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Plug Load Behavioral Change Demonstration Project

Ian Metzger, Alicen Kandt, and Otto VanGeet

Produced under the direction of Pacific Northwest National Laboratory by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IWO-138785 and Task No. WUR1.1000

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-7A40-52248
August 2011

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Executive Summary

The EPA's Region 8 Headquarters is located in a LEED Gold certified building in Denver, Colorado. Fully occupied in January 2007, the 420,000 ft^2, nine-story building houses approximately 775 employees.[1] In addition to earning numerous design awards and a LEED Gold rating for the building, EPA, GSA (the government leaseholder), and All Capital/GPT (the building's owner) have made sustainable operations a priority. The EPA building participated in a research study quantifying the effect of different mechanical and behavioral change approaches on plug load energy reduction.

Any device that plugs into wall outlets distributed throughout a building is a plug load. These loads do not relate to general lighting, heating, ventilation, cooling, or water heating, and typically do not provide comfort to the occupants[2]. Plug loads account for an average of 9%[3] but as much as 28% of the electricity consumption in office buildings depending upon the nature of the work.[4] Plug loads can also affect cooling and heating loads and associated cooling energy use, but these affects are not considered in this report. An entity that strives to reduce energy use, energy costs, and greenhouse gas emissions in an effort to operate sustainably must devise a strategy to reduce plug load electricity consumption.

This research study was undertaken in an effort to identify the most effective way to reduce plug load energy, using three primary approaches. The first was an automated energy management system which turns off equipment when a pod was unoccupied for a given period of time. The second method involved behavioral change using information feedback and selected messaging. The third involved behavioral change by encouraging competition amongst occupants.

The research was conducted by establishing a baseline, testing experimental applications, and a returning to baseline to see if behaviors "stick" when messaging is no longer deployed. Each condition was applied for four weeks. The study ran from February 2011 to June 2011 and was conducted with 126 occupants on four different floors of the building. Occupants sit in clusters of six to eight people, called pods. Energy usage data were collected per pod.

In the first experimental phase, a control system automatically turned off plug load devices after 15 minutes of no occupancy in a pod. In the second experimental phase, occupants were sent weekly letters with information on the energy use associated with a variety of plug load devices

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[1] "Greening EPA," U.S. Environmental Protection Agency: http://www.epa.gov/greeningepa/facilities/denver-hq.htm. Accessed July 26, 2011.

[2] Lobato, C., Pless, S., Sheppy, M., and Torcellinin, P. "Reducing Plug and Process Loads for a Large Scale, Low Energy Office Building: NREL's Research Support Facility." NREL/CP-5500-49002, February 2011.

[3] "Buildings Energy Data Book," Energy Efficiency and Renewable Energy: http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.13. Accessed July 26, 2011.

[4] "Survey of Plug Loads," Energy Efficient Products: http://www.efficientproducts.org/product.php?productID=11. Accessed July 26, 2011.

as well as conservation tips. All letters are included in Appendix A. In the final phase, occupants were sent notifications comparing carbon dioxide equivalent (CO2e) accountability per person and encouraging occupants to participate in a competition to reduce their energy consumption. All notifications are included in Appendix B.

The study found that the most effective method for reducing plug loads was through the control system, which turned off plug load devices after 15 minutes of no occupancy in a pod. The competition among pods was also effective at reducing plug load energy consumption, although less so than the control system. The letters sent to occupants educating them about plug load energy use and opportunities for conservation had negligible savings. Extrapolated annual energy savings estimates and associated cost savings for the 126-person test group are presented in Table 1.

Table 1: Cost Savings Analysis for Each Experimental Method

Experimental Method	Total Annual Energy Savings (Extrapolated for 775 People) (kWh/yr)	Percent Energy Reduction from Baseline	Percent of Whole Building Electricity Reduction (Extrapolated for 775 People)	Total Annual Cost Savings ($/yr)	Total CO2e Savings (tons)
Control System	34,757	21%	0.9%	$3,476	30
Letters	-407	0%	0.0%	$-41	0
Competition	9,912	6%	0.3%	$991	9

This study shows that energy control systems have a potential for large plug load-related energy savings, as does social norming through competitions. This study did not combine the three methods (energy control system, educational letters, and competition) at the same time to quantify energy savings. Based on these findings the best case scenario for energy savings would include a control system and occupant competition with significant promotion for occupant education. Alternatively, implementing a competition as a behavioral change mechanism without a control system may be the most cost effective. However, without the submetering system the savings could not be verified and normalized comparisons of occupant energy consumption would not be possible.

Lessons learned stemmed from all aspects of this project.

- Site support and occupant participation and interest are critical to the outcome of behavioral change research.
- Approval from the EPA Union required additional time and planning for all interactions with the occupants and required the research to comply with protocols that would ensure that occupant anonymity could be maintained. Anonymity is typically required for field research and should be included in dashboard interfaces for displaying data.

- Installation of the control and submetering system took longer and was more costly than expected. However, costs are expected to decrease significantly with scale and experience working in federal facilities.
- The wired installation of the control system and communications were very cumbersome and complex. Wireless communications and controls with "plug and play" installation are expected to have less complexity, quoted at lower costs, and are currently commercially available.
- Cybersecurity created a hurdle for the dashboard and data storage of the submetering system.
- Several generalizing assumptions are required to account for all of the uncontrolled factors in behavioral change research.
- Occupant participation and willingness to take actions to reduce energy was met with some resistance
- The control system had significantly higher energy and cost savings compared to behavioral change methods. However, it is expected that incentivizing behavioral change could significantly improve occupant participation and energy reductions. Previous studies have indicated that the level of occupant involvement usually correlates with the incentive.[5] Incentives can be in many forms including money, prizes, food, public recognition, etc.
- Implementing behavioral change mechanisms without a control system would significantly improve the cost effectiveness. However, energy and cost savings could not be verified and normalized occupant energy comparisons could not be generated without a submetering system.
- Developing the appropriate plug load management process can have a significant influence on the success of energy reduction goals. This may include behavioral change mechanisms, controls systems, or other policies. Establishing a program champion, developing a business case, benchmarking, identifying occupant needs, equipment selection/replacement, controlling equipment schedules, institutionalizing reduction measures, and promoting occupant awareness can all be critical steps in the process.[6]
- Higher energy savings from plug loads may be accomplished by expanding the research beyond just workstations. This study focuses on the workstation and did not include equipment typically found in shared spaces such as large multifunction printers, refrigerators, microwaves, water-coolers, and other equipment.
- Prolonged energy savings were found to be significant during the occupied period and weekend periods. However, longer term monitoring is recommended to verify the estimated prolonged savings.

[5] Birch, D., and Veroff, J. (1966). *Motivation: A Study of Action*. Belmont, CA: Brooks/Cole
[6] Lobato, C., Sheppy, M., Bracknet, L., and Torcellinin, P. *MELs Management Selection Process and Lessons Learned*. NREL/TP-5500-51708, July 2011.

Next steps for additional research may include:

- Combining multiple methods to determine if even greater savings could be achieved
- Comparing the energy savings between non-incentivized and incentivized competition
- Evaluating the results of institutionalizing reduction measures through information technology (IT) policy[7]
- Achieving occupancy-based control at the cubicle level rather than at the pod level
- Install and monitor a wireless monitoring and control system and compare to the current system.

The GSA Green Proving Grounds program is pursuing future work to test different plug load submetering and control systems for ease of installation, scalability, energy savings, and cost-effectiveness. The lessons learned from this research should be incorporated into the future work.

[7] *Assessing and Reducing Plug and Process Loads in Office Buildings*. NREL/BR-5500-51199, June 2011.

Table of Contents

1. Background

The Department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL) is one of the ten national laboratories managed by the DOE Office of Science. PNNL also performs research for other DOE offices as well as government agencies, universities, and industry to deliver breakthroughs in science and technology. PNNL has been tasked by GSA's Office of Federal High-Performance Green Buildings, under the American Recovery and Reinvestment Act (ARRA), to provide energy efficiency and research support. PNNL, in collaboration with the National Renewable Energy Laboratory (NREL), is providing energy efficiency and research support for the U.S. General Services Administration (GSA) and the Environmental Protection Agency (EPA).

The GSA is a leader among federal agencies in aggressively pursuing energy efficiency (EE) opportunities for its facilities and installing renewable energy (RE) systems to heat and power these facilities. Since the enactment of the Energy Policy Act of 2005 (EPAct 2005), Executive Order (EO) 13423 (2007), the Energy Independence and Security Act (EISA 2007), and Executive Order 13514 (2009), other federal agencies are looking to GSA for strategies for meeting the EE and RE goals laid out by these pieces of legislation.

The EPA is a federal agency established to protect human health and the environment. EPA's main priorities under the current administration include: taking action on climate change, improving air quality, assuring safety of chemicals, cleaning up our communities, protecting America's water, expanding the conversation on environmentalism and working for environmental justice, and building stronger state and tribal partnerships. EPA strives to meet and exceed the energy efficiency and renewable energy goals laid out by federal legislation.

NREL is the only DOE national laboratory solely dedicated to advancing EE and RE technologies and applications. Since its inception, NREL has supported both federal and private sectors in implementing EE and RE systems and strategies to lower energy use and to meet remaining energy needs with resources having minimal environmental impact.

The EPA Region 8 Headquarters located at the Wynkoop Building in downtown Denver, Colorado participated in a research study to quantify the effect of different control methods and behavioral change approaches on plug load energy reduction. Through active participation by the site to implement the submetering and behavioral change demonstration projects, EPA will be closer to meeting and exceeding the goals set forth in the applicable legislation. Applicable legislation includes but is not limited to the EPAct 2005, EO 13423, EISA 2007, EO 13514, and other mandates. The specific goals set forth in the applicable legislation are summarized in Appendix D.

2. Introduction

Any device that plugs into wall outlets distributed throughout a building is a plug load. These loads do not relate to general lighting, heating, ventilation, cooling, or water heating, and typically do not provide comfort to the occupants[8]. Plug loads account for an average of 9%[9] but as much as 28% of the electricity consumption in office buildings depending upon the nature of the work.[10] Standby power–electricity used by appliances and equipment while they are switched off or not performing their primary function–associated with plug loads presents a large opportunity for energy savings. This power is consumed by power supplies, the circuits and sensors needed to receive a remote signal, soft keypads and displays including miscellaneous light-emitting diode (LED) status lights. Standby power use is also caused by circuits that continue to be energized even when the device is off. Standby power use is responsible for approximately 1% of global carbon dioxide (CO2) emissions.[11]

Plug loads can also increase cooling loads, and decrease heating needs, and affect the associated HVAC energy use. An entity that strives to reduce energy use, energy costs, and greenhouse gas emissions in an effort to operate sustainably must devise a strategy to reduce plug load electricity consumption.

This research was conducted at the EPA Region 8 Headquarters building to examine methods of decreasing energy consumption associated with plug loads. Desktop computers (permanent computer towers), desktop printers, laptop computers, under-cabinet task lights, and computer monitors are the top energy-consuming workstation plug load equipment in the EPA Region 8 Headquarters building.

This study aimed to identify the most effective way to reduce plug load energy, using three primary approaches. The first is an automated energy management system which turns off equipment when it is unused for a certain period of time. The second involves behavioral change using information feedback and selected messaging. The third involves behavioral change using a competition to encourage occupants to reduce their energy consumption.

This study, conducted over five four-week study periods, included a baseline, testing experimental applications, and a returning to baseline to see if behaviors "stick" when messaging is no longer deployed.

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[8] Lobato, C., Pless, S., Sheppy, M., and Torcellinin, P. "Reducing Plug and Process Loads for a Large Scale, Low Energy Office Building: NREL's Research Support Facility." NREL/CP-5500-49002, February 2011.

[9] "Buildings Energy Data Book," Energy Efficiency and Renewable Energy: http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.13. Accessed July 26, 2011.

[10] "Survey of Plug Loads," Energy Efficient Products: http://www.efficientproducts.org/product.php?productID=11. Accessed July 26, 2011.

[11] "Frequently Asked Questions," Standby Power, Lawrence Berkeley National Laboratory: http://standby.lbl.gov/faq.html. Accessed July 26, 2011.

3. Previous Related Work

There have been many studies using submetering systems to quantify and understand how plug loads consume energy and the amount of time spent in active mode or sleep mode. There have also been many psychology studies about how to influence human behavior. However, not many studies have attempted to implement behavioral change as it relates to plug load energy consumption. While reviewing previous work, lessons can be learned from various sources that are often seeking to accomplish different goals. However, understanding both the psychology of behavioral change and the energy implications of plug loads is essential to this project.

Previous research using submetering systems to monitor plug loads have been very successful in quantifying various metrics about plug load energy consumption. For example, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has published a great deal of information about diversity factors and power consumption in active, standby, and off modes.[12] Submetering systems have also been used to examine how specific pieces of equipment contribute to the bigger picture energy consumption of the building and metrics such as kilowatt-hours per square foot (kWh/ft^2) have been used to extrapolate annual energy consumption.[13] Other studies have used submetering to establish baselines and have extrapolated market analysis for plug load-related policies.[14] These publications are extremely useful for understanding how and when energy is being consumed by various office plug load equipment.

The psychology of behavioral change is a very important topic that needs further examination in the context of energy consumptions. A study entitled *Changing Behavior and Making It Stick: The Conceptualization and Management of Conservation Behavior* by Raymond De Young has provided an excellent resource for this project. De Young's study examines conservation behavior in order to change individual behavior while reducing the need for repeated intervention. It also categorizes and evaluates behavioral change techniques. This previous work has found informational prompting to be untrustworthy and nondurable, with varied effectiveness. Material incentives initiate rapid change and effective results but are nondurable once the material incentive has been obtained. Social pressure and material disincentives were found to initiate rapid change and effective results but also create negative psychological resistance from individuals. Commitment techniques encouraging individuals to "pledge" their commitment to behavioral change for a specific amount of time were found to be the most durable and effective. However, securing individual commitment has proven to be difficult to accomplish.[15]

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[12] ASHRAE Fundamentals, 2005.

[13] Moorfield, L., Frazer, B., and Bendt, P. *Office Plug Load Field Monitoring Report*. ECOS: December, 2008.

[14] Porter, S., Moorfield, L., and May-Ostendorp, P. *Final Field Research Report.* ECOS: October, 2006.

[15] Young, R. "Changing Behavior and Making It Stick: The Conceptualization and Management of Conservation Behavior," Environment and Behavior, 25:4, p. 485: July, 1993.

4. Building Overview

The EPA Region 8 Headquarters facility (Wynkoop Building) was designed and constructed as a high-performance building through a public-private partnership comprised of GSA Region 8 (R8), EPA R8, EPA's Office of Administration and Resource Management, EPA's Sustainable Facilities Practices Branch, and Opus Northwest with Zimmer Gunsul Frasca Architects. The design and construction process was well-documented and all partners are still actively engaged in activities aimed at better understanding facility operations and energy consumption. The EPA Region 8 Headquarters Building was selected to serve as the site for several ongoing research activities, including plug load behavioral change.

