2012 0:00	Bosch Refrigerator	like	8/1/2012 7:38	1
304	7/20/2012 0:00	thermostat	like	7/21/2012 10:37	1

homeID	recoDate	recoType	feedback	feedbackTime	TimeLagDays
305	9/14/2012 0:00	energy	like	9/15/2012 19:43	1
305	9/12/2012 0:00	Energy	like	9/14/2012 5:22	2
305	9/11/2012 0:00	lighting	like	9/14/2012 5:21	3
305	9/10/2012 0:00	Energy	like	9/14/2012 5:22	4
305	8/28/2012 0:00	home	like	8/30/2012 18:44	2
305	8/21/2012 0:00	baseload	like	8/22/2012 20:48	1
305	8/14/2012 0:00	refrigerator	like	8/15/2012 20:39	1
305	8/10/2012 0:00	My pool pump	like	8/15/2012 20:38	5
305	8/7/2012 0:00	thermostat	like	8/7/2012 20:25	0
305	8/3/2012 0:00	home	like	8/7/2012 20:25	4
305	7/31/2012 0:00	Bosch Refrigerator	like	8/2/2012 19:10	2
305	7/27/2012 0:00	baseload	like	8/2/2012 19:10	6
305	7/17/2012 0:00	home	like	7/19/2012 19:55	2

The table below shows the response time in days provided by each home owner.

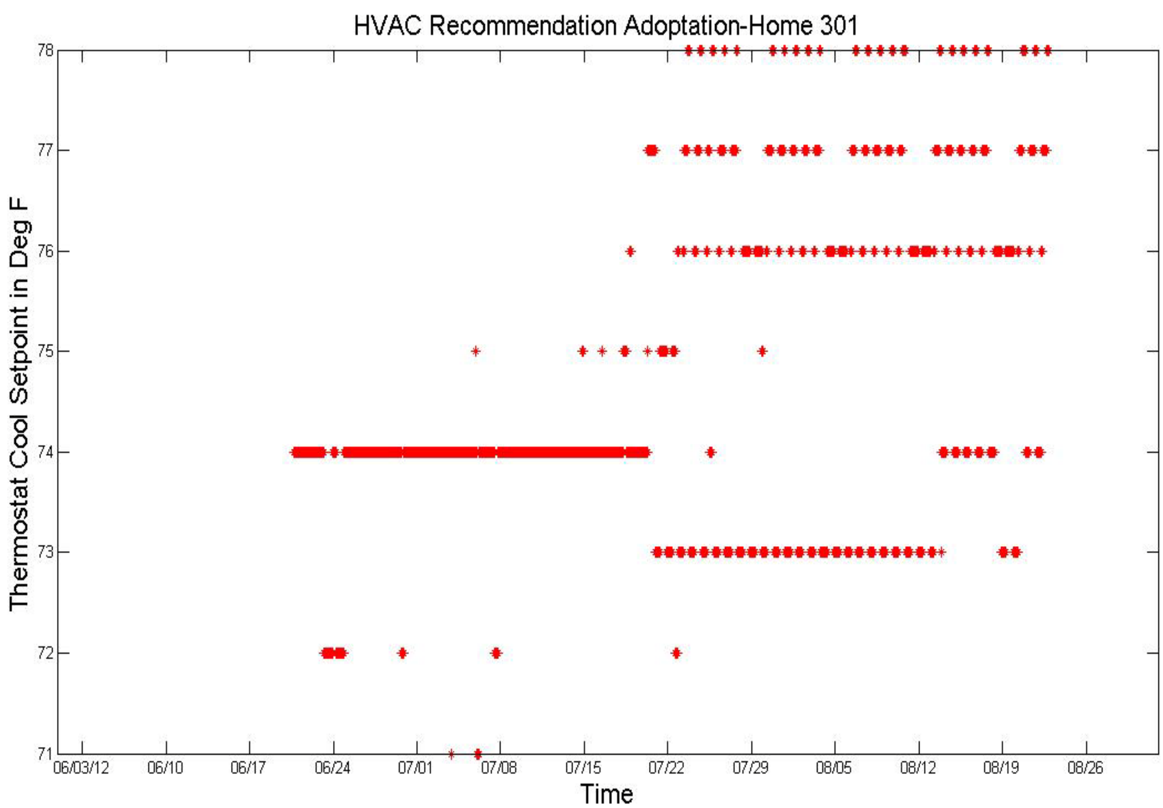
Home ID	Feedback Time (Days) - LIKE	Feedback Time (Days) - DISLIKE
301	4.6	3.33
302	2.17	4
303	7	-
304	1.6	-
305	2.5	-

6.5 Recommendation Adoption Analysis

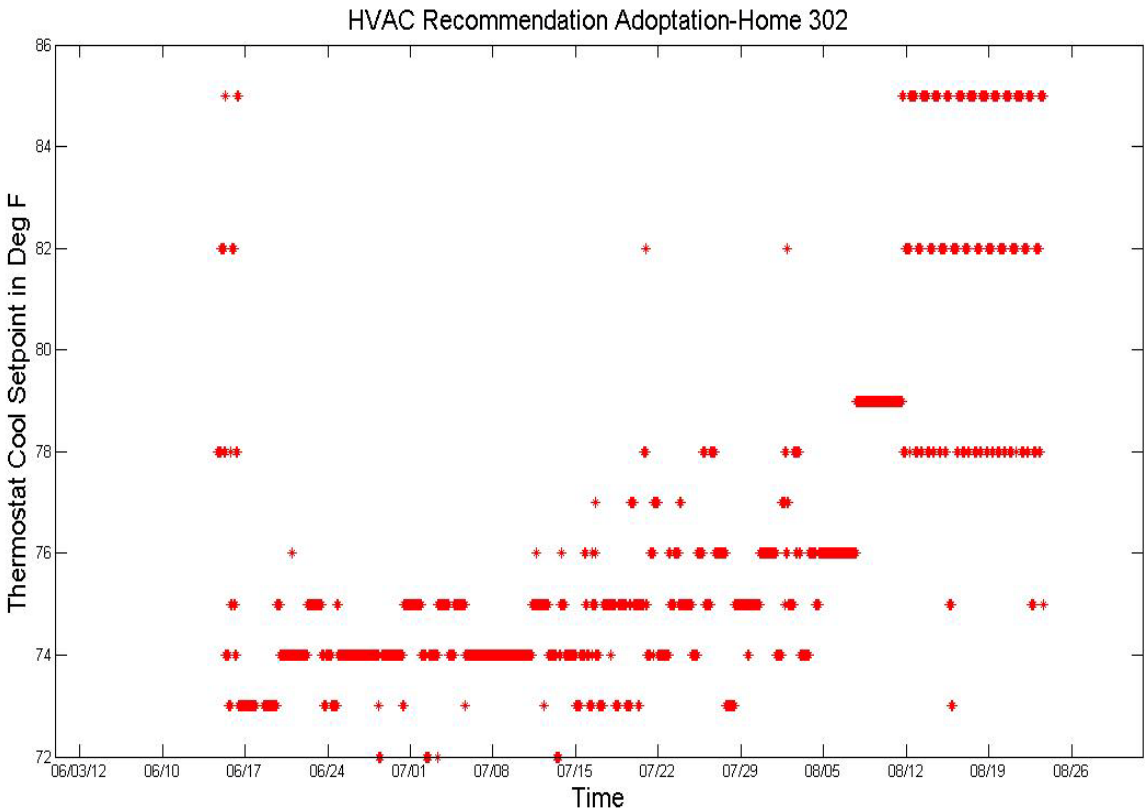
We observed that users liked many of the recommendations provided by CASHEM. We analyzed the setpoints and equipment modes preferred by the user before and after the recommendations. In this section, we provide details of the effect of the recommendations and observed changes in user behavior. The observed equipment setpoints and states are displayed along with the observable change in the behavior.

