Prepared for the U.S. General Services Administration
By the National Renewable Energy Laboratory

September 2012

Plug-Load Control and Behavioral Change Research in GSA Office Buildings

Ian Metzger
Dylan Cutler
Michael Sheppy

GPG
Green Proving Ground Program

The Green Proving Ground program leverages GSA’s real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the National Renewable Energy Laboratory (NREL), nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or NREL. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or NREL.

The work described in this report was funded by the U.S. General Services Administration (GSA) and the Federal Energy Management Program of the U.S. Department of Energy under Contract No. [GSA: PX013232, NREL: IAG-11-1827].

Acknowledgements

GSA: Kevin Powell, Michael Hobson, Michael Lowell

GSA Region 3: John Tegan, Joseph Parisi, John Remis, Scott Wooten, Douglas Tranter, Zach Spears, Natalie Draa, and all participating staff in GSA Region 3 field offices.

National Renewable Energy Laboratory: Alicen Kandt

For more information contact:

Kevin Powell
Program Manager
Green Proving Ground
Office of the Commissioner
Public Buildings Service

U.S. General Services Administration

555 Battery Street, Room 518

San Francisco, CA 94111-2312

Email: kevin.powell@gsa.gov

Table of Contents

Page

I. Executive Summary

Background

The U.S. General Services Administration (GSA) owns and leases over 354 million square feet (ft^2) of space in over 9,600 buildings [1]. GSA is a leader among federal agencies in aggressively pursuing energy efficiency (EE) opportunities for its facilities and installing renewable energy (RE) systems to provide heating, cooling, and power to these facilities. Since the enactment of the Energy Policy Act of 2005 and Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management (2007)," other federal agencies are looking to GSA for strategies for meeting the EE and RE goals laid out by these pieces of legislation and executive orders.

This demonstration project was hosted by GSA's Mid-Atlantic Region, which includes Delaware, Pennsylvania, West Virginia, southern New Jersey, and much of Maryland and Virginia [2]. According to several energy assessments of GSA's buildings conducted by the National Renewable Energy Laboratory (NREL), plug-loads account for approximately 21% of the total electricity consumed within a standard GSA Region 3 office building. This percentage includes standard office equipment, but excludes data center and telecom equipment. The range varies widely, with plug-loads accounting for anywhere between 8% and 35% of the total building electricity consumption. In office buildings, as other energy systems become more energy efficient, plug-loads make up a bigger piece of the building's energy footprint. Other studies in the United States have shown that plug-loads account for approximately 25% of total load in a minimally code-compliant office building. However, they may account for more than 50% of the total load in an ultra-efficient office building [3]. They also produce considerable heat, which increases cooling loads. Minimizing plug-loads energy consumption is a primary challenge in the design and operation of an energy-efficient building, because it is an aggregate of small distributed loads under the control of individual occupants.

Currently, there is very limited information available on how much energy plug-loads consume. A complex array of technologies that meter and control plug-loads have emerged in the marketplace. Control strategies that match plug-load energy use to user work schedules can save considerable energy and are replicable for most commercial buildings. Plug-load control strategies are also effective in minimizing peak demand.

This project tested the effectiveness of two types of plug-load reduction strategies:

- Schedule timer: controls that allow the user to set the day and time that a circuit may be energized and de-energized.
- Load-sensing: controls that monitor a specific device's (master) power state and will de-energize the auxiliary devices (slaves) if the master goes into a low-power state.

Typical electronic equipment is designed for tens of thousands of switch cycles which would typically extend beyond the useful life of the equipment, even with controls energizing and de-energizing the equipment multiple times daily. For a complete discussion of different types of plug-load controls, please refer to Section III-B (Technology Description).

This study aims to provide insight on how to effectively manage plug-load energy consumption and attain higher energy and cost savings for plug-loads.

What is the Technology?

An advanced power strip (APS) was selected to be evaluated. The demonstrated product provides capabilities that are typical in other APSs on the market. This product is not the only APS on the market. There are an abundance of APSs that offer a variety of complexity, control strategies, data collection abilities, and costs.

This APS technology saves energy by controlling up to four plug-in devices according to a schedule and/or based on a given device crossing a power threshold. The APS also meters the energy use of the connected plug-in devices, which can be used to quantify energy savings. The manufacturer claims that its device can reduce plug-load energy costs by up to 50%. It also claims a payback period of less than 3 years.

Some APSs come with a Web-based dashboard that allows users to implement and change control strategies as well as look at the real-time energy consumption of plug-loads in their buildings. This centralized, Web-based approach to plug-load management is novel because conventional plug strips typically have to be configured and controlled locally.

Training and Technology Setup

Ensuring optimal energy savings from APS technology requires correct operation for multiple years of usage. This continued operation will provide persistent savings and will result in shorter payback periods. To achieve the maximum savings, it is important to provide adequate training for the user on how to operate the APSs. This will help smooth the transition to plug-load control for the occupant and enable him/her to maintain control over the workspace while still achieving energy savings.

The APS training must be accompanied by a quality technology installation. It is important to make sure that the controls are implemented correctly and that the correct devices are being controlled. This is especially important when the APS system is communicating with a remote server for either data storage or control logic.

Study Design and Objectives

The APSs were deployed in eight GSA office buildings in Region 3:

- Veterans Administration Center Building – Philadelphia, Pennsylvania
- William J. Green, Jr. Federal Building – Philadelphia, Pennsylvania
- Cohen Complex – Camden, New Jersey
- Clarkson S. Fisher Federal Building and U.S. Courthouse – Trenton, New Jersey
- Spottswood W. Robinson III and Robert R. Merhige, Jr., U.S. Courthouse – Richmond, Virginia
- Edward A. Garmatz U.S. Courthouse – Baltimore, Maryland
- William S. Moorhead Federal Building – Pittsburgh, Pennsylvania
- Robert C. Byrd Federal Building and U.S. Courthouse – Charleston, West Virginia.

These buildings were selected as representative spaces that reflect typical office setups and equipment in the wider GSA building stock. The findings for these buildings can be extrapolated for potential energy savings for plug-load control technologies in other GSA facilities and government offices. This study looked at the average power draw of and total energy consumed by individual equipment as well as aggregated equipment categories. The following control strategies implemented in the selected locations are listed in Table 1.

Table 1: Control strategy for each building

Location	Control
Veterans Administration Center Building	Load-sensing
William J. Green, Jr. Federal Building	Schedule timer
Cohen Complex	Load-sensing and schedule timer
Clarkson S. Fisher Federal Building and U.S. Courthouse	None
Robinson and Merhige U.S. Courthouse	Load-sensing
Edward A. Garmatz U.S. Courthouse	Schedule timer
William S. Moorhead Federal Building	None
Robert C. Byrd Federal Building and U.S. Courthouse	Load-sensing and schedule timer

The performance parameters monitored in this study were energy and cost savings for the different device types monitored (laptops, printers, monitors, etc.) and for the different space types evaluated (workstation, print room, kitchen, etc.) (see Section V). Payback period and return on investment were also investigated for the range of equipment costs currently in the marketplace (see Section VI).

Project Results and Findings

Under the test conditions, APS implementation resulted in an average electricity savings of 21% for laptops, 35% for printers, 7% for monitors, 12% for under-cabinet lights, and 48% for shared equipment (office and kitchen combined). The results for each device type, listed by each control type, are in Table 2 (below).

Table 2: Electricity use reduction by device type for three different control types

		Printer	Laptop	Monitor	Under-Cabinet Light	Misc. Equipment	Kitchen Equipment	Total
Schedule timer	Edward A. Garmatz U.S. Courthouse	68%	13%	14%	14%	25%	13%	43%
	William J. Green, Jr. Federal Building	31%	54%	27%	34%	67%	79%	52%
Load-sensing	Robinson and Merhige Courthouse	69%	-4%	-6%	n/a	51%	n/a	23%
	Veteran Administration Building	-5%	16%	11%	0%	54%	n/a	10%
Both	Robert C. Byrd U.S. Courthouse	18%	35%	-2%	22%	40%	n/a	23%
	Cohen Complex	27%	14%	-1%	-1%	68%	n/a	12%
Average	Average	35%	21%	7%	14%	51%	46%	27%

Table 2 above shows that schedule timer controls generally outperformed load-sensing controls in this study. The largest savings were achieved when schedule timer controls were applied to plug-loads that were powered 24 hours per day, 7 days per week (e.g., printers, kitchen equipment, and miscellaneous equipment). Miscellaneous equipment includes other peripheral plug loads, such as radios, speakers, pencil sharpeners, calculators, and phone chargers. Small negative savings for some equipment types can be attributed to normal variations in usage coupled with disabled or non-functioning load-sensing controls. Combination of the two control types also realized limited savings due to complications with load sensing control implementation and the priority of combined rules.

In some instances, large variations between data sets for sites with the same control strategies were observed. This result implies that a larger sample size is necessary to achieve more consistent data. As a result, there may be significant uncertainty with average savings results in some instances.

A larger case study was developed for the Cohen Complex (one of the eight buildings selected for this study) to demonstrate whole-building implementation in a typical GSA office building. This building is 289,214 ft^2 and has mixed use, including office space, courthouses, and a post office. A detailed inventory of the plug-loads was collected as part of an energy efficiency and renewable energy site assessment conducted by NREL in June 2011. This facility had a plug-load energy consumption that contributed to approximately 15% of the total building annual electricity consumption. The savings that were shown to be achievable by this research project were extrapolated to the whole-building, plug-load inventory to demonstrate a larger-scale implementation of the technology.

Savings for the different control types were estimated from the average of the two buildings where that control had been implemented and monitored. The results show good payback periods in certain applications. The higher payback period for workstations is primarily attributed to the fact that GSA Region 3 has excellent computer power management settings.

The total power and energy use were calculated from the inventory of devices. Energy savings were calculated using the percent savings results from this study. Finally, simple-payback periods were calculated assuming a cost of $100/device. Load-sensing controls in shared spaces such as print rooms, kitchens, and miscellaneous require the sensed load to be at the occupant workstations. Therefore the simple payback for load-sensing and load-sensing with schedule-timer includes APS costs and energy cost savings for all workstations in addition to the shared space types APS cost and cost savings. The extrapolated savings for the whole building are presented below in Table 3.

Table 3: Calculated total savings for the Cohen Complex based on metered energy reductions and equipment audit during site visit

	Current Condition			Electricity Savings (kWh/yr)			Payback Periods (Assuming $100/device) (years)		
	Total power (kW)	Electricity use (kWh/yr)	Percent of plug-loads end use	Schedule timer	Load-sensing	Schedule timer + load-sensing	Schedule timer	Load-sensing	Schedule timer + load-sensing
Workstation	21.3	93,465	31.7%	24,153	4,112	10,437	7.8	46.0	18.1
Print Rooms	30.9	135,342	46.0%	67,287	43,309	30,452	1.1	5.5	6.4
Kitchen	14.7	64,386	21.9%	29,618	NA	NA	0.7	NA	NA
Miscellaneous	0.3	1,314	0.4%	603	690	710	4.1	39.9	17.2

The device cost used for this analysis was based on the technology selected for this demonstration project. Costs vary depending on the desired control and sub-metering capabilities.

Conclusions

This project revealed a number of findings that can potentially save energy across GSA's portfolio of office buildings. The largest savings were on loads that run 24/7, such as printers (27%-69% reduction, depending on the type of control) and miscellaneous equipment (51%-81% reduction, depending on the type of control). Most of the workstation equipment (laptops and monitors) were already demonstrating relatively good power-saving behavior due to the computer power management system that was pushed out by the information and technology department at GSA at the beginning of 2012.

Office energy use was most significantly reduced by schedule timer controls in this study. Less savings were achieved with the load-sensing and combined controls. This could present a significant opportunity to utilize some of the simpler and lower-cost, schedule timer power strips to address a majority of office plug-loads. This would both optimize energy savings and require a lower initial investment.

Load-sensing controls could potentially perform as well as, or better than, schedule timer controls in certain applications. However, the excellent computer power management already in place at GSA Region 3 office buildings as well as good occupant awareness and minimal auxiliary devices at the workstation limited the savings potential for load-sensing controls. In addition, this technology required the user to manually set the power threshold that a plugged-in device(s) would be controlled by, which was a significant challenge. For example, if you wanted to use the power draw of a laptop to control the power state of a monitor, you might choose the threshold to be 2 watts (W). However, the standby mode of the laptop might not drop its load below 4 W. In this case, the monitor will never be controlled by the power state of the laptop. During this study, finding the appropriate threshold of a given device was found to be challenging. However, one strategy in future efforts would be to take a baseline of energy usage from each device and use this to determine thresholds. Lastly, higher costs for load sensing controls also contributed to longer payback periods because the "master" and "slave" devices would not be on the same plug strip for shared equipment in print rooms, kitchens, or some miscellaneous applications.

The manufacturer's claim of 50% savings and payback under 3 years was confirmed in certain instances, but not for all applications. However, all applications with less than a 10-year payback should be considered for larger-scale deployment.

Wide spread acceptance of the devices within the office environment was achieved in most instances. Occupants experienced some issues turning devices on in the mornings or unexpected shutdowns in the evenings when working late. This typically was resolved by pressing the manual override button on the APS, which in some instances was expressed to be a nuisance. When asked whether or not occupants would like more control over their individual devices, the majority of respondents said "no." However, an overwhelming majority of respondents indicated that they would be willing to program their individual schedules into an APS. Almost all respondents indicated that behavior was not changed as a result of this research. Those who had access to the online dashboard indicate that they rarely or never checked the real-time energy performance of the plug-loads, which reduces the value of the submetering capabilities.

II. Background

A. Assessment

Plug-loads are the electrical loads in a building due to the various devices that are plugged into receptacles throughout the building. Examples of plug-load devices include, but are not limited to, the following: computers, printers, task lights, vending machines, desk fans, etc. Recent research shows that desk-based technologies and electronics in office settings can consume significant amounts of energy that are often not taken into account in energy monitoring and reduction strategies. These technologies are generally under the control of individual workers rather than centrally operated, making it difficult to track their energy consumption levels. Workstation plug-loads are not the only challenge. Electronic equipment in shared spaces—such as print/copy rooms and break rooms—can also be a significant energy consumer, and with no one person responsible for turning it off, shared equipment is often left "on" indefinitely.

Many uncontrolled plug-loads have significant parasitic loads, which are generally defined as power draw in an "off" state. We define a parasitic load more broadly as the power draw of a plug-load, in any state, that is not performing useful work. All parasitic loads waste energy and should be transitioned to the lowest power state possible, preferably completely powered down.

Plug-loads are driven primarily by user behavior. Occupants in office buildings are typically seated at their desks for less than one third of the average workday [4]. More than two thirds of the year consists of non-business hours when users are not in the workplace, which means that some office plug-loads are used only about 10% of the year. Control strategies that match PLUG-LOAD energy use to user work schedules will save considerable energy.

Plug-loads span a wide range of equipment types, provide multiple functions and services, and are variously operated. The same plug-load type may have completely different use patterns in different locations, so control strategies must be individually tailored. Currently, no single commercially available control device can control all plug-loads properly. Manufacturers market their control devices as the solution to plug-load energy use, but do not specify where they apply. Building owners and occupants may believe these devices control all loads effectively, but they are oftentimes uninformed about which control strategy should be used for specific applications. Some plug-loads can be effectively controlled with inexpensive scheduling devices such as electrical outlet timers; others require much more complicated solutions.

Various technologies have been emerging to address this gap, claiming significant energy savings. The most prominent emerging technologies addressing plug-load energy consumption are known as advanced power strips (APS). These devices offer a variety of control solutions to help turn off electronic devices during unoccupied periods. The two most common control approaches are the following: schedule timer, and load-sensing. The definitions of these control approaches are listed below:

- Schedule timer: controls that allow the user to set the day and time that a circuit may be energized and de-energized.
- Load-sensing: controls that monitor a specific device's (master) power state and will de-energize the auxiliary devices (slaves) if the master goes into a low-power state.

Each of these different control approaches offers unique benefits to reduce plug-load energy consumption when equipment is not in use. This study tests the energy-saving potential of schedule timer controls, load-sensing controls, and a combination of both. The ultimate goal is to reduce plug-load energy consumption with a minimally invasive technology, without affecting occupant productivity. Table 4 below shows some appropriate control applications that resulted from this study.

Table 4: Advanced controls applications. All controls should have a manual override that is easily accessible. Extensive occupant training is required

Control Type	Applicable Deployment Location	Notes
Schedule timer	Print/Copy Rooms, Break Rooms, Workstations, Conference Rooms	Weekday/weekend schedule capability is desired.
Load-sensing	Workstations	Not as effective if workstations auxiliary devices have been already been removed and occupants general turn off equipment during unoccupied times(as shown by this study)

B. Opportunity

The federal government is the single largest user of energy in the nation. GSA currently owns and leases over 354 million square feet (ft^2) of building space in over 9,600 buildings. Based on the sheer size of the building portfolio, there exists a huge opportunity for potential energy savings from plug-loads. On average, plug-loads in GSA's Region 3 were found to account for 21% of total electrical end use.

