# Residential Energy Efficiency Demonstration

## *Hawaii and Guam Energy Improvement Technology Demonstration Project*


L. Earle and B. Sparn
*National Renewable Energy Laboratory*

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*Naval Base Guam*



*Produced under direction of Naval Facilities Engineering Command (NAVFAC) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement 11-01829*

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**Office of Energy Efficiency & Renewable Energy**
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**Technical Report**
NREL/TP-5500-61013
March 2014

Contract No. DE-AC36-8GO28308

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The demonstration was made possible because of the generous cooperation of the residents whose homes were used for the appliance upgrades and advanced power strip installations. We thank them for allowing us into their homes to install various equipment and for their patience when repeated visits were necessary to troubleshoot our data acquisition system.

# List of Abbreviations and Acronyms

| | |
|---|---|
| A/C | air conditioning |
| AHU | air handler unit |
| AIRR | adjusted internal rate of return |
| APS | advanced power strip |
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| BEopt | Building Energy Optimization |
| BEoptE+ | Building Energy Optimization with EnergyPlus |
| BLCC | Building Life-Cycle Cost |
| CT | current transformer |
| DHW | domestic hot water |
| DOD | U.S. Department of Defense |
| EEE | enhanced energy efficiency |
| eROI | energy return on investment |
| FY | fiscal year |
| HPWH | heat pump water heater |
| HVAC | heating, ventilation, and air conditioning |
| IR | infrared |
| JRM | Joint Region Marianas |
| kWh | kilowatt-hour |
| MWh | megawatt-hour |
| NAVFAC | Naval Facilities Engineering Command |
| NBG | Naval Base Guam |
| NEEP | Northeast Energy Efficiency Partnerships |
| NEPA | National Environmental Policy Act |
| NIST | National Institute of Standards and Technology |

| | |
|---|---|
| NOAA | National Oceanic and Atmospheric Administration |
| NREL | National Renewable Energy Laboratory |
| T&RH | temperature and relative humidity |
| TRL | technology readiness level |
| SEER | seasonal energy efficiency ratio |
| SFH | single-family home |
| SIR | savings-to-investment ratio |
| W | watt |

# Executive Summary

In order to meet its energy goals, the U.S. Department of Defense has partnered with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) to rapidly demonstrate and deploy cost-effective renewable energy and energy efficiency technologies. The scope of this project was to demonstrate tools and technologies to reduce energy use in military housing, with particular emphasis on measuring and reducing loads related to consumer electronics (commonly referred to as "plug loads"), hot water, and whole-house cooling.

A plug load-reducing technology called the advanced power strip (APS) was installed in homes and monitored for energy savings, and the residents were trained in the use of these new devices. For hot water and cooling, building energy simulation tools were used to select the enhanced energy efficiency (EEE) package of cost-effective retrofit technologies. The technologies installed in these homes included high-efficiency air conditioners and air handlers, in-line dehumidifiers (in a subset of homes), internet-connected programmable thermostats, low-flow shower heads, and heat pump water heaters. The impact on energy use of the space-conditioning and hot water system upgrades was measured to determine annual energy savings. The design of the EEE demonstration was facilitated by Building Energy Optimization (BEopt), an optimization software developed at NREL.

Overall, the APS and EEE demonstrations both saved energy, although house-to-house variations in achieved savings were large. The results from the APS demonstration indicate expected annual energy savings of 58 kilowatt-hours (kWh) in a home entertainment center and 40 kWh in a home office. The APS demonstration is projected to save $600 total for 30 homes over the next four years. Economic results of the APS demonstration were not positive, indicating deployment of this technology in a military housing environment may not yield appreciable savings without further study to evaluate effective options to implementation. The EEE demonstration resulted in much higher annual energy savings, with an average of 4,000 kWh in heating, ventilation, and air conditioning energy savings and 1,400 kWh in domestic hot water savings. These savings translate to substantial cost savings in Guam, where electricity costs 50¢/kWh. The EEE demonstration is projected to result in a net savings (after paying for the initial investment in the first three years) of $120,000 over the next 10 years for all eight homes, or an average of $15,000 per home over 10 years.

All of the products evaluated in this demonstration are commercially available and can be purchased from a variety of companies and retailers. A number of different strategies could be used to increase the use of APSs in base housing, including stocking APSs in the base Naval Exchange, distributing APSs to all new families during move-ins, or employing a direct installation program. The EEE technologies have already been integrated into the standards for new equipment for new and existing homes on Naval Base Guam.

The residential energy-efficiency equipment evaluated in this demonstration is projected to save energy and money while maintaining or improving indoor comfort, and thus, are a good investment for the U.S. Navy. APSs are a simple, low-cost way to reduce plug load consumption, but it may be a challenge to ensure they are installed properly.

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# 1 Introduction

In order to meet its energy goals, the U.S. Department of Defense (DOD) has partnered with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) to rapidly demonstrate and deploy cost-effective renewable energy and energy efficiency technologies. The common goal is to demonstrate and measure the performance and economic benefit of the system while monitoring any ancillary impacts to related standards of service and operation and maintenance practices. The standards of service may include acceptable temperature and humidity ranges, power quality, allowable setbacks, noise criteria, air quality parameters, lighting levels, and other related factors. In short, demonstrations at DOD facilities simultaneously evaluate the benefits and compatibility of the technology with the DOD mission, and with its design, construction, and operation and maintenance practices, in particular.

This report discusses one of several demonstrations of new or underutilized commercial energy technologies.

## 1.1 Background

The scope of this project was to demonstrate tools and technologies to reduce energy use in military housing, with particular emphasis on measuring and reducing loads related to consumer electronics (commonly referred to as "plug loads"), hot water, and whole-house cooling. Plug load-reducing technologies were installed and monitored for energy savings, and the tenants were trained in the use of these new devices. For hot water and cooling, building energy simulation tools were used to select cost-effective retrofit technologies. The results were compared to the simulation tool's predicted outcomes to validate the use of the tool in the retrofit selection process. The impact on energy use of the space-conditioning and hot water system upgrades was measured to determine annual energy savings.

The demonstration was organized in two tiers. As little is known about the magnitude of plug load energy use and the potential to reduce it in military housing, residential plug load measurement and reduction were the focus of the first part of this demonstration. Through the demonstration, NREL measured and provided user-friendly control over the energy consumption of consumer electronics used in the home entertainment center (TV and peripherals) and the home office (computer and peripherals) areas. In addition to the common problem of users neglecting to turn off unused appliances, plug loads waste energy in the form of "vampire" or "phantom" loads—many devices continue to draw current as long as they remain plugged into receptacles, even after the appliances are switched off. The emerging technology class of products called the advanced power strip (APS) seeks to address the growing plug load energy waste via auto-switching capabilities, where supply power is automatically shut off when the end-use appliance is detected to be in an unused state. In this project, APS devices were installed on all home office and entertainment center areas in 30 Naval Base Guam (NBG) houses, and the electrical outlets were monitored for changes in energy use. Throughout this report, the authors refer to this component of the project as the "APS demonstration."

The second part, which is called the "enhanced energy efficiency (EEE) demonstration," is a more comprehensive upgrade package designed to cost-effectively reduce energy consumption of the largest loads in these homes. Using basic information on floor plan and building construction, energy models were developed using Building Energy Optimization (BEopt) with EnergyPlus[1] for several typical houses on NBG (Christensen, Anderson, Horowitz, Courtney, & Spencer, 2006). Using these models, NREL

[1] BEopt with EnergyPlus (BEoptE+) version 2.0.0.6 was used for this project.

determined the most effective strategy to reducing energy consumption in these concrete, all-electric homes is to reduce the heating, ventilation, and air conditioning (HVAC) and domestic hot water (DHW) loads. The best way to decrease HVAC-related energy use is to improve the efficiency of the equipment, and if occupancy schedules allow, employ thermostat setups. Improving supplemental dehumidification could improve comfort, substantially decrease the sensible cooling requirements, and increase the durability of the homes by reducing moisture, which can contribute to mold growth and related health concerns. Heat pump water heaters (HPWH) are an excellent alternative to electric resistance water heaters, especially in a consistently hot and humid climate such as Guam's. NREL demonstrated the energy-saving potential of these technologies in eight NBG houses so that they may be considered in future equipment replacement, as well as new construction.

# 2 Demonstration Objective

The objective of this project was to demonstrate several cost-effective measures that can be easily implemented in U.S. Navy base housing to reduce whole-house energy consumption, with particular focus on residential plug loads, water heating loads, and cooling loads. Energy monitoring was conducted before and after the upgrades were deployed to measure resulting changes in energy use.

Military housing poses several unique challenges to energy reduction strategies. Base housing may not be individually metered, and utility bills might not be paid by the homes' occupants, resulting in no direct feedback on electricity use and no monetary incentive to reduce it. It may be common for military families to have someone at home during the day, so strategies that rely on reducing consumption when the home is empty (e.g., air-conditioning setback, whole-house green switch) may not be effective for all families. The simplest plug load reduction program for military housing would target small appliances and electronics because occupants have direct control of these end uses.

In addition, the tropical climate of Guam makes the cooling and dehumidification requirements a dominant source of electricity use. Improving the efficiency of the HVAC equipment and replacing major appliances, such as the water heater, with energy efficient models will dramatically reduce the energy use of base housing while maintaining occupant comfort.

## 2.1 Technology Description

### *2.1.1 Residential Plug Load-Reduction Technologies*

#### *Advanced Power Strips*

APS products come with a variety of control mechanisms ranging in degree of automation and can provide the appropriate balance of intelligent control and convenience to reduce plug load waste while minimizing required changes in occupant behavior. Currently available APS devices are primarily designed for use in home entertainment centers and home offices, where the concentration of consumer electronics is typically high, and the controls rely on sensing the power state of the designated “master” appliance (usually the TV or computer). Power to peripheral equipment (e.g., DVD player, game console, printer) is turned off when the master device is turned off or in standby mode.

Two different APS products were used in this demonstration: one for the home entertainment area and another for the home office. Both rely on current sensing for control, but the APS for the home entertainment center has one additional layer of control.

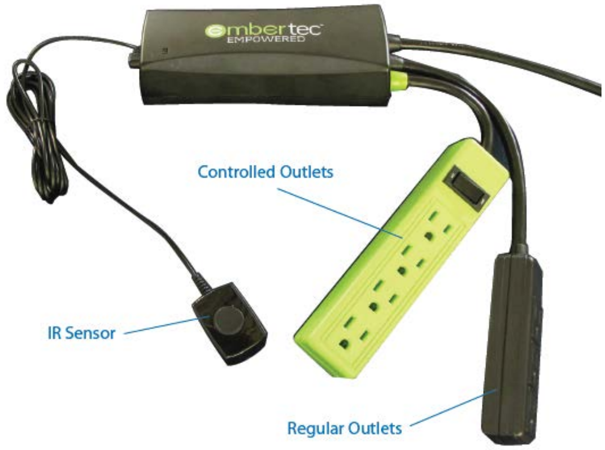


**Figure 1. Embertec Emberceptor AV APS for entertainment centers**

The Embertec Emberceptor AV, shown in Figure 1, was used in the home entertainment centers. This is a current-sensing APS that uses an infrared (IR) sensor for additional control. Power to the green "controlled" outlets is shut off if all the connected devices are turned off (i.e., the current draw is very low). The controlled outlets are turned back on when the IR sensor detects the use of a remote control (the IR sensor does not detect occupant movement). A timer function exists that turns off the controlled outlets if there has not been any remote control activity for three hours. This feature can be useful in homes where the television is often left on inadvertently. The remote control activity is used as a proxy to indicate someone is actively using the television. Before the outlets are turned off with the timer function, a green indicator light flashes to warn the user. If there is no remote control activity, it is assumed the user has left the room or fallen asleep. This timer function can be turned off if desired. There are also three "always on" outlets available for devices that need to remain powered on at all times, such as a cable box.

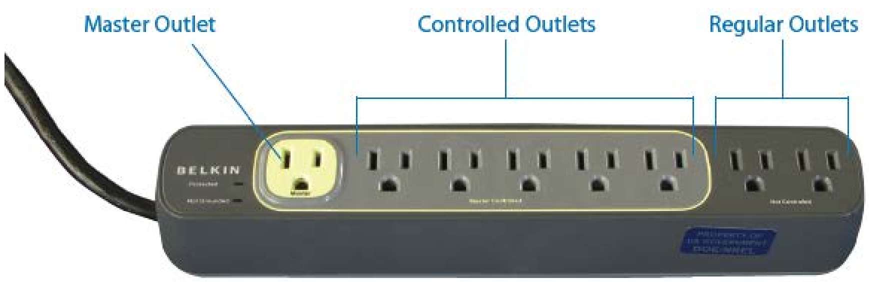


**Figure 2. Belkin Conserve APS for home offices**

The Belkin Conserve, shown in Figure 2, was used in the home office areas. This device has a typical master-controlled algorithm, where the computer is plugged into the "master" outlet and all related electronics are plugged into the controlled outlets. The controlled outlets are completely turned off when the computer is off or asleep. There are also two "always on" outlets for devices that need to remain powered on at all times, such as a wireless router.

### 2.1.2 Water Heating and Cooling Load Reduction Technologies

#### Heat Pump Water Heater

An HPWH pulls heat from the surrounding air and uses it to heat the water in a storage tank. The newest generation of this equipment is an integrated system with a built-in storage tank. Because heat is extracted from the air rather than generated directly, an HPWH offers significant energy savings over a conventional electric resistance water heater. This technology is ideally suited to Guam's hot, humid climate, and is a particularly attractive alternative where gas heating is not available, electricity prices are high, and typhoon-resistant solar water heating installation can be expensive. An HPWH can usually be installed as a direct replacement to the existing storage tank water heater without additional changes to the plumbing or surroundings, provided that sufficient space requirements are met. See Figure 3.

**Figure 3. A.O. Smith Voltex 60-gallon HPWH**

#### SEER 21 Air Conditioner and Variable-Speed Air Handler

Replacing the existing air conditioning (A/C) system with a newer, higher efficiency-rated system significantly decreases energy required to cool the house. See Figure 4 and Figure 5.

**Figure 4. Lennox XC21 A/C**

**Figure 5. Lennox CBX32MV variable speed, multi-position air handler**

### *Air Conditioner-Integrated Whole-Home Dehumidification System*

In three of the eight homes, the standalone dehumidifier was replaced with a whole-home dehumidification system that features advanced control logic designed to integrate with the new A/C system to maintain optimal indoor humidity. The dehumidifier is located in the same closet as, and positioned in series with, the air handler unit (AHU). See Figure 6.

**Figure 6. Lennox Humiditrol whole-house dehumidification system**

### *Programmable Thermostat*

The existing thermostat was replaced with a programmable thermostat that allows residents to set a schedule that works for them, such as a daytime setup. Modest increases in thermostat set points during unoccupied hours can result in substantial reduction in HVAC-related energy consumption. The thermostat is also a humidistat that is needed for control in the homes with the new whole-home dehumidifier. See Figure 7.


**Figure 7. Lennox iComfort Wi-Fi thermostat**

### *Low-Flow Shower Head*

All existing shower heads were replaced with low-flow shower heads to reduce hot water consumption. See Figure 8.


**Figure 8. American Standard 1660.717.002 FloWise three-function showerhead**

# 3 Demonstration Design

This demonstration was designed as two parts due the relative magnitude of expected savings. Larger savings were expected from improving A/C and DHW efficiency so fewer homes were needed. APSs have much smaller expected savings so a larger sample size was needed for statistical purposes. Both parts of the demonstration included a base load monitoring period before efficiency measures were installed. In addition to energy consumption of the appliances of interest, temperature and relative humidity data were collected for the EEE demonstration at five locations in each home (four in the house and one by the HPWH), along with hot water consumption data. These data continued to be collected after the efficiency upgrades were installed. In APS homes, energy consumption of plug load areas were collected (e.g., home entertainment area, home office) before and after APS installation.

The overall schedule for both parts of this demonstration was as follows: first, monitoring equipment was installed in the homes to provide base load data from before the retrofits. Equipment upgrades were then implemented, and the post-retrofit energy use was monitored for several months afterward. Data collection occurred throughout the baseline and demonstration periods. The data were analyzed at the end of the study period when the monitoring equipment was removed. All efficiency upgrades remained in place after the conclusion of the demonstration.

## 3.1 Demonstration Design and Simulation

The two demonstrations were designed using a combination of past laboratory tests and simulation studies.

### *3.1.1 Advanced Power Strip Demonstration Design*

The APS demonstration specifically targeted reducing plug loads in residential buildings, which are primarily concentrated in the home office and home entertainment center. APSs, which are designed specifically for use with consumer electronics in these areas, are commercially available and underutilized so this demonstration presented an opportunity to measure their efficacy in real home scenarios.

The choice of APSs deployed in this demonstration was based on laboratory tests performed at NREL in 2012 (Earle & Sparn, 2012). The laboratory tests were focused on assessing how effective the APSs are and how much they impact a user's normal operation of the connected electronics. The two APSs chosen for the demonstration (the Emberceptor AV and the Conserve) scored high in effectiveness and usability. The Emberceptor AV is a masterless APS with a unique feature that monitors remote control activity in the entertainment center and shuts off the controlled electronics if it detects they are no longer being used (either because the user has fallen asleep or left the room). The Conserve is a master-controlled APS with an auto-adjusting threshold, which works well in home office environments.

### *3.1.2 Enhanced Energy Efficiency Demonstration Design*

Guam is a tropical island with year-round cooling and dehumidifying loads, which make up a large fraction of the energy used in residential buildings there. While the home’s envelope plays a large role in the space-conditioning needs of the house, it was not feasible in this project to improve the windows or walls of the existing homes. With this in mind, this demonstration focused on reducing cooling and water heating loads by replacing existing large equipment with higher-efficiency models. The most cost-effective choice for the suite of new appliances was determined using BEopt, a building energy optimization software developed at NREL (Christensen, Anderson, Horowitz, Courtney, & Spencer, 2006).

Results from the BEopt simulation for one of the EEE homes are shown in Figures 9 and 10. Beginning with a model of the existing house, a set of options to be considered was selected, and utility costs were specified. The software then created a model for each possible combination of features, and output the cost and energy savings associated with each option, as shown in Figure 9. The total cost takes into account the cost to purchase and install a particular option, as well as the effect on the home's utility bills. A detailed comparison by energy end use is shown in Figure 10.

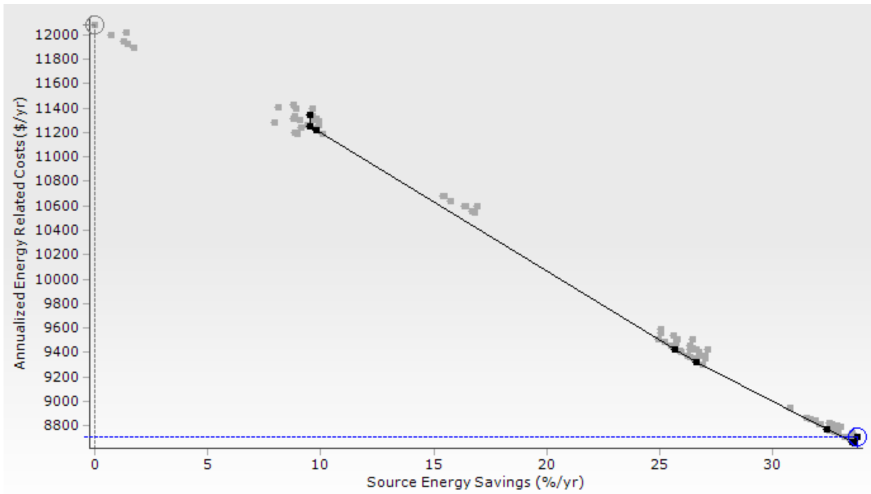


**Figure 9. BEopt optimization curve for one of the EEE homes**

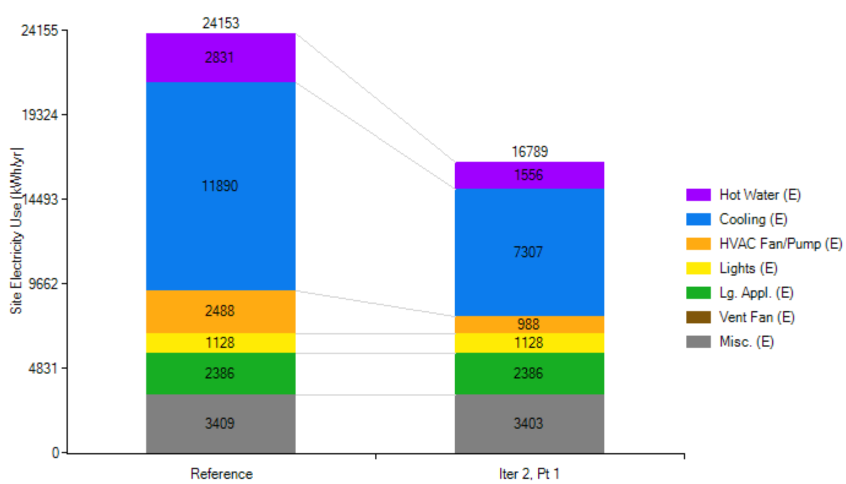


**Figure 10. Simulated annual energy consumption by end use for pre- and post-retrofit home**

In order to address the largest energy consumers in the home, several energy efficiency measures were installed. The current air conditioning units (approximately SEER 13) were replaced with SEER 21 units. In three of the eight homes, a Humiditrol whole-home dehumidification system was also installed to help maintain the desired humidity level in the home. The Humiditrol is a product made by Lennox that integrates with the air handler, downstream of the evaporator coils. This replaced the existing standalone dehumidifier that supplies warmer and dryer air to the intake of the air handler. To control the HVAC equipment based on temperature and humidity, a programmable combined thermostat and humidistat was installed in all homes, including those that did not have the Humiditrol installed. This gave the residents more control over their space-conditioning systems if they chose to take advantage of it. All residents were trained by the installation contractor on how to use their thermostat and the rest of their new equipment. Improved dehumidification should lead to improved comfort, not necessarily reduced energy consumption, so four temperature and relative humidity (T&RH) sensors were installed throughout each house.

