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FINAL PROJECT REPORT

MONITORING COMPUTER POWER MODES USAGE IN A UNIVERSITY POPULATION

Prepared for: California Energy Commission
Prepared by: California Plug Load Research Center
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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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ABSTRACT

This study takes a computer-based approach to understanding computer power management behaviors. It is a follow-up to a large online survey conducted by the same University of California Irvine research team, which asked respondents about all the computers they use, including office desktops. The online survey results showed a high rate of reported engagement of automatic power management settings, and moderate use of manual steps, such as manual shutdown. The current study examines the office desktops of a subsample of staff members, faculty members, and graduate students of the earlier study, enabling comparison across the two studies. Researchers examined the power settings of 125 office desktops, and remotely monitored the power states of 119 of the computers for several weeks. Participants also completed questionnaires. Power state monitoring shows that desktops were off an average of 16 percent of the time and in sleep mode for 7 percent. The majority of time (61 percent) was spent on but user-inactive. While 84 percent of these participants had reported using automatic settings in the earlier survey, only 20 percent of their desktops had any automatic settings enabled. A minority of computers exhibited manual use of sleep mode and 25 percent of computers exhibit some manual shutdown or hibernation. Greater power management engagement was found for participants with more control over their computers and those with more computer expertise; this helps to explain the lower enabling rates for staff members (versus faculty members) and for women. The findings are consistent with the idea that differences between the survey reports and the monitoring study data are due to users' confusion about power management settings; sources of that confusion and its possible connection to lower enabling rates are discussed.

Keywords: computers, computer users, behavior, energy, efficiency, power management, university, laptops, desktops, monitoring, sleep, hibernate, Verdiem Surveyor

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EXECUTIVE SUMMARY

Background

A significant portion of plug load energy in both residences and businesses is used for computers, including desktops, laptops, and related computing devices. Studies indicated that computers account for about 2 percent of California's electricity consumption.

New computers typically have built-in features such as sleep or hibernation that reduce energy consumption when the computer is not in active use. These features allow the computer to be switched to one or more low-power modes, or to transition into such a mode automatically. Study after study has made it clear that computer users are not employing these power management options effectively, and that doing so could significantly reduce both residential and commercial electricity use. However, little research has addressed how, when, and why users engage—or do not engage—these options. A better understanding of user behavior is thus a crucial part of increasing energy efficiency for computers.

Many research studies have addressed power management issues. Numerous studies measure the energy usage of a specific model or category of computer, and make projections of the total energy savings possible from power management. However, those estimates depend on various assumptions about user behavior. There is a plethora of literature encouraging computer users to use their power management settings and explaining how to do so. Variations in operating systems, however, make a broad campaign difficult, and the effectiveness of those efforts is difficult to evaluate. Many energy audits of computers and related devices in commercial and university buildings and in residences have measured hours of use and power levels; however, monitoring alone cannot determine which power settings were selected or why. There are also numerous surveys of households and individuals, but most of these surveys have been limited to a few questions in a broader study of household energy use. A few previous studies have combined surveys and monitoring, but none have studied computer power management at home and work for the same persons.

The general agreement among all of these studies is that users do not shut down their computers or engage power-saving modes as often as they could. However, the findings, definitions, and situations in these studies vary widely, so there is little consensus on estimates of power management behavior.

Purpose

This study investigates how people use the power management features on their desktop computers at work. This study was designed to supplement an online survey conducted by the same researchers in the spring of 2013, at the California Plug Load Research Center at the University of California, Irvine. That survey had a total sample of 2,081 respondents, including students, staff members, faculty members, and retirees. Those respondents were asked about all their office desktops, home desktops, and laptops, for a total of 3,369 computers. The researchers also gathered additional background information about the respondents themselves.

This follow-up monitoring study in 2014 focused on a subset of office desktops reported in the 2013 survey, The subjects of this follow-up study were survey respondents who were staff members, faculty members, or graduate students and who were sole or primary users of at least one office desktop on campus. Recruitment was further limited to those who had agreed in the survey that they would be willing to consider participating in a follow-up study. There were 125 participants; comparison results are also provided for a matching subsample of 572 respondents from the spring 2013 survey.

This monitoring study provides three sources of data: monitoring of computer states over a period of several weeks, supplementary questionnaire data, and researcher observations of the automatic power management settings on the participants' computers. The monitoring study includes questionnaire and observational data for 125 office desktops and computer state monitoring data for 119 of them. All three types of data are combined and compared to participants' self-reports from the 2013 survey.

This report is organized around the following research questions:

- What are the observed patterns of computer states and user activity, and how do they differ on weekdays and weekends, and at various times of the day or night?
- What are the rates for enabling automatic power management settings for these computers, and which settings are enabled?
- What are the rates for enabling manual power management among computers without automatic power management engaged?
- How do the current power management settings and usage patterns compare to what participants reported in the earlier survey?
- How do power management behaviors vary by aspects of the computers, such as operating system?
- How do power management behaviors vary by aspects of the users, such as work role, gender, or computer expertise?

This monitoring study is groundbreaking in several respects. It combines direct observations of computer power settings, questionnaire data, and hours-of-use monitoring for the same participants; systematically compares self-reported and observed data for a large number of users; and addresses both automatic and manual power management. This monitoring study also had the advantage of access to the 2013 survey data about the same persons.

Although respondents reported a high rate of using automatic power management in the 2013 survey, examining those same computers in the 2014 monitoring study showed that for many, their settings were in fact disabled. This finding highlights the major advantage of having survey data and monitoring data for the same users: it provides a very unusual opportunity to explore explanations for the differences in monitoring versus survey data.

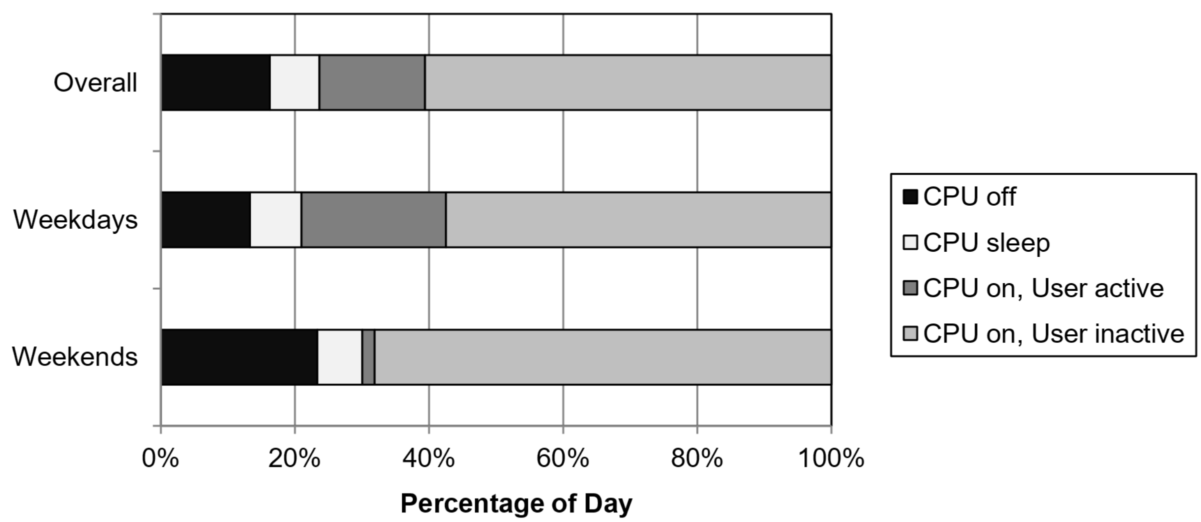
Given the large number of variables in this study and the 2013 survey, the current report focuses on descriptive analyses and selected comparisons of the 2014 monitoring study to the results of the 2013 survey. The breadth and depth of the combined dataset will eventually allow the exploration of many more possible relationships and interpretations than are presented in this report.

Conclusions

This section summarizes results from the monitoring study.

- The monitoring results indicate that, on average, participants' office desktops spend very little time off (16 percent) or in sleep mode (7 percent). (See Figure ES-1.) The majority of the day, these computers are on, and most of that time, they are not being used. On average, computers are in user-inactive mode 61 percent of the day Computers are off more on weekends than weekdays, but they are also being used a much smaller percentage of the time they are on, indicating substantially less efficient computer use on weekends.

Figure ES-1: Percentage of Day that Office Desktops Spent in Each State on Average, Overall and by Time of Week



- The majority of computers (72 percent) are off less than 20 percent of the time, and most of those are off for only a few minutes a day.
- Direct observations of participants' computer settings by the researchers showed that only 20 percent of computers had any automatic power management enabled. None of those computers were set to automatically shut down.
- Users also engage in manual power management steps. Even though computers were not set to automatically shut down, 25 percent were off for at least 20 percent of the time. Using manually engaged sleep mode is less common than manually engaged shutdown. Users who have automatic sleep enabled may also be engaging the sleep mode manually at times.
- Participants who reported in the survey that they had control over the power management settings for their office desktops, and especially those who reported changing the settings,

were more likely to have automatic power management settings actually enabled. The computers of those who had changed their own settings spent more time in sleep mode and less time in user-inactive mode.

- Participants who rated themselves as more knowledgeable about power management in the 2013 survey were more likely to have automatic power management enabled in the monitoring study. Furthermore, the computers of users more knowledgeable about power management spend more time in sleep mode, less time in CPU-on, and less time in user-inactive mode.

- A unique feature of this study is that observations of users' settings and computer use can be compared to those same users' reports of power management behaviors in the earlier survey. Among these participants, 84 percent had reported using automatic power management in the survey, while only 20 percent had any settings enabled in the monitoring study. This difference cannot simply be accounted for by the self-serving reporting bias found in some surveys of socially desirable behaviors. The disparity between self-reported and observed results for automatic power management is much greater than for other measures studied here, and much greater than in other surveys of socially desirable behaviors. The results instead point to reporting errors by users who are confused by power management. Accuracy in reporting was greater for respondents with more power management experience: those who rated themselves as more knowledgeable about power management, who had more control over their office desktops, and who had ever changed the power management settings on their office desktops.

Other findings include:

- Participants who use multiple computers spent less time using their office desktops.

- Staff members use their office desktops significantly more hours per week than faculty members or graduate students. Staff members are also less likely to use multiple computers.

- The user interfaces for automatic power management settings appear to create confusion about whether power management is enabled. Default power plans may have names like "balanced" or "performance," but the settings that were actually enabled often bore little resemblance to the nominal purpose. Also, even the trained researchers had difficulty locating the settings on many participants' desktops.

Overall, the researchers conclude that confusion about power management settings is pervasive: a substantial portion of participants appear to believe they have automatic power management enabled when they do not. Not having automatic settings enabled leads to energy inefficient computers, but a user believing they have solved the problem when they have not creates additional issues. For instance, these users may be less motivated to use manual power management. Also, users who believe they already have efficient power settings may be less responsive to campaigns to encourage or educate them about power management. At the same time, these participants' erroneous belief that their power settings are enabled could be seen as an opportunity for education, as they represent a large group of computer users who are apparently willing to use automatic power management but currently are not doing so.

This monitoring study highlights confusion about power management settings for office desktops. The situation may be better for home desktops and laptops: the 2013 survey results indicate that users have more control over their home desktops and laptops, and are less likely to give “don’t know” responses when asked about them. However, since desktops use more power than laptops, and office desktops outnumber home desktops, any problem that affects office desktops has substantial implications for total energy efficiency.

This monitoring study and the 2013 survey were designed to answer the frequent calls for more understanding of behaviors toward computer management, not to estimate projected levels of energy savings, and the two studies together have accomplished that goal. More is now known that can guide both education and manufacture.

Benefits to California

Power management behaviors and the reasons for the behavior are better understood, which enables:

- More effective education of computer users and training of information technology managers
- More precise and realistic estimates of user behaviors toward power management
- More effectively targeted future research on computer use and variation in user behavior
- Better design of user interfaces for power management
- Better design of computer restart procedures and network access in low-power modes

CHAPTER 1: Introduction

A significant portion of plug load energy goes into using computers, in both residences and businesses, and including desktops, laptops, and related computing devices. Various studies estimate that computers account for about 2 percent of California's electricity end-use consumption and annually consume approximately 7.8 TWh (Delforge 2013a), and a 2011 study estimated that computers accounted for 66 percent of the energy use by IT equipment in several offices (Moorefield et al. 2011).

Computers typically have pre-programmed automatic power management settings that enable reduced energy consumption when the computer is not in active use. These settings allow the user to control how and when the computer switches to various power modes. In sleep mode, the computer reduces power to unneeded subsystems and powers RAM at a minimal level; open programs and files are held in RAM, allowing for quick revival of recent activity. Hibernation deactivates almost all computer functions, storing the current state of processes to the hard disk and then powering down. Like sleep, hibernation restores any open programs and files upon reactivation, but it requires more time to reactivate. By contrast, shutdown also powers down the computer but does not save the current processes, meaning all programs must be closed. An open industry standard exists for such settings and is used by most manufacturers: the Advanced Configuration and Power Interface (ACPI). Hybrid sleep is a relatively new option, combining sleep and hibernation; it consumes as much energy as sleep mode, but it also saves processes to the hard drive for retrieval in case of power loss.

Computers displaying an ENERGY STAR® label have automatic power management enabled when shipped by the manufacturer. More specifically, the manufacturer's sleep mode must be set to transition to sleep mode within 30 minutes of inactivity. The ENERGY STAR requirements set the sleep mode, specifically ACPI level "S3," commonly referred to as "sleep, standby, or suspend to RAM" (Intel 2009). However, the energy savings actually achieved by these default settings depend on what people do once their computers are in use. There is little consensus on if and how those settings are used, disabled, or changed, or when and how often the power mode change is made manually.

Computer users can also save energy with manual forms of power management, turning computers off when they are not needed or engaging sleep or hibernate mode before any automatic settings would have done so.

When considering user behavior, the two types of power management are quite different. Changing power settings requires a certain level of skill or familiarity for the user, but once changed, the settings automatically affect computer energy use without additional user input, potentially for very long periods. By contrast, switching the computer manually into shutdown, sleep, or hibernation is relatively simple but requires deliberate decisions and regular repetition by the user to be effective.

Past research shows that many computers are left on for long periods of time and spend fairly little time in sleep mode, indicating that automatic power management settings are not widely enabled (Barr et al. 2010, Mercier and Moorefield 2011, Roberson et al. 2004). Many studies have sought to define the extent of this problem and to understand why it happens. However, studying the "enabling rate" of power management is quite difficult due to a wide variation of power management settings and power plans used by manufacturers and operating systems.

Studies using physical power measurements of computers can detect various low-power states and high-power states, but they cannot infer which particular power management menu option has been chosen by the user, or if the transition to that state was made automatically or manually. Studies using surveys must rely on users' reports, which is problematic for those users unfamiliar with their power settings. Researchers who have direct access to the computers being studied can look up the automatic settings that are active at the time, but this gives only a partial picture if users also employ manual power management strategies or change their settings.

This report presents the results of a monitoring study of office desktops conducted by the California Plug Load Research Center at the University of California, Irvine (UCI) in the spring of 2014. This study is a follow-up to an online survey of staff members, faculty members, students, and retirees, conducted by the same research team in the spring of 2013 (Pixley et al. 2014). That survey asked about automatic and manual power management for office desktops, home desktops, and laptops, and included one of the largest populations ever surveyed for power management issues. The spring 2013 survey asked more questions, about more computers per person, than most other surveys, seeking information about many specific power management behaviors. The survey's user-based design focused on the behaviors and decisions involved in power management, in contrast to the technical data collected from computers in the monitoring study.

In the monitoring study, researchers examined the office desktops of a subsample of 125 of the earlier survey respondents. The monitoring study provides a supplement to the 2013 survey study, by conducting remote nonintrusive monitoring of the computer power levels of these desktops over several weeks. This follow-up monitoring study also includes answers from a brief questionnaire administered to participants, and researchers' examination of the participants' computers, including recording their automatic power management settings.

This monitoring study is groundbreaking in several respects. It combines direct observations of computer power settings, questionnaire data, and hours-of-use monitoring for the same participants; systematically compares self-reported and observed data for a large number of users; and addresses both automatic and manual power management. This monitoring study also had the advantage of access to the 2013 survey data about the same persons.

Since this study draws comparisons to some findings from the spring 2013 survey, the text of this report uses or repeats portions of the survey report, so that this report can be read as a stand-alone document. Full coverage of the survey procedures and results can be found in the survey report (Pixley et al. 2014), as well as a discussion of how the monitoring study data influences the interpretation of the survey data.

CHAPTER 2: Background

2.1 Prior Studies

Studies of the energy consumption of computers have taken various approaches. Prior studies include physical energy measurements and user interviews, studies of households and studies of offices, broad surveys and in-depth case studies, studies that are only about computers and studies that include computers with other devices, and some studies that include more than one approach. The specific findings about duty cycles and enabling rates still vary widely, and few studies have explored user behavior toward computer power management in detail.

There are many studies, for example, in which the energy consumption by specific computer models or types is directly measured. Such measures are useful in making projections of savings from proposed policies or proposed large-volume purchases, by multiplying the proposed power changes by the assumed number of computers and the assumed usage pattern. Some of these studies incorporate measurements of the various possible power management settings. However, these studies are less useful for making estimates for a wider population that may use a range of computers.

Numerous studies have performed physical audits or measurements of computers and other electronic office equipment in situ, in commercial and university buildings. These studies typically incorporate one-time measurements of power levels or long-term monitoring. For example, Roberson et al. (2004) performed physical audits of office IT equipment in three states. Schoofs et al. (2011) used remote monitoring to track 450 office machines in a university department. Barr et al. (2010) monitored over 91,000 desktops and over 19,000 laptops in several large companies for about six weeks. Kawamoto et al. (2004) studied computers and other equipment in offices in Japan to determine the effects of power management settings. Acker et al. (2012) monitored computers and other plug loads in six offices in Idaho to assess energy-saving interventions such as smart plug strips. Moorefield et al. (2011) monitored 450 plug load devices in 25 California offices. Cabrera et al. (2011) monitored three computer labs at a university. Mercier and Moorefield (2011) inventoried plug loads in a library and a small office in California. Lawrence Berkeley National Laboratory and Ecova (formerly Ecos) have done several related studies, with support from the California Energy Commission and other sponsors.

These audits and monitoring studies, along with others, have found that in practice a high percentage of computers were left on unnecessarily when not being actively used, and that substantial energy savings could be possible with better power management practices (for example, Mercier and Moorefield 2011, Bensch and Pigg 2010, Cabrera et al. 2011, Acker et al. 2012). However, if they have no data from the users or access to the internal settings of the computers, such studies cannot determine why, by whom, or in what particular mode the computers were left on.

In addition to measuring the activity levels of computers directly, some researchers have used questionnaire surveys about energy use and power management, and some have combined physical measurements with extensive survey or interview interactions.

Several surveys have been conducted, addressing either residential or commercial users. Typically the larger surveys cover a broader range of energy use topics and have been limited to only a few questions about computer power management. Urban, Tiefenbeck, and Roth (2011; 2012) conducted a survey of energy usage by televisions, set-top boxes, and computers in 1,000 U.S. households to determine hours of active use, idle, and off. TIAX LLC conducted a similar study for the Consumer Electronics Association in 2006 (Roth, Ponoum, and Goldstein 2006a). Every four years the U.S. Energy Information Administration conducts a Residential Energy Consumption Survey (RECS); the most recent published results are from 2009 (U.S. Energy Information Administration 2013). The California Energy Commission has sponsored a similar study of California residences, the California Residential Appliance Saturation Survey (RASS), also last published for 2009 (KEMA 2010). Tiedemann, Sulyma, and Mazzi (2013) surveyed 1,437 residential customers in British Columbia, about various household appliances. Among surveys related primarily to computing, Dimensional Research (2009) surveyed more than 500 IT administrators and managers from around the world, for KACE Systems Management; the survey focused on the managers' awareness and implementation of power management systems for the enterprise's computers. The consulting firm 1E and the Alliance to Save Energy surveyed workers in the United States, United Kingdom, and Germany in 2008, asking whether and why employees turned off computers at night or otherwise powered them down (1E 2009).

Studies integrating physical measurement of computers and users' self-report of behavior are fewer and smaller, as might be expected. The work by Bensch and Pigg began with a telephone survey of 1,000 homes in Minnesota and mailed an appliance survey to 260 of those homes before physically monitoring 50 of them (Bensch, Pigg et al. 2010). Chetty et al. (2009) focused on computer use, employing interviews as well as monitoring in their study of 20 households in the Seattle area. The study by Kawamoto et al. (2004) included surveys with the office workers to understand the impact of alternative delay times for sleep modes.

In general, these studies reveal that many office computers are left on all night, that the users do not often employ the possible power management features, and that long periods when the computer is on but not being used consume much of the energy. For example:

- A study at Lawrence Berkeley National Laboratory found among various offices that, on average, only 36 percent of the computers were turned off at night (whether the shutdown was manual or automatic is unknown) and only 6 percent of the computers that were not off were in a low-power mode. These findings suggest that automatic power management is used little and manual power management is not filling the gap (Roberson et al. 2004). The EPA subsequently used that 36 percent figure as the default in its calculator for life-cycle savings for bulk computer purchases (see www.energystar.gov), although the offices in the study ranged from 5% to 67%.

- The software and services company 1E and the Alliance to Save Energy (1E 2009) found that 38 percent of U.K. respondents, 17 percent of German respondents, and 32 percent of U.S. respondents "said they either have no idea what power scheme settings are, or how to change the power settings on their PC"(p. 4).
- Barr et al. (2010) found, by electronic monitoring in offices that had no corporate enforcement of PM modes, that only 7.6 percent of desktops and only 59.8 percent of laptops had automatic PM turned on.
- In 2010 a team led by Ecos inventoried plug load devices in a library and small office in California and also monitored some of the equipment for one month (Mercier and Moorefield 2011). The researchers found that computers consumed 68% of the plug load energy at those sites and that computers were left on at regular power levels (including active and idle) 59% to 100% of the time. Although most of the office computers were one of only two models, metered energy use varied widely. Energy use varied much less in the public areas of the library, where machines were regularly shut off at night and rebooted each workday morning. "Despite the fact that most desktops have the capability to shift to low-power state after a period of inactivity, only a small fraction of those computers actually do so" (p. 36).

The exact findings and situations vary widely. The California Energy Commission staff noted the lack of consensus about the best figures for turn-off rates, duty cycles, or automatic PM enabling rates in a recent workshop on computer energy efficiency regulations (Rider 2013). Further research in this area is warranted, as understanding enabling rates and duty cycles is essential to evaluating options to reduce the waste of energy.

