Impacts of Office Plug Load Reduction Strategies

Quantifying plug load usage, the potential for reduction, and the impact on users

Conservation Applied Research & Development (CARD)
FINAL REPORT

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DISCLAIMER

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Executive Summary

Background and objective

Plug load energy used by everything from computers to water coolers represents a relatively untapped energy savings resource in commercial buildings. And these loads, defined as all electric end uses that are not HVAC, lighting, or DHW, are increasing (CBECS 2016). This is especially true in contrast to other end uses. There is a need for those in the commercial buildings industry to both identify and quantify strategies for reducing these loads.

Seventhwave, along with the Center for Energy and Environment and LHB have completed a field research study to demonstrate and measure the savings from potential plug load reduction strategies in office buildings. We also characterized the types of devices and baseline usage in those offices, and documented occupant acceptance, operational issues, and cost-effectiveness of reduction strategies.

We used what we learned to identify actions that utilities and policy makers could take, including increasing the impact of these strategies in Conservation Improvement Programs (CIPs) in Minnesota. We also put plug loads into context and established some best practices for building designers and operators.

Approach and initial measurement

Our research began by characterizing a few dozen offices in Minnesota. From there, a sample of eight buildings was chosen for further field data collection. Baseline data was collected in each of those offices. Next we implemented energy reduction strategies. We tested the following strategies, each separately:

1. Advanced power strip (APS) with an occupancy sensor
2. APS with a foot pedal (also includes timer)
3. Computer power management (CPM)
4. Behavior campaign including feedback, rewards, and information
5. Timers on common area equipment

After these strategies were implemented, we collected more data, and surveyed occupants to gauge their satisfaction.

In characterizing Minnesota offices, we counted both workstation and common area equipment. It was clear that offices have shifted away from using CRT monitors—we found none in the 34 offices characterized. Also, there is a shift toward laptop computers: 40% of workstations in these offices now use laptops in place of desktop computers.

For the eight offices that were monitored in detail, we found that the average workstation used 332 kWh per year. Slightly over half of that energy was generally consumed by the computer itself (whether laptop or desktop) and the remainder was consumed by monitors, electronics, and peripherals. The total workstation usage translates to 4.1 kBtu/ft^2. We put this in context in our *Plug loads and whole-building energy performance* analysis, which shows that modern high performance office buildings tend to have a *total building* plug load usage of between 5 - 15 kBtu/ft^2 (including kitchen equipment, etc.). This total makes up as much as 55% of the energy usage in some of these high performance buildings.

Common area equipment that we measured used a similar order of magnitude of energy as did each workstation, from 67 kWh per year for televisions to 352 kWh for medium-sized multi-function devices (MFDs), to 548 kWh for coffeemakers. One type of plug load that we did not measure was the server closet. A parallel study to ours was monitoring server usage in some of the same buildings and found that servers use energy on a similar order of magnitude to the workstations: in some buildings server usage was higher than workstation usage, in others it was less.

Energy savings

We implemented four plug load reduction strategies in workstations and directly measured the energy savings from each. The average energy savings is shown in Table 1.

Table 1. Summary of energy savings for each strategy.

	Energy savings			
Strategy	kWh per station	% (with 95% conf. int.)		**N**
APS/occupancy sensor	**67**	**21.7%**	± 14%	95
Computer power management	**106**	**29.1%**	± 18%	116
APS/foot pedal	**42**	**19.0%**	± 13%	74
APS/foot pedal + behavior campaign	**70**	**22.4%**	± 13%	48

Not every site received every strategy, so this table is not meant to provide direct comparison between them. Looking at the broader data set, some conclusions can be drawn:

- Computer power management saved the most at almost every site, saving an average of 106 kWh, or 29% of average workstation energy. Savings ranged from 10 to 41%.
- The two APS measures saved 42 and 67 kWh (19% and 22%, respectively). Savings depended heavily on equipment at each site, ranging from 5 to 28%.
- The behavior campaign was built on the APS with foot pedal; the APS was left in place for the duration of the campaign to enable users to save more energy by adjusting their behavior. Though it's not clear from Table 1 due to the different sites tested, comparing data from just the two sites where the behavior campaign was implemented shows an increase in energy savings of 50 kWh for adding the behavior campaign.
- When HVAC energy is included, the energy savings increases by approximately 3%.

We also tested reduction strategies on common area equipment. The plug load timers that we tested yielded about 100 kWh (per device) in savings for beverage equipment such as water coolers and coffeemakers. It yielded about 50 kWh in energy savings for workroom equipment like printers and medium-sized MFDs. Our measurements of coffeemaker usage also showed that the newer single serving coffeemakers used an average of 470 kWh per year less than standard pot coffeemakers. Finally, we identified devices that could likely be extraneous in some situations (like extra printers in offices) and detailed the energy savings from removing these.

Economics

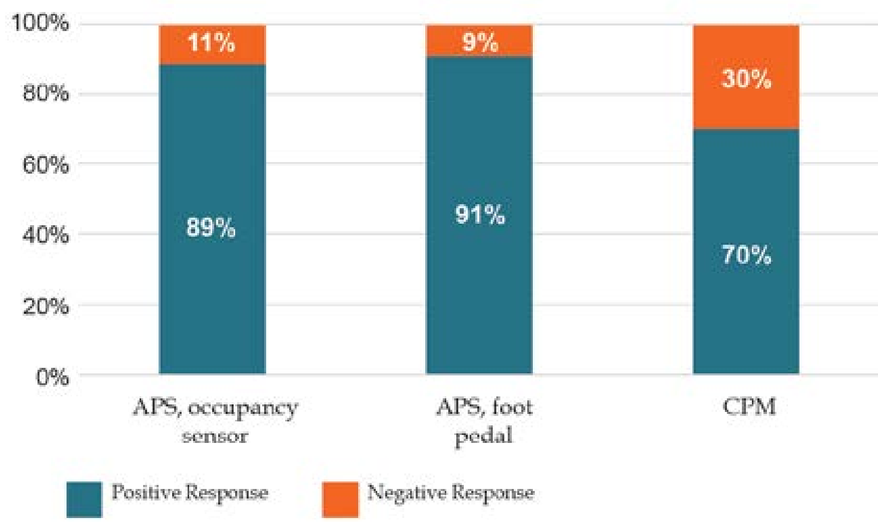
Implementing plug load reduction strategies has a cost, in this case anywhere from $17-55 per installation. We used life-cycle cost analysis to analyze the cost effectiveness of each strategy, using break-even cost as a key metric (the cost at which the installation makes financial sense). For a typical private organization, the break-even cost for CPM was found to be $143 per workstation, substantially higher than it likely would cost most firms. The break-even cost for timers on common area equipment was similarly higher than typical implementation, at $66-144 per instance depending on device. Simple payback for these measures was two to four years. (See Table 17 in the *Economics of plug load strategies* section for details.)

APS strategies were closer to marginal depending on the nature of their installation. Though they are likely cost effective in many situations, with a break-even cost close to $75. Simple payback for the APS strategy was about eight years. Assuming a typical utility incentive of $20 per device, the payback drops to five years.

Participant satisfaction

Our survey of research participants suggests that the APS with foot pedal is the most widely accepted of the strategies we tested. The occupancy sensor was noticeably less popular because its responses were not always transparent to users, and they could not control it as they could the foot pedal. The satisfaction with CPM varied widely from site to site, with an average of 70% responding positively (see Figure 1). The higher negative response rate and participant comments for this strategy suggest that some applications will call for slightly less aggressive settings than those we tested. Other sites were highly satisfied with the settings we implemented.

Figure 1. Workstation plug load strategy survey responses.



We found that each IT department's approach and opinion of CPM was a significant factor in its success. We had a mix of reactions from IT departments we worked with, from absolute refusal to implement CPM to offering help to maximize savings. Though several of the personnel we worked with expressed concerns and named some potential barriers, we were able to overcome all these barriers at most of the sites we worked with. We document specific strategies for overcoming these barriers in *IT integration of computer power management*.

Recommendations

Results from our study suggest the following recommendations for Minnesota's Conservation Improvement Programs (CIPs):

- Provide incentives and assistance to increase adoption of CPM, and provide technical support for those implementing it.
- Provide incentives and assistance to increase adoption of simple controls, especially APSs with appropriate user interaction, and simple device timers.
- Develop a strong relationship with IT departments to facilitate these offerings.
- Consider more innovative program approaches (beyond a basic incentive), such as direct install, behavioral, targeted outreach, and upstream offerings.
- Integrate simple plug load reduction strategies into more holistic programs like retrocommissioning, turnkey small business, and new construction programs.
- Include messaging for the user in all program offerings.

We also translated these lessons learned for office owners, operators, and designers. These stakeholders could benefit from working more closely with IT to improve CPM. They also need to understand that APSs are highly cost-effective in certain situations. Finally, when new or renovated offices are being designed teams need to spend more time understanding the magnitude of plug load energy, and integrating control solutions in appropriate places.

Introduction

Plug load energy used by everything from computers to water coolers represents a relatively untapped energy savings resource in commercial buildings. And these loads, defined as all electric end uses that are not HVAC, lighting, or DHW, are increasing (CBECS 2016). This is especially evident in contrast to the decrease in other more regulated end uses such as heating, ventilation, air conditioning (HVAC) and lighting. In Minnesota, the average plug load energy use in office buildings was about 2% (or 2 kBtu/ft^2/year) in the 1970s and has grown to 15-25% in an average building today.

Plug load energy use is most critical in building projects that are striving for a much lower energy use intensity (EUI), based on targets such as LEED or Architecture 2030. These buildings are often being designed to attain building EUIs of below 40. With rising plug loads, it can mean up to 50% of that target EUI is consumed by plug load devices. In other words, plug load usage is making it increasingly difficult to meet energy performance goals for the built environment.

As a result, there is a need for those working with buildings to both identify and quantify specific strategies for reducing these loads. Currently, owners and their design and construction teams are simply not aware of such strategies. A study of building projects in Minnesota that used extensive energy modeling during design noted that engineers and modelers assumed plug loads were a constant throughout all building design iterations, and seldom considered or even listed plug load reduction strategies (Carter 2011). Similarly, there is a need to prioritize the strategies based on their potential to help achieve utility program goals, which are increasingly constrained to regulated loads.

In this study we have evaluated plug load energy usage in office buildings in Minnesota in order to determine the extent of the problem, and have also tested solutions to the problem. While other studies have focused on one or two new plug load reduction widgets, often within a single commercial building, we have conducted a much broader, multi-level field experiment that studies the magnitude of these loads in typical commercial buildings. The primary value of the data we have collected is in its breadth: we have monitored over 1000 devices across eight diverse office types.

Objective

The primary objective of the study was to demonstrate and measure the savings from potential plug load reduction strategies and technologies in commercial buildings. But there were broader objectives as well. These included:

- Characterizing the electricity consumption and type of plug load devices in Minnesota offices
- Identifying key savings strategies for plug load reduction in such buildings
- Testing some of those energy reduction strategies in a sample of buildings, and measuring energy impacts
- Documenting occupant acceptance, operational issues, and cost-effectiveness of the installed strategies

- Understanding plug load energy usage in the broader context of building design and operation (as compared to other end uses, total building energy, and other design and code considerations)
- Identifying actions that utilities and policy makers could take based on the results of the study including inclusion of these strategies in Conservation Improvement Programs (CIPs) in Minnesota

In this study we not only measured usage, but also tested energy and cost savings from five different strategies including two general types of power strips, timers, computer power management, and a multi-faceted behavior change campaign. This latter strategy demonstrates that the human element of plug load technology must be addressed for optimal savings. In this report we present the approach and results of our broad field study and subsequent analysis, as well as qualitative lessons learned from the occupant and operational observations. The report closes with some conclusions pertaining to utility CIPs as well as building owners and operators.

Literature Review

The study of plug load energy use in commercial office buildings has only been significant in the recent past. One study (Dirks 2012) developed several theories as to why plug loads have not been at the forefront of building research. Plug loads were found to be an undefined problem with few clearly identified solutions, and therefore less likely to get research funding. The high cost of metering plug loads was also identified, especially compared to the possible savings. The study concluded that better understanding of plug load usage was needed and justified in order to appropriately allocate resources. Despite these barriers, plug load research has increased in recent years, and we were able to conduct a literature review of about 30 separate studies.

One of the earliest comprehensive field studies (Sanchez 2007) audited 16 U.S. office buildings and documented all miscellaneous and office equipment end uses. The number of units were counted, energy usage was estimated, and "turn-off rates" were determined. The study also calculated the plug load use as a percentage of total building energy usage and found ranges of 11-19%. This did not correlate well with other recent estimates that nearly 50% of total office building electricity was consumed by these end uses, leading to the conclusion that the method of modeling plug loads needed to be examined in more detail and that bottom up determination of plug load energy usage has limitations.

Two studies focused on the design of field metering studies such as ours. In one (Lanzisera 2013), researchers attempted to determine the breadth of a field study required to obtain quality data. Based on one building over an 18-month period, their conclusion was that inventorying 50% of the area for devices, and metering 10-20% of key devices over a two-month time period at one minute intervals would generate the most representative data. The second study (Brown 2010), tested metering methodologies at four national labs and ten buildings. Multiple meters were tested and one was even developed within the lab for this project. The primary outcome of this study is a series of recommendations suggesting further development of data collection methodologies, continued and expanded data collection, improvements in metering technology and utilization of the collected data. Both of these studies informed our experimental method for this study.

The National Renewable Energy Lab (Lobato, 2011) calculated and documented the estimated energy savings from a large number of different plug load reduction strategies employed in designing and building its new office building. They demonstrated specific, large potential for reducing plug load energy in every area of the new building including workstations, conference rooms, break rooms, work rooms, server closets, the lobby, the data center, and more. The broad quantitative results are based on measurement of baseline plug load usage, with modeled savings against this baseline.

One of the first studies to investigate reduction strategies (Moorefield 2011, Mercier 2011) involved installation of plug load meters to collect detailed (one-minute interval) data as well as total building energy use in 47 office buildings. The results showed that about 20% of the total electricity use was attributed to plug loads and that 66% of that was used for computers and monitors. The study also defined five power states for these devices: disconnected, standby, sleep, idle and active. The research concluded that understanding the differences between these states is important in understanding the problems and possible solutions of plug load power usage. This same study continued on to measure energy savings from a few reduction strategies, including software (power management), hardware (advanced power strips, timers and more efficient equipment) and occupant behavior (education and awareness). A new behavioral strategy tested in this study was an energy use feedback monitor. Providing real-time feedback to the user with this device reduced the electricity use by 51% per workstation. These low and no-cost measures were tested on 39 of the 100 devices. Overall, plug load energy use went down by 17% in one building (a library) and 46% in the other (a small office).

More recent research has tested more strategies for saving energy. One study (Metzger 2012) evaluated load sensing controls and scheduled timers in eight Federal office buildings and compared the savings differences between the two methods. The schedule timer controls resulted in the greatest reduction in energy use, ranging from 43-52% savings. Load sensing controls resulted in savings from 10-23%. One of the biggest drivers in the effectiveness of the controls was the type of equipment being controlled. User education also proved to be important. The term advanced power strips (APS) appears in this study for one of the first times in peer reviewed research. This research specifically called out occupancy controls, low-power start, and manual-on / vacancy-off strategies as deserving additional study.

Acker (2012) conducted another study that considered savings from APSs. In this study two different types of APSs, occupancy sensing and load sensing, were installed in separate spaces throughout five different office buildings. This study also involved a behavioral intervention comprised of education and reminder messages as well as installation of ENERGY STAR equipment. The researchers found that the load sensor plug strips saved nearly twice the amount of energy as the occupancy sensors. In addition, savings of about 5% were seen due to behavioral changes and the ENERGY STAR equipment installations saved close to 15%.

One of the first studies to focus primarily on behavioral impacts on plug loads was conducted in the Environmental Protection Agency's Region 8 Headquarters building (Metzger 2011). This study evaluated three methods for reducing miscellaneous energy consumption like plug loads: an automated energy management system that turns equipment off when the workstation is unoccupied for some period of time, an attempt to change behavior through communication, and a competition among occupants. The conclusion was that the automated system, which turned off workstation plug strips after being unoccupied for 15 minutes, worked better than the behavior-based approaches. This method created savings of about 20%. The competition method of behavioral change ranked second at about 6% savings, and the communication strategy yielded negligible results. The study also concluded that mixes of strategies would be useful to test. Subsequent behavioral impact studies include those by Kamilaris (2015), Murtagh (2013), and Carrico (2011).

Software and computer power management (CPM) measures have also been studied, though with less directly-measured energy savings results. In addition to Moorefield's (2011) study discussed above, Agarwal (2010) tested one specific CPM software and showed significant savings to the workstation computers. A study of many of the offices at UC-Irvine (Pixley 2014) surveyed the different operating modes that computers are found in at different times of day in a typical campus-environment. Martin (2014) studied the power management not in computers but in multifunction devices (MFDs) and found significant savings in those devices as well, from implementing ideal power management settings.

Our study takes the research further by involving a variety of office types in Minnesota buildings and studying multiple strategies in combination. In addition, our study is conducted primarily at the workstation level, measuring energy usage and savings of the entire workstation, as well as satisfaction of each workstation occupant with plug load control. Our study also builds on behavioral impact studies by combining behavior with enabling technology.

Research Method

The research design for this project involved:

- characterizing 34 offices in Minnesota,
- collecting baseline data from a sample of these offices,
- implementing plug load reduction strategies in those offices,
- measuring energy reduction resulting from plug load reduction strategies and surveying occupants on their experience and satisfaction with those strategies

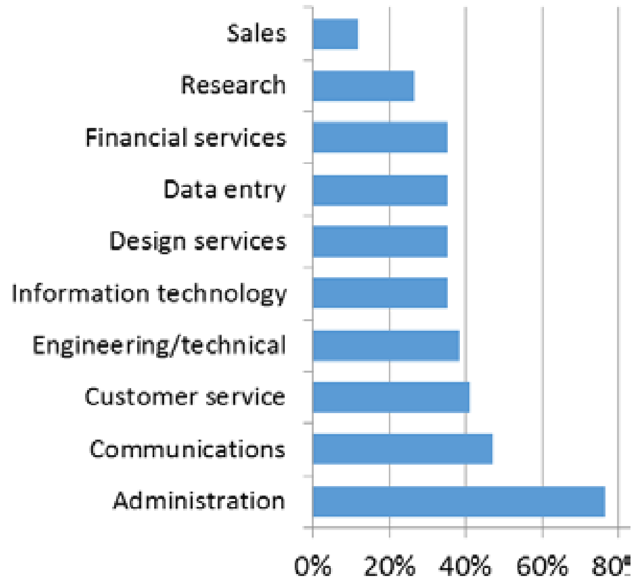
Characterization Survey

We developed a 76-question survey instrument designed to collect information on business type, hours of operation, type of work spaces, and types of plug load devices. It also asked respondents to comprehensively inventory typical workstations at their office. The survey itself was based on methods and taxonomies of plug load surveys previously developed (including those by Seventhwave; Bensch, 2010). The survey instrument is provided in *Appendix A: Characterization survey instrument*.

We contacted several dozen potential project participants through our existing business networks and asked them to complete the online characterization survey (guiding them through it at times). Self-reported results were received from occupants of 34 offices. In all, these offices included 3.2 million square feet of space with over 18,000 occupants. The results of the survey were used as a first level screening of sites to approach for testing plug load reduction strategies. Though we were not able to distribute it to a statistically representative sample, the responses also gave us a better understanding of Minnesota offices, and helped determine the distribution of different offices types of plug loads across typical offices in Minnesota.

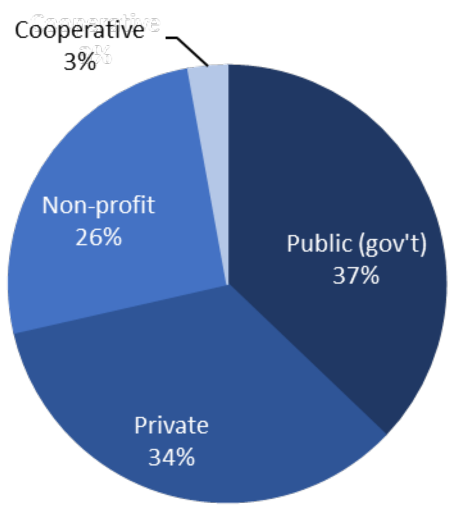
The buildings surveyed include commercial, educational and government facilities, each housing a wide variety of office activities as shown in Figure 2. Most offices included more than one activity, some as many as ten. Only five of the surveyed offices (15%) were dedicated to a single activity. This diversity of uses helped ensure that our building sample represented a wide range of office types.

Figure 2. Office types surveyed.



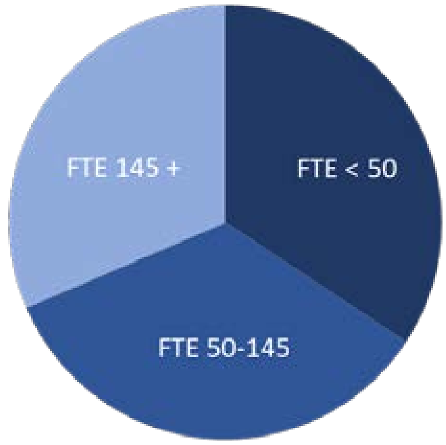
Survey respondents included both owners (22) and tenants (12). They also identified their organizations as public, private, nonprofit, or cooperative organizations. Figure 3 shows the number of each type of organization represented. Because we recruited survey participants through our business networks, these organizations skew slightly toward public and non-profit entities.

Figure 3. Sites characterized by organization type.



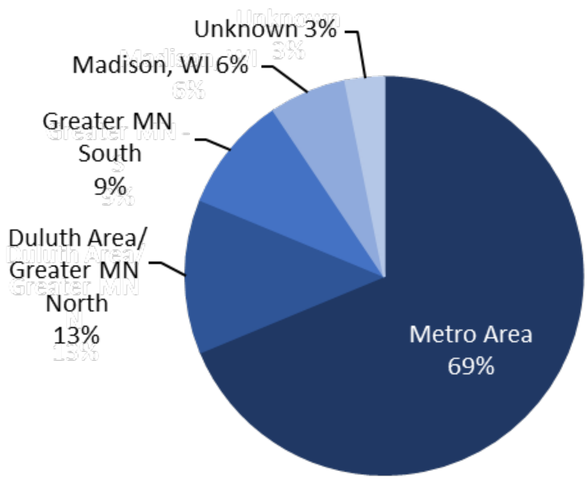
We wanted diversity in organizational size as well as type. Figure 4 shows the number of full-time equivalent employees (FTE) in each office.

Figure 4. Sites sorted by full time employee (FTE) ranges.



The majority of the buildings surveyed were located in the Minneapolis-St. Paul Statistical Area (i.e. the Twin Cities), which is reflective of the distribution of the state population. Figure 5 shows the location of sites that participated in the survey. A few sites from Wisconsin participated as well.

Figure 5. Sites sorted by location.



Sites for further study

A subset of eight buildings was selected for on-site measurement from the characterization survey respondents. The criteria for field study selection were that the office must have more than 40 workstations (for statistically significant results) and be willing to participate. Because there is a large diversity in office types there was no ability to make the sample statistically representative of Minnesota offices; there is therefore selection bias in our subset of buildings for the field study. We did attempt to make the sample diverse; it included all types of offices: public and private, owned and leased, small and large, standalone and connected to other building types (e.g. labs, service buildings, etc.). All field study sites were in the Twin Cities Metropolitan area of Minnesota, though in different communities within that area. The eight office spaces we chose for deeper study are described in Table 2.

Table 2. Characterization of the eight office spaces chosen for in-depth study and full measurement.

Location	Name (used in report)	Conditioned area (ft^2)	Space ownership	How organization pays for utilities	Occupants	Organization type	Activity / program of the space studied
Site A	Architecture	16,350	leased	metered	60	Private	Architecture and engineering
Site B	City public works	236,176	owned	metered	145	Public	Public works department of a city government
Site C	Real estate	7,789	owned	% of building	29	Private	Commercial real estate and property management
Site D	Prod. develop.	290,000	owned	metered	1,250	Private	Product development
Site E	Engineering	78,000	leased	part of rent	265	Private	Engineering department in architecture firm
Site F	County office	198,739	owned	metered	660	Public	County services
Site G	City office	78,000	owned	part of rent	340	Public	Public service in city government
Site H	Energy non-profit	16,700	leased	% of building	70	Non-profit	Energy consulting and research

Data Collection

We collected data on energy use at the eight building sites both before and after implementing the plug load reduction strategies. We also collected qualitative feedback on occupant satisfaction.

Site inventory and measurement

On-site data collection included inventory, baseline usage, and testing of energy reduction strategies, in progressive measurement periods. To facilitate these periods, participating sites were visited a minimum of four times over the course of the study (many had more than four in order to test more than one reduction strategy). Each visit had a different purpose:

1. In the first visit we discussed an overview of the project with our contact, toured the space, and planned for the remaining visits.

2. In the second visit we installed monitoring equipment and collected device inventories.
3. In the third visit we checked on our monitoring equipment and data, and then installed an energy reduction strategy to test. At several sites this visit was repeated with a fourth or even fifth visit, to test additional reduction strategies.
4. In the final visit we downloaded data and removed all of the equipment, concluding data collection at that site.

Five strategies (see *Plug* load reduction strategies in more detail below) were tested in the study: two types of advanced power strip (APS), computer power management (CPM), a behavior campaign, and a timer for common area equipment. Each strategy was applied at two or more sites. Each strategy was independently applied (i.e. no overlap in time and space). We implemented each strategy and its corresponding equipment as closely as possible to how we felt an owner or contractor would implement it in an existing office as part of an energy efficiency program.

The pre-strategy measurement that is described in *Analysis* below refers to measurements taken between the second and third visits, and the post-strategy measurement describes measurements taken between the third and fourth visits. These pre- and post-treatment measurement periods were all approximately one month. This was based on previous research in which measurement periods of at least four weeks were shown to reasonably reduce variability (Lanzisera 2013).

We targeted a total of about 40 workstations to study at each site. This represented a balance between budget and estimated statistical significance. A control group of approximately one-third of the monitored workstations at each site allowed for correction of seasonal and other temporal variation, or other unknown factors affecting the pre-versus post-treatment comparison. This control group did not receive any reduction strategy. Assignment to treatment group versus control group (versus exclusion from the study) was randomized. The desired sample size of 27 strategies and 13 controls at each office was independent of the total number of subjects available.

The first visit was done during normal business hours to understand operation of the office but all subsequent visits were done outside of the normal office hours to minimize the disruption of any individual's work activities and to mitigate our influence on the office occupants. Occupants were informed of our work in enough detail that their daily routine would not be adversely affected.

First visit: overview and planning

At the initial visit to each site we explained the project in greater detail, identified and confirmed a key contact person, and chose the specific areas to be included in the field study. A device inventory was also taken. The inventory included a comprehensive listing of the plugged-in devices in the common areas, as well as a count and cursory listing of devices at the workstations (noting, for example how many different configurations of computer equipment were present). The workstation inventory was also helpful in preparing for the future measurement periods of the project. We obtained floor plans showing the location of all workstations and verified their accuracy in the field. The number of workstations that might require additional power strips to consolidate devices or extension cords was estimated so that our monitoring setup would go smoothly.

At larger offices (some sites included multiple floors of 60+ offices each) we selected a specific floor or area of the office to conduct the study. We made an effort to select an area for study that represented an entire department with some diversity of activity (support, management and functional staff). This selection was large enough to maintain randomness of workstation selection, while being small enough to make field work efficient. At half of the sites we also identified one or more electrical panels serving the area and made arrangements to monitor them. This panel measurement would be used for the *Plug loads and whole-building energy performance* analysis.

Second visit: detailed inventory and monitoring installation

Prior to the second visit, we selected the 40 workstations to be monitored using a random sampling tool. These selections were marked on copies of the building floor plans that were then used by the project team. The sample included all types of workstations: individual offices, shared offices and cubicles. Unoccupied workstations were excluded, as were workstations where a person had a specific reason not to be involved in the study (there were only one or two of these at a typical office site). Data closets and servers were not included; they are being investigated in a different study currently taking place in Minnesota (see *Comparison to server strategies*).

Four people worked together on the inventory and installation so that visits took about three hours; visit time was minimized due to our need to be escorted in the offices after hours. One person on each of two teams took a detailed inventory of each workstation, including a description of each device with a plug, the type of computer(s), number and size of monitors, while the other member of each team connected the monitoring devices and counted plugs to ensure the inventory was complete.

We placed two monitoring devices at each workstation; one to monitor the entire workstation energy usage, and one to monitor just the computer (desktop or laptop, without external monitors). We then easily obtained a measurement for all “other” plug loads beside the computer, via subtraction. Figure 6 shows how we set up the metering equipment. The laptop computer in the photo represents whatever computer was at the workstation and the white extension cords going behind the desk represent the other workstation plug loads, including computer monitors. Following the picture from left to right, all of the plug devices in the workspace are connected through a single data logger (Onset UX120-018) which recorded voltage (V), current (A), real power (W), energy (kWh), apparent power (VA) and power factor (PF) at one-minute intervals. These loggers have approximately six months of memory at these settings. A power strip is connected to this data logger and in one of its outlets a Watts-Up Pro meter is dedicated to monitoring the computer, measuring the real power and energy.

Figure 6. Metering configuration at a typical workstation.

Initially we collected the data at one-minute intervals with the Onset logger and at four-minute intervals with the Watts-Up loggers, in order to avoid missing important events. But due to the limited memory and slower download times of the Watts-Up meters, and after analyzing data from our first site, we found we could use 15-minute intervals with the Watts-Up loggers (for just the computer data). We changed our protocol, reducing collection time by about 75%. Total workstation energy usage, the more critical value, was still collected at one-minute intervals. With the revised protocol, the memory of both types of loggers was sufficient to allow a single data download at the end of each site study, significantly reducing the time required for the intermediate field visits.

We also set up monitoring of common space equipment during this visit. The number of common space devices monitored was determined by the number and type of devices (for example, if there were three identical coffee makers or printers, we would monitor no more than two of them). Devices that had consistent energy use profiles and little potential for reduction strategies (e.g. toaster ovens) were simply counted after we monitored them at two or three sites.

Third visit: install plug load control measures

Prior to the third visit, we used the randomization tool described above to divide the sampled workstations into treatment and control groups. The control group allowed us to account for environmental effects such as season, day length, and even changes in office work schedules between data collection periods of four weeks. In this visit we implemented one of the five different energy reduction strategies at each of the treatment workstations, as well as at several of the common area devices.

Again, four people worked together on the installation. These visits generally took about two hours. During this visit the teams also validated the original inventory of each workstation, and noted any cases where the monitoring setup had been changed.

At six of the eight sites this visit occurred with the same protocol again – four weeks later – at which time we installed a second strategy. The same treatment and control groups were used for each strategy. And at one of those sites the protocol was repeated twice (four and eight weeks later) allowing for three strategies to be compared at that one site.

Final visit: remove equipment and download data

In the final visit we removed all equipment and downloaded all the logger data. Some initial data processing was performed at the time of downloading, and data from both the Watts-Up and the Onset loggers were compiled and formatted to create data files for each specific period of measurement: pre-strategy (i.e. baseline), post-strategy-1, post-strategy-2, etc. For each period separate datasets were compiled for the control group and for the treatment group.

Plug load reduction strategies

We measured five reduction strategies directly. The common area timers were tested at every site; the other four were tested at a few sites each as described in Table 3.

Table 3. Offices studied and plug load reduction strategies applied to each.

Location	Strategy 1 (4 weeks)	Strategy 2 (4 weeks)	Strategy 3 (4 weeks)
Architecture	Occupancy sensor APS	Computer power management	
City public works	Foot pedal APS	Occupancy sensor APS	Behavior campaign
Real estate	Occupancy sensor APS	Computer power management	
Prod. develop.	Foot pedal APS	Computer power management	
Engineering	Foot pedal APS	Behavior campaign	
County office	Occupancy sensor APS		
City office	Computer power management		
Energy non-profit	Computer power management	CPM + user chosen APS[1]	

[1] Users were given the choice to have either the foot pedal or occupancy sensor APS in addition to CPM.

We investigated several other reduction strategies analytically, with calculations based on baseline energy data that we collected for different devices. Each strategy is described in detail below.

Advanced power strip with occupancy sensor

This advanced power strip (APS) strategy used an occupancy sensor attached to an-otherwise standard power strip. The APS was swapped for the existing power strip at each workstation. The occupancy sensor had a long cord so that we could place the APS on the floor and then mount the sensor using temporary adhesive either under the front edge of the desk or to the underside of the monitor. Figure 7 shows an APS and an APS with occupancy sensor installation. In this case the APS is installed under a desk and the attached occupancy sensor is mounted on the underside of the desk (the white rectangular object in the upper right of the installation photo). The occupancy sensor allowed for a variable time-to-off setting. We initially set the sensors at 10 minutes, and left instructions for our contact at each office to change the timing for anyone who complained about the strategy. The APS included both controlled and non-controlled outlets; all devices were plugged into the controlled outlets except for desktop computers and laptop docking stations (unless users actively plugged their laptop into the controlled outlet).

Figure 7. Example of an APS (left; Photo courtesy of Tricklestar) and photo of an APS installation.

The APS that we chose for this strategy was the Tricklestar TS1802 with a TS1904 motion sensor attached. This APS, and its savings results, is similar to others like it on the market but was chosen due to its low internal power draw. This strategy also serves as a reasonable test of using lighting occupancy sensors for plug load control when there is one occupancy sensor per workstation (such as in private offices). This is becoming a common approach in new office buildings to meet the new plug load control code requirement (see *Code implications*).