EPA's R8 Headquarters is located in lower downtown Denver. It is a privately owned facility built to federal specifications and leased on behalf of EPA by the General Services Administration (GSA).[16] Occupied in early 2007, the 420,000 ft^2, nine-story building houses approximately 775 employees.[17] In addition to earning numerous design awards, the building achieved a Gold rating under the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) for new construction.[18] The building, located at 1595 Wynkoop Street, includes nine floors of office space, two levels of below-grade parking, and ground-level retail spaces.[19]

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[16] "Sustainable Design and Operations," EPA: http://www.epa.gov/region8/building/design.html. Accessed July 26, 2011

[17] "Green Building and Green Operations," EPA: http://www.epa.gov/region8/building/index.html. Accessed July 26, 2011

[18] "1595 Wynkoop Building Awards and Recognition," EPA: http://www.epa.gov/region8/building/awards.html. Accessed July 26, 2011

[19] "EPA Region 8 Headquarters," EPA: http://www.epa.gov/region8/building/pdf/EPApressbook.pdf. Accessed July 26, 2011.

Figure 1: EPA's Region 8 Headquarters Building (*Photo by Alicen Kandt, NREL/PIX 19447*)

The building features a variety of sustainable and efficient design features. These include:

- Siting. The building is located on an urban brownfield that previously housed a United States postal annex.[20]

- Construction management and materials. A variety of sustainable materials were used throughout the building, including corn-based fabric and wheatboard, recycled glass tile, recycled-content carpets, recycled steel, cork floors, bamboo wall panels and doors made with rice hull cores. Additionally, fly ash was used in the concrete portions of the building and regional materials–those manufactured, produced or harvested within 500 miles of the building–were used for more than 50% of the structure's manufactured materials. Construction waste was also reduced, with as much as 80% of the total waste generated recycled or diverted from local landfills.

- Water efficiency and water management. High-efficiency and waterless plumbing fixtures are employed throughout the building and are estimated to achieve a 44% water savings over standard buildings. Moreover, a stormwater management system removes 80% of total suspended solids and 40% of total phosphorus from the water running off the building.

- Green roof. A green roof was installed as a means of both removing pollutants from stormwater and reducing the rate and quantity of stormwater runoff. Populated with

[20] "EPA Region 8 Headquarters," EPA: http://www.epa.gov/region8/building/pdf/EPApressbook.pdf. Accessed July 26, 2011.

native, drought-tolerant plant species that minimize irrigation requirements, the 20,000 ft^2 vegetated roof covers three terrace levels and filters stormwater while reducing the urban heat-island effect of the building.

- Energy efficiency. To reduce heating, ventilation, and air conditioning (HVAC) energy consumption, an under-floor air distribution system with individual controls is used throughout all office floors, as are occupancy sensors, energy-efficient lighting, optimized insulation levels, daylight-responsive lighting controls, and daylight redirection and control devices optimized for daylight harvesting.

  Variations of a glazed curtain-wall system were designed for the different façades–the sunward (southeast and southwest) façades were designed with horizontal exterior sunshades and a system of internal light shelves designed to cut glare and solar gain. The windward (northeast and northwest) façades have a series of exterior vertical shades to cut glare from low-angle winter sun while simultaneously harvesting diffused light from the clear north sky. As the net result, 75% of workstations receive significant daylight.

- Green power. A 10-kilowatt (kW) rooftop photovoltaic (PV) system generates electricity for the facility.

  Additionally, EPA offsets 100% of the electricity consumption of this building with renewable energy certificates (RECs).[21]

- Occupancy awareness. The EPA realizes that building a green building is not the only component in sustainable and efficient operations. Important factors include how the building is operated and the behavior of the occupants. Region 8's Environmental Management System helps the EPA improve environmental performance by quantifying the impact of operations (e.g., electricity, water, materials management and transportation) and taking actions to reduce those impacts. Region 8 is working toward a project Gold rating in LEED for Existing Buildings: Operations and Maintenance (LEED EBOM) to ensure continued high performance in building design and operations.

  Additionally, many employees are allowed to work alternative schedules, such as four ten-hour days, or telecommute. There are abundant bicycle parking racks in the parking garage, and the building is located in close proximity to buses and light-rail lines. Employees are given EcoPasses or commuter checks for public transit.[22]

[21] "Denver, Colorado, Region 8 Office," EPA: http://www.epa.gov/greeningepa/facilities/denver-hq.htm. Accessed July 26, 2011.
[22] "Benefits Designed with Today's Commuter in Mind," Commuter Check: http://www.commutercheck.com/Home.aspx. Accessed July 26, 2011.

- Plug loads. EPA management created guidelines associated with what types of plug load equipment are or are not allowed at workstations. Some equipment, such as space heaters, fans, and humidifiers, require approval. The policy states that approval will be granted after attempts to make the employee more comfortable using building controls have not been successful. The building is required by the lease to provide tempered air within comfort range guidelines. Only in cases in which the building HVAC systems can't provide acceptable temperature control will the use of space heaters, fans, or humidifiers be approved.[23]

These sustainable design features were modeled to use 39% less energy than the ASHRAE Standard 90.1-1999 baseline. The building's modeled energy usage was 47,500 British Thermal Units (Btu) per square-foot per year.[24] Based on the electricity and steam consumption over the past four years the building is operating around 52.7 kBtu/ft^2. An overview of the incremental energy savings attributed to energy use categories is displayed below in Figure 2.

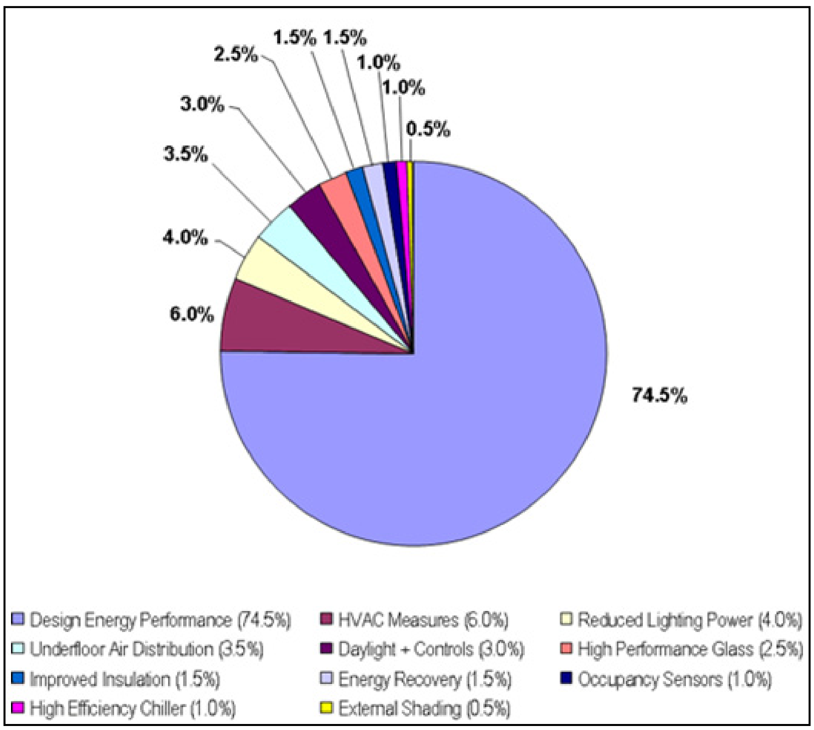

Figure 2: Incremental Energy Savings Pie Chart[25]

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[23] Final Decision, 9/13/2006: Personal Property Decisions and Procedures for 1595 Wynkoop

[24] "EPA Region 8 Headquarters, "Whole Building Design Guide": http://www.wbdg.org/references/cs_epadenver.php. Accessed July 26, 2011.

[25] "Denver, Colorado, Region 8 Office," EPA: http://www.epa.gov/greeningepa/facilities/denver-hq.htm. Accessed July 26, 2011.

4.1 Utility Analysis

The EPA Region 8 Headquarters Building has two primary panels providing electrical service to the building. The annual electricity consumption was analyzed for the past four years (2007-2010). The average total electricity consumption between 2007 and 2010 was 4,034,397 kilowatt-hours per year (kWh/yr). The average blended electric rate for the period analyzed was $0.10/kWh. Figure 3 shows the total (meter #1 plus meter #2) monthly electricity consumption and Figure 4 shows the total (meter #1 plus meter #2) monthly electricity cost.

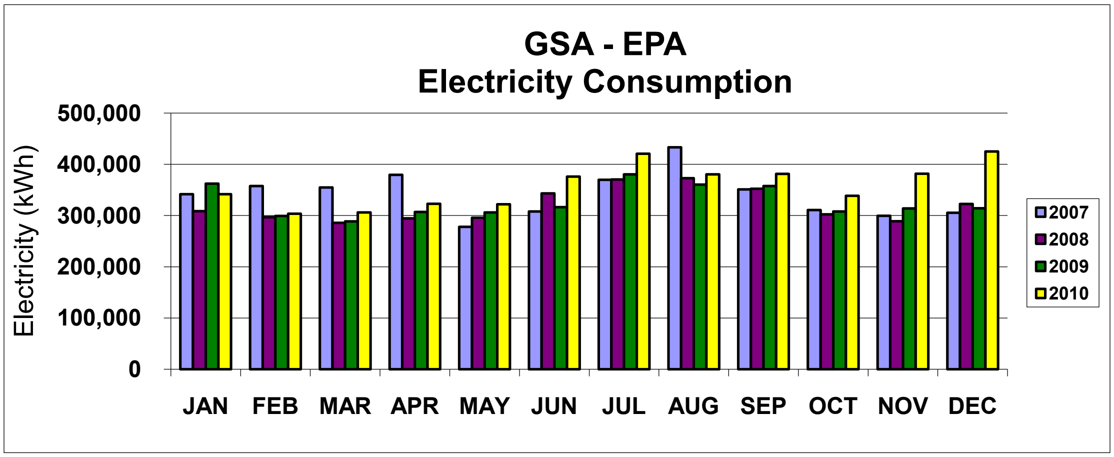

Figure 3: Total Electricity Consumption for EPA Region 8 Headquarters Building (Including Meters #1 and #2)

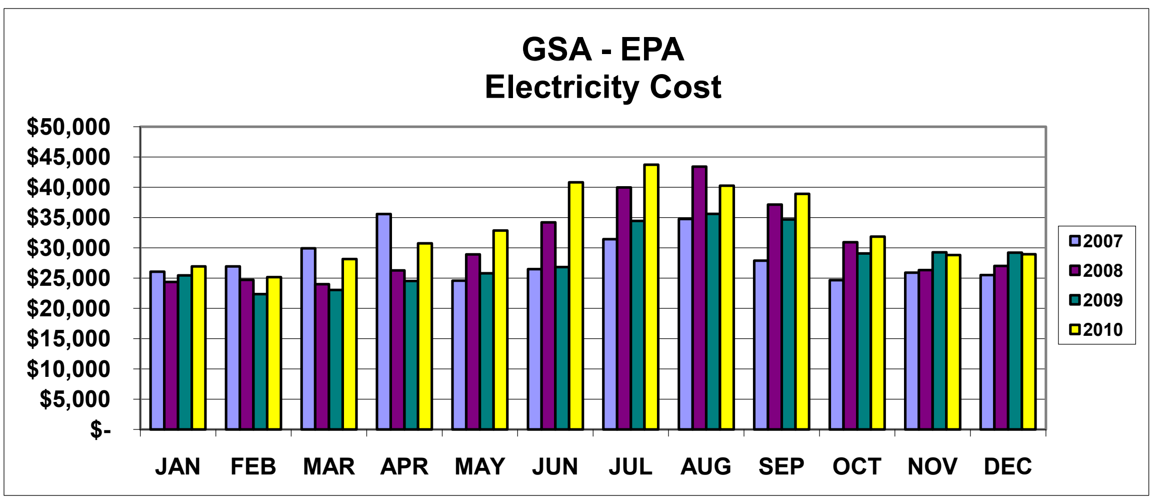

Figure 4: Total Electricity Costs for EPA Region 8 Headquarters Building (Including Meters #1 and #2)

5. Research Methodology

This research study was undertaken in an effort to identify the most effective way to reduce plug load energy use, using three primary approaches. The first was an automated energy management system which turns off equipment when a pod of cubicles is unoccupied for a certain period of time. The second method involved behavioral change using information feedback and selected messaging. The third involved behavioral change using an occupant competition to reduce energy relative to their coworkers. The data analysis calculates the average amount of energy saved.

The research method included establishing a baseline, testing experimental applications, and a returning to baseline to see if behaviors "stick" when messaging is no longer deployed. Each condition was applied for four weeks. The study began in early 2011 and was conducted with 126 occupants on four different floors of the building. Occupants sit in clusters of six to eight people, called pods. Energy usage data were collected on a pod basis.

Plug loads were monitored with a submetering and control system. This device monitors occupancy and electricity use and is capable of shutting off non-critical equipment after an area has been unoccupied for a preset amount of time. Up to four separate circuits can be attached to the system, with four output zones (A, B, C and D). Two of the output zones (usually C and D) remain energized in order to power critical equipment, such as computer central processing units (CPUs) and clocks. The other two output zones (A and B) are switched off based on whether the entire pod is unoccupied for a pre-set amount of time, which in this case was 15 minutes. This is accomplished by mounting a passive infrared (PIR) motion sensor to the underside of the work surface of each workstation. The submetering system reports the energy usage data to an online management system and dashboard.

This provides a technology platform that was used in this study to monitor plug load usage. The occupancy information was stored and used for space utilization reporting and the actual electrical power consumption, including time of use, of each of the output zones was collected and used in this study. Energy use data were available to study participants online via a secure website.

5.1 Inventory Analysis

An inventory of all plug load equipment included in this analysis was taken at the beginning and end of the study. A walk-through of the pods was conducted in January and July, preceding and following the experimental phase. Detailed data regarding the inventory can be found in Section 7.1.1 Inventory and ASHRAE Schedules.

5.2 Baseline Periods

The first baseline period ran for four weeks at the beginning of the study, during February 2011. In this period no messaging, education or outreach was performed and no automated controls were deployed.

A second baseline period ran for four weeks following the experimental phase, during Jun 2011. The goal of this second baseline period was to evaluate the extent to which behavioral changes continue when messages are no longer delivered to occupants. Therefore, no messaging was conducted during this baseline period; however, occupants could use the online dashboard by visiting the Web page. Also during this time period, no automated controls were deployed.

5.3 Experimental Phase

Three experimental phases were conducted for four weeks each, during March-May 2011. The goal of these phases was to quantify how much energy was saved due to different energy conservation strategies.

5.3.1 Control System

In the first experimental phase, during March 2011, the control system was enabled and controlled the non-critical circuits based on pod (group of cubicles) occupancy. When the entire pod was unoccupied for a period of 15 minutes, all non-critical circuits serving that pod were turned off. Occupants were made aware of this control and were informed to plug the appropriate equipment into specific outlets. Also, facilities staff surveyed the test group and informed participants on how to comply. However, it was observed that some occupants plugged all of their equipment into the critical, non-interruptible circuits so that none of their equipment would be turned off by the control system. This could have been a result of issues with power outages during the installation of the submetering and control system. This action reduced the energy savings, but is important to incorporate in the findings as a negative occupant reaction.