The diversity of answers presented so far is partly an indication that terms have not been defined or measured precisely or uniformly, and partly due to the variation in populations and computers studied and the lack of knowledge about which behavioral factors might explain the observed differences. Schoofs et al. (2011: p. 6911) noted, "Usage patterns have the greatest uncertainty of any component in annual energy consumption calculations." Acker et al. (2012, p. 21) stated, "Further work is needed to better define the saving potential of behavior-based interventions." Mercier and Moorefield (2011, p. 55) observed that "differences in [desktop computer] energy consumption stemmed from variations in user behavior and power management settings (or lack thereof)." Somavat et al. declare that "the cost of electricity for computing …requires careful thought on usage behavior" (2010, p. 148). Chetty et al. (2009, p. 1034) observe that "Fewer studies explore what people would like their devices to do or account for user behaviors," Meier et al. (2008), Moorefield and Calwell (2011), and Moezzi et al. (2009) echo similar concerns.

There is a plethora of efforts encouraging computer users to employ their PM settings and explaining how to do so. Examples are widely available. On the ENERGY STAR website, for example (www.energystar.gov), there is a set of activation instructions for computer users and an "EZ Wizard" that guides the reader through using power management settings, although it currently covers only Microsoft Windows® 2000, XP and Vista. The federal government established the Federal Electronics Challenge, requiring that federal agencies ensure that ENERGY STAR power management features are enabled (see www2.epa.gov/fec). Many universities, cities and large companies have websites, fliers or posters providing instructions and encouragement (for example, City of Irvine 2014; Picklum, Nordman, and Kresch 1999; Boston University 2010). See also the works by Sator (2008) and Dickerson (2011). Given the lack of consensus on the research into behavior, however, these efforts vary widely. It is unclear how effective these programs would be in broader contexts. The current report echoes prior studies that show that there is still considerable room for improvement.

This UCI monitoring study supplements the physical monitoring literature by providing data from a university population of staff members, faculty members, and graduate students for several weeks, and by including observation of the computer settings and questionnaire data from the users. This monitoring study also supplements the survey literature: being able to compare the results of physical monitoring and a survey for the same participants is unusual and provides insight into how well respondents use, understand, and report power management issues. Combining the monitoring data and the survey data makes the UCI study one of the few on this topic that have applied different methods to the same population.

2.2 The Study Approach

This current study supplements the 2013 survey by collecting more detailed data about the office desktop computers of some of the survey respondents the following spring. This study has three parts: direct observation of the automatic power management settings, a questionnaire to capture updates on the status of the computer, and remote monitoring of the power status of the computer for several weeks. The monitoring software used was Verdiem Surveyor Version 6 (Verdiem 2014), which collected and remotely transmitted computer usage data 24 hours a day for several weeks.

The spring 2013 survey was designed to address some of the acknowledged gaps in the literature about computer users’ power management behaviors and to compare those behaviors across home and work and across desktops and laptops. The survey gathered data from a broad range of people affiliated with a large university campus—students, faculty members, staff members, and retirees. One of the advantages of conducting a user-based online survey was that it quickly and inexpensively provided information not only about a wider range of users, but also about each person’s experiences and behaviors toward multiple computers. The survey asked respondents about all the computers they used at home and at work, how much each computer was used, whether computers were shared with other persons, the respondent’s behaviors and observations about automatic PM settings and manual PM steps, and basic demographic information.

The emphasis in the 2013 survey was primarily on behavior, seeking to fill the information gaps. The survey approach did not allow for recording actual computer usage or actual energy consumption.

The 2014 monitoring study focused on a single office desktop for each participant. The study was limited to sampling only respondents of the 2013 survey who were staff, faculty, or graduate students, were the sole or primary user of an office desktop, and had expressed willingness to be contacted about a follow-up study. The study evaluated 125 computers.

In addition to computer use data from the monitoring software, researchers observed and recorded the power management settings active on the computers at the beginning of the monitoring period. Participants also completed brief questionnaires updating information from the survey, particularly about their current computers, such as whether they had changed the automatic settings since the survey.

Universities and colleges together are an important part of the population for understanding power management issues. First they represent a significant portion of the adult population in the state. Adding the figures drawn from institutional web sites shows that California universities and colleges include more than 105,000 faculty members, more than 170,000 staff members, and about 3 million students: in short, about 10 percent of the population of the state. Second, the employees and students use a broad range of computers in many different circumstances of computer use. Academic roles and responsibilities cover a wide range of possibilities: faculty members are similar to professionals in other fields, generally working long hours and on evenings and weekends, and traveling more, yet also having more flexibility and control over their work situations. University staff members, by contrast, are more comparable to other 8-to-5 workforce groups. Faculty members and graduate students typically have different schedules in the summer than during the academic year. Other studies have been done at universities (a review of the computer-use studies is given in Bishop [2013]), but most of those studies were about measuring energy savings in computer labs rather than studying ranges of user behavior. A broader review of IT practices at universities is provided in Sheehan and Smith (2010).

More thorough study is needed of the range of user behaviors toward power management, both to better understand the sources of inefficiency and to get closer to establishing average enabling rates. The great advantage of this study design was the ability to combine observational data on users' computers with a wealth of self-report data from the same users' survey responses. Linking monitoring data with descriptive and behavioral data about the same users allows for a much deeper exploration of why and how the computers end up in the states shown in the monitoring data. The questionnaire and computer examination in the monitoring study provide more information about what exactly users are doing to produce the results seen in the monitoring data. Combining this with the survey data helps reveal which different users differ in those behaviors and why users do what they do.

This report will use the terminology in Table 1 when discussing the methods and results.

Table 1: Monitoring Study Terminology

Survey	Unless otherwise noted, this term refers to the spring 2013 survey conducted by UCI on computer power management.
Monitoring study	Unless otherwise noted, this term refers to the spring 2014 follow-up study to the survey, described in the current report. The monitoring study includes three types of data: remote monitoring data of computer power states, direct observations of participants' desktops, and data from a brief questionnaire administered to participants at the initial research visit.
PM	Power management, including both automatic power management settings and manual power management actions.
Respondent	Person who provided answers in the spring 2013 survey.
Participant	Respondent selected from the survey who participated in the spring 2014 monitoring study.
Respondents eligible for monitoring study	Respondents from the spring 2013 survey who are (1) staff members, faculty members, or graduate students; (2) reported using at least one office desktop at least three hours in the previous week; and (3) were the primary or sole user of that office desktop.
User	Respondent/participant or other person who uses the computer(s) in question (one of them or none of them may be the owner). The owners of the computers may or may not be respondents in the monitoring project, and there can be several users for one computer.
Role, role group	The three role groups included in the monitoring study are: faculty members, staff members, and graduate students. The spring 2013 survey had asked respondents first to designate all their roles (for instance, student and instructor, or faculty member and administrator) and then to indicate which role was primary. In the analyses reported the primary designation is used.
Computer	In this report the term "computer" refers to desktops used on campus, unless otherwise noted. The term "desktop" is used in preference to the term "PC" to avoid implications about the operating system in use.
Questionnaire	This word will be used exclusively to refer to the interview forms administered to participants during the spring 2014 monitoring study.

CHAPTER 3: Methods

3.1 Sampling

For the 2013 survey, the research team selected 7,250 subjects from the email directory of the university. The final sample size for the survey was 2,081 completed and partial cases, including 1,107 students (undergraduate and graduate), 720 staff members, 193 faculty members, and 61 retirees.

For this monitoring project, the research team recruited the 2013 survey respondents who met the following criteria: they reported using at least one office desktop three hours per week or more; they were the sole or primary user for this desktop; they had completed the survey; and they were staff members, faculty members, or graduate students. Throughout this report, survey results are presented for all respondents who are eligible for the monitoring study according to these criteria, as a comparison group for those who actually participated in the monitoring study. The decision to study only on-campus desktops was made primarily because reaching computers off campus, such as home desktops or laptops, would have been too complicated, given the time and resources available. Retirees and undergraduate students were omitted because most persons in these groups do not regularly use desktops in campus offices.

Recruitment was further limited to survey respondents who had indicated a willingness to be contacted about a possible follow-up study. Of the 572 respondents who were eligible based on the above criteria, 379 (66 percent) had given permission to be contacted for follow-up. During the process of obtaining names and addresses from the university directory, seven persons were found to be no longer associated with the university. This produced a total potential sample of 372.

There was some concern that survey respondents who expressed willingness to be contacted again for a follow-up study may over-represent persons with more experience with power management. Instead, there is a slight bias in the opposite direction. Of the 572 respondents eligible for the monitoring study, those who agreed to be recontacted rated themselves lower on knowledge of computers (6.9 versus 7.2 on a 1-to-10 scale). Those willing to participate were also more likely to be female (61 percent versus 51 percent), more likely to be staff (76 percent versus 67 percent), and less likely to be faculty (13 percent versus 23 percent). However, there were no significant differences in self-rated knowledge of power management, control over the PM settings on their office desktop, or whether they had changed the PM settings on their primary office desktop, which the current results show to be the strongest predictors of PM behavior. Furthermore, comparing these same variables for those who participated in the monitoring study versus others who were eligible reveals no significant differences.

Recruitment emails describing the monitoring study were mailed using Constant Contact in March, 2014. Persons who did not respond to the initial email were sent up to four reminder emails, the last in late April. Respondents could opt out of additional emails directly through

Constant Contact; these responses are included below as refusals. The topic of the monitoring project was not disguised in the recruitment materials. However, the researchers did attempt to use neutral phrasing when presenting the research topic and goals to reduce the likelihood that participants might feel pressured or encouraged to report or exhibit energy-saving behaviors.

Participants could respond by calling, emailing, or following a link to an online scheduling form. The online scheduling form used the same Qualtrics survey software that was used for the spring 2013 survey. Participants were asked to verify that they had an office desktop; if so, they were asked other questions about their location and schedule.

Of the 372 persons emailed, 61 percent responded. Of those, 48 refused. The refusals included some persons who might have been willing to participate but their department managers or IT managers denied permission to have the monitoring software installed. Managers who denied permission cited perceived risks to sensitive data stored on the potential participants' computers or policies against installing outside software, rather than concerns about the power management aspect of the study. A total of 39 persons were identified as ineligible to participate, most of them for not using an office desktop (say, only using a laptop) or using a desktop with a Linux operating system (which is not supported by the monitoring software, Verdiem Surveyor). Others were ineligible because they had recently separated from the university or would be otherwise unavailable during the study period. Fourteen persons began the process of scheduling a research appointment but did not complete it by the end of the study period. A total of 128 research interviews were conducted, including three respondents who were determined to be ineligible, resulting in a sample of 125.

The initial interviews were conducted by five undergraduate research assistants, after extensive training in interview methods, Verdiem Surveyor installation procedures, and the power management options for Microsoft Windows®, Mac OS®, and OS X® operating systems. In each research interview, the researcher obtained informed consent from the participant, gave the participant a $25 Amazon gift card, asked the participant to fill out a brief questionnaire, recorded information about the desktop and its monitor(s), and installed the Verdiem Surveyor monitoring software.

Three types of data were collected from each participant in the monitoring study: a questionnaire filled out by the participant, data observed and recorded by the researcher during the installation visit, and the monitoring data on power states over time transmitted by Verdiem Surveyor.

The questionnaire was customized for each participant by pre-printing certain answers the participant had provided in the survey, including about the office desktop(s) reported at the time of the survey. The questionnaire asked about any corrections or changes to selected data given in the survey, such as occupation or work status. Participants were asked whether the office desktop they were currently using was the one (or one of the ones) they had reported in the survey; they were then asked either for updated or corrected information on that computer (year, operating system, and whether shared with others) or for the same information about the new computer. The questionnaire also asked whether the participant or anyone else had changed the automatic power management settings since taking the 2013 survey. The questionnaire is shown in Appendix B.

During the installation visits, the researcher looked up and recorded the selected power plan (also called a profile or power scheme) and numerous details of the power management settings. The researcher also recorded the MAC address of the computer, for use in identifying the data sent by the monitoring software. The interviews were not timed, but it is estimated that most lasted about 10 to 20 minutes.

The software used to monitor the desktops was Verdiem Surveyor Version 6 (Verdiem Corporation 2014). The data collected by this software is described in detail in a later section. Installing the Verdiem Surveyor software requires administrative control over the computer; for participants who did not have administrative control, the research staff coordinated with the appropriate IT managers. About 19 percent of the participants (24 persons) used desktops administered by the Office of Information Technology (OIT). For those participants, the research appointments involved all steps except for the installation, which was done afterwards by OIT, remotely.

The installations were spaced over seven weeks (from March 24 to May 9) due to variation in when participants responded to the recruitment emails and when they could arrange for a research appointment. The Surveyor software begins transmitting data automatically as soon as it is installed, so participants' data collection periods began and ended at different times. Monitoring continued for at least four weeks for each participant. Participants were asked to identify any days they would be (or later, had been) away from campus when they would normally be working, such as sick days, vacations, or traveling for work. If participants said they normally work from home or travel a certain number of days per week, those weeks are included. These days were not counted in calculating the data collection period. Spring break and holidays were also omitted. This required extending some participants' data collection periods to collect the minimum of four weeks of relevant data. In a few cases, later start times, premature end times, or numerous vacation days resulted in less than 28 days of data. Regardless of variations in termination time, only data recorded through June 30 was used for the analysis, with a maximum of 35 days of data used per participant.

Participants were sent emails at the end of their data collection periods. The emails included instructions for how participants could uninstall the Surveyor software, or participants could request an appointment for one of the researchers to uninstall it. At this point participants were also sent a letter through campus mail, thanking them for their participation and giving them a second $25 Amazon gift card. Participants varied in how quickly they uninstalled the software, and how many reminder emails were necessary.

The gap between the 2013 survey and the initial research visit of the monitoring study in 2014 varied in length across participants from 9 months to 11.5 months, for an average of just over 10 months.

The research team remotely collected monitoring data from participants' computers from late March up to the end of June. That calendar period is reasonably representative of the full year, at least as an average across diverse experiences, and is a reasonable match for the spring 2013 survey period. The overall period included a few weeks of regular class schedules, one week of final examinations, and a few weeks of summer. For graduate students and faculty members, the last weeks of the spring quarter and the first weeks of summer could involve heavier and lighter computer use, respectively, although perhaps computers would be used for different purposes but still the same amount. For staff members, the two periods would not be as different from one another. This variation in work load over time is typical of many occupations and organizations, and thus common for computer monitoring studies in workplaces. Workers may not have uniform computer use over time, but experience occasional days of unusually heavy or light use. In the monitoring study, collecting multiple weeks of power state data for each participant helps ensure that their average results are not overly influenced by such anomalies. Monitoring done only during the summer or only during the academic year would likely produce more skewed data.

From the beginning of the 2013 survey data collection to the end of the 2014 monitoring study data collection, there were no major events at UCI or major changes in the university's computer network or policies that might reasonably have affected the power management or computer use behaviors of people on the UCI campus.

Campus and federal procedures and requirements for research on human subjects were followed: approval by the campus Institutional Review Board was obtained, verifying that the team would take adequate steps to protect the privacy and confidentiality of the participants and to obtain their voluntary and informed consent.

3.2 The People Studied

The role designation for each respondent (that is, faculty, staff, student) was made first by OIT when it did the sampling for the 2013 survey, using the information for each person drawn from the departments for Human Resources or Academic Personnel. The survey then asked each respondent to designate their primary role on a list of twelve standard academic categories, such as undergraduate, postdoctoral scholar, retired faculty, and medical staff. The survey further asked staff respondents to choose their occupation from a list of widely accepted occupational titles, drawn from U.S. Census categories. Where respondents' self-reports of their primary roles in the university did not match the role designation from OIT, the use of other data items made a selection straightforward in most cases. In a few ambiguous cases, the lead researcher and co-lead researcher reviewed the respondent's situation more closely and decided the final categorization.

As mentioned, the monitoring study was limited to staff members, faculty members, and graduate students; retired persons and undergraduate students were omitted from the sampling frame. Removing the large number of undergraduates included in the survey increased the average age of eligible respondents compared to that of the survey. However, even among the remaining role groups, eligible respondents were significantly older than those in the full survey (42 years versus 40 years). There were no gender differences in likelihood of eligibility. Table 2 shows the role distributions for all survey respondents with completed interviews, survey respondents eligible for the monitoring study (who serve as the comparison group for many analyses), and participants in the monitoring study. Graduate students were less likely than the other two groups to be eligible for the monitoring study (23 percent of survey respondents, compared to 60 percent for staff and 51 percent for faculty members). Eligible graduate students were also less likely to participate in the monitoring study (16 percent, compared to 23 percent for staff members and 20 percent for faculty members). Eligibility is lower because graduate students are less likely to use office desktops. Graduate student participation is probably lower due to having less control over the computers they use, which are often managed by their departments or their faculty advisors, an issue that was mentioned by several potential participants. Staff members are somewhat more highly represented in the monitoring study than faculty members, but the difference is not large. No participants had changed their role group since the survey.

Table 2: Role Groups among the Monitoring Study Participants

	Survey (completed only)		**Eligible for monitoring study**		**Participants in monitoring study**	
	Number	Percent	Number	Percent	Number	Percent
Staff Members	688	60%	415	73%	96	77%
Faculty Members	185	16%	95	17%	19	15%
Graduate Students	273	24%	62	11%	10	8%
Total	1146		572		125	

For comparison to the monitoring study participants, survey results will sometimes be shown in this report for the 572 respondents who were eligible for the monitoring study, whether or not they were willing to be contacted for a follow-up study. This provides a larger sample of individuals comparable to the monitoring study participants: that is, other staff members, faculty members, and graduate students at the same university who use at least one office desktop for which they are the sole or primary user. This approach is taken because larger samples are more likely to provide reliable estimates and statistically significant results.

The monitoring study population, as it focused on working adults, differs in average age from the statewide over-18 population, with a much lower percentage of persons under 25 and over 65 (Table 3).

Table 3: Age Distribution of the Monitoring Sample and of the California Population

Monitoring sample		California population	
18 & over	125	18 & over	27,958,916
18-19	0%	18-19	4.1%
20-24	2%	20 – 24	9.9%
25-34	26%	25 – 34	19.0%
35-49	33%	35 – 49	28.2%
50-64	34%	50 – 64	23.6%
65 & over	4%	65 & over	15.2%

California statewide data from U.S. Census 2010

Demographic information on gender, race, and ethnicity is shown in Table 4. The monitoring study sample population is slightly more female than the California population, at 57 percent. In addition, role groups vary by gender: 64 percent of staff members are female compared to 42 percent of faculty members and 20 percent of the ten graduate students.

The sample population is distinctly different from the state population on race and ethnicity, consistent with differences in the University population. The monitoring study includes a higher percentage of Asians than does the state population, and lower percentages of Hispanics and African Americans.

Almost all participants work full-time (92 percent), with 5 percent working part time and the remaining 3 percent on leave, local sabbatical, or another situation (but still using their desktop on campus). Most participants fall into one of the following three occupational groups: professional (39 percent), administrative support (33 percent), and managerial (21 percent). Participants are located in many departments and work units across campus, with 31 percent associated with the university medical center, campus clinic, or school of medicine, 19 percent in academic departments, and the rest distributed across 22 other units.

The 125 monitoring study participants do not differ significantly on demographic or work measures when compared to the 572 eligible respondents.

Table 4: Demographic Characteristics of the Monitoring Sample and of the California Population

	Monitoring Sample Population		California Population Per U.S. Census 2010
	Number	Percent	Percent
Gender			
Female	71	57%	50%
Male	54	43%	50%
Race			
Asian	26	21%	13%
Non-Hispanic White	73	58%	58%
African-American	2	2%	7%
American Indian/ Alaska Native	3	2%	1%
Native Hawaiian/ Pacific Islander[1]	*	*	1%
Multi-Racial (not counting Hispanic)	5	4%	4%
Other race	14	11%	17%
Missing on race	2	2%	
Ethnicity			
Hispanic (any race)	15	12%	38%

[1] Pacific Islanders included with Asian in Monitoring Study.

3.3 The Computers Studied

The spring 2013 survey focused on computers that met several criteria: (a) types of computers that use the most energy, (b) computers for which the user would feasibly know something about the history of the computer and about other users, and (c) computers for which the user would potentially have some control over the PM settings. The survey therefore gave the most attention to home desktops, office desktops, and laptops that were used for at least three hours a week, including computers that were shared with other users. The monitoring study focused exclusively on office desktops on campus, partly for logistical reasons and partly because office desktops are relatively more important for energy conservation in California.

The monitoring study collected data on one office desktop per participant. The majority (77 percent) of computers included in the monitoring study were reported during the 2013 survey (Table 5). The other 23 percent of computers were new to participants since the survey, or did not meet the criteria at that time of being used three hours per week. This is consistent with a rate of office desktops being replaced every four years. However, since only 14 percent of computers were purchased in 2013 or 2014 (Table 6), some participants were most likely reassigned computers. Some of the 23 percent may actually be using the same computer they reported in the survey, but did not recognize it from the description given (for instance, if the operating system had been updated in the meantime) and erroneously marked it as new. The study materials informed participants that the data collection should center on the office desktop that the participant uses the most often. In analyzing the survey data, computers were coded as "primary" if respondents reported the most hours of use for them; other computers of the same type were coded as "secondary," "tertiary," etc., based on hours. Most of the 77 percent of matching computers in the monitoring study had been the primary computer during the survey (75 percent); the remainder had been secondary computers.

Table 5: Number of Office Desktops in Survey and Which One was Used in the Monitoring Study

	Desktop used in Monitoring Study was:			
Number of office desktops reported in 2013 Survey	**Primary in Survey**	**Secondary in Survey**	**New**	**Total**
1	79	0	25	104
2	12	2	3	17
3	2	1	0	3
4	1	0	0	1
Total	94	3	28	125

The monitoring study focused on office desktops for which participants were the sole or primary users. This determination was based on a survey question about who uses the computer, selecting those who answered "I am the only user" or "I use it most often, but one or more others also use it," and omitting those who reported that they share the computer equally with someone else or that others use it more. This information was updated in the monitoring study questionnaire: 89 percent of computers are used solely by the participant, while 11 percent are used most often by the participant but shared.

The age of the computer, or the year of manufacture as reported by the participant, is shown in Table 6. Many participants didn't know the age of their computer or didn't answer (27 percent). In the 2013 survey, among respondents eligible for the monitoring study, the rate of don't know responses was much higher for primary office desktops (31 percent) than for primary home desktops (10 percent). This speaks to users' lower knowledge about their office computers relative to those they or their family members purchase and maintain.