Currently, energy consumption is just now starting to become a consideration in electronic equipment procurement. Most building occupants have a computer, monitor, and task lighting. Some occupants have peripherals at their workstation such as fans, radios, phone chargers, tablet chargers, or individual printers. GSA is transitioning occupants to using central printer stations rather than individual printers, yet this is on a building-by-building basis. The energy consumption of this equipment may seem negligible, but when you multiply it by hundreds and maybe thousands of occupants in a building, it aggregates into a significant end use. Current practice across most of GSA is that each workstation device is manually controlled by individual users, and they are constantly drawing power either in active or standby modes, even during unoccupied periods. A new, emerging approach is applying some level of controls either by scheduling, load-sensing, or occupancy-sensing. These controls would cut power to devices during periods of non-use or unoccupied times.

The majority of GSA offices use standard plug strips that have all circuits energized all of the time, regardless of whether or not the space is occupied or the equipment is being used. These plug strips do have a manual on/off switch that could be used to de-energize the strip, but these strips are generally mounted underneath the desk and are rarely accessed, if at all. These plug strips cost approximately $5-$20 and typically come with surge protection [5].

GSA Region 3 has recently deployed a centralized computer power management strategy, which shuts down computers and puts monitors into sleep mode at 6 p.m. every evening, unless the occupant manually delays the shutdown. This is an excellent best practice, which has already significantly reduced the parasitic loads associated with computer energy use at workstations. However, shared spaces—such as print rooms and kitchen plug-loads, as well as other auxiliary plug-load equipment in offices—have not been addressed.

The APS device selected for this study offers performance that is available from multiple vendors. The plug strip has been commercially available for approximately 2 years and is in a transition phase from “pilot testing” to commercially deployable. This product has been deployed in over 40 building installations primarily as technology demonstration pilot projects, including a building at the NASA Ames complex in Mountain View, California. Other APSs, such as schedule timers, have been commercially available for several years now. Improvements in electronic logic controls and communication techniques have been the largest advancements for these devices in recent years.

The APSs used for this study come with a Web-based dashboard that allows users to implement and change control strategies as well as look at the real-time energy consumption of plug-loads in their buildings. This feature is widely available from multiple vendors. The manufacturer of the APS that was tested claims that its device can reduce plug-load energy costs by up to 50%. They also claim a payback period of less than 3 years [6]. In general, online dashboards can be convenient and valuable if personnel time has been allocated to actively monitor and analyze data. Another benefit is that online dashboards can be used for occupant education and awareness. They can also be useful if there exists some sort of fault-detection service built into the system that can alert a building manager/operator if certain devices are demonstrating odd behavior. This feature is not currently available but could be an avenue for future development.

The communications and data storage can be a moderate risk because these systems are susceptible to downtime for a multitude of reasons. It would take a large time investment to take the data from a website, understand it, and turn it into actionable insights for GSA or other federal energy managers.

APSs have been demonstrated in other federal buildings but have yet to be deployed on a wide scale. For example, the U.S. Environmental Protection Agency’s Region 8 headquarters in Denver, Colorado, tested occupancy-sensing control of plug-loads on a sample of its occupants as well as behavioral change mechanisms to reduce plug-load energy consumption [7]. Private sector companies have also been demonstrating interest in APSs for reducing plug-loads.

APSs may have some considerable risk if the controls don’t function as intended or occupants are not well educated about the devices. Undesirable performance could lead to frustration that impedes occupants from performing work, or disabling/disconnecting of the APS. A few key elements of APS deployment that can alleviate these challenges are:

- Simple devices
- Occupants having the ability to customize their controls
- Manual override
- Thorough training for occupants
- Installation support from the provider.

These devices are not applicable for all electronic equipment, and different control strategies may be more effective than others when controlling specific devices. Lastly, some products offer submetering capabilities that require a communication protocol and service to be provided. These services require personnel time to actively monitor and analyze data in order to capture the benefit of this feature. When the issues noted above are addressed, there exists the opportunity for significant energy and cost savings with little or no adverse impacts on the work environment.

III. M&V Project Plan

A. Technical Objectives

This research project is a demonstration of an APS plug-load control system, which was provided by a vendor whom was selected through normal GSA contracting protocol. However, several other vendors provide similar products, control capabilities, and services. GSA's Region 3 was responsible for procuring the submetering equipment, installation, and programming requirements to set up the system. NREL worked with GSA to identify electronic devices that were studied in the research, and collaborated with the submetering installation team to set up devices and collect desired data from a group of research participants.

In the measurement and verification (M&V) phase, NREL analyzed data from the plug-load demonstration project, including baseline energy use and an experimental period, followed by participant feedback. This analysis also investigated scalability; examined staff interfacing and user and facilities management acceptance; estimated a return on investment; and validated the manufacturer's claims.

B. Technology Description

Plug load control comes in two basic forms. Energy savings are achieved when the device is either transitioned to a low-power state, or it is de-energized to eliminate the power draw. Both can be executed either manually or automatically. A low-power state is between a de-energized state and a ready-to-use state. This includes standby, sleep, and hibernate modes as well as any "off" state that has a parasitic power draw. A de-energized state is when electricity is not being provided to the device. This is analogous to physically unplugging a device's power cord from a standard electrical outlet.

APSs, such as simple timers, have been commercially available for a long time and would have a Federal Energy Management Program (FEMP) Technology Readiness Level (TRL) of 9 relating to late deployment where savings are proven, but market transformation/penetration is needed [8]. Newer electronic and logic-based controls have started becoming commercially available over the past 3-5 years. The most significant improvements in APSs have been related to electronic logic controls and communication techniques. These newer devices would fall into a FEMP TRL of 7 relating to early deployment where products are commercially available, but savings are not yet proven in a whole-building context.

Potential barriers for APSs include: occupant acceptance, communications, lack of personnel time for analysis, and complex controls in some instances. These devices may require operations and maintenance to update controls, manage data, and troubleshoot incorrect operations and communication failures on a regular basis.

All control strategies should provide manual override to accommodate atypical times when a plug-load device wouldn't normally be in use (e.g., using a device outside normal business hours). The design team must evaluate each control strategy relative to a specific plug-load, examine its parasitic load versus the plug-load's parasitic load, and determine its costs versus the energy cost savings.

Manual Control (Baseline Control)

Most plug-loads can be manually powered down with built-in power buttons, shutdown procedures, or a control device that energizes and de-energizes electrical outlets based only on manual input. Depending on the equipment, a built-in switch may provide a quick-and-easy manual method of powering down or up the device. Other devices may have a shutdown procedure that users must perform to shut down the device. For some devices, manual control is the best or only method. Manual control is the incumbent technology and is rarely used because the plug strip is typically located under the desk where occupants do not have easy access to the on/off power switch.

The effectiveness of manual control depends entirely on user behavior and should be implemented only if no other methods apply. Plug-loads could remain powered up at all times if users do not actively use manual control. When manual control is the only option, all users must be made aware that they are responsible for the operation and energy use of their equipment. They need to be educated about proper use and how their behavior can save or waste energy and money.

Automatic Low-Power State (Not Evaluated in this Study)

The first, and in some cases most effective, control method is a built-in, automatic low-power state functionality such as standby or sleep. Some manufacturers include this functionality to reduce energy consumption of idle devices. Internal processes monitor idle time, and when the device has been in an idle state for a given period, it will power down to a low-power state.

Built-in automatic low-power state functionality can be a cost-effective control strategy because it is integral to the device and does not require additional control devices. However, it may have several issues:

- Users can configure computers and other items and deactivate the automatic low-power state functionality.
- The power draw in a low-power state may be only slightly lower than in the ready-to-use state. In this case, the functionality is working as intended, but the power drop is less than desired or needed.
- A device may need to be activated or accessed remotely, which may not be possible in a low-power state.
- The time to transition from a low-power state to a ready-to-use state may be too long.

Automatic low-power states provide limited control, yet they are the most accessible (and cheapest) form of plug-load control.

Schedule Timer Control Device (Evaluated in this Study)

Certain plug-loads have predictable load profiles. These devices are used during the same times each day or at regular intervals. A scheduling-control device can effectively manage a predictable plug-load. It applies user-programmed schedules to de-energize the plug-load to match its use pattern and energize the plug-load so that it is ready for use at the time when it is required.

A scheduling-control device can take multiple forms:

- Basic electrical outlet timers that control a single outlet, or power strips with integrated outlet timers to control multiple outlets, provide local scheduling control. Users program the schedules.
- Scheduling can be controlled with devices in a centralized location. These are typically wireless, plug-and-play devices that control one or more outlets and communicate with a centralized controller that energizes and de-energizes the outlets based on user-programmed schedules.
- There are also plug strips that can be scheduled remotely instead of on-site programming.

Scheduling devices are generally straightforward, consistent, and reliable. They target the energy that is wasted during non-business hours, but do not necessarily provide the greatest energy savings. For instance, a plug-load may not be needed during all business hours. All scheduling controls should allow for manual override during the times when energy is needed outside the preset schedules.

Load-Sensing Control Device (Evaluated in this Study)

Plug loads may have a primary-secondary relationship. A primary device, such as a computer, operates independently of other (slave) devices. A secondary device, such as a monitor or other peripheral, depends on the operation of other (master) devices. A load-sensing control device should be implemented for such a relationship. It automatically energizes and de-energizes secondary devices based on the “sensed” power load of the primary device(s). Whenever the primary device goes into a power state below a given threshold, the load-sensing control can power down the secondary devices. The sensed (primary) load is typically an electrical outlet or an auxiliary port [e.g., universal serial bus (USB) in the case of a computer].

Load-sensing control may save more energy than scheduling control because it can reduce energy use during business and non-business hours; however, it depends on “good” operation of the primary (sensed) device. “Good” operation is where users manually control the primary plug-load by forcing a low-power state when the device is not in use (e.g., a user puts his/her laptop into standby when away from his/her desk). Alternatively, built-in automatic, low-power state functionality in the primary device must be working effectively to put devices into a low-power state. Otherwise, the load-sensing control method does not save energy.

A load-sensing device can take several forms including:

- Power strips that sense the load of a primary device and control several secondary devices locally
- Central controls, which are typically wireless, plug-and-play devices that control a single outlet or multiple outlets. They communicate with a centralized controller that energizes and de-energizes the outlets based on user-programmed load thresholds. Primary and secondary devices can be in different parts of a building. Also, the controller can be programmed such that when the primary device transitions between states, the secondary device(s) can be either energized or de-energized. Again, like the scheduling control, the central control can be provided by a dedicated plug-load control system or integrated into the building management system.

Occupancy-Control Device (Not Evaluated in this Study)

In theory, occupancy control can save a great deal of energy. It energizes plug-loads only when users are present and de-energizes them when the space is vacant. This approach pinpoints the main source of wasted energy during non-business hours and reduces wasted energy during business hours.

Some of its drawbacks are:

- It may energize and de-energize outlets at inappropriate times.
- It must focus on the immediate zone surrounding the plug-load to be controlled, but not extend into other areas. The plug-load should be energized only when a user is nearby.
- Its significant parasitic load may reduce the net energy saved by de-energizing plug-loads.

Manual-On, Vacancy-Off Control Device (Not Evaluated in this Study)

A manual-on, vacancy-off control device (which is currently not available) is a slight modification of the occupancy-control device. It energizes a plug-load when it receives manual input from a user and de-energizes the plug-load automatically based on lack of occupancy. This control should be implemented for plug-loads that are needed only when users are present (e.g., task lights, monitors, and laptops).

This approach also has an even higher potential for energy savings than a typical occupancy-control device. The plug-load will stay in a de-energized state until a user manually energizes the device, thus eliminating the wasted energy associated with false positives. This strategy is commonly implemented in lighting controls because it effectively reduces wasted energy.

Manufacturer Description

An APS which provides capabilities that are typical in other APSs on the market was selected to be evaluated. This vendor was selected after it responded to a request for proposal and was determined to bring best value to the government. This product is not the only APS on the market. There are an abundance of APSs that offer a variety of complexity, control strategies, data collection abilities, and costs.

The selected APS saves energy by controlling up to four plug-in devices according to a schedule and/or by load-sensing. The APS also meters the energy use of the connected plug-in devices, which helps quantify energy savings. The APS was selected due to the fact that it reported energy and power use, and it allowed for the testing of three different control methods:

- Load-sensing control
- Schedule timer control
- Both load-sensing and schedule timer control.

These three control types were the control strategies evaluated in the current study. These three control strategies encompass a large majority of the strategies available in APSs in the marketplace today. The interface for enabling and monitoring the control would be different with different manufacturers, yet the general type of control would not differ.

The selected APS also comes with a Web-based dashboard that allows users to implement and change control strategies as well as look at the real-time energy consumption of plug-loads in their buildings. This centralized, Web-based approach to plug-load management is novel because conventional plug strips have to be configured locally (which is a time consuming effort). This Web-based interface also allowed for continuous monitoring of the energy usage and power draw of the various devices at 1-minute time intervals.

The manufacturer claims that its device can reduce plug-load energy costs by up to 50%. It also claims a payback period of less than 3 years.

C. Demonstration Project Location(s)

The APSs were deployed in eight GSA office buildings in Region 3 as part of a research effort to evaluate emerging technologies through the GSA Green Proving Ground (GPG) Program. Approximately 12 plug strips were deployed at each GSA field office. The plug strips were connected to a variety of equipment selected to represent a typical office. These devices were located in cubicles, private offices, print stations, copy rooms, and break rooms. Each site is different and contained different equipment. The following is a list of the eight GSA field offices where APSs were deployed:

- Veterans Administration Center Building – Philadelphia, Pennsylvania
- William J. Green, Jr. Federal Building – Philadelphia, Pennsylvania
- Cohen Complex – Camden, New Jersey
- Clarkson S. Fisher Federal Building and U.S. Courthouse – Trenton, New Jersey
- Spottswood W. Robinson III and Robert R. Merhige, Jr., U.S. Courthouse – Richmond, Virginia
- Edward A. Garmatz U.S. Courthouse – Baltimore, Maryland
- William S. Moorhead Federal Building – Pittsburgh, Pennsylvania
- Robert C. Byrd Federal Building and U.S. Courthouse – Charleston, West Virginia.

These buildings were selected as representative spaces that reflect typical office setups and equipment in the wider GSA building stock. The findings for these buildings can be extrapolated for potential energy savings for plug-load control technologies in other similar GSA facilities. However, each control strategy was implemented at only two sites which, for some instances, produced a large variation in results. Energy savings can be evaluated independent of climate, with reasonable reliability. However, reduced plug-loads will reduce the cooling load and increase the heating load inside of a building. These interactive effects are not considered in the analysis for this study. Figures III-1 and III-2 below show the typical office locations where APS devices were installed.

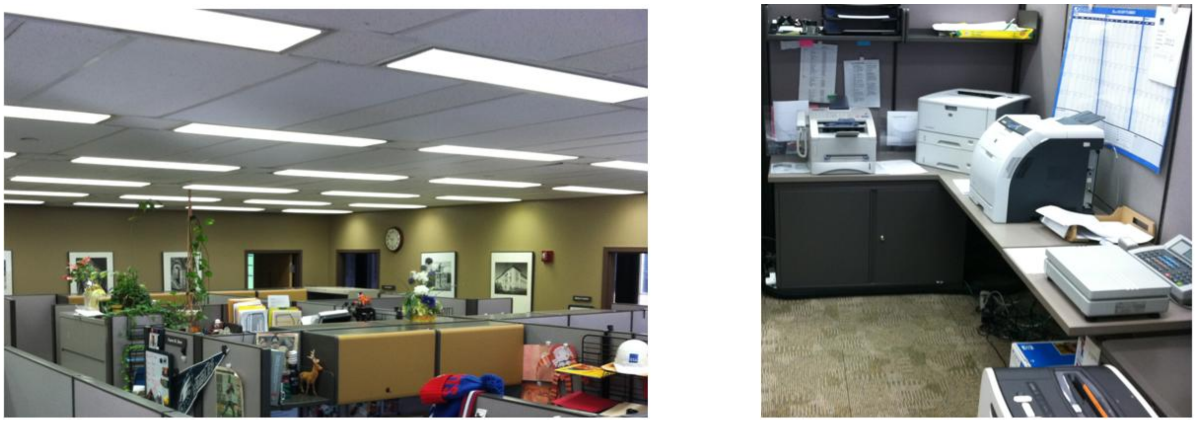


Figure III-1: Typical workstations that were studied (left) and typical print station with multiple printers, scanners, and copiers (right). ***Credit: Ian Metzger, NREL***

Figure III-2: Typical kitchen with toaster, coffee maker, microwave, and refrigerator. ***Credit: Ian Metzger, NREL***

IV. M&V Evaluation Plan

A. Facility Description

As noted above, the demonstration was carried out at eight different office buildings throughout GSA Region 3. In each building, 12 APSs were deployed throughout a single floor. Each APS strip contains four individual plugs. This makes a total of 48 different plugs that could be controlled at each office building. Table 5 shows the type and quantity of each device that was monitored, broken out by location. It should be noted that not all of the buildings have a total of 48 devices being controlled. This is due to the fact that not all plug strips had four applicable devices nearby. In this situation, certain outlets in the plug strip were left empty, resulting in less than 48 monitored devices. In the case of the Clarkson S. Fisher Courthouse, there were very few deployable spaces on this floor of the office.