6.5.1 HVAC Analysis

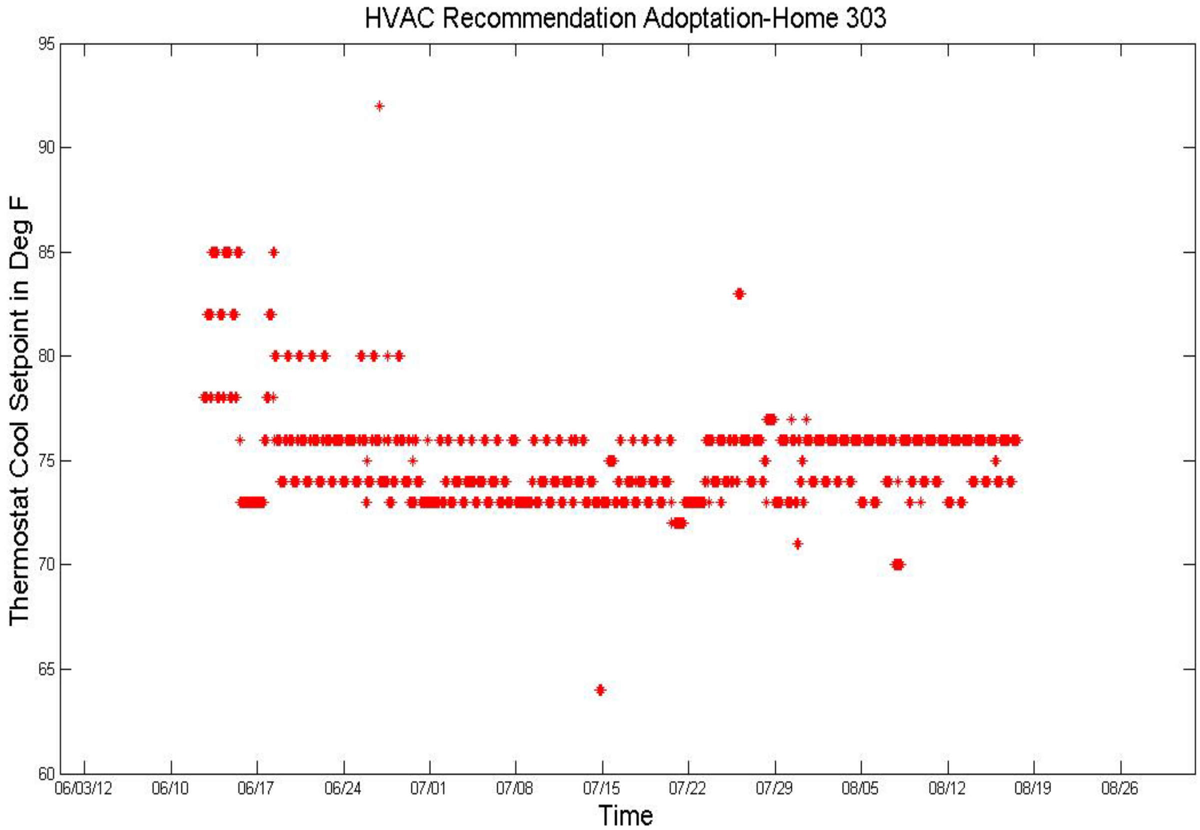
Home ID	Reco dates	Before	After
301	7/20/2012 7/24/2012 8/7/2012 8/17/2012 8/21/2012	HVAC cooling setpoints were kept continuously at 74° F; HVAC was not programmed at all.	HVAC comfort setpoints were changed to energy conservation modes after the recommendations. An estimated 43% reduction in HVAC energy was observed during one month. User started programming the thermostat and followed one schedule for week-days and another schedule for weekends. User tried to follow energy star recommendation which was provided by CASHEM



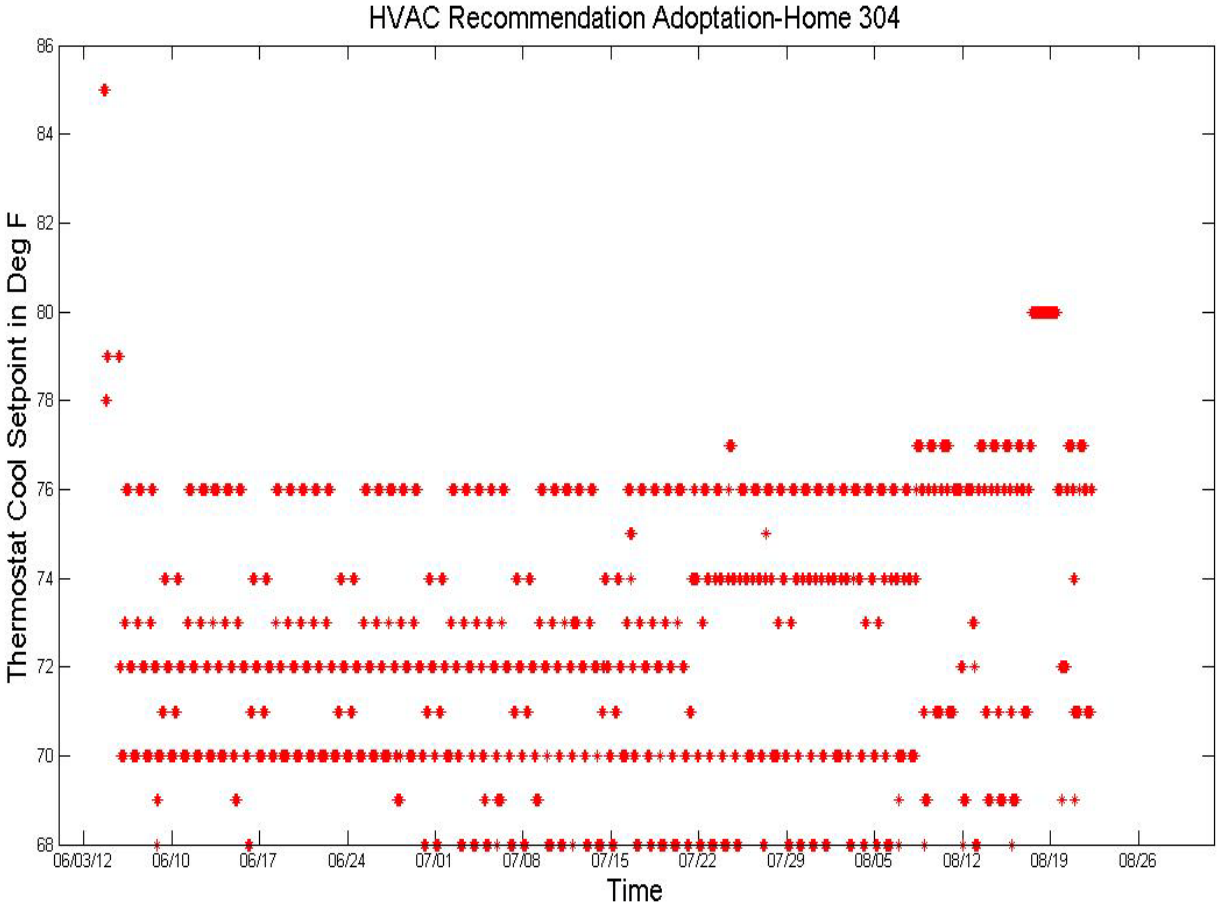
Home ID	Reco dates	Before	After
302	7/20/2012 7/24/2012 8/7/2012 8/17/2012 8/21/2012	Two broad sets of programs were followed for week days and weekends. 88% of the time, the setpoint was kept below 55°.	Home owner started exploring energy conservation set points such as 76° F and 78° F after July 20. Home owner explored Energy Star settings such as 82°F and 85°F after August 7 recommendation. CASHEM quantified the savings to the homeowner and further recommended to increase the setpoint on higher side for further savings, which was promptly followed by the home owner.