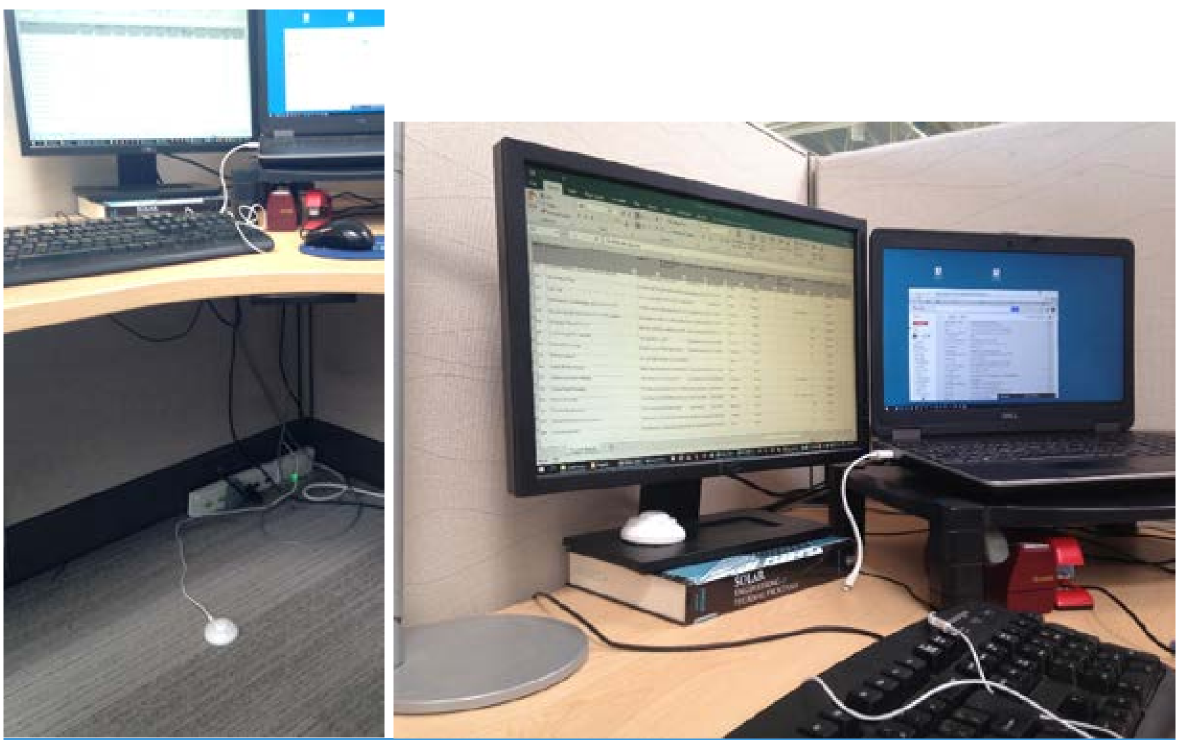
Advanced power strip with timer and foot-pedal

This APS strategy used a foot-pedal switch with an internal timer connected to the APS. The foot-pedal allows for convenient manual off/on operation. The APS used the same controlled/uncontrolled outlet configuration as the previous strategy.

For participants willing to actively manage their energy use, the foot pedal could easily be pressed to turn off power to all controlled devices whenever they left their workstation; even for a short break. For those less willing to actively manage their energy use, the foot pedal would simply have to be pressed once when they arrived at the office for the day. The internal timer would then keep the power strip on for 10 hours of power. If they are not engaged enough to turn the strip off when they left for the day, it would turn off on its own 10 hours after they initially turned it on.

The button attached to this APS (shown in Figure 8) was designed to be used as a foot pedal as shown in the configuration to the left. Many occupants preferred to move the button to the top of desk, near their monitor as shown to the right.

Figure 8. APS with foot pedal, with button used as foot pedal (left) and hand-operated button (right).



The APS that we chose for this strategy was the Tricklestar TS1802 with a TS1903 footswitch attached. This APS, and its savings results, is similar to others like it on the market but was chosen due to its low internal power draw.

Computer power management

The computer power management (CPM) strategy employed existing infrastructure at each site to adjust power settings on each computer to conserve energy. The computers' default power settings were modified to turn off monitors after 15 minutes of inactivity, enable sleep mode in all computer types after 30 minutes, and stop hard disks after 5 minutes. Laptops were also set to remain on in presentation mode, so that sleep settings would not cause shutdown during presentation. If in any instance the existing power settings had shorter time-outs than these settings, then the existing settings were left as they were.

In each case, the study site's IT staff made the adjustments. The primary method of implementation of new power settings was to push these new settings to each computer in the *Treatment* group using existing IT network tools. In one instance, additional modification was required locally at each computer. In a couple instances, IT personnel were so hesitant to modify computer power settings that we ultimately did not test the strategy at those locations. In general, the concerns they voiced were similar to those voiced and subsequently overcome at other sites. The qualitative, operational issues associated with implementing CPM are as integral to its success as the quantitative energy savings, so we have included additional discussion about this strategy's implementation in *IT integration of computer power management*.

Behavior change campaign

Hardware alone can only realize a portion of the potential energy savings in office plug loads. Office devices must remain ready for immediate use for many hours of the day in order to keep users as productive as possible. Subtly modifying the behavior of the users can unlock some additional energy savings potential. To test for this additional potential, we designed and implemented a behavior change campaign strategy. To design the behavior campaign, we solicited input from experts in behavior change research and programs in the Midwest. A number of key tenets of a successful behavior campaign were identified:

- Campaign should be comprehensive: more than just a single nudge
- Communications should come from an internal source at each site
- Social interaction is important to disseminate behavioral impacts
- Feedback is a key driver of impact
- All elements should be positive in nature

In addition to these basic tenets, we decided that we would test our behavior campaign together with a hardware strategy. The hardware would empower users to have more control over their plug loads. It also reflects a future (driven by codes or programs) where plug load control hardware is more pervasive. As a result, we always implemented the behavior campaign together with the APS with foot pedal, thereby testing two different ends of a spectrum: technology installed with bare minimum instruction and technology installed with significant communication and engagement with the stakeholders. The key results of the campaign were therefore a comparison between the foot pedal strategy and the behavior campaign strategy. A key task in designing this behavior campaign was a design charrette that was held with other Minnesota stakeholders to understand what approaches would most likely have a real impact (see *Appendix D: Behavior campaign development*).

We combined three behavioral elements for the campaign, outlined below.

Education

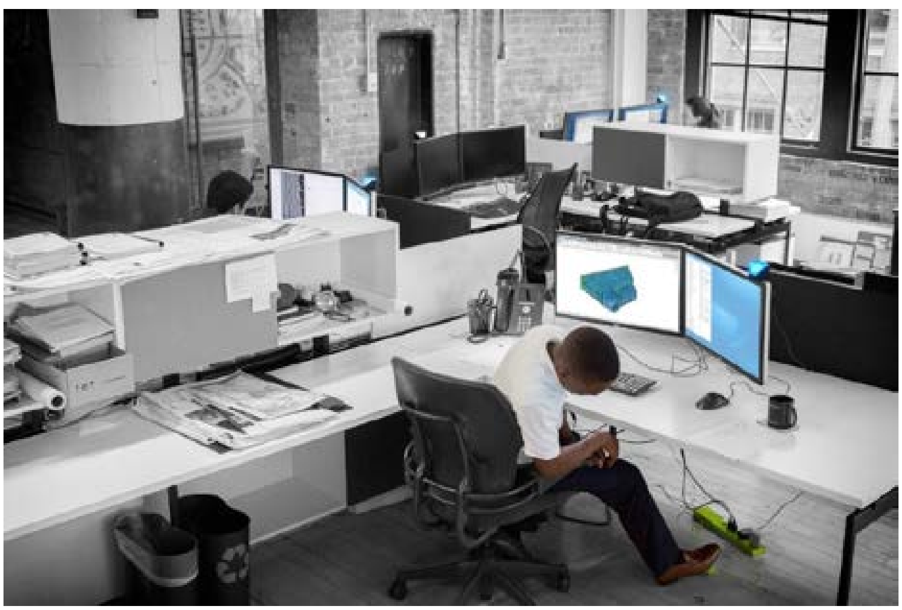
Posters and emails were used to educate participants about the different ways that they could impact plug load energy through their behaviors. An initial email (see *Appendix E: Behavior campaign materials*) was sent out with an inspirational message and a few key ways that participants could save energy. This message was echoed in posters posted in the space a few days later. Finally, a second email was sent a couple weeks after the first that provided a broader list of ways that participants could save energy (targeted at those who would be willing to do more than just a couple basic steps). All of these communications came from an internal contact at the firm where the campaign was being tested. And all messaging was positive in nature – "Consider turning off your device…" as opposed to "Do NOT leave your device on….."

Feedback

Feedback is important both in creating initial behavior change but also in sustaining that change. In our test campaign we used an LED light for feedback, telling the participant whether their power strip was on or not. The LED was blue to differentiate it from typical electronic LEDs which are often green or red, and it was placed on the desktop or monitor of each user so it was always clearly visible. This provided a reminder as they left their workstation of whether the power was indeed on or off to all their peripherals. It also provided a touchstone for social interaction, whether for simple conversation or through users noticing each other's energy behaviors (and even providing occasional reminders for each other).

The LED used was actually a lensed box that was custom-built for this study. The lens provided a glow as opposed to a single point of light. An example of the LEDs installed in the space is shown in Figure 9. Note the angular blue lights at the top of each monitor in the photo.

Figure 9. LEDs installed at one of the study sites.



This LED was simply connected to the APS, so that when the APS was on the LED was also on. The LED's energy usage was extracted in post-processing of the data. In doing so, we were assuming that a mainstream version of this approach would use a more sophisticated design in which the status LED that is present on all power strips would simply be moved to the desktop, perhaps adjacent to or along with the control button that is provided to users. As some (Tier 2) APSs now being developed have a connection to the computer and software included, it is also possible that this indicator could be a software widget on the computer desktop. That would be a fundamentally different feedback mechanism though, because when the APS is off the monitor is also off and such a widget wouldn't be visible.

Rewards

Finally, our contact at each site was provided with rewards to pass out to users who were observed employing energy saving behaviors such as shutting off power strips while away at lunch or meetings, and removing devices from workstations. A number of small rewards were used at each site such as chocolates and gifts cards for coffee. This provided a positive reinforcement of the other aspects of the campaign and created additional social interaction.

Timers for common area equipment

The potential strategies for reducing energy usage of devices in common areas differ from those in the workstation for several reasons. Because there are a large number of people that share use of these devices each day, options for control measures are limited. For example, occupancy sensors are not a feasible strategy for common area equipment that is located in areas of the office where a sensor would be triggered nearly continually whether the devices are being used or not.

Our study opted to test a simple timer power strip that disabled all power to the common area equipment when the office was largely unoccupied. We placed these timers on a number of different types of devices in office common areas: coffeemakers, televisions, copiers, etc., of each site.

Additional reduction strategies analyzed

In addition to directly measuring the impact of the five strategies above, we also had the opportunity, through some additional analysis, to infer the impact of a number of other plug load energy reduction strategies. These include the strategies described below.

Switching from desktops to laptops. A key technology decision for IT departments and office managers is whether to purchase laptop or desktop computers for their employees. Though this is overwhelmingly a decision based on productivity considerations (e.g. portability, power needed for software, etc.), the decision has a significant energy impact as well.

We collected computer-only energy consumption data at every workstation that we encountered (over 300 data points), and had a relatively even mix of desktops (60%) versus laptops (40%). We used this data to make a direct comparison between the energy used by a typical desktop and that of a typical laptop, across eight different offices. We simply compared the usage in the baseline period for each computer so that the reduction strategies did not confound the results of this comparison.

Purchasing smaller computers. Within the desktop computer market, there is a significant difference in both power and energy usage between the smallest machines available and the largest. IT departments could attempt to purchase a computer whose performance, and therefore power consumption, is most appropriate for each user. Or they could consider standardizing on a common computer for most employees that is highly efficient and smaller, and only purchase larger more powerful computers for those few who need them to operate more demanding software.

We attempted to capture the impact of computer size on energy use. Our data collection methodology did not allow a direct comparison of energy usage *with the same types of hardware and software usage* but different sizes. However, we were able to show the potential magnitude of computer size on energy usage.

Purchasing smaller or more efficient monitors. Similarly, IT departments have the ability to determine the efficiency of the monitors that are purchased for each workstation. IT staff make three decisions that impact the energy usage of monitors: 1) whether to have one or two monitors at each workstation, 2) how big the monitors are, and 3) how efficient the monitors are (whether to choose ENERGY STAR, light-emitting diode, etc.). Every monitor in all of our measurement samples was a relatively modern, flat screen monitor, which allowed us to make some comparison based on monitor size. Unfortunately, we were not able to determine which monitors were ENERGY STAR rated at the time of purchase or not, so we are not able to make that comparison.

Different approaches to coffee service. We were able to measure the energy consumption of coffee services in six different offices. There are three common approaches that we witnessed to providing coffee for office employees. The first is the traditional coffee pot kept warm on a burner. The second is a larger thermal carafe, generally well-enough insulated to not need to be kept warm on a burner. And the third method is the single cup coffeemaker, which as the name implies simply makes a cup of coffee on-demand when one is needed, but does not store coffee to be ready to use at a later time. Since our sample size of offices was small, we compared single serve coffeemaker energy usage to energy used by all the other types combined.

Removing extraneous common area devices. Energy consumed by common area equipment can be reduced very simply by having less of each type of equipment.

Participant satisfaction survey

Approximately one week after the final treatment was removed from each site, a post-treatment survey was sent to each participant who had a strategy installed at their workstation. This asked participants to evaluate each strategy installed at their workstation or on common equipment. The survey consisted of five questions and a comment section that participants could use to further describe their experiences with the technologies. The survey was tailored for each site based on the strategies implemented. From the eight sites studied, 145 participants responded. Seventy-nine (79) participants rated the APS with occupancy sensor, 69 rated the APS with foot pedal, 94 rated CPM, and 57 responded to questions about common area equipment. All participants responded to questions about more than one technology.

Results from the Participant Satisfaction Survey are summarized below in the *Participant satisfaction survey results* section. The participant satisfaction survey instrument is included in *Appendix C: Participation satisfaction survey instrument*.

Analysis

The pre- and post-strategy measurements were both checked for quality, and analyzed to determine the amount of energy usage in a typical year as well as typically-expected savings.

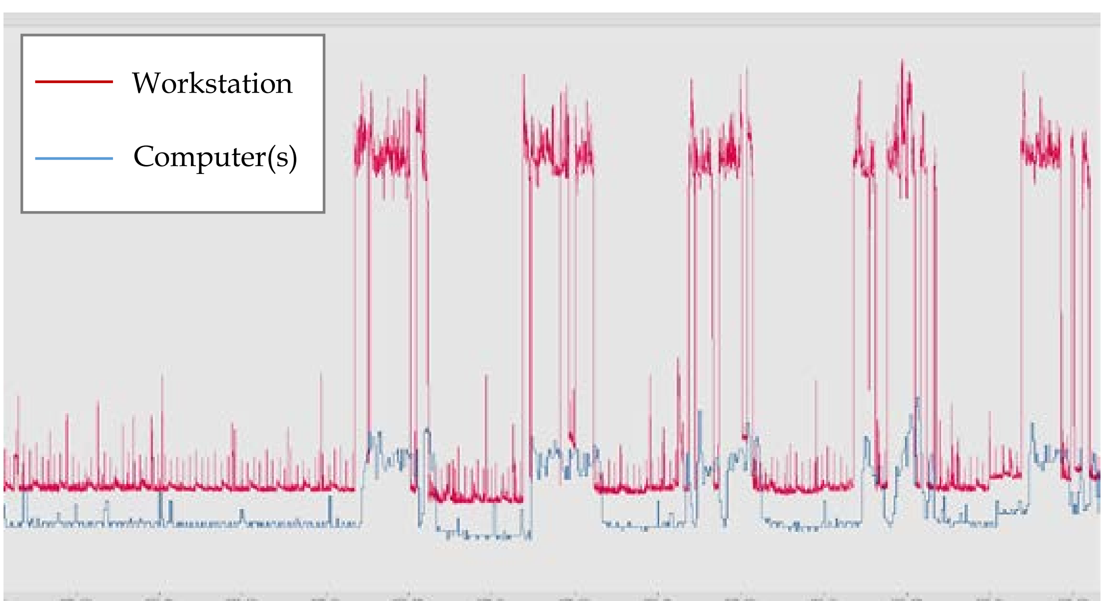
Data compilation and quality control

All field data and calculations from the project were compiled and organized according to either 1) individual workstation, for devices in workstations, or 2) individual device, for common area equipment. This section will focus on our approach with workstation data, though all data analysis was conducted identically for the common area equipment except for its lack of a control device to compare against.

Data were first checked for gaps and extreme outliers (negative energy usage, for example). From there, basic statistics were examined for each workstation, including the average energy usage for each day of the week, the percentage of workstation usage from computer(s) in total and during each day type, the peak workstation usage, and the peak computer usage.

Each workstation's data was then visually examined to check for data quality. Those with statistics that differed significantly from average values were investigated in even more detail, to determine why they deviated. Generally, the data exhibited a robust relationship between computer and workstation energy, and clear indication of days of the week, making it possible to quickly identify bad or missing data. Figure 10 is an example of such a visualization; data for this laptop workstation clearly represents a weekend followed by five distinct weekdays of operation.

Figure 10. Typical visualization of workstation plug load energy for quality control purposes.



Where questionable, bad, or missing data was found, it was either resolved by more detailed investigation or removed from the set.

Calculation of energy usage and savings

The first step in analyzing the clean data was to determine the typical energy usage for each workstation or common area device. We were only able to measure each workstation for about a month, so we first extrapolated to a typical year. A primary element of variance was temporal variance across a week, from weekend to weekday to holiday, to even the type of week (for example, Fridays generally lead to less energy usage than Tuesdays), so our extrapolation was done by day type. If E is the energy usage of a given workstation, and i is a given day type, then we extrapolated to the typical annual energy usage for each workstation in a year by:

$$E_{annual} = \sum_{i=Sunday}^{Saturday} \left[E_i \times \frac{N_{i,annual}}{N_{i,measured}} \right]$$

where $N_{i,annual}$ is the number of days of type i in an average year, and $N_{i,measured}$ is the number of days of type i in our measurement period. Note that for day types we individually broke out all seven days, Saturday through Sunday, plus federal holidays as an eighth type of day. We recorded the average of E_{annual} per workstation for each site, as well as the average across all sites, and various other categories (e.g. all workstations with two monitors).

The next major metric to calculate was energy savings. We repeated the energy savings calculations below separately for each of the energy reduction strategies that we tested. The energy savings from a given strategy S were calculated for each workstation j as:

$$S_j = E_{annual,post-strategy} - E_{annual,pre-strategy}$$

where *post-strategy* denotes expected annual usage extrapolated based on measurements in the period after the strategy was applied and *pre-strategy* is based on the period before the strategy was applied. At this point we calculated and noted the standard deviation of S_j at each of the eight sites, as well as the standard deviation of S_j across all sites of a given strategy. These standard deviations were used to calculate confidence intervals for energy savings stated throughout this report.

We could then calculate the expected annual energy savings for a given strategy by comparing the average savings of all the workstations in the treatment group to the average savings of all the workstations in the control group:

$$S_{net} = \frac{\sum_j^n S_{j,treatment}}{n_{treatment}} - \frac{\sum_j^n S_{j,control}}{n_{control}}$$

where $n_{treatment}$ is the number of workstations in the treatment group and $n_{control}$ is the number of workstations in the control group. We completed these calculations to find net average *workstation* energy savings for each strategy at each of the eight sites we studied. We then conducted all the same calculations above for average energy usage and net savings of just the *computers* at each site, and finally for average energy usage and net savings of all workstation equipment *other* than the computer at each site.

These same usage and savings calculations were repeated for common area equipment as well, except that the energy savings *S* for each device relied only on those devices treated with a strategy; there was no control group for common area devices. So the final equation above was unnecessary for those devices.

Heating and cooling impacts

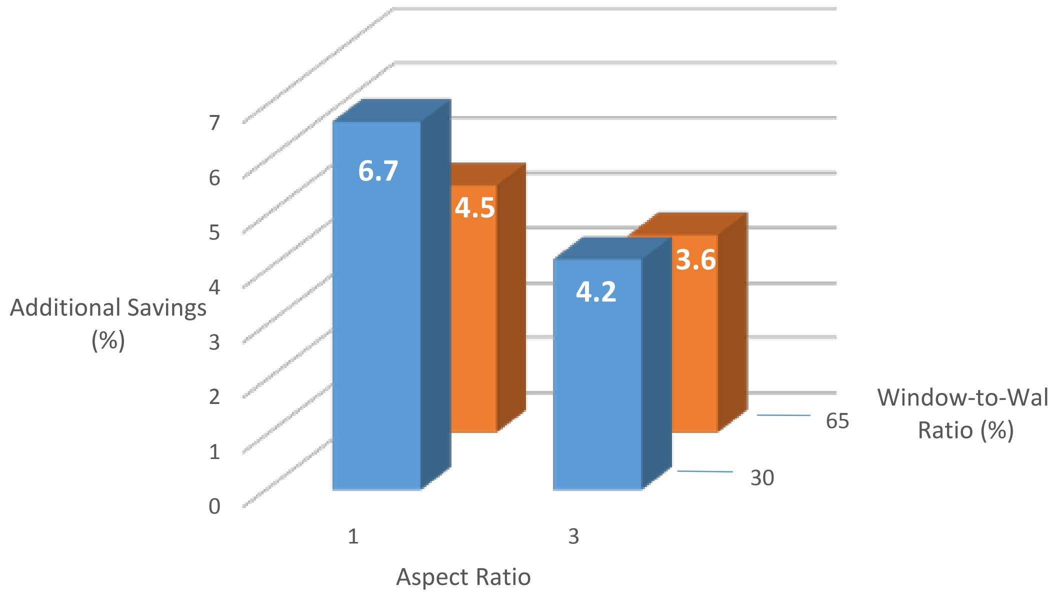
Any reduction in plug load electricity usage in an office also has the potential to impact either heating or cooling energy due to the conversion of all plug load usage to heat within the space. If an office space is predominantly in need of cooling, then reducing plug load would lead to additional energy savings from heating, ventilating, and air conditioning (HVAC) impacts, because there is less of this waste heat adding to the cooling load. We did not have the ability to measure HVAC impacts of plug loads in the field. But we did conduct an energy modeling exercise to approximate how much these additional impacts could change the results of the study.

We first built a whole-building energy model of a large office building using DOE-2-based software. The model matched the specifications of DOE's reference model for large office buildings (DOE 2016), with a hot water variable air volume HVAC system. The building was modeled with Minneapolis weather.

Different models were then built with two different aspect ratios (3 and 1) and two different window-to-wall ratios (30% and 65%). The impact of a change in internal loads (like plug loads) on HVAC is heavily dependent on the balance between heating and cooling in that office. This is because plug load reduction results in savings in spaces that are in cooling mode, but results in an energy penalty in spaces that are in heating mode. This balance changes substantially depending on both aspect ratio and window-to-wall ratio.

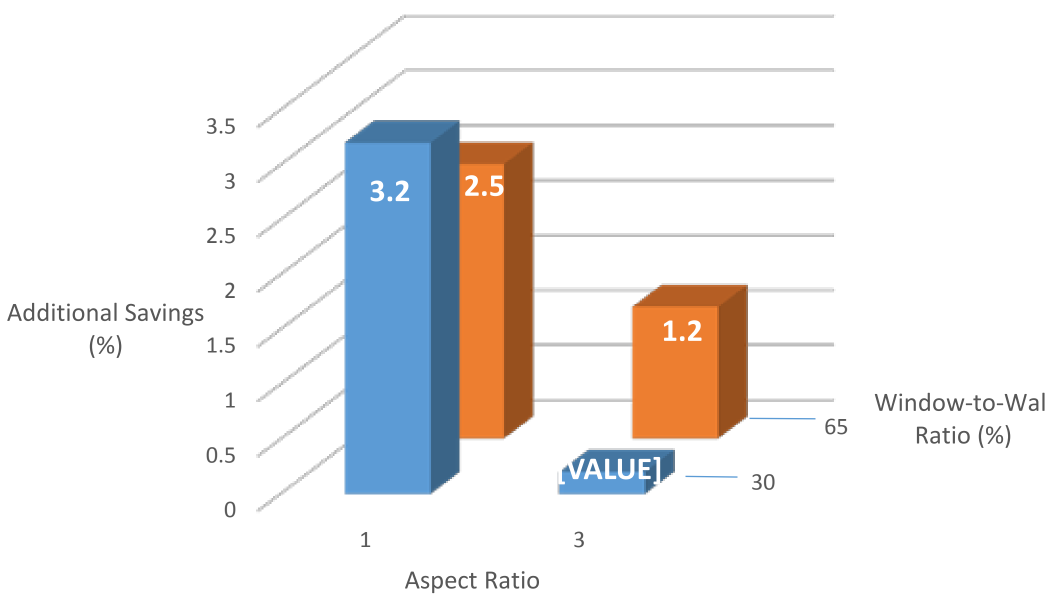
We then applied two different reduction strategies, CPM and an APS, in the model, with the magnitude of plug load reduction matching the average reduction demonstrated in our study's results. The APS primarily impacts night and weekend plug load usage, while CPM has a more uniform impact throughout occupied and unoccupied (i.e. nights and weekends) times. With the results from the models, the HVAC impact of each strategy was calculated by converting the total plug load, electric and gas savings all into source energy (so gas and electricity could be compared directly). The additional savings due to HVAC were compared against the savings from just the plug load strategy in the model. For example, when modeling CPM in a building with an aspect ratio of 1 and a window-to-wall ratio of 30%, for every 1 source unit of plug load energy reduced, the total building energy (including HVAC) was reduced by 1.067 source units. This suggests that the additional savings from HVAC is 6.7% for this scenario. Full results of additional HVAC savings for each scenario modeled are shown in Figure 11 for CPM, and Figure 12 for the APS.

Figure 11. CPM HVAC savings relative to plug load savings.



For these four scenarios, the average additional HVAC savings for CPM was 4.8%. The scenarios with an aspect ratio of 1 had significantly greater HVAC savings, because a building with a low aspect ratio has a large core space that is *always* in cooling—plug load reduction is always saving additional cooling energy in that space.

Figure 12. APS HVAC savings relative to plug load savings.



For the APS, the average additional HVAC savings was 1.8%, which was three percentage points less than that of CPM. This is because the APS saves most of its energy at night and on the weekends, and there are relatively higher heating loads in an office at night (in Minnesota) than there are during the day. The same significant impact is seen for the variance in aspect ratio. With the APS scenarios though, there is greater impact from changes in window-to-wall ratios as well.

Across both CPM and the APS, additional HVAC savings averaged 3.3% beyond plug load savings alone. It should be noted that this impact varies with design of the building form and envelope: HVAC savings are 58% higher when the aspect ratio is 1 compared to aspect ratios of 3.

Results

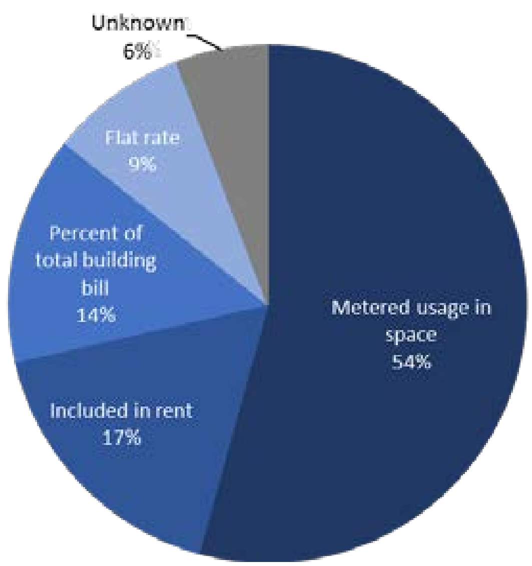
The results of the study follow the progression of the research method. First, we discuss the results of characterizing plug load devices in Minnesota offices. Then we report the baseline energy usage of devices we measured in the field and the energy impacts from reduction strategies in terms of both energy and economics. Then, participant satisfaction results are given. Finally, we close with some broader context, comparing these results to broader building energy usage.

Plug load characterization results

We characterized plug load devices in typical offices through both a remote survey of 34 offices (see *Characterization Survey* for a description of our method and breakdown of the offices we reached) and the more specific onsite inventories for the sites that we measured in person.

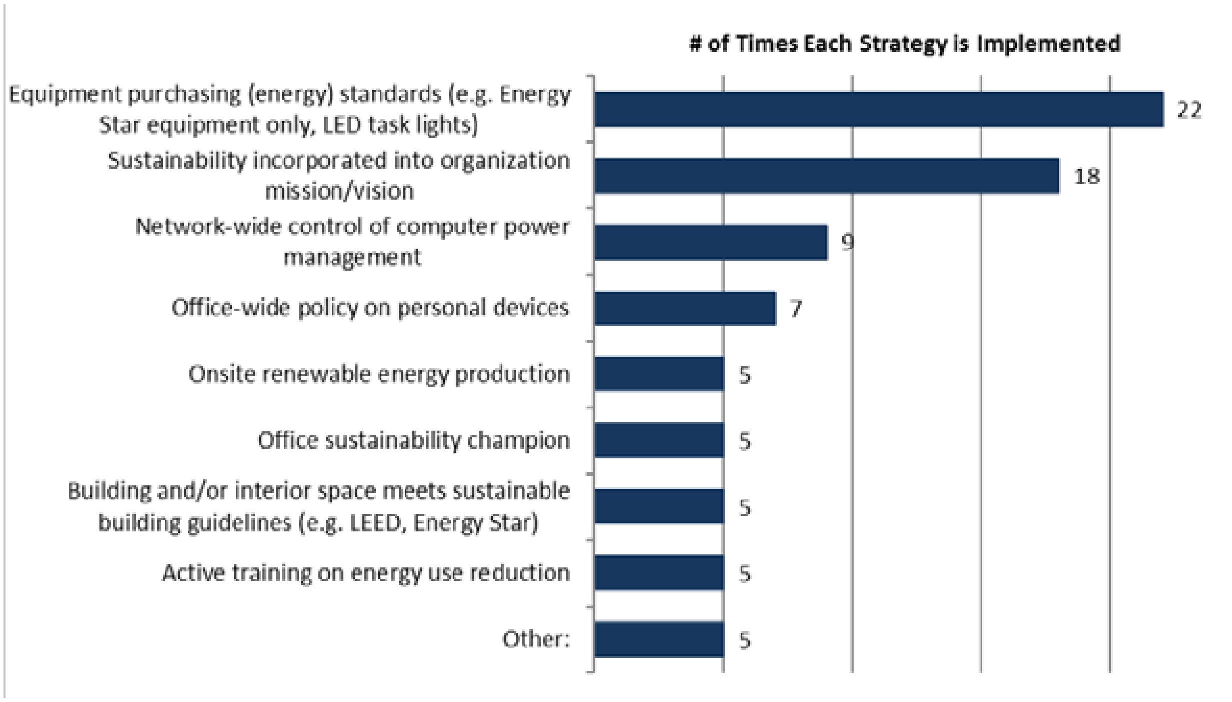
We first consider the office's motivation for saving plug load energy: how does plug load energy reduction affect them financially? Over half of all organizations indicated that their utility billing is based on actual usage for their office space, as shown in Figure 13.

Figure 13. Sites sorted by type of utility billing (electric).



This suggests that many offices will be motivated by financial gain from energy reductions. But organizations can also be motivated by more altruistic goals. We also asked them about any organizational commitments they had made to sustainability. Most, but not all, of the organizations had already undertaken some step to improve operational sustainability. Figure 14 shows how frequently each sustainability strategy is implemented in the offices surveyed.

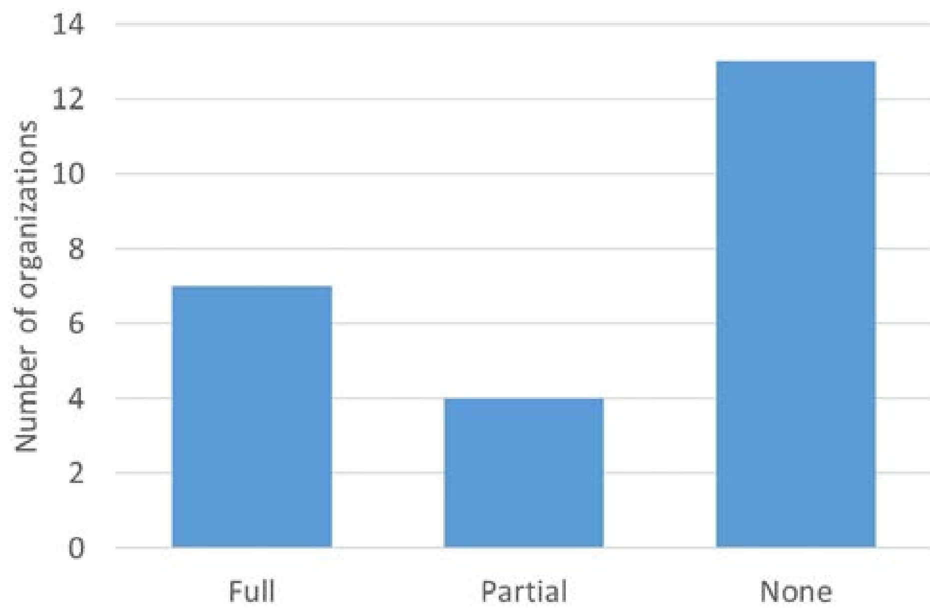
Figure 14. Frequency of sustainability measures implemented.



The most commonly implemented strategy was the policy to purchase certified sustainable equipment (such as ENERGY STAR), which occurred at 22 of 34 offices. The second most commonly implemented strategy was to incorporate sustainability into the organization's mission statement. In all, 65% of offices had implemented two or more sustainability strategies.

It is important to note that none of the offices surveyed reported widely implementing the five strategies that we tested in this study, other than CPM. Figure 15 shows the implementation rate of CPM in the offices surveyed. Of the 24 offices that responded to this question, 7 had fully implemented CPM.

Figure 15. Implementation of CPM in offices surveyed.



The broad characterization results for workstations are shown in Table 4, as Characterization, self-reported. These are displayed next to the devices characterized in the eight buildings that were Field observed.

Table 4. Data from plug load inventories.