5.3.2 Letters

In the second experimental phase, during April 2011, occupants were given information on the energy use associated with a variety of plug load devices as well as conservation tips. Information was conveyed via four, 1-page, email letters–one sent each week. All letters included background information about the study and provided occupants with contact information if they had questions, concerns or problems. The intention of this phase was to passively suggest energy conservation measures through occupant awareness, leaving the decision to take action up to the occupants. However, there was no way of tracking how many occupants read the letters and were actively participating. All letters from this experimental phase are included in Appendix A.

> Letter #1: The first letter notified occupants about the study and informed them that they would be receiving additional letters with facts about energy and conservation tips and

plug load energy awareness. The letter included the definition of plug loads and the average percent contribution of plug loads to a building's total electrical use. It listed the five pieces of workstation equipment with the highest energy consumption in the EPA Region 8 Headquarters Building (desktop computers, desktop printers, laptop computers, under-cabinet task lighting, and computer monitors) and provided an estimate of 629 pounds of CO2 equivalent per person annually associated with plug load electrical consumption in the EPA Region 8 Headquarters Building.

Letter #2: The second letter focused on education regarding computer energy settings. It provided facts about computer energy use and suggested an energy conservation idea whereby occupants activate power management settings on computers and monitors. It provided guidance on how to enable power management settings.

Letter #3: Printers and their associated energy use were the focus of the third letter. Facts were provided regarding printer energy use and an energy conservation idea was suggested. The letter stated that removing all personal printers and using the networked printer instead could reduce energy consumption and loads during inactive periods, reduce additional waste streams, and improve office air quality.

Letter #4: The focus of the fourth letter was energy and occupancy and it conveyed the message that plug loads can consume significant energy even when spaces are unoccupied, and some equipment draws electricity even when it is turned off. Several energy conservation ideas were presented, including:

- Shutting down equipment, unplugging devices, and turning off power strips when leaving the office.
- Using compact fluorescent (CFL) or LED lighting in task lamps.
- Replacing office equipment with ENERGY STAR models.

5.3.3 Competition

The final phase, during May 2011, was a competition. All occupants were provided directions, via email, on how to access an online digital dashboard to determine how much plug load-related electricity their pod was consuming, and the associated greenhouse gas (GHG) emissions, relative to other pods in the experiment.

The data were presented for each pod and normalized for pod occupancy. It was hoped that by enabling occupants to compare their pod electricity use with other pods they would be able to understand how their energy use ranked comparatively, and they would be motivated to reduce their energy use in an attempt to outperform their peers in terms of energy efficiency. Data, such as that in Figure 5, below, was accessible to all occupants in the study.

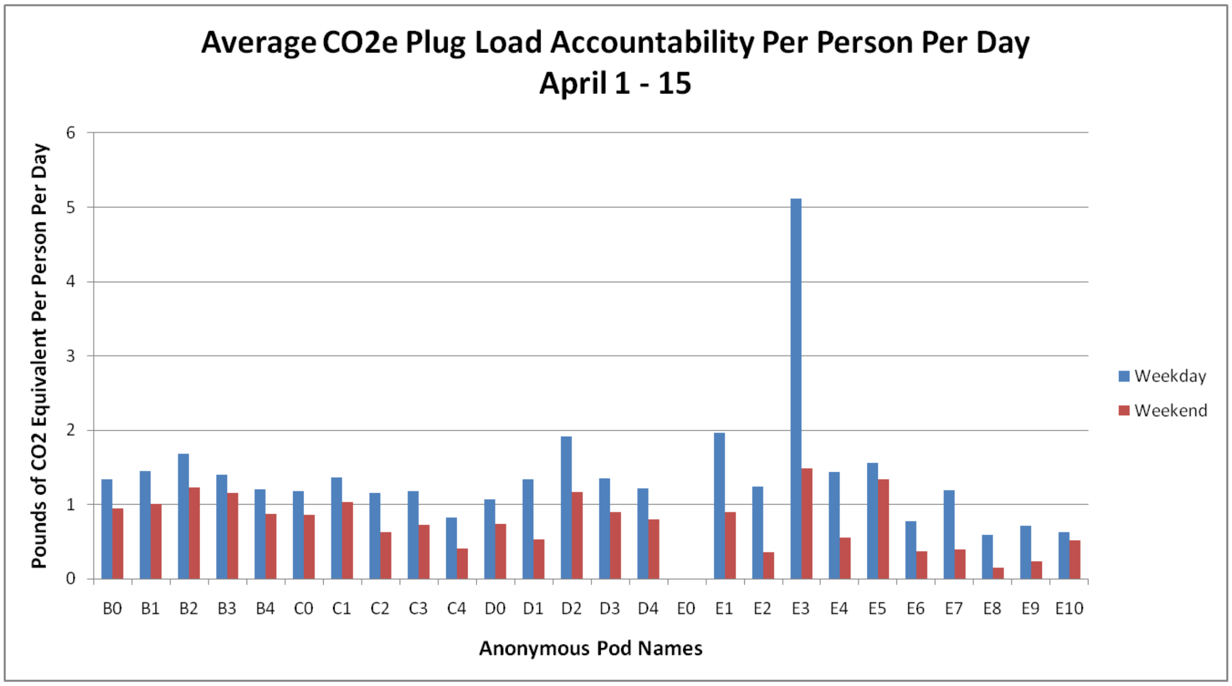

Figure 5: Plug Load Accountability by Pod

The competition prompts also provided key questions for occupants to consider in regards to their plug loads:

- Is your plug load carbon dioxide equivalent (CO2e) accountability higher than others, and why?
- Why is the plug load CO2e accountability so high on the weekends?
- What can you do to reduce your plug load CO2e accountability?

Pod E3 was an outlier for all stages of this research. Upon further inspection it was observed that a network multifunction copy/printer was plugged into the pod circuit. This significantly altered the energy results. However, it is shown that the copy/printer did go into standby mode over the weekends. Pod E0 was disconnected or vacant throughout the study

6. Results

The following results summarize the finding of the baseline and experimental phases that were conducted from February through July, 2011.

6.1 Inventory and ASHRAE Schedules

An inventory of plug load equipment for all participants included in this analysis was taken at the beginning and end of the study. A walk-through of the pods was conducted in January and July, preceding and following the experimental phase. Equipment wattages were estimated, because interaction with the occupants was restricted, and diversity factors were applied based on ASHRAE publications. Diversity factors take into account the fact that all equipment that is plugged into the outlets are not always in use at the same time, and provide a more accurate representation of actual operating loads. Average cubicle sizes were measured to be 80 feet squared (ft^2) with an average total connected equipment load of 145 Watts (W) without diversity and 71 W with diversity. Average cubicle equipment power densities were calculated to be 0.9 Watts/ft^2 with diversity factors. The ASHRAE equipment schedule was used to approximate the estimated annual energy consumption and average usage profiles. Table 2 shows the equipment inventory, assumed wattages, and diversity factors. Table 3 shows the ASHRAE equipment schedules for weekdays, Saturdays, and Sundays.

Only slight differences were observed between the equipment inventories taken prior to the research and after the research. Table 2 shows the comparison. A reduction in the number of desktop computers and increase in number of laptops reflects the EPA policy to gradually replace desktop computers with laptops and occupant requests for laptops. Numbers of desktop printers, task lights, desktop speakers, and radios also decreased slightly. However, it is also shown that there are increases in the number of other workstation plug load equipment. Equipment that was shown to increase included desktop fans, heavy duty calculators, phone chargers, and label makers. These shifts in the equipment inventory may be due to several factors. One possibility is that occupants were influenced by the research and removed some of their desktop equipment such as printers, task lights, speakers, and radios. Another possibility is that shifts in occupation such as changes in desk location, personnel shifts, new hires, retirees, or other changes may have affected these inventories. The shifts in occupation are unquantifiable and have been stated as assumed to remain constant in this study. Overall, there were minor shifts observed when comparing the inventories from before and after the research but not significant enough to show a distinct influence on behavioral change.

Table 2: Inventory of Plug Load Equipment, Assumed Wattage, and Diversity Factors for Baseline Period

	Pre-Experiment Count Totals	Post-Experiment Count Totals	Assumed Wattage	Diversity Factor	References
Desktop Computer	35	21	85	75%	May 2011, ASHRAE Journal, Plug Load Design Factors, Wilkins, C.K., Hosni, M.H.
Laptop Computer	92	95	40	75%	May 2011, ASHRAE Journal, Plug Load Design Factors, Wilkins, C.K., Hosni, M.H.
LCD Monitor	130	127	34	60%	May 2011, ASHRAE Journal, Plug Load Design Factors, Wilkins, C.K., Hosni, M.H.
Under-cabinet Task Light	266	266	31	5%	ASHRAE Fundamentals Ch. 30
Desktop Printer	8	4	80	33%	ASHRAE Research Project 1482-RP
Fax/ Scanner	1	1	20	33%	ASHRAE Research Project 1482-RP
Task Light	94	92	13	33%	
Desktop Fan	5	10	15	33%	
Desktop Speakers	62	53	20	33%	
Radio	4	2	5	33%	
Radio with Lit Clock	14	11	10	100%	
Heavy Duty Calculator	11	20	10	33%	
Phone Charger	7	10	10	50%	
External Hard Drive	2	2	15	100%	
Electric Stapler	1	1	5	10%	
Wireless Headset Charger	5	5	10	50%	
Label Maker	1	2	10	33%	

Table 3: ASHRAE Equipment Schedule from Standard 90.1

ASHRAE Equipment Schedule			
Hour of Day	% Usage Weekday	% Usage Saturday	% Usage Sunday
0	5	5	5
1	5	5	5
2	5	5	5
3	5	5	5
4	5	5	5
5	10	5	5
6	10	10	5
7	30	10	5
8	90	30	5
9	90	30	5
10	90	30	5
11	90	30	5
12	80	15	5
13	90	15	5
14	90	15	5
15	90	15	5
16	90	15	5
17	50	5	5
18	30	5	5
19	30	5	5
20	20	5	5
21	20	5	5
22	10	5	5
23	5	5	5
Total	1040	280	120
Average % Usage	43%	12%	5%

6.2 Data Conditioning and Development of the Baseline

The baseline period was developed from submetering the test group in a "business as usual" situation. Data were collected without any interaction with the occupants or any attempt to control circuits. Figure 6 shows an example of the hourly energy consumption and occupancy trends over a period of a several weeks.

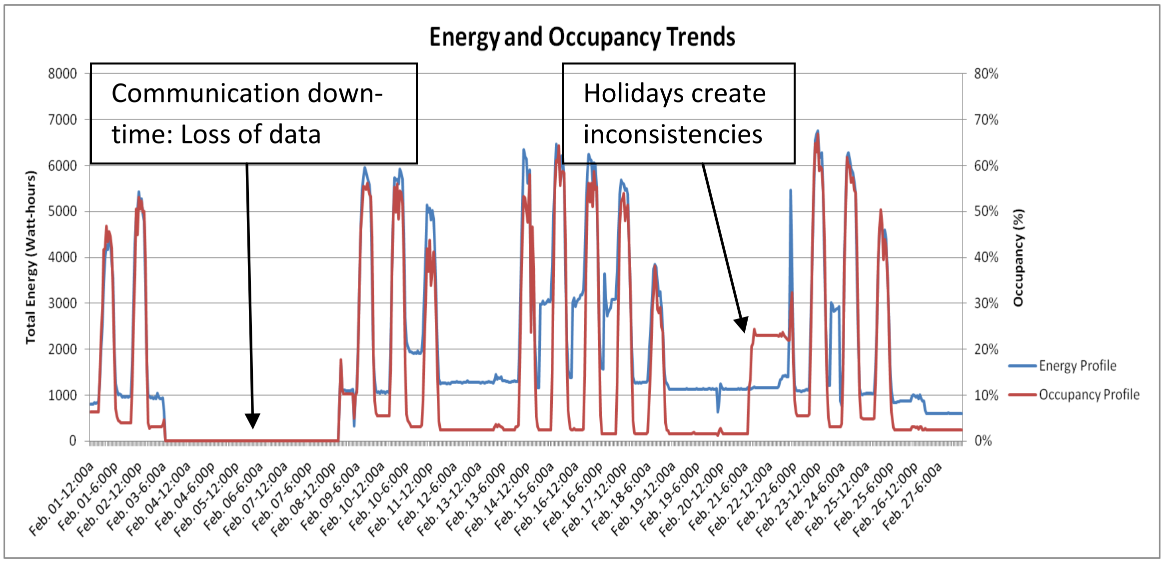

Figure 6: Sample Data Showing Energy and Occupancy Trends

Figure 6 was selected to show an example of both the energy and occupancy trends. In addition, some key issues with data collection are illustrated by this graph and are important in discussing how these issues are handled in this analysis.

First, it is noted that between February 3rd and February 8th, submetering equipment communications were not working properly, so no data were collected during those periods. This issue occurred on a couple of occasions. For the purposes of this analysis, these periods were omitted so that the data were not skewed, and replaced with average performance from similar days of the week and hours of the day during the same experimental method test period.

Second, it is noted that February 21st was a federal holiday, Presidents' Day, and therefore employees were not in the office as they would be on a typical Monday. Therefore, holidays were also omitted from the final data set and replaced with average performance from similar days of the week and hours of the day during the same experimental method test period.

Third, occupancy data could only be collected for the control system phase due to limitations in the submetering system. The reason for this limitation was due to the way that the control capability was configured and linked to the occupancy. For the purposes of this research, it was required to turn off the control mode, which is not the normal intention for this submetering and control system. The only way to disable the control mode was to disable the occupancy modules, which significantly limited the occupancy data desired for this research. As a result, average occupancy profiles were assembled for a typical week and applied to all experimental methods.

The final data set for each experimental method represented four full weeks (Monday-Sunday) of hourly data for typical operating conditions, omitting periods of lost data and schedule discrepancies such as holidays. This final data set was used for all analysis and the average occupancy profile was applied to each experimental method. Figure 7 shows the average energy and occupancy profiles for the baseline period for a typical week.