Table 6: Reported Age of Computers in the Monitoring Study

	Number	Percent
2014	4	3%
2013	14	11%
2012	19	15%
2011	19	15%
2010	19	15%
2009	9	7%
2008	1	1%
2007 or earlier	7	6%
Don't know	31	25%
No answer	2	2%
Total	125	

The operating systems of the monitored computers, as reported by the Surveyor software, are shown in Table 7. In total, 102 (82 percent) of the desktop computers have a Windows® operating system, and 23 (18 percent) have a Macintosh® operating system.

Table 7: Operating System of Computers in the Monitoring Study

	Number	Percent
Windows XP	11	9%
Windows 7	83	66%
Windows 8	8	6%
OSX10-5	1	1%
OSX10-6	6	5%
OSX10-7	3	2%
OSX10-8	2	2%
OSX10-9	10	8%
OSX10-10	1	1%
Total	125	

3.4 The Computer Monitoring Data

The Verdiem Surveyor 6 software records the power use state of the computer at all times and continually transmits that data to a designated server. The software records four possible states for the CPU: off, sleep, on, and unknown. Sleep is defined as ACPI level S3, "standby, sleep, or suspend to RAM." In the Surveyor data, hibernation mode is not distinguished from CPU-off. Surveyor collects and transmits data continuously while the computer is on. If the computer is turned off, it ceases transmitting; when the computer is turned on again, Surveyor retroactively codes the time since the last recorded state as CPU-off. Surveyor records a status of CPU "unknown" to indicate missing data. Missing data can be caused by temporary interference from other programs or hardware; it usually lasts for only one or two minutes at a time, most often during transitions from one CPU state to another. As the average CPU unknown time makes up only .00019 of the minutes per day, this state is not displayed in figures; however, it is considered in all calculations. As with other monitoring software, an important limitation is that Surveyor cannot determine the cause of a CPU state transition: that is, the same transition from CPU-on to CPU-off is registered whether the computer is turned off manually or shuts down due to an automatic power management setting.

When the computer is on, the software uses mouse movements and keystrokes to establish whether the computer is being actively used or is idle. The specific keystrokes are not recorded. No information is recorded about what applications the computer is running, or about the users' files or web activity. Surveyor records three possible states for the user: active, idle, and unknown. User-active is recorded for any minute in which there was any mouse or keyboard activity. Remote access of the desktop is thus recorded as user-active, but automatic updates and backups are not.

The user status is coded as unknown in a variety of conditions, such as when the CPU is in sleep mode or when the CPU transitions from one state to another. A case-by-case examination suggests that user-unknown can be reasonably assumed to not involve user activity. Thus, the user measures were collapsed into user-active and user-inactive, which sum to the total amount of CPU-on time.

For ease of data processing, the per-minute data for each day was collapsed into 96 periods of 15 minutes each. Examining these periods revealed that the measure of minute-by-minute user activity is an extreme definition of "active use." The data showed very few instances of constant user activity: that is, a full 15 minutes of user-active within a given period. Rather, most periods including minutes coded as user-active also included minutes of user-inactive. This makes sense, as most computer usage involves some keyboard or mouse activity interspersed with no direct activity, such as occurs when reading text or watching short videos. For this reason, an additional measure was created that counts any 15-minute period in which any user activity was observed as a full 15 minutes of user activity. This is the measure of user-active versus user-inactive used in the results presented here.

The Verdiem Surveyor software records and reports the MAC address and device name of the computer, for the purpose of identification. Surveyor also reports the operating system, manufacturer, and model of the computer.

Surveyor also reports data about the display (monitor) status. However, it was later clarified that this indicates only whether the CPU is sending signals to the display, not whether the monitor itself is on, sleeping, or off. Therefore, such data cannot be used to determine the duty cycles for monitors and is not reported here.

The research goal was to collect at least four weeks of "normal work week" data for each participant, to obtain a reasonable estimate of average use on any given day of the week. Days for which the participant reported being out of town or otherwise not on their normal office schedule were removed from the analysis. (If their "normal" work week included working at home three days a week, or traveling on Mondays, those weeks were taken as is.) The amount of data collected varied as a result of how long it took participants to uninstall their software or to arrange for someone else to do so. One participant's computer provided data for only nine days; this participant is omitted from the duty cycle analyses. The majority of participants (87 percent) provided five or more weeks of data; the analyses is restricted to the first 35 valid days. An additional 11 percent provided at least four weeks of data, and two participants provided 20 to 24 days.

For each participant, data for all valid days for each day of the week is averaged; thus, each participant has one "average" Monday, one "average" Tuesday, et cetera. These average days are then combined into measures of average weekdays, weekends, and weeks. Thus, participants with data for more days should have more accurate estimates of their average usage, but their data is not weighted more heavily in the dataset.

There were technical problems with the Surveyor data for five participants (for example, recording more than 15 minutes' worth of data for each 15-minute block). Verdiem staff explained that such anomalies can result from interference from certain other software or hardware, corrupting the data from that device. As a result of the issues for these five participants and the one mentioned earlier, complete monitoring data is available for 119 of the 125 participants.

CHAPTER 4:
Results and Discussion

This chapter begins by presenting the basic results of the duty cycle data from the monitoring study. Later sections in the chapter provide context and explanation for that data by linking data on computer states to those computers' automatic power management settings and to self-reports of computer use and power management behavior from the spring 2013 survey.

Some results are presented separately for the three role groups—staff, faculty, and graduate students—while others are presented for the entire sample. As the majority of respondents are staff members (Table 2), their answers predominate in results for the full sample. However, this may reasonably represent other types of workplaces with more employees who resemble university staff members and relatively few who resemble faculty members or graduate students.

The criterion used for statistical significance in this report is $p < .05$. The relatively small size of the monitoring study sample, especially for analyses within subgroups, makes it likely that some differences that would be significant in larger samples will not attain significance here. For this reason, non-significant results that appear to be substantively different are also mentioned if they approach the level of significance, at $p < .10$.

4.1 Duty Cycle Results from the Monitoring Study

This section reports the data collected by directly monitoring the office desktops of participants in the monitoring study using Verdiem Surveyor 6 software. As described earlier, the measures provided by Surveyor were collapsed into four possible states for each computer: CPU off, CPU sleep, user active (CPU on), and user inactive (CPU on). The percentage of time computers in the monitoring study spent in each state, on average, is shown in Figure 1. The results indicate that these office desktops spend very little time off: an average of 16 percent of the day. Even less time is spent in sleep mode. The majority of the time, these computers are left on. Furthermore, only a fraction of the time they are left on can be attributed to active use: on average, user-active mode comprises 16 percent of a day while user-inactive comprises 61 percent. That is, computers are being used only 21 percent of the time they are on. On weekends, the CPU is off a greater percent of the time and on for a smaller percent than on weekdays. However, the ratio of user-active to user-inactive while the computer is on is much lower on weekends, indicating substantially less efficient computer use.

Figure 1: Percentage of the Day that Computers Spent in Each State on Average, Overall and by Time of Week

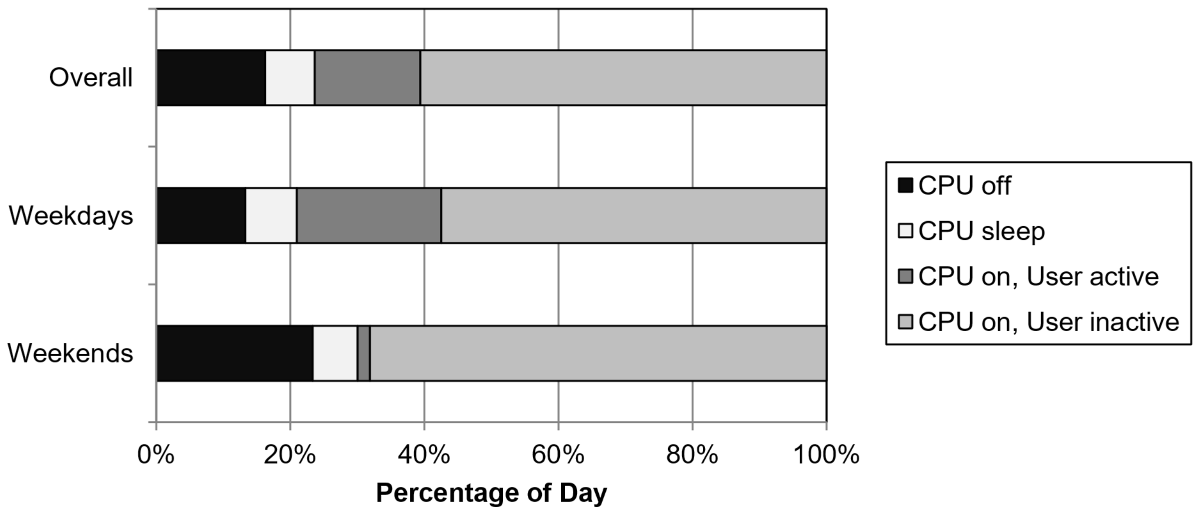
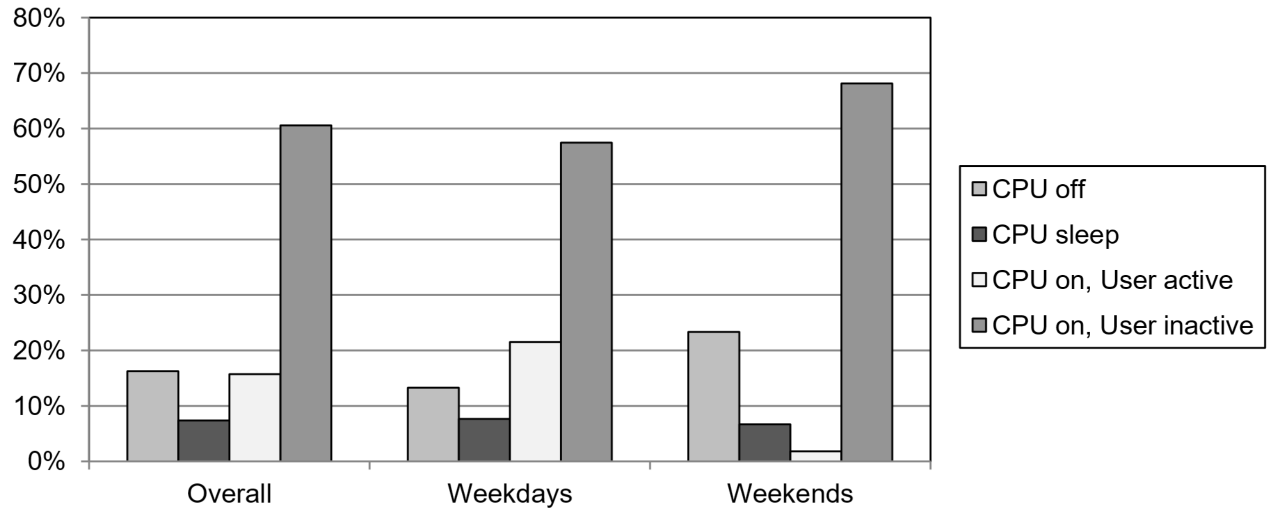


Figure 1 is formatted using a standard duty cycle presentation. This presentation helps clarify that the four states shown comprise 100 percent of the day, and allows for some level of comparison of states across groups. However, it can be difficult to assess small differences for categories shown in the middle of the bars. A chart showing separate columns for each state enables more direct comparison across states. Figure 2 presents the same information as Figure 1 in this alternate style, which will be used throughout this report. The columns sum to 100 percent of the period listed. Unless otherwise noted, this is the percent time in an average day, or 24 hours. Thus, for example, 50 percent time in a given state means 12 hours per day.

Figure 2: Percentage of Day Computers Spent in Each State, on Average, Overall and by Time of Week, in Separate Column Format

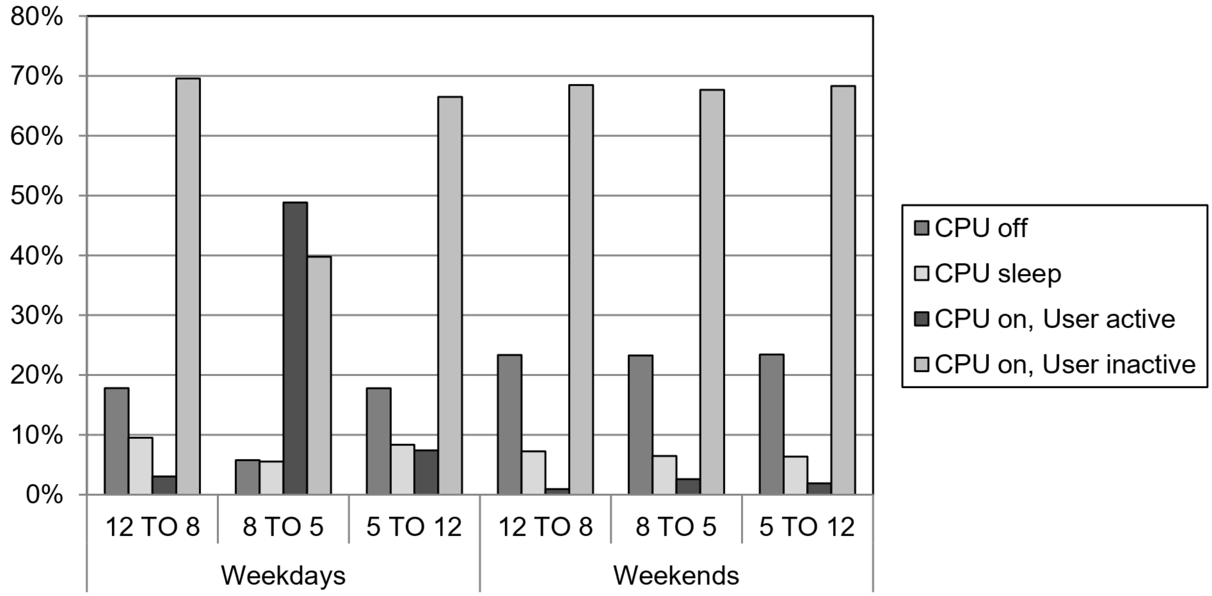


So far, the monitoring study results for duty cycle paint a very different picture than the one offered by survey respondents in their self-reports of automatic power management.

As shown in Figure 2, use of office desktops varies considerably by the time of the week. User activity is substantially higher during weekdays, and CPU-off rates are somewhat higher on weekends. However, the average time the CPU spends on and inactive is high all week long. Duty cycle figures were also calculated for three time periods: early morning (midnight to 8 a.m.), standard work day hours (8 a.m. to 5 p.m.), and evenings (5 p.m. to midnight). These periods are not of uniform length, which is important if translating the percentages given here into hours per day: the early morning period is 8 hours, the work day is slightly longer at 9 hours, and the evening is slightly shorter, at 7 hours.

Duty cycle by time of day for weekdays and weekends is shown in Figure 3. With such little user activity on office desktops on weekends, there is almost no variation across time of day. However, weekdays exhibit the expected pattern of greater user activity from 8 a.m. to 5 p.m., some user activity in the evenings (after 5 p.m.) and relatively little in the early morning hours (before 8 a.m.). Indeed, comparing the "on, user active" to the "on, user inactive" columns shows that weekdays from 8 a.m. to 5 p.m. is the only period for which user activity takes up more than half the time the computer is on. Given the lack of variation across time periods on weekends, later analyses that differentiate results by time periods focus only on weekdays.

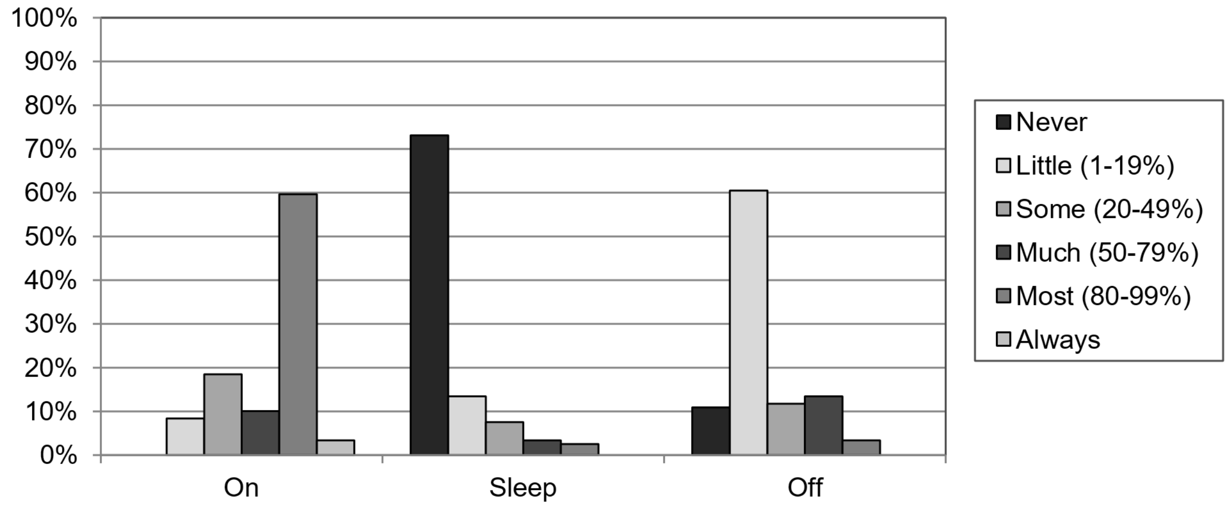
Figure 3: Percentage of Time Periods Spent in Each State, by Time of Week



The mean times given in the figures above provide an overall sense of how often computers are off or in other states. Each of the columns represents the average percentage of time that computers spend in the indicated power mode. However, if there are many computers at the extreme ends of the distribution—for instance, computers that are never off or never in sleep mode—a categorical approach can be more revealing. In Figure 4, the percent time spent in each CPU state is collapsed into six categories: never (0 percent), a little of the time (1 to 19 percent), some of the time (20 to 49 percent), much of the time (50 to 79 percent), most of the time (80 to 99 percent), and always (100 percent). Since all of these computers were used at some point during the study period, none show "never" for CPU-on, and none show "always" for CPU-off or CPU-sleep.

The categorical breakdown in Figure 4 reveals the percentage of computers exhibiting extreme behaviors versus those with more moderate time-use patterns. Very few computers are on 100 percent of the time, but many are not on for very short periods, probably due to rebooting; the majority (60 percent) are on most of the time. However, one-quarter are on for less than 50 percent of the time. The average amount of time spent in CPU-sleep mode is 7 percent (Figure 2), but Figure 4 shows that only 13 percent of computers are in the range that includes 7 percent (1 to 19 percent): over 70 percent of computers never enter sleep mode and 6 percent are in sleep mode more than half the time. Only 11 percent computers are never off, but this is misleading for the same reason that few computers are always on: brief periods spent off due to rebooting. Additional analyses show that 69 percent of computers are off for less than 5 percent of the time. Still, 17 percent are off more than half the time (total of "much" and "most").

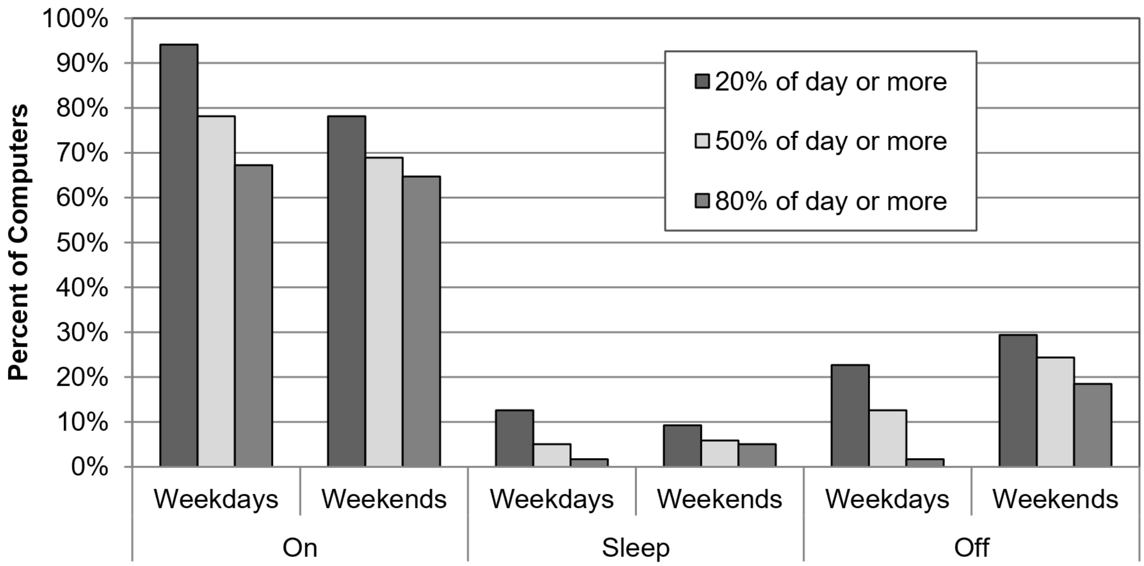
Figure 4: Percentage of Computers in Each Category of CPU State Time



As just shown, the overall rates of time spent in each state necessarily mask a range of behaviors, particularly the question of how many computers spend the most time at either extreme of the scale. Another approach is to calculate how many computers exhibit a certain state above or below a cutoff point. Figure 5 presents results using three cutoff points: 20 percent of the day or more, 50 percent, and 80 percent. As seen in the first two sets of columns, many more computers are on for at least 20 percent of day during weekdays than during weekends. However, the percentage of computers in the highest energy use category—on for 80 percent of the time or more—is almost the same for weekends and weekdays. A similar pattern is seen for CPU-off: there are more computers off for at least 80 percent of the time on weekends than weekdays, but the relative difference is much smaller for the percentage of computers off for at least 20 percent of the time. These results indicate that the computer state differences between weekdays and weekends are not due to all computers varying equally across these two time periods. Instead, about two-thirds of computers are almost always on (at least 80 percent of the time) and more than two-thirds of computers are almost never off (less than 20 percent of the time). The remaining computers vary across weekday to weekend, leading to the overall differences.

The pattern for sleep in Figure 5 is also telling. The overall average shown earlier (Figure 2) indicates an average time spent in sleep of 8 percent during weekdays and 7 percent during weekends: essentially the same rates. However, the categories differ a bit more: 13 percent of computers are in sleep mode at least 20 percent of weekdays, compared to 9 percent of computers on weekends. At the same time, more computers are in the highest sleep-use category (80 percent or more) on weekends. This is consistent with some computers being left on sleep mode whenever they are idle—all night and all weekend long—while other computers are turned off on weekends, and go into sleep mode only during workdays.