Hot water is the second largest residential energy consumer after HVAC. The existing electric resistance water heaters were replaced with HPWHs. The water heaters in each of the EEE homes were located in unconditioned spaces—either in the garage or in an outdoor closet. This means the water heaters are surrounded by warm, humid air all year long, which is the optimal environment for a HPWH. All shower fixtures were replaced with low-flow shower heads to reduce hot water consumption as well. A flow meter was installed on the water heater to monitor daily hot water consumption before and after the low-flow shower head installation. A T&RH sensor was installed near the HPWH to monitor installed performance.

The homes in each neighborhood are very similar to one another, but different occupants introduce wide variability in energy consumption patterns. Air conditioning loads are affected by set point temperature and occupant behavior, such as leaving doors or windows open. Dehumidification loads are similarly affected by the set point of the dehumidifier and occupant behavior, such as how often they cook or take showers. Hot water use is driven by occupant behavior, including how often they do laundry, run the dishwasher, and bathe. In addition to improved efficiency in the HVAC system, a programmable thermostat was installed in each home. The objective of the demonstration was not to require or expect any changes in occupant behavior, but rather to measure "effortless" energy savings achieved by simply installing higher-efficiency systems.

## 3.2 Facility/Site Description

Site selection for the two demonstrations was based on criteria set by NREL. NBG was responsible for recruiting residents for the APS demonstration, but participation was strictly voluntary. The EEE homes, on the other hand, were chosen by the housing office while they were still vacant. Specific criteria for each of the two demonstrations are outlined below.

### *3.2.1 Advanced Power Strip Demonstration Sites*

Because of the expected large variations in energy savings associated with installing APSs, 30 homes participated in this demonstration. The criteria used to recruit participants included:

- Residents must live in their homes for the duration of the demonstration (through late Fall 2013).
- Residents have at least a home entertainment center with two devices that can be controlled with the APS (such as a DVD player and game console).
- A home office is desired but not required. Similarly, the home office should have at least two devices that can be controlled with the APS (such as a monitor and printer).
- Residents must be willing to answer a survey at the beginning and end of the study.
- Residents must be willing to have their electricity use monitored by NREL during the demonstration period. No personally identifiable information is reported in the test results.

Participant recruitment was conducted by the Facilities Housing division using a combination of the following methods:

- Distribute "APS Fact Sheet" (see Appendix A) to residents at Town Hall meetings and other gatherings to solicit interest.
- Recruit participants with help from the housing inspectors during the standard intake procedure for new residents.
- Work with Barracks Housing Director to recruit residents in the Barracks.

There were 30 homes participating in the APS demonstration. The APS devices deployed in these homes are summarized in Table 1.

**Table 1. APS Demonstration Participants**

| Participating Residence | # of APSs in Entertainment Center | # of APSs in Home Office Area |
|---|---|---|
| House A | 2 | 1 |
| House B | 2 | 0 |
| House C | 1 | 1 |
| House D | 1 | 0 |
| House E | 1 | 0 |
| House F | 1 | 0 |
| House G | 1 | 1 |
| House H | 2 | 1 |
| House I | 1 | 1 |
| House J | 1 | 1 |
| House K | 1 | 0 |
| House L | 1 | 1 |
| House M | 2 | 0 |
| House N | 1 | 1 |
| House O | 1 | 1 |
| House P | 1 | 0 |
| House Q | 1 | 1 |
| Barracks A | 1 | 1 |
| Barracks B | 1 | 0 |
| Barracks C | 0 | 1 |
| Barracks D | 1 | 0 |
| Barracks E | 1 | 1 |
| Barracks F | 1 | 1 |
| Barracks G | 0 | 1 |
| Barracks H | 1 | 0 |

| Participating Residence | # of APSs in Entertainment Center | # of APSs in Home Office Area |
|---|---|---|
| Barracks I | 1 | 0 |
| Barracks J | 1 | 0 |
| Barracks K | 1 | 1 |
| Barracks L | 1 | 0 |
| Barracks M | 1 | 0 |
| **Total** | 32 | 16 |

### 3.2.2 Enhanced Energy Efficiency Demonstration Sites

The EEE demonstration targeted single-family residential housing that is typical of NBG housing (see Figure 11 and Figure 12). Eight homes were selected by the housing staff at NBG for this demonstration and are listed in Table 2. The homes were chosen because of their location in desirable housing areas, and the installed locations and layouts of their HVAC and DHW systems. The detailed criteria used to select the EEE homes and their occupants were:

- Households must have a minimum of two occupants. Families of three or more are preferred.
- Houses must have uninsulated, concrete walls and single-paned windows, to be consistent with the majority of homes on NBG.
- To ensure efficient allocation of resources and maximize demonstration effectiveness, the building's HVAC or water heater equipment (preferably both) should be due for an upgrade.
- Floor plans where water heaters are located in rooms large enough to comply with HPWH installation requirements are preferred.
- Occupants must be willing to respond to a questionnaire at demonstration closeout, which includes basic questions about their experience with the new appliances.
- Occupants must be willing to have their electricity use monitored by NREL during the demonstration period. No personally identifiable information is reported in the test results.

While the homes were unoccupied when they were chosen for the demonstration, all prospective residents were informed of the details of the project before they moved in. They were given the option of choosing a different house if they did not wish to participate.

Of the eight homes, six are in the same neighborhood (North Tipalao) and are newer homes, all of which are part of duplexes. The other two homes are in an older neighborhood (Lockwood Terrace) and are detached single-family homes (SFH). All the homes are roughly the same size (1,500 ft$^2$). The map in

Figure 13 shows the area where these houses are located.

**Figure 11. Typical residence in Lockwood Terrace neighborhood on NBG**

**Figure 12. One side of a duplex in the North Tipalao neighborhood on NBG**

**Table 2. EEE Demonstration Participants**

| Neighborhood | Participating Home | Notes |
|---|---|---|
| Lockwood Terrace | Lockwood 1 | |
| | Lockwood 2 | Dehumidifier replaced. |
| North Tipalao | Tipalao 1 | |
| | Tipalao 2 | |
| | Tipalao 3 | Tipalao 3 and 4 are two sides of duplex unit. Dehumidifier was replaced in Tipalao 3. |
| | Tipalao 4 | |
| | Tipalao 5 | Dehumidifier replaced. |
| | Tipalao 6 | |

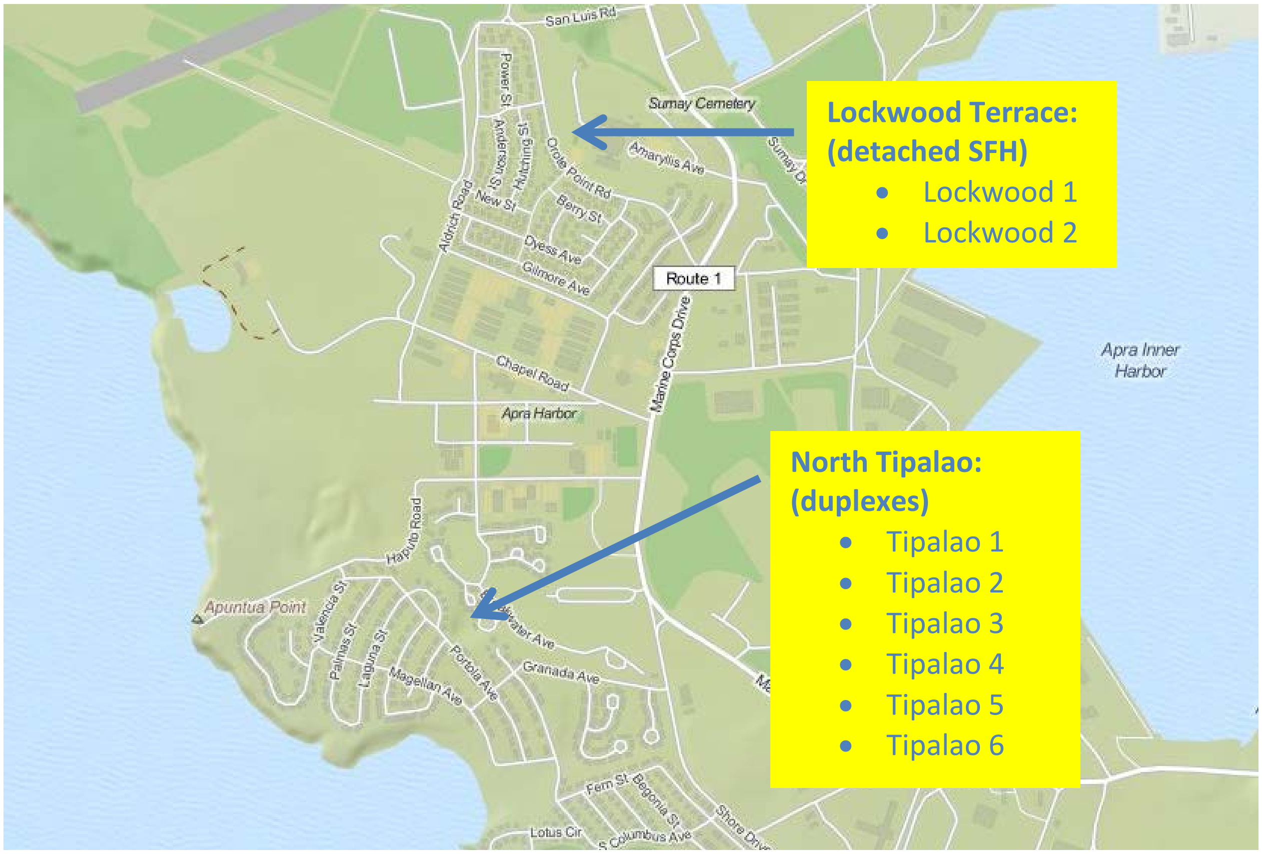


**Figure 13. Map of EEE demonstration sites**

## 3.3 Monitoring Equipment and Installation

Monitoring equipment was installed in all demonstration locations to measure baseline data before any improvements were installed. The same monitoring equipment was also used during the demonstration phase to measure the energy consumption and comfort after the new technologies were installed.

### *3.3.1 Advanced Power Strip Demonstration Monitoring Equipment*

The data for the APS homes were collected by internet-connected Watt'sUp.net meters. The plug load meter plugged into the wall outlet, and the power strip for the home entertainment area or home office plugged into the meter, allowing the meter to measure the total energy consumed by all devices that were plugged into the power strip (and nothing else). This is important because the change in energy consumption due to the APS may be small, and it would be difficult to extract the effect of the APS if the energy monitoring was done at the circuit breaker level. The plug pass-through meter does not require an electrician for installation.

The Watt'sUp.net meter has an Ethernet port that allows it to upload data to their cloud. A wireless hotspot and wireless-to-Ethernet bridge were installed in each home to enable data collection. In homes with both a home entertainment center and a home office (or two separate home entertainment centers suitable for the demonstration), a single wireless hotspot was installed, but two sets of the Watt'sUp.net meter and wireless bridge were needed. A sample of this setup, including the enclosure holding the hotspot and bridge, is shown in Figure 14.


**Figure 14. A Watt'sUp.net meter setup**

The Watt'sUp.net meters collected data every minute and automatically logged the data in their online cloud database. Additional details for the Watt'sUp.net meter is listed below in Table 3.

**Table 3. Data Collection Details for APS Demonstration**

| Meter | Description | Units | Sample Freq. | Accuracy | Data Recording and Backup | Data Collector |
|---|---|---|---|---|---|---|
| Watt'sUp.net | Power and energy consumption of electronics | W, Wh | 1 min | +/-3% for loads >10W +/-5% for loads <10W | Data recorded in cloud automatically, downloaded, and saved locally | NREL, via cloud |

After a resident volunteered to participate in the APS demonstration, an NREL researcher or local subcontractor scheduled a time to go to their house to install monitoring equipment. The pre-demonstration questionnaire was filled out the same time the monitoring equipment was installed. A laptop was used to check that the Watt'sUp.net meters were uploading data to the cloud before the installation was completed.

There were no calibration requirements for the monitoring equipment. The stated accuracy is +/-3% for loads greater than 10 watts (W), and +/-5% for loads below 10 W, which is sufficient for our analysis needs. The equipment accuracy is under warranty for 12 months from the date of purchase, long enough to cover the duration of the demonstration.

The remotely accessible data were reviewed at least every two weeks to ensure data were uploaded correctly and the results were reasonable. Any issues with connectivity or abnormal data points were investigated by NREL or local technical resources.

### 3.3.2 Enhanced Energy Efficiency Demonstration Monitoring Equipment

The monitoring package for each EEE house consisted of:

- An eMonitor energy monitor system with current transformers (CTs) in the breaker panel to monitor the energy consumption of the air conditioner (condenser unit), the air handler, the water heater, the dehumidifier, the range, and the dryer, as shown in Figure 15. (The range and dryer were not replaced but represent large heat sources that affect cooling loads in the house.) The data collected by the eMonitor were uploaded to their cloud via a wireless hotspot.
- A Minol 130 turbine flow meter was installed on the inlet to the water heater. Pulse output data were collected by a HOBO state data logger that was connected to the flow meter. The flow meter and state logger are shown in Figure 16. The HOBO logger stores data locally so hot water usage data can only be collected from the meter directly. Data collection was done at the conclusion of the demonstration period.
- Five HOBO T&RH sensors were installed around the house, including one installed near the HPWH to help determine expected performance. One T&RH sensor was installed next to the home's thermostat, as seen in Figure 17. The other three were installed around the house to capture any room-to-room variations in temperature or humidity. These loggers have local storage similar to the state logger used with the flow meter. These data were collected at the conclusion of the demonstration period.

The eMonitor system included a wireless gateway that was installed near the breaker panel. A wireless hotspot allowed the gateway to upload data from the eMonitor to their cloud. If the eMonitor logger lost connection to the internet, it would store up to two weeks' worth of data. Once the connection was reestablished, the locally stored data were uploaded to the cloud. The eMonitor data on the cloud could be accessed by NREL at any time and were downloaded regularly to ensure adequate backup. The temperature and relative humidity sensors and the state logger for the flow meter could log data for up to seven months, but were not accessible remotely. To ensure enough storage space for several months of data, the data collection rate was set to record a data point every 15 minutes. All datasets were time-stamped in a consistent fashion.

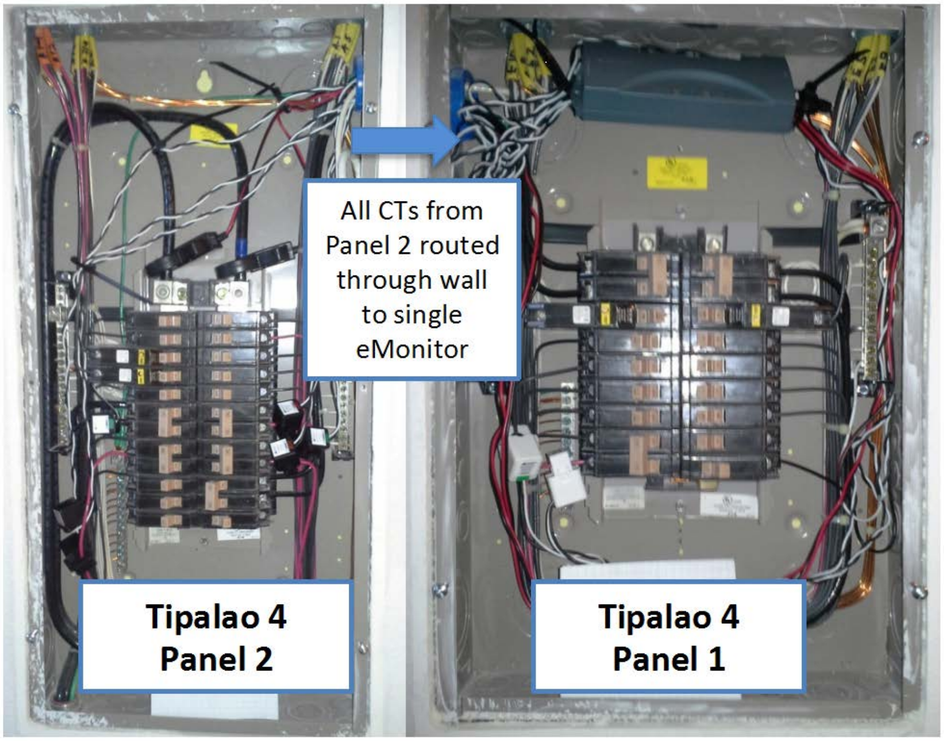


**Figure 15. An eMonitor meter installed in an EEE home with two breaker panels**

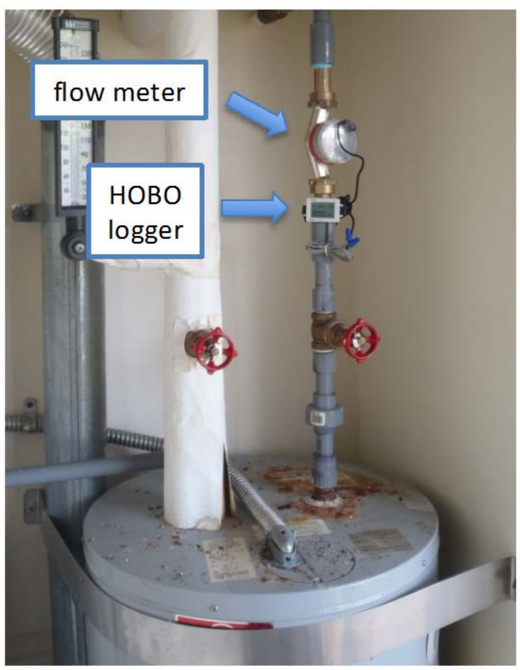


**Figure 16. A flow meter and HOBO state logger at the water heater**

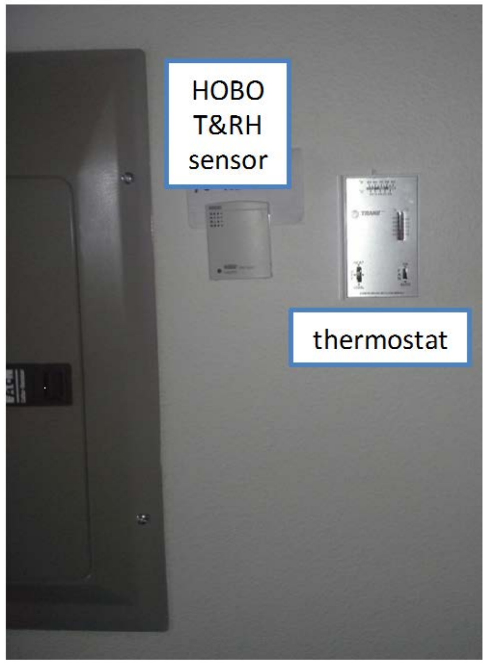


**Figure 17. A T&RH sensor next to the thermostat in an EEE home**

**Table 4. Data Collection Details for EEE Demonstration**

| Meter | Description | Units | Sample Freq. | Accuracy | Data Recording and Backup | Data Collector |
|---|---|---|---|---|---|---|
| eMonitor | Whole-house power and energy consumption | W, Wh | 1 min | +/-2% within 10%-130% range of CT rating | Data recorded in cloud, downloaded at NREL. Logger stores data for up to 2 weeks. | NREL, via cloud |
| eMonitor | A/C power and energy consumption | W, Wh | 1 min | +/-2% within 10%-130% range of CT rating | Data recorded in cloud, downloaded at NREL. Logger stores data for up to 2 weeks. | NREL, via cloud |
| eMonitor | Water heating power and energy consumption | W, Wh | 1 min | +/-2% within 10%-130% range of CT rating | Data recorded in cloud, downloaded at NREL. Logger stores data for up to 2 weeks. | NREL, via cloud |
| eMonitor | Range/oven power and energy consumption | W, Wh | 1 min | +/-2% within 10%-130% range of CT rating | Data recorded in cloud, downloaded at NREL. Logger stores data for up to 2 weeks. | NREL, via cloud |
| eMonitor | Clothes dryer power and energy consumption | W, Wh | 1 min | +/-2% within 10%-130% range of CT rating | Data recorded in cloud, downloaded at NREL. Logger stores data for up to 2 weeks. | NREL, via cloud |
| HOBO U12 T&RH sensors | Temperature and relative humidity | °C, DL | 15 min | Temp: ± 0.35°C from 0° to 50°C<br>RH: ± 2.5% from 10% to 90% | Data saved locally, stored for up to 7 months | NREL or sub, manually collected on site |
| Minol 130 turbine flow meter, HOBO state data logger | Hot water usage | gallons, gpm | 15 min | AWWA spec<br>97%-103% | Data saved locally, stored for up to 7 months | NREL or sub, manually collected on site |

The eMonitor and CTs were located inside the breaker panel and installed by an electrician. The internet gateway that transmits data to the cloud was placed inside a plastic junction box, along with the wireless hotspot. This box was mounted on a wall near the breaker panel. All of the HOBO T&RH loggers were mounted on walls around the house. They did not need to be housed in enclosures. The flow meter was installed by a plumber in the cold water inlet for the water heater. The HOBO state logger was installed nearby, with a wire connecting the flow meter and the HOBO logger.

There were no calibration requirements for the monitoring equipment. The manufacturers' stated accuracies were sufficient for our analysis needs and are summarized in Table 4. The data were reviewed at least every two weeks to ensure the eMonitor gateway was uploading correctly and the measurements were reasonable. Any issues with connectivity or abnormal data points were investigated immediately by NREL or local technical resources. While the seasonal weather variations in Guam are not significant (it is tropical year-round), the energy use data collected during the baseline and demonstration periods were used to create year-long simulations for both cases, so as not to bias the results by comparing the energy use between two different seasonal periods. The baseline data collection period coincided with the warmest part of the year and the demonstration period occurred when the weather was a little cooler. Significant occupancy changes due to school holidays (e.g., summer vacation) were evaluated for the best approach to account for them in the pre/post comparisons.

