Advancing the Last Frontier – Reduction of Commercial Plug Loads

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ABSTRACT

Plug load energy use in commercial buildings has increased, especially in contrast to the decrease in other more regulated end uses of high performance buildings, such as cooling and lighting. By combining a characterization study, field measurements of several strategies, and user satisfaction interviews, our team has investigated the most effective plug load approaches for office spaces. We have conducted a broad, multi-level field study to determine the potential for and most likely savings from implementation of four plug load reduction strategies: two types of advanced power strip (APS), computer power management, and a behavior campaign. This latter strategy demonstrates that the human element of plug load technology must be addressed for optimal savings.

Field study results demonstrated savings of 19-32%, with the APS strategies at the low end of that range and the others at the high end. Savings were highly variable, and dependent on the type and amount of loads in a typical workstation for an office. Occupants were also surveyed to determine satisfaction with each strategy. The APS devices were generally well received. Computer power management was received well by a majority of occupants, but the minority who found it inconvenient were highly vocal about its negative impacts.

This study has shown that the best paths to significant reduction in plug loads are also the more difficult-to-implement strategies, such as computer power management (which requires a level of interaction with IT staff that may be a deterrent to some). For workstations with relatively significant load (such as those with desktop computers), these strategies have enough impact to be worth consideration. For other workstations, convenient and inexpensive APS are potentially the best solution.

Introduction

Plug load energy use in commercial buildings has increased, especially in contrast to the decrease in other more regulated end uses such as heating, ventilation, air conditioning (HVAC) and lighting. In Minnesota, where this study was conducted, the average plug load energy 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. But the increasing importance of plug loads is most evident is when a building is striving for a much lower Energy Use Intensity (EUI), based on targets such as LEED or Architecture 2030. Such buildings are striving for EUIs of 40 or below. With plug load use rising, it can mean 20 kBtu/ft^2/year (50%) or greater of that target EUI is consumed by plug load. In other words, plug load usage is making it increasingly difficult to meet 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 on regulated loads.

This study has evaluated plug load energy usage in office buildings in Minnesota in order to determine the extent of the problem, and has also tested solutions to the problem. By combining a characterization study, field measurements of several reduction strategies, and user satisfaction interviews, our team has identified effective plug load approaches for new and existing office buildings. 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 study that investigates the magnitude of these strategies in a number of different office types. The primary value of the data we have collected is in its breadth – we have monitored over 1000 devices across six diverse office types so far.[1]

This study has not only measured usage, but empirical energy and cost savings from four different strategies including two general types of power strips, 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. There have been numerous studies in the last decade, primarily in the residential sector, demonstrating the impact of human behavior.

Within this paper we will present the approach and results of our broad field study, as well as qualitative lessons learned. Our objective is to fill significant gaps in the understanding of plug load impacts and in turn inform the development and refinement of plug load programs.

Approach

Commercial plug loads are diverse, highly variable, and directly impacted by user behavior. As a result, it was critical that our experiment measure the impact of plug load reduction strategies in a number of actual offices, as opposed to a single case study or purely theoretical approach using models. So our two primary activities were measurement of energy usage by plug loads in those offices, and then measurement of energy saved when strategies are put in place to reduce that usage.

We also had some additional secondary objectives for the study. The first was to characterize the plug loads in Minnesota. We therefore began with a 76-question survey instrument that was completed for 34 offices in the state. This characterization helped us determine the distribution of different types of plug loads across typical offices in Minnesota – results are shown in the next section. This also gave us a population from which to choose several typical offices for field measurement. With the large diversity in office types we did not attempt to make this sample statistically representative – there may therefore be some selection bias as we administered the survey to offices that were known to the three partners in the project. We included offices with varying attributes: public and private, owned and leased, small and large, standalone and connected to other building types (e.g. labs, warehouses, academic buildings).