	Characterization, self-reported N=34		Field observed N=8	
	Average	Range	Average	Range
Square feet per person	280	170 - 600	230	198 - 273
Desktop/workstation	0.65	0 - 1.4	0.49	0 - 1.20
Laptop/workstation	0.43	0 - 1	0.56	0 - 1.00
Monitor/workstation	1.32	0.2 - 2.4	1.58	1 - 2.60
Phone/workstation	1.00	0.6 - 1.8	0.98	0.80 - 1.03
Task light/workstation	0.80	0 - 2.6	0.68	0 - 1.40
All other	1.40	0 - 4.8	0.97	0 - 4.00

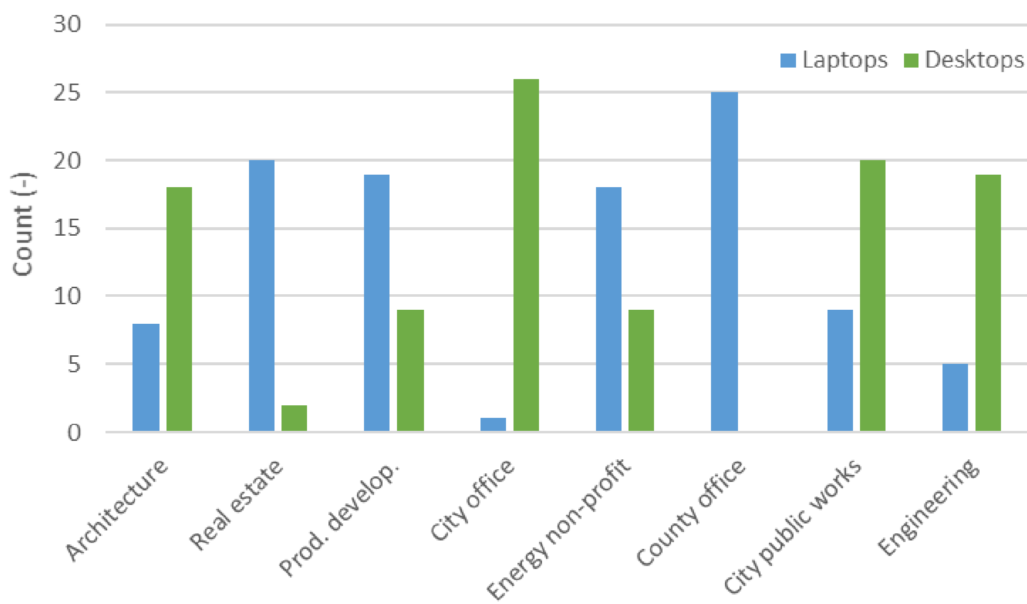
The differences between the broad characterization results and field observations are small. Our energy reduction test results are likely to be conservative, because there are fewer desktops in our field study sample (0.49) than in the characterization (0.65), and there are also fewer peripheral devices in the field study sample (0.97) than in the characterization (1.40).

A few other observations from the characterization and inventory include:

- While no sites self-reported having more than one laptop per workstation, we observed more than one laptop per workstation in several locations in the field.
- A significant majority of workstations have a single VOIP phone.
- Other equipment includes speakers (30%), printers (17%), fans (15%), handheld device chargers, and many other devices too numerous to list.
- The least dense office space had almost 40% more area per employee than the densest.
- The majority of offices are standardizing on two monitors per desk.
- No CRT monitors were observed in any site.

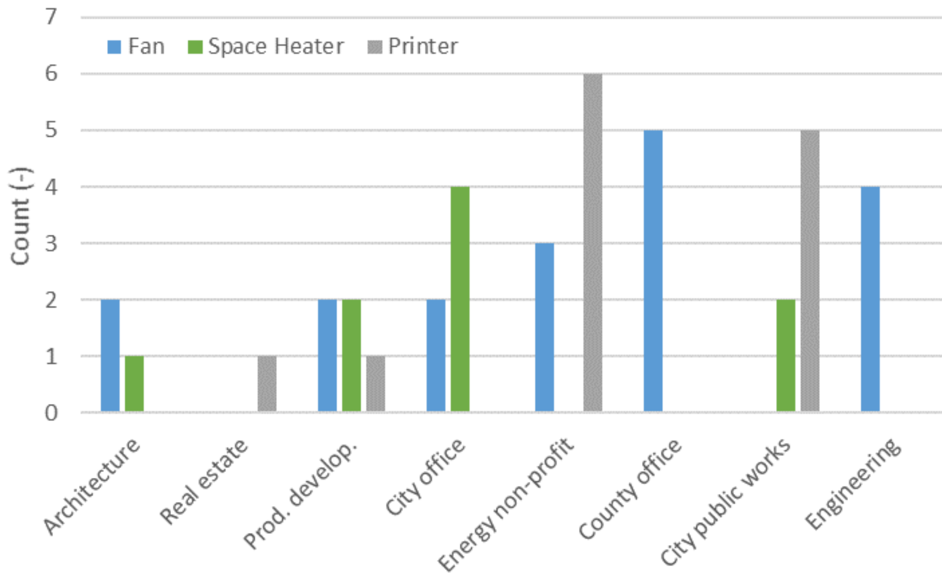
We also collected characteristics of the workstations that we monitored. Figure 16 shows the distribution of laptops and desktops in workstations that were part of the treatment group at each site.

Figure 16. Count of laptops and desktops at each site (treatment group only).



The Engineering site also had two additional workstations with thin client computers, which are not shown in the figure. Sites with more intensive production work (Architecture, Engineering) tended to use desktops, while others had migrated (or were in the process of migrating) to mostly laptops. The City office deviates from this trend, however. In addition to the laptop and desktop distribution, the number of personal devices at each workstation was recorded. Figure 17 summarizes the count of some of the bigger equipment: fans, space heaters and printers specifically. These areas were reported to generally be less thermally comfortable.

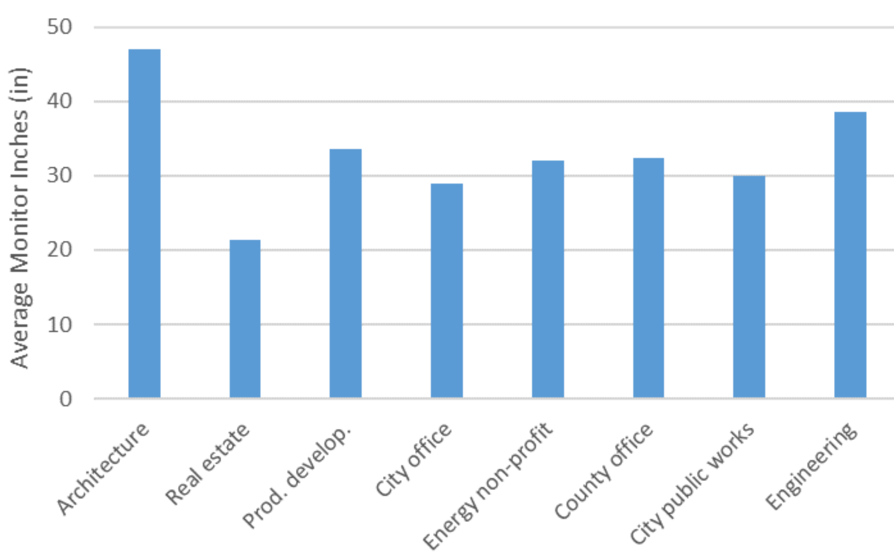
Figure 17. Count of larger personal devices found in workstations at each site (treatment group only).



Personal printers were most commonly found at workstations that did not have easy access to a common area printer. Additionally, fans and space heaters were randomly distributed with no discernible trend.

As expected each workstation generally also had a monitor. We used the metric of total *monitor inches* to describe both the count and size of all monitors at the workstations. This metric is the sum of the diagonal size of all external display devices at a workstation (not including laptop screens). The average number of monitor inches for each site are plotted in Figure 18.

Figure 18. Comparison of average monitor size at each site.



We also inventoried common area devices. The results of the equipment inventory (coffee makers, printers, etc.) for the common spaces associated with each of the eight office areas studied are shown in Table 5.

Table 5. Common area equipment inventoried.

Equipment Type	Total number observed	Number of sites with at least one
Microwave	24	7
Desktop printer	22	6
MFD (copier/printer)	21	8
Flatscreen TV (digital display)	18	7
Coffee machine	15	7
Mini-fridge	13	5
Large printer	12	2
Refrigerator	11	7
Toaster / toaster Oven	11	6
Projector	10	5
Conference display device	7	4
31 other different devices	62	Up to 4

Additional results of our device characterization can be found in *Appendix B: Inventory of plug load devices*.

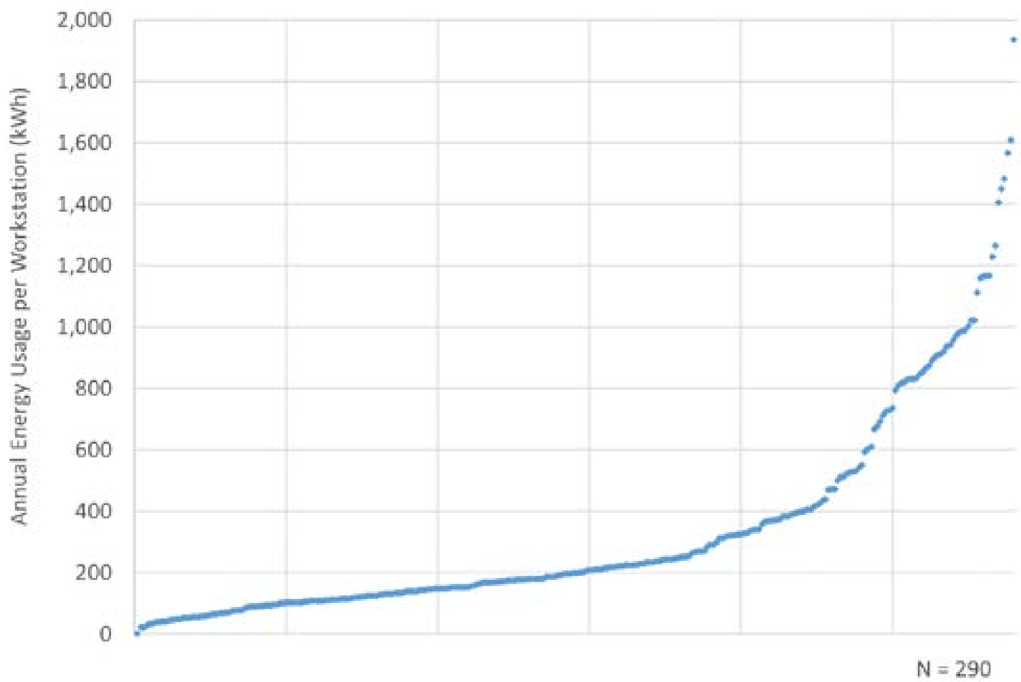
Baseline usage of typical equipment

Plug load energy usage is highly variable with business type, IT approach, and user behavior. We were able to measure the baseline usage of 312 workstations, 312 computers, and a number of individual, larger plug loads. Though not necessarily statistically representative of all offices in Minnesota, we can see some relevant trends with a sample of this size.

Workstations

At the workstation level, energy usage varies significantly from user to user. The highest user in our study used energy at a rate of 1936 kWh/year, for a single workstation. This user was an architect with significant performance requirements at their workstation for design work. On the other end of the spectrum, there were a number of users who barely used their computing equipment; many of these users spend almost their entire day away from their workstation. In the middle, the average workstation used energy at a rate 332 kWh/year, and 75% of all workstations used less than 400 kWh/year. The (extrapolated) annual energy usage of each workstation we measured is shown in Figure 19.

Figure 19. Annual plug load energy usage for each workstation in the study, sorted by usage.



At each workstation, the total energy consumption is driven primarily by the computer, which contributed approximately 66% of the workstation's total consumption for desktops and 30% of the workstation's total consumption for laptops. In cases where the user is preforming computationally intensive tasks, the computer will contribute a larger portion of the workstation consumption. This is seen in Figure 20, where the significant majority of the Architecture and Engineering firm's consumption is from their computers (see *Computers* below). For other offices, at or somewhat less than half of consumption was due to computers.

Figure 20. Average workstation consumption. Percentages in parenthesis – e.g. (96%) – indicate percentage of workstations that were desktops.

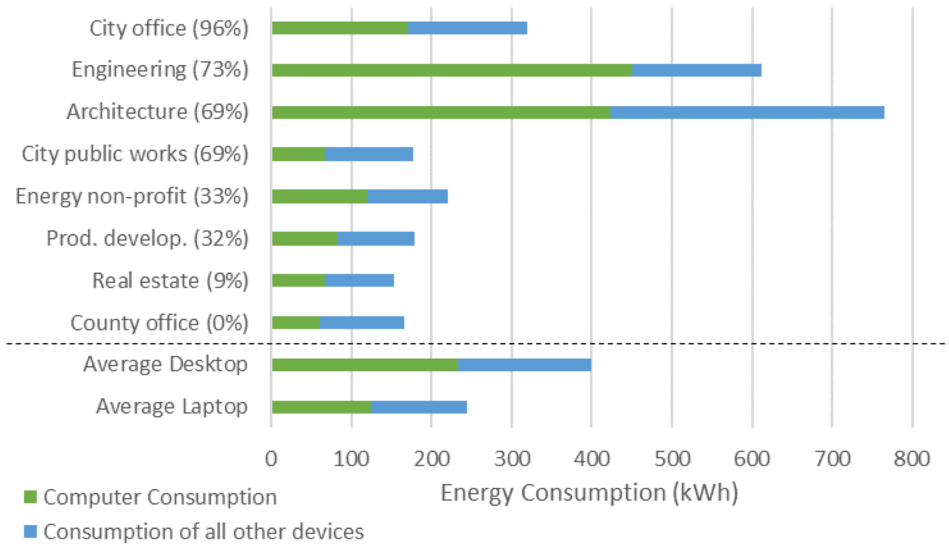
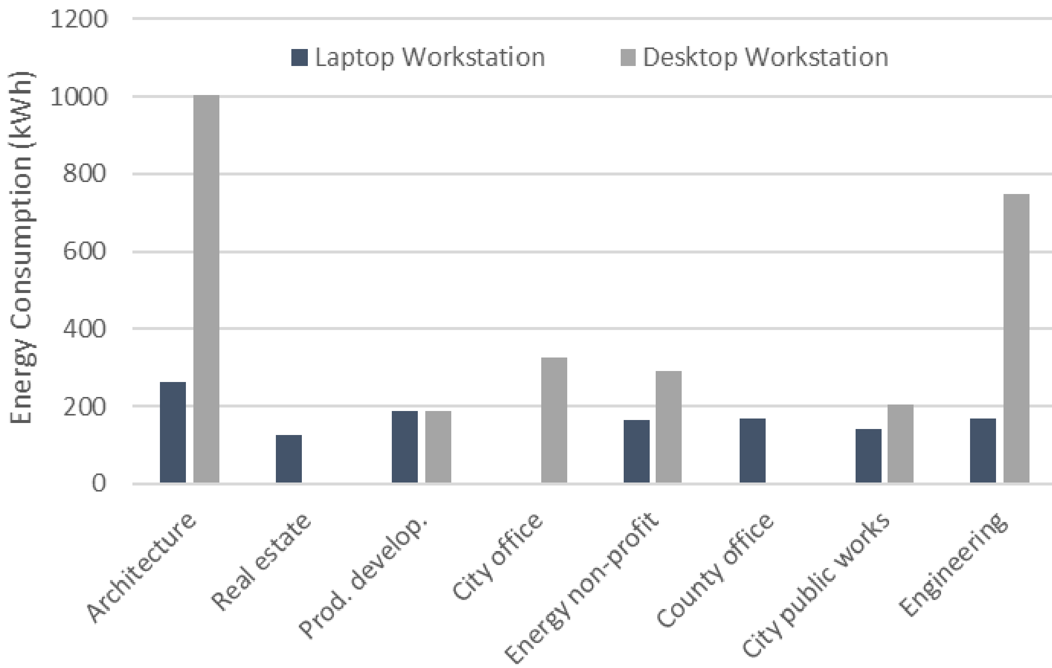


Figure 20 also shows the impact of desktops versus laptops on computer energy usage. The percentage of each site that used desktop computers is shown in parenthesis (e.g. 96%). The average energy usage of all desktops and all laptops respectively is also shown at the bottom of the figure. Workstations with desktops of course use more energy than those with laptops, and a significantly higher fraction of the energy used at workstations with desktops is used by computers.

The difference between desktop and laptop workstation energy usage is shown in more detail in Figure 21. Desktop workstations use more energy regardless of usage type both because they have larger, more energy intensive components and because they are less likely to have integrated power management software.

Figure 21. Baseline workstation consumption of desktop and laptop workstations.



We can convert the values for workstation energy usage to plug load *energy* density using the workstation density found in our characterization. At the average density of 280 ft^2/workstation found in the characterization, the workstation loads translate to an average of 1.2 kWh/ft^2. In terms of EUI this is 4.1 kBtu/ft^2/year. The offices we studied ranged from 0.3 kWh/ft^2 to 3.4 kWh/ft^2. Note that these are densities for the workstation energy only, not for all plug loads, and so leave out a lot of equipment including kitchen equipment, copiers, and elevators. In the *Plug loads and whole-building energy performance*, we document how these numbers compare to several modern high performance buildings which have documented *total* plug load EUI's (including elevators, etc.) of generally between 1.2-5.1 kWh/ft^2.

We also considered the energy usage in workstations temporally, to understand how much energy usage is occurring during a typical working day, versus overnight, versus on the weekend. Figure 22 shows the energy usage over the course of an average weekday for each office, and Figure 23 shows the same for an average weekend day.

Figure 22. Workstation energy usage in a typical weekday for each office.

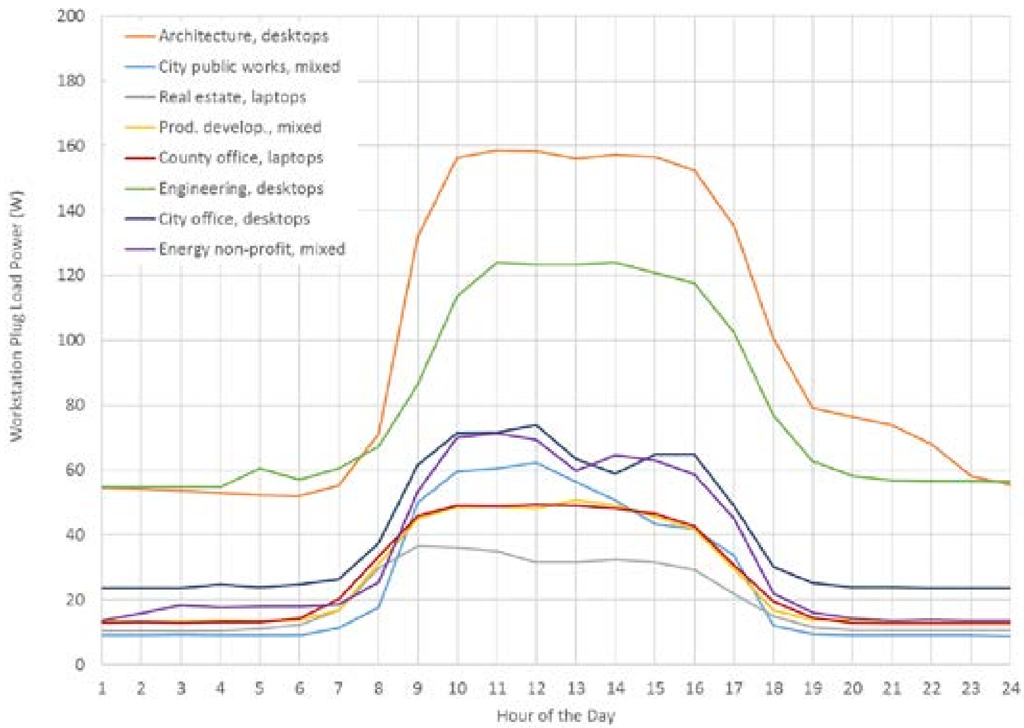
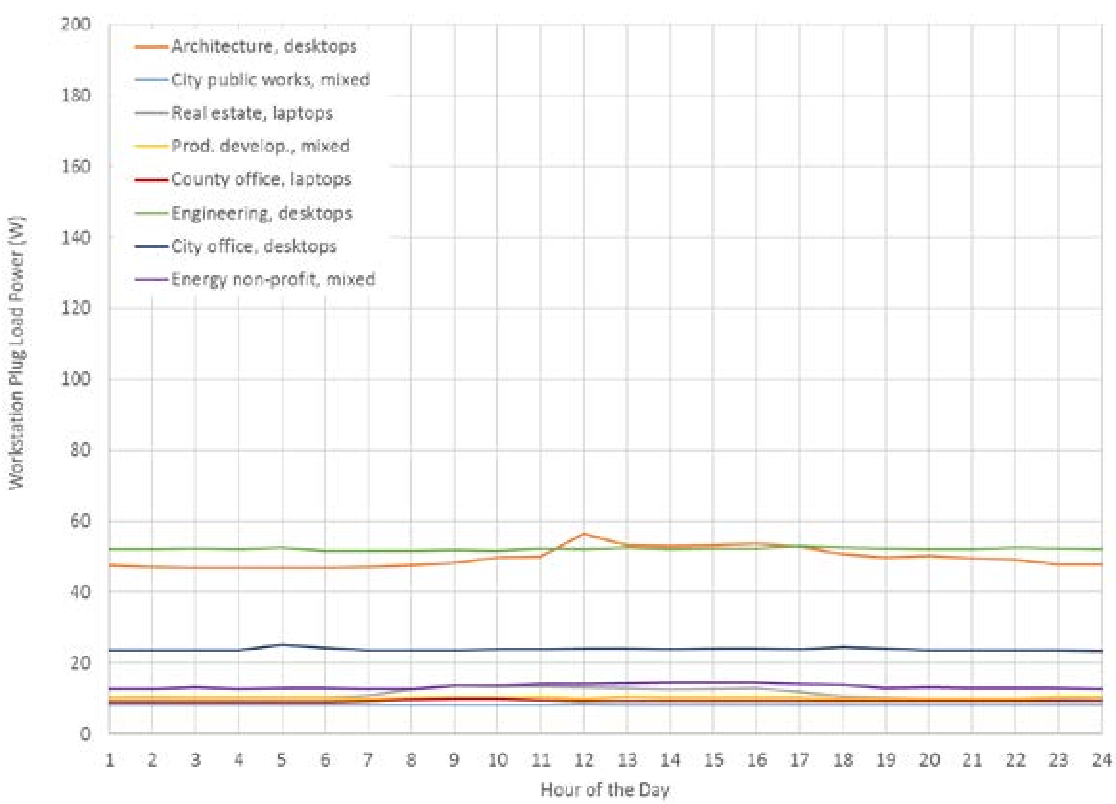


Figure 23. Workstation energy usage in a typical weekend day for each office.

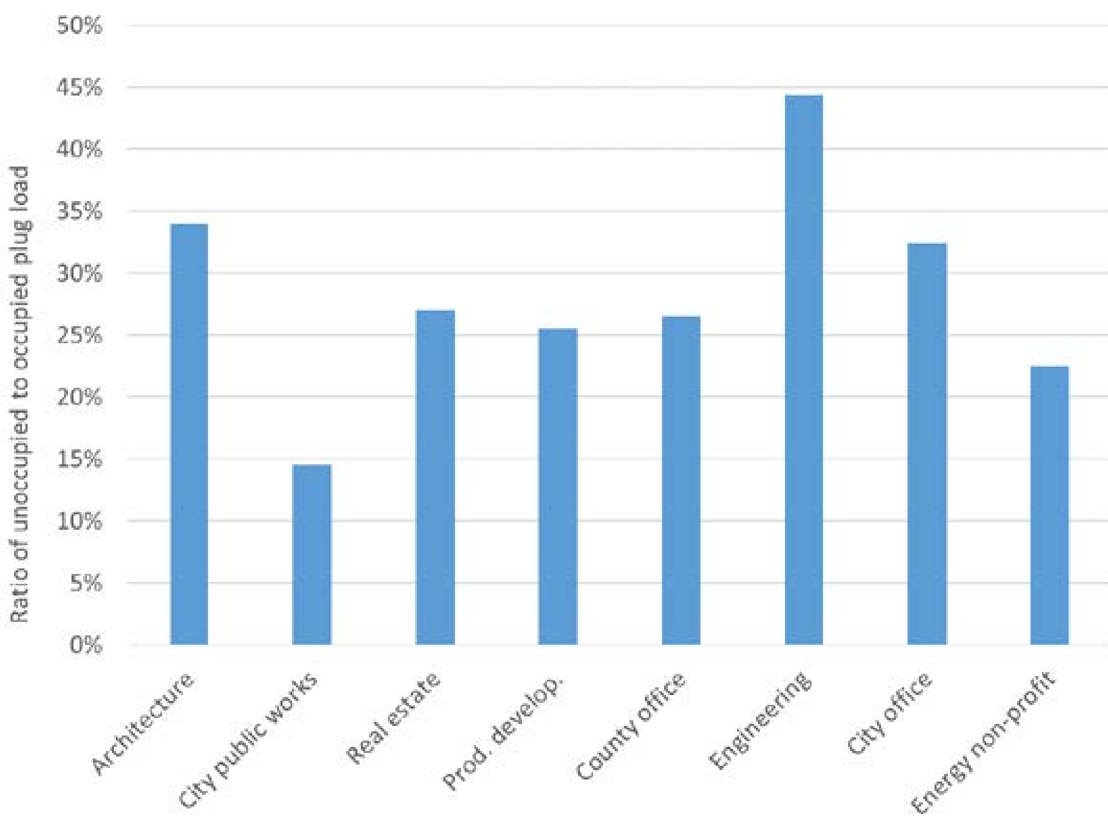


The plug load *power* density can be calculated similarly to the energy usage density. This translates to an average of 0.35 W/ft^2', though the offices ranged from 0.11 W/ft^2 to 0.69 W/ft^2. Again, these values are for workstation loads only. Incidentally, these are at the low end of what is used as assumed plug load density for sizing electrical circuits, sizing heating and cooling equipment, and running energy models – engineers are likely oversizing in all of these processes.

We see from Figure 22 and Figure 23 that, as expected, plug loads are significantly higher during the weekdays than at night and on the weekends. We can draw a few other conclusions as well. First, the plug load usage during weekends and during the night are nearly identical. In other words, users shut down or turn-down equipment at a similar rate each weekday evening as they do over the weekend. The one exception is the Architecture office, where anecdotally the architects would keep their equipment on in the evenings to allow remote access to software, and on the weekends were more likely to simply shut their equipment down. We can also use these figures to calculate the potential for energy savings during unoccupied periods, which should be savings that are relatively easy to achieve. For example, the average workstation in our study used 193 kWh annually just on nights and weekends.

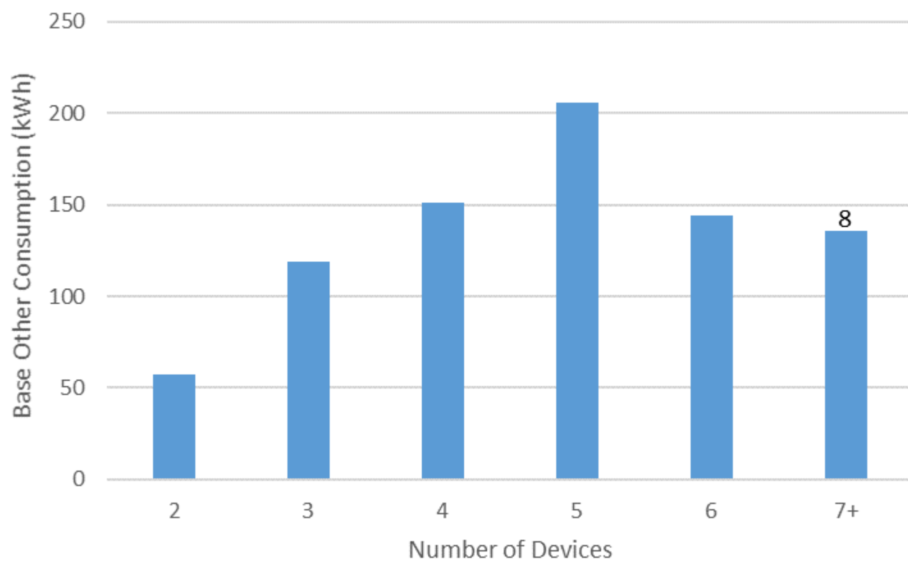
Each office we studied varied in its ability to turn down plug loads on nights and weekends. A good measure of this is the periods; this fraction is shown in Figure 24.

Figure 24. Ratio of the average unoccupied plug load to the average peak occupied plug load, for each office.



Another view of the data is to plot the workstation consumption (excluding computer consumption) versus the number of devices. The expected trend is that increasing the number of devices present at a workstation will increase the overall energy consumption. The data plotted in Figure 25 supports this assumption for two to five devices.

Figure 25. Plot of average baseline "other" equipment consumption (excluding computer usage) sorted by number of devices.

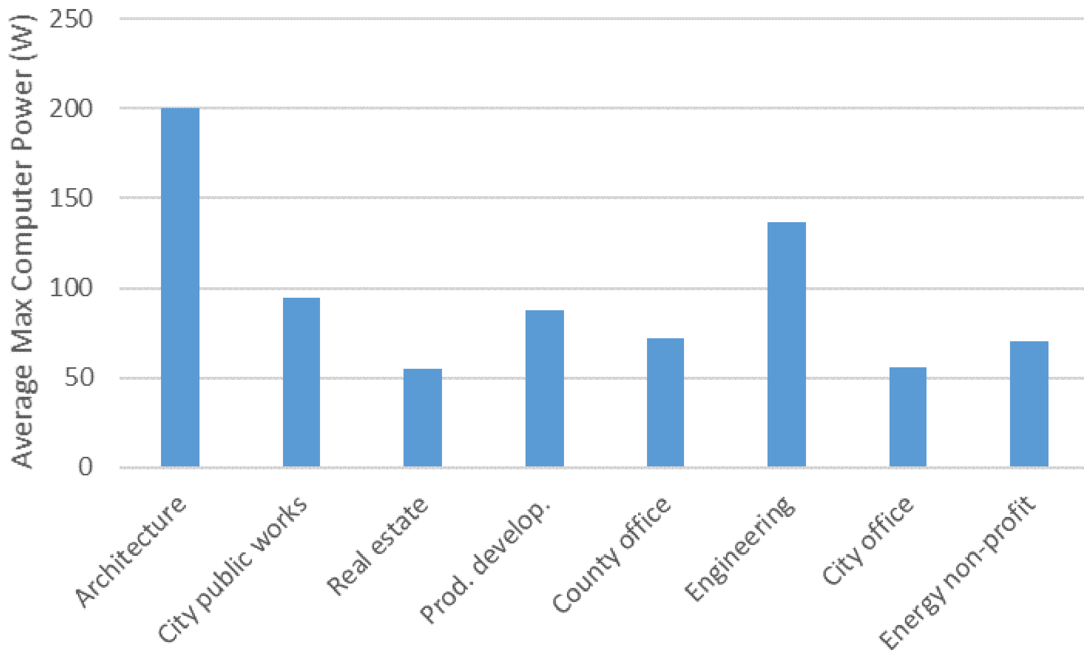


Computers

The majority of energy usage in a typical workstation is due to the computer. This was already demonstrated in Figure 20, which shows total workstation energy usage for each office type, broken into computer and other usage. The average consumption for a laptop was 123.9 kWh (51% of workstation total) while the average consumption for a desktop was 232.5 kWh (58% of workstation total).

The maximum computer power is one metric that we used to gauge the size of the computer at each workstation: we simply recorded the maximum computer power usage (in Watts), which generally occurs during computationally intensive tasks. Sites which have more computationally intensive tasks, such as Architecture, will show higher peak computer power usage than those that do primarily email and spreadsheet work (Figure 26).

Figure 26. Peak computer power.



Equivalent full load hours (EFLH) is another metric that is often tracked for energy-using equipment, and reflects the equivalent length of time a computer would operate at its *maximum* power in order to reach its annual level of energy consumption. Spaces with steady computing requirements will likely see higher EFLHs, while spaces with very diverse computing usage will see lower EFLHs. Figure 27 shows the average EFLH for each site.

Figure 27. Average computer equivalent full load hours (EFLH) per year for each workstation.