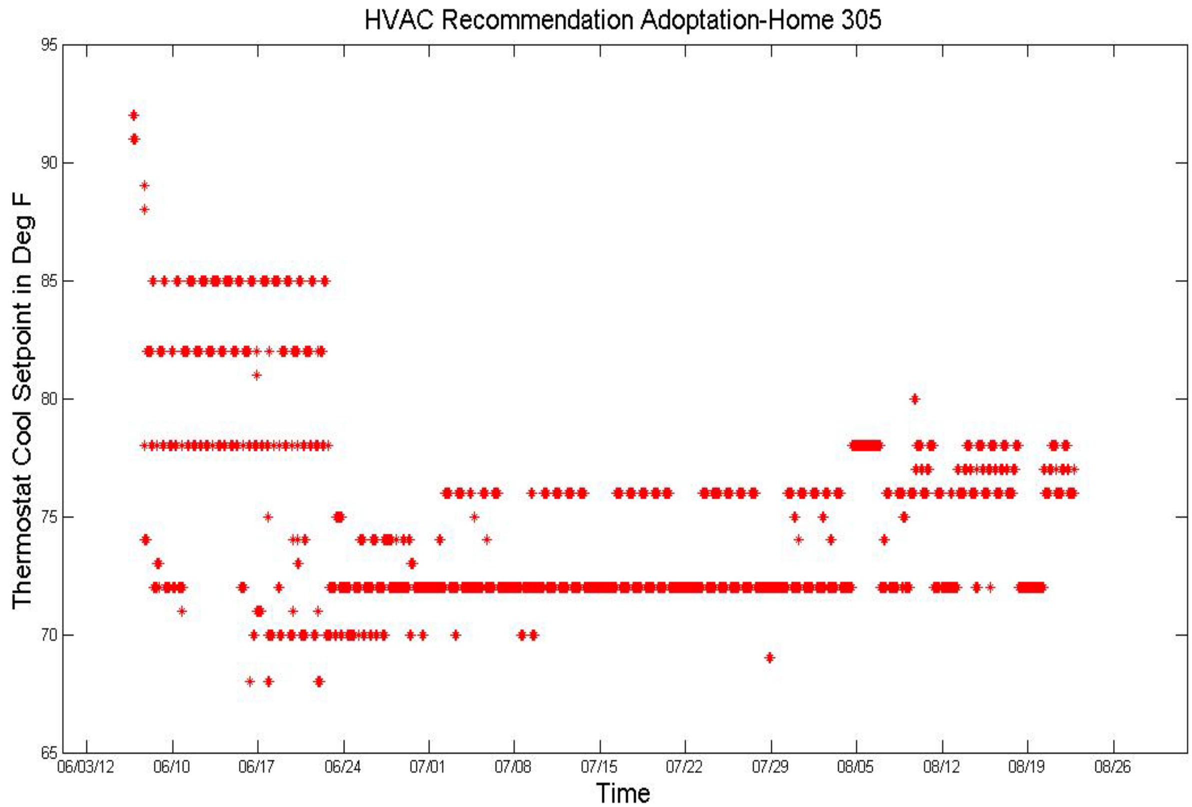
Home ID	Reco dates	Before	After
303	7/20/2012 7/24/2012 8/7/2012 8/17/2012 8/21/2012	Two broad sets of programs were followed for week days and weekends. 93% of the time, the setpoint was kept below 75°F.	Home owner responded to the CASHEM recommendation. The cooler setpoints on average were set between 72°-76°F. These were changed to 74°-76°F, which saved around 35% of HVAC energy consumed. User did not experiment much compared to other home owners.



Home ID	Reco dates	Before	After
304	7/20/2012 7/24/2012 8/7/2012 8/17/2012 8/21/2012	Two broad sets of programs were followed for week days and weekends. 80% of the time setpoint was kept below 75° degree or less.	No perceived change in user behavior. User did increase the comfort setpoints from 72°F to 74°F after July 20th recommendation. But this was not statistically significant to perceive to be behavior change.



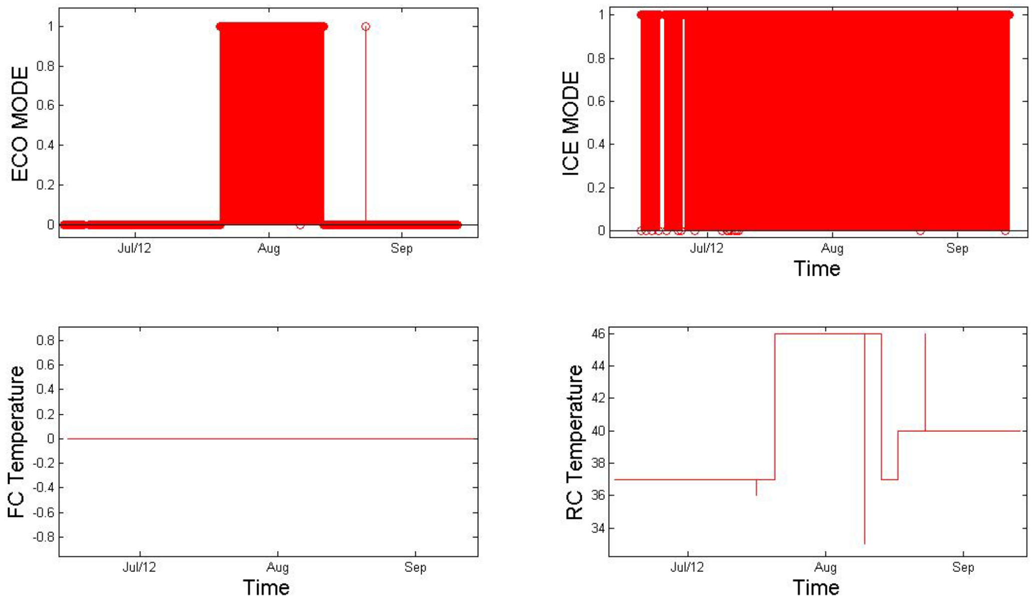
Home ID	Reco dates	Before	After
305	7/20/2012 7/24/2012 8/7/2012 8/17/2012 8/21/2012	Two broad sets of programs were followed for week days and weekends. 80% of the time setpoint was kept below 75°	No perceived change in user behavior August 7. User explored energy conservation set points after suggestion on August 7th which yielded around 30% HVAC improved energy consumption. User mentioned that he liked the recommendation of Aug 7, and we attribute the change in behavior as an effect of the recommendation.