While we were conducting the survey we also conducted a thorough literature review of existing plug load studies. There were a number of studies that had characterized plug loads in

[1] The initial phase of the project is complete, in which we've directly observed and measured plug loads and savings strategies in six offices. When both phases are complete we will have measured eight offices, and completed analysis of common area equipment.

office space. Roberson (2004) monitored after hours plug load usage in 12 offices. A few years later, Sanchez (2007) conducted a broad study of plug loads in 16 buildings, including detailed inventories of all the plug loads found in each. Moorefield (2011) measured baseline usage in 25 offices, including both inventory data and observed operational modes. Pixley (2014) conducted an even broader study using a self-administered survey in which they determined typical computer power settings and mode usage. In addition to helping us scope our study, these papers allowed us to compare our characterization results with other areas of the country.

A few studies have taken the next step and measured energy impacts of plug load reduction strategies. Mercier (2011) considered savings analytically, calculating potential savings for a number of different strategies theoretically based on measured baseline energy usage. Metzger (2014) directly field-measured savings from three different types of advanced power strips (APS) at one federal office building. Acker (2012) measured savings from APS at six different office buildings in the Western US. And Metzger (2012) measured savings from both timers and APS in eight GSA office spaces.

Once the literature review and characterization effort were complete, we were able to finalize the energy reduction strategies that we would measure in the field based on 1) gaps in existing research on the subject and 2) strategies that had a higher likelihood of success with the plug loads we observed in our characterization. We also eliminated strategies that would be easy to calculate based on baseline usage data (such as task light wattage reduction); we could estimate savings from these strategies based on the baseline equipment usage data alone.

We then used randomized control trials to measure savings in the field for each of the strategies. In each office, we randomly selected forty workstations for measurement. For each workstation we measured both the total workstation energy usage as well as the energy usage of just the desktop or laptop computer(s) present. We then easily obtained a measurement for all "other" plug loads beside the computer, via subtraction.

Of those forty workstations, we randomly selected two-thirds as a treatment group and one-third as a control group. All forty workstations were measured for one month as they were found. Individual plug load data loggers were used to measure both the total workstation energy, and just the energy going to the PC. After that first month, we implanted energy saving strategies at all the workstations in the Treatment group, and measured for one more month.

To calculate typical energy savings for each strategy we used a difference in differences method. We first calculated gross savings for each workstation (in both treatment and control groups) by subtracting measured usage with the strategy to measured usage without the strategy.[2] Literature (Acker 2012) suggests that usage is generally lower during certain months like vacation-heavy August. To account for this seasonal variability the ultimate net savings was then calculated by comparing the difference between gross savings in the treatment group and gross savings in the control group.

Finally, in addition to measuring the energy impact of each strategy, we captured data on occupant satisfaction to determine whether energy was being saved to the detriment of occupant comfort and productivity. We captured this information by conducting a survey of each occupant who experienced a plug load reduction strategy throughout the course of our research.

[2] To account for variability by day types, usage for the baseline and strategy periods of measurement were first normalized by the number of each weekday type, and holidays, in each period.

Plug load inventories

To begin the study, an online survey of potential project participants was conducted. Self-reported results were received from occupants of 34 offices. The respondents included both owners (22) and tenants (12). 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. Information was collected on: business type, hours of operation, type of work spaces, and types of plug load devices. Finally, respondents were given instructions 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 buildings surveyed include commercial, educational and government facilities, each housing a wide variety of office activities as shown in Figure 1. 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. The diversity of uses ensures that the survey and study represent a wide range of office types. Most, but not all, of the organizations had already undertaken some step to improve operational sustainability, as is shown in Figure 1. The primary steps taken were purchasing policies favoring energy efficient devices (such as EnergySTAR) and organizational mission statements that include sustainability.