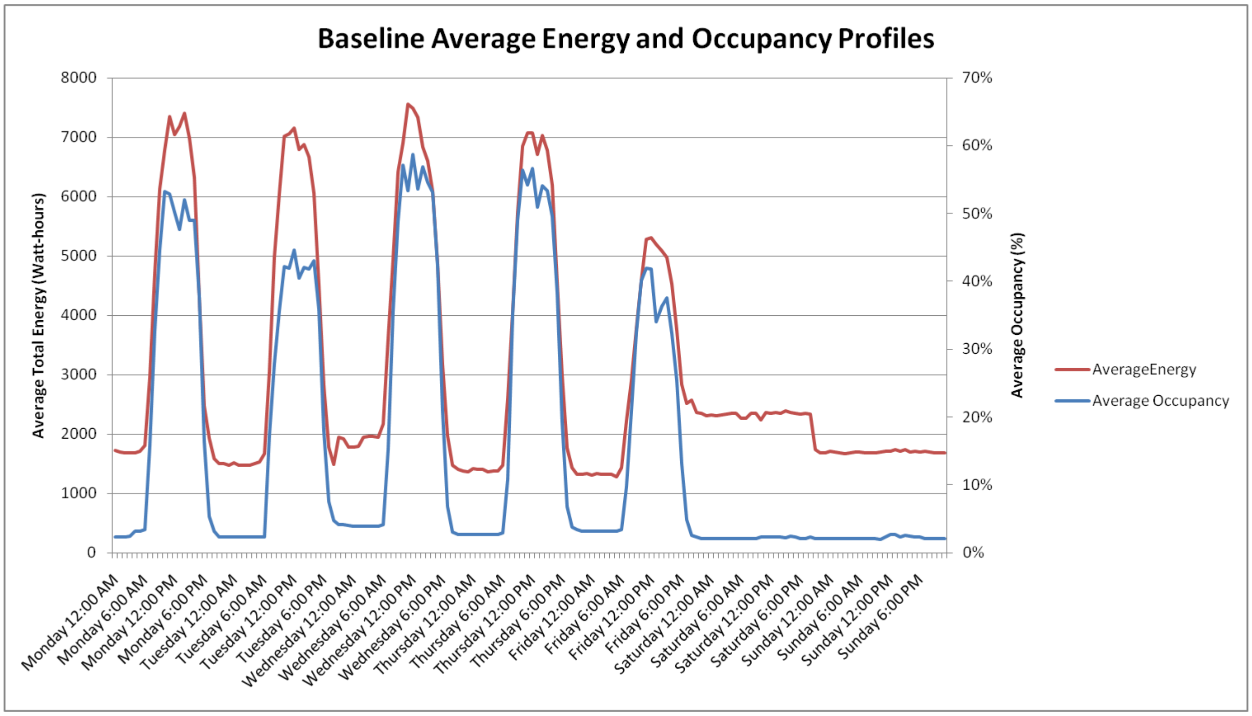

Figure 7: Baseline Period Average Energy and Occupancy Profiles

As expected, the energy and occupancy follow a similar trend. It is noted that some of the occupancy sensors were continually reading in active mode resulting in no times of 0% occupancy. It was observed that some of the occupants reacted negatively to the sensors and disabled, repositioned, or placed obstructions over them to give faulty readings continuously. During the baseline period, relatively high energy consumption was observed during unoccupied periods.

The results of the baseline showed a total consumption over the four week period for the 126 person test group of 2,090 kWh, which is 16.6 kWh/person. Normalized by day, the baseline showed a consumption of 0.6 kWh/person/day. When this number is extrapolated to all 775 occupants in the building it shows an annual consumption of 167,576 kWh/yr. This extrapolation shows that workstation plug loads only account for 4.2% of the total building electricity. This could be an indication that other plug load equipment accounts for a larger portion of the plug load consumption, or that other energy use systems in the building significantly outweigh the plug loads.

6.2.1 Submetered and ASHRAE Comparison

The baseline period was compared to the typical plug load assessment using estimated power ratings for equipment and ASHRAE-defined diversity factors and equipment schedules for modeling purposes. Figure 8 shows the comparison of the baseline period to the projected

ASHRAE energy and occupancy profiles, derived from the inventory of equipment and typical modeling assumptions.

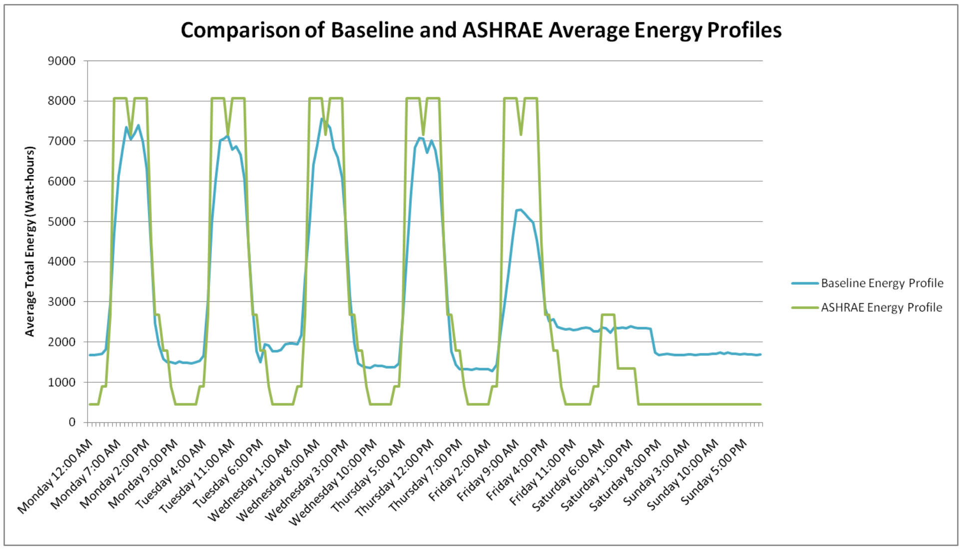

Figure 8: Comparison of Baseline and ASHRAE Average Energy Profiles

It is shown that the energy profile from the baseline period tracks very closely, within 10% of the projected energy profile using the equipment inventory data with ASHRAE diversity factors and equipment schedules. However, it is noted that the profile for a typical Friday significantly differs. This indicates the possibility of alternative work schedules or telecommuting, which would reduce the energy consumption of a typical Friday. Site staff indicated that at least 50% of the occupants participate in an alternative working schedule, which confirms the reduced occupancy levels on Fridays. Also, the baseline energy consumption during unoccupied periods, nights and weekends, is significantly higher than the projected energy use. This shows a good opportunity for energy savings during unoccupied times.

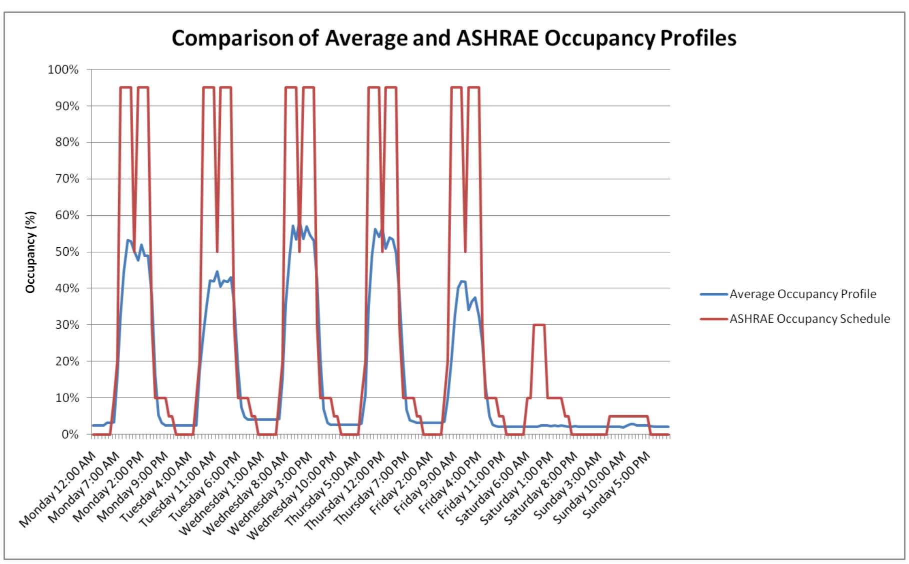

Figure 9: Comparison of Average and ASHRAE Average Occupancy Profiles

Figure 9 shows that the time intervals of typical occupancy match well between the average and the projected ASHRAE schedule; however, the magnitude of percent occupancy varies significantly. This shows that the ASHRAE occupancy schedule is not a good representation of the actual time that occupants spend at their workstations for this building. Also, this indicates the high likelihood of alternative work schedules and telecommuting policies, which are intended to reduce the occupancy in buildings. Another possibility is that the occupants working in the test group could be subjected to high travel rates causing them to work remotely for a high percentage of the time. ASHRAE occupancy schedules suggest a projected 95% occupancy rate in buildings, but this study and others indicate that occupancy levels at the workstations are significantly lower than the projected total building occupancy rate.[26]

6.3 Average Energy Profiles

This section compares the average energy profiles for each experimental method to the baseline and ASHRAE energy profiles. The following graphs clearly illustrate whether or not energy reductions were achieved and when those reductions occurred (occupied versus unoccupied).

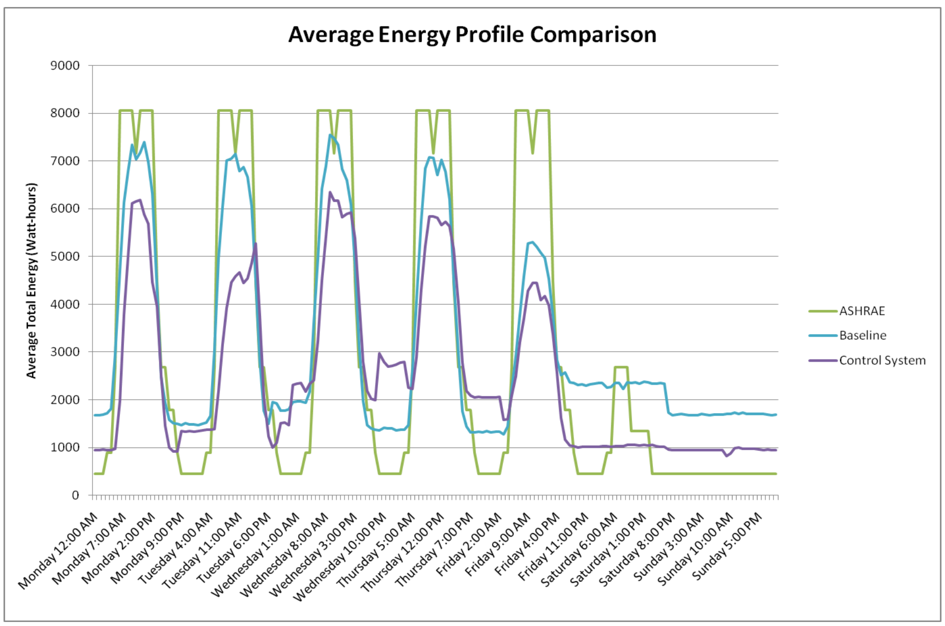

Figure 10: Average Energy Profile Comparison for Control System

The control system showed significant energy savings during the occupied periods. This is as expected considering the low percent occupancy illustrated in the occupancy profile. With a lower percent occupancy, the control system was able to turn off several circuits during the occupied period. Weekend unoccupied periods also showed a significant energy savings over the baseline. However, the control system had mixed results during week nights, which may be

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[26]Morrow, W, Rutledge, B. Maniccia, D., Rea, M. "High Performance Lighting Controls in Private Offices," World Workplace, Chicago, IL, Oct. 1998. http://www.starfieldcorp.com/pdf/publications/Field%20Study%20of%20Lighting%20Controls.pdf.

caused by after-hours staff (i.e., security staff walking between pods) triggering the occupancy sensors and causing circuits to cycle on and off.

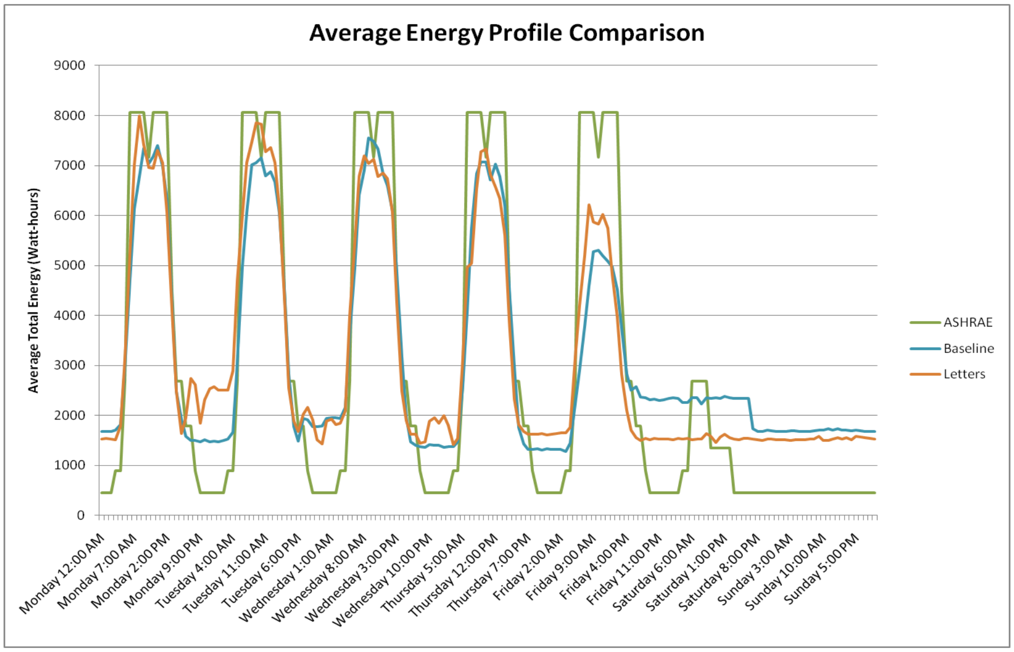


Figure 11: Average Energy Profile Comparison for Letters

The experimental method of sending plug load energy awareness letters to the occupants showed almost negligible energy savings and tracked very closely to the baseline period. Only very slight energy savings were observed during the weekend unoccupied periods.

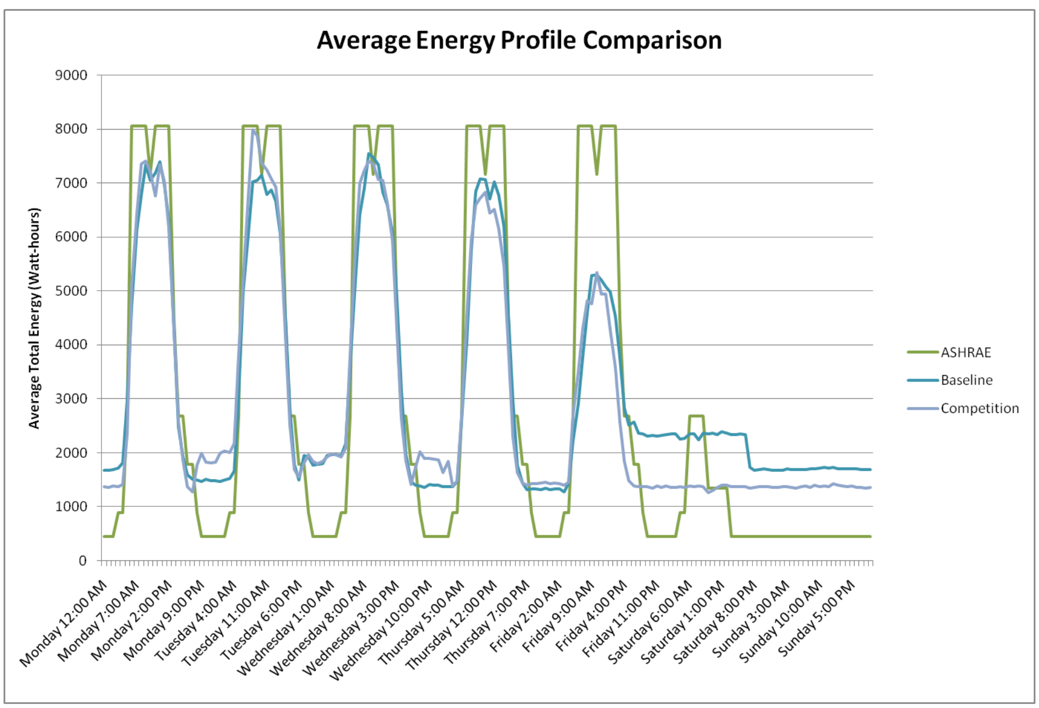


Figure 12: Average Energy Profile Comparison for Competition

The experimental method of encouraging competition between occupants showed almost negligible energy savings during the occupied periods and tracked very closely to the baseline period. However, moderate energy savings were observed during the weekend unoccupied periods.