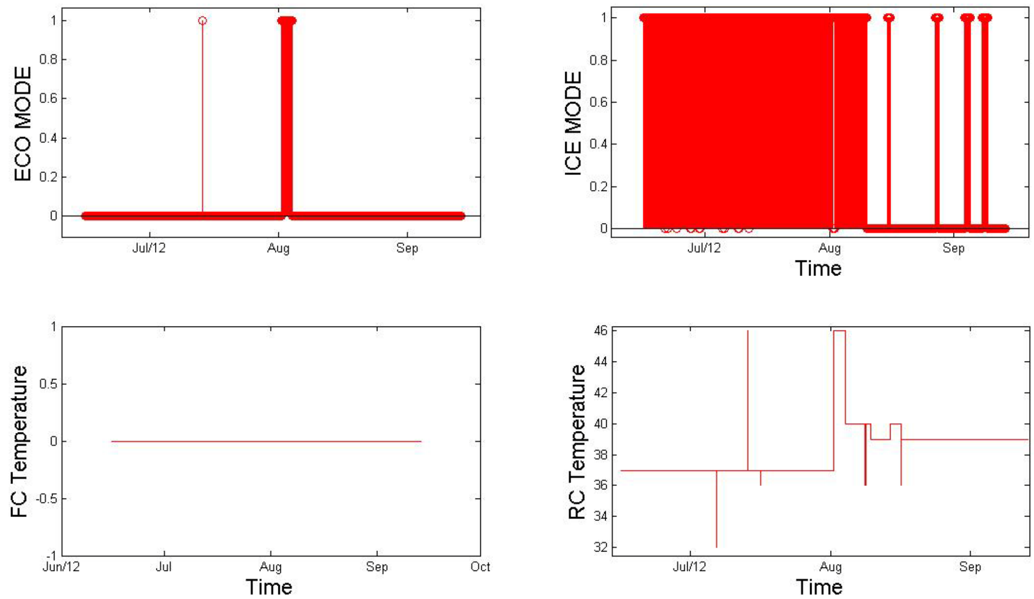
Overall significant change in user behaviors' was observed from Home ID 301, 302, 303, and 305. Home owner 304 did not respond to HVAC recommendations.

6.5.2 Refrigerator Analysis

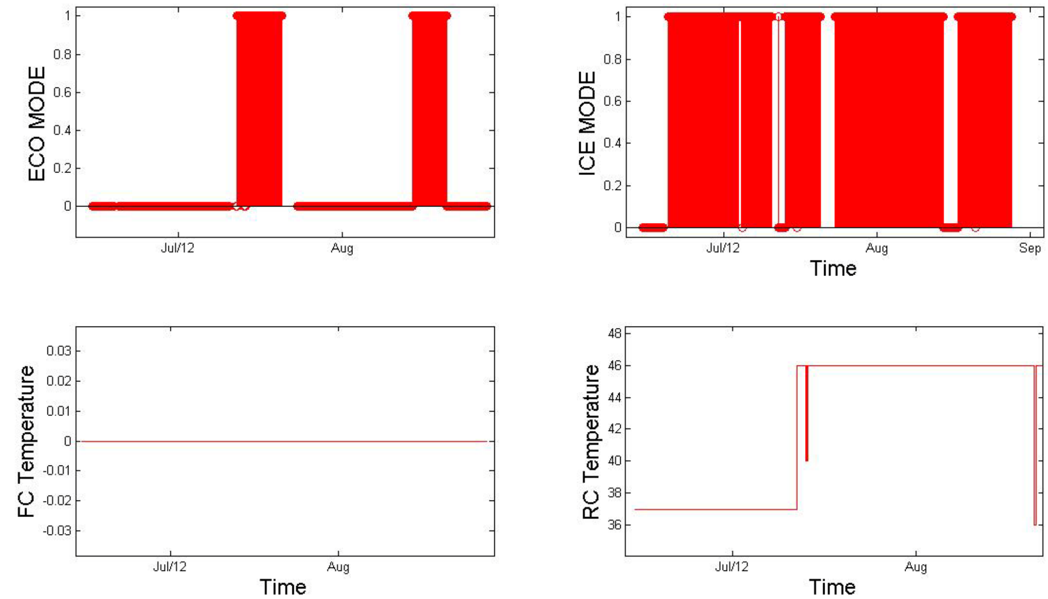
Home ID	Reco dates	Before	After
301	7/31/2012 8/14/2012 8/31/2012	• ECO Mode was used • ICE Mode was ON • Freezer and Refrigerator compartment temperature was kept constant.	• ECO Mode enabled and Disabled ICE Mode was continuously enabled despite higher energy usage warnings. • Refrigerator Temperature was kept in energy conservation mode. • Overall behavior change was observed; however, there is no strong correlation seen between CASHEM recommendation and user behavior.



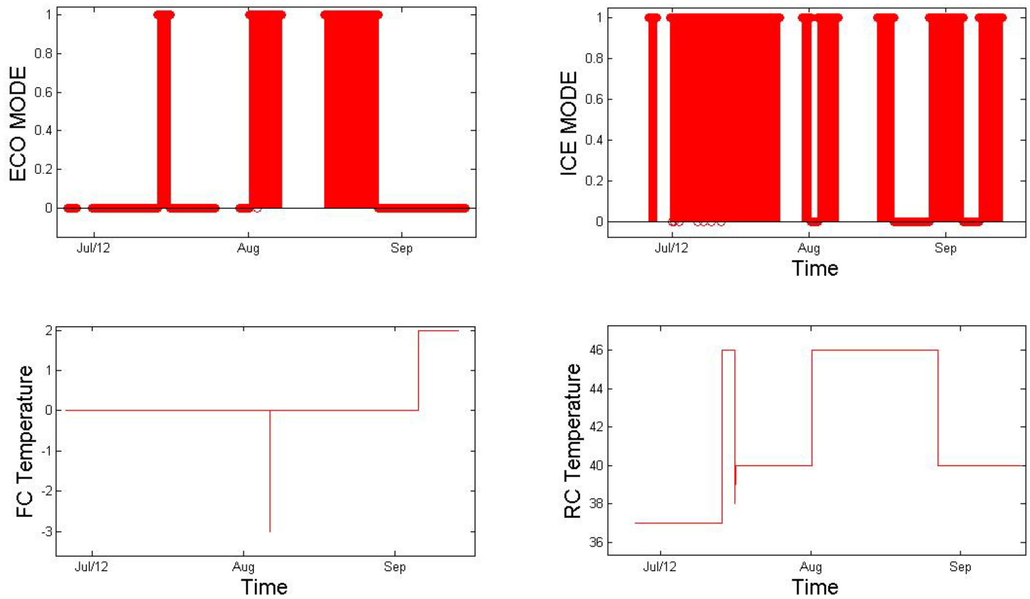
Home ID	Reco dates	Before	After
302	7/31/2012 8/14/2012 8/31/2012	• ECO Mode was not used. • ICE Mode was continuously ON. • Freezer and Refrigerator compartment temperature was kept constant.	• ECO Mode enabled after recommendation and disabled later as per user convenience. • ICE Mode was enabled and disabled as per user convenience. • Refrigerator Temperature was kept in energy conservation mode. • Overall significant behavior change was observed and attributed to CASHEM recommendations.