Figure 5: Percentage of Computers in Each Category of CPU State Time, by Time of Week



4.2 Active Use

This section looks more closely at the hours participants actively used their office desktops, and how that relates to information they reported in the 2013 survey. One factor that could affect the use of any specific computer is the number of other computers used by the same person, and the amount they use those other computers, information that is often not collected in other monitoring studies.

In the survey, respondents reported the number of hours they spent using office desktops and other types of computers each day in the previous week. Respondents were asked about six types of computers: desktops on campus, desktops at home, desktops in open labs on campus, desktops in locations other than home or campus, laptops, and tablets. Questions about hours of use in the past seven days were asked for desktops in open labs, desktops in other locations, and tablets. A larger set of detailed questions, including the question on hours of use, was then asked for each office desktop, home desktop, or laptop the respondent reported using at least three hours per week.

The next two figures look at how many office desktop users also use other types of computers, and for those who do, how much time they spend using each type. Figure 6 shows the percentage of respondents eligible for the monitoring study who reported using each other type of computer at least three hours per week (the criterion used for "regular" use in the 2013 survey). Overall, these respondents are more likely to use laptops in addition to their office desktops than to use home desktops or tablets. Few use desktops in other locations or in open computer labs. Staff members are significantly less likely than the other two role groups to use laptops.

Figure 6: Percentage of Respondents Reporting Using Computers of Each Type, for Those Eligible for the Monitoring Study

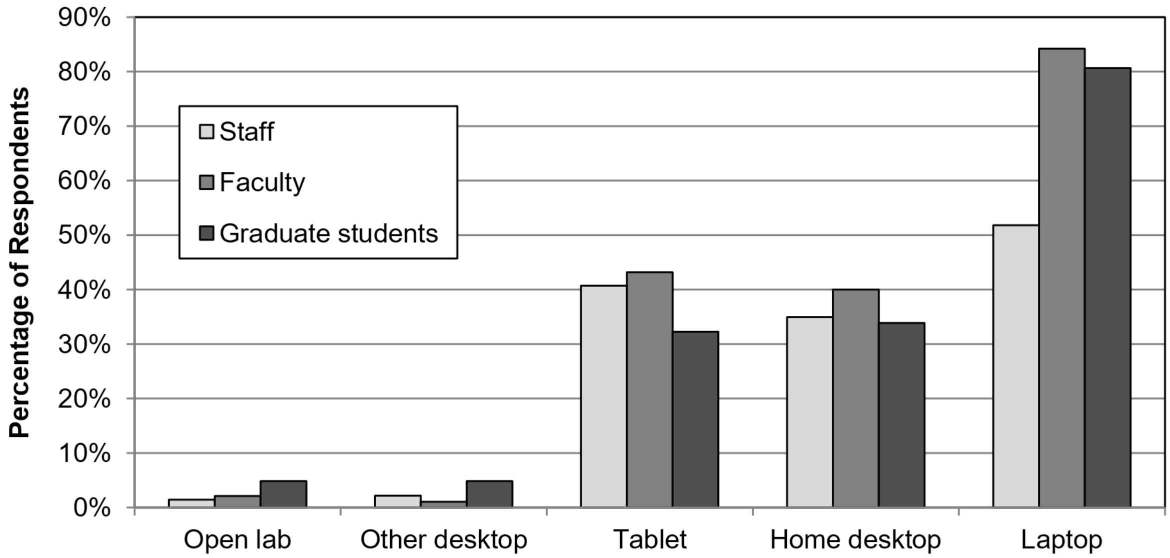
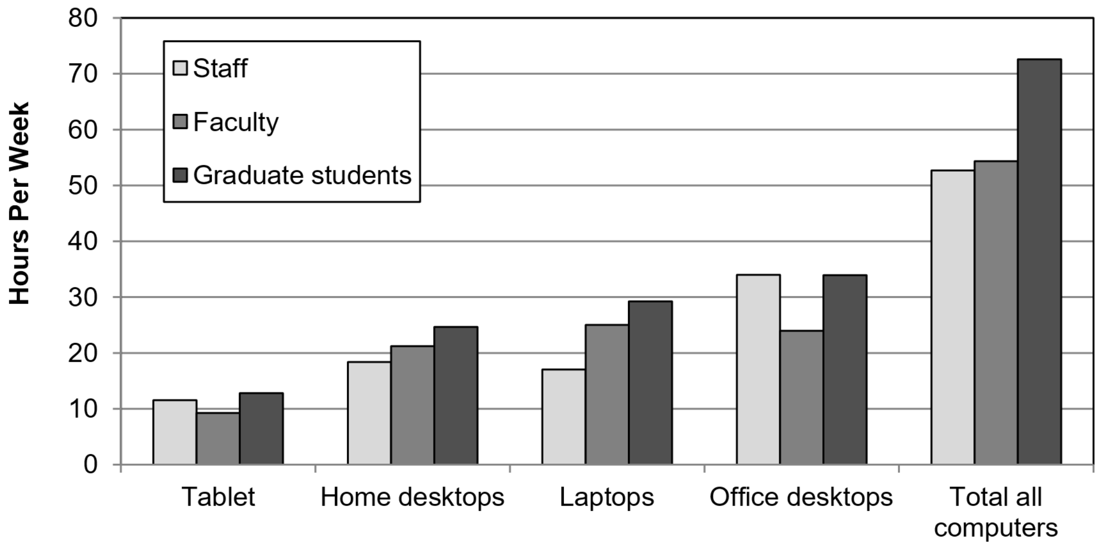


Figure 7 shows the average weekly usage hours reported for the four most-used types of computers, by role group, for the 572 survey respondents who were eligible for the monitoring study. All of these respondents reported at least one office desktop; for the other types, the means represent mean hours only for those who use that type of computer. Desktops in open labs and in locations other than home or campus were not used by enough respondents in this subsample to generate reliable means, but that usage is included in the total computer usage bar. There are several role group differences in computer time use. Faculty members report significantly fewer hours using office desktops than the other two groups; staff members who use laptops report significantly fewer hours using laptops than the other two groups; and graduate students report significantly more computer use hours overall than the other two groups.

Figure 6 and Figure 7 highlight the distinction between whether office desktop users use each other type of computer (more likely to use laptops than home desktops or tablets), and how much time they spend on each type of computer they do use (similar for home desktops and laptops and less for tablets).

Figure 7: Mean Hours of Reported Use for Respondents Who Use Each Type of Computer, for Respondents Eligible for the Monitoring Study



Narrowing down the focus to the actual participants in the monitoring study, Table 8 shows a summary of the other types of computers that participants reported during the 2013 survey. The majority of participants reported using at least one other computer, in addition to the focal office desktop, with just over half using two computers and almost a third using three or more. A substantial minority reported using two office desktops. Comparing staff and faculty, staff members are more likely to have an additional office desktop, while faculty members are more likely to have at least one laptop, and more likely to have multiple computers. Given the small size of the graduate student subsample, the percentages are not considered reliable, but the numbers do show that most graduate students reported using one or more computers in addition to the focal office desktop. The survey did not ask for the number of tablets used, so tablets are not included in this table. Few of the monitoring participants reporting using tablets at least three hours a week: two staff members, one faculty member, and one graduate student.

The numbers of computers per person for the monitoring study participants are very similar to those for the 572 survey respondents who were eligible for the monitoring study, indicating that the monitoring study did not disproportionately attract participants who use more computers.

Table 8: Number of Computers Reported in 2013 Survey by Monitoring Study Participants

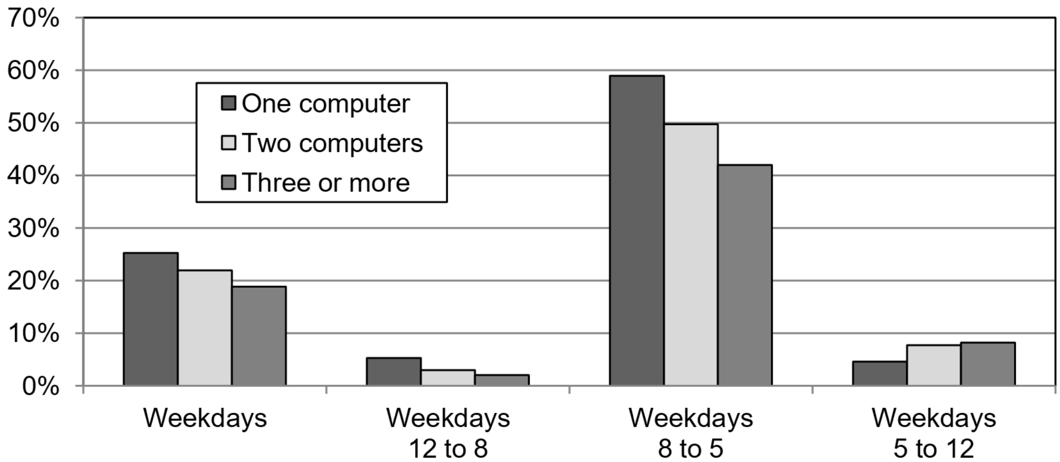
		Office desktops		Home desktops		Laptops		Total number		
	N	1	2+	0	1+	0	1+	1	2	3+
All	125	104	21	76	49	47	78	18	68	39
		83%	17%	61%	39%	38%	62%	14%	54%	31%
Staff Members	96	79	17	60	36	43	53	17	52	27
		80%	18%	63%	38%	45%	55%	18%	54%	28%
Faculty members	19	18	1	11	8	1	18	0	11	8
		95%	5%	58%	42%	5%	95%	0%	58%	42%
Graduate students	10	7	3	5	5	3	7	1	5	4
		70%	30%	50%	50%	30%	70%	10%	50%	40%

Participants may have added or subtracted computers since the 2013 survey; that information was not updated in the monitoring study.

Using other computers affects use of the monitored office desktop during weekdays (Figure 8). Participants who used one or more other computers spent less time actively using the monitored office desktop on weekdays, especially during the day and to a lesser extent in the early mornings. The difference between those with one computer (no computer other than the office desktop studied) and those with three of more computers is significant for weekdays overall and for the midnight to 8 a.m. and 8 a.m. to 5 p.m. time periods. For the 8 a.m. to 5 p.m. period, the differences between one and two computers and between two and three or more computers both approach significance, at $p < .10$. No significant differences by number of computer are seen for the evening period or during weekends.

Additional analyses indicate that there are no significant differences by number of computers used for CPU-off, CPU-sleep, or user-inactive, and no difference in whether automatic power management settings are engaged. Using other computers thus affects hours of active use on the main office desktop, but does not affect power management behaviors.

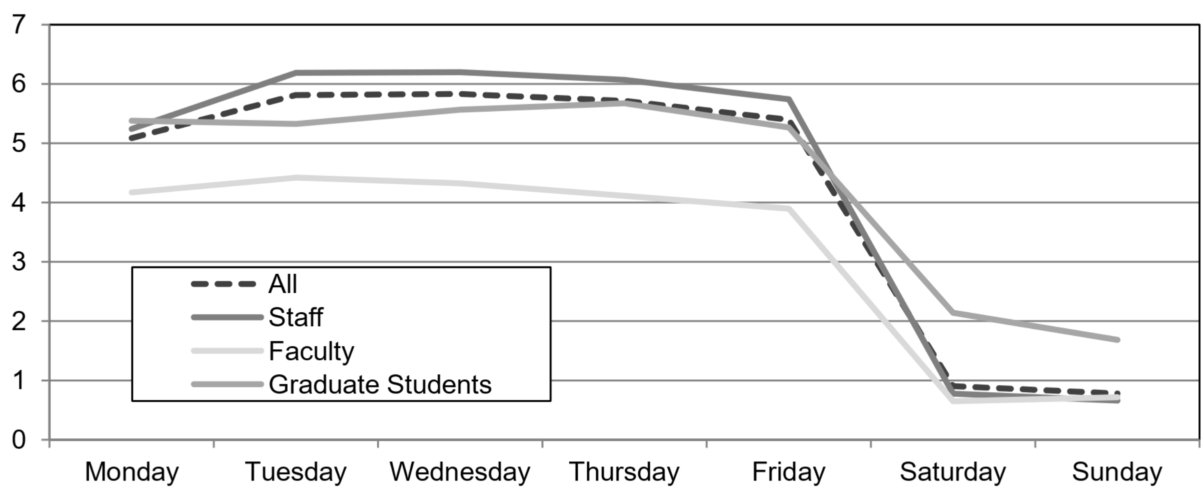
Figure 8: Percentage of Day or Time Period Spent in User-Active State in Monitoring Study by Number of Computers Reported in Survey



4.2.1 Pattern of Active Use by Day of Week

The pattern of hours throughout the week is examined in many studies of computer energy use. Figure 9 shows the pattern of hours the 572 eligible respondents reported for each day of the week in the 2013 survey for the office desktop they used the most often at that time. The expected pattern emerges in the data: much more computer use for office desktops on the workdays and relatively little on the weekends. The average hours of use per workday was 5.6 hours and the average hours of use per weekend day was 0.8.

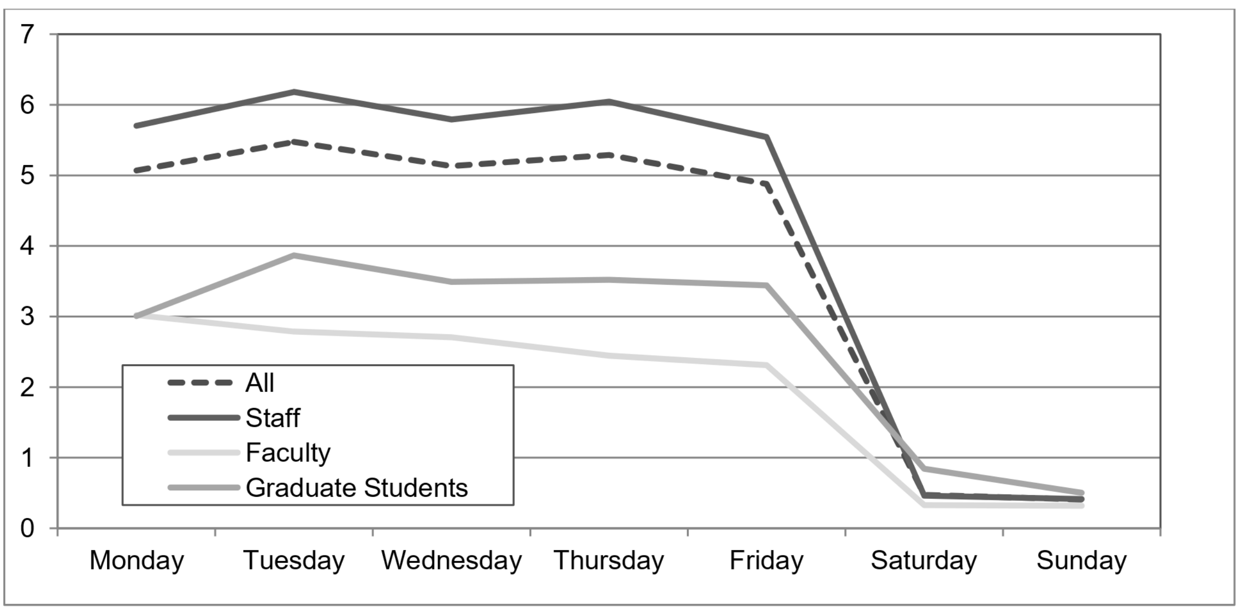
Figure 9: Mean Hours of Reported Use of Primary Office Desktop per Day of Week, for Respondents Eligible for Monitoring Study, by Role



All role groups show higher hours on office desktops on weekdays than on weekends. Overall, faculty members reported significantly fewer hours on office desktops during the week than other groups, while graduate students reported significantly more hours on weekends than other groups. As mentioned earlier, the lower use of office desktops by faculty members can be partially explained by their higher likelihood of using multiple computers (Table 8).

Figure 10 shows the observed average user-active hours from the monitoring study for each day of the week, overall and by role group. Consistent with the overall averages, weekdays show higher active use than weekend days, and staff members show higher active use for all weekdays than faculty members or graduate students. Translating percentages into hours, staff members show an average of 29.8 hours of active use per week, compared to 13.8 hours for faculty members and 18.5 hours for graduate students. Compared to the self-reported hours of use by all eligible respondents from the survey (Figure 9) the observed hours are somewhat lower. However, when comparing hours that monitoring study participants reported for their primary office desktop in the survey to the hours observed in the monitoring study, there is little difference. Overall, the hours reported in the survey are an average of only 0.2 hours lower for the week than the hours observed in the monitoring study. Staff members reported lower usage by an average of 0.7 hours per week, faculty members reported 0.7 hours more, and graduate students reported 2.5 hours more.

Figure 10: Mean Hours of Active Use per Day of Week in Monitoring Study, by Role



A correlation analysis (not shown) indicates significant positive correlations between the hours respondents reported using their primary office desktop in the survey and the hours of active use observed in the monitoring study. The overall correlation coefficient is .38 ($p < .0001$), which is moderately strong. Hours for each day are significantly correlated for weekdays, with the weakest correlation for Mondays ($r = .18$, $p = .0463$) and the strongest for Wednesdays ($r = .49$, $p < .0001$). However, self-reports and observed hours were not significantly correlated for Saturdays or Sundays.

4.3 Enabling of Power Management Features

The duty cycle results show how often computers are off or in sleep mode, which is important for identifying problematic behaviors and estimating energy use. However, monitoring data cannot identify how the computers got into those states, nor the reasons why they are not in those states more often. There are only two ways for computers to transition to low-power states: users manually switching the computer off or to a lower-power state and automatic power management settings, which can be changed by users. In workplace settings, users do not always have control over their PM settings. Even then, many can still employ manual power management (in the 2013 survey, 40 percent of respondents with no control over their automatic PM settings used manual PM consistently and 63 percent used manual PM at least some of the time). In any case, many users who could be engaging in power management behaviors are not. Any attempt to improve computer energy use must address the user behavior component.

The 2013 survey was framed more broadly than many other studies of computer energy use, asking separately about whether automatic settings are enabled and whether users are manually switching their computers off or into low-power modes. Both are important. A conscientious manual PM strategy of initiating shutdown immediately after every use would of course save more energy than if the computer sat idle for 30 minutes before automatic transitioning to a lower-power state. However, it is also true that users who rely only on manual steps may sometimes forget, potentially leaving the computer on and idle for long periods. In practice, it is likely that the most energy will be saved if both methods are employed to support each other. Thus, both automatic and manual PM were studied and differentiated to give a more comprehensive analysis of power management behavior.

In the survey, users were asked separate questions about their automatic PM settings and how often they manually put their computers into hibernate or shutdown mode when not being used. In the monitoring study, the PM settings on the participants' desktops were directly observed at the beginning of the monitoring period. It was not possible to observe manual PM actions over the course of the study, but some conclusions can be drawn from the data. As mentioned earlier, Surveyor records when the CPU is off or in sleep mode, but cannot determine whether the transition to this state was achieved automatically or manually. However, if the PM settings for sleep or shutdown are not engaged, yet the CPU is observed to be in sleep or off states, manual transitions can be inferred.

A sequence analysis of the data could reveal whether each CPU transition into sleep or off mode followed a period of user-inactive, as results from automatic PM settings, or followed a period of user-active, indicating a manual transition. This could identify computers that transition manually, automatically, or both, regardless of the PM settings, and measure how often each type of transition occurs. Such analyses are beyond the scope of the current report, but may be attempted in the future.

The following sections each briefly summarize the self-reported usage of automatic and manual PM from the 2013 survey and presents the observational data from the monitoring study.

4.3.1 Automatic Power Management from the Survey

The 2013 survey used a set of questions that did not require respondents to access the actual power-mode menus. This allowed the researchers to ask about all the computers respondents used, rather than only the one(s) they could access while taking the survey. For each computer used, respondents were asked whether the computer ever transitions automatically into any of a list of low-power states, which were described in detail as they would appear to the observer: sleep, hibernate, sleep or hibernate but the respondent isn't sure which it is, and shutdown. Note that although all computers can be set to automatically transition to sleep mode, only computers with Windows operating systems can be set to automatically transition to hibernation, while only those with Macintosh operating systems can be set to transition to shutdown (at a certain time, not after a period of being idle).

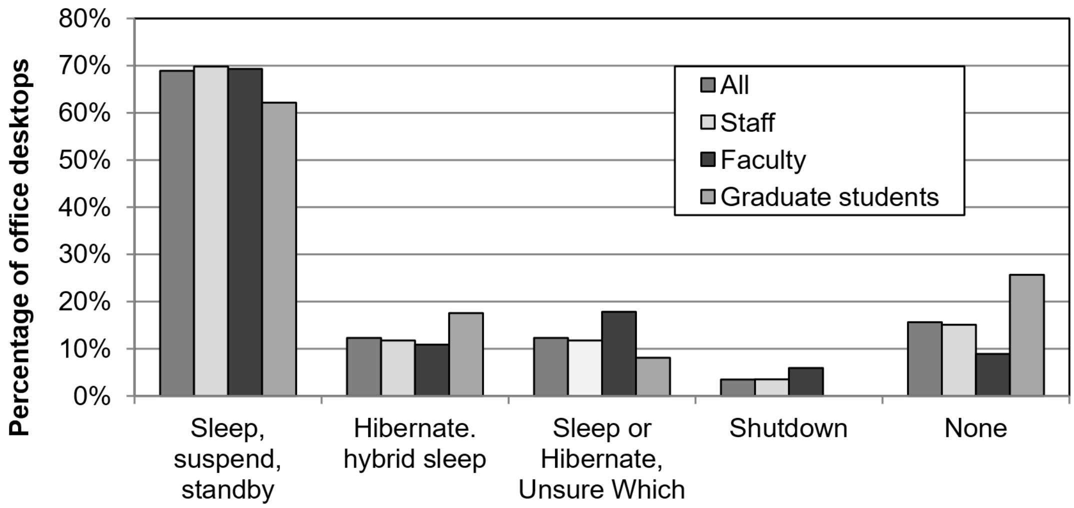
The survey data on automatic power management strategies were not seen as objective measures of the computers' actual settings, but as what users know—or think they know, or admit that they do not know—about how their power settings operate in practice. Nor is it presumed either that respondents had set the modes by themselves or that the modes were the ones shipped by the manufacturer; the questions asked only about the recent automatic behavior of the computer.