Table 5: Plug-load inventory: number and type of monitored devices at each demonstration site

Edward A. Garmatz U.S. Courthouse		Cohen Complex		Clarkson S. Fisher Federal Building and U.S. Courthouse		Veteran Administration Building	
Laptop	7	Laptop	10	Laptop	4	Laptop	9
Monitor	8	Monitor	11	Monitor	3	Monitor	10
Printer	4	Printer	4	Printer	3	Printer	5
Undercabinet Light	4	Undercabinet Light	10	Undercabinet Light	4	Undercabinet Light	3
Coffee Maker	2	Desktop	1	Paper Shredder	1	Stereo Speakers	2
Fax Machine	1	Desktop Fan	1	Stereo Speakers	2	Electric Stapler	1
Desktop Fan	2	Stereo Speakers	3	Radio	1	Radio	1
Pencil Sharpener	1	Electric Stapler	1			Wireless Mouse	1
Fax Machine	1	Radio	1			Cell Phone Charger	1
Clock	1	Other Peripheral	1				
Plotter	1						
Water Cooler	1						
Video/Teleconference	2						
Total Devices	**35**	**Total Devices**	**43**	**Total Devices**	**18**	**Total Devices**	**33**
William J. Green Jr. Federal Building		**Robinson & Merhige Courthouse**		**William S. Moorhead Federal Building**		**Robert C. Byrd Federal Building and U.S. Courthouse**	
Laptop	8	Laptop	9	Laptop	9	Laptop	10
Monitor	15	Monitor	10	Monitor	14	Monitor	15
Printer	2	Printer	9	Printer	5	Printer	5
Undercabinet Light	10	Undercabinet Light	4	Undercabinet Light	3	Undercabinet Light	5
Desktop	1	Desktop	1	Space Heater	3	Electric Stapler	1
Desktop Fan	1	Plotter	1	Radio	1	Space Heater	1
Space Heater	2	Stereo Speakers	4	Stereo Speakers	2	Paper Shredder	1
Coffee Maker	2	Walkie Talkie	1	Paper Shredder	1		
Cell Phone Charger	1	Pencil Sharpener	1	Electric Stapler	3		
Other Peripheral	1	Calculator	1	Electric Typewriter	1		
		Cell Phone Charger	1				
		Other Peripheral	1				
Total Devices	**43**	**Total Devices**	**43**	**Total Devices**	**42**	**Total Devices**	**38**

Overall, 295 devices were monitored during the study. The study consisted of three separate test periods; each test period was 4 weeks long. The different test periods are described in M&V Project Plan, D. Test Plan (page 17). Eight buildings were separated into four groups of two. The four different groups were assigned the following control strategies:

- Load-sensing control
- Schedule timer control
- Load-sensing and schedule timer control
- No control.

For a description of the different control strategies, see the section on M&V Project Plan, B. Technology Description (page 9). Table 1 summarizes the control strategies implemented at the eight different demonstration locations.

In each demonstration location, standard power strips with no control capability (the incumbent technology) were currently being used. It is important to note that the information and technology department in Region 3 had pushed a region-wide computer power management system in early 2012. This computer power management system implemented a schedule timer control where computers would be shut down and monitors would go into sleep mode at 6 p.m. every evening, unless the occupant manually delays the shutdown. . This system accomplished many of the goals of APS controls for devices such as laptops. Many other devices in the buildings did not have the capability to receive this power management system and still benefited from the APS schedule timer control. The APS schedule timer control also provided the flexibility for occupants to customize their schedules individually.

B. Technology Specifications

The technology that was deployed in this project consists of multiple components. This device is UL listed and has the same form factor of a conventional plug strip. It has four receptacles for plug-in devices. It has a fuse that trips at 1,800 watts (W). There is a manual reset button, which allows the user to override the controls that were programmed into the device. This manual override option is important to allow for device operation at abnormal hours or to override any operational inconsistencies during the demonstration. Each APS draws a small amount of electricity when in use, 0.7 Watts with all outlets de-energized and 1.3 Watts with all outlets energized.

The device selected for this study uses a proprietary variation of Zigbee communication (a low-cost, low-power, wireless mesh network) to transfer data to the second component—the bridge. The bridge is an intermediary between the APS and an Internet connection. The bridge can collect data from up to 50 APSs. The bridge must be within 50 meters (164 feet) of each APS, and requires a 120-volt, one-phase plug for power. Power over Ethernet (PoE) is also an option. The bridge also has a small continuous power draw of approximately 1 Watt.

Examples of the advanced power strip and bridge used in the study are shown below in Figure IV-1.

Figure IV-1: APS (left) and communications bridge (right). ***Credit: Enmetric Systems Incorporated***

The bridge then transmits the plug-load data (including average power, energy consumption, etc.) to a Web-based interface. Data is stated to be accurate to +/- 0.3 Watts. This Web-based interface is the last component of the system. It provides the ability to view the power consumption in real time. It also compiles and stores the data on a server that the user can access to download data for a certain time period into a comma-separated value (CSV) file.

One of the potential issues with the wireless system employed during the study was interruptions in the data feed from the APSs to the server. This could impact the consistency of reported data.

One of the central focuses of this report was the comparison of different types of plug-load controls. The three control strategies evaluated in this report represent the main plug-load control capabilities throughout the marketplace. These three control strategies were the following: load-sensing, schedule timer, and both load-sensing and schedule timer control. The selected APS system allowed for evaluation of all three of these controls methods. It also provided a built-in, data -logging capability for compiling 1-minute, time-series data over the course of the study.

C. Technology Deployment

The incumbent technology is a conventional plug strip that has no built-in controls other than a physical on/off switch. These plug strips are generally located underneath desks, and it can be assumed that the on/off switches were not utilized. Other devices were plugged directly into receptacles.

These strips were replaced by the APS devices in each of the eight offices that were monitored during this study. The APSs accommodate four devices per strip. The local devices were removed from the existing strips and plugged directly into the new APSs. The system also required a wireless communication router (in this specific application) to transmit the metered data to the vendor’s remote server. This was a requirement of GSA because it would not allow the bridges access to its network. This wireless equipment was installed to provide the best wireless signal.

Example photographs of the technology deployment are shown in Figure IV-2 and IV-3 below.

Figure IV-2: Image of a deployed APS in a GSA Office. Four devices are plugged in to the APS. The power strip is mounted on the desktop for easy user access. ***Credit: Enmetric Systems Incorporated***

Figure IV-3: Image of wireless communication system. A wireless bridge and the cellular modem are shown here next to a window for optimum cellular reception. ***Credit: Ian Metzger, NREL***

D. Test Plan

The study consisted of three different phases of data collection. Each condition ran for 4 weeks, and data were filtered and normalized to account for site inconsistencies and communication gaps, which led to missing data. The study also included two of the eight sites as control groups for the entire three phases. This allowed accurate quantification of the inherent variability in plug-load power consumption without any controls implemented. The three different phases are outlined below:

- **Phase 1 – Inventory and Baseline:** A site visit was conducted at each field office to inventory the existing plug-load equipment and note any inconsistencies between sites. Submetering without control was used to monitor energy consumption prior to the control phase.
    - The schedule timer and load-sensing controls were disabled during the baseline.
    - Occupants were not given access to the online dashboard.
    - No notifications were sent to occupants in order to maintain business-as-usual behavior.

- **Phase 2 – Initial Controls Deployed:** The sample of eight field offices was divided into four groups, each testing different control features (except for the control group). Prior to the experimental phase, occupants were provided with a brief notification including operating instructions, access to the online dashboard (limited to the facility site managers), and plug-load energy efficiency educational information. The groups are defined as:
    - Group 1: Control group, submetering only
    - Group 2: Schedule timer controls
    - Group 3: Load-sensing controls
    - Group 4: Schedule timer + load-sensing controls.

- **Phase 3 – Controls Refined:** The controls strategies were refined in an attempt to achieve higher savings and incorporate lessons learned from phase 2 (initial control deployment).
    - The same set of four groups was used for the various controls strategies.
    - The online dashboard was still available for viewing by the facility site managers.
    - A survey was sent to occupants upon completion.

The three phases, along with their dates, are shown in Figure IV-4 below.

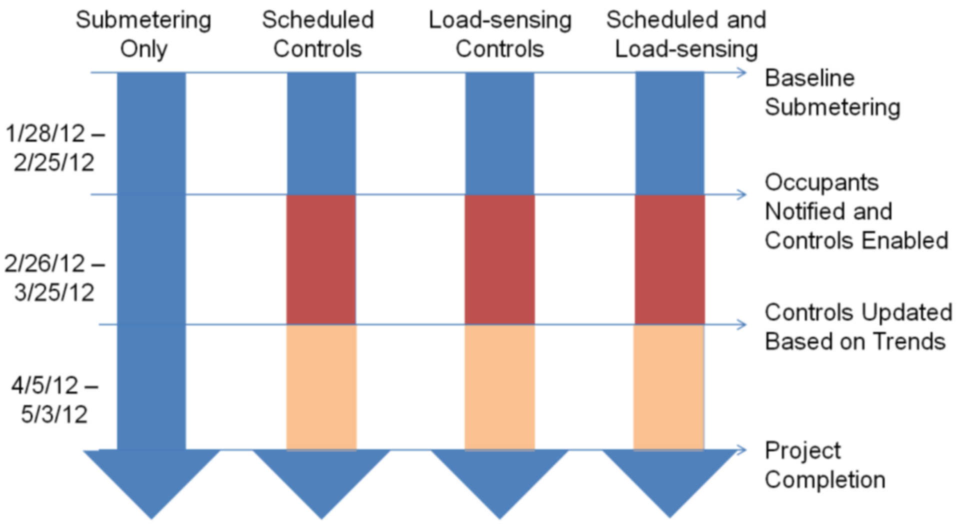


Figure IV-4: Diagram of project timeline

During each of these three stages, 1-minute, time-series data were transmitted wirelessly from the different project locations to the cloud. At the completion of each phase, the 4 weeks of monitored data were downloaded into a CSV file by the NREL team. These data were then processed and analyzed to evaluate average power draw and total energy consumption for each device type and for each type of control.

E. Instrumentation Plan

Select equipment at workstations, print rooms, break rooms, and other miscellaneous locations were outfitted with APS devices to monitor energy consumption and usage patterns. These devices were configured to communicate through a bridge, which transferred data to a remote server, where data could be accessed over the Internet. All of the selected devices were instrumented and monitored with components described in Section IV-C. It is recommended that future deployments of this technology follow similar guidelines.

V. Results

A. Data Processing

The quantity of the data compiled during this study was one of the initial challenges that needed to be overcome. Data were collected from 295 different devices divided throughout the eight different study locations. Each of these data feeds consisted of 1-minute, time-series data that were collected for a period of over three months. Initially these data were compiled into Microsoft Office Excel files, and given the size limitations inherent to Excel, this method proved incapable of handling the large amount of information gathered during this study. To accommodate the incoming data quantities, a Python script was written to read the data contained in the CSV files and upload the files into a SQLite database. Python is an open-source programming/scripting language that supports multiple types of databases and contains comprehensive data analysis packages that aided in the compiling and screening of the data. Once all of the data for a given phase was stored in the SQLite database, the data could be queried in whatever way necessary to evaluate the savings achieved by the APSs. In the case of missing pieces of data (due to loss of communication with wireless signal), the energy and power consumption were linearly interpolated to fill the gap in the time-series data. With the exception of the Moorhead Federal Building in Pittsburgh, Pennsylvania, these gaps were generally short (5-30 minutes). At the Moorhead Federal Building site, significant issues occurred with the communication bus that did not allow for data collection beyond the initial 2-3 week periods of the study. Due to noted communications issues during the install, this site was designated as one of the two control sites (where no advanced control was implemented); therefore, this did not result in significant loss of data on the advanced control features being studied in the report. It should be noted that this could be a potential barrier for this specific type of APS at certain sites (only where cellular modems are required, which is not the APS manufacturer's standard method of communicating data to its servers). Data were normalized based on the number of days in the research period including weekdays and weekends. Holidays were not considered, which could be a small source of error. However, error introduced by data processing is negligible when compared to the variations found in the control group.

B. General Results – Comparing Control Strategies

Three different control strategies were evaluated during this study including: schedule timer control, load-sensing control, and both load-sensing and schedule timer control. These control strategies are representative of the control options represented by many of the technologies available in the marketplace today. The total savings achieved by the three different control types were calculated for each monitoring period. The control group was calculated as well to demonstrate typical variation over the period. Energy consumption for each type of control was documented for three separate phases:

- Baseline – submetering only, no controls implemented
- Controls Phase 1 – various control strategies implemented
- Controls Phase 2 – controls strategies refined.

The data that were gathered for the three different phases were normalized to represent the exact same length of data collection (30 days for each phase). This ensured a fair comparison of energy consumption between the different time periods.

It should also be noted that the ratio of the devices varied slightly from site to site (i.e., a different number of printers versus laptops); therefore, there were some inherent differences in total energy consumption between the sites. This was addressed by calculating the average energy consumption for each individual device and then applying a "typical" office building device distribution to each of the buildings. The "typical" distribution of devices was based on the complete inventory of plug-loads at the Cohen Complex, gathered during an energy efficiency and renewable energy assessment conducted by NREL in June 2011. The distribution used is shown in Table 6.

Table 6: Distribution of devices in Cohen Complex used to provide equal comparison across buildings

Printer	Laptop	Monitor	Under-Cabinet Light	Misc - Workstation	Misc-Shared	Kitchen
16	100	100	91	20	10	2

Miscellaneous equipment includes other peripheral plug loads, such as radios, speakers, pencil sharpeners, calculators, and phone chargers. Workstation equipment did not include clocks that would require the time to be reset if an outlet was de-energized. Kitchen equipment did not include refrigerators, because they require 24 hour operation to maintain the thermal environment.

The monthly energy usage for each of the three control strategies (along with the control group) is shown in Figure V-1. Even though each building is normalized for the same quantities of equipment, baseline energy consumption is different because of variations in occupant behavior and usage patterns observed at each site.

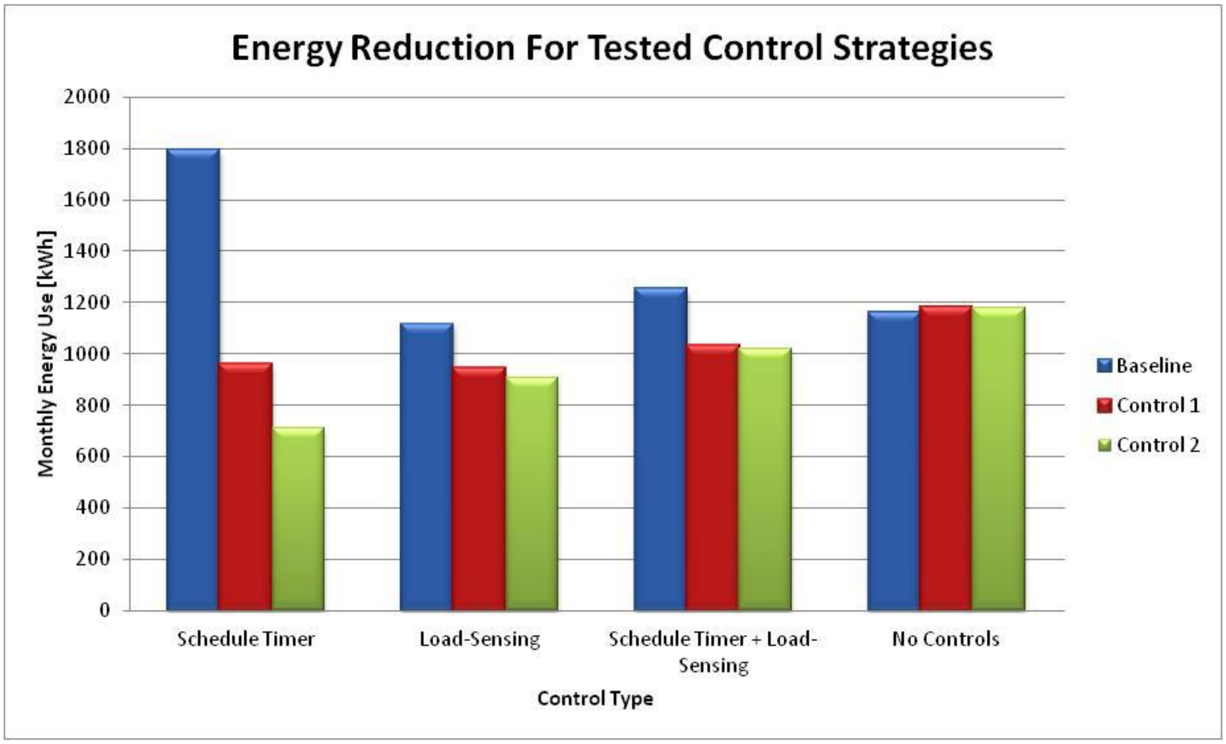


Figure V-1: Monthly energy reduction for tested control strategies

The control phase 2 consisted of refinements to the schedule timer controls only. The schedules were tightened according to monitored workstation usage. This was attempted to improve upon the original schedules of 6 a.m. – 6 p.m. It can be noted that the refined control resulted in reduced energy usage for the schedule timer controls. The refined controls also resulted in increased complaints from occupants due to their computers not powering up appropriately or shutting down before they had finished their day. This control refinement proved to be unacceptable and was relaxed to the previous schedules after approximately 3 weeks.