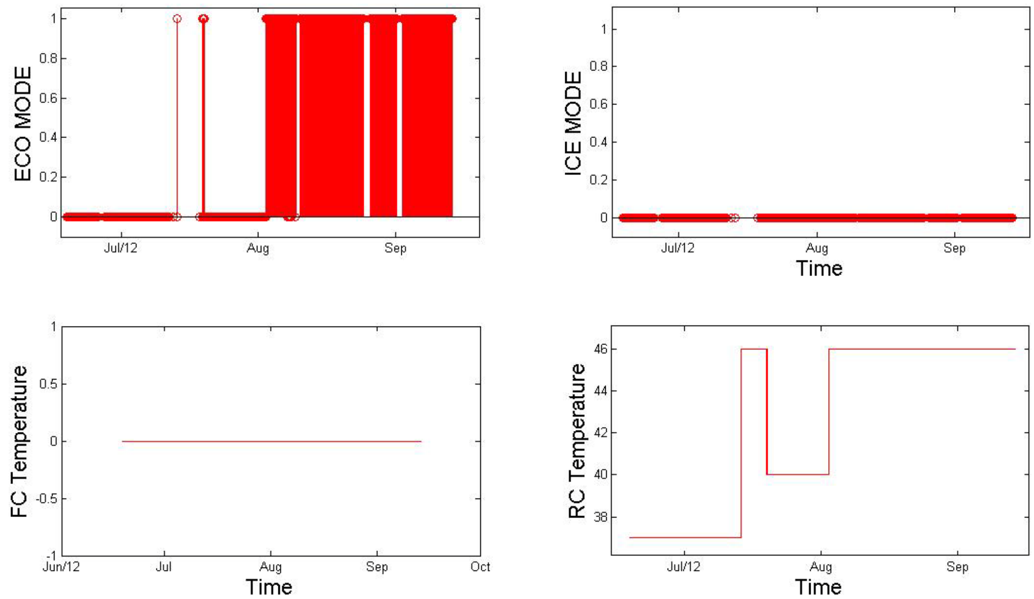
Home ID	Reco dates	Before	After
303	7/31/2012 8/14/2012 8/31/2012	• ECO Mode was used • ICE Mode was used as per convenience • Freezer and Refrigerator compartment temperature was kept constant	• No perceived change in ECO mode usage. • ICE Mode was enabled and disabled as per user convenience. • Freezer and refrigerator settings were not altered. • User 303 was aware of refrigerator settings and used them for convenience.



Home ID	Reco dates	Before	After
304	7/31/2012 8/14/2012 8/31/2012	• ECO Mode was used • ICE Mode was continuously ON • Freezer and Refrigerator compartment temperature was kept constant	• ECO Mode enabled after recommendation and disabled later as per user convenience. • ICE Mode was enabled and disabled as per user convenience. • Refrigerator Temperature was kept in energy conservation mode. • Overall significant behavior change was observed, which is attributed to CASHEM recommendations.

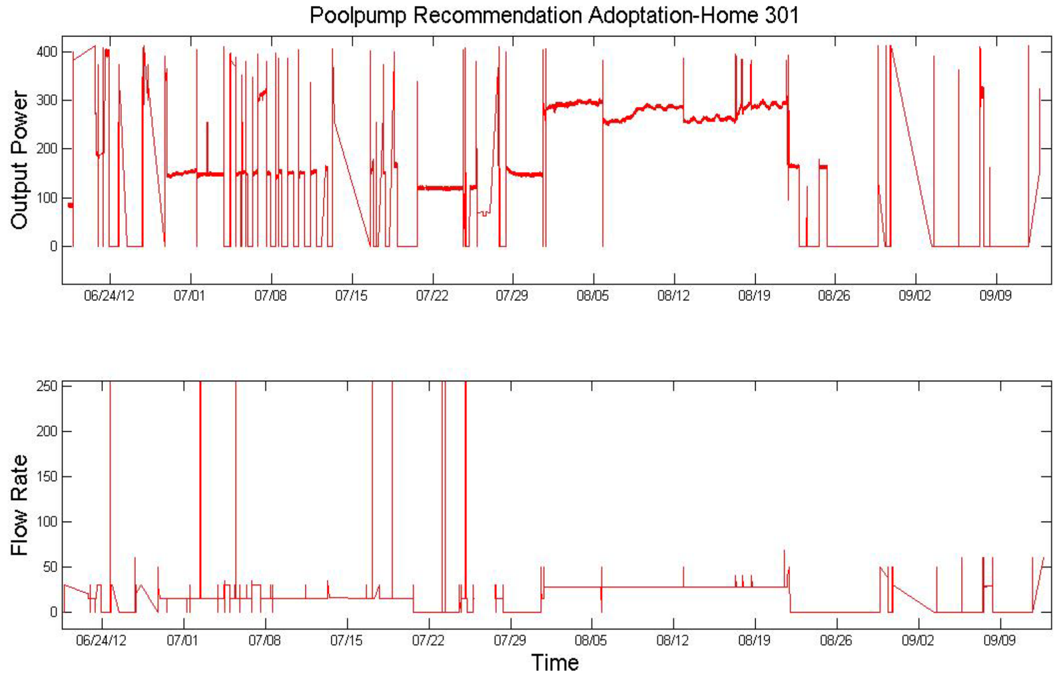


Home ID	Reco dates	Before	After
304	7/31/2012 8/14/2012 8/31/2012	• ECO Mode was not used significantly. • ICE Mode was continuously OFF. • Freezer and refrigerator compartment temperature were changed as per requirement.	• ECO Mode enabled after recommendation and altered as per convenience. • ICE Mode was never ON. • Refrigerator Temperature was kept in energy conservation mode. • Overall behavior change was observed. However, there is no strong correlation seen between CASHEM recommendation and user behavior.