Figure 11 shows the survey results for automatic PM behavior for all office desktops, for respondents eligible for the monitoring study, including multiple computers per person. The question allowed for multiple answers, to capture all the automatic modes that might be enabled on a computer. Over two-thirds of respondents reported that their primary computers automatically entered sleep, suspend, or standby mode when it was inactive, but few reported that their computers automatically hibernated or shut down. For all the role groups combined, 16 percent of computers were reported to have no automatic PM settings enabled. There are no significant differences in reported automatic PM behavior by role group within this subsample.

The figures are very similar for the subsample of actual participants in the monitoring study, who reported that no automatic PM settings were enabled for 16 percent of their office desktops. The 84 percent of computers reported to have any PM settings enabled included 76 percent reporting sleep, suspend, or standby.

The results in Figure 11 do not include cases where respondents indicated that they didn't know or gave no answer. In the 2013 survey, this included about ten percent of office desktops. However, the monitoring study subsample is somewhat more confident about their automatic PM settings: no desktops reported by graduate students and only 6 percent each of those reported by staff members and faculty members had "don't know" or "no answer" responses.

Figure 11: Percentage of Office Desktops Reported to Have Automatic PM Settings Enabled in the 2013 Survey, for Respondents Eligible for the Monitoring Study, by Role



4.3.2 Automatic Power Management in the Monitoring Study

The monitoring study questionnaire asked participants if they or anyone else had changed the power management (PM) settings on this computer since the 2013 survey, which was about ten months earlier for most participants. For new computers, they were instructed to think about the period since they got the computer. (See the questionnaire in Appendix B for the full question wording.) Of the 125 participants, only 6 percent report changing the power management settings since the survey the previous spring (Table 9). The majority indicated that nobody had changed the PM settings in that period, and 10 percent each said that maybe someone else changed the settings or that they didn't know if the settings had been changed.

Table 9: Whether Participants Report Changing the Power Management Settings Between the 2013 Survey and the 2014 Monitoring Study

	Number	Percent
I changed the settings	7	6%
Someone else changed them	3	2%
I did not change them but maybe someone else did	13	10%
Nobody has changed the settings	90	72%
Don't know	12	10%

Participants' low likelihood of changing their PM settings since the survey has one positive interpretation: taking the 2013 survey on PM behaviors does not appear to have prompted participants to become substantially more engaged with PM, which could have biased the results of the monitoring study. Also, rates given for the period since the survey (9 to 11 months) does not mean that the PM settings on these office desktops have never been changed. In the 2013 survey, 34 percent of the monitoring study participants reported being the last person to change the settings for their primary office desktops, and only 31 percent reported that nobody had changed the settings. It is likely that some of them changed the settings when they first acquired the computer, and did not do so again. In addition, many respondents used the same computer for several years prior to the survey, giving them more opportunities to change the settings prior to the survey than in the much shorter time period since the survey.

For the 97 participants who are currently using a computer they reported on in the survey, only 2 reported in the monitoring study that they had changed the settings since the survey. Both of these participants had also reported in the survey that they had changed the PM settings on that same office desktop.

For participants who changed the settings themselves since the survey, the monitoring study questionnaire asked the direction of the changes. However, with so few persons answering those questions, the results cannot be used.

The actual automatic PM settings enabled on participants' desktops were observed and recorded by researchers during the initial visit of the monitoring study. This provides a snapshot at a given time for this population, which can be compared to what respondents reported during the 2013 survey and to their duty cycle results. There is no certainty that the same settings continued to be enabled over the course of the monitoring period, but given the small percentage of participants who report changing the settings in the 9 to 11 months since the survey (Table 9), it is unlikely that PM settings were changed in the subsequent four to six weeks.

The monitoring study researchers recorded the following PM settings from the users' computers:

- Whether the computer was set to transition into sleep, standby, hybrid sleep, hibernate, or shut down mode, and if so, after what period of being idle or at what time(s).
- Whether hybrid sleep was allowed (that is, any transition to sleep mode would become hybrid sleep instead).
- Whether the hard disk(s) were set to turn off, and if so, after what period of being idle; also, whether hard disks were set to sleep "when possible."
- Whether the monitor was set to transition into sleep, and if so, after what period of being idle.

The PM settings observed in the 125 monitoring study computers are shown in Table 10. Some settings are available only on certain operating systems. For example, standby mode is available on Windows XP (and not available on other operating systems) but sleep mode is not. Automatic hibernation is available only on Windows computers while automatic shutdown is available only on Macintosh computers. There are several instances where interviewers could not locate a PM setting that should have been available on that computer; these are coded as missing data. The number of missing results is telling in itself. The interviewers went through extensive training, practice, and testing on how to locate and record PM settings on a variety of computers; yet even they were unable to locate the hibernate, shutdown, or hybrid sleep options on many computers in this sample.

Overall, Table 10 shows a fairly low enabling rate for automatic power management for CPUs. Only 20 percent of CPUs are set to go into sleep or standby mode, none are set to automatically shut down, and almost none are set to automatically hibernate. All the computers set to automatically transition to hibernate mode are also set for sleep mode. If enabling automatic PM is defined as setting automatic transitions to sleep or standby, shutdown, or hibernation, 20 percent of these computers have automatic PM enabled. Some better news for energy conservation is that hard disks are set to sleep in over half of computers, and monitors are set to sleep in more than four-fifths. The sleep setting for hard disks is in the "advanced" portion of the PM user interface; the high rate of enabling for this setting may be due largely to users not deactivating it rather than users knowingly activating it.

Table 10: Percentage of Computers with Each Type of Power Management Setting Enabled, Observed in the Monitoring Study

	Set to transition after a number of minutes	Set to transition when possible or allowed	Disabled	Not available on this OS	Missing
Sleep	19%		70%	9%	2%
Standby	1%		7%	91%	1%
Sleep or standby	20%		77%	0%	2%
Hibernate	2%		57%	18%	23%
Shut down	0%		4%	82%	14%
Hybrid sleep	0%	44%	5%	27%	24%
Hard disks	54%	16%	24%	0%	6%
Monitor sleep	83%		16%		1%

Some rows do not add to 100% due to rounding.

The efficiency gain for enabling automatic transitions to a low-power mode depends in part on how long the computer remains on and idle before the transition takes place. Of the 25 computers that had sleep or standby enabled, 14 were set for about 10 minutes (9, 10, or 11 minutes), 2 for about 25 minutes (24, 25), 5 for 30 minutes, 4 for 60 minutes, and 4 for much longer (specifically, 120, 180, and 240 minutes). In total, 68 percent are set to transition in 30 minutes or less, a conventional time setting for sleep, but 32 percent do not transition into sleep or standby for at least an hour or much longer, reducing the possible energy savings.

The comparison between automatic PM settings reported in the survey and settings observed in the monitoring study is shown in Table 11. The survey question asked respondents whether the computer ever automatically transitions to that low-power mode when left idle, yes or no, based on a description of how the computer responds when the user returns. A negative response could mean the mode is disabled or that it is not available on that computer (or could be an error). The “any automatic PM” measure includes computers for which respondents reported one or more of the modes shown: sleep, hibernate, and/or shutdown; it also includes the few cases for which respondents reported only “sleep or hibernate, not sure which one,” an answer which cannot be directly compared to the actual PM settings and is not shown in Table 11. For the observed PM settings in the monitoring study, missing cases arise when the trained researcher was unable to locate the setting and erroneously marked the setting as "not available" for that computer; these cases are treated as not enabled for the "any automatic PM" measure.

Table 11: Comparison of Automatic PM Settings in Survey versus Monitoring Study

			PM settings observed in monitoring study			
PM reported in survey		**N**	**Enabled**	**Disabled**	**Not available**	**Missing**
Sleep or standby	Yes	57	30%	67%	0%	4%
	No	17	12%	88%	0%	0%
Hibernate	Yes	8	13%	75%	13%	0%
	No	66	2%	48%	23%	27%
Shutdown	Yes	2	0%	0%	100%	0%
	No	72	0%	4%	78%	18%
Any automatic PM	Yes	64	30%	70%		
	No	10	0%	100%		

N = 74 who report that nobody has changed the PM settings on the focal desktop since the survey.

Direct comparisons can be made only for participants who are using the same computer they reported on during the 2013 survey and have valid data for the survey question. Results are further limited to those participants who reported that nobody has changed the PM settings since the survey (n = 74). If the participant is correct and the settings have not been changed, any difference between the survey report and the monitoring study observation suggests a problem with the survey report.

The results in Table 11 indicate a large discrepancy between participants’ observed PM settings in the monitoring study and what they reported in the 2013 survey, at least for this subsample of the survey respondents. However, the two measures of automatic PM are still related:

respondents who reported each specific PM setting are more likely to have that state enabled on their desktop than those who reported the setting to be disabled. This relationship is not statistically significant for sleep mode, but it is for hibernate and for whether any low-power mode is selected. The errors are almost all in one direction: participants were much more likely to report that a setting was enabled when it was not than to report that a setting was not enabled when it was.

As with other surveys, there are two likely sources for the discrepancy between the survey reports of automatic PM settings and the PM settings observed in the monitoring study. The first is a reporting bias: that is, respondents knew that they did not have PM enabled on their computers but reported that they did anyway. This may be due to social desirability, if they wanted to make themselves look better to the researchers, or to survey demand effects, if they wanted to be a "good subject" and say what they believed the researchers wanted to hear.

The second likely source is reporting error, likely due to problems with respondents' observation, perception, or recall of these events: that is, respondents were truthfully reporting what they believed, but were incorrect about whether their computers ever automatically transitioned to low-power modes. The survey did not ask what the specific PM settings were (because many people do not know) but asked respondents to identify states such as sleep, hibernate, or shutdown based on how the computer behaves after it has been idle: in particular, whether programs are still open and how long it takes to resume. There are numerous plausible mechanisms through which respondents would believe they are employing energy-saving automatic PM strategies when they are not. The subjective experience of waiting for the computer to resume may make the time delay seem longer than it actually is. For instance, the majority of these desktops have their monitors set to automatically transition to sleep mode. Some of the participants could judge the time it takes for their monitor to wake from sleep mode to be long enough that they erroneously assume the computer itself was in sleep mode. They may also forget turning their computer off, or not realize that someone else has done so, and thus believe that their computer is set to automatically transition to hibernate or shutdown mode. Similarly, they could confuse times when they manually put their computer into sleep mode as indicating that the computer automatically transitions to sleep mode. Indeed, past studies have found that users were confused by power management settings and terminology. An international survey found that 17 to 38 percent of office workers did not understand PM settings (IE 2009); an in-depth study of households in Seattle found that "many people we interviewed claimed they did not know how to alter their power settings to be more energy efficient" (Chetty e al. 2009).

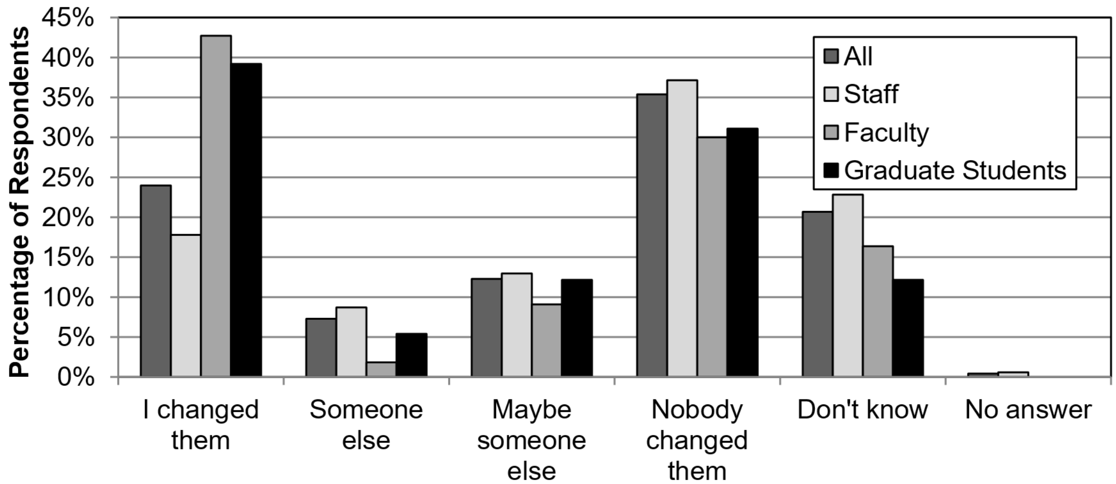
Both sources of reporting error probably affected the survey results. However, there is reason to believe that user error may be more problematic than user bias. The survey was deliberately phrased in neutral terms to reduce demand effects and other reporting biases. Social desirability bias and demand effects are most problematic in face-to-face interviews, and least problematic in anonymous self-administrated surveys. The online survey was self-administered, private, and confidential, which reduces the likelihood of both types of reporting bias. This increases the probability that errors were due to respondents' incorrect beliefs about their PM settings. More discussion of why respondents may be confused about automatic power management is given below.

4.3.3 Control of Power Management Settings

One factor that could affect respondents' awareness of their power management settings is whether they have accessed and changed those settings themselves. Respondents would have less control over power management when the PM settings for a group of office computers are centrally managed by an IT manager. The respondents in the survey were in many different departments and other units, which vary in how much they do or do not control their IT resources. The 2013 survey results indicate that for office desktops, many users have not changed their PM settings, and in some cases, do not have control over those settings.

The survey asked if the respondent or anyone else had changed the PM settings each of the respondent's computers. Specifically, the options were: nobody has changed the settings; I changed them; someone else changed them; I did not change them but maybe someone else did; don't know; and prefer not to answer. The "maybe someone else" option helps identify respondents who don't know if the settings were changed because other people have had access to the computer. The survey text advised the respondent, "If the settings were changed multiple times, answer for the most recent change." Thus, some respondents may have changed the settings in the past, but not marked "I changed them" because they were not—or didn't know if they were—the last person to do so. Figure 12 shows the results for the primary (most-used) office desktops of the 572 respondents who were eligible for the monitoring study (that is, staff members, faculty members, and graduate students who are primary or sole users of office desktops).

Figure 12: Who Changed the Power Management Settings on their Primary Office Desktop, if Anyone, for Respondents Eligible for the Monitoring Study, by Role



According to respondents' reports in the 2013 survey, most office desktops had their PM settings changed by someone at least once up to that point: only 35 percent reported that nobody had ever changed the settings. However, even fewer respondents (24 percent) reported changing the PM settings themselves. There are substantial differences across role groups. Compared to faculty members and graduate students, staff members are much less likely to report changing the PM settings themselves and more likely to say that someone else changed them, nobody changed them, or that they do not know. Supplementary analyses show that these same staff members are just as likely as faculty members to change the PM settings on their home desktops (52 percent v. 53 percent, respectively), suggesting that the differences for office desktops are due to situational rather than personal factors. This evidence suggests that people feel less control over their PM settings in the office environment than at home, especially staff members.

The survey asked respondents with office desktops, for the one they used the most, "Do you have control over the power management settings on that computer?" The results are shown in Figure 13. Relatively few respondents in any role group report following a formal or informal policy about PM settings. It is possible that more respondents are subject to a policy than realize it; however, their behaviors cannot be affected by policies they are unaware of. Faculty members and graduate students gave similar responses: fairly high rates of controlling PM settings, and low rates of not having control or not knowing. By contrast, staff members were much more likely to say they had no control over their PM settings (27 percent) or that they did not know if they had control (34 percent).

Figure 13: Respondents' Reported Control over PM for their Main Office Desktop, for Respondents Eligible for Monitoring Study, by Role

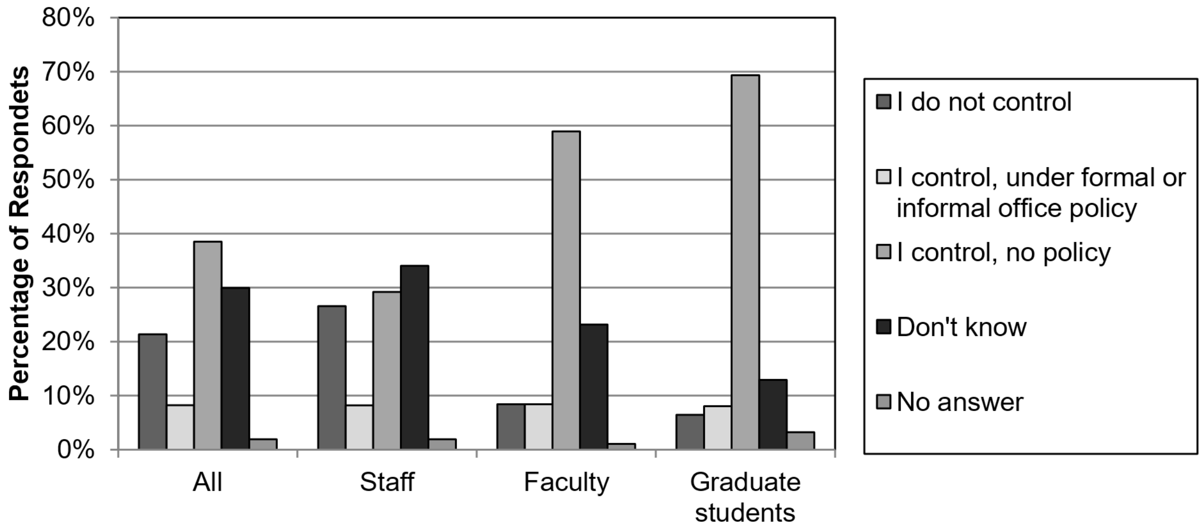
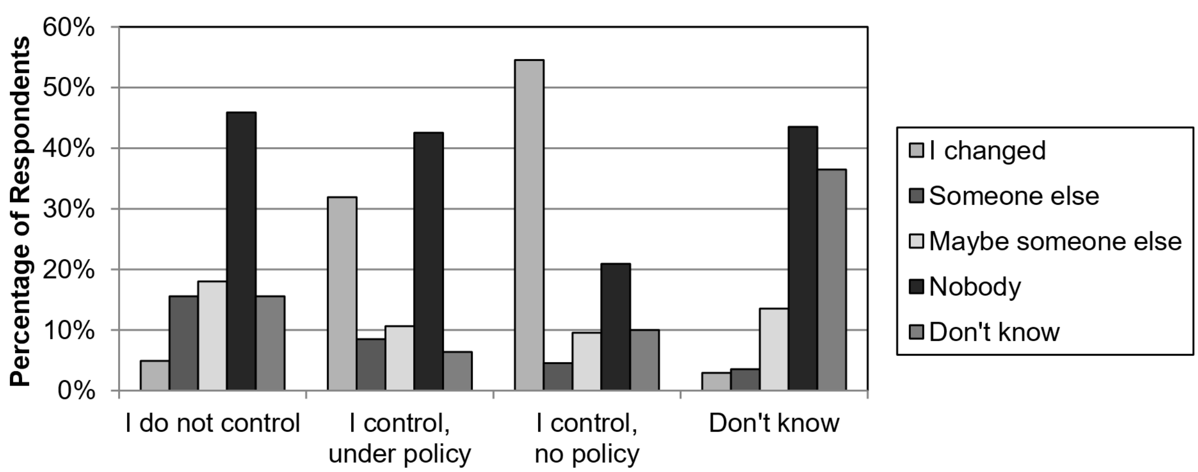


Figure 14 shows how many respondents within each level of control of their PM settings (Figure 13) changed their own PM settings (Figure 12). As expected, respondents who reported having control over the PM settings, whether under a policy or not, were significantly more likely to report having changed the PM settings for their primary office desktop than those without control. Furthermore, those who said they control the PM settings without any policy were significantly more likely to report changing the settings than those who reported following a policy. Those who control their settings without any policy are also least likely to report that nobody has changed the PM settings.

Figure 14: Whether Respondent Reported Changing the PM Settings for their Primary Office Desktop by Control over Settings, for Respondents Eligible for the Monitoring Study

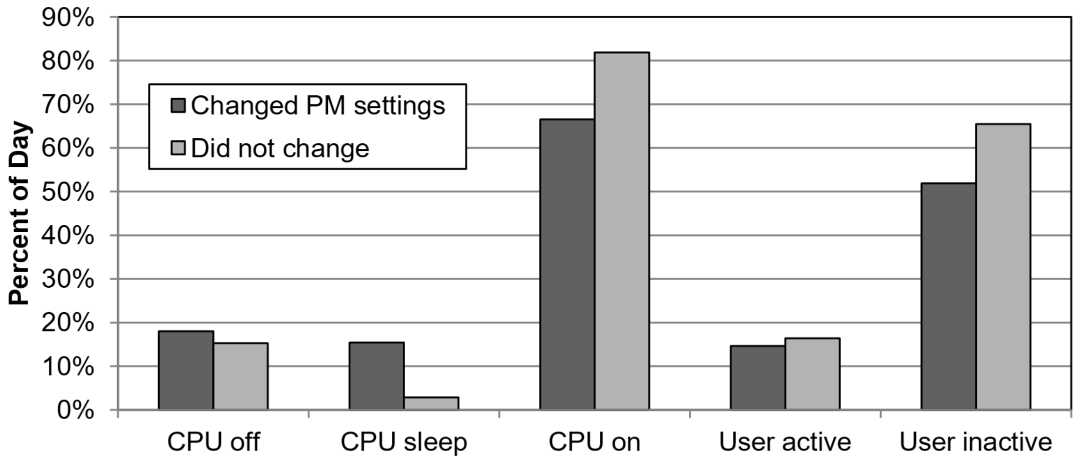


Results were similar for the smaller group of monitoring study participants. Of the 123 with valid data for that survey question, 43 percent reported controlling their PM settings without a policy, while 9 percent controlled under a policy, 16 percent had no control, and 32 percent did not know if they controlled their PM settings. Those who reported controlling their settings with no policy were by far the most likely to also report changing the settings for their primary office desktop (62 percent).

The extent to which participants currently control the PM settings on the desktops examined in the monitoring study is not known. The process of scheduling installations for the monitoring study did identify some participants who did not have administrative control over their computers., but as this information is not available for all participants, it cannot be used as a measure of control over PM settings. Instead, control over office desktops reported in the survey is used as a proxy for current control. Additional analyses reveal that those with control over their PM settings do exhibit higher rates of CPU sleep, lower rates of CPU on, and lower rates of user-inactive, but in this small sample, the differences are not large enough to be statistically significant.

Whether participants actually change their PM settings may be more important than whether they could potentially change them. A measure was constructed identifying participants who had reported changing the PM settings for their primary office desktop in the 2013 survey or for their current office desktop since the survey. Those who had changed the PM settings for their office desktop at either time showed a higher likelihood of having sleep or standby enabled on their current office desktops than those who had not (29 percent versus 15 percent); this result is not statistically significant in this small sample but closely approaches that level ($p = .06$). Furthermore, Figure 15 shows that the computers of participants who reported changing their PM settings at either of those times exhibit higher rates of sleep, lower rates of CPU-on, and lower rates of user-inactive, differences which are all statistically significant. Overall, these results suggest that when participants have changed their own PM settings, they are more likely to actively use power management.