## 3.4 Baseline Characterization

### 3.4.1 Advanced Power Strip Demonstration Baseline Testing

Once the monitoring equipment was installed, the baseline characterization began. The residents were asked to use their electronics as they would normally. The start date and duration of the baseline phase was dependent on when the residents were recruited and how much time was available before the end of the project. The energy consumption in the home entertainment center and/or home office was measured during this time to establish reference conditions.

Because the participants for the APS demonstration were recruited over several months, the baseline monitoring period did not start or end for all homes at the same time. Monitoring equipment for the APS homes was installed on a rolling basis so the baseline period varied between homes. NREL did not expect noticeable seasonal variability in home entertainment and home energy use (with the possible exception of occupancy changes related to school holidays), so a couple of months of baseline data were deemed sufficient.

### 3.4.2 Enhanced Energy Efficiency Demonstration Baseline Testing

For half of the EEE homes, the baseline period began as soon as the monitoring equipment was installed in January 2013, as they were occupied by that time. The other homes were unoccupied at the time the monitoring equipment was installed, and their baseline testing began once people moved in. The last home to be occupied (residents moved in July 2013) had a little over a month of baseline data collected before the new equipment was installed. The other homes generated several months of baseline data. Because Guam is a cooling climate all year long and there is little seasonal variation, a month of baseline data was deemed sufficient as long as there were no extreme weather events during the month. The measurements listed in Table 4 were all recorded during the baseline period to establish a reference for the energy consumption, indoor comfort conditions, and hot water consumption before the retrofits.

Local weather datasets from the National Oceanic and Atmospheric Administration (NOAA) website from the monitoring period were used to drive our energy simulation tool. The simulations were used to extrapolate separately the baseline and the demonstration data over a full year for broader comparison. This helped us account for changes in weather that could affect space-conditioning energy consumption. Even though Guam's weather is fairly consistent over the course of a year, short-term events like tropical storms have noticeable impacts on residential energy use. Also, the baseline testing happened to coincide with the warmest time of the year and demonstration period was in the slightly cooler fall season, which could exaggerate the energy savings if annual simulations are not used for normalization.

## 3.5 Demonstration Period

### 3.5.1 Advanced Power Strip Demonstration

After a minimum of four weeks of monitoring the baseline energy consumption, the residents were mailed their APSs with detailed instructions (See Appendix B) on how to set them up. They were also provided with contact information for local technical support if they needed additional help. In several cases, a local technical support person went to the homes to install the APSs for the residents. Once NREL had confirmation the APSs were installed, either by observing a change in the energy consumption data or by speaking with the residents, the demonstration period began. The monitoring equipment used for baseline data collection remained installed and was used to collect energy use data during the operational testing period.

The beginning of the demonstration period varied between volunteers because they signed up at different times and they installed their APSs at different times. The first group of homes was fully instrumented in late January 2013, and APSs were sent in April. The demonstration period lasted for two to three months, so the demonstration for the first group finished in June. The second group of participants had their monitoring equipment installed in March and the APSs sent in June. The last group of participants had their monitoring equipment installed in July and the APSs sent in September.

At the conclusion of the demonstration period, the residents were given a final questionnaire designed to help NREL assess qualitative aspects of the technology's effectiveness. The monitoring equipment was removed, but the APS devices were theirs to keep.

### 3.5.2 Enhanced Energy Efficiency Demonstration

The installation of EEE equipment was scheduled for late summer 2013, to ensure that all the homes were occupied and we had sufficient baseline data before the demonstration began. Chugach World Services was selected through a competitive bidding process to procure and install all the equipment for the eight EEE homes. The installations began on July 30, 2013, and were finished a month later, on August 30, 2013.

In each home, the water heater was replaced with a 60-gallon A.O. Smith HPWH, and the shower heads were replaced with low-flow ones. The condensing unit and air handler for the air conditioner were replaced with higher-efficiency Lennox units. The homes in North Tipalao had 3-ton A/C units installed, while the slightly larger homes in Lockwood Terrace had 4-ton units installed. In three homes, Lockwood 2, Tipalao 3, and Tipalao 5, the standalone dehumidifier was replaced with an in-line dehumidifier that is installed downstream of the fan coil in the air handler. All the homes had their thermostat replaced with a programmable thermostat, which also serves as a humidistat for the homes with new in-line dehumidifiers.

Once the installation of new equipment was completed at each house, the demonstration period began. The residents were given training on their new appliances and the thermostat, and were instructed to maintain comfort in the home. They were free to change the set points for the water heater and air conditioner. The demonstration period lasted two to three months, depending on when their installation took place. All monitoring equipment was removed at the beginning of November. All of the energy-efficient equipment (the appliances that were upgraded) remained installed and will be maintained by the facility staff at NBG.

## 3.6 Summary of Performance Objectives

Data were collected before and after the energy-efficiency measures were implemented to evaluate the technical objectives of the project. The performance objectives are summarized in Table 5.

**Table 5. Performance Objectives**

| | Performance Objective | Metric | Data Requirements | Success Criteria |
|---|---|---|---|---|
| **Quantitative Performance Objectives** | | | | |
| 1 | Whole-house energy savings | Energy (kWh) | Whole-house electrical energy consumption | 10% reduction compared to baseline |
| 2 | DHW energy savings | Energy (kWh) | DHW electrical energy consumption | 20% reduction compared to baseline |
| 3 | HVAC energy savings | Energy (kWh) | A/C electrical energy consumption | 20% reduction compared to baseline |
| 4 | Indoor comfort | Temperature (C)/ Relative Humidity (DL) | Temperature and relative humidity measured at 3-4 locations in each home | Conditions comparable or better than before while occupants are home |
| 5 | DHW use reduction | Volume consumed (gal) | Volumetric flow measurement at outlet of water heater | 20% reduction compared to baseline |
| 6 | Home entertainment center and home office plug load energy savings | Energy (kWh) | Energy monitor at the electrical receptacle where APS is located | 10%-50% reduction compared to baseline, depending on type and vintage of consumer electronics used |
| **Qualitative Performance Objectives** | | | | |
| 1 | User satisfaction with HPWH | | Post-demonstration survey (see Appendix C and D) | Resident satisfaction with implemented measures, as indicated by survey responses |
| 2 | User satisfaction with thermostat | | | |
| 3 | User satisfaction with APS | | | |

## 3.7 Pre- and Post-Demonstration Surveys

The volunteers for the APS demonstration were asked to fill out pre- and post-demonstration questionnaires. The pre-demonstration questions asked residents to describe the equipment used in their home entertainment and office spaces and frequency of use. The post-demonstration questions asked the residents whether their new APSs interfered in any way with normal operation of their electronics. The pre- and post-demonstration questionnaires are attached in Appendix C.

The residents of the EEE homes were also asked to fill out post-demonstration questionnaires about their new equipment. They were asked whether they liked their energy efficient appliances and whether they noticed any changes in performance (see survey in Appendix D). Survey results are presented in Section 4.

# 4 Technical Performance Analysis and Assessment

## 4.1 Overview

### *4.1.1 Overview of Technical Performance for Advanced Power Strip Demonstration*

The lengths of the baseline and demonstration periods for each APS house differed depending on when the residents signed up to participate. The baseline and demonstration data were analyzed in similar fashion—the measured energy use was totaled for each day, and the mean daily energy use was computed separately for the pre-APS (="baseline") and post-APS (="demonstration") phases. Data were collected at one-minute intervals and uploaded to the Watt'sUp cloud, where it could be downloaded at NREL. The internet connection for the Watt'sUp.net meters was provided by cellular hotspots subscribing to a data service from Docomo Pacific. The data connection was not always reliable and frequent power outages resulted in some lost data. Incomplete days of data were excluded from our analysis.

### *4.1.2 Overview of Technical Performance for Enhanced Energy Efficiency Demonstration*

The energy consumption data were logged every minute and uploaded to the eMonitor cloud for remote collection at NREL. The eMonitor data logger's gateway used an internet connection provided by a cellular hotspot with Docomo Pacific data service. If the internet connection was lost, the eMonitor's on-board storage could log data for up to two weeks or until the internet connection was restored. The T&RH sensors and hot water flow meter in each house were standalone loggers with no remote data upload capability, so the T&RH and hot water use data for the entire duration of the project were collected at the end of the demonstration. The energy measurements allowed NREL to compare the mean daily energy consumption before the retrofit and after the new equipment was installed. The T&RH information was used to evaluate indoor comfort, and to see whether the residents operated their homes any differently after the retrofits were installed (e.g., changes in cooling set point). The flow meter was used to measure the effect of the low-flow shower heads and determine how much of the reduction in hot water energy use can be attributed to the water heater upgrade and how much was caused by a reduction in hot water end use.

## 4.2 Results

### *4.2.1 Advanced Power Strip Demonstration Results*

Data collected from the Watt'sUp.net meters was aggregated into daily energy consumption. Many days of data were not complete as a result of the persistent connectivity problems. Any day with less than 14 hours of data (or 60% of the day) was excluded from the analysis. The number of days that had to be excluded varied significantly from house to house. Some homes had reliable data throughout, while other homes generated only a few days of usable data despite having monitoring equipment installed for months. A handful of residences (mostly in the barracks) had monitoring equipment installed, but the signal reception for the hotspot was so poor that connectivity problems resulted in no useful data for pre/post comparison. Those homes were excluded from the savings analysis. A summary of the total number of installations and the reasons why some data were excluded is given in Table 6.

**Table 6. Summary of APS Installations**

| | Total Installations | Installations that Resulted in Useful Data | Reasons Why Some Homes Were Excluded |
|---|---|---|---|
| Entertainment Center | 32 | 23 | • TV was inadvertently left off the energy monitor during the pre-APS period so unable to do pre/post comparison<br>• Fewer than 2 total days of post-APS data were available<br>• Data showed no use of electronics after APS was installed, so unable to compare pre/post |
| Office | 16 | 12 | • Energy use is too small for both pre- and post-period, indicating no use of electronics<br>• Apparently APS installation was followed by a period of zero electronics use (resident out of town?) so unable to do fair pre/post comparison<br>• Only 1 day of post-APS data available |

The mean daily energy consumption for pre- and post-APS installation for each entertainment center installation is given in Table 7. The results from the home office installations are given in Table 8. The uncertainties reported for the daily mean energy use are standard deviation of the mean, which dominate over sensor accuracy. The predicted annual savings is an extrapolation assuming the mean daily energy use in the pre- and post-APS periods provide reasonable estimates for a full year when multiplied by 365. Significant variability in the magnitude of expected savings exists across our sample, and this underscores the difficulty of this type of demonstration where the signal-to-noise ratio is small for any given house. Plug load energy use characteristics are unique to each family, and a large sample size is required to achieve statistically meaningful results.

In some cases, the savings number is negative, and this could be explained by a number of things. There could have been unusually low use during the baseline period (or equivalently, heavy use after the APS was installed). In cases where sample size (number of days of monitoring data) was small, a few outliers in the datasets could dramatically impact the mean energy use, and it may be the savings is essentially statistically zero. While it is reasonable to expect some homes will not save energy with APS, it is difficult to explain increased energy use without a corresponding increase in equipment use unrelated to APS installation.

**Table 7. Mean Daily Energy Consumptions for Home Entertainment Center Installations**

| Residence | Location Within Home | Pre-APS Mean Daily Energy Use (Wh) | | Post-APS Mean Daily Energy Use (Wh) | | Annual Savings Predicted (kWh/yr) | |
|---|---|---|---|---|---|---|---|
| House A | Main | 3010.3 | ±205.1 | 2673.4 | ±109.1 | 123.0 | ±84.8 |
| | Bedroom | 352.2 | ±26.1 | 509.0 | ±50.1 | -57.2 | ±20.6 |
| House B | Main | 1315.8 | ±75.3 | 1300.3 | ±118.6 | 5.7 | ±51.3 |
| | Bedroom | 1529.7 | ±168.7 | 442.3 | ±25.2 | 396.9 | ±62.3 |
| House C | Main | 368.7 | ±17.9 | 277.8 | ±31.1 | 33.2 | ±13.1 |
| House D | Main | 3612.8 | ±179.4 | 3482.5 | ±171.1 | 47.6 | ±90.5 |
| House E | Main | 842.2 | ±61.3 | 618.0 | ±61.7 | 81.8 | ±31.7 |
| House F | Main | 2248.3 | ±60.3 | 2014.4 | ±337.3 | 85.4 | ±125.1 |
| House G | Main | 814.8 | ±24.6 | 403.1 | ±24.3 | 150.3 | ±12.6 |
| House H | Main | 2245.2 | ±110.5 | 2756.2 | ±507.1 | -186.5 | ±189.4 |
| | Bedroom | 1998.6 | ±110.3 | 2819.6 | ±1162.6 | -299.7 | ±426.3 |
| House I | Main | 845.1 | ±32.1 | 889.1 | ±60.5 | -16.1 | ±25.0 |
| House J | Main | 1381.0 | ±54.4 | 1088.4 | ±107.6 | 106.8 | ±44.0 |
| House K | Main | 1934.8 | ±58.7 | 482.4 | ±50.5 | 530.1 | ±28.3 |
| House L | Main | 3217.2 | ±110.2 | 2840.3 | ±109.6 | 137.6 | ±56.7 |
| House M | Main | 2513.4 | ±67.9 | 2024.8 | ±204.3 | 178.3 | ±78.6 |
| House N | Main | 1193.4 | ±32.2 | 1040.0 | ±74.4 | 56.0 | ±29.6 |
| House O | Main | 1762.7 | ±103.0 | 1924.8 | ±389.9 | -59.2 | ±147.2 |
| House Q | Main | 1956.2 | ±63.2 | 1788.5 | ±195.6 | 61.2 | ±75.0 |
| Barracks E | Main | 727.0 | ±185.6 | 2443.2 | ±275.9 | -626.4 | ±121.4 |
| Barracks I | Main | 197.3 | ±37.7 | 363.5 | ±144.6 | -60.7 | ±54.5 |
| Barracks L | Main | 1330.7 | ±75.4 | 862.9 | ±78.4 | 170.7 | ±39.7 |
| Barracks K | Main | 578.0 | ±60.0 | 1075.5 | ±681.5 | -181.6 | ±249.7 |

**Table 8. Mean Daily Energy Consumption for Home Office Installations**

| Residence | Pre-APS Mean Daily Energy Use (Wh) | | Pre-APS Mean Daily Energy Use (Wh) | | Annual Savings Predicted (kWh/yr) | |
|---|---|---|---|---|---|---|
| House A | 2901.4 | ±121.8 | 2427.5 | ±132.2 | 173.0 | ±65.6 |
| House C | 348.0 | ±23.8 | 282.0 | ±26.0 | 24.1 | ±12.9 |
| House G | 1576.8 | ±23.5 | 1503.1 | ±26.3 | 26.9 | ±12.9 |
| House H | 2057.4 | ±47.3 | 1678.8 | ±220.0 | 138.2 | ±82.1 |
| House I | 1624.3 | ±48.2 | 793.8 | ±108.3 | 303.1 | ±43.3 |
| House J | 459.3 | ±17.2 | 799.3 | ±577.8 | -124.1 | ±211.0 |
| House L | 908.4 | ±13.0 | 887.6 | ±11.0 | 7.6 | ±6.2 |
| House N | 542.4 | ±23.0 | 597.2 | ±34.6 | 53.5 | ±15.1 |
| House O | 727.6 | ±51.0 | 763.6 | ±88.7 | -13.1 | ±37.3 |
| House Q | 733.8 | ±87.2 | 338.3 | ±213.6 | 144.4 | ±84.2 |
| Barracks E | 159.1 | ±12.5 | 279.4 | ±61.4 | -43.9 | ±22.9 |
| Barracks K | 112.9 | ±12.5 | 48.8 | ±7.2 | 23.4 | ±5.2 |

### 4.2.2 Enhanced Energy Efficiency Demonstration Results

Energy use recorded by the eMonitors was totaled for each day, for each circuit measured, and for each house. Because of connectivity problems and power outages, there were occasional periods of missing data. For brief outages, NREL interpolated the accumulated energy by taking the mean of the adjacent timestamps. Where data were missing for longer than one hour, NREL flagged the entire day as "incomplete" and disregarded that day's data for pre/post comparison. The mean daily energy savings is the difference between the pre-retrofit and post-retrofit daily means. These results are summarized in Table 9, Table 10, and Table 11.

**Table 9. Summary of Mean Daily Energy Use for DHW Systems in EEE Homes**

| | Pre-Retrofit Mean Daily Energy Use (kWh/day) | | Post-Retrofit Mean Daily Energy Use (kWh/day) | | Daily Energy Savings (kWh/day) | | Percent Savings (%) |
|---|---|---|---|---|---|---|---|
| Lockwood 1 | 4.6 | ±0.3 | 0.9 | ±0.1 | 3.7 | ±0.3 | 79.8 |
| Lockwood 2 | 6.2 | ±0.4 | 1.5 | ±0.1 | 4.7 | ±0.4 | 75.7 |
| Tipalao 1 | 5.7 | ±0.3 | 2.1 | ±0.2 | 3.6 | ±0.4 | 63.2 |
| Tipalao 2 | 6.5 | ±0.2 | 1.7 | ±0.1 | 4.8 | ±0.3 | 73.5 |
| Tipalao 3 | 3.0 | ±0.2 | 1.1 | ±0.1 | 1.9 | ±0.2 | 63.6 |
| Tipalao 4 | 5.2 | ±0.3 | 1.6 | ±0.1 | 3.6 | ±0.3 | 68.9 |
| Tipalao 5 | N/A[a] | | | | | | |
| Tipalao 6 | 4.6 | ±0.3 | 1.8 | ±0.1 | 2.8 | ±0.4 | 61.5 |

[a] No water heater energy was measured before the retrofit.

**Table 10. Summary of Mean Daily Energy Use for HVAC Systems in EEE Homes**

| | Pre-Retrofit Mean Daily Energy Use (kWh/day) | | Post-Retrofit Mean Daily Energy Use (kWh/day) | | Daily Energy Savings (kWh/day) | | Percent Savings (%) |
|---|---|---|---|---|---|---|---|
| Lockwood 1 | 46.2 | ±2.5 | 34.6 | ±1.5 | 11.6 | ±3.0 | 25.0 |
| Lockwood 2[a] | 69.6 | ±3.2 | 45.0 | ±2.1 | 24.6 | ±3.8 | 35.3 |
| Tipalao 1 | 31.1 | ±1.4 | 23.0 | ±1.8 | 8.1 | ±2.3 | 26.0 |
| Tipalao 2 | 46.1 | ±1.3 | 22.2 | ±0.9 | 23.9 | ±1.6 | 51.9 |
| Tipalao 3[a] | 32.8 | ±1.3 | 19.4 | ±0.8 | 13.4 | ±1.5 | 40.8 |
| Tipalao 4 | 48.8 | ±2.0 | 20.8 | ±0.8 | 28.0 | ±2.1 | 57.4 |
| Tipalao 5[a] | 52.7 | ±3.0 | 36.4 | ±2.3 | 16.2 | ±3.8 | 30.8 |
| Tipalao 6 | 45.2 | ±2.4 | 32.3 | ±1.5 | 12.9 | ±2.8 | 28.6 |

[a] Homes with in-line dehumidifier installed.

**Table 11. Summary of Mean Daily Whole House Energy Use for EEE Homes**

| | Pre-Retrofit Mean Daily Energy Use (kWh/day) | | Post-Retrofit Mean Daily Energy Use (kWh/day) | | Daily Energy Savings (kWh/day) | | Percent Savings (%) |
|---|---|---|---|---|---|---|---|
| Lockwood 1 | 71.0 | ±3.8 | 53.9 | ±2.4 | 17.1 | ±4.5 | 24.1 |
| Lockwood 2[a] | 96.1 | ±4.4 | 65.4 | ±2.8 | 30.7 | ±5.2 | 32.0 |
| Tipalao 1 | 56.7 | ±2.6 | 50.7 | ±3.8 | 5.9 | ±4.6 | 10.5 |
| Tipalao 2 | 86.6 | ±2.5 | 49.0 | ±2.0 | 37.6 | ±3.2 | 43.4 |
| Tipalao 3[a] | 55.5 | ±2.2 | 38.4 | ±1.5 | 17.1 | ±2.7 | 30.8 |
| Tipalao 4 | 69.4 | ±2.7 | 38.7 | ±1.5 | 30.7 | ±3.1 | 44.3 |
| Tipalao 5[a] | 62.5 | ±3.5 | 46.5 | ±2.9 | 15.9 | ±4.6 | 25.5 |
| Tipalao 6 | 71.6 | ±3.8 | 57.8 | ±2.7 | 13.9 | ±4.6 | 19.4 |

[a] Homes with in-line dehumidifier installed.

Representative daily data for two homes, Lockwood 1 and Tipalao 3, over the demonstration period are shown in Figure 18 through Figure 23. These homes were chosen to show typical results from both neighborhoods. The energy used by the water heater is shown in Figure 18 and Figure 19. The dates marked by a light blue horizontal line indicate dates where data are missing or incomplete. The vertical green dotted line corresponds to the date of the retrofit. The red horizontal line shows the mean kilowatt-hour consumption for the periods before and after the retrofit. While there is clear variability in the day-to-day hot water needs of each house, there is also a marked reduction in the baseline and mean after the retrofit. Similar figures follow for HVAC and for whole house for these two homes. The change in hot water energy use is most dramatic, but the absolute energy savings for the HVAC system is larger and drives the whole-house energy reduction.