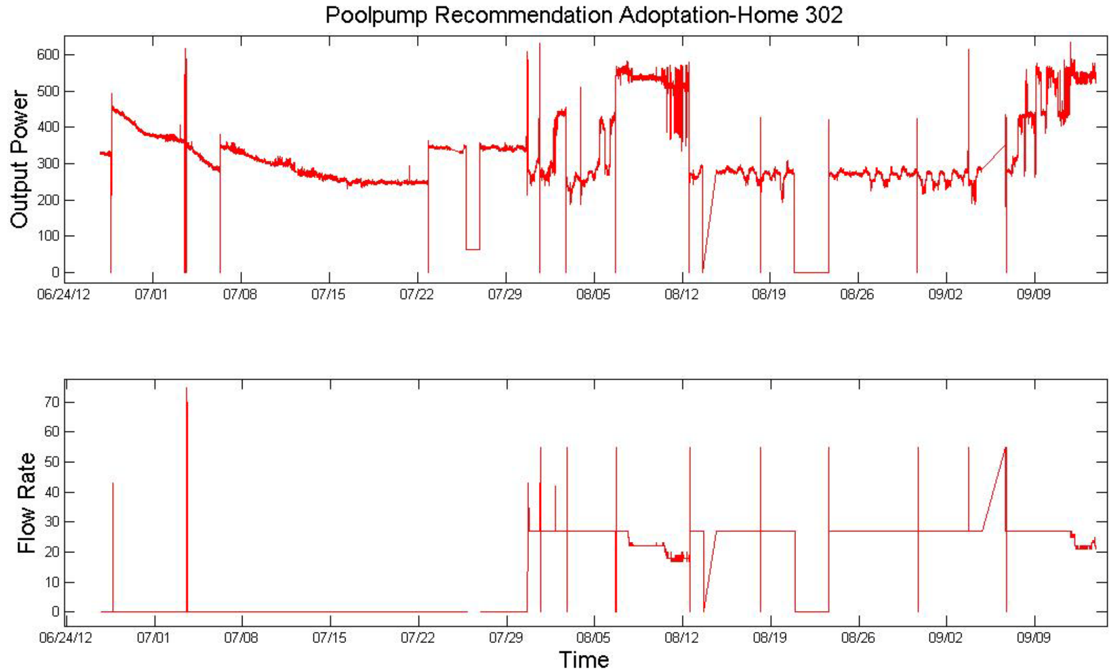


6.5.3 Pool Pump Analysis

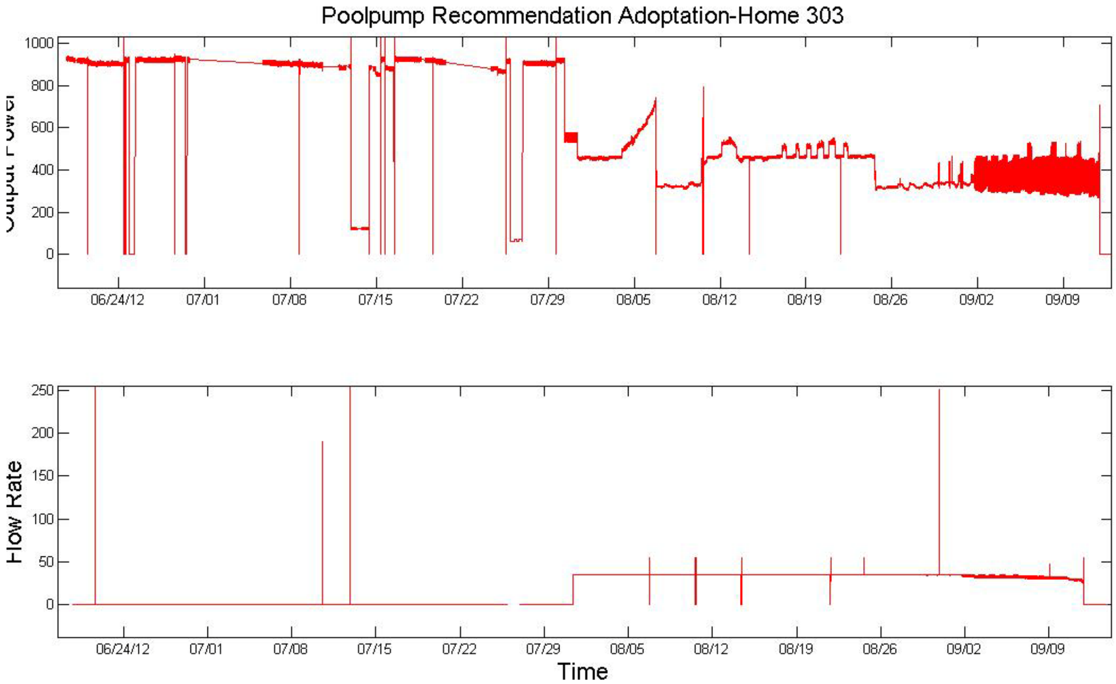
Home ID	Reco dates	Before	After
301	8/10/2012 8/28/2012	• Pool pump was on MANUAL mode with lower flow rate than required for the pool size. • Large variation in Power consumption indicating transients	• Regulated flow as per pool requirement • Weekly backwash as suggested by CASHEM • Pump issues during the end of experiments were observed. • Overall behavior change was observed. User was meticulously following backwash routine, which save as high as 30% of energy.



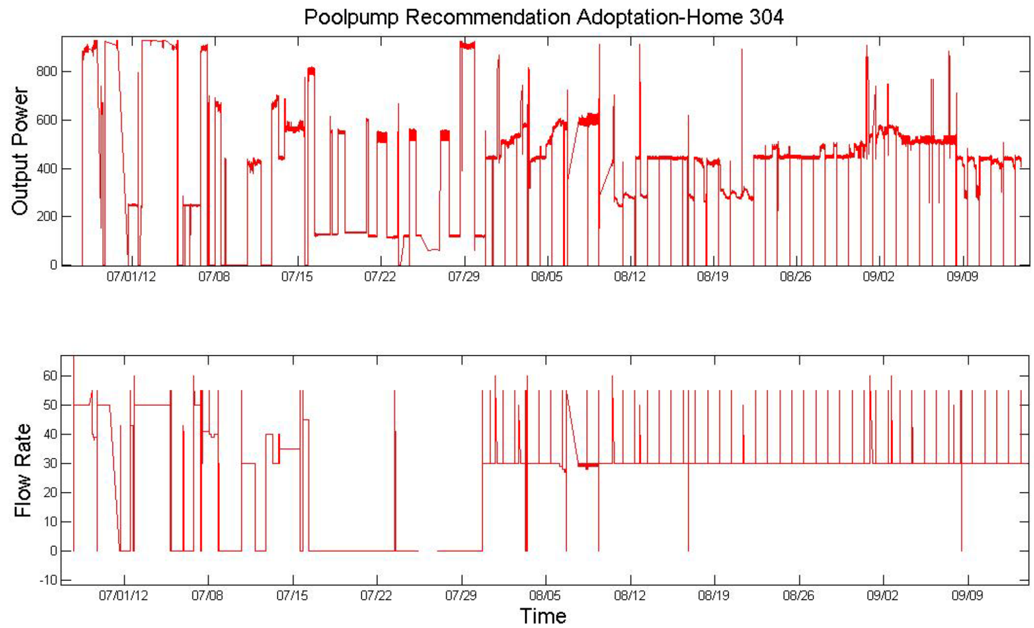
Home ID	Reco dates	Before	After
302	8/10/2012 8/28/2012	• Pool pump was on MANUAL mode with flow rate presumably higher than required wasting energy. • Filter was clogged resulting in drawing large power.	• Regulated flow as per pool requirement • Weekly backwash as suggested by CASHEM • Overall behavior change was observed. User was following backwash routine. User maintained the required flow rate as per CASHEM suggestion.