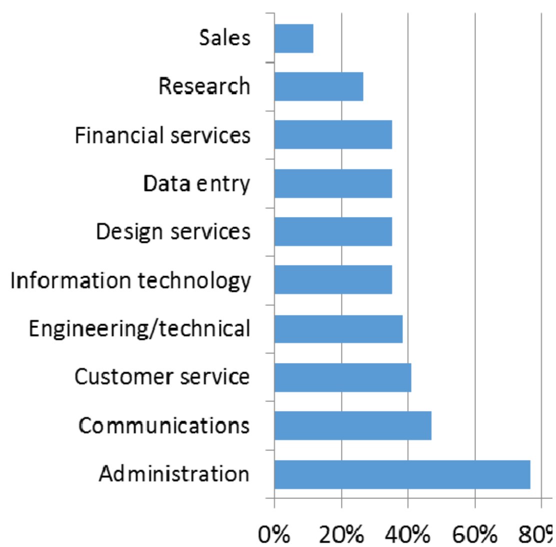

Figure 1. Office activities at buildings in online survey. percent of offices with each activity.

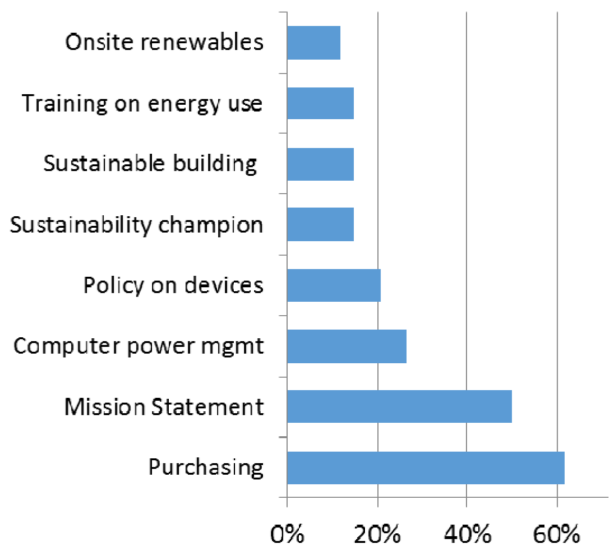

Figure 2. Sustainability practices at businesses in the online survey, percent of offices with each practice.

Other notable attributes of these office spaces included:

- 54% pay for their electricity based on a meter dedicated to their space.
- Over 75% have replaced computers, monitors and multifunction devices within the past three years.
- 75% report that the employee labor occurred primarily in the office, with less than 25% of work time spent outside the office.
- 69% of the employees are in cubicles in open offices, 22% are in private offices, and the remaining 9% are in shared offices.

Eight field study sites were then selected from the sites that filled out the online survey. At these sites the project team was able to validate the inventories for a sample of the offices. Detailed inventories were performed on 45 randomly selected workstations at each site as well as all adjacent common spaces. Table 1 compares the inventory results.

Table 1. Data from plug load inventories.

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

Other observations on the inventory include:

- While no sites reported having more than one laptop per workstation, this was observed in several sites in our on-site work.
- A significant majority of workstations have a single VOIP phone.
- “Other” equipment includes speakers (30%), printers (17%), fans (15%), handheld device chargers, and more.
- The least dense office space had almost 40% more area per employee than the densest spaces.
- The majority of sites now standardize on two monitors per desk.
- No CRT monitors were observed in any site.

Plug load reduction strategies

In the initial phase of work completed at the time of this writing, measurements were complete at six of the eight sites:

- Site A: a medium-sized architecture firm
- Site B: a city’s public works department
- Site C: a small commercial real estate firm
- Site D: the R&D office of a large manufacturer
- Site E: a large architecture and engineering firm
- Site F: a large county office

Our experimental design included four energy reduction strategies tested at each site (though not every strategy can be tested at every site).

We chose four reduction strategies to measure in the field based on criteria described in the *Approach* section. We implemented these as closely as possible to how we felt an owner or contractor would implement each strategy if it were inserted into an existing office as part of an energy efficiency program. Hardware was installed after-hours, but occupants were informed of the changes in enough detail that the change would not adversely affect their daily routine. The four strategies are described below.