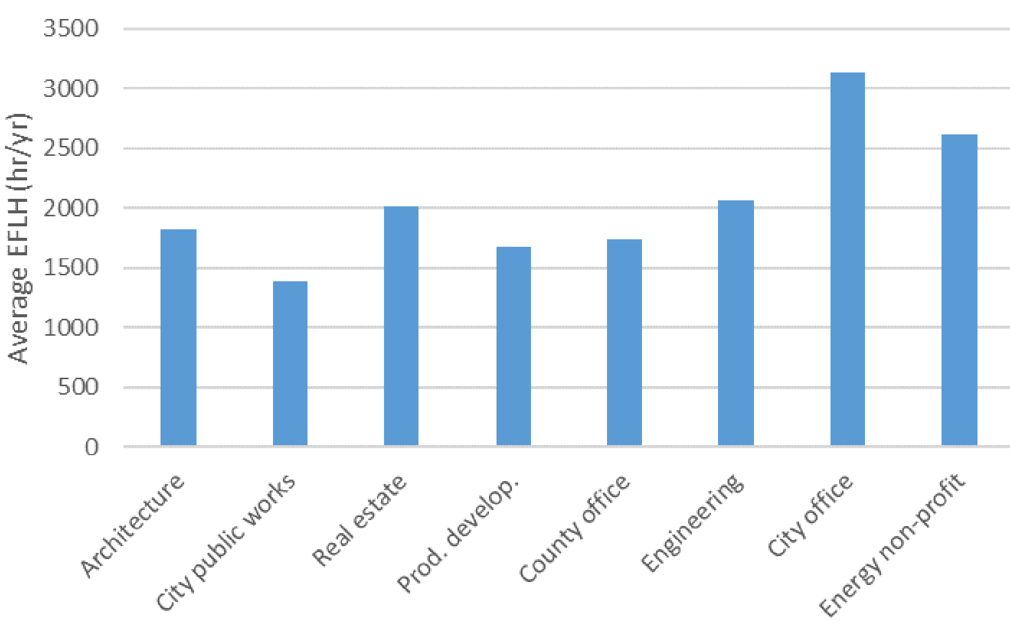
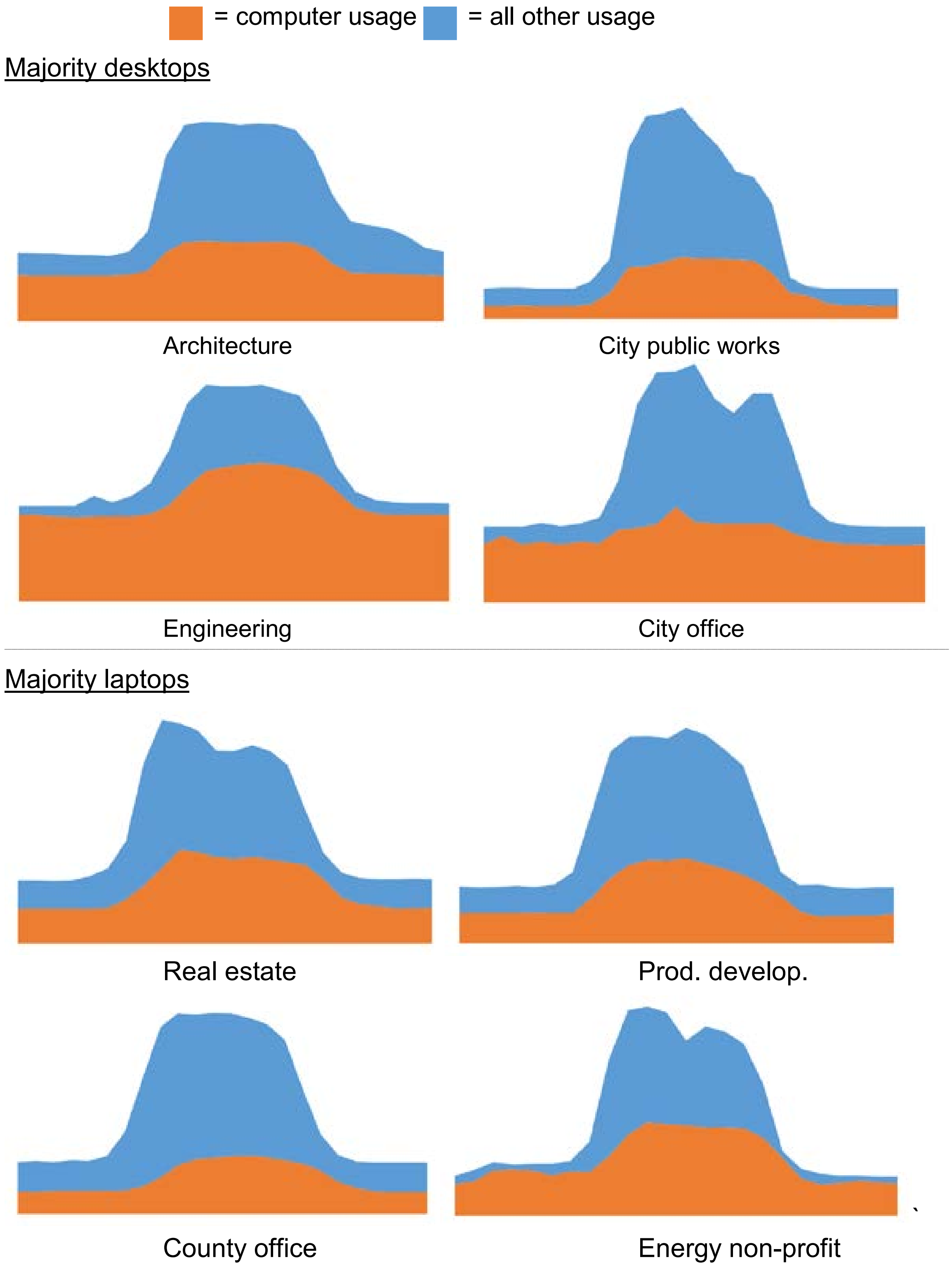


Figure 28. Average weekday plug load profiles for each of the measured offices.



The Architecture site has a low average EFLH, likely driven by short periods of time doing very computationally intensive work that is not sustained much of the year. Conversely, the City office site has steady, moderate computer usage and therefore a higher EFLH. These usage patterns can also be viewed according to their average daily profiles for both computer and all other workstation usage. These profiles are shown in Figure 28.

The total of the two shaded color areas is equivalent to the daily profiles from Figure 22. We can draw some conclusions from the additional breakout of computer and "other" usage in this figure. During the day, for example, the other usage in a typical workstation is generally greater than that of the computer. The reverse is generally true at night, when users are better about shutting off their other equipment than they are their computer. It is this balance between daytime and nighttime usage that determines whether a site has more computer usage (Engineering) or more other usage (Product development). We can also see how many sites tend to be conscientious about turning off their computers at night (County office) versus turning off their other equipment (Energy non-profit) versus shutting off both (City public works).

Common area equipment

In addition to measuring energy usage at individual workstations, we measured equipment in the common areas of the office. We limited our measurements to five types of common area equipment that had potential for energy savings with a plug load timer, which was the reduction strategy we tested for this type of equipment. The five device types we measured were:

- **Desktop printers**: medium-sized desktop printers, generally laser jet variety and generally shared by a few users. (N=7 measurements)
- **Medium-sized MFDs**: multifunction devices (MFDs, which are printer/copier/scanners) larger than the desktop variety but smaller than central printing stations that served the entire office (the large variety were generally on higher amperage circuits that we were not able to measure) (N=7)
- **Coffeemakers**: a mix of three types of coffeemakers: traditional coffee pots, thermal carafes, and single cup makers. (N=7)
- **Televisions**: televisions, primarily in conference rooms, that were only turned on as needed, as opposed to those used for signage or announcements that run non-stop. (N=6)
- **Water coolers**: refrigerated water coolers used to supply cold, and sometimes filtered, drinking water for users. (N=5)

The median annual energy usage (extrapolated) for each device type that we measured is shown in Table 13, inserted in the discussion of common area savings further below. The energy usage of these common devices ranged from 67 kWh for televisions up to 548 kWh for coffeemakers. This is a similar order of magnitude as a typical workstation—recall that the average workstation we measured used 332 kWh/year. All of these devices were left on overnight and on weekends, and used a measureable amount of power during those idle times.

Plug load savings potential

We were able to test and measure the impact of a number of energy savings strategies on the plug loads that we studied. The results of those tests are laid out in the following sections. The strategies that were applied to workstations are discussed first, followed by those that were applied to plug loads in common areas. Each section first discusses the energy impact of strategies that we directly tested, followed by comparison to the impact of some other strategies, estimated based on our data.

Workstation strategies

Four of the strategies that we tested were applicable to workstations, which were generally either individual enclosed offices or cubicles, characterized by a single individual occupant and generally a single computer. These strategies include two of the advanced power strips (APS), computer power management (CPM), and the behavior campaign. The results of testing each of these strategies on workstations are described below.

All energy savings discussed in this section are in units of kWh *per workstation* unless otherwise noted.

Advanced power strip with timer and foot pedal

The APS with timer and foot pedal was tested in three different offices. The results for each office are given in Table 6. The average for all workstations tested is highlighted at the right, with the 95% confidence interval for that average given next to it.

Table 6. Energy savings results for APS with foot pedal.

	City public works	Product develop.	Engineering	Median	Average	95% CI
Baseline usage (kWh)	177	187	637			
Net savings (kWh)	49	45	34	45	42	42
Net savings (%)	**27.6%**	**24.0%**	**5.3%**	24.0%	**19.0%**	12.6%
N, control group	11	11	13	35	35	
N, treatment group	24	27	23	74	74	

This APS saves 19.0% ± 12.6% of workstation energy. This savings equated to 42 kWh ± 42 kWh in the offices that we tested it in. Savings varied from 34 to 49 kWh per workstation, which was 5 to 28% of total energy usage. The variation in percent-savings was likely due to the size of the computer energy usage, because computer energy cannot be saved by the APS. The APS savings is due to the peripheral loads, such as task lights and monitors. This is why the percentage savings is much lower at the Engineering site where computers had higher average energy use.

Advanced power strip with occupancy sensor

The APS with occupancy sensor was tested in four different offices. The results for each office are given in Table 7. The average for all workstations tested is highlighted at the right, with the 95% confidence interval for that average given next to it.

Table 7. Energy savings results for APS with occupancy sensor.

	Architects	City public works	Real estate	County office	Median	Average	95% CI
Baseline usage (kWh)	747	176	156	189			
Net savings (kWh)	143	48	21	48	48	67	45
Net savings (%)	**19.2%**	**27.3%**	**13.5%**	**25.4%**	22.3%	**21.7%**	14.0%
N, control group	12	11	10	13	46	46	
N, treatment group	25	24	20	26	95	95	

This APS saves 21.7% ± 14.0% of workstation energy. This savings equated to 67 kWh ± 45 kWh in the offices that we tested it in. Savings varied from 21 to 143 kWh per workstation, which was 19 to 27% of total energy usage. The significant variability in kWh saved is due to the Architecture office having a much larger peripheral energy load than all other offices.

Computer power management

Computer power management was tested in five different offices. None of these offices had *widely* implemented the best-practice CPM settings on their computers prior to our arrival. The results for implementing ideal settings at each office are given in Table 8. The average for all workstations tested is highlighted at the right, with the 95% confidence interval for that average given next to it.

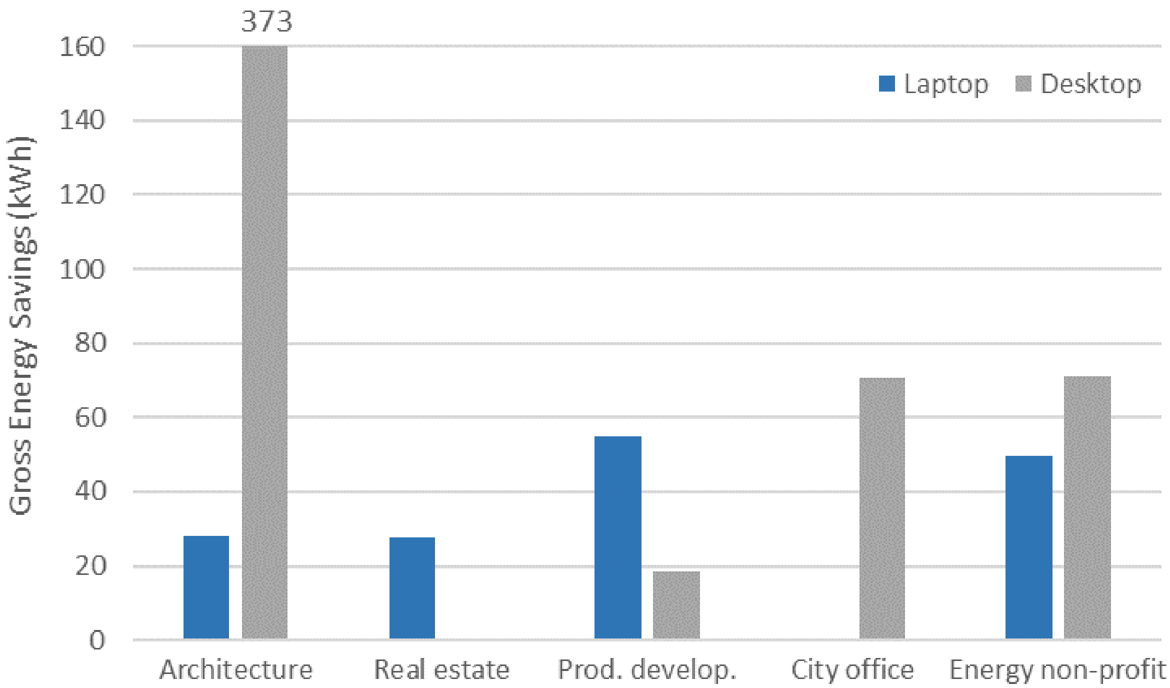
Table 8. Energy savings results for CPM.

	Arch.	Real estate	Prod. dev.	City office	Energy n-profit	Median	Average	95% CI
Baseline usage (kWh)	742	165	189	299	240			
Net savings (kWh)	263	16	78	70	65	70	106	63
Net savings (%)	**35.4%**	**9.9%**	**41.4%**	**23.5%**	**26.9%**	26.9%	**29.1%**	18.4%
N, control group	13	10	11	11	12	57	57	
N, treatment group	25	12	27	26	26	116	116	

CPM saves 29.1% ± 18.4% of workstation energy. This savings equated to 106 kWh ± 63 kWh in the offices that we tested it in. Savings varied from 16 to 263 kWh per workstation, which was 10 to 41% of total energy usage.

We also looked at the comparative impact of CPM between desktops and laptops. Figure 29 compares savings between laptops and desktops at several sites. In addition to laptops and desktops, two thin client computers were also measured at the energy non-profit site. The thin clients saved 96 kWh (average) when equipped with CPM.

Figure 29. Savings from CPM sorted by laptop and desktop workstations. Note that the Real estate office had zero desktops, and the City office had zero laptops.



Behavior campaign

A behavior campaign was tested, along with the APS with foot pedal, in two different offices. The results for each office are given in Table 9. The average for both offices tested is highlighted at the right, with the 95% confidence interval for that average given next to it.

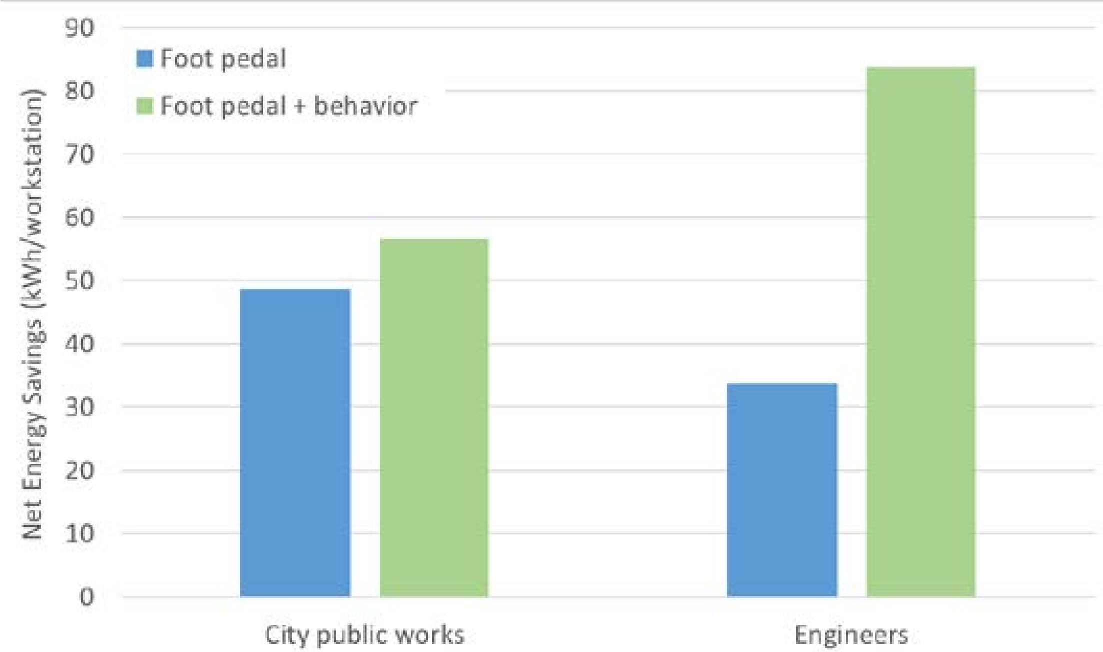
Table 9. Energy savings results for APS with foot pedal and behavior campaign.

	City public works	Engineers	Median	Average	95% CI
Baseline usage (kWh)	177	650			
Net savings (kWh)	57	84	70	70	55
Net savings (%)	**32.1%**	**12.9%**	22.5%	**22.4%**	13.2%
N, control group	11	12	23	23	
N, treatment group	24	24	48	48	

The behavior campaign with APS saved 22.4% ± 13.2% of workstation energy. This savings equated to 70 kWh ± 55 kWh in the offices that we tested it in. Savings varied from 57 to 84 kWh per workstation, which was 13 to 32% of total energy usage. The variation in percent-savings was likely due to the size of the computer energy usage, because it is harder for occupant behavior to influence computer energy use than all the peripherals (such as monitors).

The behavior campaign was implemented along with the APS with foot pedal in order to empower the users in the study to actually make a change in their plug load usage. In this context, the behavior campaign that we tested is really a test of the incremental increase that an added behavioral element can have when added to a technology strategy. To understand this increase, we show the net energy savings of the foot pedal with and without the behavior campaign in Figure 30.

Figure 30. Net energy savings from the foot pedal both with and without a behavior campaign, for the two sites where both of these strategies were tested.

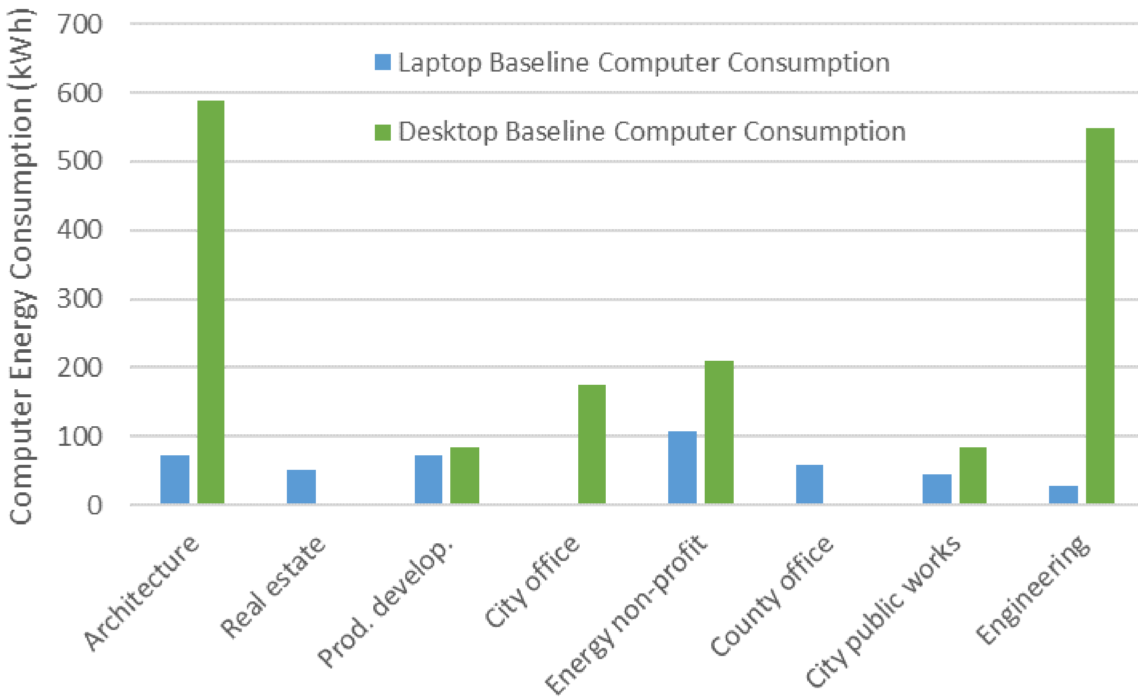


The additional energy savings from the behavior campaign is statistically significant, using a paired comparisons method. For all of the workstations at these two sites, the average increase in savings is 50 kWh/workstation, with a 95% confidence interval of ± 45 kWh. The mean energy savings from the foot pedal alone at these sites was 42 kWh/workstation. This suggests that adding a behavioral component has the *potential* to double the energy savings from implementing APSs. But as the figure shows, it is also possible for behavior to have only a small impact. It is difficult to say why the impact was so different between the two sites, but it may have been due to the fact that the Public works site had more laptops than the Engineers, or that the office culture had already led to adoption better behaviors due to sustainability efforts. We also learned significant qualitative lessons from interaction with the participants of the campaign. These qualitative results are documented in *Participant acceptance and operational issues*.

Switching from desktops to laptops

Though this is overwhelmingly a decision based on productivity considerations (e.g. portability, power needed for software, etc.), the decision to purchase laptops versus desktops has a significant energy impact as well. Some sites we observed relied heavily on desktops, such as Architecture, whereas others relied on a mix of laptops and desktops. The energy impact of this decision is demonstrated by the baseline computer energy consumption data we collected, shown in Figure 31. If we consider just the sites that had an even mix of laptops and desktops to compare (Product dev., Energy non-profit, and City public works) we find that the average desktop consumed 114 kWh/year in the baseline, while the average laptop consumed 81 kWh. This suggests the decision to purchase a laptop versus a desktop saves about 33 kWh per year.

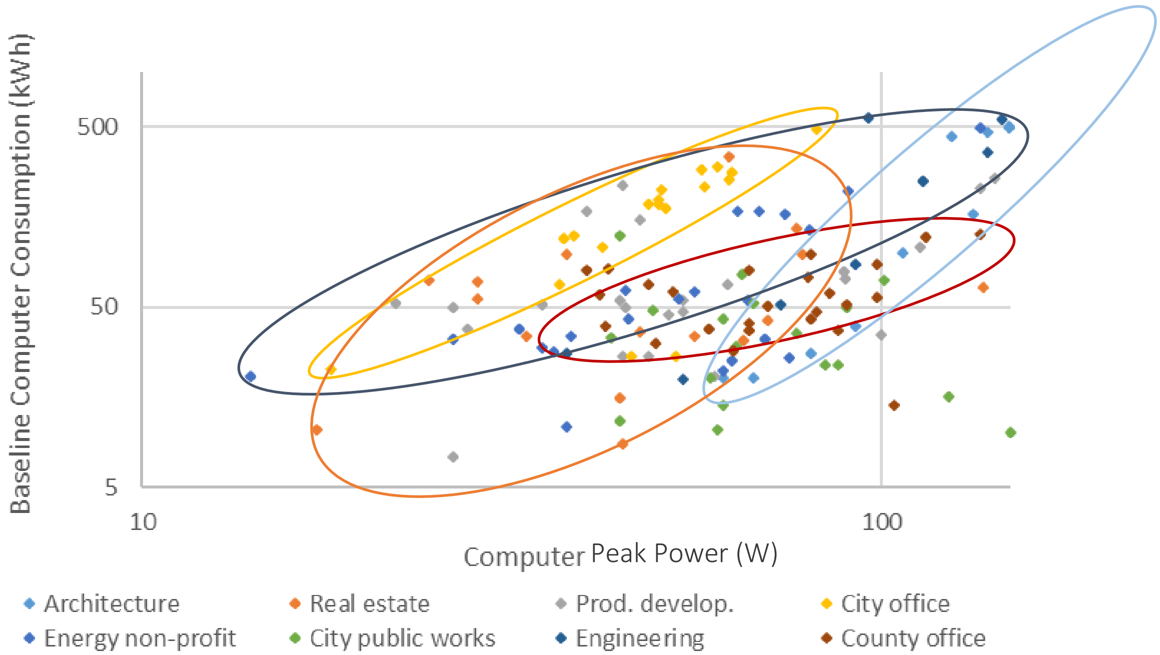
Figure 31. Baseline consumption of laptops and desktops.



Purchasing smaller computers

There is potential for saving energy by purchasing the right size computer for a given user and their tasks, because there is a fixed amount of energy usage for certain components of the computer. We generally found that each site we visited purchased the same computer for each employee, with the exception of three sites in which a more even mix of laptops and desktops was present. In Figure 32 we show a very rough cluster analysis of computer energy usage (in the baseline) versus peak computer power for each of the other five sites.

Figure 32. Cluster analysis of computer energy consumption versus peak computer power for each site.

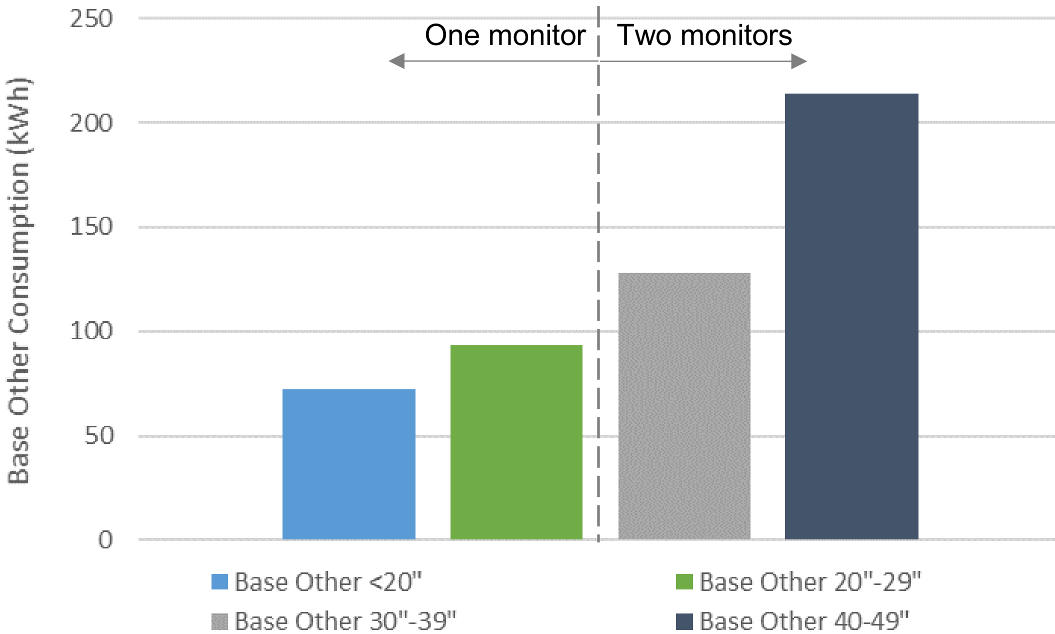


If the impact of this fixed energy usage dominated the energy usage of each computer, then at those five sites that purchased a similar computer for each occupant, the energy usage would not vary significantly from user to user. Or we would at least only observe two clusters per site: those who shut their computer down regularly and those who did not. But we do not observe any tight clustering (note the y-axis is logarithmic) and all sites have computers that range down to below 25 kWh of usage. At the most extreme, the County office site had computers that ranged in usage from 20 kWh to 100 kWh; not enough clustering to be visually apparent. There is likely some fixed size to computer usage, but from our data fixed usage is not enough to have a large impact on workstation energy usage.

Purchasing the right size monitor

Another piece of equipment analyzed at the workstation were monitors. We first asked how the size of the monitor impacts energy consumption. In Figure 33 the non-computer (or "other") energy consumed in each workstation is plotted against total monitor size, measured in total diagonal length of all monitors at the workstation. The 40-49" category is a bit of an outlier driven by some higher-end 2 x 24" monitor configurations that we metered. The other categories show an approximately linear change in energy consumption with total diagonal size. For every 6" of additional monitor size, workstation energy increases by roughly 27 kWh/year.

Figure 33. Base Other Consumption sorted by total monitor size.

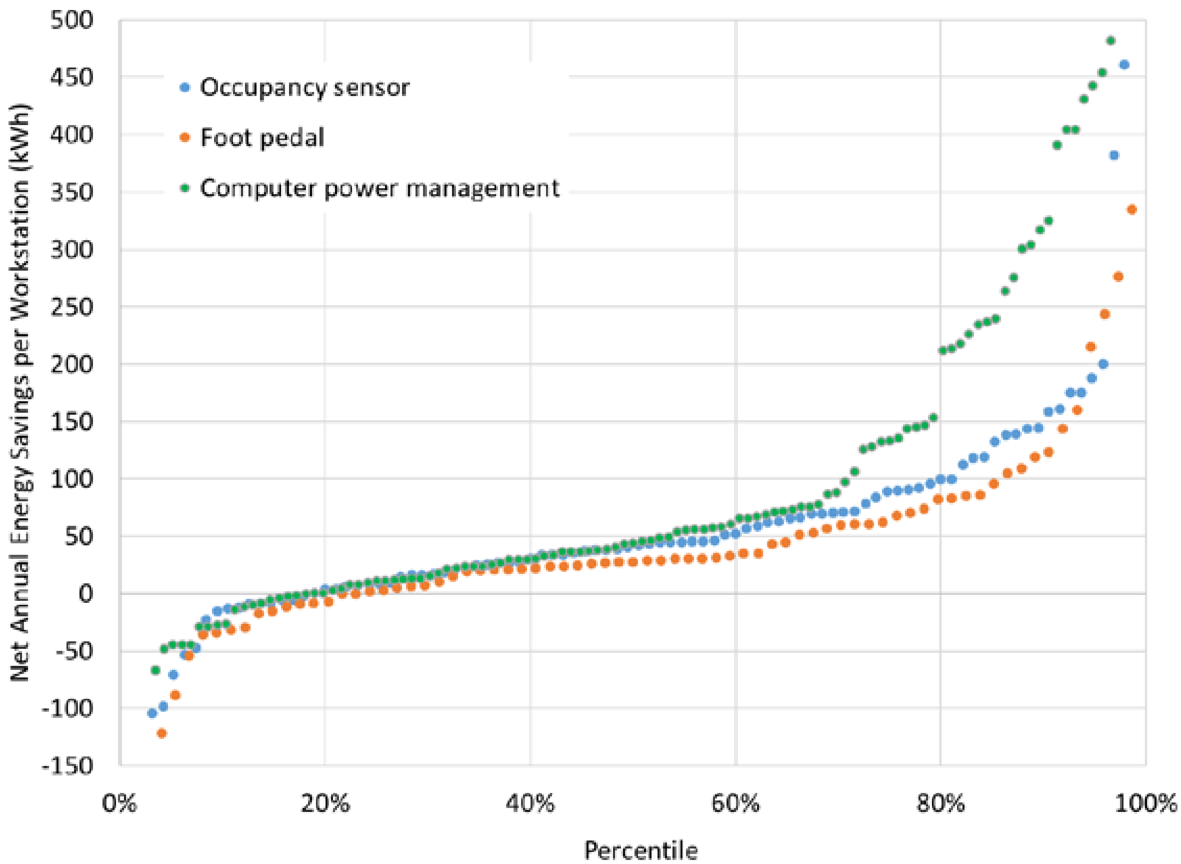


We also considered how monitor size may impact energy savings from the plug load reduction strategies. If the total monitor size is plotted against energy savings (for all measures), the savings at each workstation is relatively similar except for very large (generally 48″ total size) monitors. For these large monitors, energy savings from all reduction strategies was generally about double the average rate.

Comparing Workstation Strategies

We can use our results to compare the possible reduction strategies for workstation plug loads. First, we compare those that we tested in the offices. Figure 34 shows the net energy savings at every workstation that we measured, sorted from least to most savings, with the percentile given on the x-axis.

Figure 34. Distribution of energy savings for each strategy across workstations.



For workstations with lower savings, below about the 50th percentile, savings are similar for all three reduction strategies shown in the figure. For workstations that demonstrated more savings there is a more significant difference between the strategies. These larger savers are generally those workstations that use more energy (see *Baseline usage of typical equipment* for a similar plot of baseline usage). We can also see from this distribution (by looking at the area under the curves) that the 30% of savers above the 70th percentile represent the majority of the energy saved by all workstations; this is true for any of these strategies.

For the higher users and savers, we also begin to see some differentiation in the impact of each strategy. Occupancy sensor and foot pedal power strips continue to be similar, with some possibility of greater savings from the occupancy sensor. CPM shows a clearly significant increase in energy savings beyond the power strip strategies in those upper percentiles.

We have also calculated the average savings for each reduction strategy that was tested in the offices. Table 10 summarizes the annual energy saved per affected workstation, in terms of both kWh and percentage (of total energy). A 95% confidence interval is also given, in units of percent-savings (for example, we can be 95% confident that the average savings for an APS with occupancy sensor is between 8% and 36%). *N* represents the number of workstations treated with each strategy. These results are also compared in Figure 35.

Table 10. Summary of energy savings for each strategy.

	Energy savings			
	kWh per station	% (with 95% conf. int.)		N
Occupancy sensor	**67**	**21.7%**	± 14%	95
Computer power management	**106**	**29.1%**	± 18%	116
Foot pedal	**42**	**19.0%**	± 13%	74
Foot pedal + behavior campaign	**70**	**22.4%**	± 13%	48

Figure 35. Comparison of plug load savings between strategies, with 95% confidence interval.

Table 10 is generally consistent with Figure 34 when we consider the percent savings. Percent savings has less variation and is more appropriate for drawing comparisons than the kWh-saved metric. It is more appropriate here because we implemented different strategies in different offices and each office had a different magnitude of baseline plug load energy. For example, there is a large difference between foot pedal and occupancy sensor APSs when comparing kWh saved, but some of this difference is because the occupancy sensor was tested on a set of offices with more intense baseline plug loads; the more similar percent-savings metrics of these two strategies is a better comparison. For this reason, the strategies are compared according to their percent-savings in Figure 35.

The figure shows that average savings for the two APS strategies are similar, with a slight edge for the occupancy sensor over the foot pedal. Specifically, the occupancy sensor APS saved an average of 21.7% (or 67 kWh for the stations we measured) of total workstation energy, and the foot pedal APS saved 19.0% (or 42 kWh for the stations we measured).

The behavior campaign had the smallest sample of any strategy due to the complex nature of implementing it; we had the opportunity to implement it in only two offices. We would only extrapolate this result widely with caution. However, the behavior campaign was implemented as an augmentation of the APS with foot pedal strategy—we always conducted the behavior campaign immediately following that APS strategy, and the campaign itself included use of the APS. So it is appropriate to make a direct comparison between the foot pedal APS with and without the behavior campaign. In this case, energy savings increased from 19% to 22.4% with the addition of a behavior campaign. This suggests an 18% increase in energy savings from adding a few behavioral techniques to a technology-focused strategy like an APS.

CPM demonstrates significantly higher savings than all of the APS-based strategies, with savings of 29% of total workstation energy (or 106 kWh for the stations we measured). This comparably-larger savings is presumably due to the fact that computer energy usage is such a high portion of workstation energy usage, and CPM is the only strategy that addresses that element.