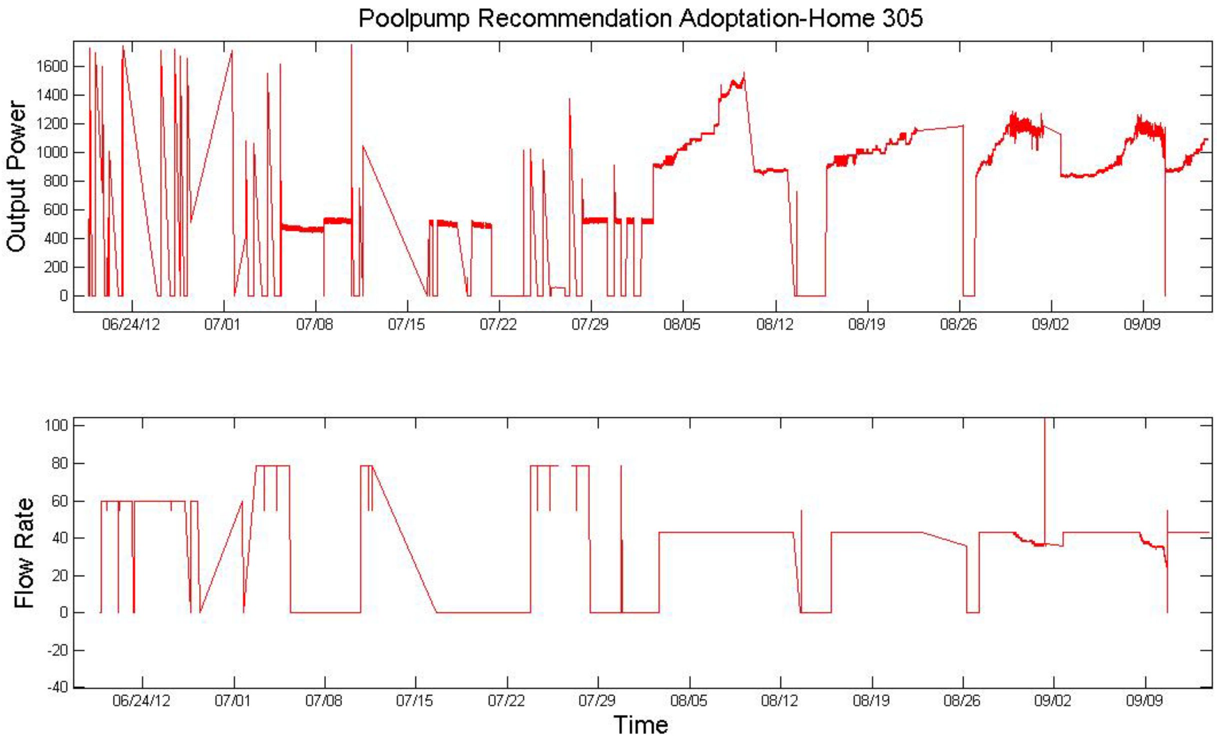
Home ID	Reco dates	Before	After
303	8/10/2012 8/28/2012	• Pool pump was on MANUAL mode with flow rate presumably higher than required wasting energy. • Filter was clogged resulting in drawing large power.	• Regulated flow as per pool requirement. • Weekly backwash as suggested by CASHEM. • Overall behavior change was observed. User was following backwash routine. User maintained the required flow rate as per CASHEM suggestion.



Home ID	Reco dates	Before	After
304	8/10/2012 8/28/2012	• Pool pump was unregulated with varying flow rate and speed.. • No conclusive evidence of backwash	• Regulated flow as per pool requirement, which was maintained throughout the experiment • No data driven back wash routine was observed • There is no correlation between CASHEM recommendation and user behavior. However, the user maintained the flow rate as prescribed by CASHEM.



Home ID	Reco dates	Before	After
305	8/10/2012 8/28/2012	• Pool pump was operating unscientifically without meeting the cleaning demands of the user. • Varied flow rates and intermittent transients were observed in the output power.	• Regulated flow as per pool requirement • Bi-Weekly backwash was observed. • Overall behavior change was observed. User was following backwash routine. User maintained the required flow rate as per CASHEM suggestion.



Overall, we observed that users responded to many of CASHEM recommendations and changed the settings on home equipment to conserve energy and save dollars. Home owners liked many of the recommendations, and chronological event and parameter analysis revealed that they indeed experimented with the home eco-system as advised by CASHEM. There were encouraging results and home owners reported surprisingly lower electricity bill compared to their neighbors. Based on our experiment, we conclude that crisp, personalized messages pinpointing the gaps in an existing set up and providing alternatives will be well received.

7 Project Findings

7.1 Field Experiment Results

There were four main research questions in the CASHEM field experiment. The answers to each are elaborated below.

1. Does the presence of CASHEM lead to better cost/energy savings?

   The answer to this question is, yes.

2. Does the presence of CASHEM lead to more effective behavior and usage of appliances?

   The answer to this question is, yes. For example, homeowners started using the scheduling function in their thermostats, started showing a decline in the base loads, programmed their pool pumps to function more efficiently, had more conversations with their families on how to manage energy more efficiently, and became generally more aware of energy management in their homes.

3. Does the presence of CASHEM lead to better subjective ratings (on satisfaction, motivation to save energy, etc.) compared with the prior system?

   The answer to this question is, yes. As indicated by the survey responses, the homeowners were more motivated to save energy, were more knowledgeable of their energy usage, and wanted to even recommend the CASHEM system to their friends and family. In addition, when CASHEM was taken out of their homes, all homeowners *missed* the tips.

4. Based on subjective experience and ratings, do users reflect the same behavioral patterns post CASHEM (i.e., do they still represent CASHEM-like behavior)?

   The answer to this question is, partly yes. Homeowners were generally aware of how to save energy, and what the behaviors were that led to more efficient management of energy. However, they explicitly mentioned that they would like to continue receiving tips to make sure that they were doing the right things. In other words, they were taking the effort, however, with additional feedback they could continue to do even better.

7.2 Lessons Learned

The field study was an excellent method to understand homeowners' needs and challenges from the perspective of energy management in their homes. The field study also helped to explore and provide insight to some of the mechanisms that help to drive and sustain behavior change. The major learnings from these two perspectives are provided below:

7.2.1 Needs and Challenges for Homeowners

1. Homeowners want to save energy, but they are not fully aware on how to make it happen

2. Homeowners typically want a 10-15% reduction on utility costs when adopting (or buying) an automated tool to help them manage energy better
3. Reduction of cost through appropriate energy management behavior is important, but comfort is relatively more important
4. Homeowners like to receive tailored feedback about their energy usage rather than an abstracted and high level feedback

7.2.2 Changing and Sustaining Behavior Change

1. Three main factors helped to build homeowners' trust with CASHEM, which drove behavior change. These factors were:
   a. Tailored feedback on their energy usage
   b. A game based ranking approach for their energy usage
   c. The ability to retrieve information quickly (e.g., through the tablet UI)
2. As the homeowners became aware of their behavioral patterns, they were more cognizant and committed to making a change for the better
3. Format of the tips was helpful; generic information and educating, information specific to the home's energy usage, generic and specific recommendations to improve
4. A "pat on the back" or appreciative comments (through the tips) when one did well was encouraging for homeowners to do even better
5. Once homeowners were educated on, and exposed to the strategies for effective energy management, they were motivated to sustain such an effective behavioral pattern
6. However, sustaining behavior is relatively more difficult without a system like CASHEM in place, where homeowners can monitor and tweak their behavior as apt. In other words, it is easier to lose momentum if they do not receive consistent feedback on their behavior

7.2.3 Field Installation

Keep it simple—

The most reliable system was the refrigerator since it was hard wired and used serial communications. However, this system required a hard wire connection and forced the computer to be near the refrigerators.

We also learned that, to date, no standard has been set for appliances to communicate with each other.

For a larger scale field test, consider using a lower cost refrigerator that does not require cabinetry modifications.

Develop more modules—

When wired Ethernet cables could not be used, a Wi-Fi infrastructure connected the different devices. Wi-Fi extenders made the Wi-Fi infrastructure acceptable, but problems occurred in making connections outside of the home to the pool pump and to a load panel in a garage. For larger scale field test gaining connectivity to the pool pump could be done by developing a RedLINK module. Another option could be to develop a module using a power line Ethernet bridge.