Advanced Power Strip with Occupancy Sensor

This advanced power strip (APS) strategy utilized an occupancy sensor attached an-otherwise standard power strip. The APS was swapped for the existing power strip at each workstation. The occupancy sensor has a long cord such 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 (the APS is shown in Figure 3). The occupancy sensor allowed for a variable timeout 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 (“switched”) and non-controlled (“always-on”) outlets; we plugged all devices into the controlled outlets except for desktop computers and laptop docking stations (unless users actively plugged their laptop into the controlled outlet).

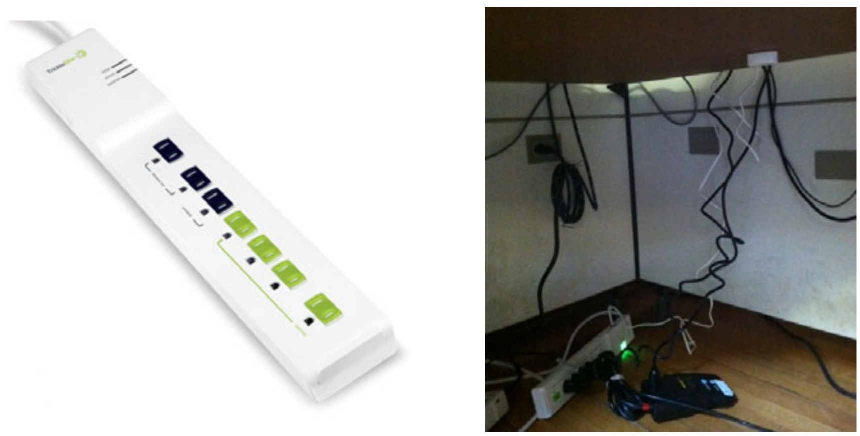

Figure 3. Example of APS (left; Photo courtesy of Tricklestar) itself, and an APS installed under a desk and attached to an occupancy sensor mounted on the underside of the desk (right; sensor at top right of photo).

Advanced Power Strip with Timer and Foot-pedal

This APS strategy utilized both an internal timer and a foot-pedal 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 those willing to engage with their power strip, 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 if they wish. For those less willing to engage, the foot pedal would simply have to be pressed once when they arrive at the office for the day. The internal timer would then keep the APS on for 10 hours of power. If they are not engaged enough to turn the strip off when they leave for the day, it would turn off on its own 10 hours after they initially turned it on.

Computer Power Management

Our computer power management (CPM) strategy utilized existing infrastructure at each site to adjust power settings on each computer to make them more energy conserving. The 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.

In each case, local 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 a location. In general, the concerns they voiced were similar to those voiced and subsequently overcome at other sites.

Behavior Change Campaign

Hardware alone can only realize a portion of the potential energy savings in office plug loads. Office devices must still 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 also tested a behavior change campaign strategy that built upon the APS with foot pedal. In this campaign, we used communications such as emails and posters to inform users of the potential that their behaviors had for saving energy. The users were, in part, empowered to follow-through on those behaviors through the use of the APS with foot pedal.

Finally, in addition to communication and empowerment, we included two feedback mechanisms. First, our contact at each site was provided with nominal rewards (e.g. gift cards, chocolate) to pass out to users who were observed employing energy saving behaviors. And second, a bright blue LED was placed on the desktop of each user signaling when their power strip was on. This provided a reminder as they left their workstation of whether the APS was indeed on or off. It also provided a touchstone for social engagement, whether for simple conversation or through users noticing each other's energy behaviors (and even providing occasional reminders). This behavior change campaign tested test two different ends of a spectrum – just technology installed with bare minimum instruction – and technology installed with some much more significant component of communication and engagement with the stakeholders

Energy Impacts

Plug load energy usage is highly variable with business type, IT approach, and user behavior. Per workstation energy usage (including computers, monitors, and all other plug loads) ranged from 150 kWh/year in the least energy intensive office, to 720 kWh/year per workstation in the most energy intensive office (based on the as-found baseline). At its highest, single workstation usage was as high as 1600 kWh annually. Those with desktop computers tended to be on the high end, and those with laptop computers tended toward the low end of that range.