Schedule timer control, and the combination of load-sensing and schedule timer control performed better over the entire period than the load-sensing only controls. The largest portion of the savings was generally due to constant loads such as printers that were not being turned off or kitchen/workstation equipment that was not being de-energized. As previously mentioned, the computer power management system that was pushed by the GSA information and technology department was already limiting unoccupied power consumption in laptops and monitors. Under the test conditions, schedule timer controls resulted in the largest percent electricity reductions: an average savings of 33% for laptops, 50% for printers, 20% for monitors, 24% for under-cabinet lights, and 46% for shared equipment (office and kitchen combined). The results for each device type and each control type are listed in Table 7 (below).

Table 7: Energy savings by device type (i.e., printers, laptops, etc.) for the three different control strategies that were tested (i.e., schedule timer, load-sensing, and both schedule timer and load-sensing)

		Printer	Laptop	Monitor	Under-Cabinet Light	Misc. Equipment	Kitchen Equipment	Total
Schedule timer	Edward A. Garmatz U.S. Courthouse	68%	13%	14%	14%	25%	13%	43%
	William J. Green, Jr. Federal Building	31%	54%	27%	34%	67%	79%	52%
Load-sensing	Robinson and Merhige Courthouse	69%	-4%	-6%	n/a	51%	n/a	23%
	Veteran Administration Building	-5%	16%	11%	0%	54%	n/a	10%
Both	Robert C. Byrd U.S. Courthouse	18%	35%	-2%	22%	40%	n/a	23%
	Cohen Complex	27%	14%	-1%	-1%	68%	n/a	12%
Average	Average	35%	21%	7%	14%	51%	46%	27%

The limited savings realized with the load-sensing control were due in part to difficulties in implementing load-sensing controls. Ideally, the master device would be the monitor (due to its already programmed, short time periods for entering a reduced-power state), yet when the laptops were placed into a low-power state using this load-sensing logic, they would not turn back on immediately upon reactivation. This was due to the fact that the control rules were only checked once per minute leading to a lag in reaction time for the system. This should not preclude other types of load-sensing controls from being more successful, and further investigation is warranted here. Small negative savings for some equipment types can be attributed to normal variations in usage coupled with disabled or non-functioning load-sensing controls. Combination of the two control types also realized limited savings due to complications with load sensing control implementation.

In some instances, large variations between data sets for sites with the same control strategies were observed. This implicates that a larger sample size is necessary to achieve more consistent data. As a result, there may be significant uncertainty with average savings results in some instances.

Two of the eight sites were left as control groups during the entire 3-month monitoring period. These two control groups did not receive any programmable controls and simply transmitted energy-usage data for the entire 3-month period. This provided a method by which to quantify the average variation in energy usage due to different work schedules or different routines from month to month. The results for the Clarkson S. Fisher Federal Building and U.S. Courthouse (one of the control groups) are presented in Figure V-2, comparing the total energy usage during the phase 1 data to the phase 2 data. As previously mentioned, there were significant issues with the communications bus at the William S. Moorhead Federal Building, and a minimum amount of data were procured for that site.

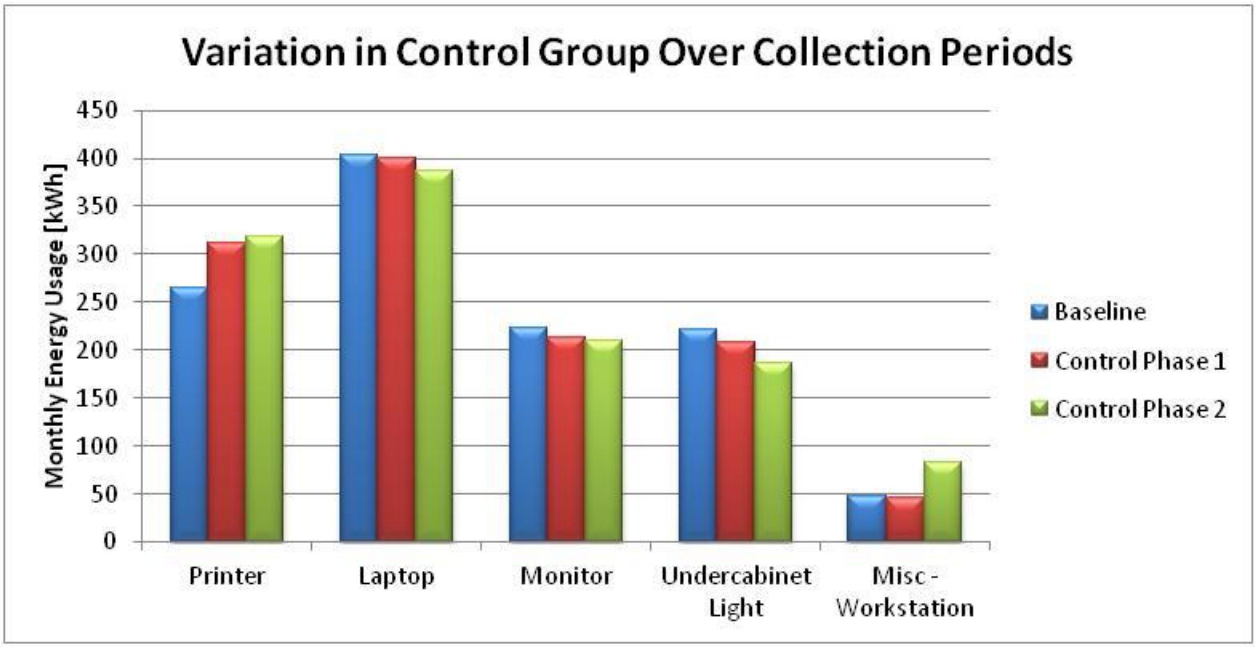


Figure V-2: Variation of plug-load energy usage in the control group (Clarkson S. Fisher Federal Building and U.S. Courthouse)

It can be noted that there is some variation between the 3 months of collected data. In general that variation is between 1%-6%, with printers and miscellaneous being exceptions at 18%-20%. This variation provides an estimate of the uncertainty in the data from month to month. The collection period for the 2 months was the same number of days, yet changes in work schedule, personal time off, and other usage variation cannot be completely accounted for without occupancy sensors at each device to allow for usage normalization.

C. Results for Each Control Strategy

Each control strategy was evaluated individually to assess the savings realized by each device type and by each space type. These results are presented by control strategy in this section. In each case, two types of analysis are presented. The first type is a bar chart demonstrating the average energy consumption for pre- and post-control implementation by device type. For example if there were nine laptops monitored at a particular site, the monthly energy consumption would be averaged across the nine devices for both pre and post control, and both of those values presented. The second type of analysis shows the average power draw profile (for both weekday and weekend) for three different device types: printers, laptops, and miscellaneous workstation equipment. The figures for the other device types are included in Appendix F. This is shown for both pre- and post-control implementation in the same figure.

1. Load-Sensing Control

Load-sensing controls were implemented in the Spottswood W. Robinson III and Robert R. Merhige, Jr., U.S. Courthouse in Richmond, Virginia, and the Veterans Administration Center Building in Philadelphia, Pennsylvania. The best results were achieved for printers, laptops, and miscellaneous workstation equipment.

With load-sensing control, the most significant savings were achieved with printers (in Richmond) and miscellaneous equipment. The printers were placed into a lower power state during the evenings and weekends. In addition, results show daytime reductions which are only possible with load-sensing controls, but savings may also be attributed to normal variations in usage between the baseline and controls phase. The laptops, monitors, and desktops did not realize any savings at Robinson and Merhige, and realized only limited savings in the Veterans Administration Building. Limited or no energy savings can be attributed to master devices failing to go into a standby mode and never crossing the specified threshold and lack of occupant training which lead to disabling of controls. For laptops, it can be seen that the computer power management system was already turning these devices down to very low-power states during unoccupied hours, and the load-sensing did not add much value to this device type (Figure V-6). Finally, the miscellaneous equipment did demonstrate reduced power and effective control by the APS, yet the small total draw of the devices did not add much to the overall savings achieved.

The results are presented below in Figures V-3, V-4, V-5, V-6, and V-7. Aggregate savings are presented for both buildings using the normalized equipment distribution in Table 6. Power draw profiles are presented for the printers, laptops, and miscellaneous workstation equipment for the Robinson and Merhige Courthouse. All other draw profiles are in the appendices.

Aggregate Savings:

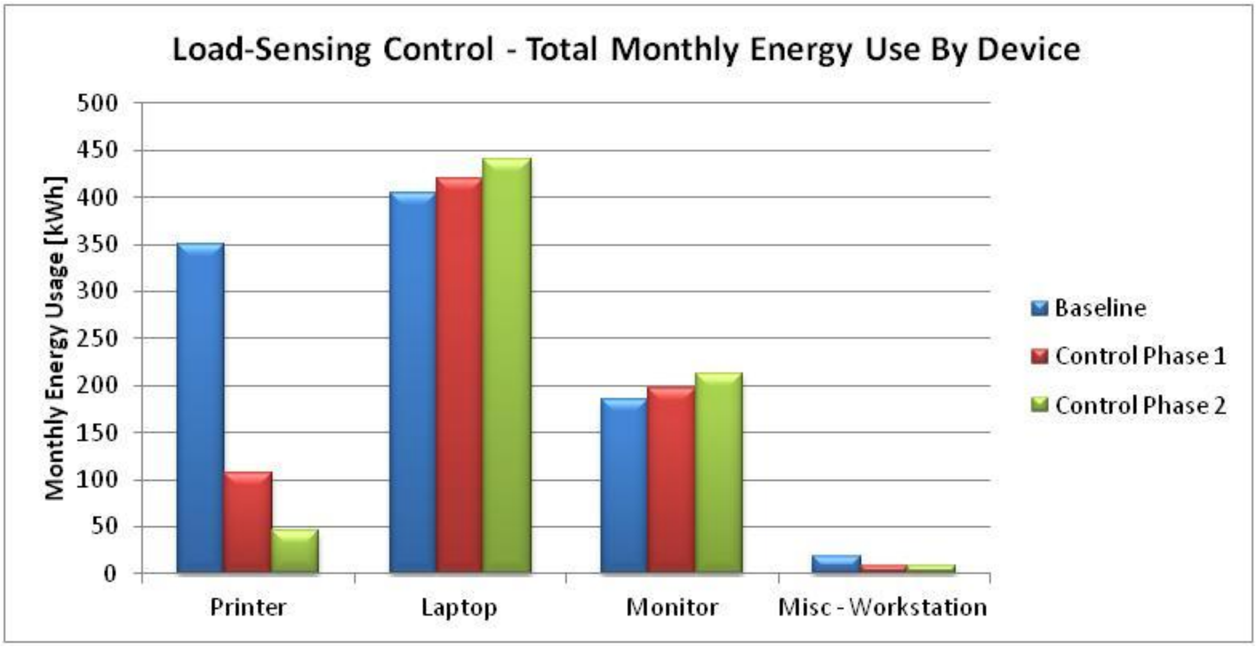


Figure V-3: Comparison of monthly energy consumption before and after APS installation (Spottswood W. Robinson III and Robert R. Merhige, Jr., U.S. Courthouse)

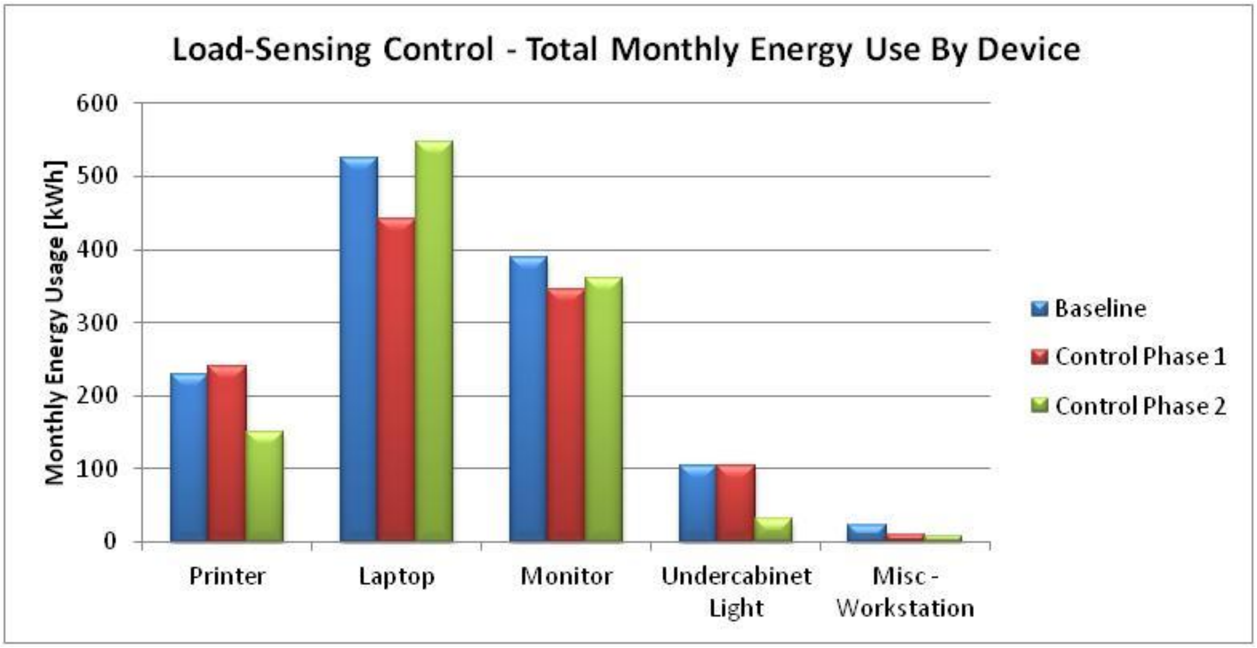


Figure V-4: Comparison of monthly energy consumption before and after APS installation (Veterans Administration Center Building)

Printers:

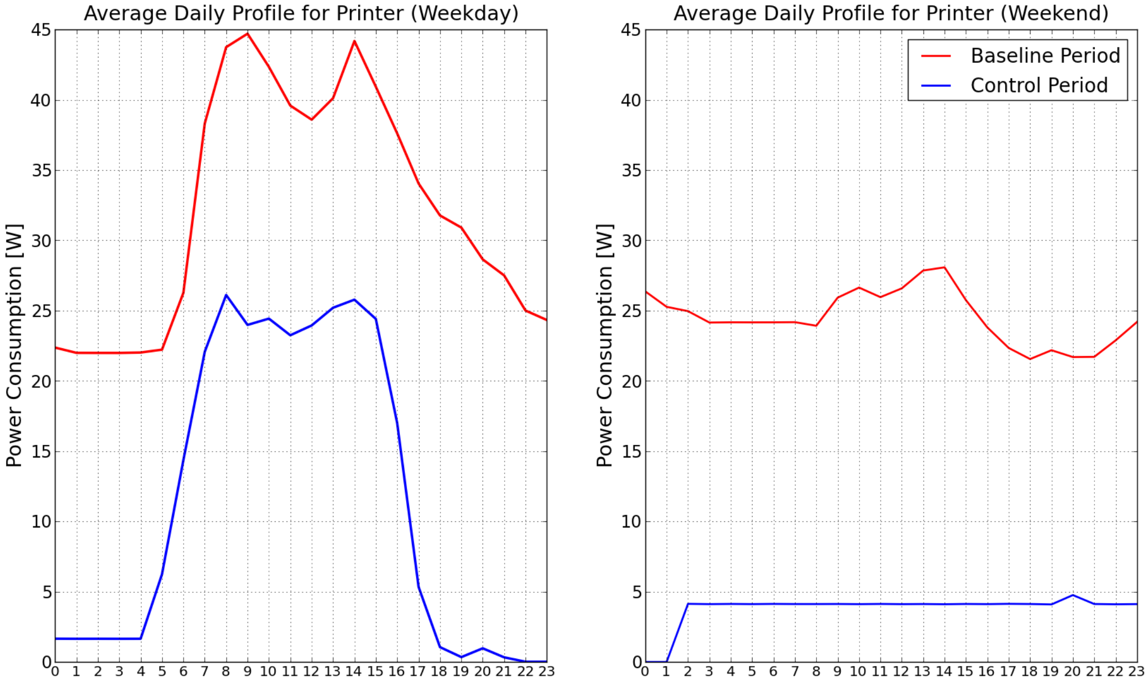


Figure V-5: Weekday and weekend power-draw profiles (printers)

Laptops:

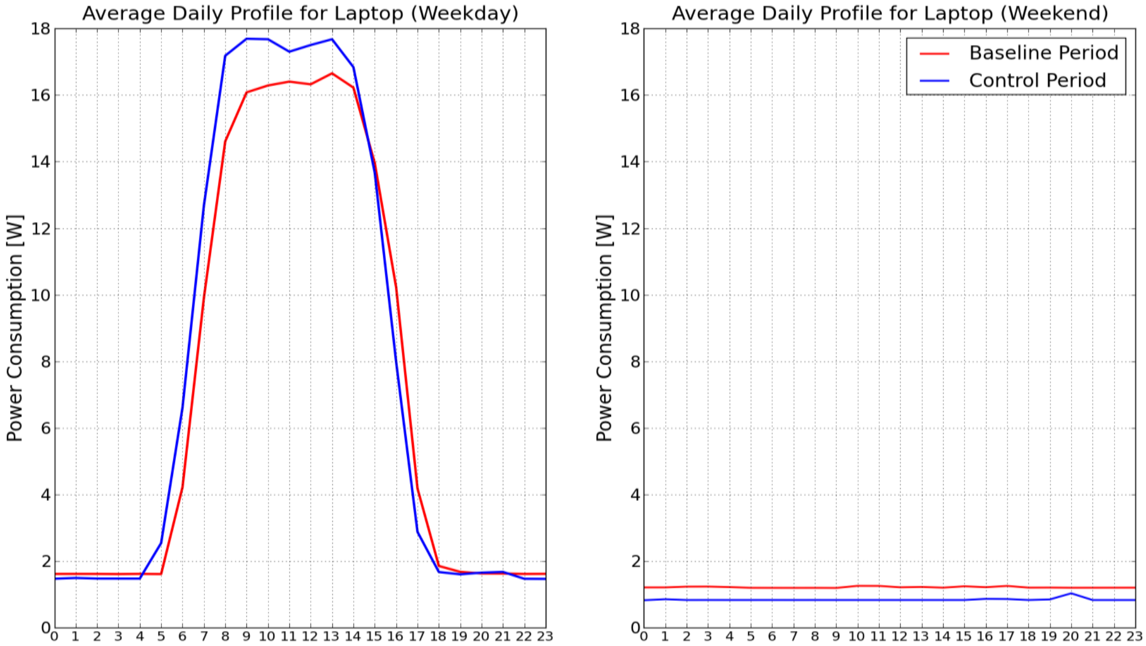


Figure V-6: Weekday and weekend power-draw profiles (laptops)

Miscellaneous:

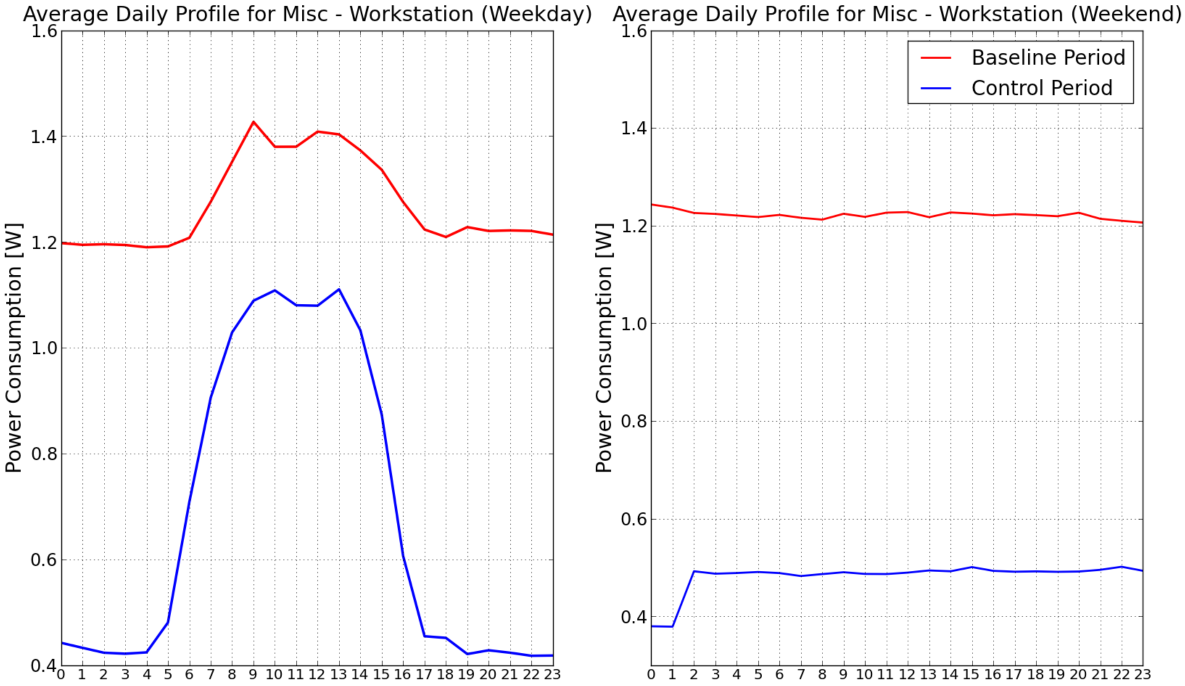


Figure V-7: Weekday and weekend power-draw profiles (misc-workstation)

2. Schedule Timer Control

Schedule timer controls were implemented in the Edward A. Garmatz U.S. Courthouse in Baltimore, Maryland, and the William J. Green, Jr. Federal Building in Philadelphia, Pennsylvania. The best results were achieved for printers, laptops, and miscellaneous workstation equipment.

With schedule timer control, savings were achieved in all categories except miscellaneous workstation equipment (at Edward A. Garmatz). The largest savings were achieved by the printers. As can be seen in Figure V-8, the scheduling controls took the average weekend draw from a constant 60 W to nearly zero (at Edward A. Garmatz). There were also large savings throughout the weekday profile which can be attributed to normal variations in usage between the baseline and controls phase. The laptops also realized good energy savings during the evenings and weekends, in addition to the savings already being achieved by the computer power management system.

The results are presented below in Figures V-8, V-9, V-10, V-11, and V-12. Aggregate savings are presented for both buildings using the normalized equipment distribution in Table 6. Power-draw profiles are presented for the printers, laptops, and miscellaneous workstation equipment for the Edward A. Garmatz U.S. Courthouse. All other draw profiles are in the appendices.

Aggregate Savings:

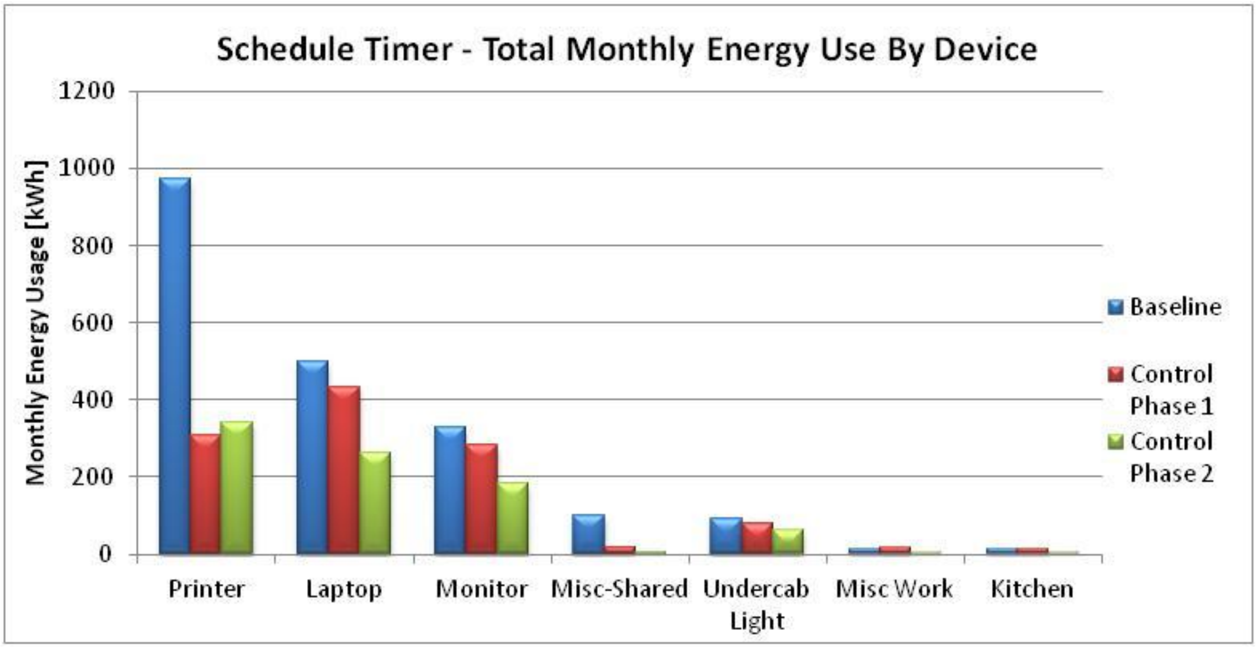


Figure V-8: Comparison of monthly energy consumption before and after APS installation (Edward A Garmatz U.S. Courthouse)

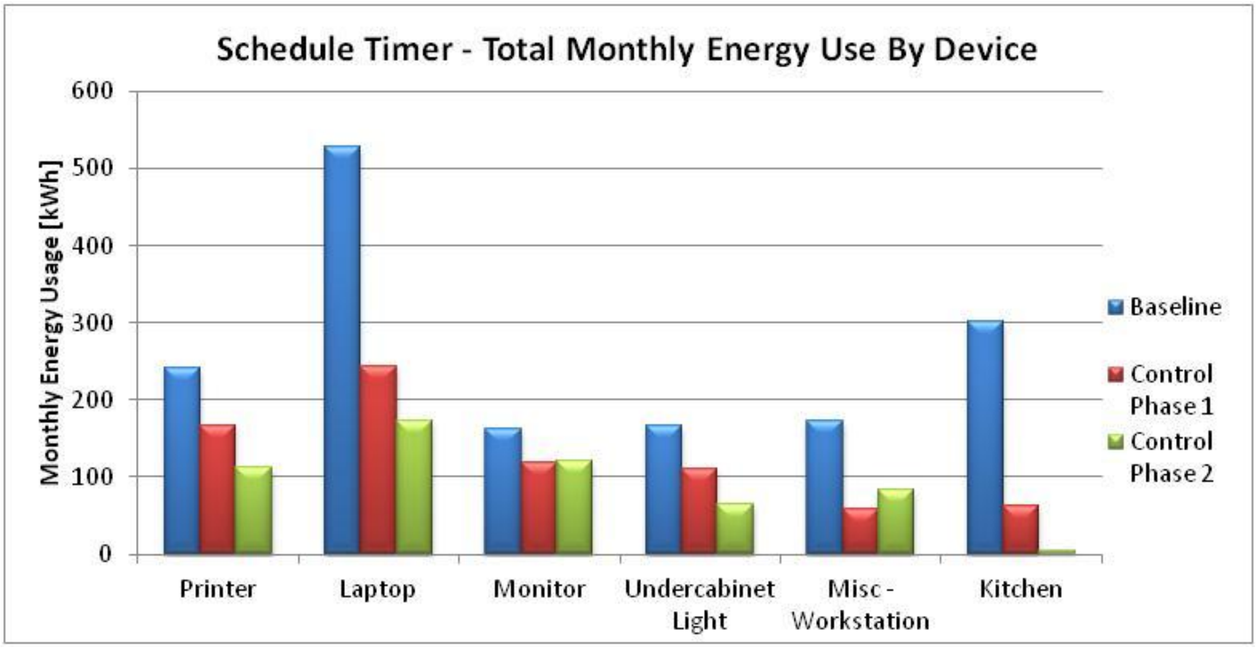


Figure V-9: Comparison of monthly energy consumption before and after APS installation (William J. Green, Jr. Federal Building)

Printers:

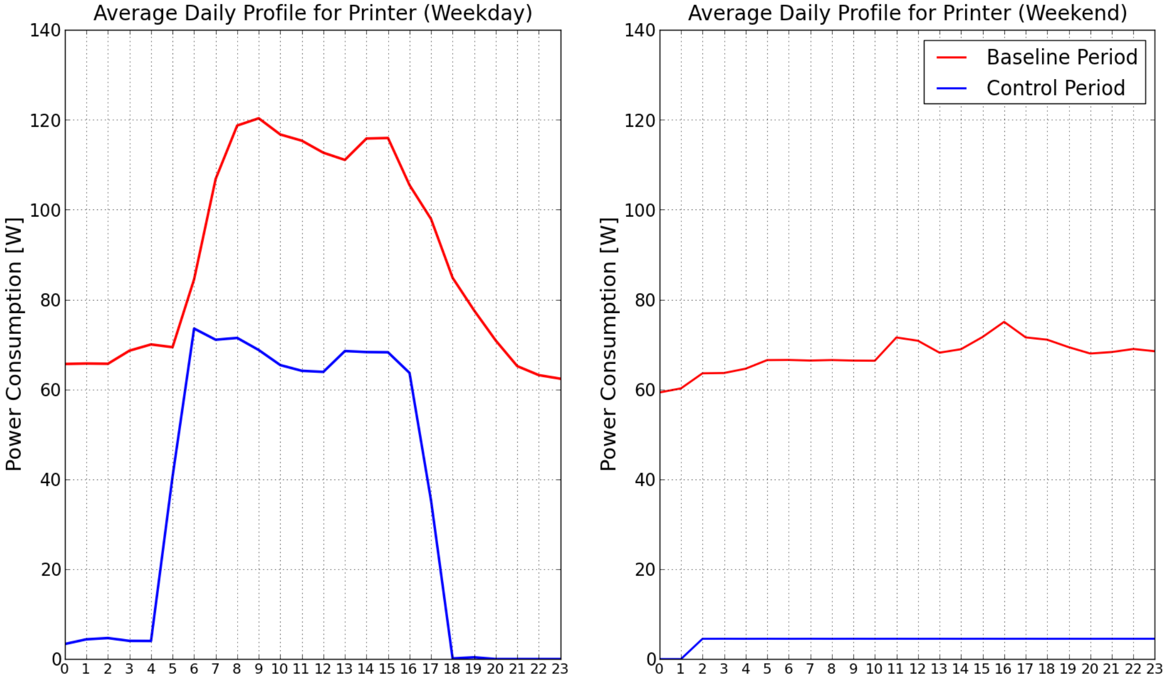


Figure V-10: Weekday and weekend power-draw profiles (printers)

Laptops:

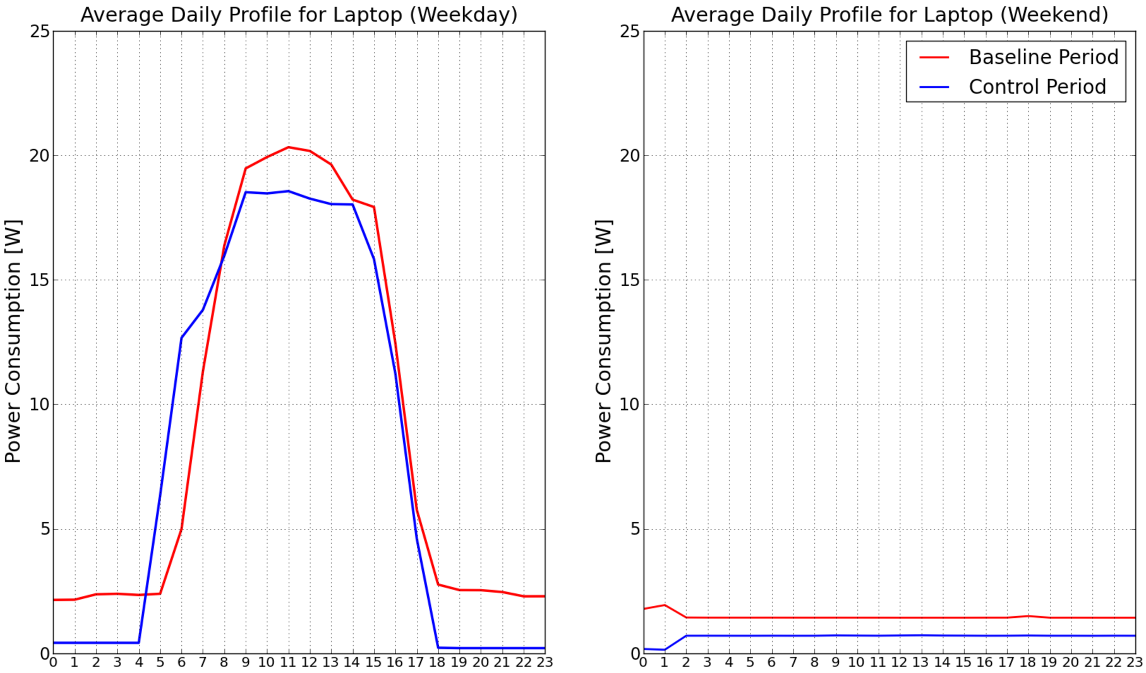


Figure V-11: Weekday and weekend power-draw profiles (laptops)

Miscellaneous:

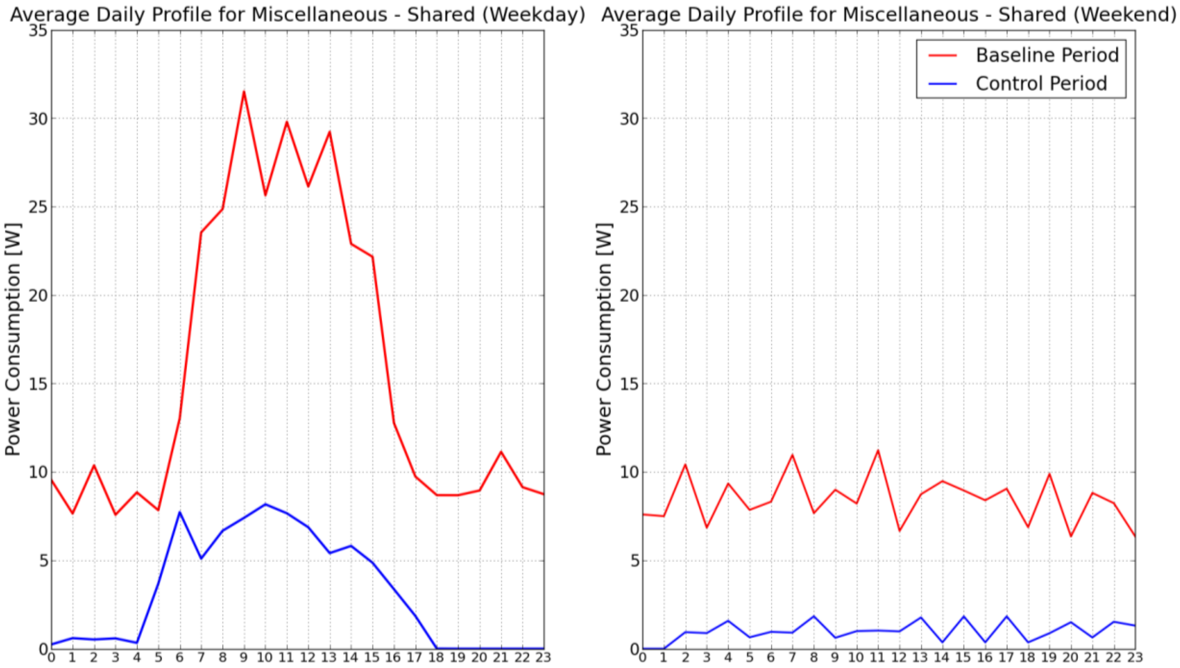


Figure V-12: Weekday and weekend power-draw profiles (misc – workstation)

3. Load-Sensing and Schedule Timer Control – Combined

Schedule timer and load-sensing controls were implemented in the Cohen Complex in Camden, New Jersey, and in the Robert C. Byrd Federal Building and U.S. Courthouse in Charleston, South Carolina. The best results were achieved for printers, laptops, and miscellaneous workstation equipment.