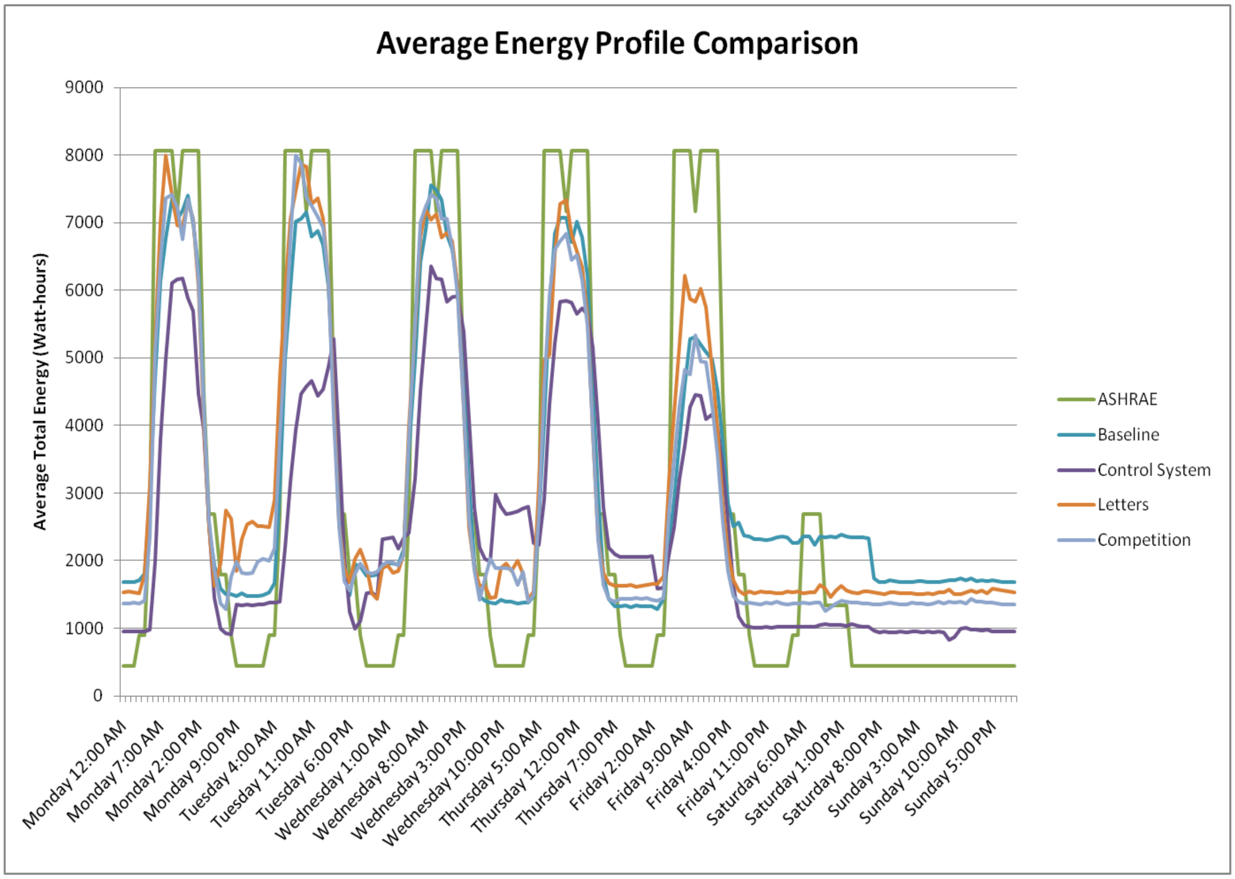


Figure 13: Average Energy Profile Comparison for All Experimental Methods

Figure 13 compares the average energy profiles of all experimental methods to the baseline and ASHRAE energy profiles. The control system performed the best out of the three methods and showed significant energy savings during the occupied periods and during the weekend unoccupied periods. Between the two behavioral change methods, the competition performed the best, especially during the weekend unoccupied periods. The results indicate that the behavior of occupants was influenced and most effective at reducing weekend energy consumption. The letters experimental method showed little to no effect on energy consumption.

Figure 14 shows the raw data for the four week periods and 126 person test group for the baseline and three experimental methods. Approximate savings can be seen, but also a large variability in data. This may be an indication that longer test periods were needed to obtain a larger more reliable data set.

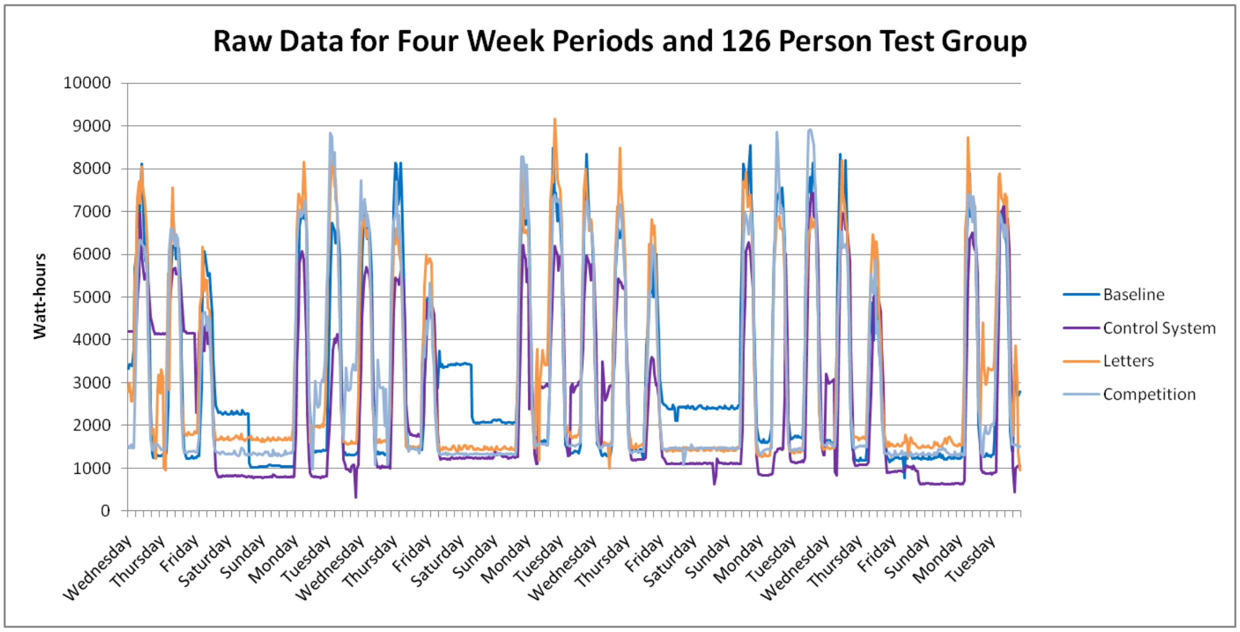


Figure 14: Raw Data for Four Week Periods and 126 Person Test Groups

6.4 Statistical Results

In this section, the data are analyzed for statistical significance. Summary statistics and the results from hypothesis testing are reported for each experimental method. Confidence levels at 95% are calculated and confidence intervals are given for the mean energy savings of the hourly difference from baseline. Terms used in this analysis are defined below.

Sample Size (N): The number of observations within a statistical sample. In this study, it is the number of hourly data points collected from the submetering system.

Mean Difference (M): The sum of the differences between one data set and another, divided by the number of values. In this study, it refers to the average hourly savings from an experimental method compared to the baseline.

Standard Error: The estimate of uncertainty around the mean. In this study, it represents the uncertainty of the mean difference, or "savings" for the hourly data.

Standard Deviation (SD): The measure of variability, diversity, or dispersion from the average in a data set. In this study, it shows the large spread of energy savings within each data set.

Confidence Level (95%): The boundary of reliability around a parameter. In this study, it represents the value that forms a reliability boundary around the mean difference.

Confidence Interval (C.I.): The estimate of a range used to indicate the reliability of a parameter. In this study, it is the range about the mean difference that has a 95% confidence level.

Null hypothesis: The default position that there is relationship or effect. In this study, it represents the assumption that an experimental method has no effect on energy savings.

T-statistic (t-stat): The ratio of the mean difference to the standard error, used in hypothesis testing. In this study, the higher the t-stat value, the more evidence there is to reject the null hypothesis, indicating that energy savings are statistically significant.

P-value: The probability of achieving a test statistic similar to the observation, assuming the null hypothesis. In this study, the lower the p-value, the stronger the evidence that energy savings are statistically significant.

Sum of Savings: The sum of energy savings, in kWh, throughout the test period for the entire test group. In this case it represents the savings from 672 hours of data and 126 cubicles in the test group, for each experimental method.

6.4.1 Totals

Table 4 summarizes the statistical results for the total test group and total test period. Data represent four weeks of hourly data collected for 126 cubicles for each experimental phase. All data are presented as a difference compared to the baseline period that is discussed above.

Table 4: Summarized Statistical Results for the Total Experimental Period

Experimental Phase	Sample Size	Mean Difference (Watt-hrs)	Std. Error	Std. Deviation	Confidence Level (95%)	t-stat	P(T<=t) two-tail	Sum of Savings for 126 Cubicles (kWh)
Control System	672	645.07	53.16	1378.18	+/- 104.39	12.13	9.03E-31	433.49
Letters	672	-7.56	37.33	967.73	+/- 73.30	-0.20	8.40E-01	-5.08
Competition	672	183.98	37.14	962.75	+/- 72.92	4.95	9.22E-07	123.63

A paired t-test was performed to determine if each experimental method was effective:

Control System

The mean energy reduction for the control system in Watt-hours (M=645.07, SD =1,378.18, N= 672) was significantly greater than zero, t(671)=12.13, two-tail p = 9.03E-31, providing strong evidence that this experimental method is effective at reducing plug load energy consumption at the workstation. A 95% C.I. about mean energy reduction is (540.68 Wh, 749.46 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

Letters for Behavioral Change

The mean energy reduction for the letters phase in Watt-hours (M=-7.56, SD =967.73, N= 672) was not greater than zero, t(671)=-0.20, two-tail p = 8.40E-01, providing evidence that this experimental method has little to no effect on reducing plug load energy consumption at the workstation. It is also noted that the standard error for this data set is greater than the mean savings, again showing evidence that this experimental method had little to no effect on reducing the energy consumption at the workstation. A 95% C.I. about mean energy reduction is (-80.86 Wh, 65.74 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

Competition for Behavioral Change

The mean energy reduction for the competition phase in Watt-hours (M=183.98, SD =962.75, N= 672) was greater than zero, t(671)=4.95, two-tail p = 9.22E-07, providing strong evidence that this experimental method is effective at reducing plug load energy consumption at the workstation. A 95% C.I. about mean energy reduction is (111.06 Wh, 256.90 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

6.4.2 Occupied Period

Table 5 summarizes the statistical results for the total test group only during the occupied period. Data represent four weeks of hourly data, only between the times of 7 a.m. and 7 p.m., collected for 126 cubicles for each experimental phase. All data are presented as a difference compared to the baseline period that is discussed above.

Table 5: Summarized Statistical Results for the Occupied Period

Experimental Phase	Sample Size	Mean Difference (Watt-hrs)	Std. Error	Std. Deviation	Confidence Level (95%)	t-stat	P(T<=t) two-tail	Sum of Savings for 126 Cubicles (kWh)
Control System	260	821.28	96.53	1556.57	190.09	8.51	1.44E-15	213.53
Letters	260	-51.76	60.45	974.72	119.04	-0.86	3.93E-01	-13.46
Competition	260	135.32	57.27	923.40	112.77	2.36	1.89E-02	35.18

A paired t-test was performed to determine if each experimental method was effective:

Control System

The mean energy reduction for the control system in Watt-hours (M=821.28, SD =1,556.57, N= 260) was significantly greater than zero, t(259)=8.51, two-tail p = 1.44E-15, providing strong evidence that this experimental method is effective at reducing plug load energy consumption at the workstation during the occupied period. A 95% C.I. about mean energy reduction is (631.18 Wh, 1,011.37 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

Letters for Behavioral Change

The mean energy reduction for the letters phase in Watt-hours (M=-51.76, SD =974.72, N= 260) was not greater than zero, t(259)=-0.86, two-tail p = 3.93E-01, <u>providing evidence that this experimental method has little to no effect on reducing plug load energy consumption at the workstation during the occupied period</u>. It is also noted that the standard error for this data set is greater than the mean savings, again showing evidence that this experimental method had little to no effect on reducing the energy consumption at the workstation during the occupied period. A 95% C.I. about mean energy reduction is (-170.80 Wh, 67.27 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

Competition for Behavioral Change

The mean energy reduction for the competition phase in Watt-hours (M=135.32, SD =923.40, N= 260) was greater than zero, t(259)=2.36, two-tail p = 1.89E-02, <u>providing moderate evidence that this experimental method is effective at reducing plug load energy consumption at the workstation during the occupied phase</u>. A 95% C.I. about mean energy reduction is (22.55 Wh, 248.09 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

6.4.3 Unoccupied Period

Table 6 summarizes the statistical results for the total test group only during the unoccupied period. Data represent four weeks of hourly data, only between the times of 7 p.m. and 7 a.m. and 24 hours on Saturday and Sunday, collected for 126 cubicles for each experimental phase. All data are presented as a difference compared to the baseline period that is discussed above.

Table 6: Summarized Statistical Results for the Unoccupied Period

Experimental Phase	Sample Size	Mean Difference (Watt-hrs)	Std. Error	Std. Deviation	Confidence Level (95%)	t-stat	P(T<=t) two-tail	Sum of Savings for 126 Cubicles (kWh)
Control System	412	533.87	61.18	1241.80	120.26	8.73	6.64E-17	219.95
Letters	412	20.34	47.46	963.43	93.30	0.43	6.69E-01	8.38
Competition	412	214.69	48.61	986.64	95.55	4.42	1.28E-05	88.45

A paired t-test was performed to determine if each experimental method was effective:

Control System

The mean energy reduction for the control system in Watt-hours (M=533.87, SD =1,241.80, N= 412) was significantly greater than zero, t(411)=8.73, two-tail p=6.64E-17, providing strong evidence that this experimental method is effective at reducing plug load energy consumption at the workstation during the unoccupied period. A 95% C.I. about mean energy reduction is (413.61 Wh, 654.13 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

Letters for Behavioral Change

The mean energy reduction for the letters phase in Watt-hours (M=20.34, SD=963.43, N= 412) was slightly greater than zero, t(411)=0.43, two-tail p=6.69E-01, providing evidence that this experimental method has little to no effect on reducing plug load energy consumption at the workstation during the unoccupied period. It is also noted that the standard error for this data set is greater than the mean savings, again showing evidence that this experimental method had little to no effect on reducing the energy consumption at the workstation during the unoccupied period. A 95% C.I. about mean energy reduction is (-72.97 Wh, 113.64 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

Competition for Behavioral Change

The mean energy reduction for the competition phase in Watt-hours (M=214.69, SD=986.64, N= 412) was significantly greater than zero, t(411)=4.42, two-tail p=1.28E-05, providing strong evidence that this experimental method is effective at reducing plug load energy consumption at the workstation during the unoccupied phase. A 95% C.I. about mean energy reduction is (119.13 Wh, 310.24 Wh). This range indicates the observed hourly energy savings for the 126 participants, with a 95% confidence level.