In terms of plug load density, this translates to measured density from a low of 0.63 to a high of 2.66 kWh/ft^2, or in terms of EUI from 2.2 to 9.1 kBtu/ft^2/year.

As a result of the variability in energy usage, energy savings was highly variable from workstation to workstation, and even from site to site. The results must therefore be considered in relation to their variability, and associated uncertainty. The annual energy savings for each strategy (extrapolated from our monthly measurements) is shown in Table 2.

Table 2. Annual energy savings by strategy (N is the number of workstations measured)

	Energy savings			
	kWh per station	%	(with 95% conf. int.)	N
APS occupancy sensor	**67**	**22%**	± 14%	95
APS foot pedal	**42**	**19%**	± 13%	74
APS foot pedal + behavior campaign	**67**	**22%**	± 13%	49
Computer power management	**136**	**32%**	± 27%	64

All strategies are saving between 19-32% of workstation energy. The APS-based approaches saved 19-22%. The difference in savings between the APS with occupancy sensor and APS with foot pedal is not significant, because these savings results are from different offices with different types of devices and operations.

The additional savings demonstrated by the behavior campaign, however, is more significant because the behavior campaign was tested in the same offices as the foot pedal. The behavior campaign always immediately followed testing of just the foot pedal (without behavior). In this way it built upon the foot pedal APS by adding multiple behavioral influences while occupants were empowered by their access to the foot pedal. As expected, adding the behavioral components increased savings, in this case by 25 kWh per workstation, or 3% of total workstation plug load usage.

It's also worth noting that the occupancy sensor's impact seemed to be hindered somewhat by passersby activating the sensor when in fact nobody is at the workstation – this was reported most significantly in the more open cubicle-based offices, the configuration that is increasingly popular in office design.

Computer power management's impact was hindered somewhat by a handful of participants that disabled their power settings at various times, primarily to allow for remote access into their computers in the evening. And note savings was only measured for sites where IT staff would allow computer power management to be implemented; some sites were not willing to accommodate this strategy (see the discussion of the CPM strategy above for more detail). With these caveats, CPM represented the highest potential energy savings, at 32% of total plug load energy, or 136 kWh per workstation. This is a result of desktop and laptop usage representing the single largest energy user at the vast majority of workstations.

In order to compare this potential savings to other types of building energy efficiency strategies, it is useful to consider the statistic that in our broader survey of Minnesota offices, the average floor area of office (including hallways, adjacent conference rooms, etc.) per workstation was 280 ft^2/workstation. This means that a savings range of between 40 – 140 kWh per workstation would typically translate to a plug load density savings of 0.14 – 0.50 kWh/ft2. In an office this is the equivalent of reducing the lighting power by anywhere from 0.06 to 0.19 W/ft^2 – a significant reduction.

One primary driver of variability in energy savings was the typical equipment setup in each office, with the primary difference being whether computing is done on a laptop or desktop computer. All sites had a mix of laptops and desktops. That mix was generally either mostly laptops with just a few desktops for computationally intensive activities, or mostly desktops with a few laptops. In Table 3 we demonstrate the impact of this mix by comparing the impact of the computer power management strategy for stations with desktops vs. those with laptops.

Table 3. Savings for computer power management for laptop vs desktop offices

	Energy savings		
	kWh per station	%	N
Desktop treatment	263	35%	25
Laptop treatment	47	26%	39

In addition to kWh savings being lower due to the laptops lower base energy usage, the percent savings for the laptop stations is also noticeably smaller. This is likely due to the fact that laptops' more strict default computer power management settings are keeping the potential for savings lower.

Occupant feedback

Toward the end of each field study period, we conducted an online survey of each occupant who experienced a plug load reduction strategy throughout the course of our research. Participants gave generally positive responses when asked about their experiences with the strategies installed. The survey included questions with multiple choice selections as well as comment boxes for open-ended feedback.