With the combined control, savings were achieved in all categories except for monitors and under-cabinet lights. The largest savings were achieved by the printers. The printers demonstrated less reduction in this case, yet this may be due to a lower total power draw by the printers in this location (Figure V-13). The laptops achieved a slightly lower power state during the evenings and weekends, but it can be seen that the computer power management system was already turning these devices down to very low-power states during unoccupied hours. The miscellaneous equipment demonstrated good control by the APS despite the low total power draw by the device type.

Results for the combined controls did not improve energy savings as expected. Issues with the load-sensing controls as well as instances of conflicting controls may have contributed to the limited savings. Also, a significant number of complaints were received from occupants in this research group during control phase 2 leading to several of the schedule and load-sensing rules being disabled. This caused small increases in energy use in some instances, within the normal variation of uncertainty attributed to behavior as shown by the results for the control group.

The results are presented below in Figures V-13, V-14, V-15, V-16, and V-17. Aggregate savings are presented using the normalized equipment distribution in Table 6. Power-draw profiles are presented for the printers, laptops, and miscellaneous workstation equipment. All other draw profiles are in the appendices.

Aggregate Savings:

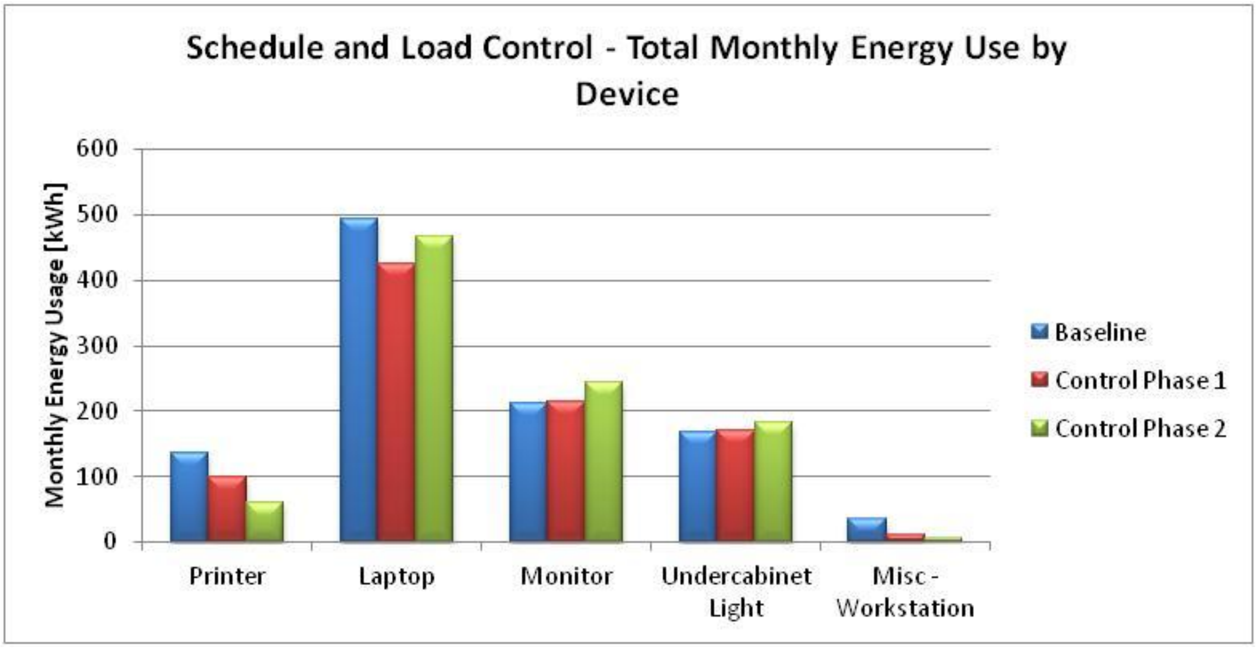


Figure V-13: Comparison of monthly energy consumption before and after APS installation (Cohen Complex)

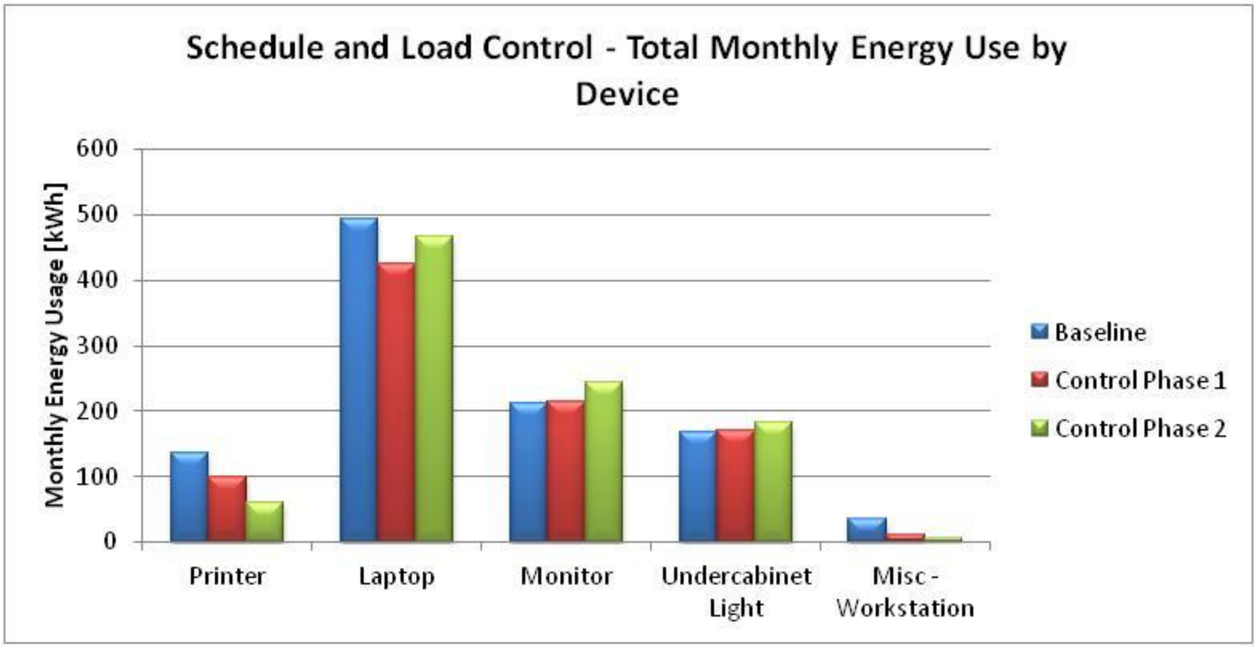


Figure V-14: Comparison of monthly energy consumption before and after APS installation (Robert C. Byrd Federal Building and U.S. Courthouse)

Printers

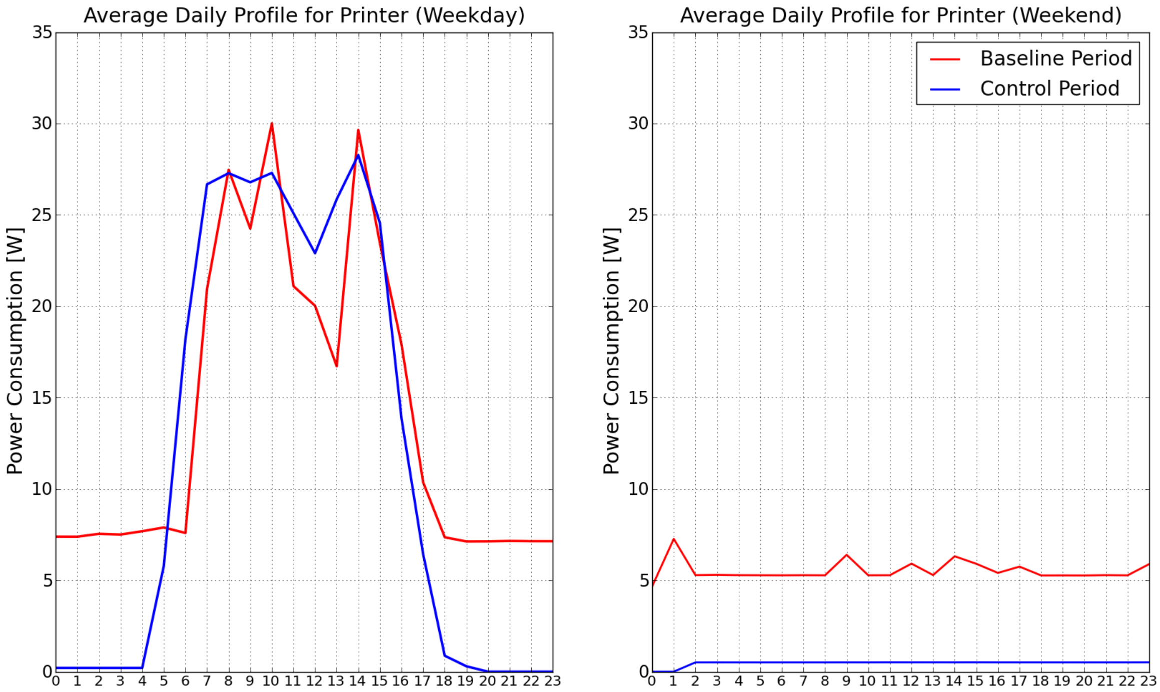


Figure V-15: Weekday and weekend power-draw profiles (printers)

Laptops

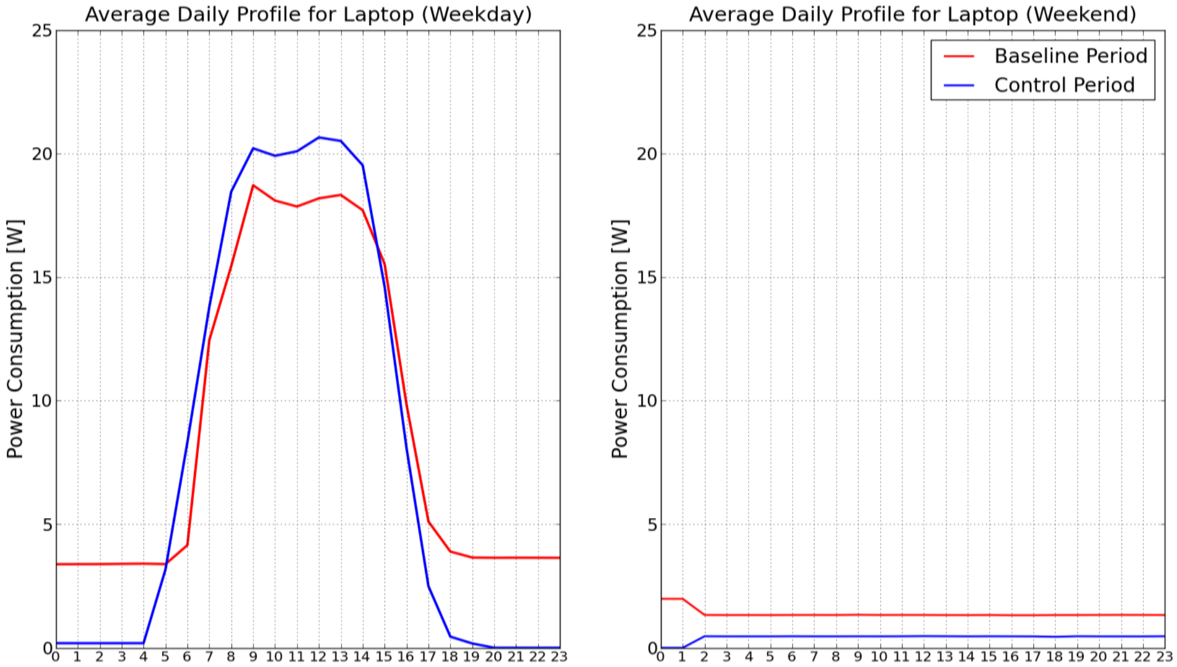


Figure V-16: Weekday and weekend power-draw profiles (laptops)

Miscellaneous

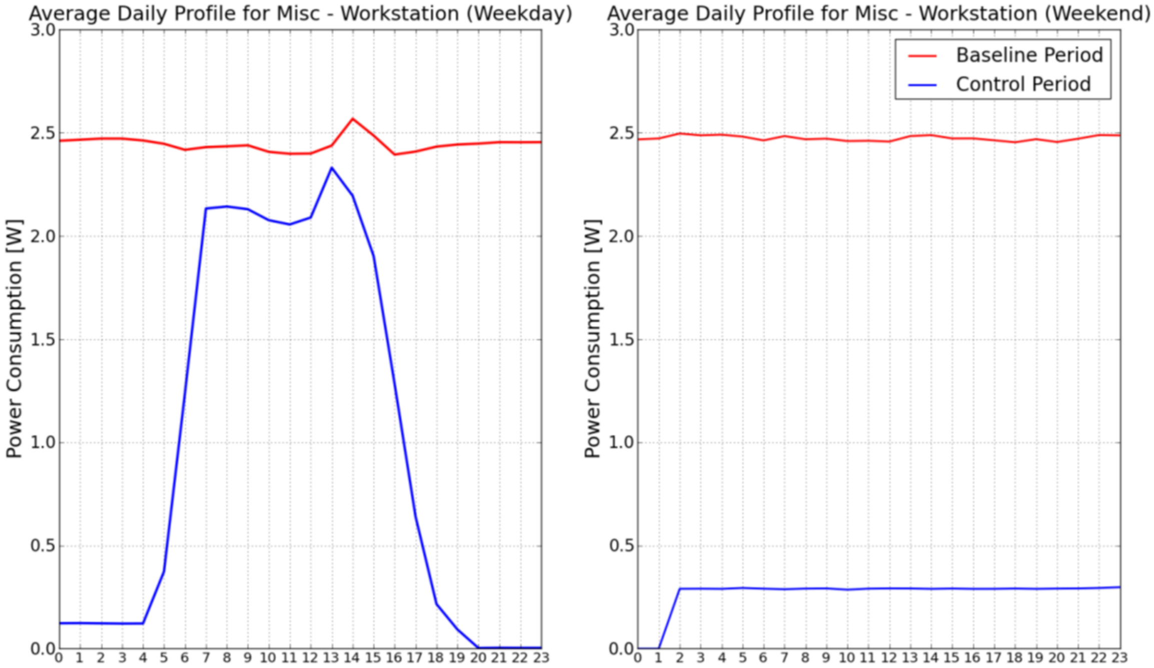


Figure V-17: Weekday and weekend power-draw profiles (misc - workstation)

VI. Summary Findings and Conclusions

The initial value proposition of this study was that plug-loads account for 25% to 50% of the electricity consumed in office buildings. The office equipment in GSA buildings is potentially wasting significant energy from being energized during unoccupied hours, or when not in use. A complex array of technologies that meter and control office equipment has emerged in the marketplace. Control strategies that match office equipment energy use to user work schedules can save considerable energy in most office buildings. These control strategies are also effective in reducing peak demand.

The hypothesis that led the GPG Program to take on this assessment was that schedule timer and load-sensing control strategies could be tailored to the work patterns of GSA staff to reduce the energy consumption of office equipment. Also, if GSA had real-time, plug-level data on equipment energy use, measures could be taken to prevent wasted energy. These data could be used to:

- Conduct a competition among building occupants to reduce energy
- Identify equipment that is being left on 24 hours per day, 7 days per week
- Identify equipment that has failed or is about to fail.

The technology that was evaluated was an APS. It has four outlets that are metered individually. The metered data from the power strip are sent through a wireless hub, to a modem, and then out to a database. The manufacturer provides a website where users can view or download the metered data, and implement schedule timer or load-sensing controls on one or more outlets on the power strip.