6.5 Energy and Cost Savings

Energy savings for each test period are extrapolated to estimate the annual energy savings in kWh. These savings are shown below for the total test period and broken out by occupied and unoccupied periods for each experimental method. The estimated annual savings were used to estimate the annual cost savings and simple payback period derived from the utility data discussed earlier in this report.

6.5.1 Energy Savings

The following graphs summarize the results for the total test group and total test period. Data represent the estimated annual energy savings extrapolated from four weeks of hourly data, and normalized into a per-person basis for each experimental phase.

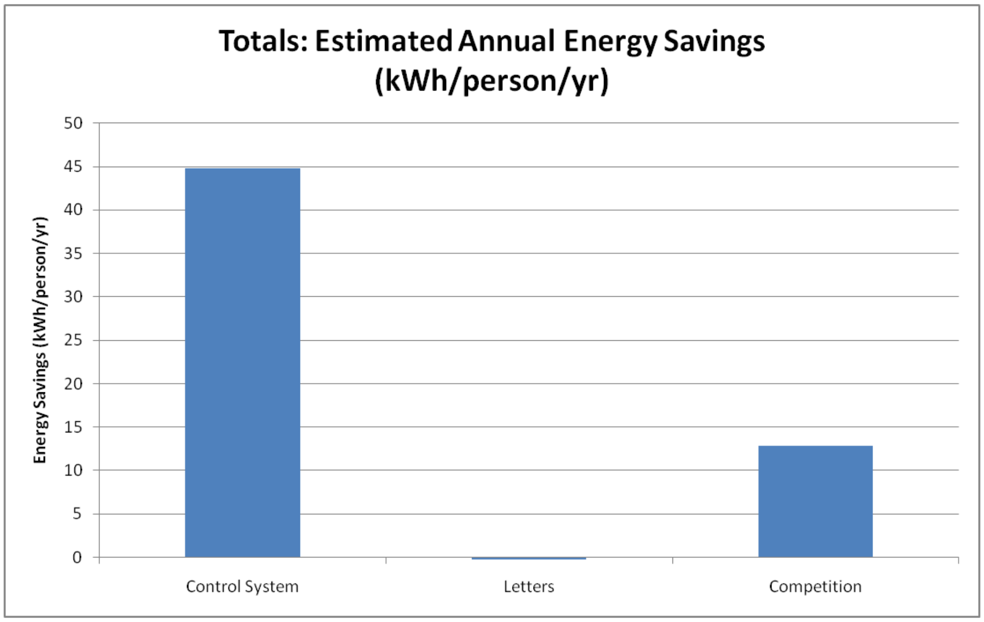


Figure 15: Estimated Total Annual Energy Savings per Person

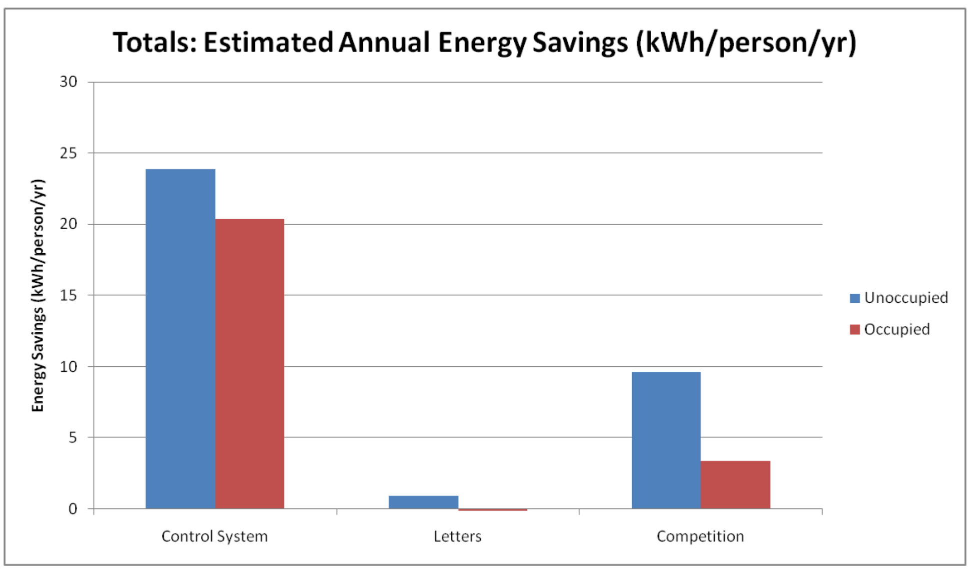


Figure 16: Estimated Total Annual Energy Savings per Person during Occupied and Unoccupied Periods

Figure 15 and Figure 16 show that the control system performs best, with an estimated 45 kWh per person annual energy savings. The competition phase had the second best results with approximately 13 kWh per person annual energy savings. The letters achieved little to no annual energy savings. Also, the figures show that the majority of savings occurred during unoccupied periods for all experimental methods.

Figure 17 shows the percent energy savings when compared to the baseline. Figure 18 shows the energy savings extrapolated to all occupants in the building, approximately 775, compared to the whole building electricity consumption. The total energy savings potential from the control system was calculated to be 34,757 kWh/yr, which represents a 0.9% reduction in the whole building electricity consumption (4,034,397 kWh/yr) and a 21% reduction from the baseline. The total energy savings from the letters method was negligible. The total energy savings potential from the competition method was calculated to be 9,913 kWh/yr, representing a 0.3% reduction in the whole building electricity consumption and a 6% reduction from the baseline.

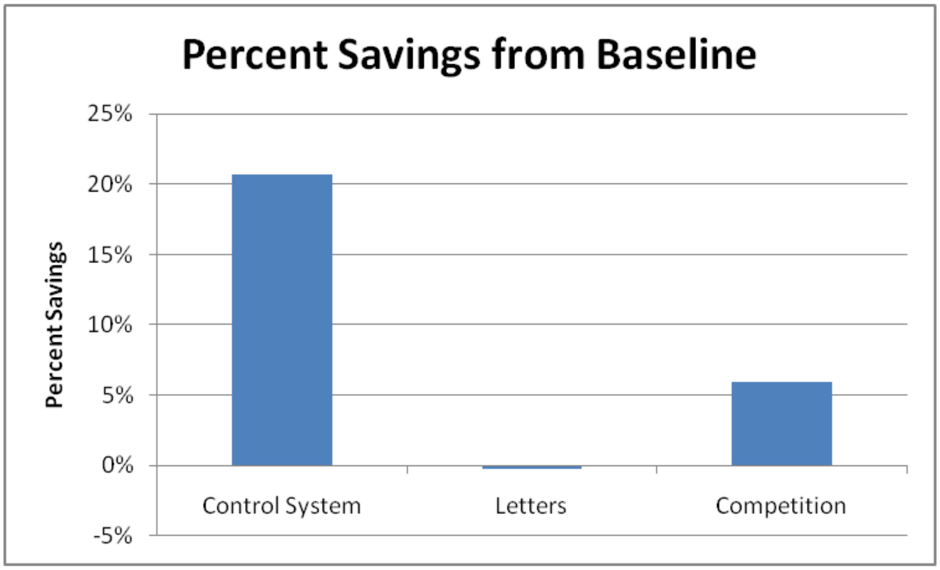


Figure 17: Percent Energy Savings from Baseline

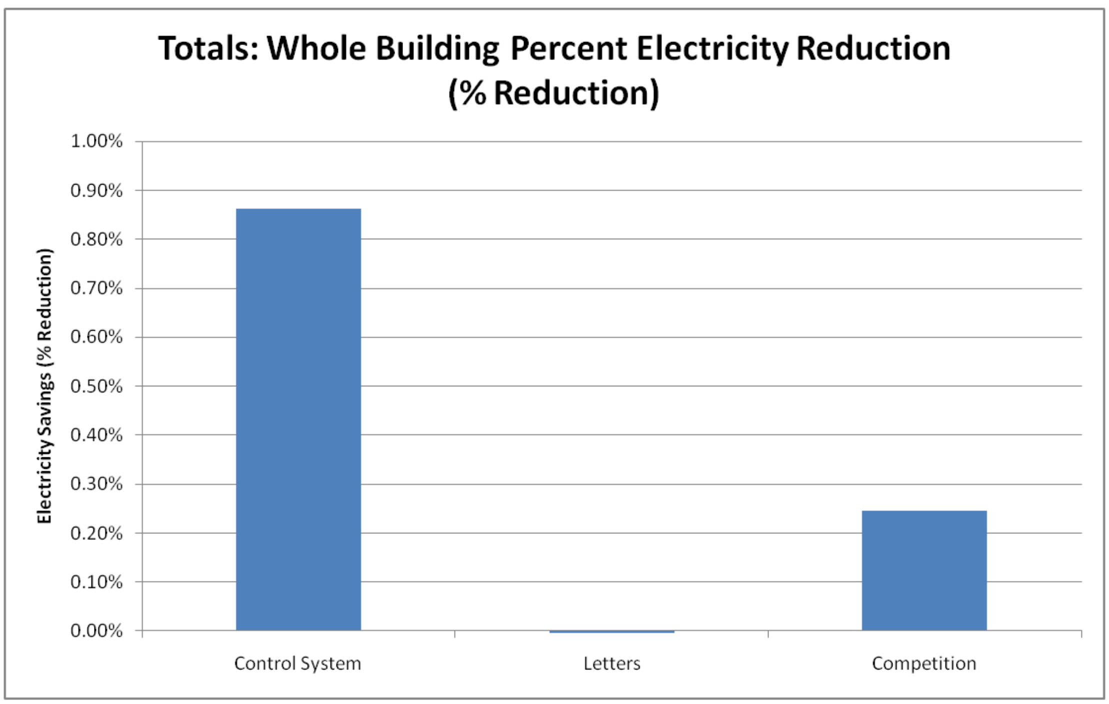


Figure 18: Whole Building Percent Energy Reduction Estimated for 775 Occupants

Figure 19 shows the mean hourly load reduction per person. It is important to note that these graphs present the load reduction as if it is constant throughout the hour. This is not a realistic assumption because the load can vary significantly during a one-hour timeframe. Therefore, these load reduction graphs cannot be taken as a constant demand reduction resulting from the different experimental methods.

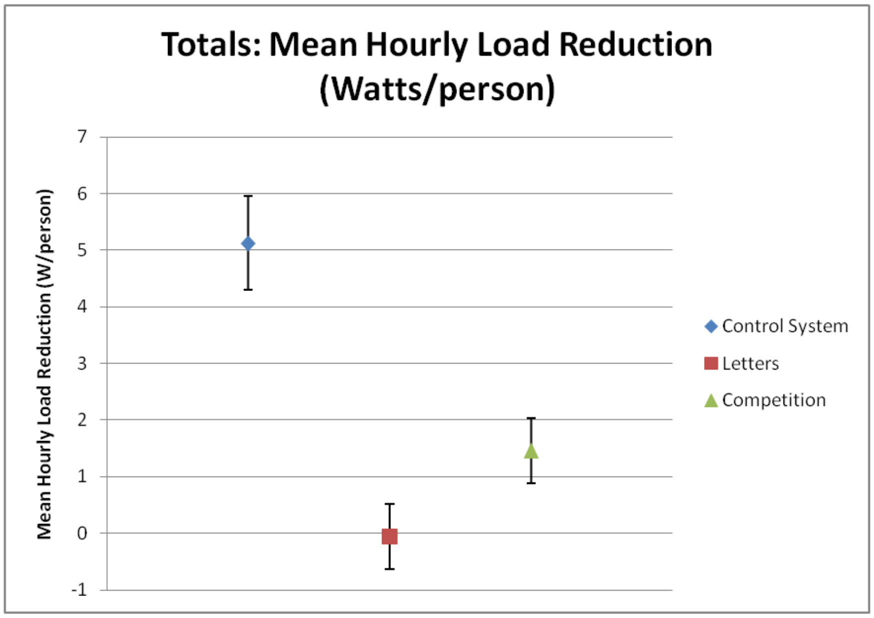


Figure 19: Total Mean Hourly Load Reduction

Figure 19 shows that the control system achieved a significantly higher hourly load reduction than the letters or competition. This indicates that the control system achieved greater watt reductions than occupant actions taken to reduce their workstation plug loads during the behavioral change experimental periods.

6.5.2 Cost Savings

Cost savings were estimated from the extrapolated estimated annual energy savings for all 775 occupants in the building. The average blended utility rate from the past four years is approximately \$0.10/kWh. CO_2e emissions factor for Colorado was assumed to be 1920.4 pounds per megawatt-hour (lb/MWh).[27] Table 7 summarizes the cost savings analysis for each experimental method.

Table 7: Cost Savings Analysis for Each Experimental Method

Experimental Method	Total Annual Energy Savings (Extrapolated for 775 People) (kWh/yr)	Percent Energy Reduction from Baseline	Percent of Whole Building Electricity Reduction (Extrapolated for 775 People)	Total Annual Cost Savings (\$/yr)	Total CO2e Savings (tons)
Control System	34,757	21%	0.9%	\$3,476	30
Letters	-407	0%	0.0%	\$-41	0
Competition	9,912	6%	0.3%	\$991	9

[27] eGRID, EPA: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. Accessed July 26, 2010.

The best case energy savings would most likely result from operating the control system and the competition phase simultaneously with significant promotion of occupant awareness. Alternatively, implementing a competition as a behavioral change mechanism without a control system may be the most cost effective. However, without the submetering system the savings could not be verified and normalized comparisons of occupant energy consumption would not be possible.

6.6 Occupant Feedback

Occupant feedback was recorded throughout this research project. Some feedback occurred during the letters phase which is shown in section 6.6.1.

During the competition phase, the online dashboard was monitored for how many people visited the website. The total number of visits was 374, which equates to an approximate average of three website visits per person. The majority of these visits occurred within a day immediately following the notifications.

In addition, occupants were asked to fill out an exit survey at the end of the research, and provide feedback and comments about the actions taken to reduce energy and their perception of the different experimental methods. Results of the exit survey are summarized in section 6.6.2.

6.6.1 Experimental Phase

Throughout the test period, occupants occasionally responded to the behavioral change methods, which provided some unique insight. During the letters phase, the facilities manager received two responses from occupants. Both comments were in response to Letter #2. Both of the occupant responses had somewhat negative connotations toward putting the computers into standby mode, because of the time to reboot. This shows a lack of awareness about the different modes of operation for the computer. In standby mode, the computer uses far less energy and maintains all active applications; there is no reboot time. Depending on security, login is typically required but the computer returns to active mode in a matter of seconds. In addition, these responses state that occupants do not have the administrative privileges to change the computer power settings. Therefore, to change the settings on the computer would require an IT policy change and probably support from upper management. However, there were no requests from occupants to support the change. The two occupant responses are shown below.