The savings discussed in the report so far represent the direct electricity saved from plug loads only. Our analysis of the impact on heating and cooling loads (*Heating and cooling impacts*) suggests that there is additional energy saved in reducing cooling loads on the building (more than is spent on increased heating loads). This cooling impact adds between 4-7% additional savings for the CPM measure (which saves energy during the day) and between 0-3% additional energy savings for APS measures. This interactive impact varies based on the design of the building, including how heating or cooling dominant it is.

Finally, we can consider how well these strategies perform relative to the overall potential for energy savings in workstations. As each reduction strategy operates in a different and somewhat complex manner, we had to somewhat arbitrarily choose a single measure of energy savings potential: in this case the amount of energy used at each site on nights and weekends. So we calculated the *relative performance* of each reduction strategy as the energy saved as a percentage of that night and weekend (or "unoccupied") energy usage. This relative performance is listed in Table 11.

Table 11. Relative performance of each of the reduction strategies.

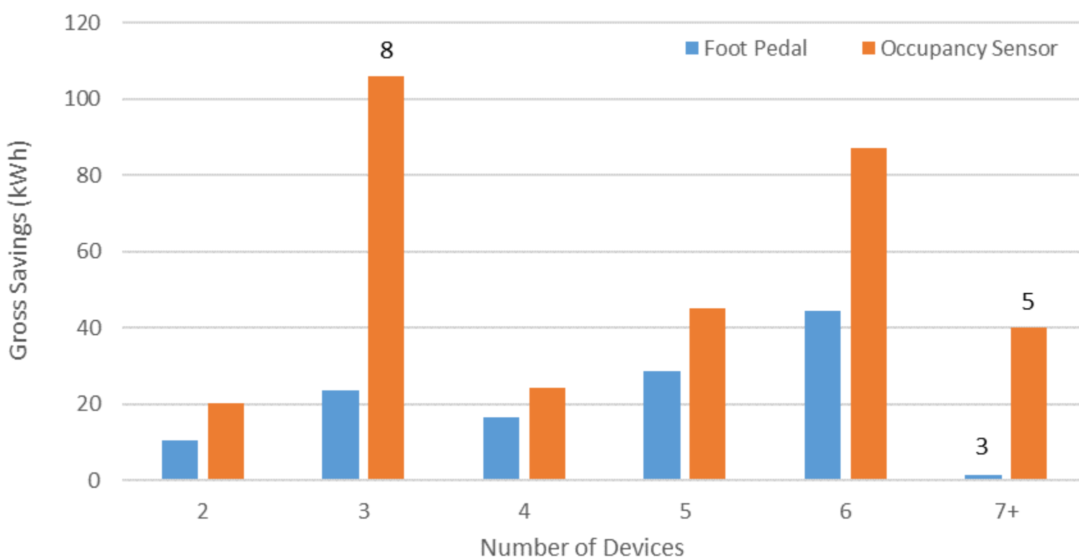
	Relative performance (% of unoccupied usage)
Occupancy sensor	59%
Computer power management	69%
Foot pedal	53%
Foot pedal + behavior campaign	65%

All of the reduction strategies save between 53-69% of the nighttime and weekend energy usage on average, with a similar rank-order of performance by strategy as with the other metrics above.

Predicting savings based on devices found

The presence of electronic devices in a given workstation has an impact on the magnitude of energy savings possible. We wanted to consider if it was possible to predict the energy savings potential of a workstation based on the number of extra devices found there, especially since the bulk of energy savings comes from the top quartile of energy users. Figure 36 shows the gross energy savings in each workstation versus the number of devices, other than the computer, found in each. The results are shown for the foot pedal and occupancy sensor APSs, which each control all the peripheral devices in the workstation (as opposed to CPM, which does not).

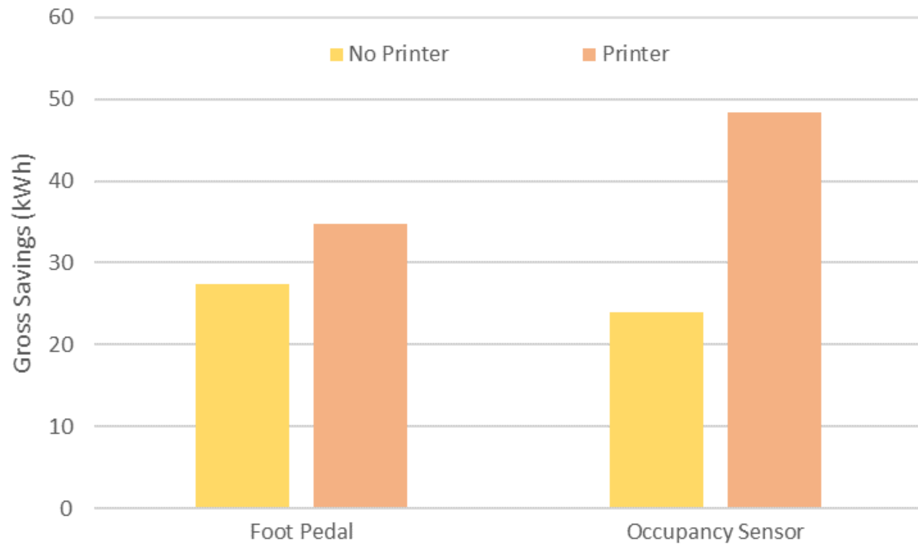
Figure 36. Gross savings versus number of devices sorted by foot pedal or occupancy sensor measures. Numbers above bars represent sample size, where the sample was small.



There is a general trend of savings increasing with the number of devices, especially when we consider that the number of workstations with seven or more devices represented a very small sample. However, there is significantly less variance in savings with foot pedal versus number of devices. And with the occupancy sensor, the largest energy savings was found in workstations with only three extra devices. So it appears difficult to predict APS savings based on the number of devices alone.

Certain devices have a bigger impact than others. Figure 37 shows the energy savings at one site for workstations which had a personal printer compared to those which did not have a personal printer, for both the occupancy sensor APS and the foot pedal APS. The data is for the City public works site where both APS measures were tested.

Figure 37. Comparing gross savings for workstations with and without a personal printer.



With the occupancy sensor APS, there was a substantial increase in the energy saved when a printer was present. If building owners or operators are conducting a more targeted campaign against plug loads, they could consider targeting workstations with larger extra devices—like printers—first.

Common area strategies

Workstation energy usage from computers, monitors, etc. may be the most commonly considered type of office plug load energy. But there are significant opportunities for energy savings in equipment outside of the workstations as well. We considered a number of reduction strategies to reduce this energy usage. **All energy savings discussed in this section are in units of kWh *per workstation* unless otherwise noted.**

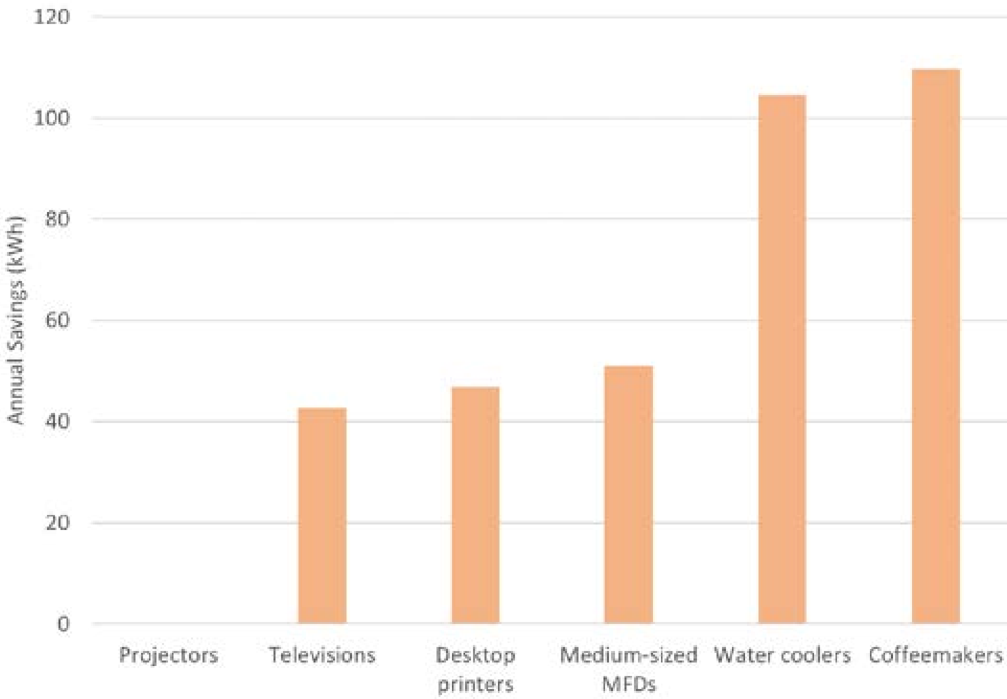
Plug load timer

The one common area strategy that we tested was a simple timer that shut off the device's energy completely during hours when the office was typically unoccupied (hours varied from office to office). We installed the timer on five different types of devices, and the energy saved for each type is summarized in Table 12 and compared in Figure 38.

Table 12. Energy savings from placing timers on common area devices.

	Energy savings		Idle Power	
	kWh	%	W	N
Projectors	0	0	0	6
Televisions	43	42%	12	3
Desktop printers	47	27%	16	6
Medium-sized MFDs	51	17%	19	7
Water coolers	104	21%	---	4
Coffeemakers	110	18%	30	5

Figure 38. Energy savings from placing timers on common area devices.



The devices that are used for hot and cold beverage service, coffeemakers and water coolers, have the largest potential for energy savings. Putting timers on a coffeemaker saves approximately 110 kWh per device (annually), and water coolers could save approximately 104 kWh per device. (It should be noted that the N is not very large for either device.) This energy savings is somewhat larger than the energy saved by a typical APS at a computer workstation. Additional investigation may be needed as to the effects of storing warmer water in a water cooler at night.

The energy saved from putting a timer on the other devices, desktop printers, medium-sized MFDs, and televisions, were all similarly around 50 kWh per device. This is of the same order of magnitude as the savings for installing an APS in a workstation.

We also tested the potential for saving energy on medium-sized projectors for conference rooms, but the standby energy usage of the projectors we tested was 0 W, so there were no savings demonstrated.

Table 12 also shows the typical idle power for each device type, or the power it draws when it is not being used at all (for example, what the devices would draw at night if they did not have a timer to shut off their energy use). Idle power is one indicator of how much energy can be saved using a timer or other plug load reduction device, but it is not the sole indicator. Devices like coffeemakers and water coolers will actually cycle on in the evening (to keep their reservoirs warm or cool, respectively). So potential savings for some devices can be much greater than that from their idle power alone.

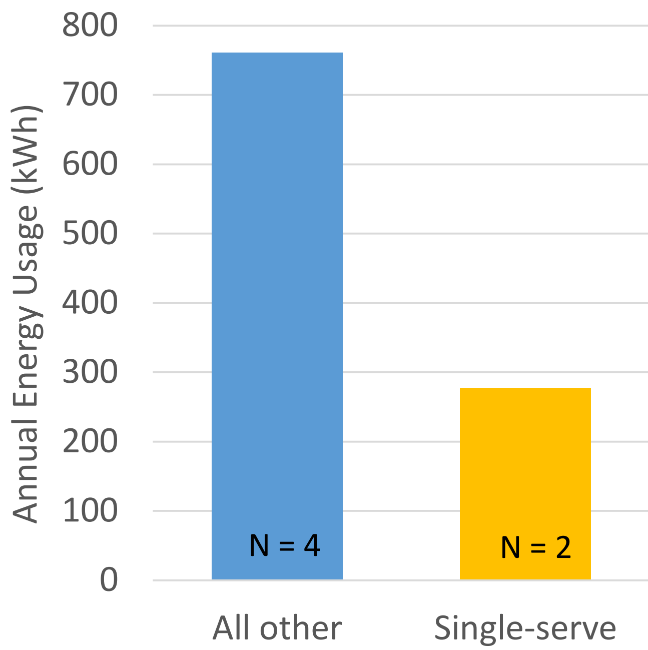
Different approaches to coffee service

Coffee service for the majority of the places we have data for is provided using a single coffeemaker used to fill one or multiple insulated containers known as airpots. This configuration most commonly appears as seen in Figure 39, with the coffeemaker on the left and two airpots at the right. The airpots are filled from the coffeemaker and are then set aside to be used (without any energy consumption once removed from the coffeemaker). This seems to be a change from the previously common practice of providing coffee via glass pots kept on burners.

Figure 39. Typical office coffee configuration.

Some offices may also use a single-serve coffeemaker (perhaps the best known example being a Kuerig coffeemaker). The limited amount of data that we were able to collect on coffeemakers suggests (but far from proves) that there may be significant energy savings for offices that are able to shift to a single-serve approach. Figure 40 demonstrates the annual energy usage of two single-serve coffeemakers and four coffeemakers of other varieties (airpots, traditional glass pots on burners, etc.) that we monitored.

Figure 40. Annual energy usage of different approaches to coffee service.



The single-serve coffeemakers used 64% less energy than traditional coffee configurations, with a potential savings of 483 kWh per year. All seven coffeemakers monitored served a similar number of office workers: the single-serve type averaged 34 occupants per device, while the other four served an average of 35 people each (our characterization survey yielded an average of 38 occupants per coffeemaker). Of course, the single-serve coffeemakers create significant additional packaging and the embedded energy of that packaging is worth consideration, though outside the scope of this study.

Removing extraneous common area devices

One simple strategy for reducing energy usage from devices in common areas is to remove those that are not really being used. We were able to find examples of extraneous devices in all device categories. In some cases, devices are extraneous because there are more than are needed in the office. For example, as employees increasingly rely on electronic processes as opposed to paper, there is less need for printers in many offices. The National Renewable Energy Lab (NREL) has demonstrated that an office can function well (Lobato, 2011) with just one printer/multi-function device for every 60 employees, plus some small number of additional printers for those with sensitive printing needs (e.g. human resources) or other constraints. In an office with three such sensitive-printing needs, and otherwise one printer per 60 employees, results in a total of one printer for every 15 employees. In the 34 offices that we surveyed, we found an average of one printer per 3.8 employees. This suggests that a 75% reduction is technically feasible in Minnesota offices.

Similar impacts are possible from increasing the number of employees per coffee station. The same study by Lobato found that a well-designed office can function with 60 employees per coffee station. Our survey found the average in Minnesota to be 31 employees per coffee station. Even greater savings could result from increasing the number of employees per kitchenette, though this is only possible to implement during large new construction or major renovation projects and was outside the scope of this study.

Another example of extraneous equipment would be a device that is not important to the productivity or well-being of the employees. Some offices provide water filters instead of water coolers for example, eliminating the cooling energy altogether without sacrificing the amenity of good drinking water.

Table 13 shows the energy that could be saved from removing five types of common area device, along with the number of each device type that we were able to measure. These values represent the average measured baseline energy usage of all the common area devices we measured.

Table 13. Potential energy to be saved by removing common area equipment.

	Annual Energy Usage kWh
Desktop printers	170
Medium-sized MFDs	352
Coffeemakers	548
Televisions	67
Water coolers	386

Television brightness settings

We did characterize some televisions (or digital displays) that were either used for continually displaying general messaging, or were in interior conference rooms, and therefore candidates for adjusting brightness settings from the factory defaults. We spot tested adjustment of two settings in internal conference rooms: the brightness setting and the backlight setting. Brightness had a minimal effect. The backlight setting, however, could potentially reduce the power of the television by 54% before a noticeable reduction in readability was seen. For the occasional-use conference room televisions that we measured, this would translate to a 36 kWh savings per device just for adjusting settings. Savings for continuously streaming message displays would be an order of magnitude higher.

Comparison to strategies from literature

There are other strategies for reducing plug loads beyond those tested in this study. For example, putting timers on workstations and implementing aggressive standby power settings on MFDs have both been shown to reduce plug load energy significantly. The potential energy savings of these two strategies, as well as a few others, are given in Table 14.

Table 14. Other plug load reduction strategies with energy savings demonstrated in literature.

	Strategy	Offices studied	Energy savings (kWh/station, kWh/device)	Energy savings (%)[2]	Source
Workstations	Timer power strip	2	115	53%	Metzger 2012
		1		26%	Metzger 2014
	Load sensing power strip	2	22	17%	Metzger 2012
		1	134	21%	Acker 2012
		1		4%	Metzger 2014
	ENERGY STAR desktops	-	89		ENERGY STAR
	ENERGY STAR laptops	-	23		ENERGY STAR
	ENERGY STAR monitors	-	29		ENERGY STAR
	LED task lighting, sensor	1	35		Lobato 2011
Break rooms	Timer (whole-room)	2	30	46%	Metzger 2012
	ENERGY STAR refrigerator	-	41		ENERGY STAR
Work room	Timer (whole-room)	2	108	50%	Metzger 2012
	MFD sleep mode	1	140		Martin 2014
	ENERGY STAR printer	-	154		ENERGY STAR

As shown in Table 14, the energy savings from placing timers at workstations is substantial. It was measured at 115 kWh in one study of two different federal agency departments (Metzger 2012), and 26% (no kWh number given) at another study of a different federal office space (Metzger 2014). Though these offices were likely much more plug load-intensive than those we tested (just based on the potential for energy savings in unoccupied hours of the day). The device tested by Metzger et al was an APS with a timer element. Energy savings from enabling an aggressive sleep mode on MFDs was similar in magnitude at 140 kWh per device in a study of two MFDs at a different federal facility (Martin 2014). Note that sample sizes are quite small in all three of these studies, but there does appear to be significant potential.

Two other measures that show potential in Table 14 are replacement of equipment with ENERGY STAR equipment, and load sensing power strips. In the case of equipment replacement, this strategy is less relevant to utility programs and office owners because the majority of office owners replace office equipment on a set schedule and replace with ENERGY STAR equipment as a policy (so there is no need to offer incentives). In the case of load sensing power strips, two of the three studies (Metzger 2012 and 2014) of this strategy show weak savings. Significant potential seems less likely with this strategy.

Finally, one study (Metzger 2012) tested timers on work room equipment, similarly to our tests of timers on printers and MFDs. But that test used a timer on all outlets in the work room. Energy savings for an entire work room (in two different office buildings) averaged 108 kWh per room, which was more than double the savings our study demonstrated for individual device control on printers and MFDs. Whole-room control would be most practical to implement in new construction or tenant build-out, when a schedule could be placed on the operation of the entire room.

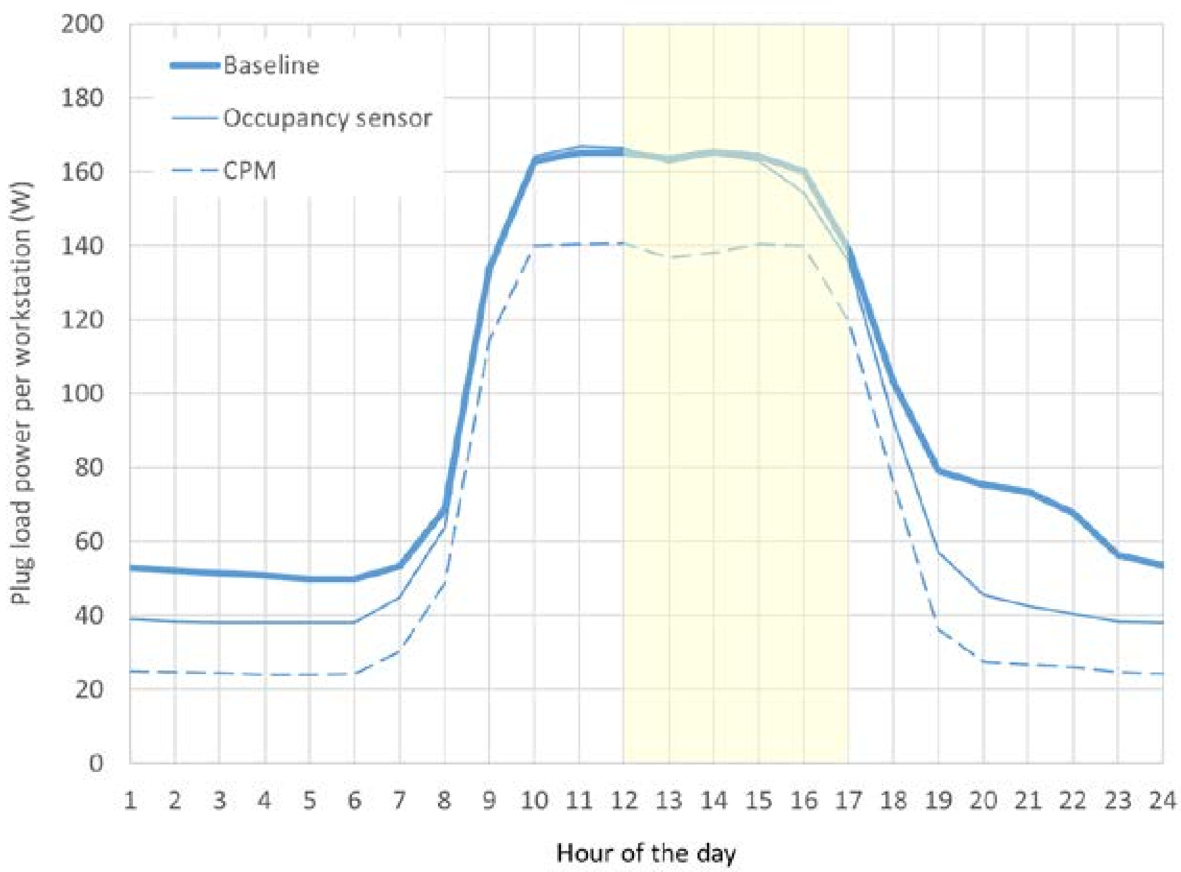
[2] Savings are given as a percentage of the energy used by the entire workstation or room.

Peak demand reduction potential

Many utilities are as interested in reducing peak demand (i.e. kW) in their service territory as they are in reducing overall electricity usage (i.e. kWh). As a result, we also calculated the change in the daily load shape caused by each of the tested reduction strategies, and the resulting reduction in peak demand. The same experimental and analytical methodology was used for peak demand as for energy consumption; the metric was just changed to the average demand at five different hours of the day: each hour from 12:00 pm to 5:00 pm, when an office building in Minnesota would be expected to peak in electricity usage during the summer months (when utilities are most concerned with capacity and demand).

Figure 41 demonstrates the demand impact for the Architecture office, with this 12:00-5:00pm timeframe highlighted. The average workstation power is shown for the baseline, followed by each of the two measures tested there.

Figure 41. Demand in the Architecture office during the baseline and two treatment periods.



The profile of this impact was similar for other sites. CPM reduces demand throughout the day and into the night (and weekends). An APS only has a significant impact on demand during the evenings and weekends, because it has less ability to impact energy usage while users are present.

Specifically, we found that the demand reduction from the foot pedal APS was not significant within our sample size because it primarily saves energy (and demand) during less occupied periods such as early morning, late afternoon, evening, and weekends. The occupancy sensor APS reduced peak demand slightly, with an average peak demand reduction of 3 W per workstation. Its demand reduction potential is curtailed for the same reason as the foot pedal. CPM demonstrated much larger peak demand reductions due to its greater impact during occupied times (as seen in Figure 41). CPM's peak demand reduction averaged 9 W per workstation.

Economics of plug load strategies

Although low-cost, all plug load reduction strategies do have a first cost, in terms of both labor and equipment. The strategies that we tested had costs ranging from $17 to $55 per workstation (including labor). Table 15 lists these costs in detail, based on labor and equipment costs that we incurred in setting up our tests. The lowest cost measure was CPM, because the software for implementation is included in modern computer networks and minimal labor is required for initiation. Note that our CPM cost includes costs for pre-testing of the strategy for feasibility but does not include any major troubleshooting, which might be incurred in some scenarios if individual software or work habits do not work well with the CPM. The upper end of the cost range applies to the APS strategies, because these require both setup and purchase of equipment.

Table 15. First costs, per workstation, for implementing each strategy.

	Equipment	Labor	Total
APS, existing workstation	$40	$15	**$55**
APS, new workstation	$20	$15	**$35**
Common area timer	$27	$9	**$36**
CPM		$17	**$17**

It is not obvious whether this first cost increase is justifiable based on energy savings on all projects. We have therefore completed a life cycle assessment based on the benefit of the energy cost saved. This does not include some other potential cost impacts such as incentives, increased productivity, carbon credits, etc. This assessment is valid for building design teams or owners considering incorporating the technology, and also for utility program personnel in Minnesota who need cost information to implement and evaluate these programs.

We conducted life cycle cost analysis in accordance with the procedures of the Federal Energy Management Program (FEMP) (NIST 1995). The inputs to this analysis are shown in Table 16.

Table 16. Inputs and assumptions for economic analysis.

	Value	Basis
Electricity cost	$0.095 / kWh	Average commercial electric rate in MN, based on EIA 2015 data.
General inflation	1.5%	Difference between 20-year treasury bills, inflation adjusted and not
Fuel inflation, electricity	2.2%	FEMP 10-year outlook
Total tax rate	45%	Nominal federal business tax rate + MN corporate tax rate
Depreciation of equipment	20 years	Straight-line depreciation
Discount rate	5-9%	9% for the corporation scenario, 5% for an institutional scenario
Life cycle cost timespan	20 years	Estimated lifespan of a power strip

We considered two categories of building owners, corporation and institution, and the economic outcome of these owners choosing plug load reduction strategies in Minnesota. Corporations are assumed to use a higher discount factor of 9% and pay corporate tax rates typical of Minnesota businesses. Institutions are assumed to pay no taxes and use a lower discount factor of 5%. Following FEMP guidelines to decide whether to adopt a technology, these organizations would need to determine whether the net present value of the technology was positive or negative.

Because the costs of these systems can vary significantly, we first calculate the cost at which the owner would break even (have a net present value of zero). For our median values of energy savings, this results in the break-even costs for corporations and institutions shown in the first row of Table 17 and Table 18. Though we recommend that decision-makers consider this break-even cost as the primary metric (because it includes all financial elements), some will still be interested in simple payback. This is reported in the second row of each table.

Table 17. Economic analysis results for corporate owners.

	APS new workstation	**APS** exist. workstation	**CPM**	**Timer** beverage	**Timer** MFD / printer
Break-even cost	$75	$75	$143	$144	$66
Simple payback	5.8 years	8.4 years	1.6 years	3.3 years	6.6 years

Table 18. Economic analysis results for institutional owners.

	APS new workstation	**APS** exist. workstation	**CPM**	**Timer** beverage	**Timer** MFD / printer
Break-even cost	$81	$81	$154	$155	$68
Simple payback	6.6 years	10.4 years	1.7 years	3.6 years	7.8 years

CPM is the most cost effective measure by this analysis, with a break-even cost of $143 for corporations and slightly higher for institutions. Most offices should be able to implement CPM for well below this cost. Simple payback is on the order of one and a half to two years.

APSs show reasonable cost-effectiveness, with a break-even cost between $75-81 per workstation, which far exceeds the cost of the device itself. Though installation must also be considered. Two scenarios were evaluated for the simple payback of APSs: one in which an existing workstation with a functional power strip has an APS added and another in which a new workstation is being constructed or added and needs a power strip. For new workstations, only the additional incremental cost is used for the cost of an APS beyond that of a standard power strip. Simple payback varies from 6 to 10 years depending on the scenario.

The economics of the APS strategies look considerably better if we consider the possibility of an incentive (upstream or downstream) for each device. In some large utility programs, a $20 incentive is available for each APS. When accounting for this, the simple payback time decreases from a little over eight years (8.4) to just under six (5.7) years in existing workstations, for a corporation. For new offices, the payback decreases from 5.8 years to 2.5 years.

For timers on common area equipment, cost effectiveness is dependent on the type of equipment. For beverage devices such as water coolers and coffeemakers, the break-even cost of installing a timer is $155 per device. In comparison, MFDs and printers yield less energy savings with timers due to better standby energy control on those devices. Therefore, the payback period for a timer installed on a MFD/printer is significantly longer.

Participant acceptance and operational issues

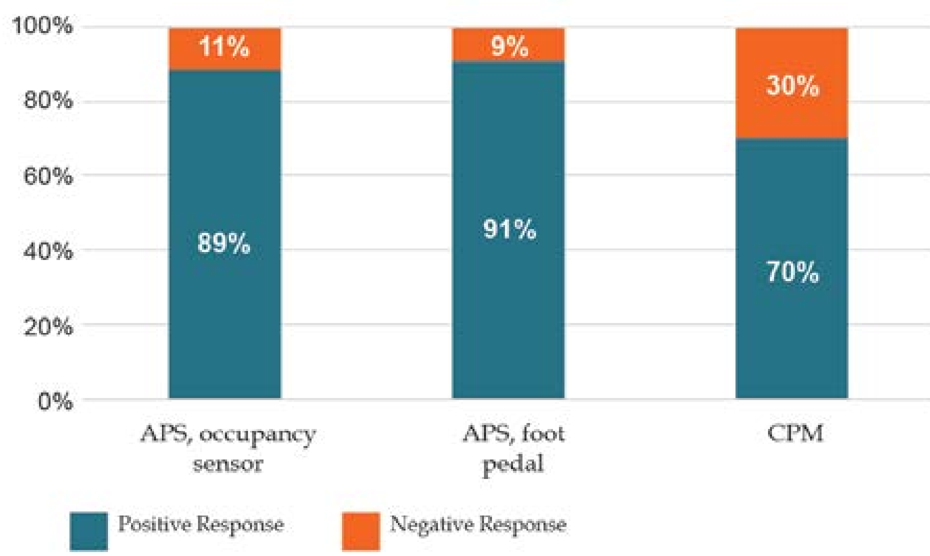
We surveyed participants to gauge their satisfaction with the plug load reduction strategies implemented. We also observed and recorded operational issues encountered.

Participant satisfaction survey results

Participants that took part in testing each of the strategies were given a follow-up survey to gauge their satisfaction with each strategy (see *Participant satisfaction survey* in the *Research Method* for more details). Participants gave generally positive responses when asked about their experiences with reduction strategies for both their workstations and common area devices.

Figure 42 summarizes the responses for each strategy that was implemented at the workstation.

Figure 42. Workstation plug load reduction strategy acceptance.



At least two-thirds of participants responded positively to each workstation measure. The strategy that received the most favorable responses was the APS with foot pedal, with 91% favorable responses, and consistent response across all sites. The APS with occupancy sensor was also well received. CPM was generally well received though less so than the APSs. Seventy percent (70%) of participants responded favorably to the CPM settings. But a full 30% of surveyed participants indicated that they would like their devices to remain on longer, indicating that more outreach, training, or less aggressive settings may have been optimal.

Response to APS with foot pedal

The APS with foot pedal was favorably received by participants, with a significant majority stating that it was convenient and only 9% suggesting some inconvenience (Figure 43).

Figure 43. Convenience of APS with foot pedal.

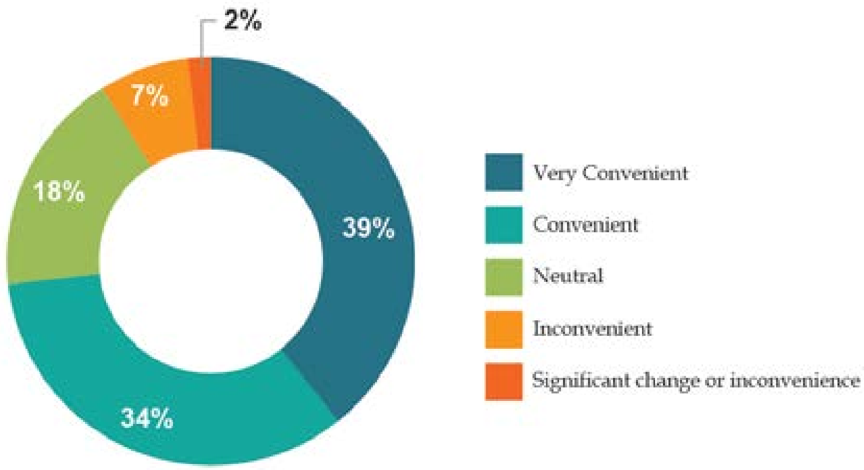
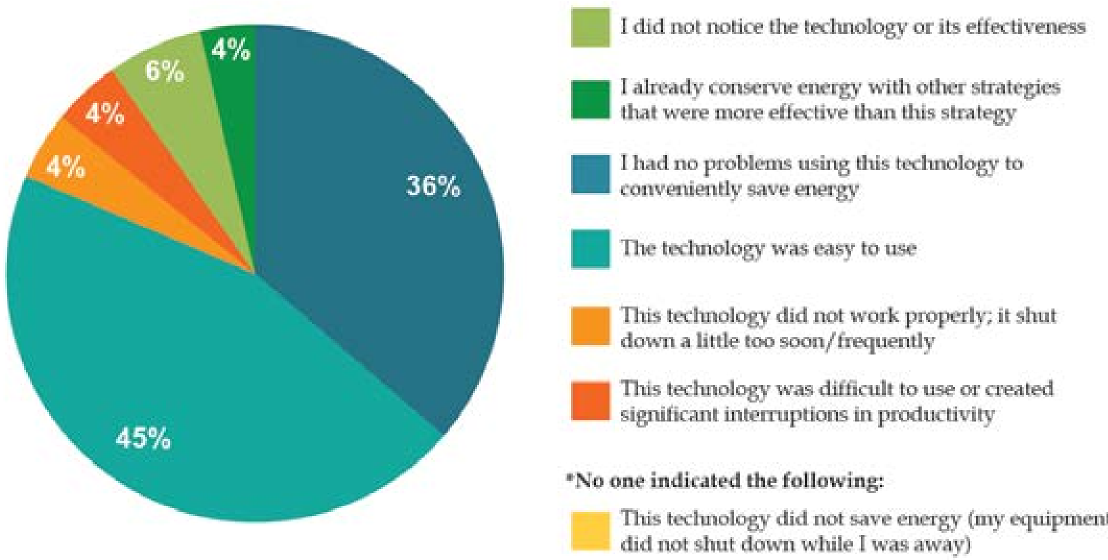


Figure 44 describes the participants' reactions more specifically, and relates those responses to the effectiveness of the strategy. Of those with negative responses, 4% indicated that the APS shut down devices too frequently; this issue can potentially be addressed by changing the timer setting. Only 4% of participants indicated that the technology was difficult to use or created a significant interruption in productivity. Unlike other strategies, nobody indicated that the foot pedal failed to save energy.