Schedule timer controls achieved the highest energy savings. Load-sensing and combination controls provided somewhat limited savings. This type of control is more complex and requires users to set a threshold for the load of a “master” device. When the “master” goes above or below that threshold, the “slave” outlets are powered on or off. During this study, the evaluation team found it difficult to set the load threshold for some equipment, such as monitors. Without metering monitors before the load-sensing controls are implemented, it is hard to know what the “in-use,” “standby,” and “off” power draws are. The evaluation team estimated that monitors use less than 10 W when in standby mode. Monitors were initially used as the “master,” and the laptop and workstation peripherals were the “slaves.” This resulted in equipment being powered off when the occupants needed them to be powered on. This control strategy was eventually dropped in favor of a more conservative approach where laptops were not controlled with load-sensing, and only the peripheral equipment was controlled (with the monitor as master device).

The APS that was evaluated in this project is a great way to reduce plug-loads for equipment that (1) is used on a predictable schedule, and (2) is left powered on during non-business hours, weekends, and holidays. If this product were to provide some sort of “smart” load-threshold setting functionality (i.e., the plug strip would set a load threshold based on the load profile of the device that it is attached to), there is a potential for significantly saving energy during the daytime when occupants are not at their workstations.

In general, schedule timer and load-sensing controls are effective in saving energy for office equipment. There are advanced plug strips on the market that incorporate one, but not both, of these technologies and have an MSRP (manufacturer’s suggested retail price) of approximately $20 to $60. Although less expensive, these plug strips currently do not provide metering capability.

This study showed that user education is important. Users need to know the following: (1) how the plug strip will help them to save energy, (2) what actions are required on their behalf to save energy (i.e., do they need to put their laptops into standby for their monitors and peripherals to turn off), and (3) how to override or reset the plug strip if it is not functioning properly or if the equipment is occupied outside of the defined schedule. Occupant feedback indicated a lack of education in some instances. Thorough education programs are recommended for any future installations. Schedule timer controls are simple and easy to understand for users, which led to larger energy savings in this study. Load-sensing controls are more complicated and difficult to understand leading to complaints and disabling in some instances, which resulted in limited energy savings.

The plug strip that was evaluated provided an abundance of data on the associated plug-loads. These data are valuable in spotting wasted energy use, informing the future procurement of low-energy equipment, and identifying equipment that is behaving erratically (which is often a precursor to equipment failure). These data are also valuable to building energy modelers, allowing them to more accurately model plug-loads in a building. However, as the product's data management website currently stands today, a significant investment of time is required to download, sort, filter, and analyze the data before they can be used to take action to save energy. In this study, a custom set of scripts was developed to streamline this process. However, this also required a significant investment of engineering time up front. The manufacturer is continually improving its data management software. Future revisions of its website may provide a more streamlined way to use the metered data.

Figure VI-1: An example set of advanced plug strips that is currently on the market (left) and incumbent technology: standard no-control plug strip (right). ***Credit: Chad Lobato and Ian Metzger, NREL***

A. Best Practices

This study revealed a number of best practices for future implementation of APSs in GSA office spaces. At a very high level, simple devices with simple controls are desirable. There should be thorough training for all of the occupants and facility site managers. Occupant should have the ability to customize their own controls to better understand and obtain ownership of the APS.

More specific observation indicated that the system should be mounted at the desk level for easy access to manual override button and the plugs themselves. There were several instances during this study where building occupants had to reach under their desks to trigger the manual override switch. This typically frustrates the occupants. Second, the system should reduce unnecessary standby loads during unoccupied hours as well as when occupants are away from their workstations. Third, GSA should continue to procure low-energy office equipment that has consistent, automatic, built-in, low-power functionality; this is conducive to using load-sensing control strategies. Figure VI-2 below is an example low-energy workstation that has been successfully implemented in U.S. Department of Energy facilities.

The default schedule used in the first phase of controls was to turn off outlets at 6 p.m. and power them back on at 6 a.m. This schedule was very conservative, and a minimal amount of complaints was received. During the second phase of controls, the schedules were custom tailored to each occupant's work schedules. Many complaints were received due to occupant's computers not being powered on in the morning if they decided to come in to work early. Another best practice for schedule timer controls is to allow sufficient warm-up time. For example, an ice machine should be energized on weekdays an hour or so before the first group of occupants arrive for work. This allows sufficient time for the machine to produce ice so that it is ready to use when occupants need it.

There are several best practices that are specific to the product that was tested. First, devices with peak loads anywhere close to 1,800 W, such as vending machines and large printers, should get their own plug strip. This is due to the 15-amp fuse on the plug strip itself. If users have to frequently reset the fuse on the plug strip, it could be an annoyance. Second, the threshold for the load-sensing controls is an input that the user has to provide. However, this threshold can be difficult to determine for someone who is unfamiliar with how much energy a particular device consumes. If load-sensing control is desired, it is recommended that an advanced plug strip with "smart" threshold functionality be used (i.e., the plug strip automatically adjusts the threshold based on what is plugged into the "master" outlet).

Figure VI-2: Example of low-energy workstation recommended as best practice. ***Credit: Mathew Luckwitz, NREL***

B. Barriers and Enablers to Adoption

There are several barriers that might affect adoption of this technology. Note that the particular product had its own benefits and drawbacks that are not ubiquitous in all schedule timer /load-sensing/meter-enabled APSs. For some APSs, an Internet connection is required to allow users to change control settings and/or collect metered data. This can be a barrier for GSA and other agencies where cyber security issues make it difficult for devices to connect to the Internet through LAN (local area network) or WAN (wide area network) services. For this study, the power strip connected to the Internet through a cellular modem. In one building (Moorhead Federal Building), the cellular signal was very weak, and it prevented data from being reliably transmitted to the Internet.

Occupant adjustment to the new controls can also be a barrier to effective operation of the technology. A manual override should be available to the occupant, and appropriate educational material/training should be given to all users.

C. Research Participant Survey

A research participant survey was conducted at the conclusion of this research project. The survey was designed to capture the interaction of the occupants with the APS devices. Occupants were asked to answer several questions about their experiences during this research project. The results of the survey are shown below in Figure VI-3.

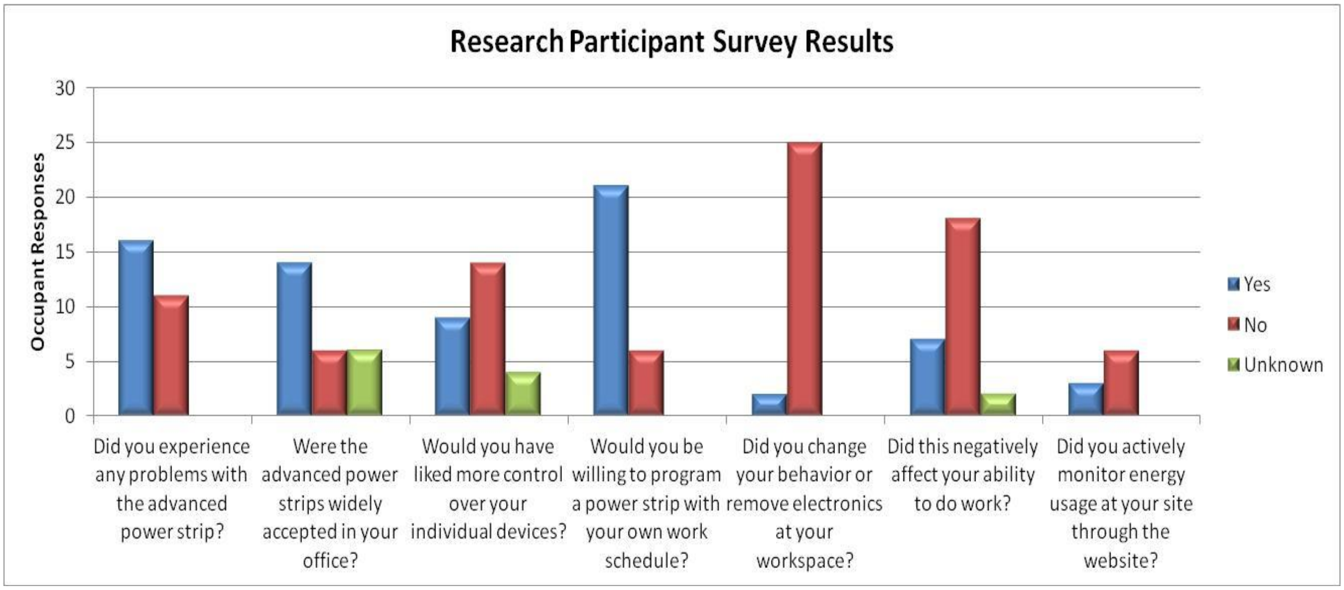


Figure VI-3: Research participant survey questions and response results

Results of the research participant survey identified several interesting insights into the occupant perspective of APSs. A majority of respondents experienced issues turning devices on in the mornings or unexpected shutdowns in the evenings when working late. This typically was resolved by pressing the manual override button on the APS, which in some instances was expressed to be a nuisance. The majority of issues experienced by participants related to the load-sensing controls. However, several occupants did not experience any issues throughout the research. Results showed that wide spread acceptance of the devices within the office environment was achieved in most instances. When asked whether or not occupants would like more control over their individual devices, the majority of respondents said "no." However, an overwhelming majority of respondents indicated that they would be willing to program their individual schedules into an APS. Almost all respondents indicated that behavior was not changed as a result of this research. A majority of respondents did not experience any negative impacts as a result of the APS. The negative impacts that were experienced by occupants related to frustration caused by the inconvenience of manually turning devices on and devices unexpectedly turning off. Those who had access to the online dashboard indicate that they rarely or never checked the real-time energy performance of the plug-loads, which reduces the value of submetering capabilities.

D. Market Potential within the GSA Portfolio

GSA owns and leases over 354 million ft^2 of space in over 9,600 buildings. According to several energy assessments of GSA's Region 3 buildings conducted by NREL, the average plug-load energy consumption accounts for 21% of the energy end use within a standard office building, excluding data centers.

The overall first costs of this equipment will depend on the quantity that GSA buys, if they decide to buy it. The payback period will also depend on the quantity of equipment that GSA buys. The savings that this equipment provides depend on the control strategies that are implemented. In this study, the savings for implementing different control types are shown in Table 8 (below).

Table 8: Energy-use reduction by device type for three different control types

		Printer	Laptop	Monitor	Under-Cabinet Light	Misc. Equipment	Kitchen Equipment	Total
Schedule timer	Edward A. Garmatz US Courthouse	68%	13%	14%	14%	25%	13%	43%
	William J. Green, Jr. Federal Building	31%	54%	27%	34%	67%	79%	52%
Load-sensing	Robinson and Merhige Courthouse	69%	-4%	-6%	n/a	51%	n/a	23%
	Veteran Administration Building	-5%	16%	11%	0%	54%	n/a	10%
Both	Robert C. Byrd US Courthouse	18%	35%	-2%	22%	40%	n/a	23%
	Cohen Complex	27%	14%	-1%	-1%	68%	n/a	12%
Average	Average	35%	21%	7%	14%	51%	46%	27%

Additional savings can be obtained by using the metered plug-load data to periodically commission equipment (i.e., check for equipment that is staying powered 24/7 or behaving erratically).

Cohen Complex (one of the eight buildings selected for this study) was selected to demonstrate whole-building implementation in a typical GSA office building. This building is 289,214 ft^2 and has mixed use, including office space, courthouses, and a post office. Based on an energy efficiency and renewable energy site assessment conducted by NREL in June 2011, this facility has a plug-load energy consumption equivalent to approximately 15% of the total building annual electricity consumption. A detailed inventory of the plug-loads was collected as part of the assessment, which resulted in an estimated equipment power density of 0.35 W/ft^2. The inventory of plug-loads that are appropriate for control applications is listed in Table 6. Percent savings that were shown to be achievable by this research project, listed in Table 8, were extrapolated to the whole-building, plug-load inventory to demonstrate a larger-scale implementation of the technology.

Savings for the different control types were estimated from the average of the two buildings where that control had been implemented and monitored. Total power and energy usage were calculated from the inventory of devices. Energy savings were calculated using the percent savings results from this study. Finally, simple-payback periods were calculated assuming a $100/device charge. Load-sensing controls in shared spaces such as print rooms, kitchens, and miscellaneous require the sensed load to be at the occupant workstations. Therefore the simple payback for load-sensing and load-sensing with schedule-timer includes APS costs and energy cost savings for all workstations in addition to the shared space types APS cost and cost savings. The extrapolated savings for the whole building are presented below in Table 9.

Table 9: Calculated total savings for the Cohen Complex based on metered energy reductions and equipment audit during site visit

	Current Condition			Electricity Savings (kWh/yr)			Payback Periods (Assuming $100/device)		
	Total power (kW)	Electricity use (kWh/yr)	Percent of plug-loads end use	Schedule timer	Load-sensing	Schedule timer + load-sensing	Schedule timer	Load-sensing	Schedule timer + load-sensing
Workstation	21.3	93,465	31.7%	24,153	4,112	10,437	7.8	46.0	18.1
Print Rooms	30.9	135,342	46.0%	67,287	43,309	30,452	1.1	5.5	6.4
Kitchen	14.7	64,386	21.9%	29,618	NA	NA	0.7	NA	NA
Miscellaneous	0.3	1,314	0.4%	603	690	710	4.1	39.9	17.2

E. Recommendations for Installation, Commissioning, Training, and Change Management

Manufacturer claims of 50% savings and payback under 3 years were confirmed in certain instances, but not for all applications. However, all applications with less than a 10-year payback should be considered for larger-scale deployment.

The largest savings were on loads that run 24 hours per day, 7 days per week unnecessarily: printers (27%-69% reduction, depending on the type of control) and miscellaneous equipment (51%-81% reduction, depending on the type of control). Most of the workstation equipment (laptops and monitors) were already demonstrating relatively good power-saving behavior due to the computer power management system, which limited energy savings potential.

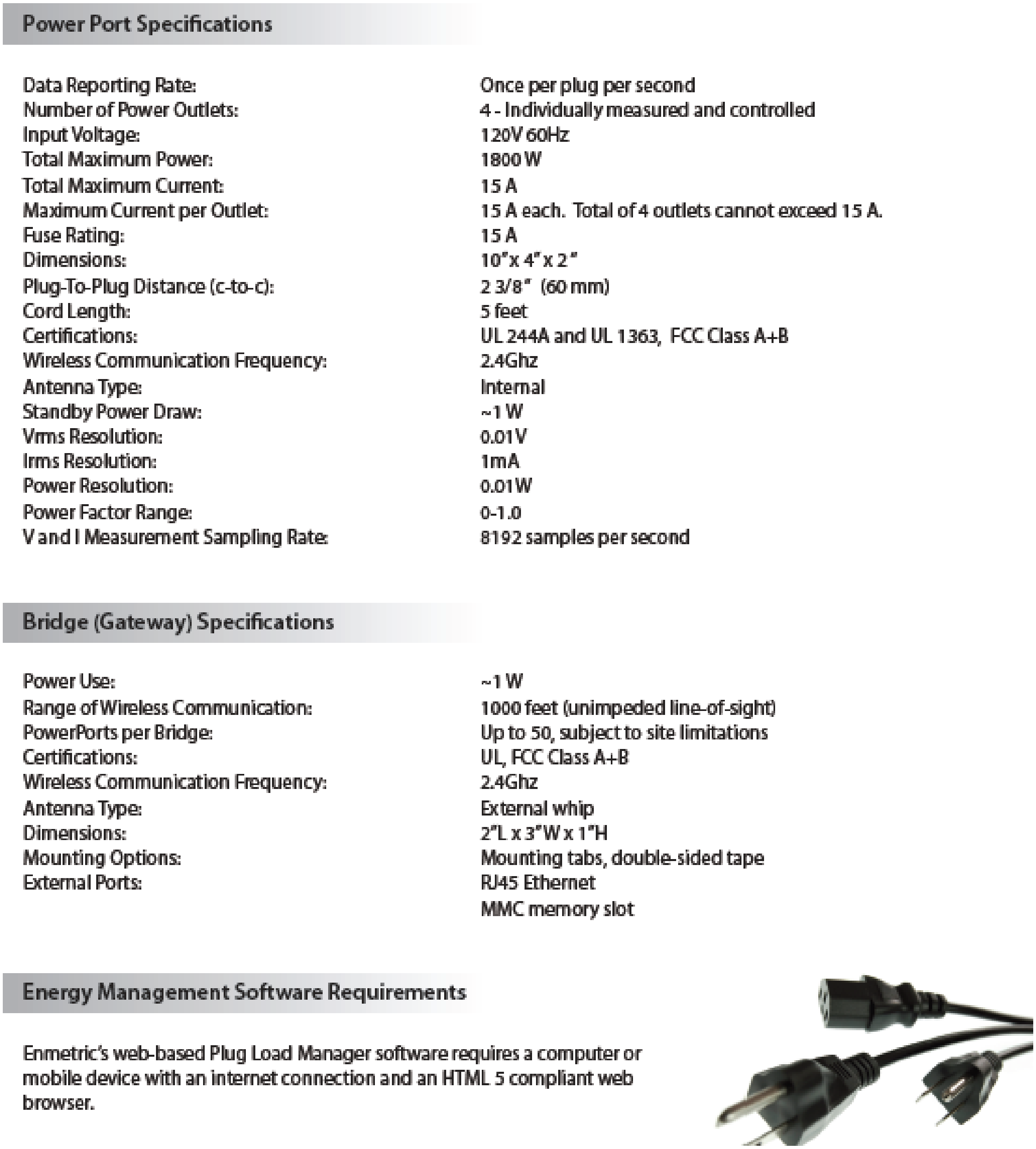
Office energy use was most significantly reduced by schedule timer control in this study. Less savings were achieved with the load-sensing and combined controls. This could present a significant opportunity to utilize some of the simpler and lower cost schedule timer power strips to address a majority of office plugs loads. This would both optimize energy savings and require a lower initial investment.