- “We (or maybe just myself) don't have the authority under the user rights to make those adjustments that you request. Unfortunately, there are times when I don't want it to go to standby (and take minutes to boot back up) because I am busy with something else. I'd love to make the change to reduce power but I am unable to comply.”

- “Since it appears that we are unable to change the times on the preset "power schemes", we essentially have to spend our work time restarting our computers and rebooting the programs we have been working on after 30 minutes of meetings, etc. Has there been a cost estimate done on the work time lost restarting/rebooting computers?”

6.6.2 Exit Survey

Occupants were asked to fill out exit surveys at the end of the research period, and provide feedback and comments about the actions taken to reduce energy and their perception of the different experimental methods. Completed exit surveys were received from only 16 occupants (12.7% of the total occupants). The exit survey questionnaire can be found in Appendix C. The results of the exit survey are summarized below.

- None of the respondents felt that this project was disruptive to their work at any point.
- When asked to describe what actions occupants took to reduce energy use at their workstation, the most frequent response (six responses) was that no action was taken. The next most frequent response (five responses) was that the respondent ensured that his or her computer and other energy-consuming devices were shut-down in the evenings. Not one respondent mentioned switching plug loads from a critical (always on) circuit to a circuit that is switched off based on whether the entire pod is unoccupied for a pre-set amount of time.
- The responses to the question of whether occupants reduced their energy consumption during the plug load experiment were:

Table 8: Response Rate to the Question "Did You Reduce Your Energy Consumption During the Experiment?"

Response	Number of Responses	Percent of Responses
Unsure	7	44%
Yes	5	31%
No	4	25%

  Respondents seemed confused regarding whether the data were normalized for weekends, holidays, vacations, and employees leaving or entering the pod. Not many respondents answered the second part of the question, which asked what method (information on energy use of devices or competition with colleagues) motivated them the most to save energy. One person said competition, one person said information regarding energy use devices, and two people stated that having access to energy usage data was motivating.
- Participants were asked if they reduced their plug load energy usage during this experiment, would they continue to do so in the future. The majority of responses (10) were yes, only one respondent indicated no, and five indicated 'N/A'.
- When asked if participants visited the energy monitoring website and what kind of information they found valuable, 75% of respondents (12) said they did visit the website, but only 56% (9) found the information useful or interesting.
- Occupants were asked to list the equipment they had plugged into the A or B outlets (non-critical and switched off based on occupancy) and in C or D (critical, always on outlets). The discrepancy in responses shows a need for occupant education.

Table 9: Response Rate to the Question "Which Equipment Was Plugged Into Non-critical and Critical Outlets?"[28]

Non-critical (A or B) Outlets		Critical (C or D) Outlets	
Equipment	Respondents	Equipment	Respondents
Computer	4	Computer	10
Light	6	Light	4
Other (phone, radio, coffee warmer)	2	Other (phone, radio, coffee warmer)	2
Nothing	1	Nothing	1
Did not respond	3	Did not respond	1

- Occupants were asked if they had any comments or suggestions for improving this study, which could result in greater energy savings. Most respondents (12 or 75%) said no or did not respond. These were the comments provided:
    - "Present the data on a cube by cube basis, rather than by pod."
    - "Compare actual energy usage for different computer models and upgrade those that are older or less efficient. Computers are the only thing most people have plugged in in their offices."
    - "Provide additional information on the energy use of devices. This may help users make conscious choices to reduce energy use. For instance, do computer accessories–like speakers or overhead workstation lights–use energy even when off? Or would it help to unplug computer monitors at night? Take better advantage of competitive aspects. Consider sending out messages indicating, by code, which pods or users reduced their energy use the most."
    - "Consider the energy use of the large, networked printers."

6.7 Prolonged Energy Savings: Post-Experiment Baseline

A second baseline period ran for four weeks following the experimental phase. The goal of this second baseline period was to evaluate the extent to which behavioral changes continue with no interaction or communication with the occupants. Therefore, no messaging or control was conducted during this baseline period; however, occupants could use the online dashboard system by visiting the Web page. Energy savings compared to the pre-experiment baseline are summarized below. These results showed that prolonged savings were achieved during the post-experiment baseline period. Savings were observed during occupied periods and weekend periods. These results indicate that behavioral change did have an effect on the overall operating practices of the test group. These savings, extrapolated to the entire building (775 occupants) for the entire year are estimated to achieve 15,669 kWh/yr, representing a 0.4% reduction in whole building electricity consumption and a 9% reduction from baseline. However, data collection for a longer period of time is required to confirm that these prolonged savings are permanent.

[28] Some respondents indicated that they had multiple items plugged into either the A/B outlets of the C/D outlets.

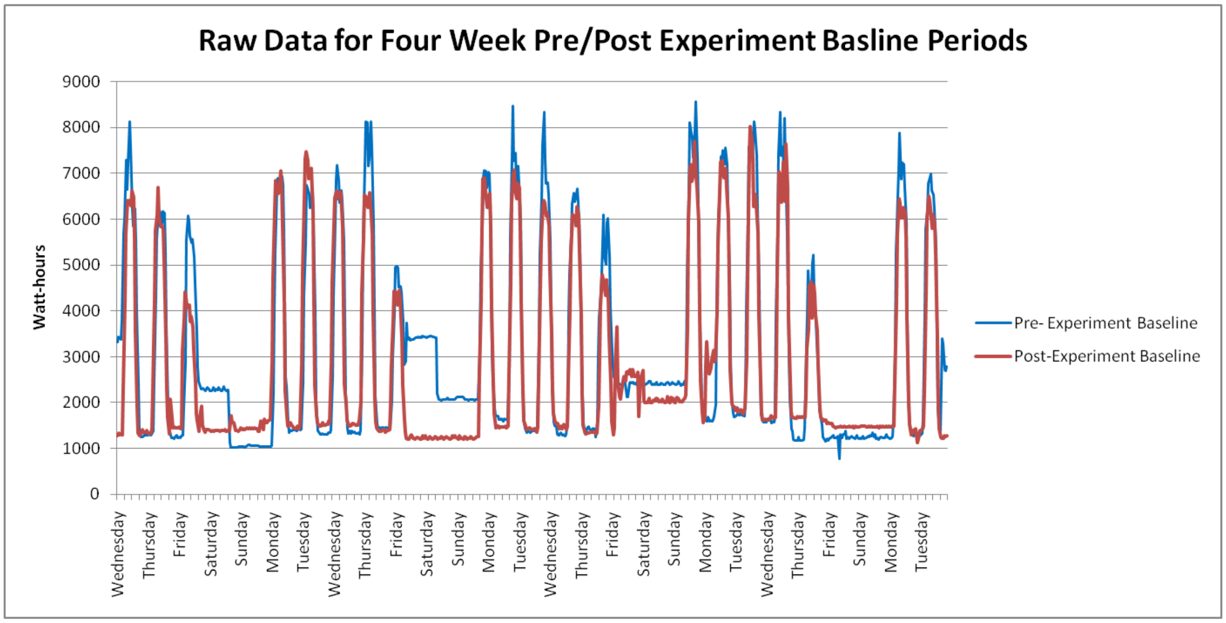


Figure 20: Raw Data for Four Week Pre- and Post-Experimental Baseline Periods

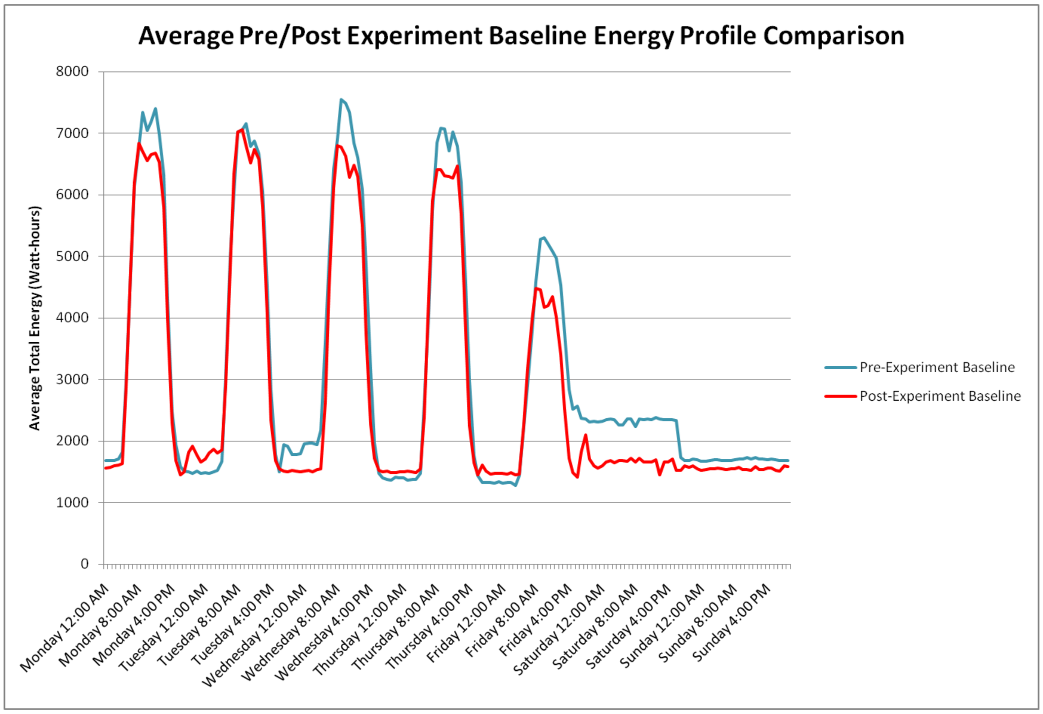


Figure 21: Average Energy Profiles for Pre- and Post-Experimental Baselines

7. Conclusion

This study found that the most effective method for reducing plug loads was through the control system, which turned off plug load devices after 15 minutes of no occupancy in a pod. The competition among pods was also effective at reducing plug load energy consumption, although less so than the control system. The letters sent to occupants educating them about plug load energy use and opportunities for conservation had negligible savings. Assuming that the submetering system was required to verify savings for each experimental method, none of the methods individually achieved a reasonable payback period. The best case scenario for energy savings would consist of a control system and occupant competition with significant promotion of occupant awareness. Alternatively, implementing a competition as a behavioral change mechanism without a control system may be the most cost effective. However, without the submetering system the savings could not be verified and normalized comparisons of occupant energy consumption would not be possible.

There were several uncontrolled factors in this research that introduced uncertainties into the analyzed data. Some of the assumptions made to account for the uncontrolled factors include:

- Employees occupying workstations remained constant during test periods
- Working hours and travel schedules align with the average profile. Occupancy data were only available for the control system experimental phase. Therefore, an average profile was created and applied to all test periods.
- Interaction with heating/cooling load was not considered
- Thermal comfort is uniform for all locations
- Seasonal changes have no effects on plug loads
- Time constraints required experimental test periods of four weeks, which was assumed sufficient for this study.

Lessons learned stemmed from all aspects of this project.

- Site support and occupant participation and interest are critical to the outcome of behavioral change research.
- Approval from the EPA Union required additional time and planning for all interactions with the occupants and required the research to comply with protocols that would ensure that occupant anonymity could be maintained. Anonymity is typically required for field research and should be included in dashboard interfaces for displaying data.
- Installation of the control and submetering system took longer and was more costly than expected. However, costs are expected to decrease significantly with scale and experience working in federal facilities.
- The wired installation of the control system and communications were very cumbersome and complex. Wireless communications and controls with "plug and play" installation

are expected to have less complexity, quoted at lower costs, and are currently commercially available.

- Cybersecurity created a hurdle for the dashboard and data storage of the submetering system.
- Several generalizing assumptions are required to account for all of the uncontrolled factors in behavioral change research.
- Occupant participation and willingness to take actions to reduce energy was met with some resistance
- The control system had significantly higher energy and cost savings compared to behavioral change methods. However, it is expected that incentivizing behavioral change could significantly improve occupant participation and energy reductions. Previous studies have indicated that the level of occupant involvement usually correlates with the incentive.[29] Incentives can be in many forms including money, prizes, food, public recognition, etc.
- Implementing behavioral change mechanisms without a control system would significantly improve the cost effectiveness. However, energy and cost savings could not be verified and normalized occupant energy comparisons could not be generated without a submetering system.
- Developing the appropriate plug load management process can have a significant influence on the success of energy reduction goals. This may include behavioral change mechanisms, controls systems, or other policies. Establishing a program champion, developing a business case, benchmarking, identifying occupant needs, equipment selection/replacement, controlling equipment schedules, institutionalizing reduction measures, and promoting occupant awareness can all be critical steps in the process.[30]
- Higher energy savings from plug loads may be accomplished by expanding the research beyond just workstations. This study focuses on the workstation and did not include equipment typically found in shared spaces such as large multifunction printers, refrigerators, microwaves, water-coolers, and other equipment.
- Prolonged energy savings were found to be significant during the occupied period and weekend periods. However, longer term monitoring is recommended to verify the estimated prolonged savings.

Next steps for additional research may include:

- Combining multiple methods to determine if even greater savings could be achieved
- Comparing the energy savings between non-incentivized and incentivized competition

[29] Birch, D., and Veroff, J. (1966). *Motivation: A Study of Action*. Belmont, CA: Brooks/Cole.
[30] Lobato, C., Sheppy, M., Bracknet, L., and Torcellinin, P. *MELs Management Selection Process and Lessons Learned*. NREL/TP-5500-51708, July 2011.

- Evaluating the results of institutionalizing reduction measures through information technology (IT) policy[31]
- Achieving occupancy-based control at the cubicle level rather than at the pod level
- Install and monitor a wireless monitoring and control system and compare to the current system.

[31] *Assessing and Reducing Plug and Process Loads in Office Buildings*. NREL/BR-5500-51199, June 2011.

8. Appendix

Appendix A: Letters to Occupants

Dear EPA Plug-Load Study Participants,

You are being notified based on your participation in the Wynkoop plug-load research study, currently being conducted. During the month of April, EPA's Infrastructure Representative (Craig Greenwell, Facilities Manager) will be sending out four (4) informational letters concerning energy consumption, conservation. These letters contain tidbits, additional 'facts' about energy, and conservation tips for energy awareness. We hope that the information provided will help you reduce the plug load energy usage in your workspace.

ENERGY Facts:

- Plug loads are any device plugging into wall outlets, as distributed throughout the building.
- Plug loads account for 9% of a building's total electrical usage on average, but can be as much as 28% depending upon the nature of the occupants work.
- Not only do plug loads use energy, but they can also increase cooling energy use and impact occupant comfort.
- The top five (5) highest energy consuming pieces of equipment in the average Wynkoop building workstation are:
    1) desktop computer towers (e.g. CPU's)
    2) desktop printers
    3) laptop computers
    4) under-cabinet task lighting
    5) computer monitors

- Other common workstation equipment that causes a large portion of energy usage is: 1) desktop fans, 2) task lighting, 3) computer speakers, 4) radio clocks, 5) plug-in calculators, and 6) various battery chargers.
- Plug load energy consumption in the Wynkoop building is estimated to contribute about **629 lbs of CO_2 equivalence/per person each year** to the environment.