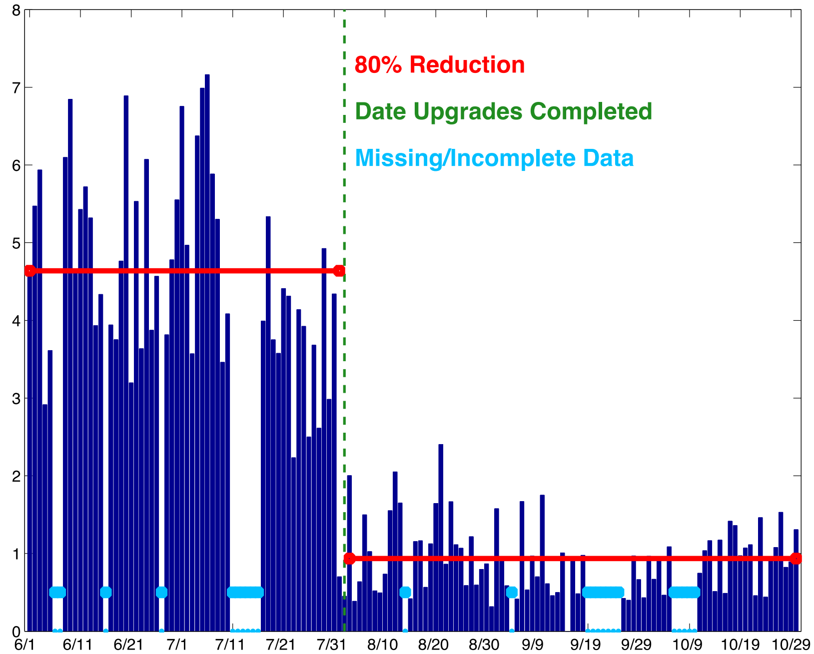


**Figure 18. Daily hot water energy consumption for Lockwood 1**

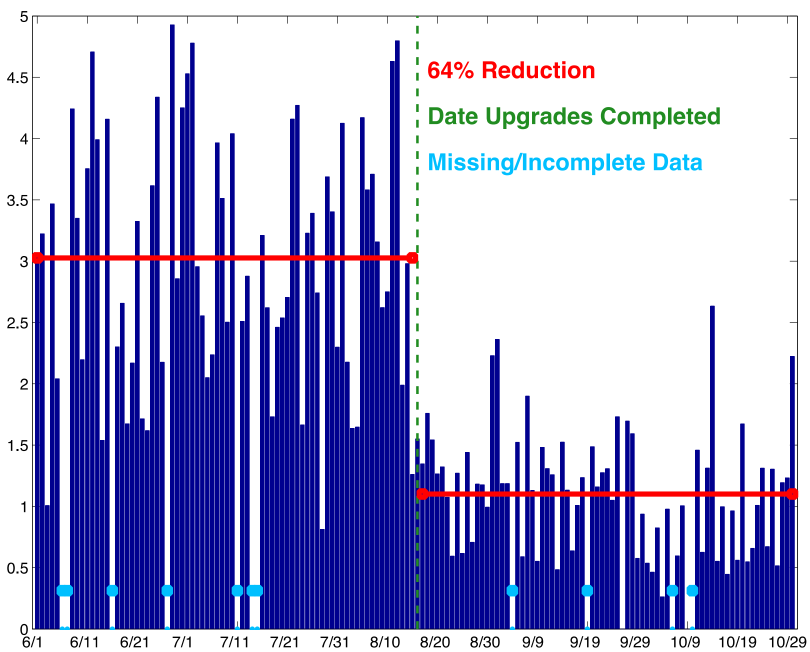


**Figure 19. Daily hot water energy consumption for Tipalao 3**

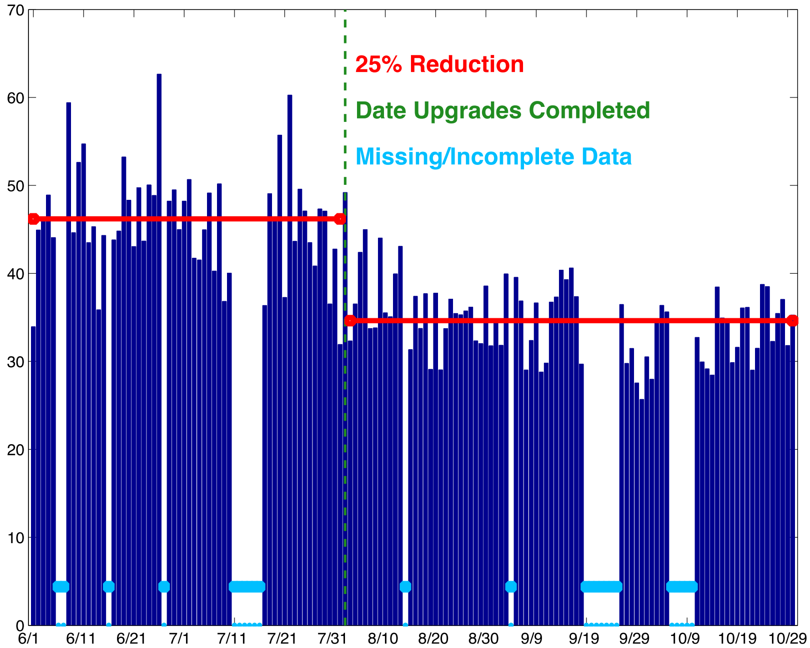


**Figure 20. Daily HVAC energy consumption for Lockwood 1**

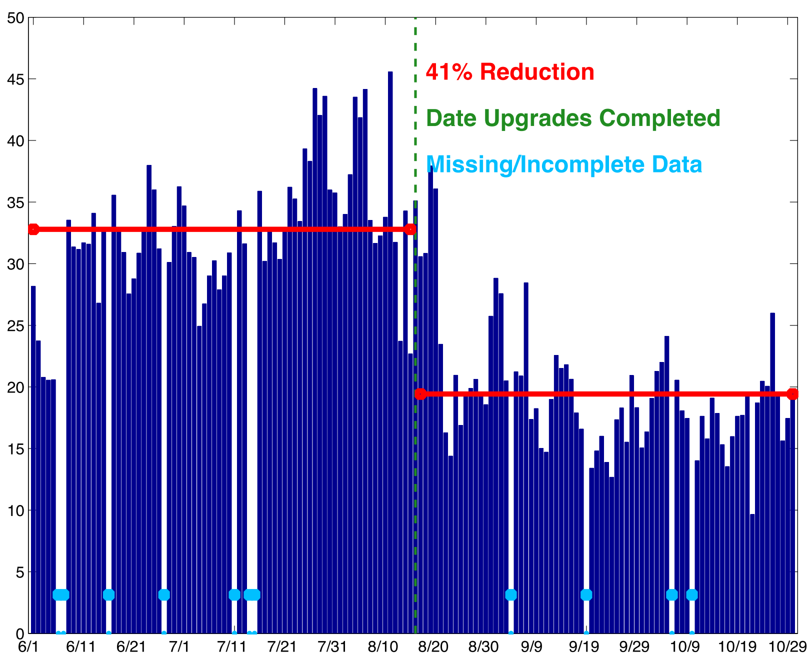


**Figure 21. Daily HVAC energy consumption for Tipalao 3**

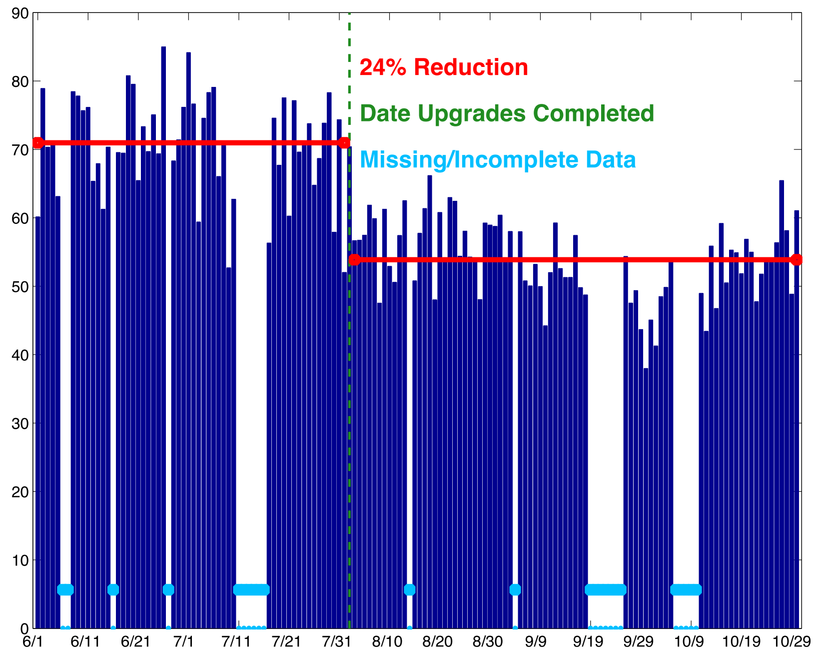


**Figure 22. Daily household energy use for Lockwood 1**

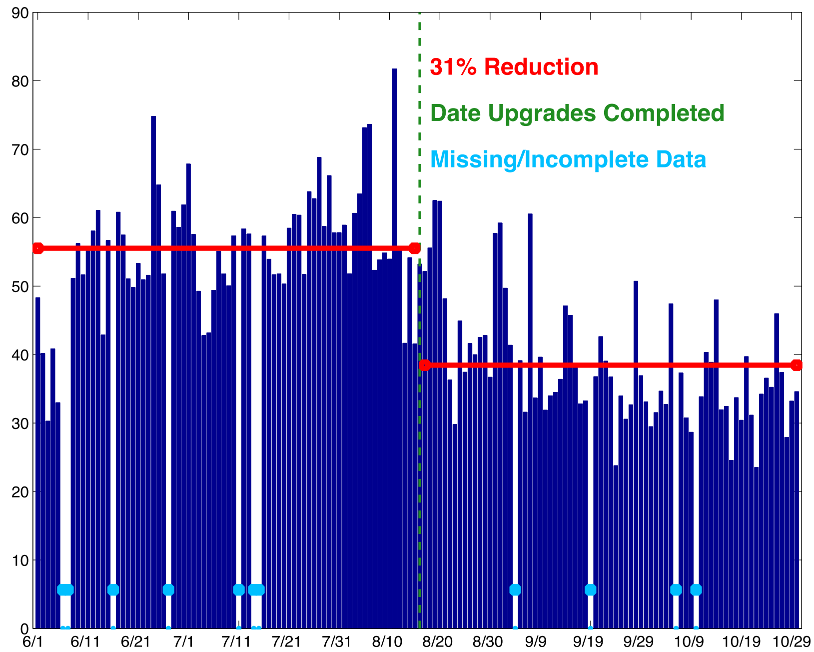


**Figure 23. Daily household energy use for Tipalao 3**

The temperature and relative humidity for each house were monitored during the pre- and post-retrofit periods to evaluate whether there were marked changes in indoor conditions that could indicate a change in occupant comfort level. As summarized in Table 12, there was little change in indoor conditions after the new equipment was installed. While the relative humidity tended to increase in the homes after the retrofit, all conditions meet American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standards for comfort. The increase in humidity inside the homes also coincided with an increase in humidity outside (see Figure 26). The uncertainties given are the statistical variations in the day-to-day mean; errors due to sensor accuracy are negligible compared to the standard deviations.

**Table 12. Indoor Conditions Before and After the Retrofit for all EEE Homes**

| | Pre-Retrofit Mean Temp (°F) | | Post-Retrofit Mean Temp (°F ) | | Pre-Retrofit Mean RH (%) | | Post-Retrofit Mean RH (%) | |
|---|---|---|---|---|---|---|---|---|
| Lockwood 1 | 71.6 | ±0.2 | 71.6 | ±0.2 | 50.4 | ±0.3 | 54.8 | ±0.4 |
| Lockwood 2[a] | 72.7 | ±0.1 | 71.8 | ±0.2 | 50.7 | ±0.2 | 58.6 | ±1.2 |
| Tipalao 1 | 77.3 | ±0.1 | 79.4 | ±0.4 | 43.6 | ±0.2 | 36.2 | ±0.8 |
| Tipalao 2 | 74.4 | ±0.1 | 77.4 | ±0.6 | 44.9 | ±0.2 | 41.9 | ±0.6 |
| Tipalao 3[a] | 74.9 | ±0.1 | 75.1 | ±0.1 | 41.5 | ±0.3 | 40.5 | ±0.3 |
| Tipalao 4 | 75.2 | ±0.1 | 73.7 | ±0.1 | 44.9 | ±0.4 | 57.7 | ±0.4 |
| Tipalao 5[a] | 72.7 | ±0.4 | 69.4 | ±0.3 | 51.8 | ±0.4 | 55.6 | ±0.2 |
| Tipalao 6 | 76.1 | ±0.1 | 75.1 | ±0.2 | 42.4 | ±0.2 | 53.8 | ±0.8 |

[a] Homes with in-line dehumidifier installed.

Low-flow shower heads were installed at the same time as the HPWH, so some DHW energy savings may be attributable to a reduction in shower hot water use. The mean daily hot water consumption before and after the retrofit was computed and the results are given in Table 13. NREL does not know the flow rate of the original shower heads, and they may have been different for different homes. The uncertainties are standard deviation of the mean, which dominate over sensor accuracy.

**Table 13. Summary of Hot Water Usage per House**

| | Pre-Retrofit Hot Water Use (gal/day) | | Post-Retrofit Hot Water Use (gal/day) | | Hot Water Savings (%) | |
|---|---|---|---|---|---|---|
| Lockwood 1 | 31.3 | ±1.8 | 32.5 | ±2.0 | -4.0 | ±2.7 |
| Lockwood 2[a] | 71.8 | ±3.9 | 49.8 | ±5.2 | 30.6 | ±6.5 |
| Tipalao 1 | 50.7 | ±2.6 | 36.7 | ±18.3 | 27.7 | ±18.5 |
| Tipalao 2 | N/A[a] | | | | | |
| Tipalao 3[a] | 52.9 | ±2.4 | 35.1 | ±6.8 | 33.6 | ±7.2 |
| Tipalao 4 | 66.2 | ±3.6 | 73.0 | ±4.2 | -10.3 | ±5.5 |
| Tipalao 5[a] | 10.8 | ±2.0 | 10.2 | ±2.3 | 5.8 | ±3.1 |
| Tipalao 6 | 36.7 | ±2.6 | 50.8 | ±2.3 | -38.5 | ±3.5 |

[a] The HOBO flow meter was defective. No flow data was collected.

## 4.3 Energy Model Simulations

### 4.3.1 Annual Energy Use Simulation for Advanced Power Strip Homes

As the demonstration period was less than a year in duration, an energy model was generated and calibrated to generate annual energy savings estimates. Year-long simulations were performed for the EEE homes, but not for the APS homes. Because of the variability in how people use their electronics, simulations may be able to approximate the effect of APSs in an average house but are not detailed enough to predict the savings for a single house and its unique residents.

### 4.3.2 Annual Energy Use Simulation for Enhanced Energy Efficiency Homes

The results from the EEE demonstrations were used to calibrate simulation models for each home in BEopt. Figure 24 and Figure 25 show houses from both neighborhoods as they are represented in BEopt. Annual simulation results were used to determine annual energy savings, which takes into account weather differences between the baseline and demonstration periods. Even though the climate in Guam does not vary significantly over the course of a year, there are still seasonal variations in weather between the baseline and demonstration periods that could impact the results. Figure 26 shows the average dry bulb temperature and relative humidity for every day of the past year. The data came from a NOAA weather station at the Guam International Airport (NOAA, 2013). The baseline data collection occurred during the hottest part of the summer, and the demonstration period was later in the fall, when the average temperature was slightly lower. As a result, neglecting to account for changes in weather would make the reduction in HVAC energy use appear artificially high. These annual BEopt energy simulations enable fair comparison of the baseline and demonstration data and give a conservative estimate for annual energy savings achieved though the demonstration.

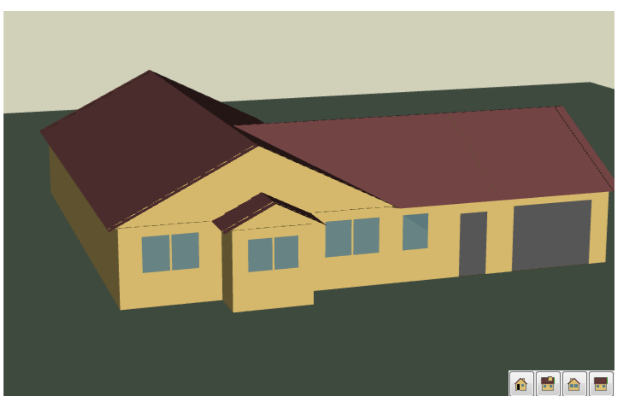

**Figure 24. BEopt model for a Lockwood Terrace home**

**Figure 25. BEopt model for a North Tipalao home (half a duplex shown)**

Two distinct models for each home were created to simulate the pre-retrofit home and the post-retrofit home. The pre-retrofit model was used during the design stage to determine the most cost-effective retrofit measures, as described in Section 3.1.2. That model was created based on the physical attributes of the house and details of the existing equipment. The process of matching pre-retrofit data to the pre-retrofit simulation results began with this base model. Local weather data for the past year was loaded into the simulation engine to ensure the model was referencing the same conditions the home experienced. With the physical details of the home and actual weather conditions captured by the model, the remaining differences are tied to the residents' preferences. The temperature and humidity set points were adjusted so the simulated HVAC energy use matched with the actual HVAC energy use. Daily hot water use and water heater set point were modified to match the simulated hot water energy use to the data. The measured indoor conditions and hot water use were used to help calibrate the model. A similar process was followed for the post-retrofit home model. The post-retrofit model was physically identical to the pre-retrofit model, except for the new energy efficiency equipment that was installed during the retrofit. The same year of weather was used for the post-retrofit simulations.

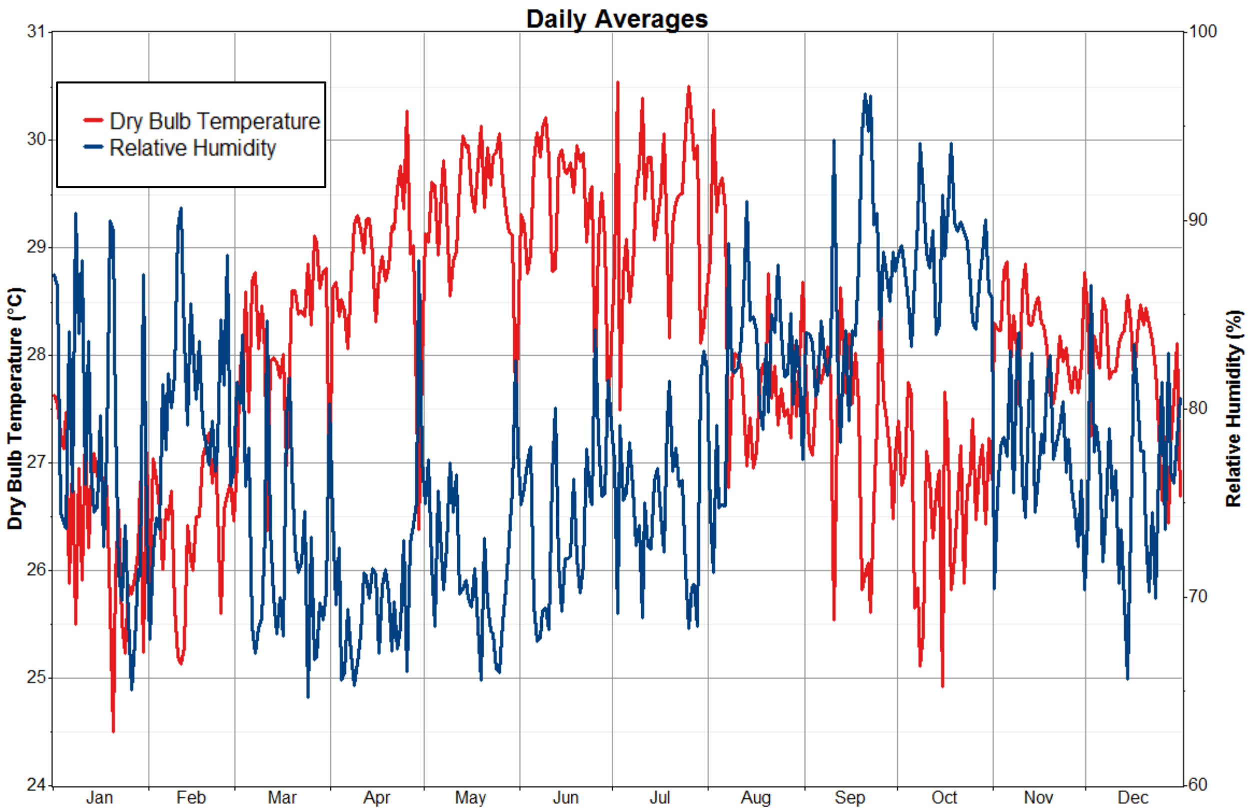


**Figure 26. Outdoor temperature and humidity over the past year in Guam**

Source: NOAA, 2013

It was not feasible to calibrate the model based on every day of data, and there were some days of data missing as a result of power outages and dropped communications. Average daily energy use over several weeks was used for comparison instead. The daily energy for the HVAC system, water heater, and the whole house was averaged over several months in chunks before and after the retrofit. The mean daily HVAC energy use over several two-to-four week-long periods in June and July were compared to the pre-retrofit simulation results for the same periods. The post-retrofit data in September and October were similarly compared to simulated energy use. When possible, the model was calibrated until the simulation results matched the data to within 5% for each period for HVAC, DHW, and whole-house daily energy use. There were some instances where the model could not be adjusted to match all the months considered, and in those cases, it was calibrated until the error over all the months summed to zero. For example, a pre-retrofit model where the difference between modeled and measured in June was -12% and +12% in July would be considered a good match to the data.