The strategy that received the most favorable responses was the APS with timer and foot-pedal. 77% of all respondents indicated that they felt this technology was easy to use and effective. When asked about the convenience of use, it was considered convenient or very convenient by 58% of surveyed participants. There were no negative comments about this technology. Occupants' positive reaction to this strategy, and its perception as an "effective" strategy, were seemingly due to occupants' ability to regularly interact with it.

The APS with occupancy sensor was also well received, with 64% of participants rating the technology's convenience as either convenient or very convenient. Occupants were also asked to rate usability and effectiveness; results for this question are shown in Figure 4.

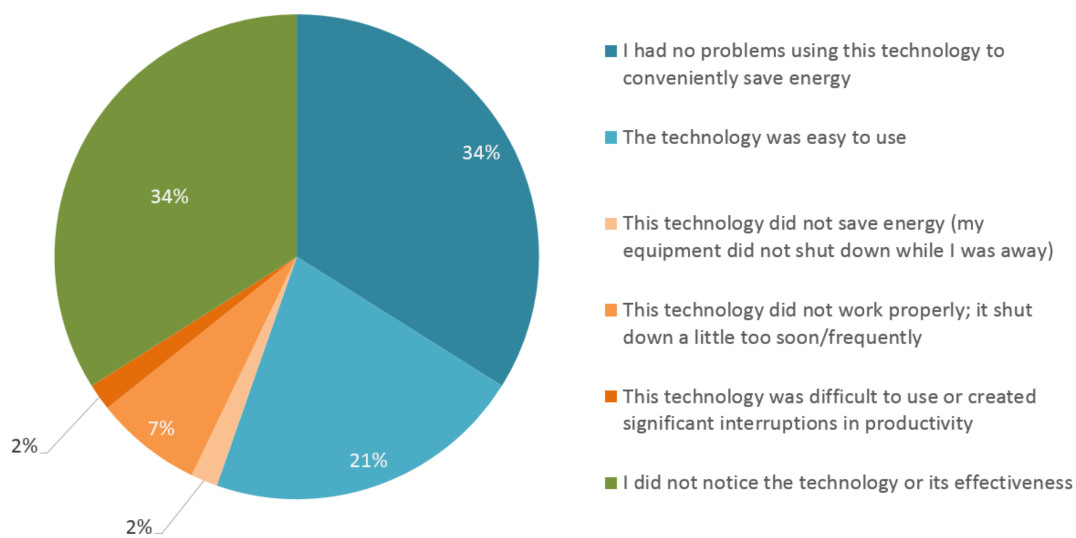

Figure 4. Summary of occupant satisfaction survey results question regarding APS with Occupancy Sensor.

While 55% of participants specifically indicated that the technology was easy to use and effective, an additional 34% of occupants indicated that they did not notice the technology or its effectiveness. 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, comments did include several instances of the occupancy sensor responding to movement in the area of the workstation and either not turning off, or turning back on when no one is at the workstation. For example, “In the morning my task lights were always on. We determined this happened when people walked by my office.” Also “Not shutting things down and letting a sensor do the work made me nervous.” The impact of false-activation on the occupancy sensor is already captured in the results above. But the inability of occupants to interact with the occupancy sensor is a separate non-energy impact that should be considered.

Computer power management (CPM) was well received by the majority of occupants as well, with 62% of responses indicating that the settings were about right, or could be more aggressive. But the 38% who responded otherwise were decidedly more vocal. They generally indicated that they would like their devices to remain on longer. CPM had by far the most comments of any strategy. In addition to some anticipated issues with remote connection (which received 9 comments), CPM also created other issues that impacted productivity. Six participants commented that they had issues with their computers waking back up slowly when they returned to their work station. Another six mentioned issues with general computer performance – programs being sluggish or not starting back up, or network connection issues. And four mentioned specifically that they needed to frequently restart the computer completely after it went into a conservation mode, which could take upwards of 5 minutes each time. There were also two comments about computers going to sleep at inappropriate times. But the positive response from the majority of occupants suggests that if appropriate CPM settings were the norm, as opposed to a “new” strategy, issues could be resolved or adapted to.