Figure 15: Percentage of Day Computer Spent in Each State in Monitoring Study, by Whether Participant Changed PM Settings Before or Since Survey



It is not possible to establish the direction of any changes to PM settings—that is, whether changes increased or decreased energy efficiency—using the current data. Nor is it possible to compare the current settings to the default settings, which are not known for these computers. UCI has a campus policy of "Green Purchasing" which requires purchasing ENERGY STAR products if they are available. No records are kept on how many computers purchased at UCI are compliant with this policy. Still, it is reasonable to assume that at least some of these desktops that have sleep disabled would have had sleep enabled as a default setting when the computer was purchased. This raises the question of who changed the PM settings, and why those persons disabled sleep mode for these users' computers. As the survey and the monitoring study focus only on the behavior of the users, the behavior of IT managers and other non-users who can change the PM settings was beyond the scope of the current project, but is a fruitful topic for future research.

Another question is whether those who have more control over and/or who changed their PM settings—who presumably know more about those settings—indeed gave more accurate reports in the survey. Further analyses show that respondents are more likely to exhibit a match between whether they reported any power management enabled in the survey and whether any power management was engaged in the monitoring study if they reported having control over their main office desktop versus those who did not (46 percent versus 0 percent). The same is true for those who changed their office desktop PM settings either before or since the survey: for sleep or standby settings the difference in accuracy is fairly large (51 percent for those who had changed their settings versus 34 percent for those who had not), but not large enough to be statistically significant. For whether any power management is engaged, the difference is somewhat larger (54 percent versus 26 percent) and does reach statistical significance. That is, participants who have changed their PM settings on their primary office desktop are more likely than those who haven't to have their reports of automatic PM on the survey match what it is observed on their computers during the monitoring study.

4.3.4 Power Plans

Another possible explanation for respondents' over-reporting of automatic power management enabling is that users may be confused by or about the power plans on their computers. Power plans—also known as power profiles or power schemes—should in theory facilitate PM use by providing users with two or more default patterns of enabled PM settings. One plan may be focused more on saving energy while another is focused more on performance, although the latter still saves more energy than having no PM features enabled. Little research is available on which power plans users choose, and whether they adjust the settings of default power plans rather than create their own custom plan. Changes to the plan settings could affect users' perceptions of their PM behavior. For instance, in Windows 8, the "balanced" power plan includes the description, "Automatically balances performance with energy consumption on capable hardware." However, as the settings associated with this power plan can be changed, they may no longer fit that description. Users may believe their computers are reasonably energy efficient because the "balanced" plan is selected, but not realize (or remember) that some or all of the PM features have been eased or disabled.

To examine the relationship between power plans and settings, the researchers recorded the power plan that was selected on each computer, as well as the power plans that were available on that computer but not selected. As multiple default power plans are used only in Windows operating systems, Macintosh computers are listed as one separate category.

The frequency of selected power plans is shown in Table 12. The most commonly selected plan is "balanced"; "high performance" is the next-most used, with half as many users in this sample. Almost no users create a new custom plan for themselves. Instead, they seem prone to modifying existing power plans. This is suggested by the fact that although the default settings for the common plans all enable sleep mode, most of these computers have sleep mode disabled. The tendency to tweak existing power plans rather than create custom plans was reported also in the study by Chetty et al. (2009).

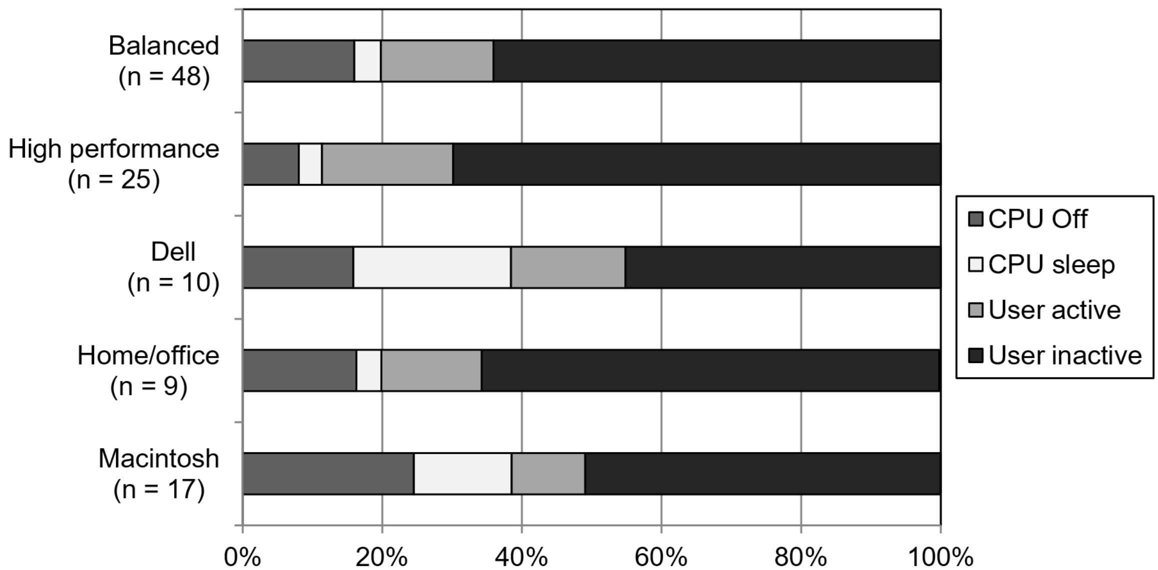
Table 12: Power Plans Selected on Computers in Monitoring Study

Power plan name	Number	Percent
Balanced	50	40%
High performance	25	20%
Home/Office desk	11	9%
Dell	10	8%
Energy saver or Power saver	1	1%
Custom	1	1%
Other	4	3%
None (Mac)	23	18%

The observed average duty cycles for computers using the four most commonly used Windows PM power plans in this sample are shown in Figure 16, along with Macintosh computers for comparison. Given variation across operating systems, the specific default settings for each plan are not known to the researchers. Based on the descriptions in the Windows user interface for "balanced" and "high performance" power plans, the balanced plan would be assumed to transition to sleep mode more often; however, this is not the case. Instead, the balanced, high performance, and home/office power plans show similar achieved rates of sleep. Computers with the high performance plan spend less time off, but as seen earlier, no computers are set to automatically transition to shutdown; only two are set to hibernate, one of which uses the high performance plan (the second uses an "other" plan). Among the Windows computers, those with Dell power plans have significantly higher rates of sleep mode than others; however, with only ten computers set with the Dell power plan, this result should be interpreted with caution.

Computers differed in which power plans were available, and may also differ in other features of the user interface which were not recorded in this study. The differences across power plans within Windows computers could be related to some unmeasured differences in the user interfaces. Likewise, Macintosh computers exhibit more efficient duty cycles than Windows computers using most power plans, other than "Dell." As discussed elsewhere, the differences between computers with Windows and Macintosh operating systems may have many explanations; the Macintosh results are included here to highlight the possible effects of the user interface.

Figure 16: Time Computer Spent in each State, by Selected Power Plan



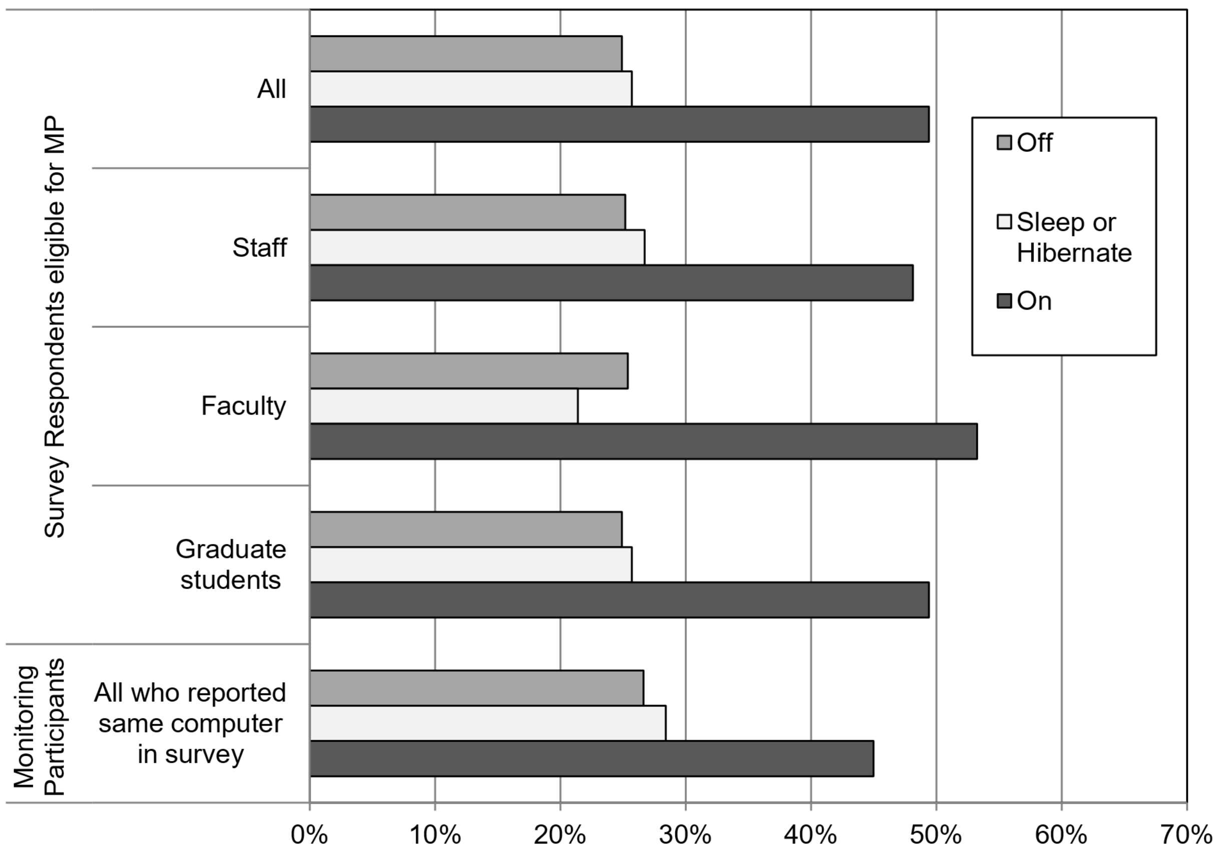
Given the variation seen here in computer behavior across power plans, the differences in achieved efficiency could reasonably be affected by how the PM settings are presented to the user, such as how easy it is to change the settings, or how obvious it is that low-power modes are enabled. For the one-third of office desktops for whom nobody has changed the settings, the variation is presumably due to differences in default settings.

4.3.5 Manual Power Management in the Survey

In addition to automatic power management settings, the 2013 survey also addressed manual power management. The survey asked, "In the past two weeks, when you knew you wouldn't be using this computer for several hours or more, what percent of the time did you do each of the following? (A) turned the computer off, (B) put it into a sleep or hibernate mode, or (C) left it on (it may or may not go into a sleep or hibernate mode automatically)." As these three states are mutually exclusive and exhaustive, the percentages given to the three states had to sum to 100 percent; answers that did not add up to 100 percent prompted an error message from the online survey until the respondent corrected the answer. Note that this question measures the percent of times or occasions the computer in left in each state when the user stops using it, not the total percent of the day it is in that state.

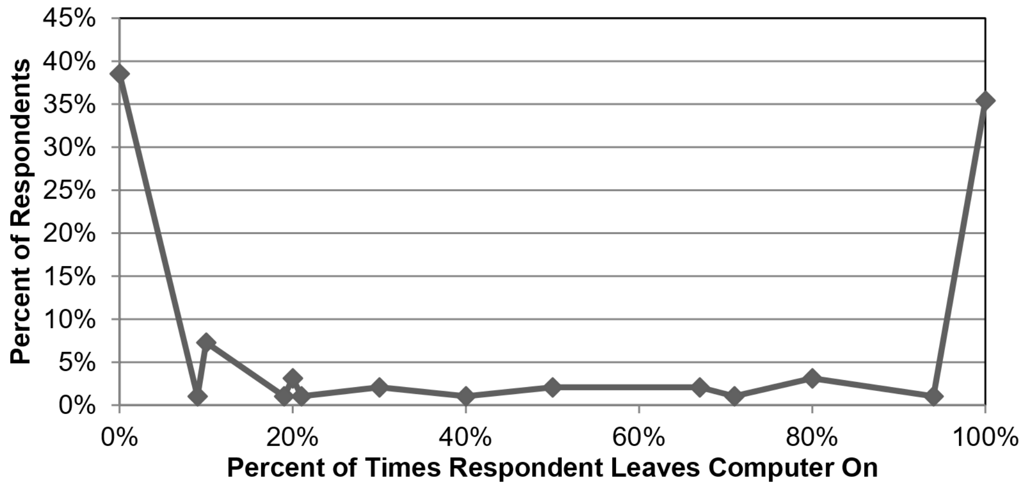
Figure 17 shows the reported use of manual PM actions for the 572 survey respondents who were eligible for the monitoring study, by role group. The figure includes all the office desktops reported by this group that have valid data for this question (a total of 671 computers). The bottom panel shows results only for those computers reported in the survey that are still being used by monitoring study participants (n = 96; one is missing data for this survey question). The results show that office desktops are left on an average of almost half the times that respondents know they will be idle for at least several hours. Users report turning their computer off approximately as often as they put the computer manually into sleep or hibernate mode. There are slight differences across role groups, but none are statistically significant.

Figure 17: Average Percentage of Times the Computer is Left in each State When User Leaves for Several Hours, as Reported in the Survey, by Role



While Figure 17 is a useful summary of the average rates of manual power management strategies, averages can mask great variation, and in this case the distribution is distinctly bimodal. Figure 18 shows the distribution of responses for how frequently the monitoring study participants reported leaving the computer on, for those who are using the same computer they reported on in the survey (valid data for 96). While the average "leaving on" rate shown in Figure 17 is 45 percent, Figure 18 shows that very few participants reported leaving their computers on between 30 and 50 percent of the times they stopped using them. Instead, two thirds of participants report behaviors at one extreme or the other, with 39 percent never leaving their office desktop on if they will be gone for several hours and 35 percent always leaving it on. The numbers are only slightly skewed toward turning computers off or manually putting them into a low-power mode. Overall, 45 percent of participants report leaving their computer on at least 50 percent of the times they leave it, with the remaining 55 percent leaving it on less than 50 percent of the time. A similar bimodal distribution, for many office machines in one large department, was found by Schoofs et al. (2010).

Figure 18: Percentage of the Times User Reports Leaving the Computer On if Leaving for Several Hours, for Monitoring Study Participants with Survey Data for Current Computer



4.3.6 Manual Power Management in the Monitoring Study

The duty cycle results in the monitoring study do not correspond directly to the self-reports about manual power management actions in the survey. The survey asked respondents what state they left their computer in when they would not be using it, but the percentage of *times* a computer is left in one state is not the same as the percentage of *time* a computer spends in that state. Also, the monitoring data cannot distinguish state transitions due to manual actions from those due to automatic power management. Still, several comparisons can be made.

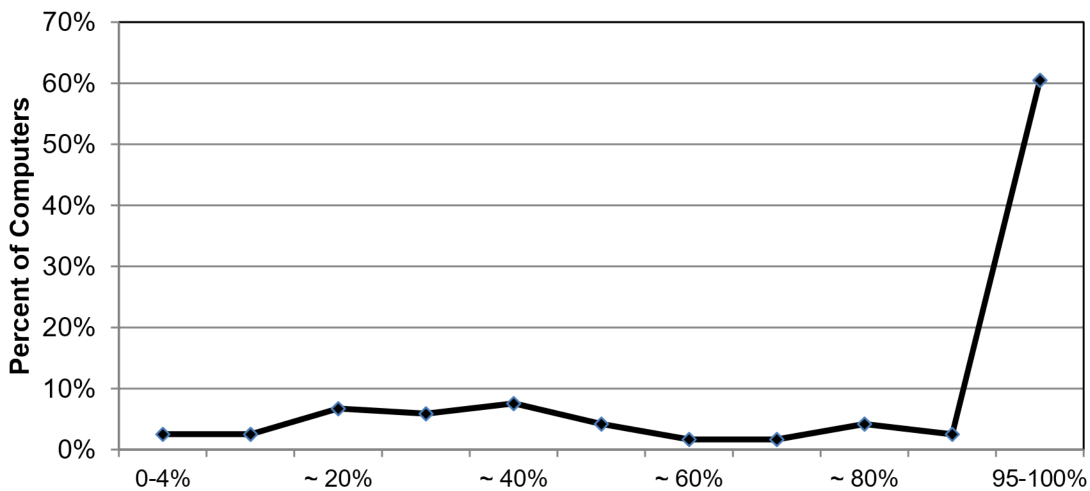
One relevant measure from the monitoring study data is the percentage of the day computers are observed to be on, the same measure used in many other monitoring studies. As an indicator of manual behavior, this measure is only roughly equivalent to the self-report of manual behavior in the survey. Computers that are always or usually left on when users stop using them should be on for more of the day. However, computers that are never or rarely left on when they are left idle will still be on sometimes: whenever they are being used, or when the user plans to return shortly. Thus, there is no corresponding measure in the observed duty cycle data for the percentage of users who report never leaving their computers on when they stop using them for several hours.

The measures are more comparable at the other end. If respondents leave their computers on 100 percent of the times they stop using the computer, some of those computers will stay on all the time while others may automatically transition into a low-power mode. Thus, for this second group, the percentage of computers that are always on should logically be the same or smaller than the percentage of computers that are always left on by the user. The results from the monitoring study are shown is Figure 19, which displays the percentage of the day, on average, computers were observed to be on. To collapse the percentage times into categories they are rounded to the nearest 10 percent: for instance, the 60 percent category includes times from 55 to 64 percent. This is most important at the extreme ends of the scales for CPU-on and

CPU-off, since there ae many computers that are almost always on (and thus almost never off), but have brief periods of being off, presumably due to rebooting. Strict definitions of "on 100 percent of the time" and "off 0 percent of the time" would needlessly omit these computers. For this reason, 0 to 4 percent of the time is treated as never or almost never and 95 to 100 percent of the time is treated as always or almost always.

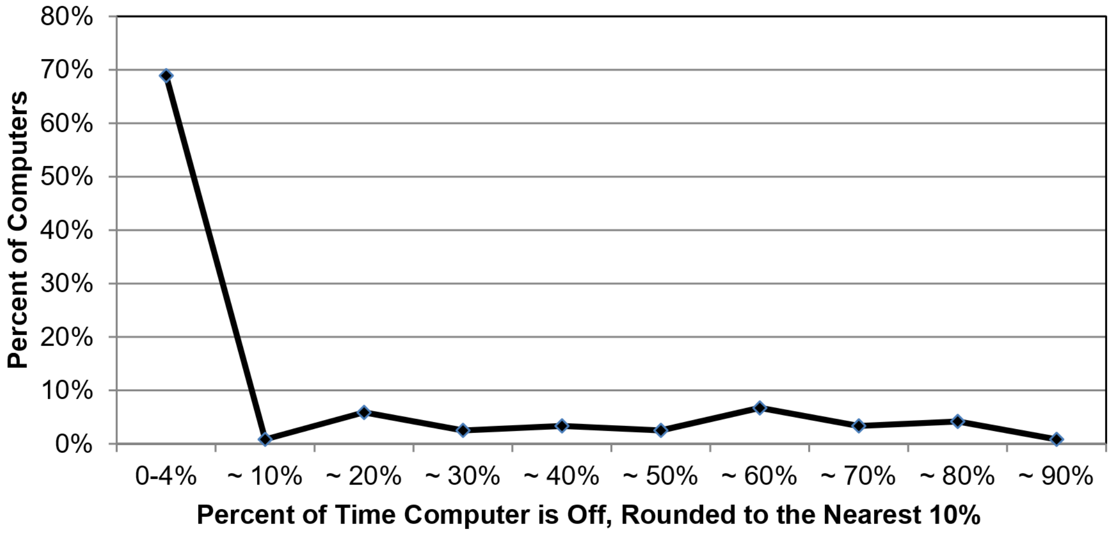
Figure 19 shows that more computers are always or almost always on—61 percent—than would be predicted by the self-reports in the survey. It is possible that participants' behavior has changed between the survey and the monitoring study. It is more likely that respondents either under-estimate or under-report their tendency to leave the computer on.

Figure 19: Distribution of Average Percentage of Time CPU is On in Monitoring Study



A similar comparison can be made for between how many respondents report never turning their computer off and how many computers are observed in the monitoring study to never be off (Figure 13). (Note that the percentage of time computers are off does not exactly mirror the percentage of time they are on, due to time spent in sleep mode.) If users never turn their computers off, those computers may still be set to automatically transition into hibernate or shutdown, both of which would register as CPU-off by the Surveyor software. So in theory, the observed percentage of computers that are never off should be the same or smaller than the percentage of users who never turn them off. In the survey, among the 90 monitoring participants who reported on the same computer they are currently using and are not missing data for the survey question, 55 percent said they never turned their computers off. However, in the monitoring study, 72 percent of computers are observed to never or almost never be off (less than 5 percent of the time). The difference in reports and observed outcomes is thus much smaller for "always left off" reports than for "never left on."

Table 13: Distribution of Average Percentage of Time CPU is Off in Monitoring Study



The comparison between the monitoring study and the survey data shows that respondents over-report how often they turn off their computers and under-report how often they leave them on. However, the self-report and observed measures are still strongly correlated. Table 14 displays the correlation matrix for the three reported behaviors (how often respondents said they left the computers on, off, or manually put them into sleep mode) and the average time computers were observed to be in those three states in the monitoring study. The *r* statistic shows the direction and strength of the relationship, where 0 means no correlation, 1 means perfectly positively correlated, and -1 means perfectly negatively correlated. As noted earlier, if the *p* value is less than .05, the correlation is considered statistically significant; if not, but *p* is still less than .10, it is considered to be approaching significance. The table shows a very high positive correlation between the two "off" measures: that is, respondents who reported turning their computers off more often do indeed have computers that are off more often, while those who reported turning their computers off less often have computers that are off less often. There is also a strong positive correlation, if not quite as high, between the two "on" measures: that is, respondents who reported leaving their computers on more often are observed to have computers that are on more often, and respondents who reported leaving their computers on less often have computers that are on less often. The correlation for the two sleep measures is also positive, but only approaches significance. As expected, there are also strong, significant negative correlations between survey reports of turning the computer off and the percentage of time computers are on in the monitoring data, and between survey reports of leaving the computer on and the percentage of time computers are off in the monitoring data.