Figure 27 and Figure 28 show how well the modeled and measured data match for HVAC energy use and DHW energy use during the time periods used for calibration. The dotted line on the diagonal represents perfect agreement between measured data and simulation. The black squares and black points are the pre- and post-retrofit energy use, respectively. The y-axis error bars represent the statistical uncertainty in the measured mean energy use; they are plus/minus one standard deviation of the mean. The error bars are color-coded by house. With few exceptions, the measured value is within one sigma of the corresponding modeled value. The reduction in energy use after the retrofit is apparent in both measured and simulated data. For example, in Figure 27, the cluster of squares with red error bars near 70-80 kilowatt-hours (kWh) in both x- and y-axes correspond to the mean daily energy use for Lockwood 2 computed over three time intervals before the retrofit installations. The cluster of points with red error bars near 45 kWh in both x- and y-axes corresponds to the post-retrofit mean daily energy use for the same house.

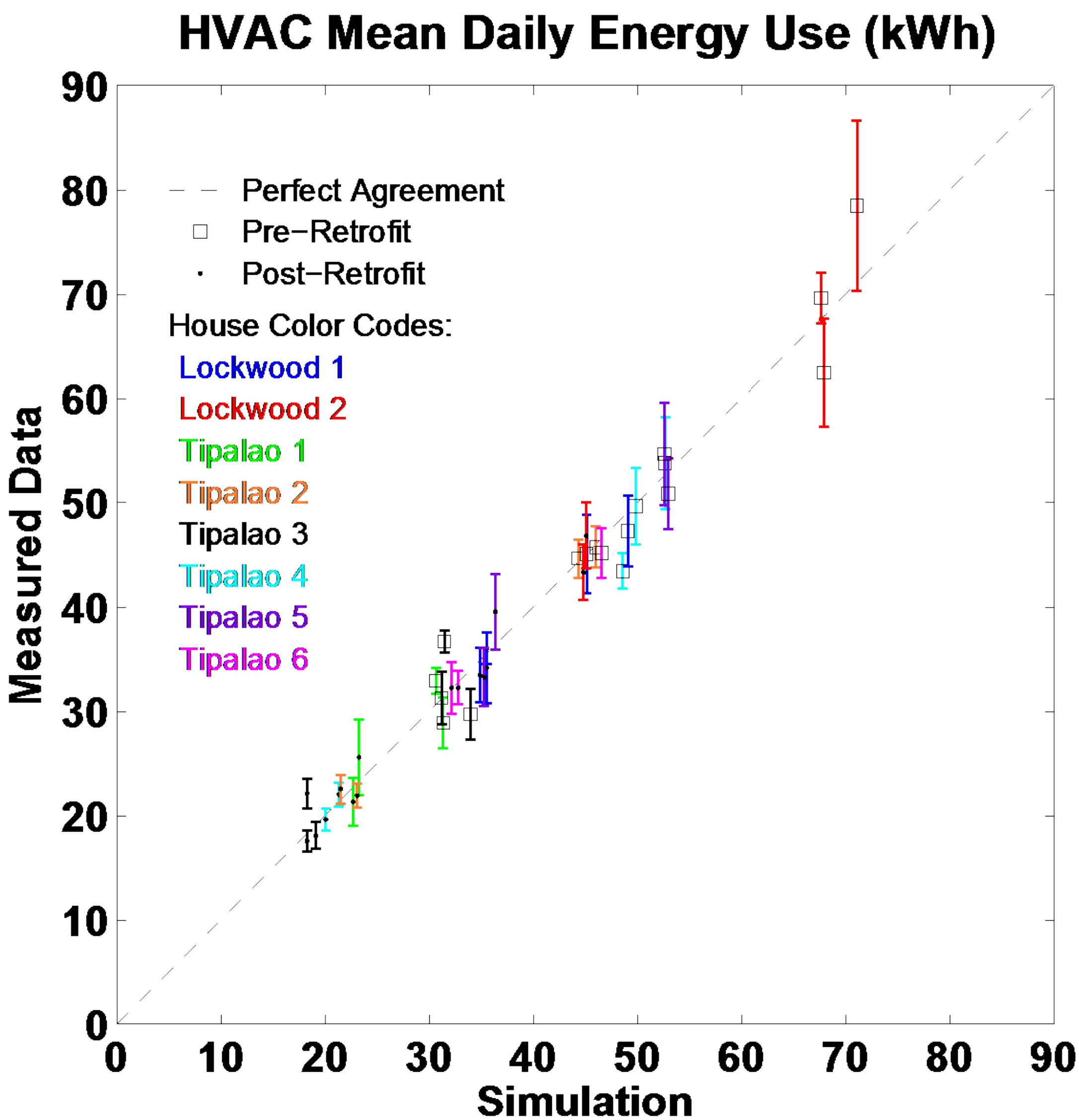


**Figure 27. Measured vs. modeled HVAC mean daily energy use**

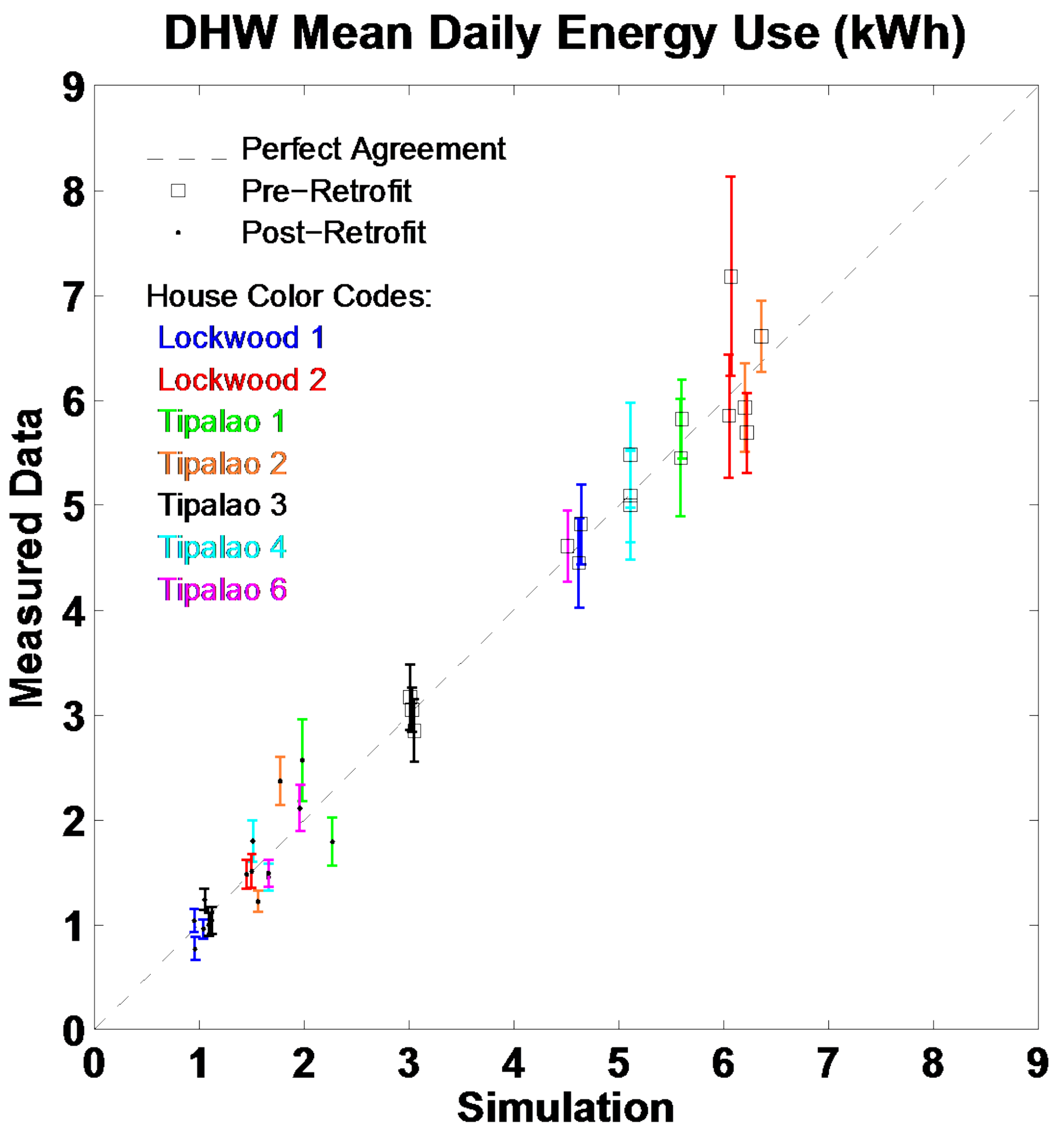


**Figure 28. Measured vs. modeled DHW mean daily energy use**

Once the pre-retrofit and post-retrofit models were well-matched with the data, simulated annual use was calculated for HVAC, DHW, and whole house. The difference between the annual energy use in the pre- and post-retrofit models is the estimated annual savings. Table 14 summarizes these results. The cost savings were calculated using the current electricity price in Guam of 50¢/kWh.

**Table 14. Annual Simulation Results**

| | HVAC Annual Energy Savings (kWh) | HVAC Annual Energy Savings (%) | DHW Annual Energy Savings (kWh) | DHW Annual Energy Savings (%) | Combined Annual Energy Savings (kWh) | Expected Annual Cost Savings ($) |
|---|---|---|---|---|---|---|
| Lockwood 1 | 710 | 5 | 1430 | 80 | 2140 | 1070 |
| Lockwood 2[a] | 4600 | 21 | 1740 | 76 | 6340 | 3170 |
| Tipalao 1 | 1470 | 14 | 1450 | 65 | 2920 | 1460 |
| Tipalao 2 | 6200 | 41 | 1780 | 75 | 7980 | 3990 |
| Tipalao 3[a] | 3200 | 30 | 800 | 67 | 4000 | 2000 |
| Tipalao 4 | 7860 | 49 | 1400 | 71 | 9260 | 4630 |
| Tipalao 5[a] | 4080 | 23 | N/A[b] | N/A | 4080 | 2040 |
| Tipalao 6 | 3240 | 20 | 1080 | 63 | 4320 | 2160 |
| **Mean** | **3920** | | **1380** | | **5130** | **2570** |
| **Standard Dev. of Mean** | **830** | | **130** | **880** | **820** | **440** |

[a] Homes with in-line dehumidifier installed.
[b] No water heater energy was measured before the retrofit.

## 4.4 Analysis of Results

### *4.4.1 Advanced Power Strip Demonstration Results Analysis*

To estimate the annual energy savings from all data, NREL employed a maximum likelihood estimator with two free parameters: net savings (kilowatt-hours/year), and intrinsic scatter (kilowatt-hours/year). The second parameter accounts for the variation in savings from home to home due to factors other than measurement error (i.e., variation in user behavior, etc.). NREL then marginalized over this “nuisance” parameter to obtain a maximum likelihood net savings and uncertainty. With this method, the reported uncertainty in the net savings accounts for both measurement error and home-to-home variation due to user behavior and other factors. Table 15 gives results (with 68% confidence interval) with intrinsic scatter taken into account.

**Table 15. Annual Energy Savings from APS**

| | Energy Annual Energy Savings for any House (kWh) | Corresponding Annual Cost Savings ($) |
|---|---|---|
| Entertainment Center | 58 ± 44 | 29 ± 22 |
| Office | 40 ± 24 | 20 ± 16 |

To illustrate the variability in the APS results, data from two homes are highlighted below. The main way that APSs reduce energy use is by reducing the standby power consumption. Any electronics that are plugged into controlled outlets will be completely turned off by the APS when they are not in use. This impact can be seen by looking at the power consumption over time. Figure 29 shows the entertainment center from House G and is an example of how this looks in an ideal installation. The power consumption when the electronics are on is unchanged, but the baseline, which is the steady standby power that is always on, drops from 20 W to 0 W after the APS is installed. It is rare to see the standby power drop to zero, as there are usually a few devices that need to remain on all time, like a cable box or modem. In this particular house, eliminating the standby power consumption reduced the daily mean energy use by 50% or about 150 kWh/year. The daily reduction in energy use is also evident in the distribution of pre- and post-APS daily energy use, as shown in Figure 30.

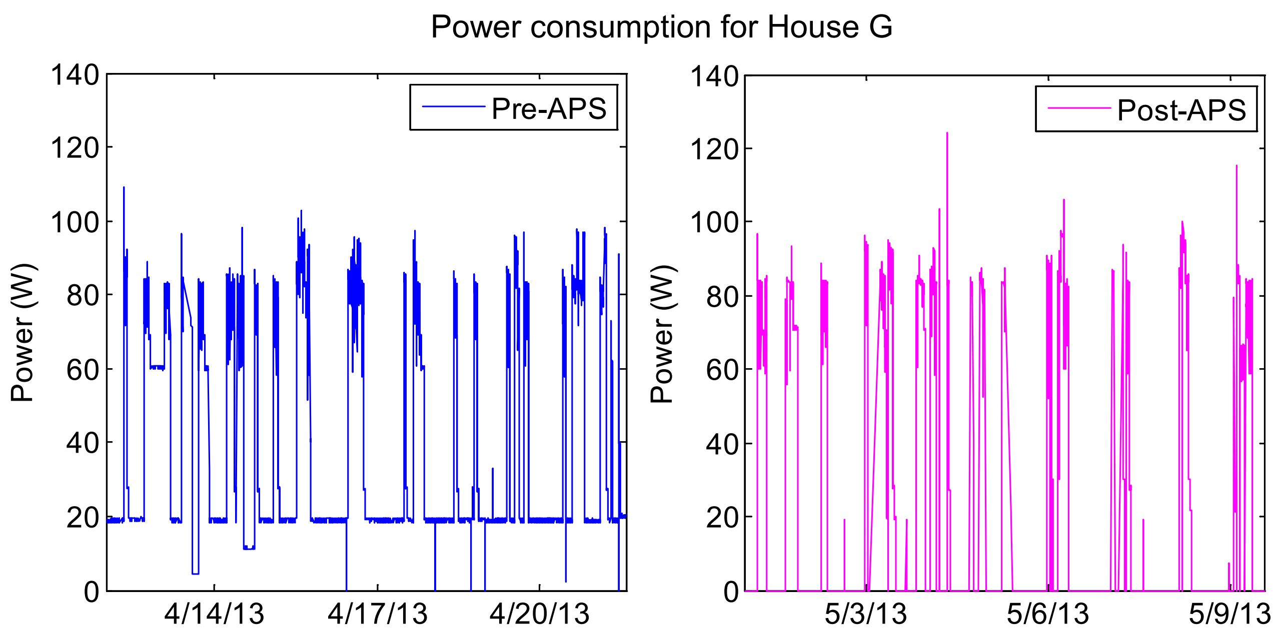


**Figure 29. Home entertainment center power consumption in House G before and after APS**

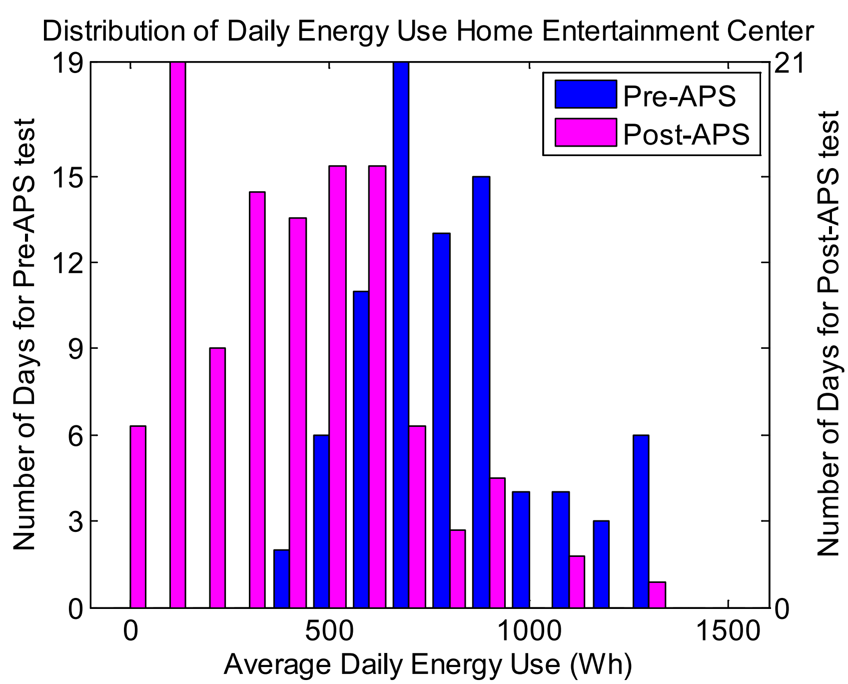


**Figure 30. Histogram of entertainment center daily energy use in House G before and after APS**

In contrast to the ideal case shown for House G above, the results from a bedroom entertainment center installation in House A are shown in Figure 31 and Figure 32. The daily mean energy use for this case increases significantly after the APS is installed, but the power trace helps to explain this result. A week of pre-APS power consumption shows the entertainment system was rarely used and a week of post-APS power consumption shows much more frequent activity. This installation is in the children's bedroom, and the APS installation happened to coincide with the beginning of summer vacation. The standby power level is basically unchanged, which may indicate there were few items in the entertainment center that could be controlled by the APS (in other words, most devices had to be plugged into the "always on" outlets). The lack of reduction in the standby power and the increase in use of the entertainment center resulted in a 44% increase in daily energy use, but in reality, this APS likely had little impact on the energy use of the electronics, and the increase was an artifact of changes in occupant behavior.

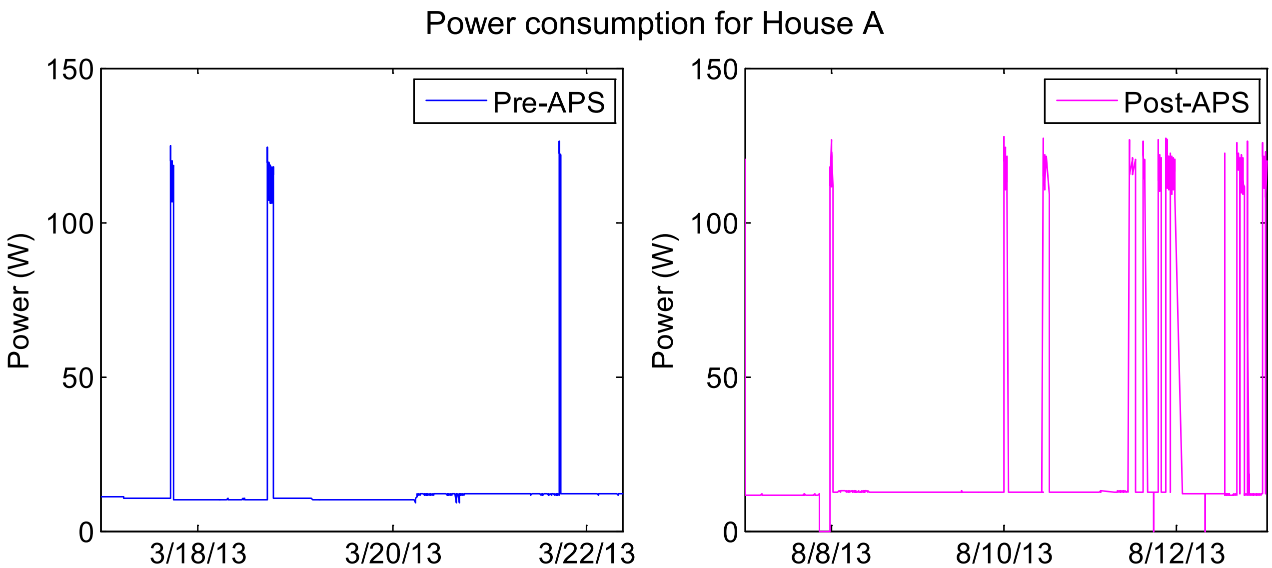


**Figure 31. Home entertainment center power consumption in House A before and after APS**

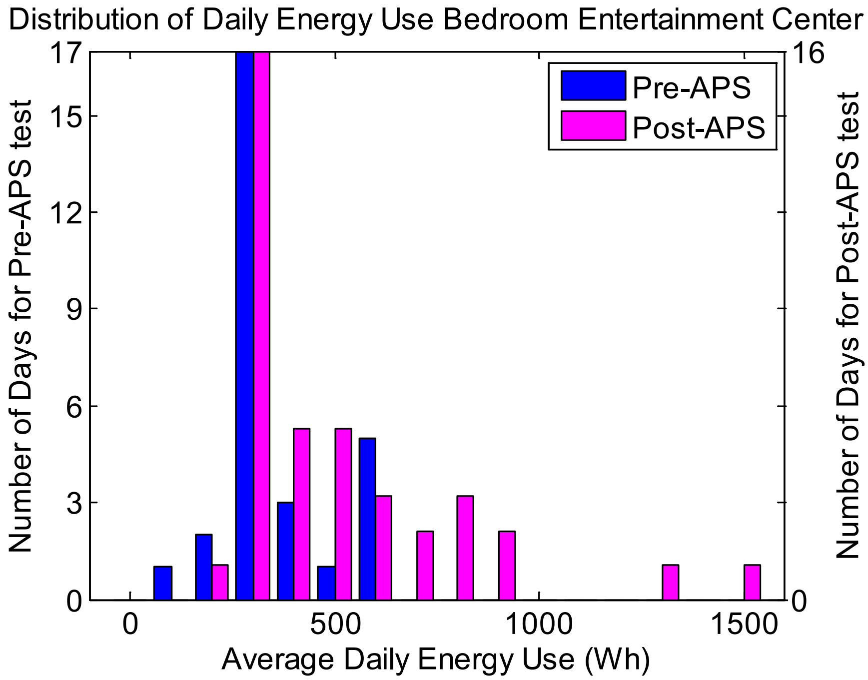


**Figure 32. Histogram of entertainment center daily energy use in House A before and after APS**

Changes in user habits can have a big impact on the apparent energy savings (or lack thereof) after an APS is installed. In the case of House A, NREL knew enough about the residents and the installation to make an educated guess as to why the energy consumption increased, but that was the exception rather than the rule. For many of the homes, interactions with residents were much more limited, and it has been difficult to explain all of the unexpected features in the distributions. To add to these complexities, people introduced new electronics frequently and that was another factor difficult to capture in this demonstration.