Overall, participant comments were enlightening. Several participants indicated that they understood the importance of saving energy, and that they were willing to be inconvenienced somewhat if they could help reduce consumption. Comments also indicated that they were less willing to utilize strategies for the long term if they impacted their productivity or ability to work remotely.

Lessons from the field

In addition to quantitative data, we captured several useful qualitative lessons though our field work:

- Some strategies, in some office cultures, may be most effective when made as “invisible” as possible to the user – in some cases those who are aware that a control strategy is being implemented are concerned about negative impacts, while those who are unaware didn’t notice any impact (negative or positive). This is in contrast to behavior campaigns or remote-control APS strategies that seek engagement of participants.
- Initially we collected the data at one-minute intervals with all data loggers, in order to avoid missing important events. This required very long download times for some loggers, for older loggers also approached the limits of their memory. After analyzing data from our first treatment site, we found that we there was no loss in accuracy or precision in using 15-minute intervals with the older loggers that were specifically measuring computer energy usage. This resulted in data collection time being reduced by

about 75% (total workstation energy usage – the more critical value – was still collected at 1 minute intervals).

- Some amount of training is needed for the APS with foot pedal. For example, the foot pedal normally turns the APS on and off. But it is also used – when clicked in rapid succession – for adjusting the internal timer on the APS in increments of one hour (each rapid press increments the duration by one hour, up to the maximum). One impatient user rapidly stepped on the foot pedal enough to reset their settings to a shorter duration. When their computer shut off prematurely, the user was even more frustrated, having no idea what had changed the settings or how to correct it.
- Occupants requested that some devices not be controlled. For example for some multifunction devices (MFDs, i.e. copier/printer/scanner) the service representative who saw the controls told the participant that the equipment was not made to be turned off overnight. At one such site, controlling the MFD to off each night did lead to an error on the MFD screen each morning. At other locations we were told that such machines could be controlled. Similarly, some receptionists with battery-powered headset devices for their phones requested that their chargers not be controlled overnight, so that their headsets could reach a full charge. We did not test how long it took headsets to reach a full charge.
- We inadvertently (and inappropriately) plugged in some devices to plug load controls, such as clock radios and wireless headset chargers, resulting in incorrect time displays and uncharged batteries. These were easily remediated by moving the plug to one of the uncontrolled outlets on the APS.
- At all sites, IT staff initially demonstrated at least partial resistance to CPM due to concerns about causing user complaints and of creating uncertainty with regard to the implementation of software updates requiring network connections in order to occur.
- While CPM offers excellent savings, users at several offices who connect to their office computer in the evening or on weekends using “remote desktop connection” found themselves unable to work remotely, losing productivity. Based on this anecdotal evidence and the resulting concerns, CPM was curtailed for those who regularly used remote desktop connection. This stands in contrast to those who use a virtualized machine approach to remote connection, for which CPM is not an issue.
- At one location essentially all of the workstations were equipped with laptops, and the staff frequently used them outside the office. In a number of cases these users took both their laptop and power supply (i.e. cord) with them at night. One consequence of this was that they often did not plug the computer back in to the correct outlet, either for control or monitoring purposes. We did not have this problem when there was a docking station permanently set up for the laptop.

Conclusion

Plug load energy usage remains an area for further reduction in energy usage, especially in high performance buildings. Our field measurements showed that the paths to significant reduction are also the more difficult-to-implement strategies such as comprehensive behavior campaigns and computer power management (which requires enough interaction with IT staff to be a deterrent to some). For workstations with relatively high load (such as those with desktop computers), these strategies have a significant enough impact to be worth consideration. For other workstations, convenient and inexpensive APS are potentially the best solution.

Acknowledgements

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