Better educational tools need to be implemented for occupant acceptance. If occupants are unaware of how their equipment is being controlled, they typically perceive the plug strip to be malfunctioning. It is recommended by NREL that the GPG Program study this issue further. A study should be conducted in which users are given their own account and the ability to make adjustments to their own plug strip. This way the occupant would have the opportunity to better understand how his/her plug strips work. Second, if metering is a desired feature, the manufacturer should provide a data management tool that requires a minimal investment in time to use and provides actionable recommendations for energy savings. Third, after the plug strips have been installed, a “second” checkup is recommended to make sure that occupants haven’t reverted back to their previous plug strips.

Because computers are the real drivers of energy use at workstations, a recommended follow-on study is to compare the cost of implementing APSs versus having information technology managers send out effective power management settings for computers. GSA implemented power management settings for all of its computers in the buildings that NREL studied. Unfortunately, this was done before the study began, so NREL was unable to quantify the energy savings. Other follow-on work could include the evaluation of behavioral change, occupant education, or other controls strategies such as occupancy-based controls, and manual-on and vacancy-off controls.

VII. Appendices

A. Detailed Technology Specifications. *Credit: Enmetric Systems Incorporated*



Power Port Specifications

Data Reporting Rate:	Once per plug per second
Number of Power Outlets:	4 - Individually measured and controlled
Input Voltage:	120V 60Hz
Total Maximum Power:	1800 W
Total Maximum Current:	15 A
Maximum Current per Outlet:	15 A each. Total of 4 outlets cannot exceed 15 A.
Fuse Rating:	15 A
Dimensions:	10" x 4" x 2"
Plug-To-Plug Distance (c-to-c):	2 3/8" (60 mm)
Cord Length:	5 feet
Certifications:	UL 244A and UL 1363, FCC Class A+B
Wireless Communication Frequency:	2.4Ghz
Antenna Type:	Internal
Standby Power Draw:	~1 W
Vrms Resolution:	0.01V
Irms Resolution:	1mA
Power Resolution:	0.01W
Power Factor Range:	0-1.0
V and I Measurement Sampling Rate:	8192 samples per second

Bridge (Gateway) Specifications

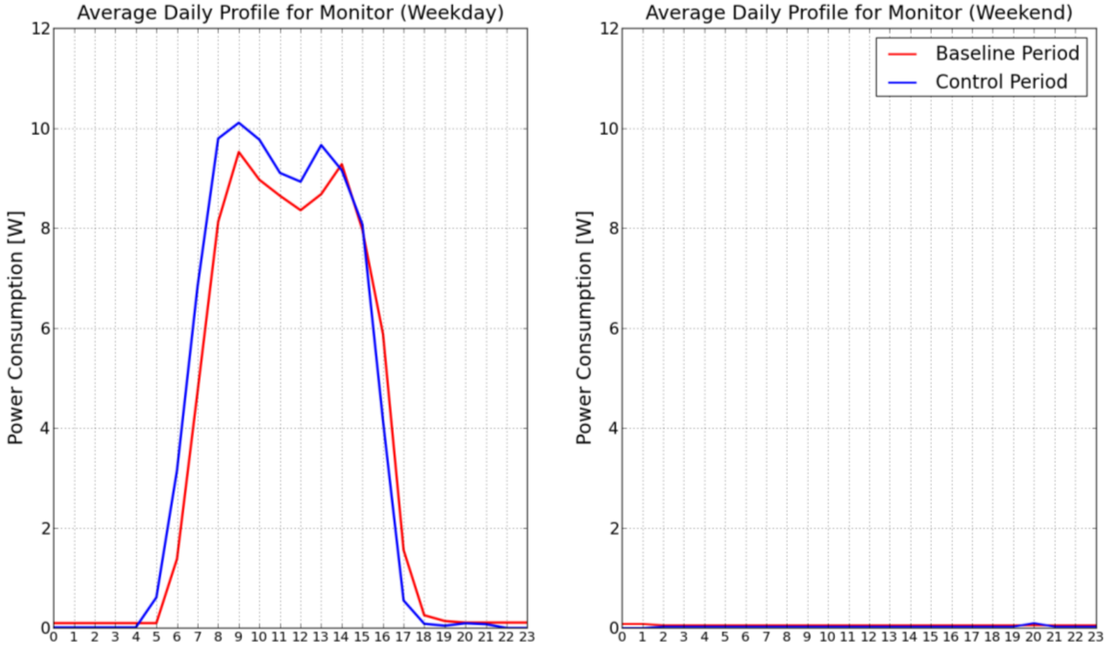
Power Use:	~1 W
Range of Wireless Communication:	1000 feet (unimpeded line-of-sight)
PowerPorts per Bridge:	Up to 50, subject to site limitations
Certifications:	UL, FCC Class A+B
Wireless Communication Frequency:	2.4Ghz
Antenna Type:	External whip
Dimensions:	2"L x 3"W x 1"H
Mounting Options:	Mounting tabs, double-sided tape
External Ports:	RJ45 Ethernet MMC memory slot

Energy Management Software Requirements

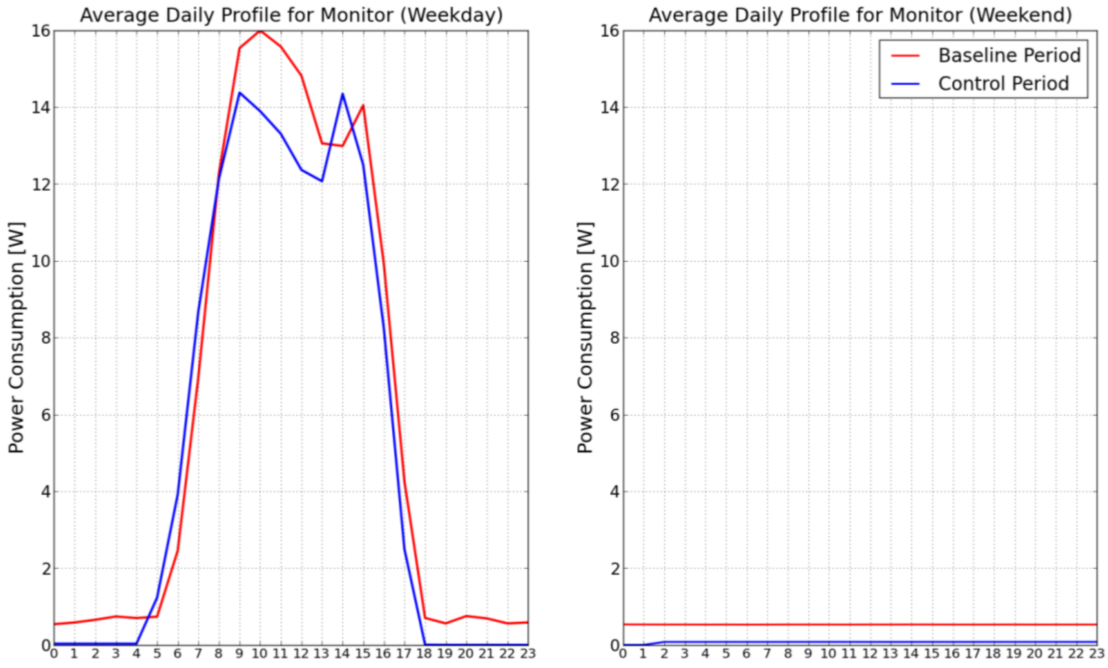
Enmetric's web-based Plug Load Manager software requires a computer or mobile device with an internet connection and an HTML 5 compliant web browser.

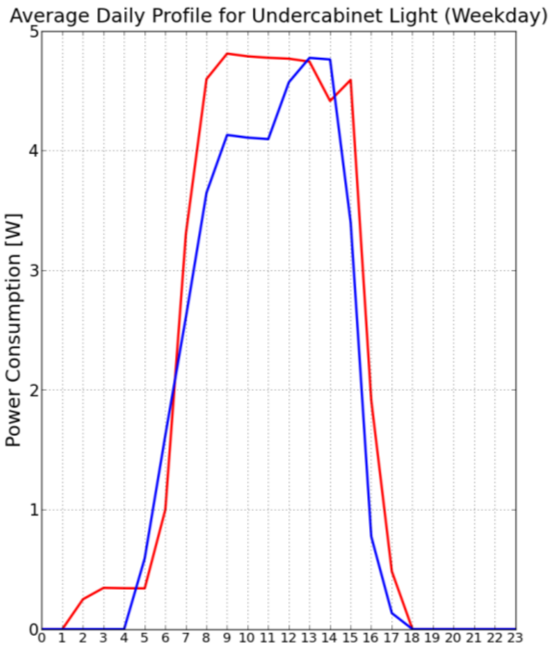
B. Research Details

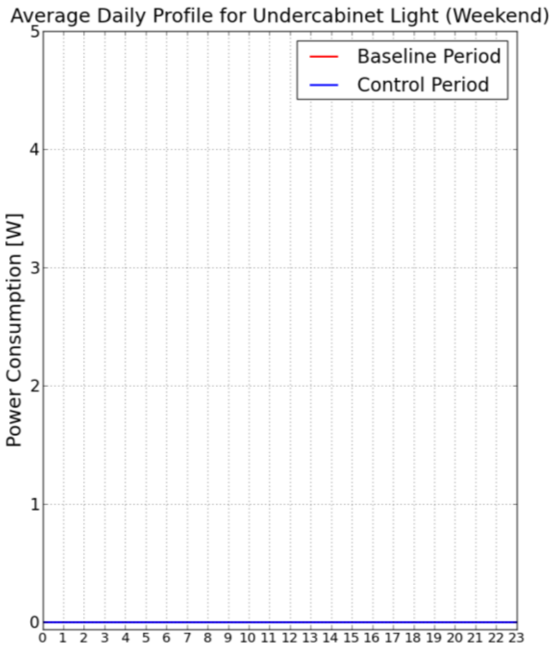
Schedule timer control (remaining devices):



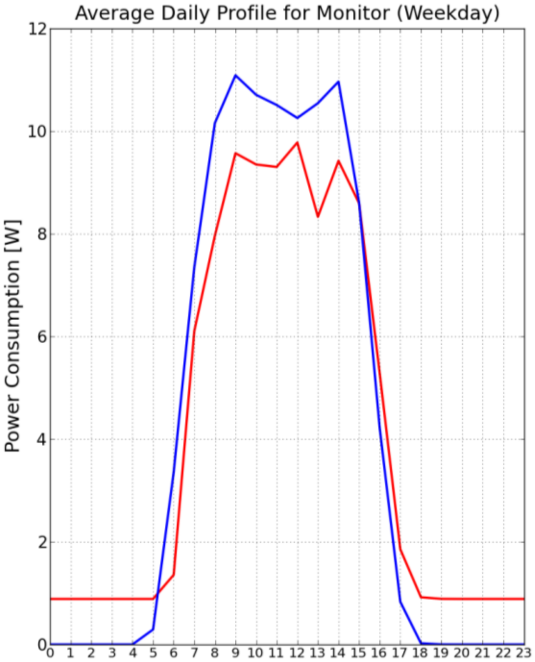
Load-sensing (remaining devices):

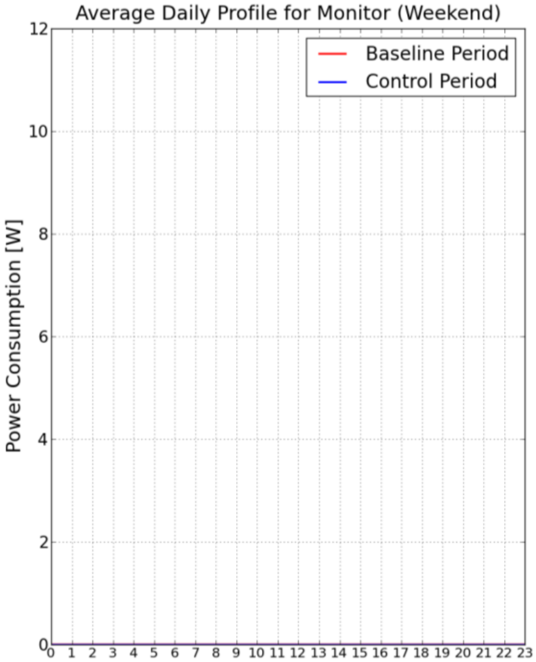


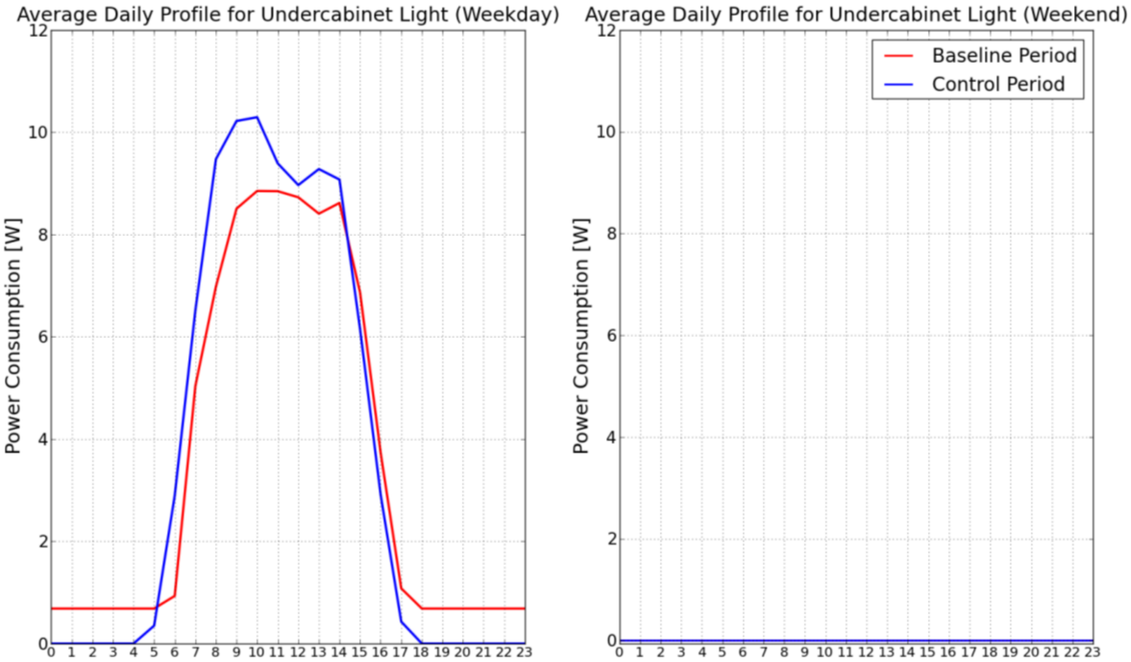




Load-sensing and schedule (remaining devices):






Average Daily Profile for Undercabinet Light (Weekday)
Average Daily Profile for Undercabinet Light (Weekend)
Power Consumption [W]
0
2
4
6
8
10
12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Baseline Period
Control Period

C. References

1. “GSA Properties Overview.” U.S. General Services Administration, 2012. Accessed June 27, 2012: http://www.gsa.gov/portal/content/104501.

2. “About the Mid-Atlantic Region.” U.S. General Services Administration, 2012. Accessed June 27, 2012: http://www.gsa.gov/portal/category/21451.

3. Lobato, C.; Pless, S.; Sheppy, M. (2011). Reducing Plug and Process Loads for a Large Scale, Low Energy Office Building: NREL’s Research Support Facility. NREL/CP-5500-49002. Golden, CO: National Renewable Energy Laboratory. Accessed June 28, 2012: http://www.nrel.gov/docs/fy11osti/49002.pdf.

4. U.S. General Services Administration, 2006.

5. “GSA Advantage!” U.S. General Services Administration, undated. Accessed May 10, 2012: https://www.gsaadvantage.gov.

6. Enmetric Brochure – Supplied by vendor.

7. Metzger, I.; Kandt, A.; Van Geet, O. (2011). Plug Load Behavioral Change Demonstration Project. NREL/TP-7A40-52248. Golden, CO: National Renewable Energy Laboratory. Accessed June 28, 2012: http://www.nrel.gov/docs/fy11osti/52248.pdf.

8. “Technology Portal.” Presented March 15, 2012. Accessed June 27, 2012: http://www1.eere.energy.gov/femp/pdfs/ns/ntwg_032012_livingood.pdf.

D. Acronyms and Abbreviations

APS	advanced power strip
CSV	comma-separated value
EE	energy efficiency
FEMP	Federal Energy Management Program
ft^2	square feet
GPG	Green Proving Ground
GSA	U.S. General Services Administration
kW	kilowatt
kWh	kilowatt-lour
M&V	measurement and verification
NREL	National Renewable Energy Laboratory
RE	renewable energy
SQL	structured query language
TRL	technology readiness level
W	watt
yr	year