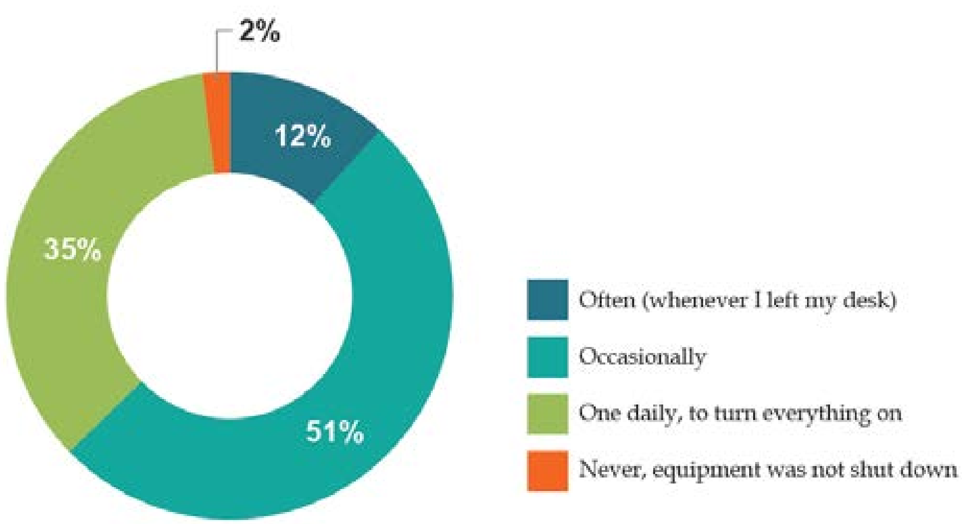
Figure 44. Ease of use and effectiveness of the APS with foot pedal.



These responses to the APS with foot pedal were also reasonably consistent across the sites we studied, with negative response rates all falling in a range between 5% and 16% of respondents.

The foot pedal differed from the other strategies in that it required interaction from the user. There were actually two primary ways that users could use the device. The APS saved energy for less engaged users by timing out at the end of the work day and shutting off all their devices. But more engaged users were able to save additional energy by pushing the foot pedal multiple times per day, such as when they left for lunch or went to meetings. Figure 45 shows that about 35% of users pushed the foot pedal only once per day, to turn on devices at their workstation. The most engaged users, 12%, reported pushing it whenever they left their desk, and 51% reported pushing it occasionally throughout the day.

Figure 45. APS with foot pedal frequency of use.



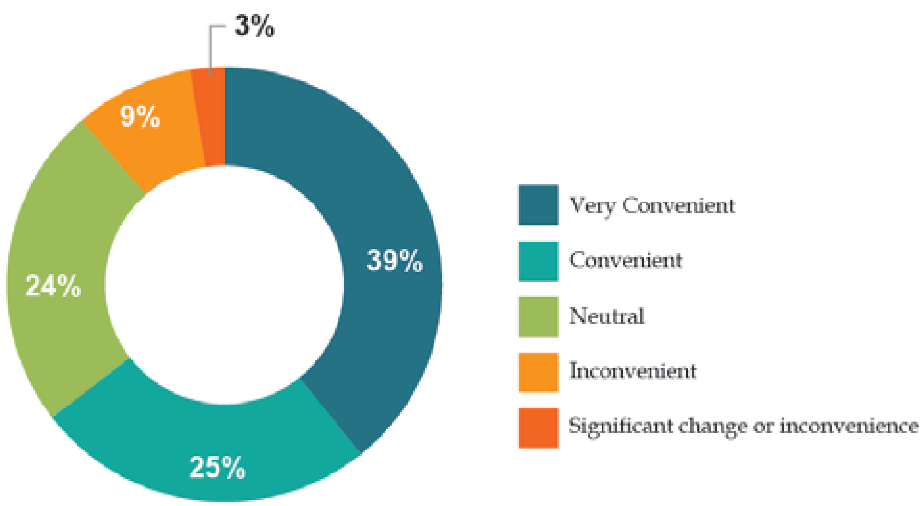
Frequency of foot pedal use did vary slightly between sites. Participant responses from City public works and Product development sites indicated that approximately half of users pushed the foot pedal more than once daily. At the Engineering site participants were much more actively engaged with the foot pedal. This is due in part to the fact that the behavior campaign was also implemented at this site, engaging more users. Only 11% indicated that they used the switch once daily, and 84% indicated that they used it more than once per day. Also, 21% of participants at the Engineering site indicated that they used the foot pedal every time they left their desks, compared to 5-8% at the other sites. Training and behavior has a significant impact on this strategy.

Specific respondent comments suggest that participants preferred the foot pedal because it let them to decide when they would shut things down, rather than relying on an automated or timed shut down (CPM and APS with occupancy sensor) which might shut down equipment prematurely, interrupting their productivity, or not soon enough. A few users suggested that the length of cord and foot pedal placement was an issue. Several users indicated preference to have the button on their desktop as opposed to the ground, but the short (3 ft.) cord prevented this. A few other users indicated that they inadvertently bumped their foot pedal at times. In all, the high rating for both ease of use and effectiveness combined with relatively high engagement suggests this APS strategy can be deployed with good user satisfaction.

Response to APS with occupancy sensor

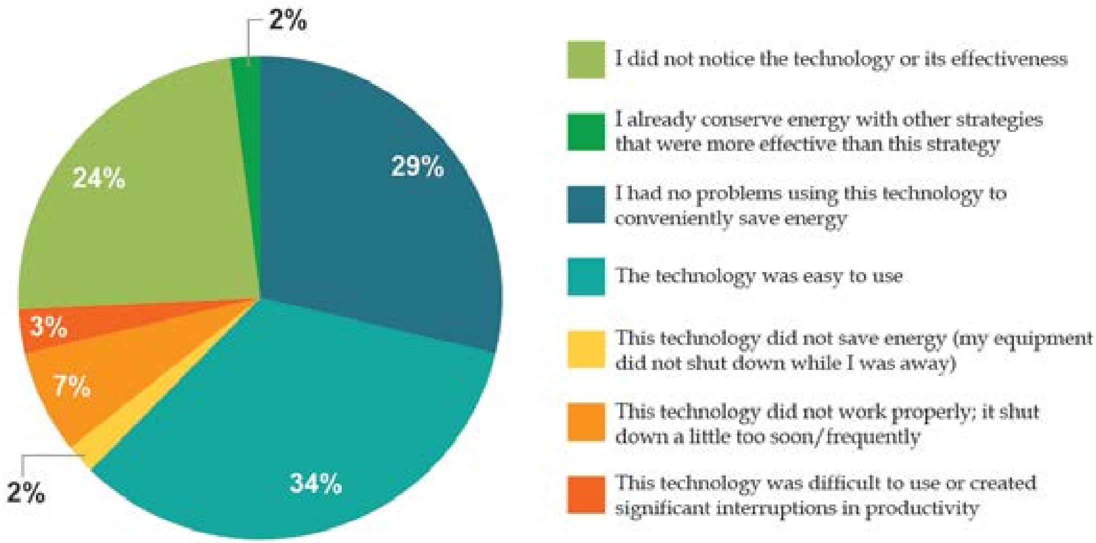
The APS with occupancy sensor was favorably received by participants with a significant majority stating that it was convenient and only 12% suggesting some inconvenience (Figure 46).

Figure 46. Convenience of APS with occupancy sensor.



The APS with occupancy sensor was generally considered to be effective by users in saving energy, as shown in Figure 47. A combined 63% of responses indicated that participants had no problems using the technology to save energy.

Figure 47. Ease of use and effectiveness of the APS with occupancy sensor.

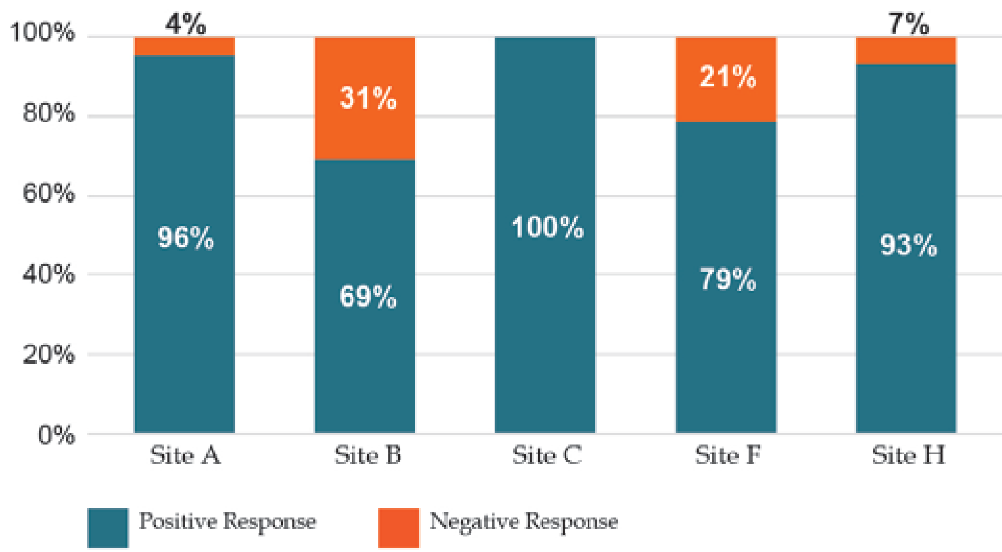


Interestingly, 24% of respondents indicated that they did not notice the technology or its benefits. As this technology is intended to seamlessly turn secondary plug loads on and off without requiring any action from the occupant, having a substantial group who did not notice the technology can be considered as positive. However, there is a converse to the hands-off nature of this strategy, as participant comments did suggest there were a few scenarios where the placement of the sensor prevented equipment from shutting down due to the occupancy sensor detecting movement in the area outside of their workstation.

Another potential negative aspect of the lack of occupant interaction with this APS is found in those who did not find the technology effective. Because the strategy relies on an occupancy sensor to detect occupancy in the workstation, and not a conscious decision to turn power on or off, it is both more prone to improper activation or deactivation, and its operation is less transparent or understandable by its user. Ten percent (10%) of respondents indicated that the technology did not work properly (shutting down too frequently or not frequently enough) or created significant interruptions. Specific comments suggested that many of these participants were reacting to this lack of interaction and transparency. One user commented: “Not [manually] shutting [my devices] down and letting a sensor do the work made me nervous.”

With the occupancy sensor, responses varied more from site to site. Figure 48 shows responses varied from 69% to 100% positive across sites.

Figure 48. Acceptance of the APS with occupancy sensor by site.



Comparison of satisfaction with APS strategies

At a high level, both APS strategies had positive user feedback. The APS with foot pedal was rated slightly higher for convenience than the APS with occupancy sensor. Those users who did show a preference liked the ability to interact with, and understand, the foot pedal. One user commented: “The power plug with the on/off [button] was by far the preferred method. It was easy to use and did not impact my ability to do my work.” Also, at the Energy non-profit site, we conducted a test in which users were given a choice of which device to have in their workstation for the final four weeks of the study, and foot pedals were a significant preference.

Participants had a similarly positive response when asked about the effectiveness of the technologies. In addition to having increased control with the foot pedal switch, there were several issues with the occupancy sensor responding to movement in the area of the workstation and either not turning off, or turning back on when no one was at the workstation. These seemed to be mostly avoided with the foot pedal.

The survey results show that either APS strategy has the potential to be an effective technology to save energy while satisfying users.

Response to computer power management

Participants were also surveyed about the convenience and effectiveness of CPM. To create the survey questions, we assumed that satisfaction with CPM was a balance between saving energy (powering down soon enough) and maintaining productivity (not powering down too much). We used the ENERGY STAR recommended CPM settings. At all sites surveyed, an average of 60% of respondents indicated that those CPM settings were just right, 30% of respondents indicated that CPM settings were too aggressive (powering down devices too early), and 10% indicated that CPM settings could have been more aggressive (powered down devices too late).

Participant survey responses to the CPM strategy varied drastically by site. Figure 49 shows the wide variation of acceptance between sites.

Figure 49. CPM preferences by site.

Four of the five sites where CPM was installed had high acceptance rates, with over two-thirds of all participants responding favorably to the technology. At three of the five sites (C, G, and H) an average of 87% of survey respondents showed a positive response. These high acceptance rates show that overall CPM can be implemented effectively with ENERGY STAR recommended settings. Site C was also the only site with an external IT group that implemented the strategy.

There was one site that had a very negative response rate to the CPM technology. At site D, 69% of participants had a negative response to the CPM settings we tested. There were also several negative comments about CPM at site D. Specific comments from this site showed that participants had issues with restarting computers after CPM went into effect, software not running properly afterward, and network connectivity or processes being interrupted. One participant commented that "it might take between 5-10 minutes to restart a computer" after CPM enabled sleep mode was activated on it. We did not hear that magnitude of concern from any other participant across the five sites. The fact that the bulk of the negative responses came from one site suggests that some amount of rigorous pilot testing should be conducted prior to implementing CPM in an office.

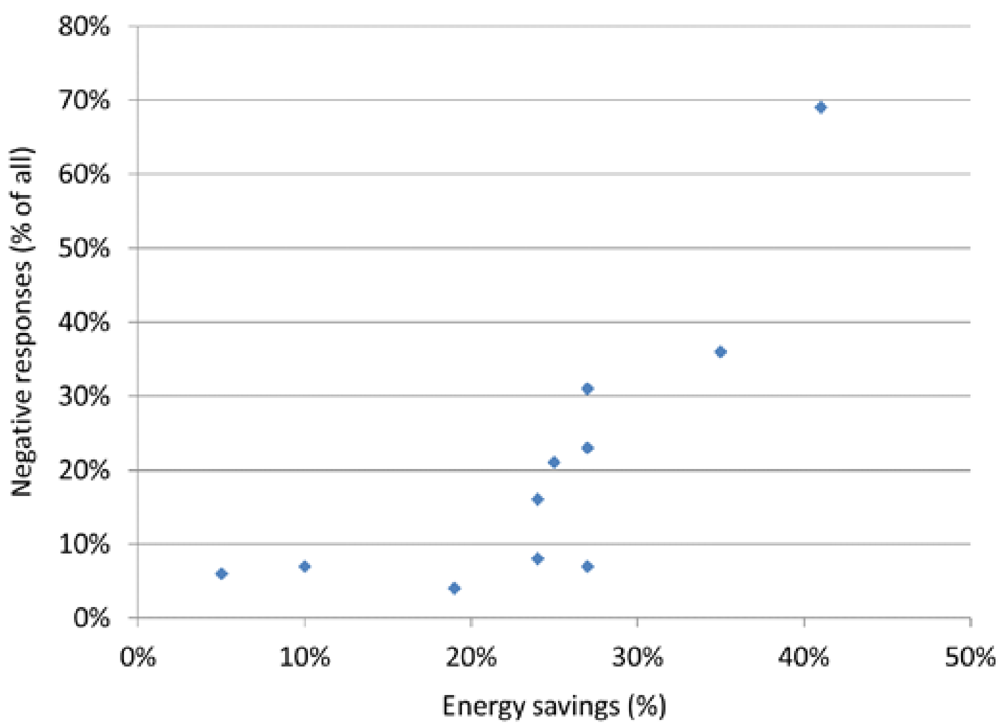
The most common issue discussed before, during, and after CPM implementation was the inability for some participants to work remotely and maintain a constant connection to their workstation. This was recognized *prior* to implementation at each site, and we dealt with reducing disruption in a number of ways (see *IT integration of computer power management*), but there were still a few instances at each site where CPM resulted in negative responses *during* implementation.

There were a few other survey results of note:

- At least some participants at three of five sites indicated that CPM levels could be made more aggressive, suggesting that CPM time-out settings could be enabled as maximum settings and users allowed to make those settings even shorter if they wish.
- Site C, the only site with CPM installed that was essentially all laptops, was the most successful implementation of CPM in terms of satisfaction, with 93% of participants indicating that levels were set appropriately for them.
- A few users commented that CPM would shut their computer down while they were referencing their screen but not actively engaging the computer.

In implementing CPM there is a balance in the aggressiveness of the settings between saving energy and satisfying occupants. Figure 50 demonstrates this balance by comparing the percentage of negative responses for a given treatment versus the amount of energy saved by each treatment. All strategies are included in this figure, not just CPM. But the figure suggests that there may be an acceptable threshold level for plug load control measures like CPM. Savings of up to 25% were broadly accepted, while above 25% users began to be dissatisfied. More research is needed in the behavioral aspects of plug load reduction to understand this in more detail.

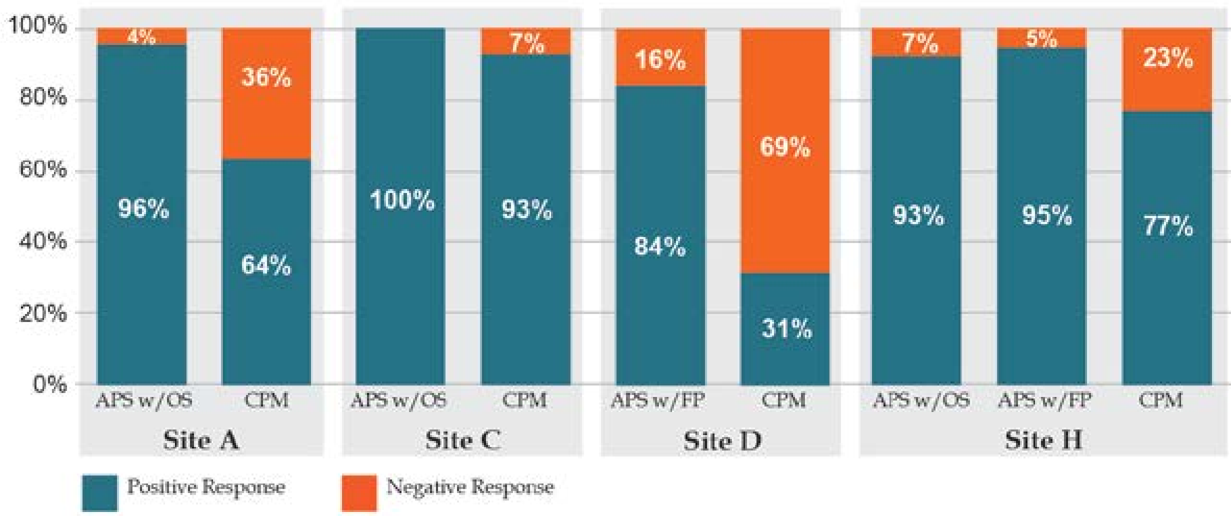
Figure 50. Frequency of negative responses versus energy saved for each treatment test.



Comparison of satisfaction of CPM and APS

To fairly compare APS and CPM strategies, we must limit the comparison to only sites where at least one APS strategy was installed in addition to CPM. Figure 51 compares positive and negative responses for this subset of sites.

Figure 51. Acceptance of APS and CPM strategies by site.

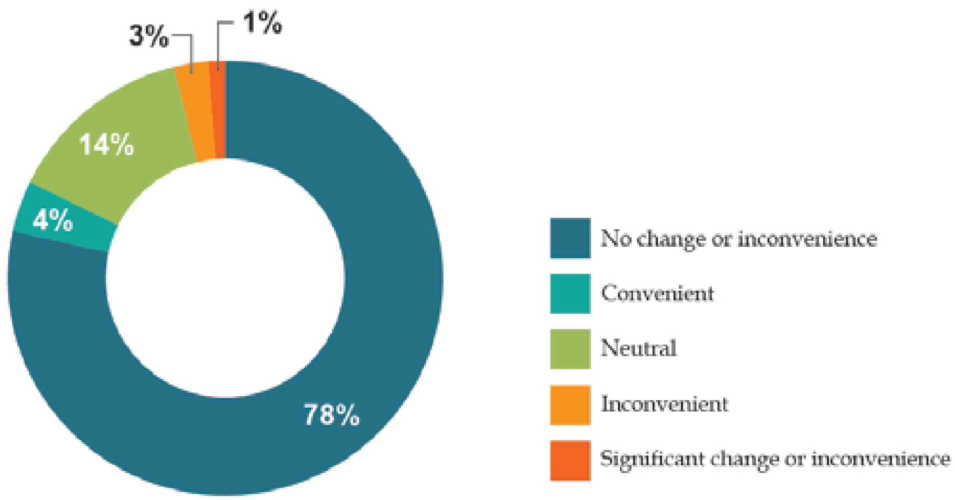


At all sites, the CPM strategy was less well received than the APS strategies. Site D showed the greatest difference in acceptance between the APS and the CPM strategies: the APS was rated positively by 84% of participants, and CPM was rated positively by only 31% of participants. Site C was the most accepting of both strategies, with 100% of participants rating the APS with occupancy sensor positively and 93% of participants rating CPM positively.

Response to common area equipment timer

The post-treatment survey indicated that the timers placed on most pieces of common equipment were not disruptive. Figure 52 shows that 96% of all respondents indicated that they did not notice any change/inconvenience in common equipment or thought the implemented strategies were convenient. There were a few devices that required more sophisticated shut down procedures than the basic timer that we tested, such as MFDs and some video conferencing equipment, which led to a few negative responses. Some of these devices, such as MFDs, have begun to be manufactured with low power standby modes that handle this issue without a timer. For the less smart equipment that we tested, devices were not negatively impacted by the timer disconnecting the power.

Figure 52. Convenience of common area equipment strategy.



Response to behavior campaign

In lieu of creating an online survey to measure post-treatment results of the behavior campaign, we had follow-up conversations with our contacts at the two sites that implemented this strategy. Both had implemented all the steps of the campaign we requested (again, our site contacts drove the campaign, not us) and continued with the campaign through the entire month of testing.

The primary takeaway from these discussions was that the blue feedback LED above the desk had a significant impact on participants. Users were heard to comment both to each other and to our site contacts about the light, including some friendly joking about colleagues' LEDs. So it accomplished one of its primary objectives, which was to get people talking about the campaign. There were a few negative comments. Some users reported that it was too bright and some changed its position on the desktop as a result. Some reported that they felt some peer pressure or shaming if the light was on while they were away from their desk. One respondent summed up what we heard from a few people:

> "I refuse to adjust my behavior on the basis of peer-based ridicule…Take the peer pressure part out of the plan and I'm totally on board. What the lights are good for is providing awareness of the energy state of my cubicle. This is more helpful when the light faces me than when it faces my peers. It's a good tool for helping me be a mindful occupant of my space."

This social norm "lights off!" was intended, but perhaps design revision is needed to avoid "ridicule" and keep the campaign positive for all participants.

There was significant positive feedback from the reward element of the campaign. One site contact reported that users "liked to be acknowledged for their efforts" to save energy. And the information was deemed helpful for informing actions as well, though our site contacts did suggest that even more integrated materials were needed: articles for their company newsletter, elements on their intranet, etc. The timing and budget of our study did not allow for these extensions, but they should be considered when conducting future campaigns.

It’s also worth noting that the campaign may have received positive responses because we chose to tie it to the foot pedal as an enabling technology and that technology turned out to be highly satisfactory to users (see above). Users seem to appreciate having that control over their power and devices and likely felt that enabling factor as a result.

Summary of strategy acceptance

As with the response to CPM, there are overall trends of acceptance, with a few variations from site to site. These site-by-site variations in response could be related to workstation equipment (age and type), typical work activities and programs, typical work hours and location. These site-specific response variations suggest that some strategies that are appropriate for one type of office or equipment may be less successful in others.

Operational issues

In addition to feedback from occupants, we also observed and recorded operational issues while working in the field and interacting with our site contacts and their coworkers. We directly observed issues with integrating new hardware, and indirectly observed issues with CPM implementation via our IT contacts.

Hardware integration

Though less complex than integrating CPM, the hardware strategies we tested did result in a few issues:

- Some electronics work better with a soft power-down. Abruptly cutting power to certain equipment like dedicated teleconferencing equipment and large copiers can be problematic. Testing may be required before wide implementation.
- A small subset of advanced graphics cards can have issues if un-matched dual monitors are abruptly shut down.
- Some laptop docking bays had issues when the APS shut of the monitor. These issues were generally resolved by resetting display settings.
- Placement of the APS occupancy sensors is very important to the success of this APS technology. If placed with too much line of sight the sensor can pick up movement in spaces adjacent to the intended workspace which results in equipment being on at unnecessary times. Or, if the sensor doesn’t have enough line of sight, it cannot sense movement at the intended workstation and shuts equipment down prematurely.
- Both APS technologies incorporated a built-in timer, which occasionally caused issues if it was not adjusted to fit the application. This issue was easily fixed on site by adjusting the timer setting.

IT integration of computer power management

Computer power management is notably different from the other strategies that we tested in that it necessitates integration with local IT department protocol. Some APSs may necessitate some interaction with IT departments, but essentially all CPM changes will need this interaction. We spoke with the IT department at each office that we studied, whether CPM was implemented or not. Figure 53 describes those interactions, including what CPM (if any) was already implemented in the baseline period, the level of concern or barriers that were communicated by IT staff, and the progress we made in implementing CPM at each site.

Figure 53. Summary of CPM progress made at each site in our study.

	CPM as found	Concerns / barriers posed	Open to improvement	Improved	Network policy used	
Architecture	None	Large	■	■	■	Nearly all concerns overcome
City public works	User-controlled	None	■			Lack of a test not due to IT
Engineering	None	Moderate	■			
City office	None	Small	■	■	■	Remote desktop was only barrier
Real estate	User-controlled	None	■	■		Fully outsourced IT
Prod. develop.	Weak settings	Small	■	■	■	
County office	None	Large				IT: computers must run 24/7
Energy non-profit	User-controlled	Small	■	■	■	

In most cases, when we arrived at a site and monitored the baseline condition, CPM settings were either not implemented at all or were left entirely up to user control. Also in most cases, there was some amount of concern posed about us implementing CPM at each site. Only two of the eight sites had no concerns and immediately invited us to dictate CPM modifications. However, after discussion and in hearing our plan for mitigating any issues, seven of the eight sites were open to improving their CPM settings. Of those seven sites, we implemented CPM at five of them, and easily could have done so at a sixth site (City public works) but project constraints on our side prevented it.

The concerns or barriers to CPM modification that were posed to us were generally in one of the following areas:

Remote access. At every site except for the County office, an immediate consideration for IT staff was the need of some of their employees to access their computer remotely (e.g. to log-in in the evening to work). CPM can present problems with accessing a computer remotely. Incidentally, many of the users using remote access reported only having to do so a few times a year for the occasional project or if a snowstorm prevents travel to work.

> *Solutions:* This turned out to be by far the most common problem that we encountered, but there were solutions to work around the problem. The first tool that IT can consider is a wake-on-LAN approach, which utilizes software on the local network to wake computers that are needed based on some communication. The Energy non-profit that we worked with used this approach.
>
> Some network setups cannot readily be configured with wake-on-LAN. For these situations, ENERGY STAR has developed some basic instructions for solving the issues that do arise. To begin, IT staff can follow the basic instructions at ENERGY STAR's Low Carbon IT Campaign website.

ENERGY STAR additionally suggests using a [remote desktop manager]() if you are using an app to initiate the connection.

Finally, if technical solutions cannot solve a given problem, a pragmatic approach is to implement CPM on just those workstations where there is a very low likelihood of a user needing to use remote access. This can be done in an opt-in fashion, where users decide whether they need remote access and IT implements CPM accordingly. This approach worked well for the City office site in our study. IT could also use an opt-out approach, in which CPM is implemented for all staff, and only those that log a complaint or comment are given different settings. This worked reasonably well in the Architecture office that we studied. Regardless of the approach, in the five offices we worked in, a minority of the users that we interacted with needed to be excluded from the CPM settings.

Technology configurations that allow users to access many of their files via a server, instead of remotely accessing their computer, can also eliminate most of the remote access problem. This type of configuration was also a mitigating factor at the Energy non-profit. Unfortunately, whether this configuration exists is not likely to be driven solely by desire for CPM.

Pushing updates. At various times IT staff need to push updates, patches, and other modifications to all computers in their purview. Depending on how this is scheduled, CPM is perceived to potentially interfere with this process. This was viewed as anywhere from a minor nuisance or a major problem by the IT departments we spoke with.

Solutions: Modern software allows updates and other modifications to be pushed the next time the computer is both on the network and awake. This is how laptops are kept updated within typical networks. Desktops can behave similarly, when they are shut off or put in sleep mode. We spoke with multiple IT staff who used this approach successfully.

Software. Some types of software do not behave properly when the computer automatically goes into sleep mode (e.g. they may not save all data properly). We encountered this in just a handful of users across the more than 100 workstations where we tested CPM.

Solutions: As a proactive step in departments with somewhat sensitive software, would be to have IT staff run tests on one or two computers to ensure that CPM will work. The Architecture office that we studied took this step with some of their software. But the other sites we worked with were simply reactive and adjusted users' settings if they complained or commented after an issue arose. This approach worked well too, as only a handful of users had issues across the four other sites. As with remote access, it makes sense to eliminate just a few individuals from the CPM settings, as opposed to avoiding all CPM just for those few.

Other priorities. IT departments in any office have a large responsibility in maintaining the robust operation of hardware and software. This hardware and software generally supports an amount of productivity that dwarfs the cost of the energy used to power the IT equipment.

Solutions: This is a legitimate concern of IT staff. One solution would be to implement CPM when IT is making other, related network changes. This way the act of modifying and pushing settings does not take any incremental time, only adding in the few additional CPM settings. Some testing time may still be needed. Another solution to this problem is for the directive to implement CPM to come from management, as opposed to from within IT. If saving energy is seen as a priority alongside other business priorities, IT staff are more likely to be successful in implementation. As we were often working with management to get our research conducted, we had this advantage in our discussions. A related example was the Real estate office, which was a smaller office that used fully outsourced IT. They simply ordered their IT subcontractor to complete the necessary steps.

Of the five sites where we implemented CPM, the majority of these barriers were overcome within the one-month test. When the test period was over, we told IT they had the opportunity to revert back to previous settings but the settings remained in place at all five sites—with the caveat that a few of those individuals that had remote access or software issues were removed from the test group. IT staff reported that running a one-month test (as opposed to telling a user that new settings are being implemented forever, with no choice) allowed for a beneficial break-in period that let users to become comfortable with the change. By the end of this period people had overcome their concerns.

In most cases, implementing CPM in a typical department reportedly took about a half day of IT time. This time is needed for testing, writing the CPM template, and pushing that template out to all the computers. This can be reduced once a template is created. In a large corporation, this would probably lead to substantial time savings across multiple departments.

Also, in all cases but one, IT staff used existing network functionality to push new settings. See the second-to-last column in Figure 53. In general, a network policy (known in Microsoft networks as 'Group Policy') was written on a template, and then pushed out to each computer. This functionality is present in essentially every network; new third-party software is not needed to implement CPM.

Potential product improvements

Improving product design is somewhat outside the scope of our study, but we did document a few issues that could only be dealt with through redesign by a manufacturer.

For the APSs, the primary design issue was the location of the status light on the products. The foot pedal and occupancy sensor were both developed to be placed under the desktop, where the user can't readily tell whether the power strip is on or not. A separate status light would mean an additional cord, so it might be easier to design the product for the top of the desk, near the monitors. Several of our participants moved their foot pedal to that location anyway. Then the status light could still be placed on the sensor or button, but made larger or positioned more prominently so that it is very clear to users whether the strip is powered or not. Finally, the better the APSs can integrate into the fit and finish of either the computer or monitors, the more likely they will be to persist.

For common area device control, manufacturers should design equipment to be used with devices rated at higher than 15 A. Several of the printers, MFDs, and coffeemakers that we inventoried would require a plug load control that fit a higher amperage outlet. And these are the devices with the greatest potential for savings.

For CPM, the primary design issue that our participants noted was in the computers returning from sleep too slowly. Operating systems should be designed to save energy by waking from sleep faster (we are aware that some manufacturers are already hard at work on this improvement). Developers of applications also need to be aware of CPM protocols and write software that returns from sleep with no loss in data or productivity. We did have to disable CPM for a few of our participants who had specific software that did not interact well with CPM.

Finally, one of the biggest issues with CPM was the ability to log in to a computer remotely while it is asleep: can manufacturers solve this problem? One approach could be to allow users to click a button that turns off CPM for one night or one weekend (or some other set time period) so that when users know they plan to work remotely they can shut off CPM just temporarily. Many of the users with remote access constraints reported only using it occasionally anyway, for particular projects. With current CPM, this type of user is likely to disable their CPM the first time they have a remote access issue, and never bother enabling it again—resulting in a lost savings opportunity from a conflict that might be occasional or even rare.

Broader context

Plug loads and whole-building energy performance

In order to understand the broader context for the plug load energy results in our study, we investigated plug load energy published in the literature for other buildings. The two primary metrics we were looking to compare were 1) the percentage of total energy use that plug load accounts for and 2) the EUI of plug loads in other offices. In addition, we were interested in determining if we could see any other drivers for increased or decreased plug loads.

The data we were able to collect is compiled in Table 19, sorted from oldest to newest building. Our two primary metrics are shown, along with some other information about each building. For some buildings, only the non-HVAC EUI was available (this is often true for tenant build-outs), so we also tracked a third metric, the percentage of EUI *excluding HVAC*. The three metrics were generally taken from the first year of each buildings operation (following building commissioning).

Values were collected from published articles and from requests to building managers at specific buildings known to have plug load sub-metering. Sub-metering plug loads has not historically been a common practice, making it difficult to acquire a significant number of case studies. By selecting only buildings with sub-metering, we end up with primarily higher performing buildings that would be interested in energy performance enough to sub-meter. As a result, the table is not representative of a typical office space, but is more likely to be representative of modern, more high performance buildings.