Power requirements—

If we were starting the field test over we would need to make sure the homes had 240 volts at the pool pump to accommodate the Pentair model used for CASHEM.

Use watt meter rather than TED unit—

The TED unit is not reliable and uses problematic power line technology. A communicating watt meter provided by the utility would be a desirable alternative, especially for large-scale field tests. We learned that these devices are not currently available and need to be developed.

Better notification application—

Modifications to the EC2 Client application or a new application should be developed to originate notifications about equipment maintenance or connectivity failures.

7.2.4 UI Lessons Learned

Ability to scale: Using a remote connection to transfer files to a home's gateway is not feasible for a system with over 10 users. An auto-updating feature should be used, where the latest CASHEM user interface files are hosted in the cloud, and each time the user accesses the home page, it should automatically check its version against the latest existing in the cloud, and download files as needed.

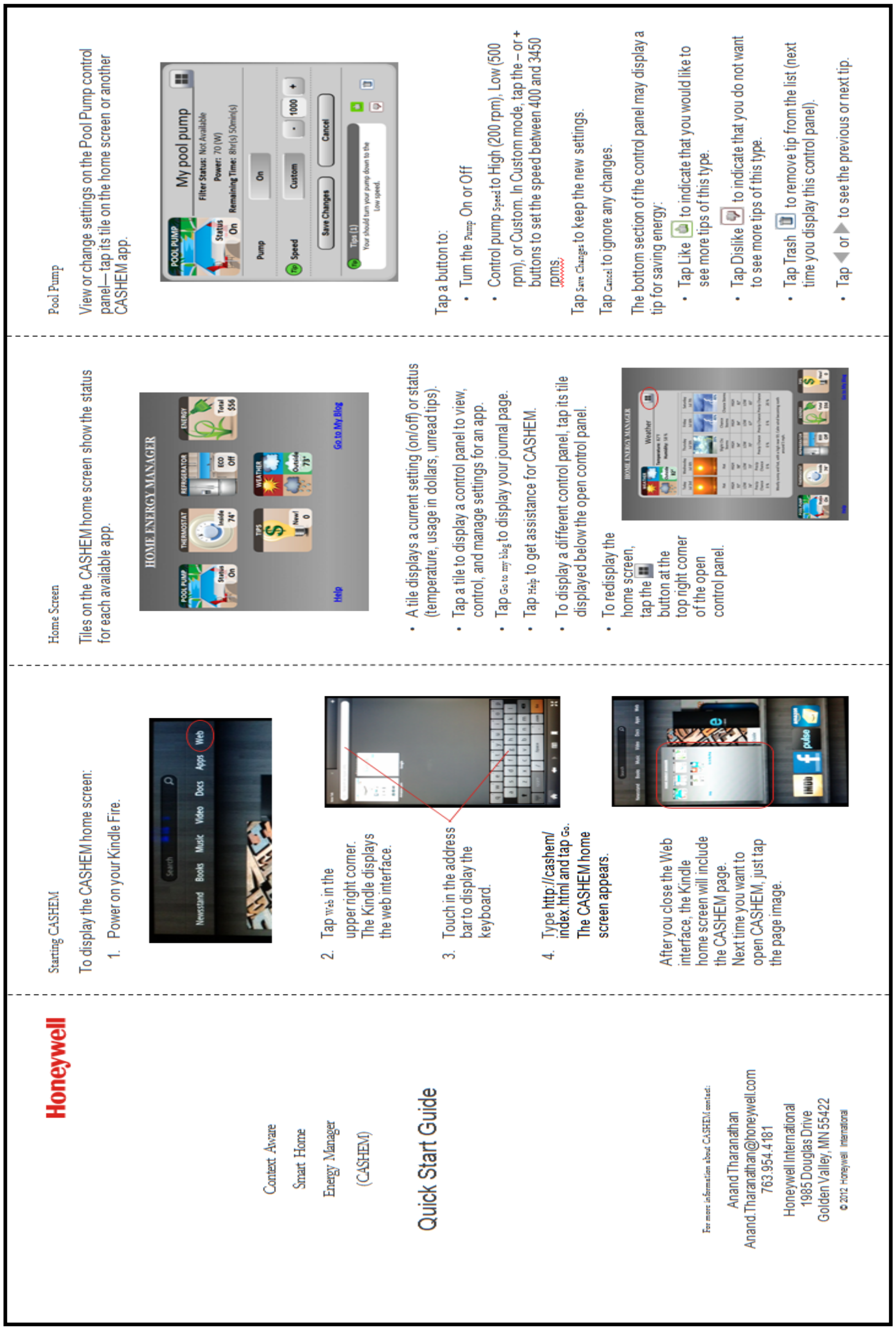
8 Future Directions

With globally expanding interest in energy management, user experience, behavior change and sustenance of energy efficient behavior, the CASHEM field study has proven to be very timely. This effort, albeit with five homes, has opened up several opportunities and future directions for exploration from a research and development perspective. It is a complex problem, but one that needs good degree of attention to pave the path for an energy efficient socio-technical system. Some of the future directions and related research questions are as follows, and it would be critical to start answering them soon:

1. How do complexity, scope and scale of a domain (e.g., homes, buildings and larger eco-systems) affect adoption of behavior change and sustenance of energy efficient behavior?
2. Are there differences in the way different personas and geographical regions adopt behavioral change and sustenance from an energy management perspective?
3. What are some of the effective feedback mechanisms by which we can sustain energy management behavior?
4. Are there any training opportunities for improving energy management behavior?

9 Appendix A: CASHEM Quick Start Guide

The following figure shows the first four pages of the Quick Start Guide provide to each user. The remaining pages of the guide are similar to the last page on the right of the image (Pool Pump).



Honeywell

Context Aware
Smart Home
Energy Manager
(CASHEM)

Quick Start Guide

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Starting CASHEM

To display the CASHEM home screen:

1. Power on your Kindle Fire.
2. Tap Web in the upper right corner. The Kindle displays the web interface.
3. Touch in the address bar to display the keyboard.
4. Type http://cashem/index.html and tap Go. The CASHEM home screen appears.

After you close the Web interface, the Kindle home screen will include the CASHEM page. Next time you want to open CASHEM, just tap the page image.

Home Screen

Tiles on the CASHEM home screen show the status for each available app.

- A tile displays a current setting (on/off) or status (temperature, usage in dollars, unread tips).
- Tap a tile to display a control panel to view, control, and manage settings for an app.
- Tap Go to my blog to display your journal page.
- Tap Help to get assistance for CASHEM.
- To display a different control panel, tap its tile displayed below the open control panel.
- To redisplay the home screen, tap the button at the top right corner of the open control panel.

Pool Pump

View or change settings on the Pool Pump control panel— tap its tile on the home screen or another CASHEM app.

Tap a button to:

- Turn the Pump On or Off
- Control pump Speed to High (200 rpm), Low (500 rpm), or Custom. In Custom mode, tap the – or + buttons to set the speed between 400 and 3450 rpms.

Tap Save Changes to keep the new settings.

Tap Cancel to ignore any changes.

The bottom section of the control panel may display a tip for saving energy:

- Tap Like to indicate that you would like to see more tips of this type.
- Tap Dislike to indicate that you do not want to see more tips of this type.
- Tap Trash to remove tip from the list (next time you display this control panel).
- Tap ◀ or ▶ to see the previous or next tip.