When APSs are installed correctly, they should reduce the standby power consumption, leading to a decrease in daily energy consumption, even if that decrease is small. Any increase in energy use is likely due to changes in usage patterns or changes to the electronics in the entertainment center or home office.

### 4.4.2 Enhanced Energy Efficiency Demonstration Results Analysis

The EEE demonstration was an overall success, with all homes saving energy in both cooling and hot water use. Despite the fact all the homes were similar in size and family demographics, the energy use and energy savings between the homes varied significantly.

The installation of the HPWH saved at least 60% of DHW energy in all homes, but there was little consistency in how the low-flow shower heads affected water use or energy use. The homes that experienced reductions in hot water use after the low-flow shower heads were installed did not save more energy than those that actually increased their daily hot water use. It is unclear why the low-flow shower heads had so little impact on the daily hot water use in the EEE homes, but it is possible that some homes already had low-flow shower heads, as the facility staff did not have any information on the existing shower heads. NREL also heard from a couple of residents that they had handheld shower heads so they never used their low-flow shower heads, which are fixed to the wall. Additionally, in homes with young children where baths are more common than showers, the shower heads in the children’s bathroom may never have been used.

HVAC savings were achieved in all homes and the magnitude of those savings varied between the homes. In general, the smallest savings were seen in the homes with the lowest average indoor temperature or lowest indoor relative humidity. The homes that saved the most energy allowed their homes to stay warmer and more humid (though still well within the comfort region as defined by ASHRAE). Residents from the two homes that saved the most energy (Tipalao 2 and Tipalao 4) both said they turned off their standalone dehumidifiers after the new air conditioners were installed, as they felt the new A/C was able to maintain low humidity better than the old system. Turning off the dehumidifier made the house quieter and also saved a large amount of energy without sacrificing comfort.

Replacing the standalone dehumidifier with in-line dehumidifiers had no obvious impact on the humidity levels or energy use in the homes. The humidistat gave residents more control over the humidity levels in their homes, but there was no consistent trend between the three homes with the in-line dehumidifiers in terms of reduced humidity or relative energy savings. The in-line dehumidifiers are quieter than the standalone dehumidifiers so they improve the noise comfort in the homes. NREL received feedback from one resident with the in-line dehumidifier that their house stayed too cold (always below the set point temperature), possibly indicating an issue with the reheat system downstream of the dehumidifier coils. This was not an issue in the other homes with the in-line dehumidifier so it is unclear what caused the over-cooling problem.[2]

In general, installing high-efficiency air conditioners and HPWHs can significantly reduce energy use, regardless of how the residents like to control their house or how much hot water they use. The in-line dehumidifiers were not found to be an improvement and in one case, actually affected the comfort adversely, albeit for reasons unknown. The standalone dehumidifiers appear to be a good solution for people who want dryer air, but may not be needed for all households. Low-flow shower heads did not show a consistent effect on daily hot water usage but should still be installed in new homes to avoid needlessly wasting hot water.

## 4.5 User Feedback and Survey Results

### 4.5.1 Advanced Power Strip User Feedback

The APS surveys were handed out when the monitoring equipment was removed, but not many were completed.

Very few people installed their APSs on their own. A local contractor followed up with residents and installed the APSs for them in most cases. Generally, there was no explicit reason given why the residents did not install their APSs, other than that people are busy and this is a tedious task that would disrupt plug load use for a short time. However, once the APSs were installed and the functionality was described to the residents, people seemed open to the minor changes the APSs may require in how they normally operate their electronics. Even one resident with a large entertainment center in his converted garage had volunteered for the demonstration and was amenable to the usability changes that were part of the APS installation.

### 4.5.2 Enhanced Energy Efficiency User Feedback

For the EEE homes, user feedback was collected almost entirely with the post-demonstration surveys that were distributed when the monitoring equipment was removed. The comments were generally positive.

[2] The over-cooling problem was corrected temporarily by turning off the dehumidifier. NREL will have the installation contractor follow up to evaluate whether there is a defect with the unit.

People were impressed with the new modern equipment, especially the look of the new thermostat (though only two households had set up a regular thermostat schedule). The new air conditioner was very favorably received, with everyone noting it was much quieter than the original system and did not run as often. A few residents found that the new air conditioner was able to remove more moisture than the old system so they stopped using the standalone dehumidifier. Residents noticed that the HPWH made noise, unlike the original electric resistance water heater, but nobody indicated whether the noise was bothersome. The water heaters in this demonstration were installed either in the garage or an outdoor closet, so the noise from the HPWH did not have a big impact on the living space. Some residents had turned up their set point to compensate for the slower recovery time for the HPWH, but they were happy with the water heater after the adjustment. The low-flow shower head received mixed reviews, but most people said they would buy low-flow shower heads in the future, even if they liked the higher-flow rate shower head better. The in-line dehumidifier also had mixed reviews, with one resident saying the house was always colder than the set point. The other two homes with the in-line dehumidifier did not have this issue, so it is unclear what caused the over-cooling.

## 4.6 Assessment of Performance Objectives

**Table 16. Assessment of Performance Objectives**

| | Performance Objective | Success Criteria | Outcome |
|---|---|---|---|
| **Quantitative Performance Objectives** | | | |
| 1 | Whole-house energy saving | 10% reduction compared to baseline | Success—Mean savings of 20% over baseline from the simulations. |
| 2 | DHW energy saving | 20% reduction compared to baseline | Success—Mean savings of 70% over baseline from simulations. |
| 3 | HVAC energy saving | 20% reduction compared to baseline | Success—Mean savings of 25% over baseline from simulations. |
| 4 | Indoor comfort | Conditions comparable or better than before while occupants are home | Success—Indoor conditions were comparable or better. Occupants enjoyed the quieter system, as well. |
| 5 | DHW use reduction | 20% reduction compared to baseline | Inconclusive—Some homes used less hot water on average per day and some did not. It is possible that some of the existing shower heads were already low-flow models. |
| 6 | Home entertainment center and home office plug load energy savings | 10%-50% reduction compared to baseline, depending on type and vintage of consumer electronics used | Limited Success—Median decrease in daily energy use of 10% for AV environment and 11% for PC environment. Results vary significantly from house to house. Energy use increased after APS installation in several homes. |
| **Qualitative Performance Objectives** | | | |
| 1 | User satisfaction with HPWH | Resident satisfaction with implemented measures, as indicated by survey responses | Success—All residents were happy with their HPWH. |
| 2 | User satisfaction with thermostat | | Success—All residents were happy with their thermostat (though few were using its programmable functions). |
| 3 | User satisfaction with APS | | Unknown—No APS surveys collected at this time. |

# 5 Economic Performance Analysis and Assessment

## 5.1 Economic Performance of Advanced Power Strip Demonstration

Economic results of the APS demonstration were not positive, indicating deployment of this technology in a military housing environment may not yield appreciable savings without further study to evaluate effective options to implementation. In demonstration of the APS devices, annual energy savings is estimated at 100 kWh/yr. Accounting for initial investment costs and a high, estimated attrition rate in APS usage over a four-year economic life, net savings comes in at a negative balance. For a follow-on, large-scale deployment initial investment cost per residence is projected to be significantly reduced. Net savings is estimated at $20 per household over a four-year economic life; however, the statistical confidence in this estimate is low, owing to the high variability in observed energy savings.

A key factor affecting economic results is the estimated, high attrition rate of APS usage over a four-year economic life. This attrition rate is attributed to residents moving to their new posts after completing their Guam tour and failing to install their APS devices correctly (or at all) when they set up their entertainment centers or home offices in their new residences. The originally deployed APS devices may be lost in the move. Owing to the high turnover rate of residents in military housing, this study estimates that 25% of the originally installed APS devices are not utilized in the subsequent year. More specifically, usage estimates are 100% in the first year, 75% in the second year, 50% in the third year, and only 25% of the originally deployed APS devices in the fourth year. If the actual attrition rate in a deployed environment can be significantly less than these estimates without appreciable new costs, the economic viability of these devices would be greatly improved.

Table 17 provides a full summary of economic results, in addition to key analysis inputs. Estimates for net savings and simple payback were calculated using the latest version of the National Institute of Standards and Technology (NIST)-developed Building Life-Cycle Cost (BLCC) program. A detailed accounting of the economic analysis performed can be found in Appendix E.

**Table 17. Economic Analysis of APS Demonstration**

| | Demo Actuals | Projected Follow-On |
|---|---|---|
| **Economic Analysis Results** | | |
| Net Savings, Four-Year Life | -$480 | $20 +/- $60 |
| SIR, Five-Year Life | N/A | 1.1 |
| Adjusted Internal Rate of Return | N/A | 5.2% |
| **Key Analysis Inputs** | | |
| Annual Energy Savings | 100 +/- 50 kWh | 100 +/- 50 kWh |
| Electricity Price | $0.50/kWh | $0.50/kWh |
| Initial Investment Cost | $600 | $100 |
| Economic Life | 4 years | 4 years |

## 5.2 Economic Performance of Enhanced Energy Efficiency Demonstration

Economic results of the EEE demonstration indicate application of the EEE technologies in Joint Region Marianas (JRM) can yield appreciable energy and cost savings. In demonstration of the EEE retrofit packages at eight NBG residences, the aggregate, annual energy savings is estimated at 40 megawatt-hours (MWh)/yr. In comparison to a minimally efficient retrofit of similar quality to the replaced equipment, NREL estimates a net savings of $120,000 over a 10-year operational life, with an adjusted internal rate of return of 16% per annum. Results are promising and indicate the U.S. Navy, on an economic basis, should consider further investment and deployment of these technologies—at least in tropical climates similar to the U.S. Territory of Guam.

Table 18 provides a full summary of economic results, in addition to key analysis inputs. Estimates for net savings, savings-to-investment ratio (SIR), and simple payback were calculated using the latest version of the NIST-developed BLCC program. Energy return on investment (eROI) values were provided using the latest available version of the Neptune eROI calculator, as provided by Naval Facilities Engineering Command (NAVFAC).[3] A detailed accounting of the economic analysis performed can be found in Appendix E.

**Table 18. Overall Economic Analysis of EEE Demonstration**

| Economic Analysis Results | | Key Analysis Inputs | |
|---|---|---|---|
| eROI Value | 10.1 | Annual Energy Savings | 40 +/- 7 MWh |
| Net Savings, 10 years | $120,000 | Electricity Price[a] | $0.50/kWh |
| SIR | 3.3 | Investment Cost Delta[b] | $56,808 |
| Simple Payback | <3 years | Units Installed | 8 |
| Adjusted Internal Rate of Return | 16% | Economic Life | 10 Years |

[a] "Electricity Price" reflects fiscal year 2014 rates at JRM.
[b] "Investment Cost Delta" reflects the calculated difference in investment cost between the installation of the enhanced energy efficiency equipment versus the hypothetical installation of a minimally energy efficient set of equipment (see Appendix E for more details). Intent of the investment delta is to infer the economic value of retrofitting residences with enhanced efficiency elements versus retrofitting with minimally efficient equipment of similar pre-retrofit performance levels.

In addition to the aggregate return of the EEE retrofits, performance was also evaluated for the individual contributions of the EEE package's domestic water and HVAC technologies. Economic returns were significant for both respective technology offerings. On a per unit basis, the DHW technologies (HPWH and low-flow shower head) showed an average, annual energy savings of 1,400 kWh/yr. The high-efficiency HVAC units showed an average savings of 4,000 kWh/yr.

Table 19 provides a full summary of results on a per unit basis.

[3] eROI is a U.S. Navy specific metric for evaluating benefits of investment in energy technologies. The benefit figure reflects the present value of the project's anticipated contribution to energy as well as its contribution, in dollar-equivalent terms, to other U.S. Navy objectives, such as improving energy reliability for critical infrastructure, reducing greenhouse gas emissions, meeting regulatory mandates, and so on. An eROI greater than 1.0 indicates the project's benefits are anticipated to exceed its costs. The higher the eROI value, the more attractive the project.

**Table 19. Economic Analysis of EEE Demonstration on a per Unit Basis**

| DHW Results per Unit | | HVAC Results per Unit[a] | |
|---|---|---|---|
| Annual Energy Savings | 1.4 +/- 0.1 MWh | Annual Energy Savings | 4.0 +/- 0.8 MWh |
| Net Savings, 10 years | $4,500 | Net Savings, 10 years | $11,000 |
| SIR | 3.9 | SIR | 2.9 |
| Simple Payback | <3 Years | Simple Payback | <4 Years |
| Adjusted Internal Rate of Return | 18% | Adjusted Internal Rate of Return | 14% |
| Investment Cost Delta[b] | $1,700 | Investment Cost Delta[b] | $6,500 |

[a] HVAC economic analysis excludes costs relating to the whole-house dehumidifiers. Evaluation of results indicates these dehumidifiers did not present statistically significant savings and were therefore removed from the economic analysis.
[b] "Investment Cost Delta" reflects the calculated difference in investment cost between the installation of the enhanced energy efficiency equipment versus the hypothetical installation of a minimally energy efficient set of equipment (see Appendix E for more details). Intent of the investment delta is to infer the economic value of retrofitting residences with enhanced efficiency elements versus retrofitting with minimally efficient equipment of similar pre-retrofit performance levels.

As evident in Table 19, application of the DHW technologies presented the best return per dollar invested, with an adjusted internal rate of return (AIRR) of 18% and a SIR of 3.9. HVAC technologies also show a promising return, excluding use of the whole-house dehumidifier, with an AIRR of 14% and SIR of 2.9. The whole-house dehumidifier did not show statistically significant savings.

Economic results were reviewed to evaluate potential sources of error and/or uncertainty in the estimates provided. Four issues were identified and are described below.

- **Utility electricity rate volatility**. Significant escalation in JRM utility rates from fiscal year (FY) 2013 to FY14 indicate analysis results as presented may be susceptible to uncertainty in projecting future utility rate pricing. More specifically, utility rates have jumped from $0.2984/kWh in FY13 to $0.4995/kWh in FY14. Based on these recent rate adjustments, forecasting future year utility rates is challenging, especially over a 10-year economic life. In addition, BLCC escalation rates were not available for Guam in providing an authoritative, reference benchmark. Accounting for the utility rate uncertainty and lack of availability of a BLCC benchmark, the analysis concluded forecasting future escalation rates could not be appropriately determined. Therefore, escalation of rates over the economic life of the study was not assumed; however, over the next 10 years escalation in utility rates is possible, if not likely, and should be noted as a potential source of error in the analysis. In this sense, the results are likely indicative of a lower limit to savings achievable; if rates go up, cost savings and SIR will increase.
- **Statistical variance in energy savings.** Significant variability in energy saving results was observed between the eight households, especially with respect to HVAC-related savings (see Table 9 through Table 11. Estimated annual energy savings for the HVAC systems over the eight residences range from 700 to 7,900 kWh/yr, whereas DHW savings ranged from 800 to 1,800 kWh/yr. The wide distribution in savings, especially for HVAC systems, is likely attributable, in part, to differences in behavioral dynamics among the residents. Residents were allowed to adjust temperature set points to meet their preferences, which will directly impact absolute savings. For example, if residents were low-volume hot water users, the water heater would not be used as

much and the absolute savings would be less pronounced. This variability presents a statistical uncertainty to the results, which should be noted when evaluating average, annual energy savings and economic yield. The standard deviation of the mean for the aggregate annual energy savings of the EEE retrofits is +/-7,000 kWh. For DHW savings per unit, the value is +/- 100 kWh, and for HVAC savings per unit, the value is +/- 800 kWh. These values, although appreciable, do not significantly alter the conclusions drawn by the economic analysis.

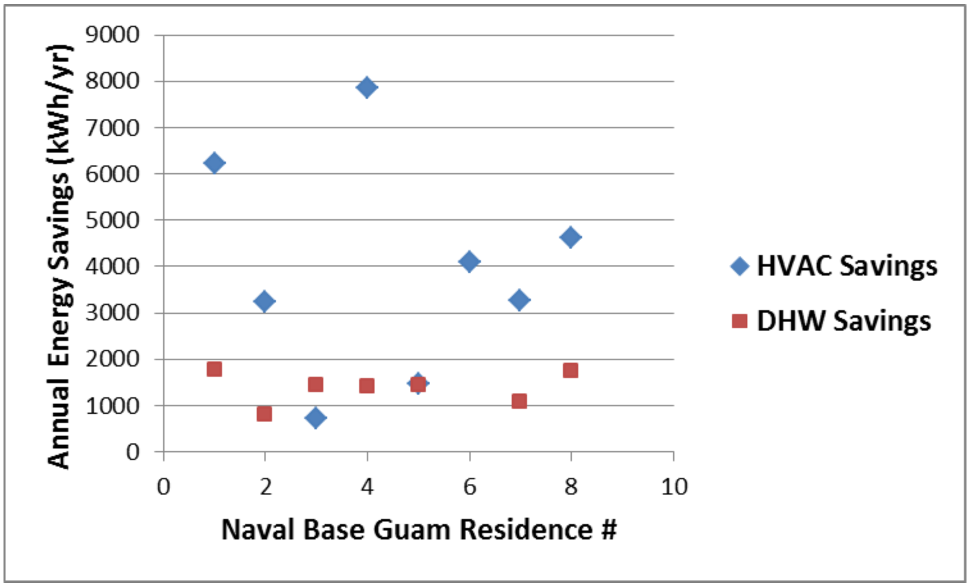


**Figure 33. Annual HVAC and DHW savings per house**

- **Uncertainties associated with calibrating BEopt models using measured data.** There are some fundamental challenges with the study's method to account for the change in season from summer to fall over the course of the demonstration period. The annual energy savings estimated using this approach was dramatically less than a simple projection of the measured savings because the weather was cooler after the retrofits, so a significant fraction of the energy reduction was attributed to the decrease in cooling load rather than an increase in equipment efficiency. Nevertheless, this method was chosen to ensure against overprediction of savings. It should be noted the actions recommended in this report would remain unchanged whether the measured savings or calibrated modeled savings was used.
- **Investment cost estimates.** Evaluation of the economic return is dependent upon accurate estimation of costs of replacing the existing residential HVAC and DHW equipment with EEE retrofits in comparison to replacing them with a less expensive and less energy efficient options. More specifically, a key economic metric of this demonstration is to determine whether the greater performance of the EEE retrofits outweighs its added investment cost relative to a less expensive option. The EEE retrofits were installed using a competitively selected contractor. Costs for the EEE retrofit installations are therefore competitively priced and fully defined by accounting of project actuals. Costs of a less expensive option, however, were not realized on this project. These costs were estimated for this analysis and are susceptible to error. To account for potential error, the analysis used conservative, minimum pricing of comparative options to ensure economic yields are not positively biased. As an example, the least expensive equipment option on the U.S. General Services Administration schedule was used for each HVAC and DHW element priced, specified at the performance levels of the equipment replaced by the EEE retrofits. Additional detail is provided in Appendix E.

# 6 Project Management Considerations

For both the EEE and APS demonstrations, programmatic activities were straightforward with limited challenges. The EEE demonstration used a local contractor for procurement and installation of demonstration equipment. For the APS demonstration, devices were procured by NREL and delivered to each respective resident. Each resident then self-performed installation of the APS devices or received help with the installation from an on-island contractor. For both demonstrations, the commercial availability of the demonstrated technologies made for easy acquisition and deployment. Table 20 provides a summary of programmatic elements of these demonstrations and a high-level timeline of events.

**Table 20. Summary of Programmatic Elements for APS and EEE Demonstrations**

| | | |
|---|---|---|
| **Programmatic Summary—APS Demonstration** | | |
| **Implementation Method** | NREL Procurement, Resident Self-Performed Installation | |
| **Key Contractors** | None | |
| **Period of Performance** | 16 Months | |
| **Project Timeline** | May 2012 | NBG Housing Approves Demonstration |
| | June 2012 to May 2013[a] | Recruitment of NBG Residents |
| | April 2013 to Sept. 2013[b] | APS Installations |
| **Programmatic Summary—EEE Demonstration** | | |
| **Implementation Method** | Service Contract for Procurement and Installation | |
| **Key Contractors** | Chugach World Services, Inc. | |
| **Period of Performance** | 16 Months | |
| **Project Timeline** | May 2012 | NBG Housing Approves Demonstration |
| | Nov. 2012 | Residences Identified |
| | Jan. 2013 to July 2013 | Pre-Install, Baseline Measurements |
| | May 2013 to Aug. 2013 | EEE Installations |

[a] Recruiting residents took significantly longer than expected. Several factors contributed to this; however, the primary challenge was gaining resident interest and election to participate in the demonstration.
[b] The significant time investment in APS installation may be misleading. APS installations were staggered as new residents signed on to participate in the demonstration. Actual time needed to perform APS install was negligible (on the order of a month for procurement, delivery, and install).

Further deployment of the EEE or APS technologies in a military housing environment should not require unique or sophisticated acquisition strategies. Some of the lessons learned from these demonstrations, however, may lend value in future deployments and are listed below:

- **APS "elect-in" vs. "elect-out" participation**. For future APS deployments, a key consideration will be determining the best approach to selecting residences. The demonstration used an elect-in approach, where residents elected to participate. This required significant upfront time and expense in educating residents and "selling them" on electing to participate. This approach yielded limited participation. In contrast, an elect-out approach, in which all residents participate unless they elect-out, may yield a more efficient approach to large-scale deployment, both in respect to deployment time and level of participation.

- **APS proper installation and operation.** Based on energy savings results, NREL believes a significant fraction of residents who received APS devices did not properly install the devices. Additional training or a different approach to installation of the APS devices should be considered to improve deployment effectiveness.
- **EEE design considerations.** Some of the EEE equipment will require a few, unique design requirements going beyond standard commercial offerings. These requirements should be noted for future retrofits. For example, high-efficiency outdoor condensers require a larger physical footprint in comparison to nominally compliant units and heat pump water heaters have air flow requirements not needed by electric-resistant water heaters. Additionally, HPWHs create cool air that could help offset the cooling load in the house if the HPWH was located inside the conditioned space or HPWH exhaust air was ducted into the conditioned space.