Table 19. Plug load energy versus whole building energy for case study buildings

Case study	Firm name	Year of completion	Conditioned area (ft^2)	Location	Plug load EUI ($kBtu/ft^2$)	Total EUI ($kBtu/ft^2$)	% of total EUI (Incl. HVAC)	% of EUI *excluding HVAC*	Type of space[3]	Program	Plug load strategies implemented
1	Seattle City Hall	2005	201,650	WA	**8.7**	87.2	**10%**	17%	B	City office	?
2	IDeAs Z2	2007	7,000	CA	**9.0**	21.2	**43%**		B	Engineering	major
3	Great River Energy	2008	167,071	MN	**26.2**	61.0	**43%**	47%	B	Utility admin.	?
4	Construction firm	2008	10,000	NC	**8.6**	43.0	**20%**	20%	B	Constr. admin.	?
5	CMTA Office Building	2009	20,000	KY	**5.1**	15.7	**33%**	50%	B	Engineering	minor
6	Manitoba Hydro Place	2009	695,241	Canada	**7.2**	36.1	**20%**		B	Utility admin.	none
7	Waterloo Regional Police	2009	44,648	Canada	**33.0**	60.0	**55%**	84%	B	Public safety	?
8	County Office	2009	1,550	ID	**7.4**		**?**		S	County admin.	?
9	NREL's Research Support Facility	2010	220,000	CO	**7.8**	35.0	**22%**		B	Research	?
10	Construction firm	2010	24,000	CA	**10.0**		**?**	39%	B	Constr. admin.	none
11	Rice Fergus Miller Office	2011	36,000	WA	**10.9**	21.2	**51%**		B	Architects	minor

[3] B= building, C= campus, S= tenant suite

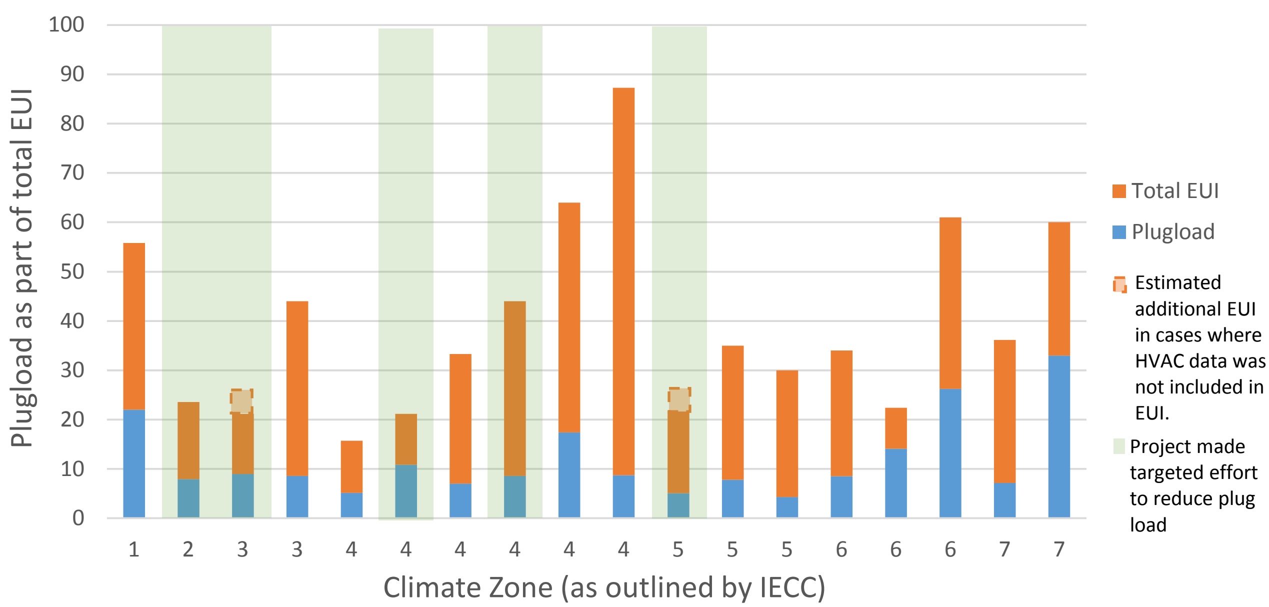
Case study	Firm name	Year of completion	Conditioned area (ft^2)	Location	Plug load EUI ($kBtu/ft^2$)	Total EUI ($kBtu/ft^2$)	% of total EUI (Incl. HVAC)	% of EUI *excluding HVAC*	Type of space[4]	Program	Plug load strategies implemented
12	DPR Construction- Phoenix Office	2011	16,500	AZ	**8.0**	23.6	**34%**		B	Constr. admin.	major
13	Bill & Melinda Gates Foundation	2011	660,000	WA	**17.4**	64.0	**27%**	40%	C	Non-profit	none
14	Iowa Utilities Boards and OCA	2011	44,460	IA	**5.1**		**?**	23%	B	Utility admin.	minor
15	Federal Center South	2012	188,587	WA	**7.0**	33.3	**21%**	23%	C	Federal office	minor
16	LHB - Minneapolis	2013	16,350	MN	**14.1**		**?**	63%	S	Arch. / engr.	none
17	Seventhwave- Madison	2014	10,000	WI	**8.5**	34.0	**25%**		S	Non-profit	?
18	Seventhwave- Chicago	2015	1,600	IL	**6.4**		**?**		S	Non-profit	?
19	Alliance Center	2014	40,393	CO	**4.3**	30.0	**14%**		B	Non-profit	?
	CBECS (from CBECS 2016)	------	--------	--	**23.1**	77.8	**30%**		B	------------	?

[4] B= building, C=campus, S=tenant suite

Unfortunately, the term Plug Load EUI in Table 19 is not a uniquely defined value for each site, there is some variability in what may be included in this category for some buildings. We attempted to include all electric end uses that were not HVAC, lighting, or DHW. But some buildings excluded some elements such as a data center. In general, we see a range of between 5 kBtu/ft² (1.5 kWh/ft²) for low energy buildings with significant plug load measures, and 15 kBtu/ft² (4.4 kWh ft²) for more computational intensive use types without plug load measures in place. In comparison, the average *workstation-only* plug load usage we found in our measurements was 4.1 kBtu/ft².

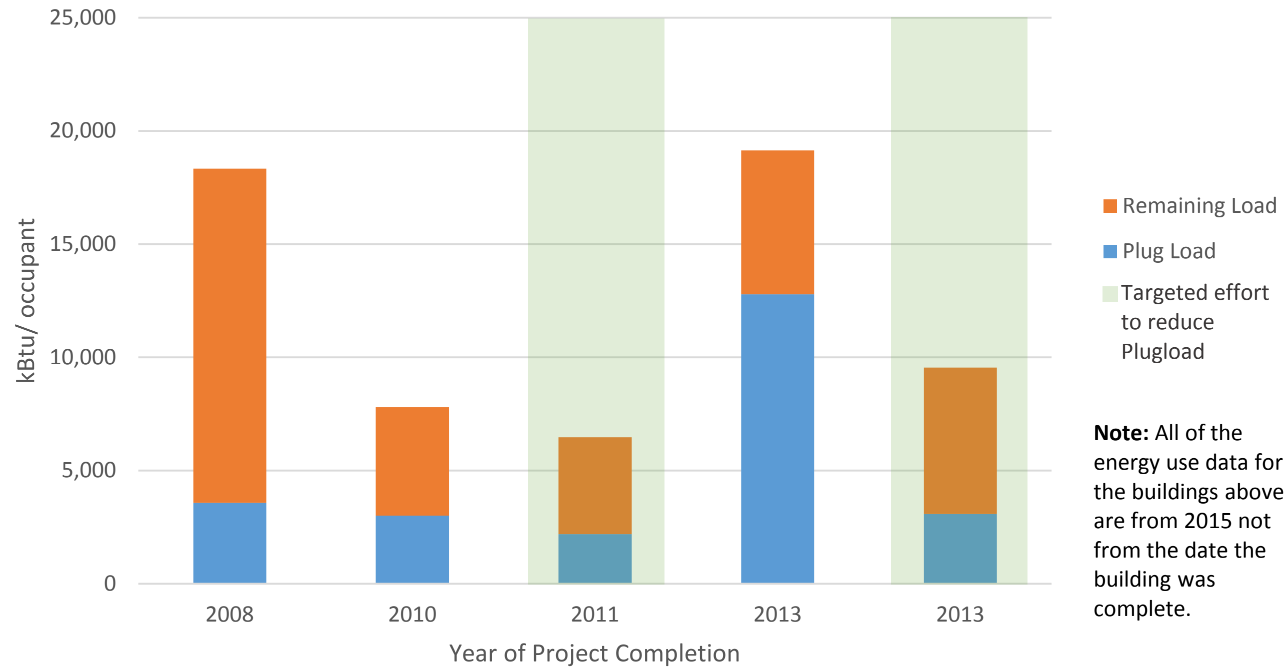
Figure 54 depicts this plug load percentage metric visually, arranged by climate. In climate zone 6 (where most of Minnesota's buildings are) plug loads constitute between 25%-63% of the total energy load for high performance buildings. If Minnesota is to achieve the goals outlined in Minnesota's Next Generation Energy Act of 2007, to decrease the state's greenhouse gas emissions by 30% by 2025 (or 80% by 2050), plug load energy reductions may have a major role to play, especially in newer and/or higher performance buildings.

Figure 54. Plug load energy use intensity based on climate zone.



Of the buildings highlighted in the case studies in Table 19, one firm, a construction company, built three of them. They also retrofitted two other existing spaces, all for their own regional offices. This was over the span of six years. All of these projects strived for a high level of energy performance and all tracked plug loads on some level. This story gives some insight into the impact of plug loads on an owner's energy goals, as well as their ability to control those loads. In Figure 55 we show the one metric that could be compared across all five buildings: energy usage per occupant (in kBtu/person).

Figure 55. Single company across different sites – a case for plug load reduction.



The 2011 and the first 2013 projects were both retrofits to existing spaces with differing scopes of work. The 2011 retrofit was able to decrease the plug load from the prior 2010 project by almost 1,000 kBtu/occupant, through the introduction of plug load control for unoccupied hours. The 2013 project was a retrofit without a targeted approach to plug load, and the results show a 580% increase in plug load kBtu/occupant. In 2013 their second building once again targeted plug load energy by including automated plug load control, and this brought the kBtu/occupant back down to values similar to the 2011 project.

Comparison to server strategies

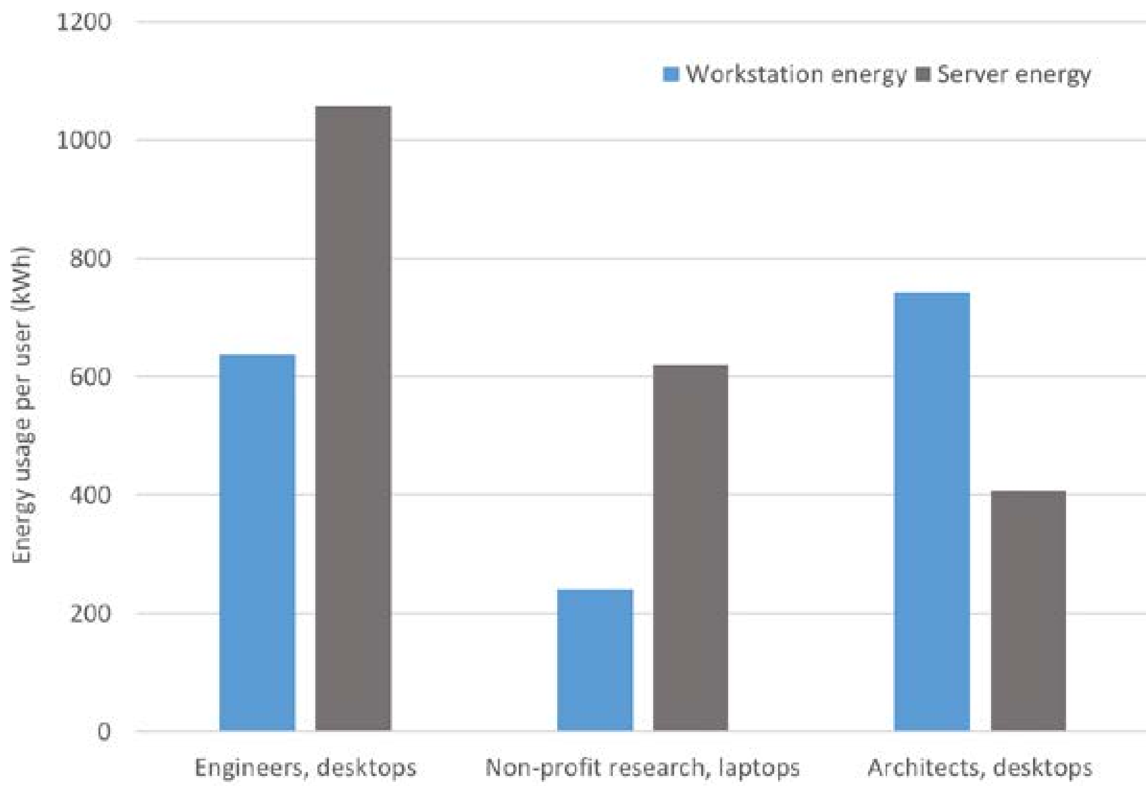
In office spaces, plug loads in the workstations themselves only represent a portion of the energy usage. A significant portion of the energy usage in an office also takes place in the server room. This can be true whether the server room is two servers in a small closet (as was the case with our Real Estate site) or a small data center embedded in a corporate office (as was the case with our Engineering site). The plug load energy usage in the server room represents another major area of plug load energy usage that is in need of reduction.

Furthermore, the two types of usage can at times be transferrable. For example, as offices move to laptops and even thin client machines at the workstation, there is less relative computing power available locally, and more functions are moved to the server. This results in less energy usage at the workstation and increased energy usage in the server room. Similar transfers can occur with an IT department's choice of methodology for remote access to software and processing power.

In order to understand the broader context of workstation energy usage relative to server energy usage, we shared data with a parallel Minnesota Department of Commerce-funded research project that is investigating energy usage and savings in small embedded data centers.

This study shared two sites with our study. We also monitored the server energy usage in one additional site. The results of the annual energy usage per workstation at each of the three sites for which we had data is shown in Figure 56.

Figure 56. Office energy usage per workstation for the energy used at the workstation as well as that used in the server room.



The results suggest that server usage in an office is of a similar order of magnitude as workstation energy usage. Also, in some types of offices and IT configurations the server usage can be higher than workstation usage. In others, server usage could be the lower of the two. More research considering a larger number of offices, and different server configurations, is required in this area.

Extrapolation to the state of MN

For program planning purposes, we have also extrapolated the energy savings results to the entire state of Minnesota. This provides an understanding for the total savings potential in the state for the primary strategies studied.

To extrapolate statewide, we begin by calculating the area of office space in the state. Building area by building type can be found in CBECS (2016). We can extract an estimate for Minnesota from the data from the West North Central region by weighting by the population of each state in that region. We needed to consider many building types; not just office buildings. For example, warehouses usually have some portion of office space. We determined how much of each building type was office by using the DOE's reference building models (DOE 2016) as representative buildings. Proportion of office space ranged from 5% in a warehouse building, to 62% in an office building (much of an office building is corridor, lobby, mechanical space, etc.). Summing all applicable building types, we arrived at 212 million ft^2 of office space in Minnesota.

Many of our results were normalized by the number of workstations in a given office. We converted the building area metric to number of workstations by using the results of our office characterization that yielded 250 ft^2 per workstation for typical density. At this density, we estimate that there are 879,000 workstations in the state. This estimate is likely conservative because our process did ignore some building types, like industrial, that probably have some offices. As a quality check, we can compare with the number of employees working in job types that would generally require an office for each employee. Based on Minnesota's Department of Employment and Economic Development database (Minnesota 2016), there are roughly 1.3 million of these jobs. This confirms our assumption that our calculation is somewhat conservative.

Using our conservative estimate, if an APS were installed in each workstation, the resulting savings would be 47.9 million kWh statewide (at 54.5 kWh saved per workstation). For CPM the savings would nearly double to 93.2 million kWh (at 106 kWh saved per workstation). These numbers could increase if behavioral impacts could be added, or if CPM and APS are combined as in a Tier 2 APS. If CPM savings increase by 20% with such a combination, and we use the more liberal estimate of 1.3 million workstations, savings could be as high as 165.3 million kWh.

Code implications

The 2015 Minnesota Energy Code has two prescriptive compliance paths; one largely references the 2012 International Energy Conservation Code (IECC), the other wholly references 2010 ASHRAE Standard 90.1 ("90.1-2010"). The 2012 IECC path does not have any requirements for control of plug loads. The 90.1 path does require control, stating that "At least 50% of all [receptacles] … installed in the following space types: private offices, open offices, and computer classrooms shall be controlled by an automatic control device that shall function on a scheduled basis …, an occupant sensor…, or a signal from another control."

Design and construction teams have a choice of which path to follow, but they generally must choose based on drivers other than this plug load requirement. So those teams that are following the 90.1-2010 path are beholden to the plug load requirement (and this includes both the prescriptive and performance paths of 90.1-2010; plug load control is mandatory in both). This would make controls such as the occupancy sensor or timer strategies that we tested a code requirement and therefore prevalent in new and renovated offices (dependent on how many projects go with the 90.1-2010 path vs. IECC). Anecdotally, in some districts we have found that the more innovative parts of new codes, such as plug load control, are not readily complied with in the first years of their existence. We spoke to a few design professionals in Minnesota who are now having to comply with this element of the code.

We found that most engineers are using the lighting control systems to control 50% of the plug loads in new office spaces. A separate output just needs to be specified on each occupancy sensor for it to perform this function. Designers have primarily implemented this approach in individual spaces. This is working well in private offices, where a single occupancy sensor controls the lights and plugs for one zone. The designers we spoke with had begun designing a similar approach in larger open-plan offices but had not yet seen it constructed. Designers are hopeful that furniture manufacturers will begin producing workstation furniture with controlled outlets that meet the code, but there is not yet a significant selection of these. At the moment, the occupancy sensor-based solutions are employed upstream of the furniture electrical system, and simply control one leg of the power to furniture outlets.

It appears that code officials are requiring permanent plug load controls to be in place, so the APS we tested would not comply. However, the APS that we tested with the occupancy sensor should perform similarly to a permanent occupancy sensor dedicated to an individual workstation (such as the private office discussed above). The results from Table 7 could be applied, with an expected energy savings of about 67 kWh or 22% for a given workstation.

Designers who are using this approach should also be aware of the findings in our occupant satisfaction survey for this measure. Those showed that though most occupants were satisfied with occupancy sensor control, there were a significant number who were not satisfied in part because they couldn't understand or control what the occupancy sensor was doing to their equipment. This issue would be exacerbated if a workstation's receptacle power were tied to an occupancy sensor serving a larger area, affected by a number of different occupants. This would lead to less understanding of and perception of proper control than even our one-sensor-one-workstation test.

According to our interview subjects, the code change is too new to have any significant response from building owners or occupants on their approach to plug load control. Code officials and inspectors, however, have been trained on the topic and are very aware of the particular change in the code. Some are actively commenting on it in design review. So the design and construction communities can expect to be addressing this issue more directly in the near future.

Conclusions and discussion

Plug load strategies in Minnesota CIPs

The results of our field study indicate that 1) there is still significant energy being used by basic plug loads in most Minnesota offices, and 2) there are some cost-effective plug load reduction measures for utilities to pursue in their Conservation Improvement Programs (CIPs). A measure like CPM has an estimated statewide savings potential of between 50-90 million kWh annually. A few CIPs in Minnesota have begun to offer incentives for plug load reduction strategies, but they have not had a significant market penetration. There is potential for all utilities to capture more savings from this end use. We recommend that CIPs take the following steps to maximize the opportunity.

Provide incentives and assistance to increase adoption of computer power management.

CPM is likely the most effective plug load reduction strategy of those that we tested. Its payback is only one to two years, and can be readily implemented using existing software at most sites. IT departments will have valid concerns, but there are reasonable solutions for most of these (see *IT integration of computer power management*). CIPs should be prepared to work directly with IT staff in both outreach and implementation phases to drive wide adoption. Flexibility should be allowed by CIPs so that CPM can be implemented using whatever software an office would prefer. This includes the existing network software (often *Group Policy*) that IT is used to using. CIPs should not require new software purchases.

CPM should also be incorporated into the Minnesota Technical Reference Manual (TRM) based on our results. The energy baseline, estimated savings, and implementation costs for the strategy are all well documented in *Results*. CPM is the one strategy we tested that also has a peak demand impact, which should be incorporated into program design (see *Peak demand reduction potential*).

Provide incentives and assistance to increase adoption of simple controls, especially APSs with appropriate user interaction, and simple device timers.

Simple, low-cost hardware like the APS and timers that we tested do have potential to cost-effectively save energy. CIPs should be strongly considering providing incentives for those APS and timers that are relatively simple to use, and whose operation is transparent to the user. For the APSs we studied the foot pedal with timer, at a price point of $30-40, met this description and was more easily accepted by users than an occupancy sensor. Basic timers on common area equipment were similarly effective, though mostly for certain high-energy common equipment. Coffeemakers and water coolers are two likely candidates, large printers and medium MFDs are others (when they can be safely powered down).

Basic Tier 1 APS and common area timers should be incorporated into the Minnesota TRM based on our results. The energy baseline, estimated savings, and implementation costs for each of these strategies are all well documented in *Results*.

Consider more innovative program approaches beyond a basic incentive.

Some of the reduction strategies we investigated (such as CPM, or timers on beverage equipment) were highly cost-effective, but relatively low adoption rates have been reported for them. Different program approaches may be required to widen adoption of these because they are directed at an audience that isn't used to looking for utility rebates or thinking about energy. A few potential approaches that could be considered:

- A **direct install** offering to install APS and timers where they make the most sense. This would also lead to high quality installations and user satisfaction. Such a program could also implement a basic version of CPM (using typical Group Policy template approaches for example).
- An **upstream** rebate program leveraging outreach and marketing from product manufacturers through collaboration. Office furniture manufacturers could also participate in such a program.
- A **behavioral** campaign could have impact. This could be included with energy management or retrocommissioning programs, or as a standalone behavioral program. Behavioral elements could also be added to simpler prescriptive offerings for plug load controls, to both increase user satisfaction and savings.

Integrate simple plug load reduction strategies into more holistic programs like retrocommissioning and turnkey small business programs.

The plug-load-specific offerings discussed above could presumably be included in a prescriptive (i.e. standard) or custom program. But other more holistic program types could consider including these strategies as well. Retrocommissioning programs could include CPM as a low-cost, software based measure. Implementers would need to add a small IT skillset, but such an offering could remain limited to basic approaches. Small business programs that are attempting to expand scope could potentially add every strategy that we tested here to their offerings. Other holistic programs such as energy management should consider these strategies as well.

Incorporate plug load research lessons into new construction programs.

New construction programs have historically ignored potential for energy reduction through plug load impacts, and in fact generally assume plug loads are a relatively static element in a building design. The fact that the new Minnesota code requires some amount of plug load control may only lead to these assumptions decreasing slightly, but then remaining static.

New construction programs in Minnesota could update their assumptions about plug loads based on the *Plug loads and whole-building energy performance* and other baseline usage results. They could also begin to recommend plug load reduction strategies be implemented in every office area, including APS (Tier 1 or Tier 2), CPM, and timers. Of course savings potential in this program type may be curtailed somewhat by the new code, but there is still potential beyond that (see *Code implications* for discussion). They could also provide behavioral information at time of occupancy.

Develop a strong relationship with IT departments.

In the longer term, as the percentage of building energy attributable to plug load continues to increase, the ability to save energy through typical interactions with building designers and facility managers decreases. For the same reason, the ability to communicate with and influence IT personnel will increase in importance. IT personnel will not only continue to manage the growing area of plug loads, but also server or data center usage, and possibly lighting controls as those grow more complex, integrate with building automation software, and interact with workstations (and plug load controls!).

CIPs need to have staff in place to interact with IT personnel in companies of different sizes as well as at third party IT consulting firms. They need to be able to understand all of their needs and constraints, and have some basic influence to drive some of the savings strategies that we studied here (as well as some server energy savings strategies documented by others). CIPs should also begin targeting more outreach at IT personnel. They can consider talking with both the IT department and sustainability leadership in a firm to establish opportunities. This combination provides more internal motivation for plug load reduction, and was a successful arrangement in our study.

Because the IT infrastructure varies from firm to firm, and IT infrastructure is so critical to every firm, CIPs should also collaborate with IT personnel in testing different strategies. Significant testing will be important in the early life of a CIP offering to ensure that user productivity is not negatively impacted, which would quickly lead to removal of any strategy put in place.

Provide technical support for computer power management.

Computer power management remains one of the most impactful plug load reduction strategies available. However, it can be the most difficult to implement, often due to fixable technical issues. The *IT integration of computer power management* section specifies some technical suggestions. CIPs should also work with ENERGY STAR's Low Carbon IT Campaign to have instructional materials available, and provide backup support (ENERGY STAR can provide some support at no cost). Relationships with IT as discussed above will help optimize these recommended approaches to CPM.

Include messaging for the user in program offerings.

Many plug load reduction strategies impact building users more than most energy end uses. And those users in turn impact the energy savings potential of plug load strategies. When CIPs implement hardware or software strategies like APS or device timers, brief, simple messaging should be provided in the office to help users understand the strategies and work well with them. This can be as simple as providing easy instructions for using an APS, or providing detailed behavioral advice (see *Behavior change campaign*). This messaging should come from within the organization wherever possible, so users understand that the motivation is coming from their leadership and coworkers, and is not simply a mandate from their utility. CIPs could partner with larger firms to co-brand messaging materials to this end.

Plug load strategies for office operators and design professionals

The results of our field study indicate that office operators can implement several cost-effective and non-disruptive strategies to reduce plug load energy usage. Some reduction strategies can be effectively implemented at any time in existing offices. Others are best implemented by office managers when purchasing new equipment or by design professionals at the time of office build-out.

Implement low-cost software and hardware strategies in existing offices.

Office operators have several cost-effective options for plug load reduction strategies including CPM and different APS options. All of these strategies resulted in cost-effective energy savings (see *Comparing workstation strategies* and *Common area strategies*) with minimal or no disruption to office worker comfort or productivity.

Computer power management, the most effective of the strategies in our tests, could be a good starting point. CPM had only a two-year payback and can be readily implemented using existing software in most offices to save energy on both monitors and computers when not actively being used. Operators will need to work closely with their IT departments or consultants. These two sides will often need to overcome a few barriers together (see *IT integration of computer power management* for tips on overcoming such barriers). Office operators may also contact ENERGY STAR for no-cost support.

APSs are the next best option, saving energy from all non-computer plug loads at workstations. At a cost of $30-40 each, the APS with foot pedal is a simple solution for a user to have control in easily turning off equipment when leaving their workstation. With utility incentives, this approach can have a payback of about three to five years. Our study showed that this technology was well accepted by users, with a higher rate of satisfaction than the APS with occupancy sensor.

At a cost of about $30 each, installing timers on common area equipment is another simple strategy to reduce plug loads, with a payback of only three to seven years. Timers are most cost-effective for certain high-energy common equipment: coffeemakers, water coolers, large printers, and medium MFDs. Before installing timers just ensure that complex electronics like MFDs are able to be safely powered down.

Save energy by influencing staff behavior in a positive way.

The actions of individual office staff can have a significant effect on plug load energy. A behavior change campaign can be an effective method for offices to not only conserve energy but educate employees about the significance of plug loads. Campaigns should maintain a positive message and be communicated by those close to the staff (as opposed to a remote corporate office or third party). If executed correctly staff can respond positively to behavior messaging. No- and low-cost campaign elements can include identifying an office sustainability champion, sending email reminders, and providing candy or small gift cards as incentives for those observed saving energy. A campaign may be more effective when used in conjunction with a technology measure (e.g. an APS installation) as in our study. Including behavioral elements can significantly increase the savings of these hardware and software strategies.

Make equipment decisions by evaluating needs.

When purchasing decisions are being made, office operators or managers have an opportunity to significantly reduce future plug load energy consumption. Managers should first evaluate individual and office-wide needs to determine what devices are really needed. Extraneous equipment can sometimes be removed entirely, saving not only energy but cost and maintenance time. Equipment that is required can be replaced with more efficient alternatives: ENERGY STAR equipment, smaller computers or laptops, and devices with low standby power.

At the time of computer replacement or when a new employee comes on board, consider the job functions of the employee and purchase the right size equipment for their tasks. Significant energy can be conserved by providing a laptop rather than a desktop. If a desktop is required, consider whether a small computer or thin client will serve the employee's needs. Also evaluate how many monitors are truly required and select the smallest appropriate size.

One low-cost strategy for reducing energy usage is to evaluate whether all common area equipment is actually being used and if some devices could serve more employees. The section, *Removing extraneous common area devices,* explains the rationale for providing one break room and coffee area per 60 employees as well as one MFD/print station for every 60 employees (plus a few printers for those with sensitive printing needs). Also evaluate whether water filters could be installed instead of water coolers. Extraneous items can then simply be removed.

Implement strategies at the time of new construction or tenant build-out.

Design professionals and office owners need to be aware of the significance of plug loads in new office construction, renovation, and tenant build-out. If teams that are developing new offices are interested in high performance, plug loads could make up a large portion (up to 55%) of their project's energy usage. Teams could also use the metrics from *Baseline usage of typical equipment* to more accurately size all kinds of buildings systems that are often oversized for plug loads. Consideration should be given to appropriate sizing of workstations, kitchenettes, beverage stations, and number/location of support spaces (e.g. print rooms, break rooms). When selecting new workstation furniture, look for options that either include or easily allow integration of plug load control and monitoring. New electrical systems may include built-in solutions for energy reduction with occupancy sensors at receptacles (see *Code implications*) as well as plug load sub-metering to track performance.

Future Work

The area of office plug loads is still highly dynamic, with new electronics and IT configurations being developed each year. In response, new approaches to reducing these loads are being developed as well. There are a number of research areas that can build off of what we've accomplished here.

There is little known about the ability of reduction strategies, like those we tested, to persist for a long period. Basic study is still needed in the area of plug load reduction persistence; such a study could revisit buildings that were studied earlier, or work with major campuses or corporations that have implemented plug load reduction strategies over a long time span.

The APSs that we tested in this study were Tier 1 devices, impacting all devices in an office other than the computer itself. Tier 2 APSs are becoming available that allow a power strip to control the computer as well. Initial study of these has only focused on a couple of offices; more study is needed to determine additional energy savings as well as cost-effectiveness (initial product offerings are substantially more expensive than Tier 1 APSs). Because this strategy essentially impacts CPM, research and development will be needed to determine how well existing technology is accepted by IT personnel, and how to improve any issues that arise with this acceptance.

We did our best to lay out the barriers and potential solutions that utility programs, building operators, and others will face in attempting to change the way IT infrastructure is controlled. However, more work is needed to bridge the divide between energy programs and IT personnel whose primary focus is to maintain robust IT infrastructure. It would be beneficial to have research that explores the real energy constraints of IT infrastructure within an office, establish a more consistent language for the two groups to use to communicate with each other, and investigate the best methods for outreach and collaboration with this sub-sector.

There is certainly room for more research into specific behavioral impacts on plug load energy usage. Our study focused on quantifying, holistically, the additional impact that behavioral elements could have on a more traditional plug load measure like an APS. But we were not able to investigate specific actions that the behavior campaign led to. We were also not able to compare the impact of different campaign elements or different overall approaches. Further research focusing on those specific actions and what best influences each would be beneficial.

There seems to be a shift toward more flexible workplaces with more work occurring outside the office and more workstations being shared with different staff using them at different times. And this shift overlaps with an increase in use of laptops as opposed to desktops. Our study captured the current state of Minnesota offices, but CIPs will need to keep tabs on how these shifts impact plug load reduction strategies.

It’s also possible that the office furniture industry could collaborate with our industry more in understanding the impact of these shifts on energy usage, and how furniture could be designed to both meet the needs of the future and reduce plug load energy.

Glossary

APS	advanced power strip
CBECS	Commercial Building Energy Consumption Survey
CIP	Conservation Improvement Program; utility programs in Minnesota
Control group	sample of workstations we monitored but didn't apply a strategy to
CPM	computer power management
CRT	cathode ray tube; an older monitor type replaced by flat screens
DOE	Department of Energy
EFLH	equivalent full load hours
EUI	energy use intensity
FEMP	Federal Energy Management Program
FTE	full-time equivalent; number of full-time equivalent employees
HVAC	heating, ventilating, and air conditioning
IECC	International Energy Conservation Code
IT	information technology
MFD	multi-function device; a device that copies, prints, and scans documents
N	size of a sample group studied
NREL	National Renewable Energy Lab
OS	occupancy sensor
Plug load	all electric end uses that are not HVAC, lighting, or DHW
Post-strategy	the time period after an energy reduction strategy was implemented
Pre-strategy	the time period before an energy reduction strategy was implemented
Strategy	a strategy (or measure) implemented to save energy
Treatment group	sample of workstations that we both monitored and applied a strategy to
Workstation	a desk, office space, or cubicle that serves a single office worker
WWR	window-to-wall ratio

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Appendices

Appendix A: Characterization survey instrument

Thank you for agreeing to complete this survey of office equipment and use. Please complete the survey by March 25, 2015.

Before beginning this survey, please print out and complete the accompanying worksheet located here: {linked reference}. The worksheet is used to tally equipment in a sample of your office space. It is possible, but perhaps more difficult, to complete the survey without using the worksheet first. When filling out this survey, management and IT personnel from your organization may be able to assist with answering some questions, including gathering information about office square footage and utility billing. The results will be used to inform research funded by a Minnesota Department of Commerce Conservation Applied Research and Development Grant with the goal of identifying and prioritizing plug load energy reduction strategies. Your responses are confidential. We will not share individual information collected in this survey with anyone outside of our research team.

Name
Email
Phone number
Title/role in organization

Please answer the following questions regarding your overall organization.

Q1 Which of the following best describes your organization?

- ❍ Public/Government
- ❍ Private
- ❍ Non-Profit
- ❍ Cooperative

Q2 What type of work does your organization do (e.g. legal, architecture, marketing, etc.)?

Building: If your organization has office space in more than one building, please select which building this survey will address, and answer the following questions accordingly.