Table 14: Correlation Table for Survey Reports of What State Users Left their Computer in versus Monitoring Study Data on Computer States

Survey self-report	Monitoring study observation: Percent time off	Percent time sleep	Percent time on
Percent times turned off			
r statistic	0.70	-0.03	-0.57
p value	<.0001	0.7597	<.0001
Percent times manually put to sleep or hibernate			
r statistic	-0.23	0.20	0.08
p value	0.0283	0.0645	0.4527
Percent times left on			
r statistic	-0.40	-0.14	0.42
p value	0.0001	0.1847	<.0001

N = 90 monitoring study participants who are using the same computer as in the survey, and answered the survey question.

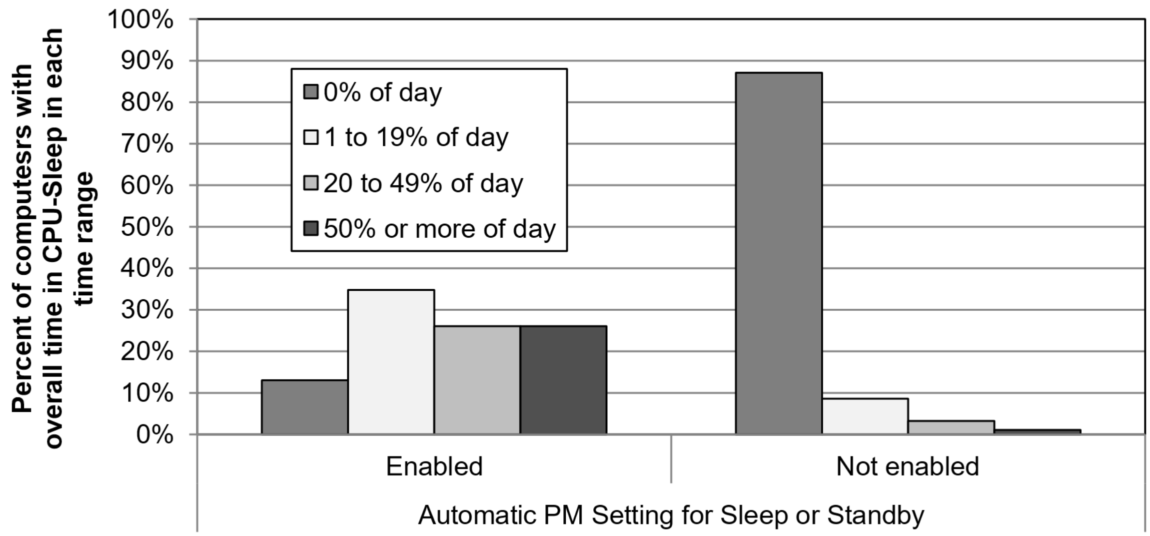
The strong correlation between the survey answers about manual power management and the monitoring study results for CPU states reflects well upon the internal consistency of the 2013 survey results, and perhaps more broadly on survey approaches to this topic. Although there are differences in absolute percentages between the self-report and observations, these appear to be over-estimations in the reports rather than random error. Those who reported good power management behaviors are still relatively more likely to engage in them than those who reported poor behaviors.

Another approach to understanding manual PM is to compare the duty cycle data to the automatic PM settings observed at the beginning of the monitoring period. Verdiem Surveyor cannot determine whether low-power states are due to manual actions on the part of the user or due to automatic PM settings. However, if a PM setting is not enabled, it can be inferred that the low-power state is due to manual actions. The next figures compare the instance of low-power states to the automatic PM settings observed by the researcher during the installation interview. As noted before, it is possible that the automatic PM settings were changed after that interview; however, given the very low rates of changing PM setting that participants reported since 2013, that is unlikely to happen.

Figure 20 shows the overall amount of time computers spent in sleep mode as a function of the initial PM settings observed for standby (Windows XP) or sleep (all other operating systems). The average amount of time spent in sleep mode per day is collapsed into four categories:

none, 1 to 19 percent, 20 to 49 percent, and 50 percent or more. The three cases that are missing data for sleep or standby setting are omitted. The measure of sleep mode provided by Surveyor includes standby and suspend; for ease of writing it is referred to here simply as sleep. As expected, computers without sleep mode enabled are more likely to spend no time in sleep mode than those with sleep mode enabled (87 versus 13 percent). Among computers that do not have sleep enabled, 13 percent spend some time in sleep mode, indicating that those users are taking manual PM steps.

Figure 20: Inferring Manual Transitions to Sleep: Amount of Time Spent in CPU-Sleep by Observed Automatic PM Setting for Sleep

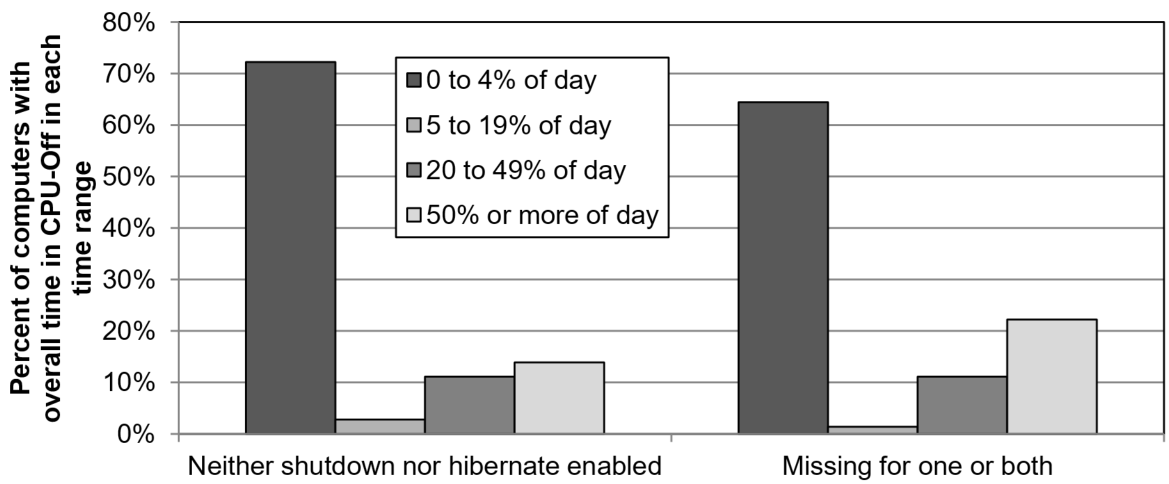


It is notable that even among computers with the sleep setting observed to be enabled, 13 percent spent no time in sleep mode. This result could be due to sleep being set to transition after a long period of being idle, if participants tend to either use the computer again or to manually turn it off before it automatically transitions to sleep. The computers with sleep mode enabled are fairly evenly distributed across the time categories: rather than most of them exhibiting only minimal sleep (1 to 19 percent a day), about half are in sleep mode 20 percent of the day or more, with one-quarter in sleep mode at least 50 percent of the day.

The Surveyor software does not distinguish between off and hibernate; both are coded in the data as CPU-off. As noted earlier, no computers were set to automatically transition to shutdown mode, and only two were set to automatically transition to hibernate mode; those two are omitted from this analysis. However, for several computers, the trained interviewers were unable to locate the proper setting and the information is missing; it is possible (if unlikely) that some of these computers have shutdown or hibernate enabled. For this reason, results are shown separately for the 72 computers that are known to not have either of these modes enabled (either because they are disabled or they are not available) and the 45 computers where that information is missing for one or both modes.

Figure 21 shows the amount of time computers spend off, relative to their automatic PM settings for shut down and hibernate. The minimum category was changed to include computers spending less than five percent of the time off, as many computers exhibit small amounts of CPU-off time, apparently as the result of rebooting. As with sleep, the main finding here is the prevalence of computers that appear to be manually turned off or put into hibernate mode, given the lack of automatic PM settings that could otherwise explain the transition. For computers with neither shutdown nor hibernate enabled, 72 percent are never observed in the CPU-off state, but 11 percent are off 20 to 49 percent of the time and 14 percent are off half the time or more. The numbers are greater for those missing data; some few of those cases may have automatic shutdown or hibernate modes enabled, but it is more likely that those users are also engaging in manual PM steps. In other words, at least 25 percent of users—and probably more—are engaging in manual shutdown or manual hibernate that keeps the computer off for at least 20 percent of the time.

Figure 21: Inferring Manual Transitions to Shutdown or Hibernate: Amount of Time Spent in CPU-Off by Automatic PM Settings for Shutdown and Hibernate



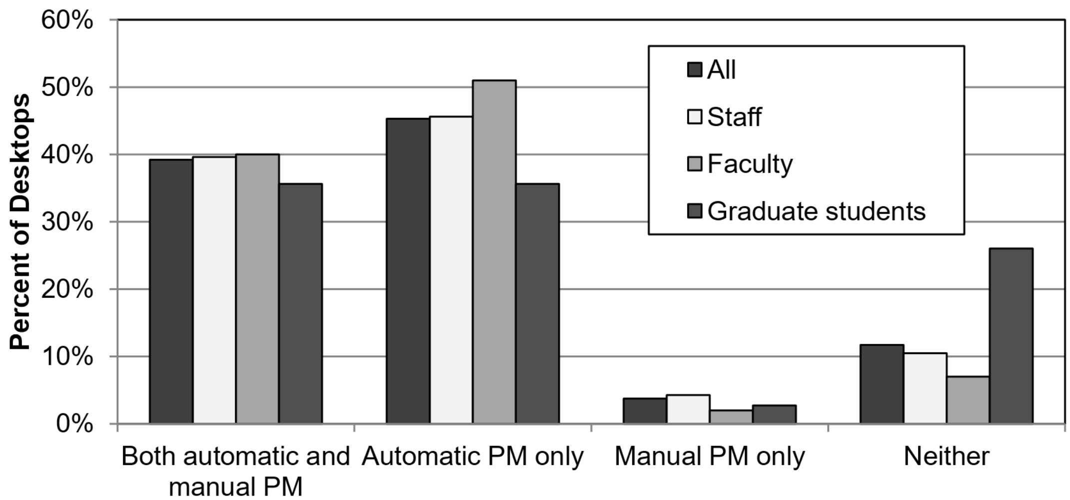
The inferred rate of manual shutdown or hibernate is almost twice as high as the inferred rate of manual sleep. This pattern suggests that when users employ manual steps, they are more likely to shut their computer down at the end of the work day or work week. Since CPU-off uses less power than CPU-sleep, this is arguably a good sign. However, it still reveals room for improvement in manual behaviors, as few users are manually transitioning their computers into sleep mode for briefer periods during the work day. If users incorrectly believe their computers are set to automatically transition to sleep, this might explain the lower inferred rates of manual transitions into sleep.

4.3.7 Combinations of Power Management Modes

It is useful to study automatic and manual power management (PM) behaviors in tandem. In part this is because users may employ one to substitute for the other: for instance, not turning the computer off because they know (or at least, believe) that it will automatically transition to sleep mode soon anyway. Also, as argued earlier, using both PM strategies instead of relying on one alone logically improves the chances of the computer getting to low-power states more quickly and more consistently.

A measure was created from the 2013 survey data to assess which respondents report using one or both PM strategies. Specifically, it combined whether the computer ever goes into any low-power mode (automatic PM) and whether respondents either turn the computer off or manually put the computer into a low-power mode at least 80 percent of the times they leave their computers (manual PM). Thus it is possible to track the reported use of only automatic, only manual, both, or neither. The results for the 572 respondents who were eligible for the monitoring study are shown in Figure 22.

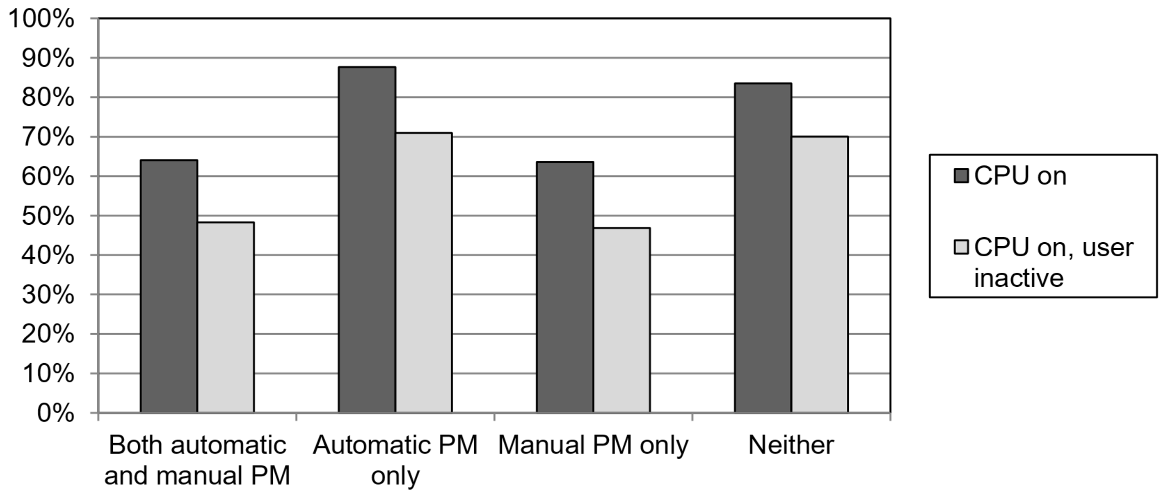
Figure 22: Percentage of Office Desktops in Each Combination of Automatic PM and Manual PM, for Respondents Eligible for the Monitoring Study, by Role



The predominance of the automatic PM strategy is clear. Although the manual PM strategy was sometimes used alone, it was almost always combined with automatic PM, while automatic PM alone was reported by many respondents. There are some significant differences across role groups: graduate students were significantly less likely than faculty members to use only automatic PM and significantly more likely than faculty members and staff members to use neither type of PM.

No comparable measure combining manual and automatic PM can be created for the monitoring study. However, the outcomes of power management—that is, the amount of time the computer spends on, and especially, on while the user is inactive—can be compared to the combined PM behavior reported in the survey (Figure 23). Although using both manual and automatic PM should on average lead to more efficiency than using just one or the other, the results show little difference between those reporting manual PM behaviors and those reporting both manual and automatic PM. Those who reported only using automatic PM have the same average rate of CPU-on and user-inactive time as those who reported using no PM. In other words, the observed rates differ depending on whether respondents report manual PM (compare only manual or both versus neither) but do not differ depending on whether they reported automatic PM (compare only automatic versus neither). This is consistent with the finding thus far that respondents are more accurate about reporting manual rather than automatic PM behaviors.

Figure 23: Percentage of Day the Computer Spends On and On with the User Not Active, by Power Management Behaviors Reported in the Survey



These averages do mask great variation within each group, and the number of those reporting manual PM only is a small group (only 5 people), so those means should be interpreted cautiously. This result should not be interpreted to mean that among those who reported only automatic PM, none actually have automatic PM enabled. Additional analyses show that 31 percent of those who reported both automatic and manual PM and 13 percent of those who reported automatic PM only in the survey do have sleep or standby enabled on their current computers. However, having sleep enabled has little effect on the user-inactive time in the above results. This may be because transition times are set so high (for instance, sleep after one hour) or the user regularly turns off the computer so quickly, that the automatic setting makes little difference.

4.4 Other Factors in Computer Use

As mentioned earlier, one aspect of the current monitoring study that is both unusual and especially valuable is that it combines computer monitoring data with a large amount of self-report data from the earlier survey. Few other monitoring studies collected as much behavioral, demographic, and/or attitudinal data from users. Taken together, these features make the current study a unique contribution to the field. In the 2013 survey, several factors helped to explain variation in self-reports of automatic and manual power management. Those factors are revisited here, to test whether the same variation is observed in the monitoring study data, and to see whether such factors can illuminate the difference between the self-reports and the observational data. The four factors covered here are the operating system of the computer, the participant's role group (staff member, faculty member, or graduate student), the user's gender, and the user's self-reported knowledge of computers and power management. The age of the computers and the age of the participants were also tested, but found to have no significant effect on PM behaviors or outcomes.

4.4.1 Computer Power Modes by Operating System

In the spring 2013 survey, the operating system of a computer was found to be related to the likelihood of users changing and enabling PM settings. First, respondents overall were more likely to report changing the automatic PM settings themselves on Macintosh desktops than on Windows desktops, both at work and at home, although there was no difference for laptops. This finding held true for respondents eligible for the monitoring study as well: 56 percent of those with Macintosh office desktops reported changing the PM settings themselves, compared to 20 percent of those who used Windows desktops.

In addition, survey respondents with Macintosh computers were significantly more likely to report that their computer automatically transitions to a low-power mode. This relationship held true for those eligible for the monitoring study: 83 percent of those using Windows office desktops reported enabling any automatic PM settings, compared to 95 percent of those using Macintosh office desktops. Among the monitoring study participants, the difference is smaller and not significant, but still in the same direction: 81 percent of those using Windows desktops reported enabling any automatic PM settings in the survey compared to 89 percent of those using Macintosh desktops.

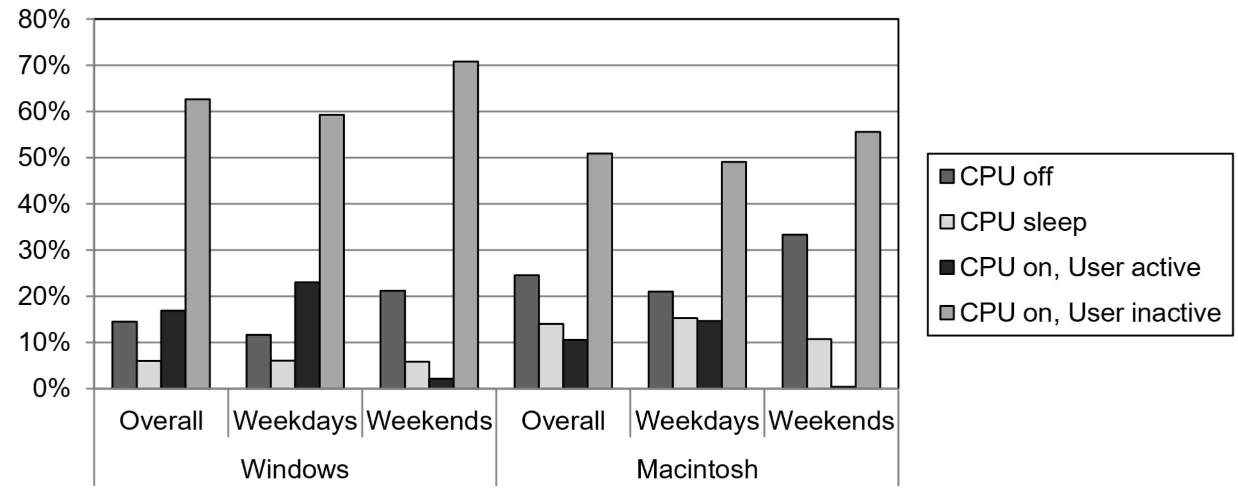
The majority of the computers included in the monitoring study have Windows operating systems (n = 98), but there are enough Macintosh desktops (n = 21) to make a reasonable comparison (Table 7). The difference in observed automatic PM by operating system was much more dramatic in the monitoring study than was reported in the survey. Based on the PM settings recorded by the interviewers, 11 percent of Windows office desktops had some automatic PM enabled compared to 61 percent of Macintosh office desktops.

The reasons for these differences cannot be determined decisively with the current data. It is possible that users find Macintosh settings easier to use, which would be consistent with the differences seen earlier in Windows power plans, possibly due to the internal menus of power plan setups. Alternately, perhaps users (or IT managers) find Macintosh settings harder to use, and are thus less likely to disable them. It is also possible that Macintosh users differ on some other, unmeasured factor. Another possibility is that the operating systems differ in some other way; for instance, in allowing updates and backups while in sleep mode. None of these explanations would account for why these differences affected desktops but not laptops in the 2013 survey. These results suggest that a closer examination of the usability of various PM setting interfaces may be useful.

Turning to the computer monitoring data, the difference in duty cycle by operating system is shown in Figure 24. For the computers in this study, user activity differs significantly by operating system: Windows desktops show a significantly higher rate of user activity than

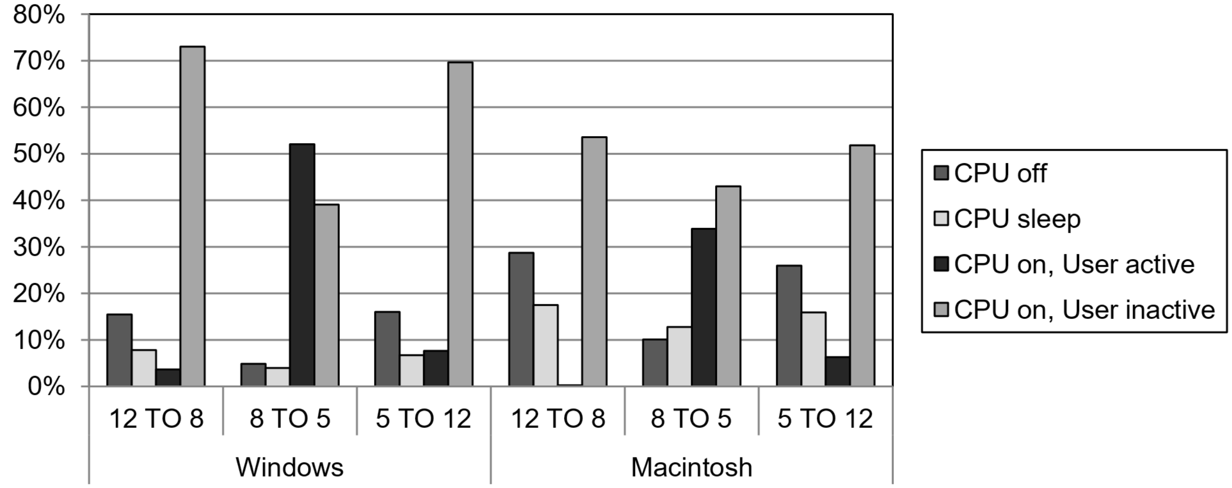
Macintosh desktops, both overall on weekdays and weekends. However, Windows desktops also spend more time on, leading to higher rates of user-inactivity in most early morning and evening time periods. Consistent with their much greater likelihood to have automatic sleep enabled, Macintosh desktops spend slightly more time in sleep mode than Windows on average, although this difference is fairly small and not statistically significant. As seen in earlier results, having automatic sleep enabled does not necessarily translate to long periods in sleep mode.