## 6.1 Site Approval, National Environmental Policy Act, and DD1391

### *6.1.1 Advanced Power Strip Demonstration*

Site selection presented some challenges for the APS demonstration. As noted in the section summary, the demonstration used an "elect-in" strategy for identifying residences for participation. This approach required developing an awareness campaign for informing residents of the demonstration, educating them on the benefits, and seeking their participation. The awareness campaign required significant time for developing pamphlets and flyers, receiving approval by NAVFAC, NBG Housing, and NREL public affairs entities, and subsequently distributing information in multiple forums (e.g., email, town hall announcements, etc.). Although information was distributed to all NBG residents, participation in the demonstration remained relatively low. For future residential deployments of APS devices, it is recommended the best strategy for acquiring resident participation is carefully considered. An "elect-out" approach may yield better results.

Site approval activities for this demonstration were minimal. DD1391 and National Environmental Policy Act (NEPA) evaluations were not required due to the nature of the work.

### *6.1.2 Enhanced Energy Efficiency Demonstration*

A minimal degree of work activity was required for EEE site selection and site approval activities. Site selection was guided by a short list of housing criteria, used by the NBG Housing Authority for selection of appropriate residences. These criteria included:

- Minimum of two occupants
- Representative of majority of NBG residential stock
- HVAC, water heater equipment due for an upgrade
- Water heater locations in compliance with HPWH installation requirements.

Several residences met this criteria and final selection was accomplished without difficulty. Subsequent site approval and other administrative activities did not pose a significant challenge or time constraint. A DD1391 submittal was not required for this demonstration owing to the nature of the work.[4] The NEPA

[4] Determination made by NAVFAC Pacific Asset Management on Jan. 09, 2013.

determination for this activity was a categorical exclusion, with its classification as a sustainment, restoration, and modernization project.

## 6.2 Contracts and Procurement

For the APS demonstration, APS devices were procured by NREL and delivered to the NBG residences. Residents then self-performed installation of the APS devices using training materials included in the delivered packages from NREL.

For the EEE demonstration, a competitively selected, general service contract was awarded to Chugach World Services Inc. for procurement and installation of all EEE equipment. Execution of this contract was straightforward and no special comment is warranted.

## 6.3 Design

Design activity for these demonstrations was very limited. All of the technologies demonstrated are standard, commercially available products. Modification or redesign of the technologies themselves was not considered for these demonstrations.

A minimal amount of site design work was required for the EEE demonstration. The contractor was required to properly size the A/C units to the conditioned space and evaluate floor plans and physical space conditions for installation and plumbing of the heat pump water heaters. No site design work was required for the APS demonstrations, as these devices are simple “plug and play” technology offerings.

## 6.4 Installation and Construction

For the APS demonstration, devices and training materials for proper installation were shipped directly to the residences. The original plan was to have all residents self-install their APS, but few took the initiative so many APSs had to be installed by a contractor. Poor understanding of the devices or lack of motivation to install may be contributing factors to this problem. For future deployments, considering options for increasing the percentage of effective installations is recommended. Additional training materials or on-site help support may help address these issues. Because the net payback for APSs in a large deployment is already small (see Table 17), hiring a contractor for site-performed installations is likely cost-prohibitive. Additionally, for a variety of reasons, 13 installations (27%) had to be excluded from the analysis. This is a significant fraction of the demonstration residences, though most of the homes were excluded for reasons unrelated to APS installation.

Installation activities for the EEE demonstration occurred over a four-month period. Procurement timeline was significant, taking over two months due to lack of local availability of HPHW and HVAC elements and time for environmental coatings treatment of the outdoor condenser. Actual, on-site installation occurred over a month. The installations were performed similar to a normal HVAC installation with no special circumstances or challenges.

## 6.5 Operation and Maintenance

The operation and maintenance requirements of the APS and EEE equipment are essentially the same as standard, commercial offerings for power strips, HVAC equipment, plumbing fixtures, and hot water heaters. The only unique feature lies with the HPWH, which, unlike standard electric resistant units, has an air filter that should be inspected monthly and cleaned if necessary. Otherwise, all elements installed require operation and maintenance activities consistent with activities already being performed by site maintenance personnel at other residences.

## 6.6 Training

For the APS demonstration, training information was included in each APS delivery package to the residents to help in proper installation of these devices. Additionally, NREL used a local, Guamanian contractor to help provide technical assistance to residents to support general troubleshooting. Unfortunately, as noted above, several APS devices were likely not installed properly—if they were installed at all. Before deploying additional APS devices in a military, residential environment, evaluating additional options to strengthen educational awareness is recommended.

Training for the EEE demonstration was performed on-site, at one of the residences with the installed EEE equipment. The field training was used to show proper operation of all installed equipment and was performed by the contractor. The training took less than one hour in duration and was presented to appropriate NBG Housing Authority staff. The residents of each EEE home were given personal training by the contractor after the installation at their home was complete.

# 7 Commercial Readiness Qualitative Assessment

## 7.1 Commercial Readiness of Advanced Power Strips

APSs are commercially available from many different manufacturers and vendors, and the technology readiness can be assessed at technology readiness level (TRL) 9. Most stores that carry power strips, including hardware, electronic, and big box stores also carry APSs, though the selection is usually limited. A much wider range of products can be found online from large retail websites like amazon.com, newegg.com, and smarthome.com. APS devices on the market cost between $15 and $70, but most options are less than $40. The price of similar capacity surge protectors is comparable, and APSs also have surge protection built in. Some utilities offer rebates for APSs that would offset any price difference in cost between an APS and a standard power strip.

One major barrier to APS acceptance is a general lack of awareness and understanding. Few of the residents that signed up for the APS demonstration had ever heard of APSs, and those that had did not know how they worked. There are a number of different types of APSs, ranging from simple remote switches to automated activity monitoring devices. They are intended for different users, but those details are not clear from the packaging (Earle & Sparn, 2012). There is very little consumer education surrounding APSs, and additional confusion is introduced by some stores that market power strips with unusual form factors (but no advanced controls) as “advanced power strips.” These obstacles led NREL to create a consumer guide to purchasing an APS that gives some information on how different APS work (see Appendix F).

Once an APS is purchased, getting it properly installed also appears to be a difficult step. In most cases, installing an APS means crawling behind an entertainment center or desk and untangling the mess of wires there. Additionally, the instructions included with the APS can be difficult to interpret—either because they do not contain enough detail or because they are overly detailed and long. The installation instructions provided by NREL (Appendix B) were created to provide simplified instructions, but they are specific to this demonstration.

Lastly, expected energy savings from APS is not well known. There is significant variability between different households, as was seen in this demonstration, and there have not been enough large-scale demonstrations to establish confidence in expected savings. Northeast Energy Efficiency Partnerships (NEEP) published a report on expected savings for APSs that assumes all standby loads in the home office and home entertainment center can be saved, which results in an estimated 75 kWh/year in savings in a home entertainment center and about 30 kWh/year savings in a home office (NEEP Data Working Group, 2012). These findings are fairly consistent with this study’s results. As more field trials and analyses evaluate APSs and studies are conducted over longer periods to enable assessment of retention, confidence will grow in the expected savings. APSs present a significant potential for a low-cost solution to a complex problem of growing plug loads in homes.

## 7.2 Commercial Readiness of Enhanced Energy Efficiency Technologies

All of the technologies included in the EEE demonstration are commercially available and can be assessed at TRL 9. High-efficiency air conditioners with a SEER greater than 20 are available from multiple manufacturers. In many climates, the more expensive, high-efficiency systems are not cost-effective. However, efficiency programs like ENERGY STAR® have continued to push the air-conditioning industry toward higher-efficiency products. As even better products come out, SEER 21 air conditioners will become cheaper and more practical for more places.

The in-line dehumidifier is somewhat unique, as it is integrated with the air conditioner and air handler, but there are many other ducted dehumidifiers on the market. The EEE demonstration results show newer air conditioners provide more latent cooling, so additional dehumidification may not be necessary. If additional dehumidification is desired, the standalone dehumidifiers currently installed should be sufficient, though quieter models would be preferred by the residents. Dehumidifiers are an additional piece of HVAC equipment that are not needed in many climates, but are becoming more important in high-efficiency homes that require less cooling. Standalone dehumidifiers are cheaper and do not require special installation like ducted systems, so they are more common.

Programmable thermostats are not a new or uncommon technology, but they are underutilized in a different sense. A study done in 2011 found that only a third of American homes had a programmable thermostat and only about half the homes with a programmable thermostat actually programmed them to save energy during times when heating or cooling was not needed (Peffer, Pritoni, Meier, Aragon, & Perry, 2011). There have been well-documented barriers to programmable thermostats that are mostly related to their usability. New products on the market, like the Nest thermostat, aim to learn people's behavior to automatically save energy. The programmable thermostat used in this demonstration has a smartphone app that allows people to change their thermostat remotely and allows them a more familiar interface to program their thermostat. These innovative features come with additional cost though, so even if the usability barrier is overcome, a cost barrier may exist.

HPWHs are a relatively new technology, even though commercial products were first created in the 1950s (albeit with substantial problems). The most recent incarnation of the HPWH has been more successful than those early attempts, and the image of the technology has been improved by reputable water heater manufacturers producing HPWHs. HPWHs are much more efficient than electric-resistance water heaters, and regions of the country that have a high saturation of electric water heaters also tend to be climates that are well-suited to HPWH (Maguire, Burch, Merrigan, & Ong, 2013). Barriers to HPWH deployment include the higher cost (they are usually $800-$1,000 more expensive than a standard electric water heater) and lack of awareness. Some big box stores carry HPWHs, and there are sizable rebates available from federal and local rebate programs. Targeted marketing in the right climates may increase awareness and consumer acceptance.

Low-flow shower heads are required by federal regulations and so are very common. There are no barriers to commercialization.

# 8 Recommended Next Steps

## 8.1 Recommended Next Steps for Advanced Power Strips

Despite the challenges of the APS demonstration, advanced power strips are a promising low-cost technology. The energy savings per APS is small, but so is the cost of each device. There are few options available to curb the ever-growing segment of plug loads in residential buildings, and APSs are a simple solution that can be employed in all types of residences. This technology is ready for deployment, though the best deployment method may depend on the situation and goals for the specific base.

Recommendations for future APS deployment:

- The best time to install APSs is when residents are moving into their homes, so APSs could be included in a move-in package.
- If a large-scale deployment was planned in the future, the APS installation should be performed by a third party to ensure the devices are installed and installed properly. This would add to the cost of the deployment, but the savings number may be better because the installation of the APS would be guaranteed.
- The net cost savings in Table 17 show that a larger deployment would result in positive savings, so the bigger the deployment, the better.
- Lack of education is a large barrier with APSs, so awareness or training activities could be used to help educate people about how to install and use an APS, and its energy savings benefits.
- Children are often more tech-savvy than their parents. At least one home in the demonstration was signed up by the family's middle school-aged daughter. Tapping into the interest of children and teenagers may be a good way to bridge education and energy efficiency.
- Especially on bases where residents pay their electricity bill, stocking APSs in the on-base Navy Exchange store may encourage the more energy-conscious residents to invest in an APS, especially if copies of the consumer education flyer (Appendix F) developed by NREL were available as well. Another option would be to provide residents with a small coupon for the APS models available at the Naval Exchange. Having the residents purchase the APS may also improve installation rates as people would be personally invested.

Lessons learned with the APS demonstration:

- No matter how enthusiastic a resident may be, the effort required to install APS on their own is usually too much.
- Once installed, residents are generally willing to adapt their habits.
- People seemed more concerned with the monitoring part of the demonstration than actually using the APS. Several of our participants uninstalled their monitoring equipment before the APSs were installed, for no obvious reason.

## 8.2 Recommended Next Steps for Enhanced Energy Efficiency Technologies

When NBG housing air conditioners and water heaters reach the end of their lives, they should be replaced with SEER 21 air conditioners and heat pump water heaters. NBG is already following NREL recommendations for next steps by updating the current standards to specify energy efficient technology.

This will ensure new homes and existing homes in need of new appliances or large equipment will receive energy efficient products.

The technologies included in the EEE demonstration had a significant impact on the houses' energy consumption, while maintaining comfort and user satisfaction. The only exception was the in-line dehumidifier that did not have a measurable impact on the indoor air conditions. High-efficiency air conditioners and HPWHs have already been integrated into plans for future upgrades on Naval Base Guam. The standard for all new water heaters was previously changed to solar thermal water heaters (found in all new homes in the North Tipalao neighborhood), but they have since changed that standard to mandate HPWHs instead. HPWHs are much cheaper than solar water heaters, especially when solar water heaters have to be protected in hurricane/typhoon prone areas, and they still provide significant energy savings.

A follow-on project currently underway will outfit 20 additional homes with the energy efficiency technologies from the EEE demonstration (excluding the in-line dehumidifier) in the Lockwood Terrace and Apra View neighborhoods on NBG. One difference in these installations is the water heater is located inside the conditioned space, in the laundry room, in the Apra View homes, so this will be a good opportunity to see if the same magnitude of energy savings is achieved and if user satisfaction is maintained for conditioned space installations.

There may be opportunities for further education on technology like programmable thermostats. Few people had used the scheduling feature of their programmable thermostat, which provides an opportunity for further energy savings. If there are people at home during the day, there is less opportunity to set a daily schedule. Education about the features and benefits of programmable thermostats may help those on base that can set up their thermostat during the day to save energy.

These recommendations are generally restricted to Guam, as the warm climate and high electricity prices lead to short payback periods for high-efficiency equipment. Even a climate like Hawaii may be mild enough to require a change in the recommendations from this demonstration. Even if the recommendations are specific to Guam, there are opportunities to work with the rest of Guam to inform the public of their options and the cost/benefit trade-offs for these energy efficient technologies. HPWHs are a technology that Guamanians are interested in but had no experience with. This demonstration may encourage more people on the island to invest in better technology in their own homes.

Lessons learned with the EEE demonstration:

- People are generally impressed by the look of new technology, even if they do not understand it.
- Noise may trump other comfort concerns, like humidity. Every single resident said they were happy with the new air conditioner because it was quieter. On the other hand, a few people noted they turned off their standalone dehumidifiers because they were too loud.
- BEopt can be used to define similar packages of energy-efficient and cost-effective retrofit measures for any home in any climate. Major retrofit efforts in other climates can use this tool to select a package of measures, including an estimate of predicted energy savings.

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# Appendix A: Advanced Power Strip Fact Sheet

## Advanced Power Strip Study

**If you qualify, you will receive one free APS for your home entertainment center and another free APS for your home office (if you have a home office).**

**Required:**

Homes must have at least one entertainment center consisting of:

- ✓ One TV
- ✓ At least two other controllable appliances*, such as a DVD or Blu-Ray player, VCR, stereo amplifier, or game console.

You must be willing to:

- ✓ Respond to an initial questionnaire, which will include an inventory of relevant appliances and basic questions about initial usage.
- ✓ Have your home's electricity use monitored by NREL during the demonstration period. No personally identifiable information will be reported in the test results.
- ✓ Participate in a second questionnaire at the end of the study, which will include basic questions about the APS user experience.

**Preferred:**

In addition to the entertainment center, homes should have a home office area consisting of:

- ✓ One laptop or desktop computer
- ✓ At least two other controllable* devices that are used in conjunction with the computer, such as an external monitor, printer, or scanner.

**Devices such as DVRs and TiVo-like video recorders, as well as wireless routers and modems will be plugged into "always on" outlets so their functionality will not be affected. Do not count these devices as "controllable" appliances.*

**Limited time opportunity**

**To participate, contact:**

**Raymond Garrido**
Housing Inspector
(671) 355-5811
Raymond.Garrido@fe.navy.mil

**Derek Briggs**
Naval Base Guam Energy Manager
(671) 333-1325
Derek.Briggs@fe.navy.mil

## You may qualify for the Advanced Power Strip study on Naval Base Guam!

We'll upgrade your power strip for free if your household qualifies.

**The purpose of this study is to promote home energy efficiency. TVs, computers, and related electronics are huge energy hogs and release excess heat inside your home, even when they are turned off.**

**Advanced Power Strips (APS) can significantly reduce the amount of electricity these devices use, making your home cooler and more energy efficient.**

Testing the effectiveness of APS devices in improving energy efficiency of homes on large-scale U.S. military bases is a collaborative effort by Naval Base Guam and the National Renewable Energy Laboratory. The study will include:

- Installing free APS devices on all home office and home entertainment centers in 100 homes on Naval Base Guam.
- Remotely measuring energy usage to determine savings achieved.
- Evaluating APS devices as an energy efficiency strategy for other U.S. military housing bases.

NAVFAC Naval Facilities Engineering Command

NREL National Renewable Energy Laboratory

## Advanced Power Strip (APS) for Home Entertainment Center

### How will I use the APS with my home entertainment center?

- Plug your TV, VCR, DVD player, stereo amplifier, game console and speakers into the green *Controlled Outlets*.
- Plug your DVR or TiVo into the black *Regular Outlets*.
- Use your entertainment center as usual.

### How does the APS work?

- When all the electronics plugged into the *Controlled Outlets* are off, power will be turned off for those outlets. →This eliminates "vampire" electricity use.
- If the remote control has not been used for 1 hour, the *Controlled Outlets* will be turned off. →This turns the TV off if someone fell asleep or left the house without turning everything off.
- Pressing a button on the remote control or the button on the IR sensor will allow all the electronics to be turned on again.

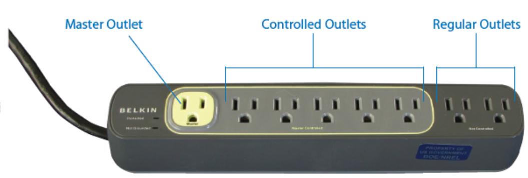
## Advanced Power Strip (APS) for Home Office

### How will I use the APS with my home office?

- Plug your computer into the *Master Outlet*.
- Plug your monitor, printer and scanner into the *Controlled Outlets*.
- Plug your modem and/or wireless router into the *Regular Outlets*.
- Use your home office as usual.

### How does the APS work?

- When the computer is on, the *Controlled Outlets* behave like a regular outlet.
- When the computer is off or in standby mode, the *Controlled Outlets* are switched off. →This eliminates energy use when electronics are off and switches off electronics that are accidentally left on.
- As soon as the computer is in use again, the *Controlled Outlets* will be turned back on.

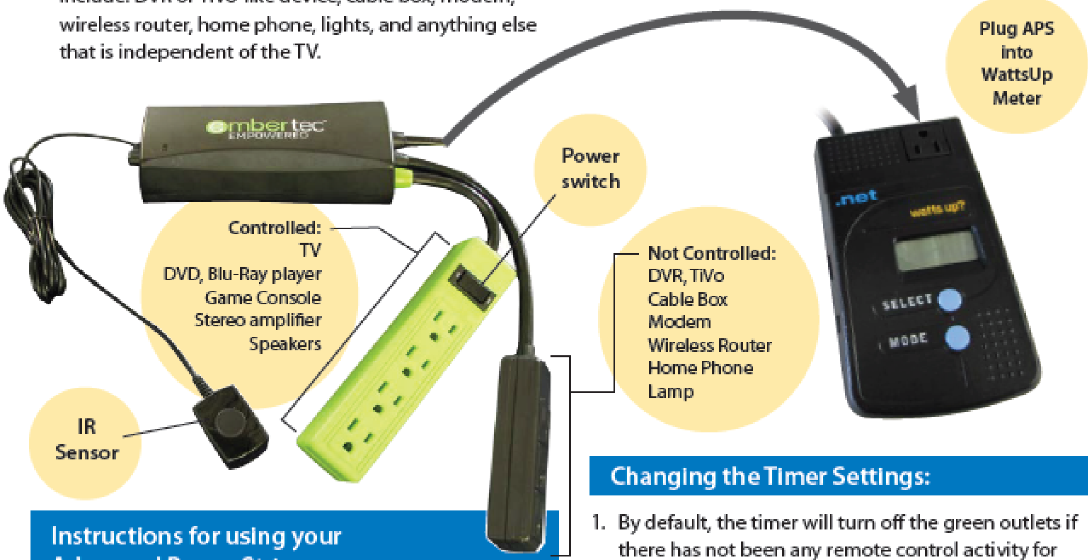



# Appendix B: Advanced Power Strip Installation Instructions

## Instruction Sheet for Home Entertainment Center Advanced Power Strip (APS)

### Instructions for Initial Setup:

1. Unplug your existing power strip from the WattsUp meter.
2. Plug your new Embertec Advanced Power Strip (called the "Emberceptor") into the WattsUp meter.
3. Plug your TV and any other associated devices into the green outlets. This should include: DVD player, Blu-ray player, Xbox, Playstation, Wii (or any other video game console), stereo amplifier and speakers.
4. Plug all other electronics into the black outlets. This may include: DVR or TiVo-like device, cable box, modem, wireless router, home phone, lights, and anything else that is independent of the TV.
5. Plug the IR sensor into the Emberceptor body, as shown in the picture below. Place the IR sensor somewhere near the TV so that it will see remote control signals.
6. If you have a stereo that you use independent of your TV, you should choose a location for the IR sensor that can pick up remote control signals for the TV and stereo, if possible.
7. Make sure that the power switch with the green outlets is switched on.




### Instructions for using your Advanced Power Strip:

1. To turn on the green controlled outlets, use a remote control to turn on the TV. You may need to hit the power button twice—once to wake up the APS and a second time to turn on the TV. All other electronics plugged into the green outlets should work normally now.
2. Turn everything off as usual. When the APS detects that everything is off, it will turn off power completely to the green outlets.
3. If you forget to turn your electronics off, there is a timer feature that will automatically turn off the green outlets if there has not been any IR activity for a long time. By default, this timer period is set to 1 hour. You can increase the timer period to 2 or 3 hours or turn it off. See additional instructions below for changing the timer settings.
4. The regular black outlets will always be powered, as these are intended for appliances that should never be turned off.
5. All the outlets are surge protected.