Q3 What is the building address?

Street address (optional)
Zip code (required)

Organization space within building: Please answer the following questions as they relate to the organization's office space within the selected building.

Q4 Which of the following best describes your office space?

- ❍ Leased
- ❍ Owned
- ❍ Other:

Q6 How does your organization pay for its electricity?

- ❍ Our electricity use is included in our monthly rent.
- ❍ We are billed a flat monthly rate.
- ❍ We are billed based on a percentage of total building use.
- ❍ We are billed based on metered electricity use for only our organization's space.

Q7 Does your organization have an electric sub-meter dedicated to measuring energy from plugged office equipment? (often called 'plug load energy' - computers, monitors, copiers, kitchen appliances, etc.)

- ❍ Yes
- ❍ No
- ❍ Not sure

Office Space and Occupancy

Q8 How many employees work in your office, in full-time equivalents (FTE)?

Q9 What is the total floor area of your organization's space (in square feet)? (If this is not known, but the previous question was answered, feel free to leave this unanswered.)

Office Practices

Q10 Please select sustainability or energy strategies actively practiced in your office (select all that apply):

- ❑ Office sustainability champion
- ❑ Sustainability incorporated into organization mission/vision
- ❑ Building and/or interior space meets sustainable building guidelines (e.g. LEED, Energy Star)
- ❑ Onsite renewable energy production
- ❑ Equipment purchasing (energy) standards (e.g. Energy Star equipment only, LED task lights)
- ❑ Office-wide policy on personal devices
- ❑ Active training on energy use reduction
- ❑ Network-wide control of computer power management
- ❑ Other:

Q11 Which of the following devices have been updated or replaced in the past 3 years? Check all that apply.

- ❑ Computers
- ❑ Monitors
- ❑ Lighting controls
- ❑ Task lighting
- ❑ Workstations (cubicles)
- ❑ Kitchen appliances
- ❑ Wiring
- ❑ Copiers/printers/multifunction devices
- ❑ Telecommunications (phones, video conferencing)

Q12 Does your office have a computer (desktop, laptop, and monitor) replacement policy based on a period of time?

- ❍ Yes
- ❍ No
- ❍ Not sure

Survey Area within Organization Space

Please select a survey area within your organization's office space that serves 25-125 employees. Depending on the size of your organization's office space, this may range in scope from the entire building or office space (for smaller organizations) to one department within your office (for larger organizations). The greater the area represented in your response, the more comprehensive the survey results will be. Answer the following questions as they relate to just the survey area

Q13 This survey applies to:

- ❍ The organization's entire office space
- ❍ Part of the organization's office space

Answer If This survey applies to: Part of the organization's office space Is Selected

Q15 What is the approximate total floor area of your survey area?

Answer If This survey applies to: Part of the organization's office space Is Selected

Q16 How many employees (in Full Time Equivalents) work in your survey area?

Q17 What is the total number of weekly operating hours for the survey area?

Q19 On average, what percent of the time does the average employee work outside of the office during weekly operating hours?

- ❍ 0-25%
- ❍ 25-50%
- ❍ 50-75%
- ❍ 75-100%

Q20 What are the primary activities conducted in the survey area? [select all that apply]

- ❑ administration
- ❑ customer service
- ❑ information technology or computer programming
- ❑ professional design services
- ❑ data entry
- ❑ research
- ❑ engineering or other technical services
- ❑ financial services
- ❑ sales
- ❑ communications and marketing
- ❑ other primary task: ____________________

Q21 How many of each of the following common spaces are included in the survey area?

Huddle/breakout areas:
Conference rooms/Meeting spaces:
Copy/work area:
Break area (or kitchenette)
Reception area
Library/resources
Mothers'/Wellness room
Other

Q52 Other specified:

Q22 How many of each of the following primary workstations are included in the survey area?

Private offices:
Shared private offices:
Open office workstations:

Use the worksheet you completed at the beginning of this survey to answer the following questions.

Q23 Refer to completed Plug Load Survey Worksheet PART 1 (the worksheet can be found here: {link to worksheet}

Select 5 primary workstations that are representative of the total survey area, and inventory all electronic devices at each of these five workstations. In choosing representative workstations consider the breakdown between private and open offices, laptop vs. desktop computers, etc. What is the total number of each electronic device inventoried in the chosen workstations?

Desktop computer
Laptop
Flatscreen (e.g. LCD) Monitor
CRT Monitor
Tablet
Desk/Task lamp
Desktop Printer/Scanner/Multifunction Device
Computer Speakers
Fans
Telephone
Other

Q53 Other specified:

Refer to Plug Load Survey Worksheet PART 2.

Please list the number of the following pieces of equipment within the survey area that are located in those five workstations

Q24 Kitchen Appliances

Refrigerator (Full Size)
Refrigerator (Mini)
Microwave
Toaster oven
Toaster
Vending machine
Pizza oven
Coffee maker
Hot water/teapot (electric only)
Electric oven/stove
Dishwasher
Refrigerated water cooler

Q26 Print/Copy Devices

Desktop Printer/Scanner/Multifunction Device
Multi-function/Printer/Scanner/ Copier device
Copier
Printer
Plotter
Scanner
Fax machine
3D printer
Laser cutter

Q27 Telecommunication Devices (consider conference rooms)

Projector
Retractable screen
TV/Digital display
Common/conference area telephones
Audio system
Dedicated video conferencing equipment
DVD/Blu-ray/VHS player
Video recording equipment
Wireless router

Q25 Office Equipment In Common Areas (not including workspaces)

Desktop computer
Laptop
Monitor
Desk/Task lamp
3-hole punch (electronic)
Label maker
Shredder
Electric pencil sharpener
Tablet
Electronic stapler

Q28 Other

Space heater
Fan
Optional: Other (please list and count)

Appendix B: Inventory of plug load devices

Organization Identifier	Select types of Equipment in Workstations											
	Workstations Surveyed	Area per workstation (ft^2)	Desktop computer	Laptop	Flatscreen (e.g. LCD) Monitor	CRT Monitor	Tablet	Desk/ Task lamp	MFD	Computer Speakers	Fans	Telephone
Research/Consulting/Policy 1	68	246	27	41	82	0	0	68	14	0	14	54
Architecture 1	71	230	57	14	99	0	0	28	14	71	14	71
State 1 - Corrections	46	-	46	0	92	0	9	9	9	46	0	46
Construction 1	7	214	9	3	2	0	0	0	2	4	4	12
Construction 2	83	964	50	33	100	0	66	83	50	50	33	83
Research/Consulting/Policy 2	45	222	0	45	54	0	0	36	0	9	9	45
Aquarium	30	-	27	5	27	0	0	33	0	5	0	35
Manufacturing 1	510	-	204	306	510	0	0	102	0	0	0	510
Higher Ed 1	15	380	15	0	21	0	6	15	3	30	3	15
Developer/Property Management	29	269	3	26	29	0	4	2	5	0	0	30
Research/Consulting/Policy 3	16	330	0	0	0	0	0	0	0	0	0	0
Research/Consulting/Policy 4	19	179	0	19	23	0	0	19	8	4	0	15
Architecture 2	139	277	111	28	139	0	0	83	0	139	28	139
State 2 - Government	1011	371	1011	0	1617	0	202	404	606	809	1011	1011
State 3 - Natural Resouce Mgt	65	246	26	39	130	0	0	91	39	26	0	65
State 4 - Corrections	40	25	40	0	40	0	0	0	0	0	0	40
Manufacturing 2	147	155	0	147	206	0	0	0	29	0	0	147
Higher Ed 2	27	130	11	16	43	0	0	38	0	11	11	27
City 1 - Government	77	234	92	0	200	0	0	77	0	0	15	62
Higher Ed 3	87	358	122	17	17	0	0	52	52	35	17	87
Higher Ed 4	4	-	4	2	4	0	0	2	0	1	1	3
Architecture 3	62	180	50	25	112	0	37	62	12	0	0	62
County - Government	120	200	120	48	288	0	24	120	96	240	72	120
Human Services 1	37	307	37	0	74	0	0	52	30	0	7	37
Higher Ed 5	25	92	25	5	5	0	0	65	5	5	10	25
City 2 - Government	37	572	22	15	59	0	15	37	7	30	30	37
Higher Ed 6	45	333	45	0	45	0	0	27	0	36	27	45
Architecture 4	251	438	251	0	502	0	0	50	0	0	50	251
Architecture 5	25	224	0	25	45	0	0	25	0	5	0	25
Human Services 2	89	230	59	2	61	0	0	97	35	4	3	53
Human Services 3	68	162	0	68	109	0	0	95	0	0	0	68
Real estate	42	-	17	34	25	0	17	17	34	25	8	50
Human Services 4	135	205	0	135	216	0	0	189	0	0	0	135
Construction 3	52	212	21	31	62	0	31	31	0	0	0	52

Organization Identifier	Select types of Kitchen Equipment					
	Refrigerator (Full Size)	Refrigerator (Mini)	Vending machine	Coffee maker	Hot water/ teapot (electric only)	Refrigerated water cooler
Research/Consulting/Policy 1	2	2		2		
Architecture 1	1	2		1	1	
State 1 - Corrections	1		4	2		2
Construction 1	1	1		1		1
Construction 2	2	0	3	3	1	4
Research/Consulting/Policy 2	2	0	0	1	0	0
Aquarium		1		1		
Manufacturing 1	10		5	5		5
Higher Ed 1	2	0	0	0	0	0
Developer/Property Management	2	1		1		1
Research/Consulting/Policy 3	1	0	0	1	1	0
Research/Consulting/Policy 4	1	1	1	5	2	1
Architecture 2	3	2	6	3		
State 2 - Government	1	13	3	9	0	1
State 3 - Natural Resouce Mgt	1	1	1	4		2
State 4 - Corrections		1				1
Manufacturing 2			2			
Higher Ed 2	0	2	0	3	1	0
City 1 - Government	3	0	0	7	3	0
Higher Ed 3	2	1	1	3	1	2
Higher Ed 4						
Architecture 3	1	1	2	2	0	1
County - Government	4	0	0	5	4	4
Human Services 1	1			1	1	
Higher Ed 5						
City 2 - Government	3	3	2	5	0	1
Higher Ed 6	3	5	2	6	2	0
Architecture 4	2	0	0	1	1	1
Architecture 5	2	0	1	1	0	1
Human Services 2	2	1	0	4	0	0
Human Services 3	2			3	1	
Real estate	0	1	0	0	0	1
Human Services 4	2			4		
Construction 3	1			1		

Organization Identifier	Select types of Work Room Equipment					
	Desktop Printer/ Scanner/ Multifunction Device	Multi-function/ Printer/ Scanner/ Copier device	Copier	Printer	Scanner	3D printer
Research/Consulting/Policy 1			3	5		
Architecture 1	2	2			1	
State 1 - Corrections	3	2				
Construction 1						
Construction 2	14		3	30	10	0
Research/Consulting/Policy 2	1	2	0	0	0	0
Aquarium				2		
Manufacturing 1						
Higher Ed 1		2		1		
Developer/Property Management	5		1	1		
Research/Consulting/Policy 3	0	1	0	0	0	0
Research/Consulting/Policy 4	1	1	0	3	0	0
Architecture 2		1	7	1	2	
State 2 - Government	0	10	2	4	7	2
State 3 - Natural Resouce Mgt		3				
State 4 - Corrections			1	1	1	
Manufacturing 2		3		4		
Higher Ed 2	1	1	0	4	0	0
City 1 - Government	0	3	0	11	1	0
Higher Ed 3	4					
Higher Ed 4	1	1				
Architecture 3	5	4	0	1	2	0
County - Government	3	5	6	3	0	0
Human Services 1	6	3	3		2	
Higher Ed 5		1			1	
City 2 - Government	1	3	0	0	0	0
Higher Ed 6	0	0	1	6	1	0
Architecture 4	0	1	1	1	1	0
Architecture 5	0	0	4	4	0	0
Human Services 2	3	6	0	1	7	0
Human Services 3		3				
Real estate		2				
Human Services 4		8				
Construction 3		2				

Organization Identifier	Select types of Conference Room Equipment				
	Projector	Retractable screen	TV / Digital display	Audio system	Video conferencing equipment
Research/Consulting/Policy 1	3		3	1	
Architecture 1	1	1	5	1	2
State 1 - Corrections	2	2	2	2	2
Construction 1			1		
Construction 2	1	0	2	1	2
Research/Consulting/Policy 2	3	1	2	2	1
Aquarium	1				
Manufacturing 1	20			2	2
Higher Ed 1	1	1			
Developer/Property Management			4		
Research/Consulting/Policy 3	1	0	0	0	0
Research/Consulting/Policy 4	1	0	0	1	1
Architecture 2	7	3	8	2	2
State 2 - Government	0	0	0	32	0
State 3 - Natural Resouce Mgt	2		1		2
State 4 - Corrections					
Manufacturing 2		1	1		
Higher Ed 2	0	0	0	0	0
City 1 - Government	2	0	0	0	0
Higher Ed 3	2	1	1	2	1
Higher Ed 4					
Architecture 3	1	1	3	0	1
County - Government	4	0	4	1	0
Human Services 1	2	1	3	1	1
Higher Ed 5	1	1			
City 2 - Government	1	0	3	2	1
Higher Ed 6	10	10	5	10	1
Architecture 4	1	0	0	0	0
Architecture 5	0	0	3	0	0
Human Services 2	1	0	1	0	0
Human Services 3	2	2	2		
Real estate					
Human Services 4	2	2			
Construction 3			2		

Appendix C: Participation satisfaction survey instrument

As part of a field study to investigate the potential to save energy in offices throughout Minnesota, we have implemented tests of some technologies at your workstation. **We have just ____ questions for you about these tests.** Thank you for taking part; your feedback will be important in developing programs to save energy in Minnesota offices.

1. How convenient was it to use the remote button for your power strip?

   1 - Very convenient

   ...

   5 - Very inconvenient
2. How convenient was it to use the occupancy sensor?

   1 - Very convenient

   ...

   5 - Very inconvenient
3. We also placed timers on common area equipment such as printers, fax machines, coffee makers, etc. Did this cause any inconvenience or significant change of your use of these devices?

   1 - No change or inconvenience

   ....

   5 - Significant change or inconvenience
4. Regarding the power management settings for your computer and monitor: would you prefer them to be…
   a. Set less aggressively than was implemented in the study (I prefer my devices to remain on longer)
   b. Set just as they were for the study (the levels were about right for me)
   c. Set more aggressively than was implemented in the study (to save more energy)
5. How often have you used the remote button for your power strip?
   a. Often (whenever I leave my desk)
   b. Occasionally
   c. Only once a day, to turn everything on
   d. Never (equipment is never shut down)
6. Regarding the remote button for your power strip:

   What is your opinion of this energy saving technology after using it for some time (check 1-3 statements that best describe your opinion)?

   - I had no problems using this technology to conveniently save energy.

- The technology was easy to use.
- This technology did not save energy (my equipment did not shut down while I was away).
- This technology did not work properly; it shut down too soon or too frequently.
- This technology was difficult to use or created significant interruptions in productivity.
- I did not notice the technology or its effectiveness.
- I already conserve energy with other strategies that are more effective than this strategy. (Please explain in the box below)

7. Regarding the occupancy sensor:

   What is your opinion of this energy saving technology after using it for some time (check 1-3 items)?

   - I had no problems using this technology to conveniently save energy.
   - The technology was easy to use.
   - This technology did not save energy (my equipment did not shut down while I was away).
   - This technology did not work properly; it shut down too soon or too frequently.
   - This technology was difficult to use or created significant interruptions in productivity.
   - I did not notice the technology or its effectiveness.
   - I already conserve energy with other strategies that are more effective than this strategy.

8. Please give us any other opinions you have, or tell us about specific problems or benefits you encountered from using plug load reduction technologies.

Appendix D: Behavior campaign development

On Saturday April 25, 2015, the project held a half-day workshop applying design thinking methods to employee plug load use in commercial offices. The workshop was hosted by CEE, the Design Thinking MN Meetup Group, and LHB and was held at LHB's Minneapolis offices. The Design Thinking MN Meetup Group has over 400 members and meets on the third Thursday of each month. The purpose of the group is to "bring people together to learn, share, and teach design thinking methodologies." Meetup is social service that facilitates a network of local groups around the world. The IoT Mpls Meetup Group (http://www.meetup.com/iotmpls/events/221933674/) and the Design Thinking Collective (https://plus.google.com/communities/111909390984421137237) also helped to publicize the event. CERTs and the Minnesota Environmental Partnership also listed the event on their online calendars.

The goals of the hands-on workshop were to:

- introduce participants to the design thinking process and allow them to experience each step of the process, and
- apply the design thinking process to developing strategies to create energy efficient behaviors with office plug loads.

About thirty participants gave up their Saturday (from 9 am to 2 pm) to participate in the workshop. Four working groups were created and volunteer facilitators were recruited from amongst the participants to lead each group through the process. Three of the four facilitators were experienced design thinking practitioners. Each were provided with gift cards for their efforts. The agenda for the workshop is provided below:

1. Welcome and Introductions
2. Overview
    a. Description of CARD project
    b. What are plug loads
    c. What is behavior (BJ Fogg model: Behavior = Motivation * Ability * Triggers)
    d. Objective of the Hands-on Workshop
    e. Explanation of design thinking
    f. Break into small groups
3. Small group design-thinking work (each group w/ facilitator)
    a. Empathize
    b. Define
    c. Ideate
    d. Prototype
4. Working lunch
    a. Test
    b. Prepare presentations
5. Presentations
6. Wrap Up

Design Thinking Process

Design thinking is a user-centered approach that has successfully been extended beyond design-oriented fields into mainstream business applications. Tim Brown, the CEO and president of the product design firm IDEO, defines design thinking as:

> "a methodology that imbues the full spectrum of innovation activities with a human-centered ethos. … by this I mean that innovation is powered by a thorough understanding, through direct observation, of what people want and need in their lives and what they like or dislike about the way particular products are made, packaged, marketed, sold, and supported."[5]

Design thinking has become a process to foment innovation for businesses. As Brown continues to explain:[6]

> Design thinking can be described as a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.

The design thinking process is performed through a sequence of five steps.[7] These are:

EMPATHIZE: This step develops a strong understanding of the users by observing their behaviors within the context of their lives. This involves both observing and interviewing the users, as well as engaging with all the stakeholders.

DEFINE: Taking the findings from the empathy step, the design problem is focused and framed into a point of view that defines the course of action.

IDEATE: Innovation begins with the ideate step. A range of solutions are brainstormed to go beyond obvious solutions and uncover new areas of exploration.

PROTOTYPE: The goal of prototyping is to bring the ideas and explorations out of the head and into physical forms that allow interaction and experimentation. Prototypes do not have to be an object. They can also be a wall of post-it notes, a process map, role-playing activity, or any other form that allows presentation, exploration, and refinement.

TEST: This is an iterative process to gain feedback from the users on the solutions in order to refine the solutions and obtain deeper insights into the user.

Stakeholder Interviews

The stakeholders for commercial plug loads were defined as:

- Office Workers

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[5] Tim Brown, "Thinking", Harvard Business Review, June 2008, pp 85-90.

[6] Ibid.

[7] Stanford University Hasso Plattner Institute of Design, d.school bootcamp bootleg, March 2011.

- Financial Officer/Accounting/Managerial
- IT Staff
- Building Owners/Operators/ Managers
- Facilities/Custodial

Because of time constraints, stakeholder interviews could not be performed during the empathy step of the workshop. In order to provide participants with the insights that would have been obtained from this step, pre-workshop interviews and surveys were performed with representatives from each of the stakeholder groups. Survey responses and transcripts from the face-to-face interviews were collected and catalogued. These were then handed out to each group. Appendices B, C, D, E, and F show the respective stakeholder responses that were obtained.

Discussion

The participants were very energetic and engaged during the workshop. Most were there to experience the design thinking process although a few attended for the energy efficiency issues too. Several were from the Humphrey School of Public Affairs at the University of Minnesota including one professor and a couple of graduates. Two building energy consultants attended as did an employee from an energy utility. An instructional designer also participated but the majority of the attendees came from the two meetup groups: Design Thinking MN and IoT Mpls. Reaction of the workshop from the attendees was very good and the feedback we received was all very positive. The workshop was very successful as a hands-on demonstration of the design-thinking process.

With regard to the development of behavioral strategies for plug lead energy efficiency, all four groups focused on the plug load use at office work stations. Most of the groups decided that the main need was to make energy use more visible in order to change behavior while the third group decided that convenience and consequently automation were the important factors. The solutions that were developed were all rather tried and true. Three groups came up with the idea of an energy dashboard while the fourth group proposed a motion-sensing power strip.

Several reasons can be found to explain why the solutions tended toward the mundane. Firstly, the participants were introduced to two new concepts that morning, the design thinking process and commercial office plug load use. Given the short time of the workshop (about three hours of actual working time), the emphasis of the workshop became more the experiencing of design thinking than creating innovative behavioral strategies.

Secondly, three of the facilitators were experienced design thinking professionals but did not have experience with the energy issues. The fourth facilitator had the energy background but was inexperienced with the design thinking process. Relying on volunteer facilitators, recruited during the workshop, did not hinder the experiential, process-oriented side of the workshop, but it did put the content, energy-piece at a disadvantage.

The short time frame was also an important determining factor. More time was needed to absorb and reflect on the stakeholder responses. Only one team focused on a stakeholder besides the office workers. That group identified the IT manager as a key player in helping office workers reduce their computer workstation plug loads. The groups did perform interviews with each other to gain some experience but this also helped to focus their point of views on the office worker rather than other stakeholders. Many insights could have been obtained from the responses of the other stakeholders and that seemed to limit the Define step.

The goal of the ideation phase is to go beyond the obvious solutions. This was an area where the small groups fell short. More guidance should have been provided to the facilitators and as the ideation phases were taking place, not enough attention to and oversight of the small group work by the workshop organizer was done.

All the groups created prototypes and they got feedback on their prototypes during the presentations. Testing could not truly be performed since users and other stakeholders were not in attendance.

Recommendations and conclusions

An important takeaway from the workshop is that the design thinking process could be an effective way to engage stakeholders in developing and implementing a commercial office plug load campaign. Pre-workshop interviews showed that stakeholders like office managers, IT staff, building property managers, and facility maintenance staff are essential to include in the process. Their participation in the process brings opportunities for motivating and incentivizing actions, providing feedback and policing, and responding to user needs and wants. A facilitated deep dive with users and stakeholders could be performed over a few days to a week to develop, test, and deliver a behavioral office plug load approach. The task group should include a facilitator versed in the design thinking process as well as members with expertise in office energy behavior methods and the ability to make working prototypes such as controlled devices and web dashboards. This process could also dovetail with any lean approaches that the office might be using.[8]

There are two potential uses for this type of design thinking event and each would have different goals and participants. The first use would be an event that gets users to more rapidly embrace the change as a positive thing that they will seek to maximize, not resist. The event would be used to recruit and engage a subset of users that would then serve as leaders, models, and evangelists for the rest of the organization.

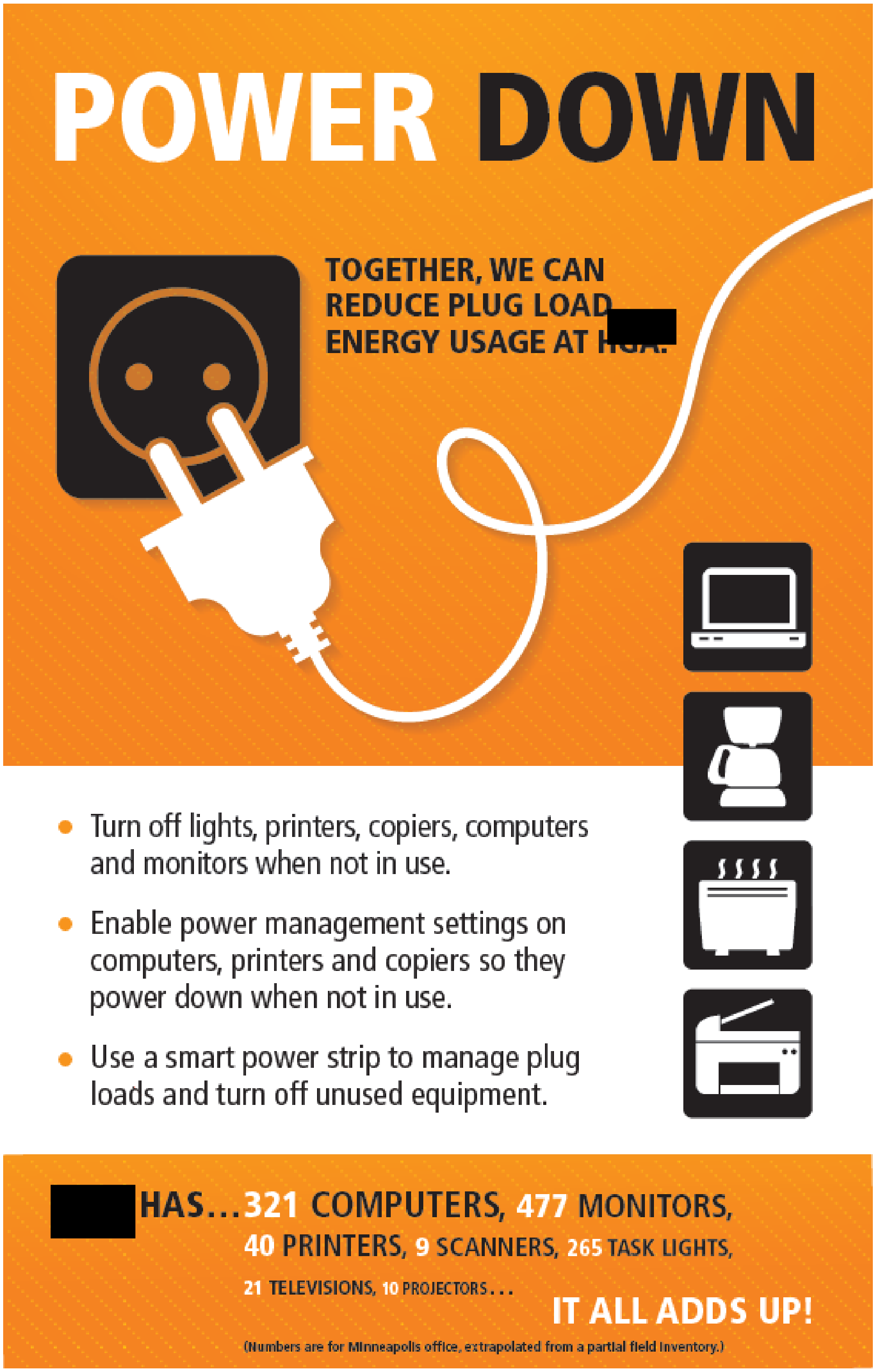
The second use would be to seek out new solutions to specialized problems. In this case the process would bring together experts in the fields of behavior and energy efficiency who have built trusting and respectful relationships with one another prior to the event. This group would be tasked to get new solutions that are worth putting into a pilot program.

The hands-on workshop was successful for the participants and served as an excellent demonstration of how the design-thinking process could be applied to the commercial plug load project. By implementing the process on site with all the stakeholders, an effective user-centered strategy could be created. The main determinants for success though would center on having a qualified and experienced facilitator, active participation of the stakeholders, and enough time to adequately apply the process.

[8] U.S. Environmental Protection Agency, The Lean, Energy, and Climate Toolkit, EPA-100-K-07-003, August 2011. http://www.epa.gov/lean/environment/toolkits/energy/index.htm

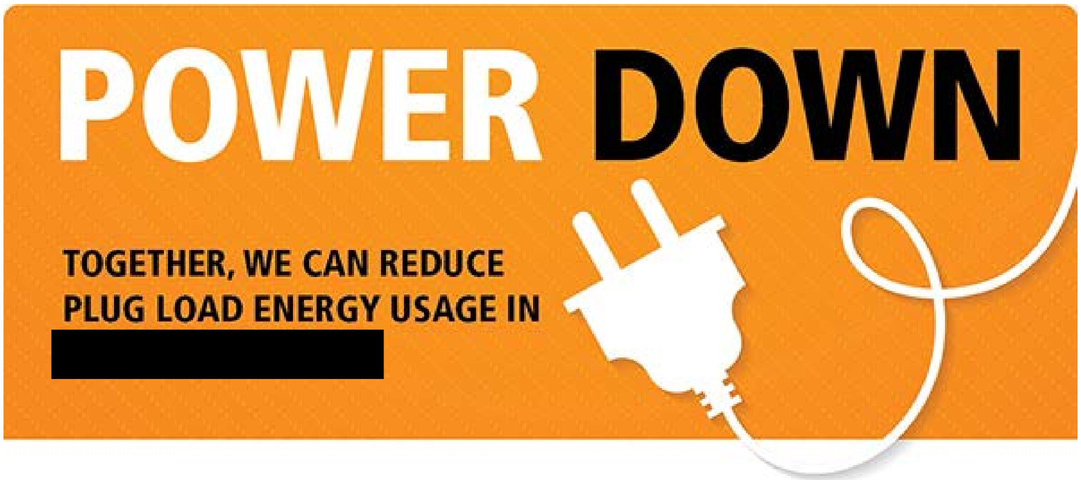
Appendix E: Behavior campaign materials

Example of a poster used in behavior campaign



Example of an email used in behavior campaign

Trouble viewing this email? View it in your browser.



In the last couple weeks we have taken some basic actions to reduce plug load energy in the office.
Are you interested in doing more?

Here are some additional steps you can take:

- ☐ **Adjust your sleep timing** in the computer's power settings. Go to ‘Power Options’ in the Control Panel, and click on ‘Change Plan Settings’...
- ☐ **Adjust monitor brightness** downward. Adjust using your monitor menu (on a laptop, use the same menu from ‘Power Options’ above).
- ☐ **Shut off your entire power strip** each evening, and especially prior to the weekend.
- ☐ **Turn off your second monitor** (or close laptop screen) when you are only using one.
- ☐ **Remove all space heaters and fans.** Compensate using clothing choices instead.
- ☐ **Remove unused electronic items** from your station entirely: printers, lamps, coffeemakers, speakers, hot plates, chargers, etc.
- ☐ **Fully shut down computer each evening**, by selecting ‘Shut Down’ from the Start menu. (If you are a remote desktop user, shut down when you won't be accessing remotely.)

- ☐ **Turn off all monitors** when leaving for a meeting or lunch. Or better yet, put computer in 'sleep' mode, via the Start menu.
- ☐ **Put computer in 'Hibernate'** mode when leaving your workstation for a longer period (e.g. long meetings). This is even better than 'Sleep' mode.
- ☐ **Turn off smaller printers** when not in use. Standby mode still uses substantial energy in these types of equipment.
- ☐ **Turn off task lights** when not in use.
- ☐ **Unplug all chargers** from the wall when not in use (for phones, electronics, etc.), to avoid vampire loads.
- ☐ **Plug peripherals into computers** (USB) instead of the wall, where possible.
- ☐ **Unplug, or at least turn off, electronics** (radios, speakers, etc.) when not in use.
- ☐ **Come up with a new idea** for energy savings that's not on the list. Be sure to share the idea with me!

Sincerely,
[redacted] Behalf of [redacted]

Appendix F: Example site summary handout

After the field study and analysis are complete, we will return to each participating site and disseminate the results of the study with a targeted presentation. This will include a handout that each participant can use to understand plug loads at their office, as well as some key conclusions from the overall study. This Appendix is a draft example of that handout.

MN Card Grant PlugLoad Reduction Study **Summary**

LHB Office:

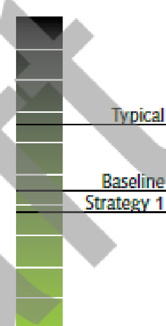
Area: XXXXX sq ft
Occupancy: XXXXX
Work Stations Tested: XX
Baseline Plugload: XXXX Watts/sf
Energy Use Intensity: XXXX kWh/sf/yr

Field Study Summary:
Baseline usage at the site was ____. Two strategies were tested...

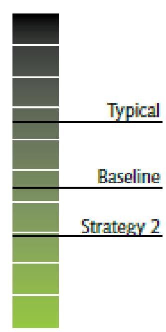
Quaesita enim virtus est, non quae relinqueret naturam, sed quae tueretur. Videmus igitur ut conquiescere ne infantes quidem possint. Verum tamen cum de rebus grandioribus dicas, ipsae res verba rapiunt; De hominibus dici non necesse est. Duo Reges: constructio interrete.

User Satisfaction Survey Results:
The strategy that received the most favorable responses was the foot pedal switch attached to the smart power strip. 80% of all respondents indicated that they felt this technology was easy to use and effective. In addition to being considered convenient or very convenient by 73% of surveyed participants, there were no negative comments about this technology.
The occupancy sensor was also well received with 64% of participants indicating that they felt the technology was convenient or very convenient, and 63% of participants specifically indicated that the technology was easy to use and effective. Approximately one quarter of all respondents indicated that they did not notice the technology or its effectiveness, making this the least noticed technology. As this technology is intended to seamlessly turn secondary plug loads on and off without requiring any action from the occupant, having a substantial group who did not notice the technology can be considered as positive.

Strategy 1: Occupancy Controls



Strategy 2: Computer Power Management



Plugload Resuction Study Results & Recommendations:

Across eight sites, four different reduction strategies were tested.
1) Behavior Change Campaign
2) Advanced Power Strip with Time and Foot-pedal
3) Advanced Power Strip with Occupancy Sensor
4) Computer Power Management

Of these strategies, ______ resulted in the most energy savings.

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Quos quidem tibi studiose et diligenter tractandos magnopere censeo. Tum mihi Piso: Quid ergo? Duo Reges: constructio interrete. Post enim Chrysippum eum non sane est disputatum. Sed in rebus apertissimis nimium longi sumus. Et ille ridens: Video, inquit, quid agas; Facile est hoc cernere in primis puerorum aetatulis. Quae similitudo in genere etiam humano apparet. An hoc usque quaque, aliter in vita? Sed haec quidem liberius ab eo dicuntur et saepius. An nisi populari fama? Duarum enim vitarum nobis erunt instituta capienda.