For questions concerning this project, please contact Craig Greenwell @ 303-312-7087 or greenwell.craig@epa.gov.

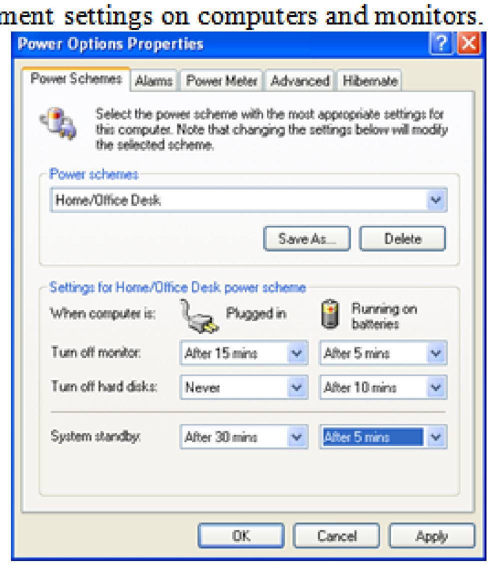
Dear EPA Plug-Load Study Participants,

You are being notified based on your participation in the Wynkoop plug-load research study, currently being conducted. During the month of April, EPA's Infrastructure Representative (Craig Greenwell, Facilities Manager) will be sending out four (4) informational letters concerning energy consumption, conservation. These letters contain tidbits, additional 'facts' about energy, and conservation tips for energy awareness. We hope that the information provided will help you reduce the plug load energy usage in your workspace. This message focuses on computers energy settings.

Facts:

- computers are typically the highest energy consumers in office workstations.
- computers have multiple energy saving settings to conserve during inactive periods.
- computers use significantly less energy in the "sleep" mode, compared to active/on mode.
- computers consume a small amount of energy even when they are turned off.

Energy Conservation Idea: Activate power management settings on computers and monitors.



- ✓ Enabling these settings will allow the computer and monitor to go into sleep mode (which consumes far less energy) after a period of inactivity.
- ✓ "Turn off monitor" = set to **15** minutes
- ✓ "System Standby" = set to **30** minutes
- ✓ "Hibernation"= set to **45** minutes

If your computer settings are different than required network settings, please contact the service desk at 303-312-6886.

For questions concerning this project, please contact Craig Greenwell @ 303-312-7087 or greenwell.craig@epa.gov.

Dear EPA staff,

You are being notified based on your participation in the Wynkoop plug-load research study, currently being conducted. During the month of April, EPA's Infrastructure Representative (Craig Greenwell, Facilities Manager) will be sending out four (4) informational letters concerning energy consumption, conservation. These letters contain tidbits, additional 'facts' about energy, and conservation tips for energy awareness. We hope that the information provided will help you reduce the plug load energy usage in your workspace. This message focuses on printers.

Facts:

- personal desktop printers can be one of the highest energy consumers of workstation equipment.
- personal printers can contribute to higher energy consumption, increased paper consumption, poor air quality, and additional waste from ink and cartridges.

Energy Conservation Idea: Remove all personal printers and use the networked printer option.

- ✓ Reduce energy consumption and loads during inactive periods
- ✓ Reduce additional waste streams
- ✓ Improve office air quality

For questions concerning this project, please contact Craig Greenwell @ 303-312-7087 or greenwell.craig@epa.gov.

Dear EPA staff,

You are being notified based on your participation in the Wynkoop plug-load research study, currently being conducted. During the month of April, EPA's Infrastructure Representative (Craig Greenwell, Facilities Manager) will be sending out four (4) informational letters concerning energy consumption, conservation. These letters contain tidbits, additional 'facts' about energy, and conservation tips for energy awareness. We hope that the information provided will help you reduce the plug load energy usage in your workspace. This message focuses on energy and occupancy.

Facts:

- Plug loads can consume significant energy even when spaces are unoccupied.
- Some equipment draws electricity even when it is turned off as shown in the table below:

Power consumed by different computer and monitor types

Computer Type	Processor Type	Active / On (Watts)	Sleep Mode (Watts)	Off (Watts)
Desktop w/ LCD monitor	Intel Core 2 Duo	76.2	6	3.5

Energy Conservation Ideas:

- ✓ Shut down equipment, unplug devices, and turn off power strips when leaving the office.
- ✓ Use CFL or LED lighting in task lamps.
    - Task lamps can reduce lighting energy if ambient lighting is turned to lower levels.
- ✓ Replace office equipment with Energy Star models.

For questions concerning this project, please contact Craig Greenwell @ 303-312-7087 or greenwell.craig@epa.gov.

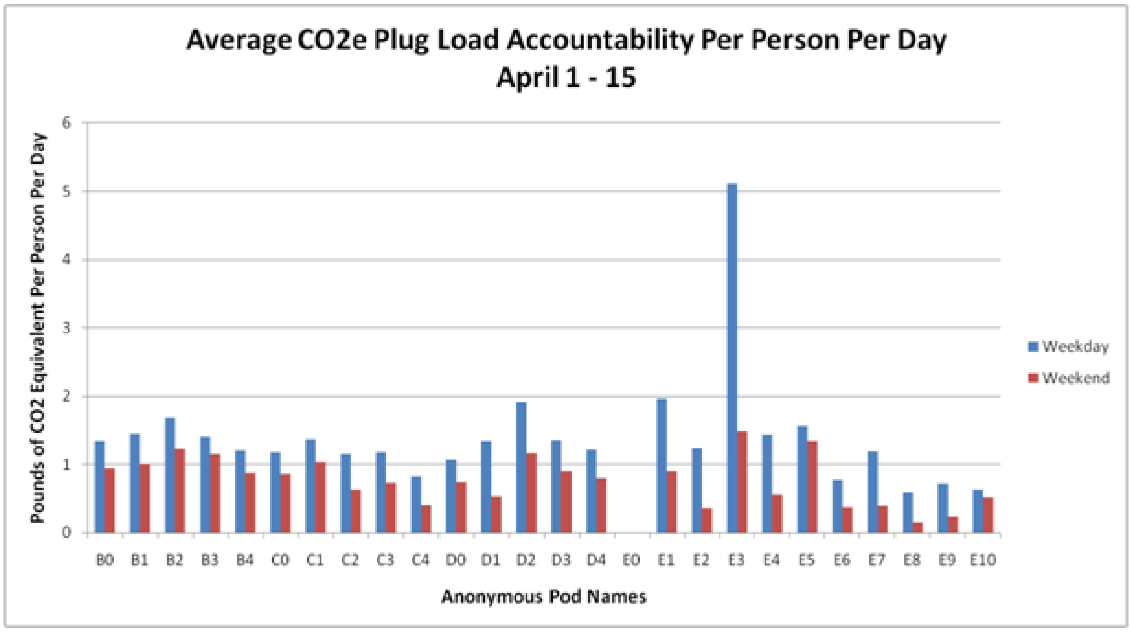
Appendix B: Competition Notifications to Occupants

Dear EPA Plug-Load Study Participants,

You are being notified based on your participation in the Wynkoop plug-load research study, currently being conducted. During the month of May, EPA's Infrastructure Representative (Craig Greenwell, Facilities Manager) will be sending out two (2) visual displays concerning cubicle POD consumption comparisons, i.e. the per person average usage is factored by dividing total POD consumption by the number of people in that POD. You are encouraged to actively participate in reducing your POD plug load energy consumption during the month of May. Follow-up data will be sent out two weeks from today revealing energy reduction progress.

Key Items to Consider:

- Whether your POD plug load consumption is higher than others, and if so what may be causing it,
- Whether your POD's plug load/energy consumption is high during weekend hours, and what may be causing that,
- Changes you can make to reduce plug load energy consumption (e.g. in reference to previous informational energy savings measures).



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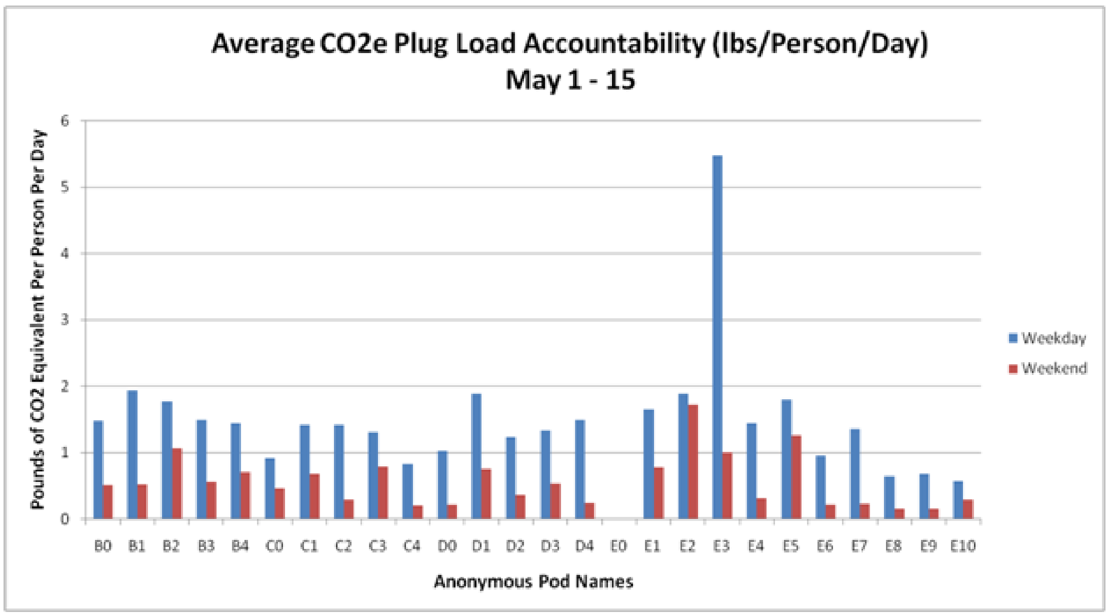
Key Items to Consider:

- Whether your POD plug load consumption is higher than others, and if so what may be causing it,
- Whether your POD's plug load/energy consumption is high during weekend hours, and what may be causing that,
- Changes you can make to reduce plug load energy consumption (e.g. in reference to previous informational energy savings measures).



For questions concerning this project, please contact Craig Greenwell @ 303-312-7087 or greenwell.craig@epa.gov.

Appendix C: Exit Survey

Dear EPA Plug-Load Study Participants,

You are being notified based on your participation in the Wynkoop plug-load research study. Now that the research has concluded we would ask you to participate in one final task. Below, we have put together an exit survey for you to provide feedback on the various aspects of the research. Please take the time to complete the survey and send you responses to Craig Greenwell greenwell.craig@epa.gov. Thank you for your participation and your time. Final results are being compiled and will be available in August.

Participant Exit Survey:

1. Please describe what actions you took to reduce energy at your workstation and why.

2. Did you reduce your energy consumption during the plug load experiment?? If so, what motivated you most – e.g., information on energy use of devices or competition with colleagues?

3. If you reduced your plug load energy use during the experiment, will you continue to do so in the future ?

4. Did you visit the energy monitoring website [redacted])? If so, what kind of information did you find valuable at the website?

5. At any point was this project disruptive to your work? If so, please explain.

6. Please list what equipment you have plugged into the following outlets:

Outlet A or B	Outlet C or D

7. Do you have any comments or suggestions for improving this study, which would result in greater energy savings?

For questions concerning this project, please contact Craig Greenwell @ 303-312-7087 or greenwell.craig@epa.gov.

Appendix D: Summary of Applicable Legislation

EPAct 2005 [32]

[§104] Federal agencies shall incorporate energy efficiency criteria consistent with ENERGY STAR and FEMP-designated products for all procurements involving energy-consuming products and services.

[§203] Renewable energy is not less than:

- 2.5% of total consumption during FY 2006,
- 3% of total consumption during FY 2007 - 2009,
- 5% of total consumption during FY 2010 - 2012, and
- 7.5% of total consumption during FY 2013 and thereafter.

Note: accounting of renewable energy can be doubled if on federal or Indian land and used at a federal facility.

EO 13423 [33]

[§2(a)] Reduction of energy intensity by 3% annually through the end of fiscal year 2015, or 30% by the end of fiscal year 2015, relative to a 2003 baseline.

[§2(b)] Ensure 50% of the required renewable energy consumed by the agency in a fiscal year comes from renewable sources on agency property.

[§2(h)] Enable the ENERGY STAR feature on agency computers and monitors.

EISA 2007 [34]

[§431] Reduce building energy intensity 3% annually through 2015, or 30% total reduction by 2015, relative to a 2003 baseline.

[§432] Energy and water evaluations must be completed every 4 years for covered facilities. Facility energy managers are also responsible for commissioning equipment and establishing operations and maintenance (O&M) plans for measuring, verifying, and reporting energy and water savings.

[§434] Ensure major replacement, renovation, or expansion projects employ the most energy-efficient designs, systems, equipment, and controls that are life-cycle cost effective.

[§524] Encourages agencies to minimize standby energy use in purchases of energy-using equipment.

[§525] Requires procurement to focus on ENERGY STAR and Federal Energy Management Program (FEMP)-designated products.

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[32] "Energy Policy Act of 2005," Federal Energy Management Program: http://www1.eere.energy.gov/femp/regulations/epact2005.html. Accessed July 26, 2011.

[33] "Executive Order 13423," Federal Energy Management Program: http://www1.eere.energy.gov/femp/regulations/eo13423.html. Accessed July 26, 2011.

[34] "Energy Independence & Security Act," Federal Energy Management Program: http://www1.eere.energy.gov/femp/regulations/eisa.html. Accessed July 26, 2011.

[§527] Each federal agency must issue an annual report that describes the status of initiatives to improve energy efficiency, reduce energy costs, and reduce GHG emissions.

EO 13514[35]

[§2-20] Greenhouse Gas Management: baseline, accounting, and reduction target reporting
"President Obama announced a Federal Government-wide target of a 28 percent reduction by 2020 in direct GHG emissions, such as those from fuels and building energy use, and a target 13 percent reduction by 2020 in indirect GHG emissions, such as those from employee commuting and landfill waste."
[§2(g)(iv)] Minimize consumption of energy, water, and materials through cost-effective, innovative strategies, such as highly reflective and vegetated roofs.
[§2(g)(v)] Manage existing buildings to reduce consumption of energy, water, and materials. Identify alternatives to renovation to reduce existing assets' deferred maintenance costs.
[§2(i)(ii)] Enable power management, duplex printing, and other energy-efficient or environmentally preferable features on all eligible Department of Energy (DOE) electronic products.
[§2(i)(iv)] Ensure procurement of ENERGY STAR and FEMP-designated electronic equipment.

Other Mandates[36]

[EPAct 1992 §152] Install in federal buildings owned by the United States all energy and water conservation measures with payback periods of less than 10 years.
[EPA Mandatory Greenhouse Gas Reporting Rule] Facilities emitting more than 25,000 metric tons of CO_2e per year must report their emissions annually.

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[35] "Executive Order 13514," Federal Energy Management Program: http://www1.eere.energy.gov/femp/regulations/eo13514.html. Accessed July 26, 2011.

[36] "Energy Management Requirements by Law and Regulation," Federal Energy Management Program: http://www1.eere.energy.gov/femp/regulations/requirements_by_reg.html. Accessed July 26, 2011.