### Changing the Timer Settings:

1. By default, the timer will turn off the green outlets if there has not been any remote control activity for 1 hour. (The user will be warned by flashing lights before the outlets are turned off—hit any button on your remote to keep green outlets on.)
2. If you wish to increase the time to 2 or 3 hours or turn off the timer function, start with the APS plugged in and the green outlets on.
3. Press the button on the IR sensor for three seconds and the light will flash several times.
4. After the light has stopped flashing, press the button twice for a 2-hour timer, three times for a 3-hour timer or five times to disable the timer.
5. The light will flash the same number of times to confirm your selection.

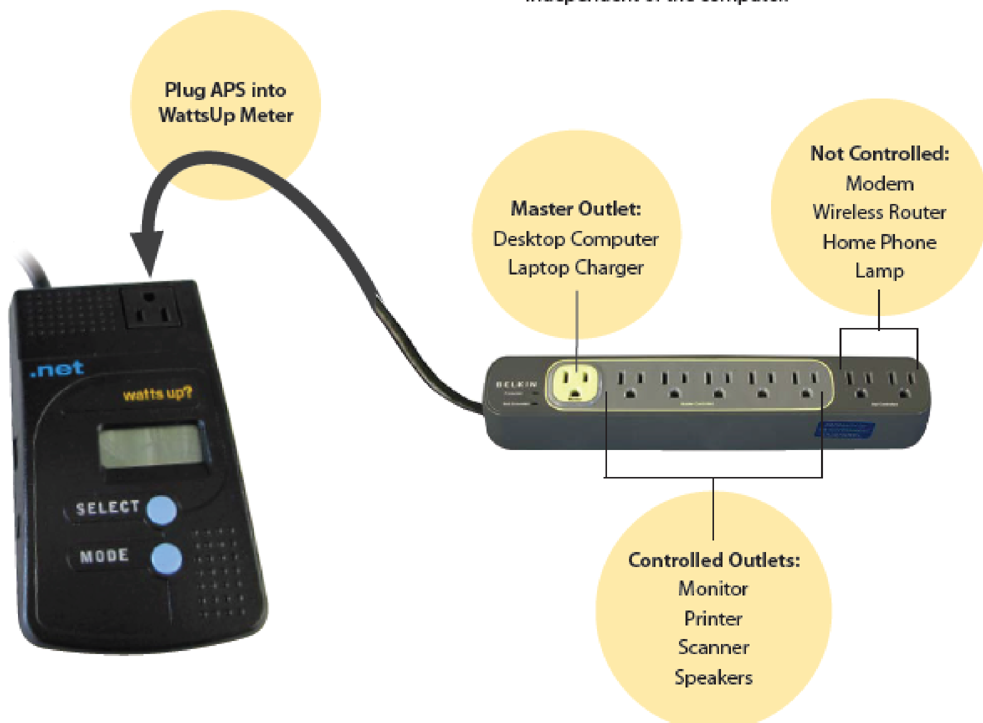
**For technical assistance, call Allison Rutter: 671-685-4416**

**Also available by email at: allison@guamsustainability.com**

# Instruction Sheet for Home Office Advanced Power Strip (APS)

## Instructions for Initial Setup:

1. Unplug your existing power strip from the WattsUp meter.
2. Plug your new Belkin Advanced Power Strip into the WattsUp meter.
3. Plug your computer into the light green outlet labeled "Master." This is also where you will plug in a laptop power cord, if you have a laptop.
4. Plug computer accessories into the middle outlets labeled "Master Controlled." This should include: monitor, printer, scanner, speakers, and any other device that you only use together with your computer.
5. Plug all other electronics into the "Not Controlled" outlets. This should include: modem, wireless router, home phone, lights, and anything else that is independent of the computer.




## Instructions for using your Advanced Power Strip:

1. When the computer is on, all the items plugged into the "Master Controlled" outlets can be turned on.
2. If the computer is off or asleep, anything plugged into the controlled outlets will be turned off. Turning on the computer or waking it up will restore power to these outlets.
3. The "Not Controlled" outlets will always have power.
4. All the outlets are surge protected.

For technical assistance,
call **Allison Rutter**: 671-685-4416

Also available by email at:
allison@guamsustainability.com

# Appendix C: Advanced Power Strip Pre- and Post-Demonstration Surveys

## Advanced Power Strips: Pre-Demonstration Questions

**Home Entertainment Area:**

| | |
|---|---|
| Is there a power strip already in use? How many, if more than one? | |
| List the devices connected to the TV. | |
| How many hours per day is the entertainment center typically used during the week? | |
| How many hours per day is the entertainment center typically used on the weekend? | |

**Home Office Area:**

| | |
|---|---|
| Is there a home office area (designated space for computer and peripherals to be plugged in)? | |
| Is there a power strip already in use? How many, if more than one? | |
| List the devices connected to the computer. | |
| Is the computer a desktop or laptop? | |
| How many hours per day is the home office typically used during the week? | |
| How many hours per day is the home office typically used on the weekend? | |

## Advanced Power Strips: Post-Demonstration Questions

1. Which APS did you have installed—home entertainment, home office, or both?
2. Did you have any trouble setting up the home entertainment APS? Were the instructions unclear? What could be done to improve instructions?
3. What did you think of the home entertainment APS? Did you notice its control features?
4. Did you uninstall the home entertainment center APS during the study? Do you plan to uninstall it now that the demonstration is over?
5. Did you have any trouble setting up the home office APS? Were the instructions unclear? What could be done to improve instructions?
6. What did you think of the home office APS? Did you notice its control features?
7. Did you uninstall the home office APS during the study? Do you plan to uninstall it now that the demonstration is over?
8. If you were paying your utility bills, would you buy a similar product in the future? Why or why not?

# Appendix D: Enhanced Energy Efficiency Post-Demonstration Survey

## Enhanced Energy Efficiency: Post Demonstration Questions

1. What was your general impression of the new equipment installed in your house?

2. Did you notice any effects of the new air conditioner—improved or worsened comfort, more or less noise, longer or shorter run times?

3. Did your home have a new dehumidifier installed? If so, did you notice any change to the indoor air conditions? Did it feel less humid?

4. What did you think of the programmable thermostat? Did you set up a daily schedule? What temperature (and humidity, if applicable) settings did you use? Did you ever use the smartphone app to change the set point remotely?

5. Did you notice the effect of the low-flow shower heads? Would you install low-flow shower heads in your home in the future?

6. Did you notice any effects of the new water heater—more or less available hot water, too noisy, more or less comfortable garage (if applicable)? Did you change the operating mode or set point to improve the amount of hot water available? What did you set the operating mode and set point to?

# Appendix E: Economic Analysis for Advanced Power Strip and Enhanced Energy Efficiency Demonstrations

## Cost Information

### *Cost Assumptions for Minimally Efficient Retrofit*

To evaluate the economic benefit of the enhanced energy efficiency (EEE) retrofits, pricing was estimated for a hypothetical, minimally efficient retrofit (lowest cost and minimum efficiency performance) for a comparative analysis. The following factors were used as the basis of estimate for the pricing of the minimally efficient retrofit.

- Equipment selection was based on the key technical specifications (tonnage, energy efficiency ratio (EER), tank size, etc.) of the equipment existing at each residence prior to the demonstration, which was replaced by the EEE retrofits.
- Equipment pricing was performed by identifying the lowest cost option meeting the equipment technical specifications, as presented by the US. General Services Administration's "GSA Advantage! Online Shopping" website.[5] See Table A-1 for the unburdened equipment pricing used.
- Design activities were considered minimal and of equivalent cost to those required for the EEE retrofits (design activities focused on appropriate sizing of the HVAC systems). No special design costs are believe needed for the EEE retrofits relative to a standard installation of commercial products.
- Aggregate installation costs were estimated at 95% of realized costs for EEE retrofit installation. The price reduction of 5% was applied to account for the added complexity of the HPWH installation versus a standard, electric-resistant hot water heater.

**Table A-1. Estimated, Unburdened Equipment Pricing for the Minimally Efficient Retrofits**

| **Summary Breakout of Equipment Costs** | | | |
|---|---|---|---|
| **Item #** | **Item** | **Units** | **Unit Price** |
| 1 | Electric-Resistant Water Heater (40 gallons) | 8 | $240 |
| 2 | Shower Head | 16 | $54 |
| 3 | A/C Unit (SEER 13, 4 ton) (AHU, Condenser) | 8 | $2,100 |
| 4 | Thermostat | 8 | $16 |
| 5 | Standalone Dehumidifier (30–40 pint/day) | 8 | $200 |

## Economic Analysis Information

### *Energy Return on Investment Analyses*

Table A-2 provides a summary of key information regarding the energy return on investment (eROI) analyses developed for the EEE project.

[5] The GSA Advantage! Online Shopping website can be found at: www.gsaadvantage.gov/advantage/main/start_page.do.

**Table A-2. Key Information Regarding eROI Analyses Performed for this Report**

| eROI Analyses: Key Information | | |
|---|---|---|
| **Input Type** | **EEE Demo** | **APS Demo** |
| **Date of Analysis** | Nov. 18, 2013 | July 16, 2013 |
| **eROI Version** | v.2.9.16 | v2.9.16B |
| **Project Overview Tab** | | |
| Project Category | Facility En. Impr. | Facility En. Impr. |
| Regional Priority Project | No | No |
| **Max. Financial Benefits Tab** | | |
| Salvage Value | $0 | $0 |
| **Provide Reliable Energy Tab** | | |
| MDI Critical Facilities | 0 | 0 |
| **Regulatory and SH Expect. Tab** | | |
| Regulatory Compliance | 2 | 2 |
| Public Perception | 0 | 0 |
| Quality of Service, Goals | 1 | 0 |
| Quality of Service, # People | 2 | 2 |
| **Develop. Enabling Infrast. Tab** | | |
| Question 1, Data Improvement | 3 | 2 |
| Question 2, Flex. Energy Inf. | 0 | 1 |
| Question 3a, Energy Indep. | 3 | 2 |
| Question 3b, % of Installations | 50% | 25% |
| **Project Risk Tab** | | |
| 1. Timeline and Cost | +/- 10% | +/- 10% |
| 2. Energy Reduction | +/- 10% | +/- 10% |
| 3a. Facility Energy Reliance | +/- 10% | +/- 10% |
| 3b. Facility Outages | +/- 10% | +/- 10% |
| 3c. Backup Power | +/- 10% | +/- 10% |
| 4. Regulatory and Stakeholders | +/- 10% | +/- 10% |
| 5. Enabling Infrastructure | +/- 10% | +/- 10% |
| 6. Aggregate Benefits | +/- 25% | +/- 10% |
| **Impact of Deferring Tab** | | |
| Impact of Deferring One Year | 0% Loss | 0% Loss |

### *Building Life-Cycle Cost Analyses*

Table A-3 provides a summary of key information regarding the Building Life-Cycle Cost (BLCC) analyses developed for this project.

**Table A-3. Key Information Regarding BLCC Analyses Performed for this Report**

| **BLCC Analyses: Key Information** | |
|---|---|
| **Input Type** | **Value** |
| Report Type | MilCon |
| BLCC Version | 5.3 |
| Location | Hawaii[a] |
| Discounting Convention | Mid-Year |
| Analysis Type | Constant Dollars |
| Base Date | Oct. 2013 |
| Beneficial Occupancy | Oct. 2013 |
| Length of Study | 10 Years |
| Energy Usage Indice | 100% throughout economic life |
| Investment Cost, Cost-Phasing | 0% |
| Energy Escalation Factor | 0% |

[a] Guam is not available in BLCC.

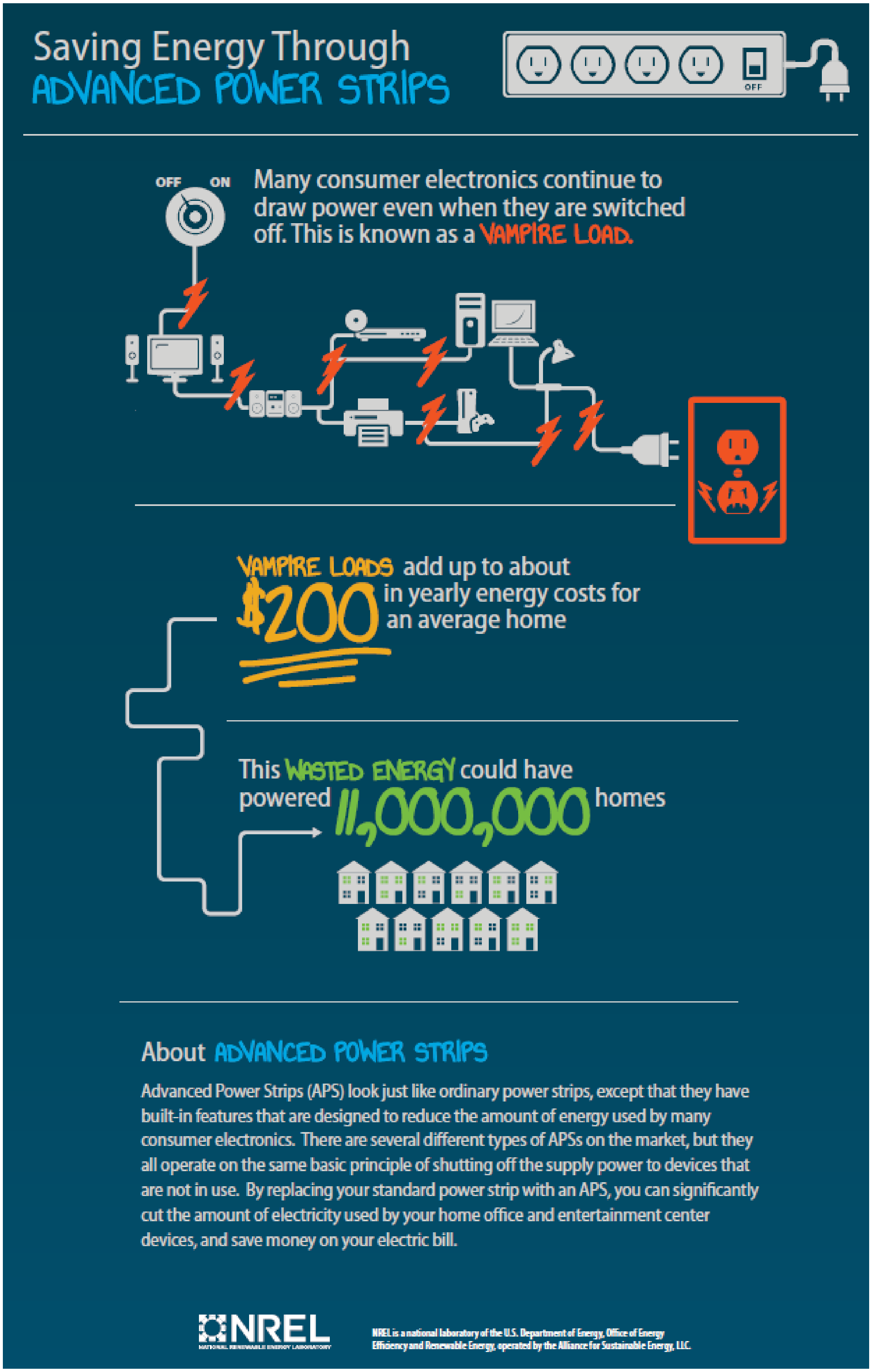
Table A-4 provides a summary of key information regarding the BLCC analyses developed for the advanced power strip project.

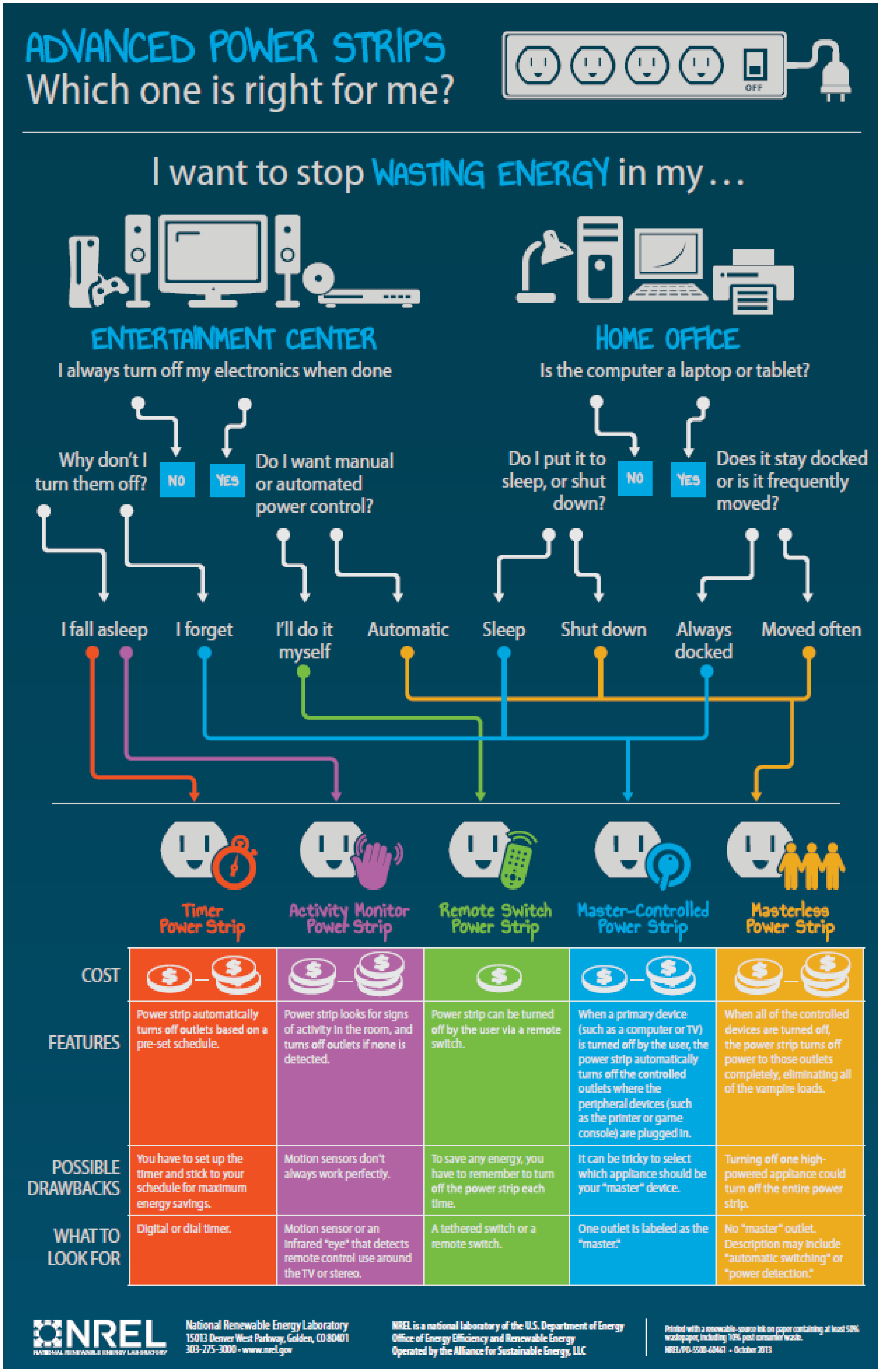
**Table A-4. Key Information Regarding BLCC Analyses Performed for this Report**

| **BLCC Analyses: Key Information** | |
|---|---|
| **Input Type** | **Value** |
| Report Type | MilCon |
| BLCC Version | 5.3 |
| Location | Hawaii[a] |
| Discounting Convention | Mid-Year |
| Analysis Type | Constant Dollars |
| Base Date | Oct. 2013 |
| Beneficial Occupancy | Oct. 2013 |
| Length of Study | 4 Years |
| Energy Usage Indice, 1st Year | 100% Usage |
| Energy Usage Indice, 2nd Year | 75% Usage |
| Investment Cost, Cost-Phasing | 0% |
| Energy Escalation Factor | 0% |

[a] Guam is not available in BLCC.

# Appendix F: Consumer Guide for Advanced Power Strips




ADVANCED POWER STRIPS
Which one is right for me?
OFF
I want to stop WASTING ENERGY in my…
ENTERTAINMENT CENTER
I always turn off my electronics when done
Why don't I turn them off?
NO
YES
Do I want manual or automated power control?
HOME OFFICE
Is the computer a laptop or tablet?
Do I put it to sleep, or shut down?
NO
YES
Does it stay docked or is it frequently moved?
I fall asleep
I forget
I'll do it myself
Automatic
Sleep
Shut down
Always docked
Moved often
Timer Power Strip
Activity Monitor Power Strip
Remote Switch Power Strip
Master-Controlled Power Strip
Masterless Power Strip
COST
FEATURES
Power strip automatically turns off outlets based on a pre-set schedule.
Power strip looks for signs of activity in the room, and turns off outlets if none is detected.
Power strip can be turned off by the user via a remote switch.
When a primary device (such as a computer or TV) is turned off by the user, the power strip automatically turns off the controlled outlets where the peripheral devices (such as the printer or game console) are plugged in.
When all of the controlled devices are turned off, the power strip turns off power to those outlets completely, eliminating all of the vampire loads.
POSSIBLE DRAWBACKS
You have to set up the timer and stick to your schedule for maximum energy savings.
Motion sensors don't always work perfectly.
To save any energy, you have to remember to turn off the power strip each time.
It can be tricky to select which appliance should be your "master" device.
Turning off one high-powered appliance could turn off the entire power strip.
WHAT TO LOOK FOR
Digital or dial timer.
Motion sensor or an infrared "eye" that detects remote control use around the TV or stereo.
A tethered switch or a remote switch.
One outlet is labeled as the "master."
No "master" outlet. Description may include "automatic switching" or "power detection."
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