Figure 24: Percentage of Time Computers Spend in Each State by Operating System, Overall and by Time of Week



As with all office desktops, active use is highest on weekdays during the period between 8 a.m. and 5 p.m. As shown in Figure 25, during this period Windows desktops spend more time in user-active mode than user-inactive, whereas active use for Macintosh desktops in this time period is still less than half the time the computer is on. However, the difference in user-inactive time during the work day—39 percent for Windows and 43 percent for Macintosh—is not statistically significant. In other words, Windows office desktops are used almost as efficiently as Macintosh desktops during the work day, but substantially less efficiently in the evenings and weekends.

Figure 25: Percentage of Time Computers Spend in Each State by Operating System, by Time Period on Weekdays



4.4.2 Computer Power Modes by Role

In the 2013 survey, among respondents eligible for the monitoring study, staff members were less likely than other groups to report changing their power management settings (Figure 12), but equally likely to report that automatic PM was engaged (Figure 11).

In the monitoring study, faculty members are significantly more likely to have any automatic PM enabled (47 percent) compared to staff members (15 percent) or graduate students (20 percent). Almost all those using automatic PM have only sleep mode enabled, with the exception of one faculty member and one graduate student who also have hibernation enabled.

Figure 26 shows the overall duty cycle results across role groups. There are substantial differences by role, especially between staff members and the other groups. Staff desktops exhibit significantly more time in user-active mode than faculty or graduate student desktops. Staff desktops also spend more time on than faculty desktops and less time off or in sleep mode than graduate student desktops. Staff members' somewhat higher rate of user-inactive time is not statistically significant for these overall measures. There are no significant differences between faculty members and graduate students, although faculty computers' slightly higher rate of CPU-off approaches significance (at $p < .10$).

Figure 26: Percentage of Time Computers Spend in Each State by Role Group

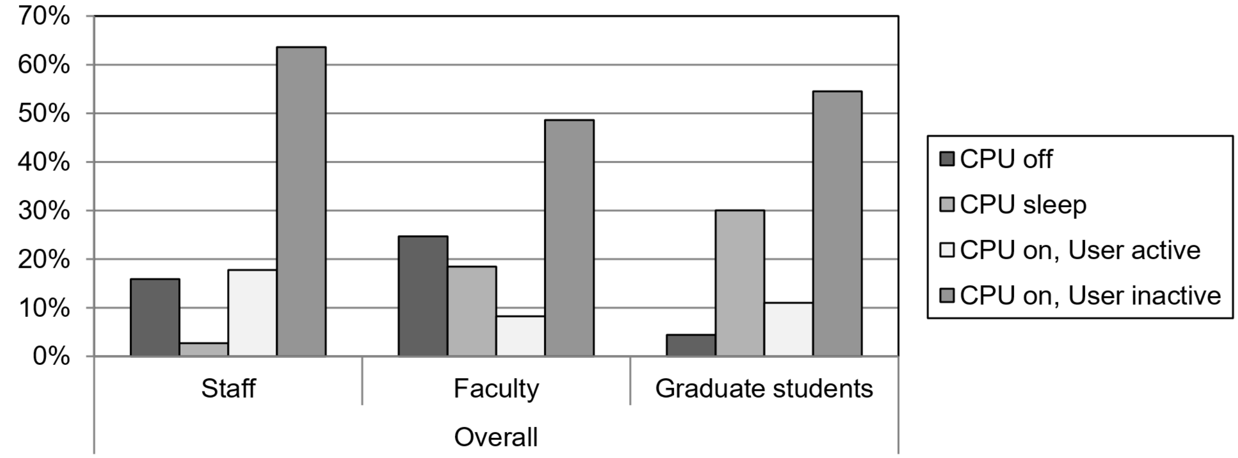
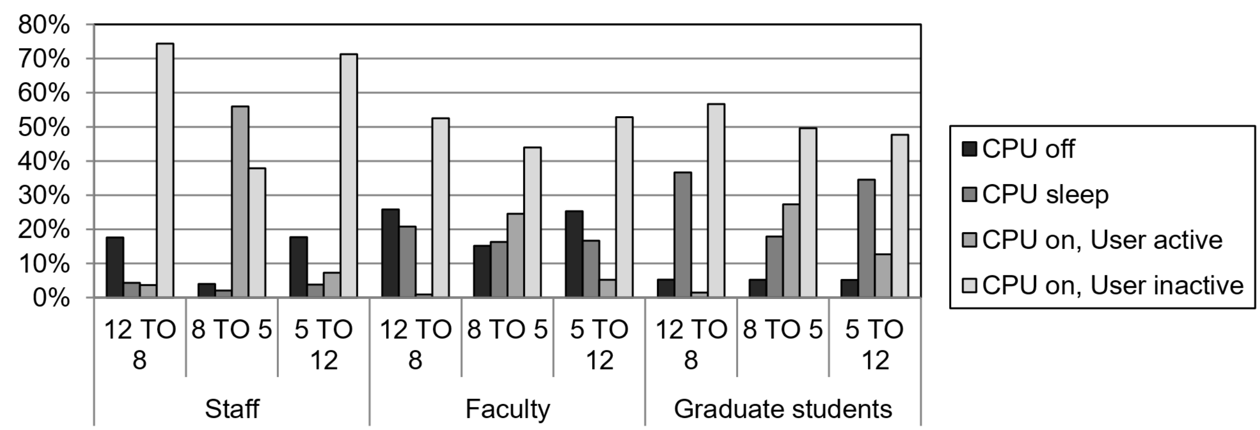


Figure 27 shows variation in computer use by role group during time of day, for weekdays only. Staff desktops are the only ones that spend more time in user-active mode than in user-inactive mode during standard work hours (8 a.m. to 5 p.m.). Many other differences between staff computers and others are significant as well. In particular, during standard working hours during the week, staff desktops are more likely to be in user-active mode than desktops used by the other two groups, and less likely to be in sleep mode and more likely to be on than faculty desktops. During evening hours on weekdays, staff computers spend more time in user-inactive mode than the other two groups and are less likely to be off or in sleep mode than graduate student computers. Again, faculty and graduate student computers do not show significant differences.

Figure 27: Percentage of Time Computers Spend in Each State by Role Group, by Time Period on Weekdays



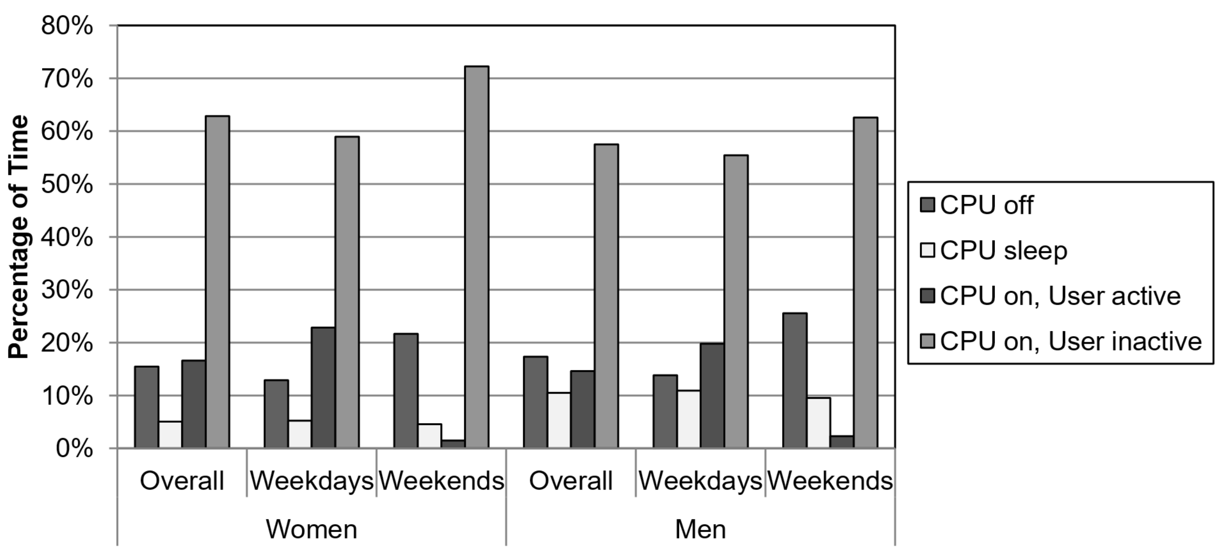
In sum, staff members use their computers more efficiently during the work day—that is, lower rates of user-inactive—largely because they use their computers more than faculty members or graduate students do. However, because staff computers are more likely than those of other groups to stay on in the evenings and weekends, their computers spend more time total in the least efficient state. This is consistent with earlier findings that staff members are less likely to have control over or to change their automatic PM settings.

4.4.3 Computer Power Modes by Gender

In the 2013 survey, women reported substantially higher rates of using automatic power management than men. The same was true for the 123 monitoring study participants who answered that survey question for their primary office desktop: 94 percent of women reported at least one automatic PM setting enabled compared to 70 percent of men. Based on the PM settings of their current desktops observed in the monitoring study, both men and women over-reported their PM enabling rates, but women did so more than men. At the beginning of the monitoring study, 26 percent of men and 15 percent of women were observed to have some automatic PM enabled. This gender difference in the monitoring study is not statistically significant, but it hardly supports the opposite conclusion from the survey self-reports, that women are more likely than men to enable automatic PM.

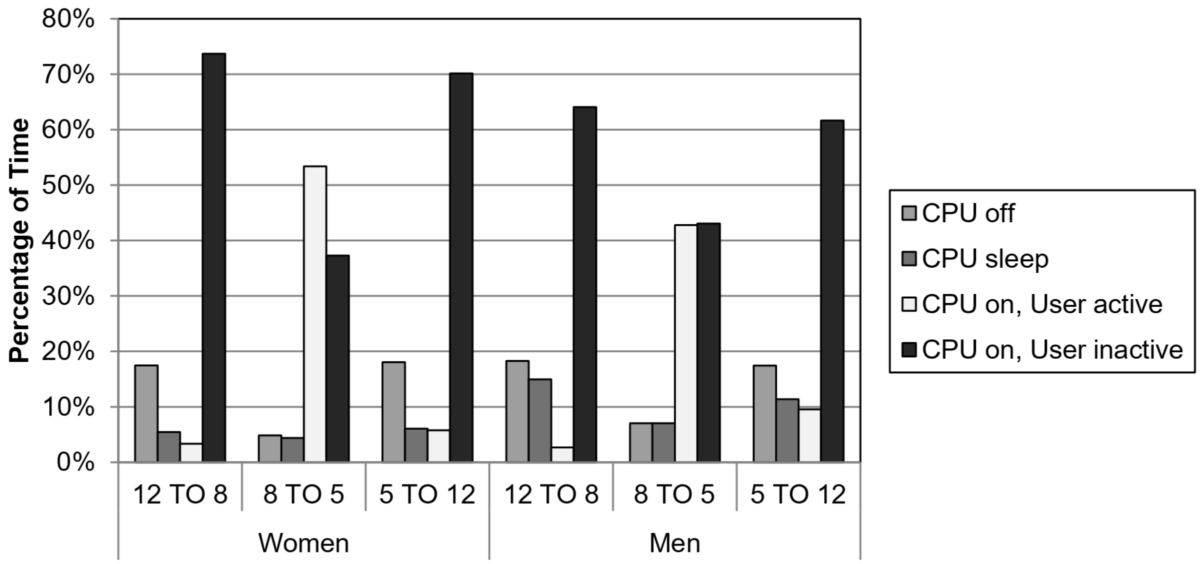
The duty cycles for men and women on average and by weekday and weekend are shown in Figure 28. Men's computers spend slightly more time in sleep mode, on average, than women's computers. This difference is not large or consistent enough to be statistically significant.

Figure 28: Percentage of Time Computers Spend in Each State, by Gender and Time of Week



Broken down by time of day, there are a few significant gender differences (Figure 29). Men exhibit significantly higher rates of CPU-sleep in the evenings on weekdays than women do, while women exhibit higher rates of user activity during the workday hours and slightly lower rates of user activity in evening hours on weekdays. Women's computers are somewhat more efficient during the standard workday, with a better ratio of user-active to user-inactive time. However, results from the monitoring study do not support the strong differences in reporting by gender from the survey.

Figure 29: Percentage of Time Computers Spend in Each State by Gender, by Time Period on Weekdays



The gender pattern seen in the previous two figures may partially explained by gender differences in role group: more of the staff members in this sample are female (64 percent) than is found for faculty members (42 percent) or graduate students (20 percent). Put another way, women are more likely to be staff members (86 percent) than men are (65 percent).

The finding that women report higher rates of automatic PM than men but actually exhibit similar rates, perhaps even lower, indicates that men are somewhat more accurate at reporting their automatic PM settings than women are. The gender differences in reporting automatic PM—and especially in their accuracy of reporting—may be related to the last factor, computer knowledge.

4.4.4 Computer Knowledge

In the spring 2013 survey, respondents were asked to rate their knowledge of computers in general and their knowledge of power management settings. Response scales for both questions ranged from zero to ten, where zero means a beginner, ten means an expert, and five is the midpoint. The overall mean scores of self-rankings for the survey respondents eligible for the monitoring study are 7.0 for knowledge of computers and 6.5 for knowledge of PM. The two types of knowledge are strongly positively correlated, as expected (r = .64).

The survey results showed a strong negative relationship between knowledge of computers and PM and reports of enabling automatic PM: those who enabled automatic PM generally had lower self-reported knowledge of computers and PM than those who reported that all automatic PM was disabled. This initially seemed to suggest that computer experts were actively disabling automatic PM on their computers, perhaps because they were prioritizing performance over energy savings; however, the monitoring study results below tell a different story.

The knowledge scales are collapsed into two categories at the approximate midpoint: those with self-ratings up to 6 are considered "low" on knowledge while those with self-ratings of 7 or higher are considered "high" on knowledge. Among survey respondents eligible for the monitoring study, those with higher knowledge were significantly less likely to report any PM settings being enabled on their primary office desktop (Table 15). The same direction of difference is seen when limiting the analysis to the smaller number of participants in the monitoring study, although this result is not statistically significant for computer knowledge, The difference for PM knowledge among monitoring study participants is even larger than for the sample of eligible respondents, but only approaches statistical significance.

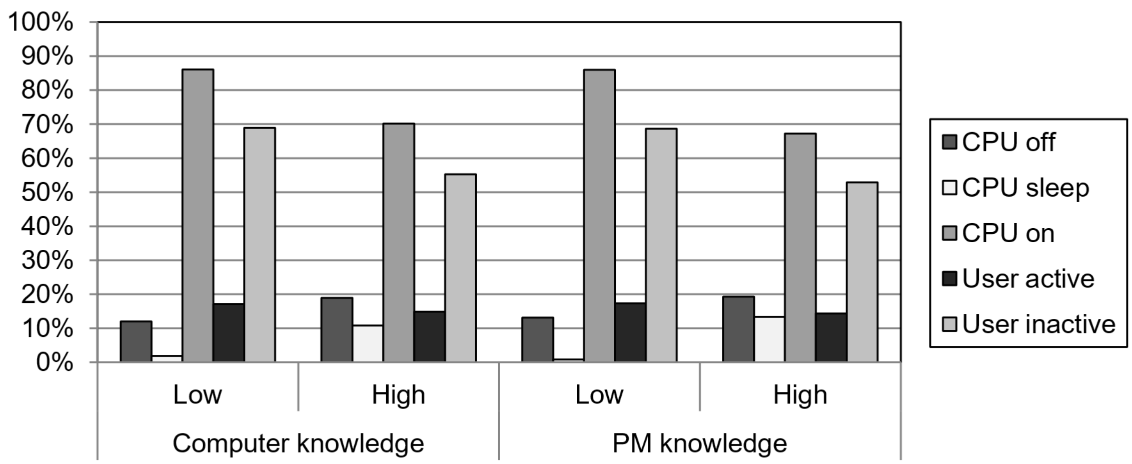
Table 15: Power Enabling by Knowledge, Comparing Survey and Monitoring Study

		Reported automatic PM enabled in 2013 survey		Any PM enabled in 2014 monitoring study	Sleep setting in 2014 matches report from 2013 survey
		Eligible for monitoring study	Monitoring study participants		
Computer knowledge	Low	90%	89%	13%	34%
	High	82%	80%	25%	43%
	N	541	123	125	95
	p value	0.0152	0.1839	0.0979	0.3852
PM knowledge	Low	88%	91%	9%	24%
	High	82%	79%	30%	51%
	N	539	122	124	94
	p value	0.0306	0.0622	0.0027	0.0090

The third column of Table 15 shows whether any automatic PM settings were observed to be enabled at the beginning of the monitoring study. Here, the opposite relationship is shown: those with higher knowledge are more likely to have PM enabled; this is significant for PM knowledge and approaches the significance criterion of $p < .05$ for computer knowledge. The last column reduces the sample even further to monitoring study participants who are using the same computer as in the survey. Those with higher knowledge of PM show significantly higher rates of a positive match between whether they reported sleep being enabled in the survey and whether sleep mode is observed to be enabled in the monitoring study.

Observed duty cycles also differ by expertise (Figure 30). In this figure, CPU-on is shown for comparison with the other two states (off and sleep), but it is also broken into its two component states: on-user active and on-user inactive. Computers of participants with higher knowledge of both types show significantly more time spent in CPU-sleep, less time spent in CPU-on, and less time spent in user-inactive. For PM knowledge, those with higher knowledge spent less time in user-active mode as well (possibly because they are more likely to use more than one computer). Furthermore, the correlations between the observed measures of CPU time off, on, and in sleep mode and the survey measures of how often respondents leave their computers on, off, or in manual sleep (Table 14) are stronger for those with higher expertise in computers and PM (results not shown). For instance, the correlation between the frequency of turning the computer off reported in the survey and percentage of time spent in CPU-off state observed in the monitoring study is .64 for those with low knowledge of PM and .86 for those with high knowledge of PM. Also, the survey and monitoring study measures of time spent in CPU sleep are significantly correlated for participants with higher knowledge of computers and PM but not for those with lower knowledge.

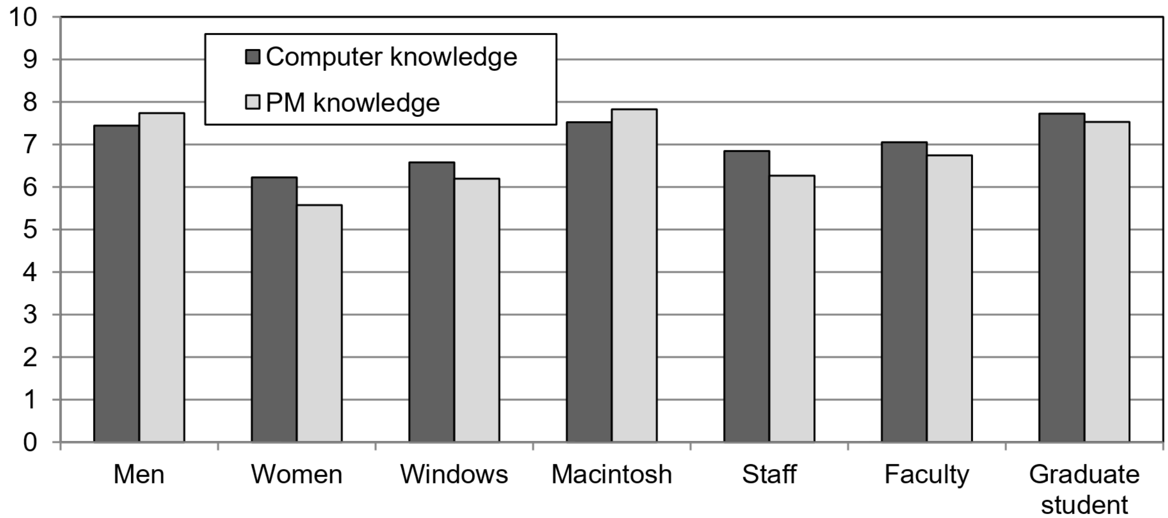
Figure 30: Percentage of Time Computers Spend in Each State, by Self-reported Knowledge



Overall, more expert computer users do display more energy-efficient computers. This is consistent with the idea that users are more likely to enable automatic PM settings if they have a better understanding of PM menus and power plans, and possibly a better understanding of the general principles of power management states as well.

In sum, the findings for knowledge of computers and knowledge of PM suggest that computer experts' lower rate of reporting PM enabling in the survey was likely due to higher accuracy, rather than to any reluctance to use low-power modes. Indeed, computer experts appear to be more likely to use automatic PM than those with lower knowledge. This corresponds to findings for gender, operating system, and role group described earlier. As shown in Figure 31, the average self-ratings for knowledge are significantly higher for men compared to women, and for Macintosh users compared to Windows users. Among role groups, self-ratings of knowledge are significantly higher for graduate students than for staff members and faculty members. These differences in expertise across groups match the direction of differences in their propensity to use power management.

Figure 31: Average Self-Reported Knowledge for Groups, for Respondents Eligible for the Monitoring Study



Some of the factors tested here may be acting as proxies for others in their relationships to PM behaviors. For instance, perhaps any observed gender differences in PM are completely due to differences between staff members and faculty members, and the gender effects would disappear if role group were considered at the same time. Given the strong effects of knowledge on PM behaviors and the strong relationships between knowledge and these other factors, it is likely that knowledge of computers—and especially of PM—is a driving force behind some or all of these other relationships. Testing the relative impact of computer knowledge, gender, role group, control over computers, and operating system may shed further light on these issues. However, such an approach requires multivariate analyses and is beyond the scope of the current report.

CHAPTER 5: Conclusions

The first section of this chapter summarizes the results from a monitoring study conducted by the California Plug Load Research Center at the University of California, Irvine in the spring of 2014. In the second section, occasioned by the relationship between this study and the UCI survey study (Pixley et al. 2014), comments are presented on how the two sets of results relate to one another.

5.1 Monitoring Study Results

This monitoring study examines computer use and power management by 125 staff members, faculty members, and graduate students associated with the same university. It includes questionnaire and observational data for 125 office desktops, and duty cycle (hours of use) data for 119 of them.

Participants for the monitoring study were selected from a pool of more than 2,000 respondents to an online survey conducted by the same UCI research team in the spring of 2013. That survey included detailed questions on all the desktops and laptop computers used by respondents, including automatic and manual power management activity and hours of use. It also included questions about factors that might affect power management behaviors, such as demographics and self-rated computer knowledge. Unlike most computer monitoring studies, this one accesses a wealth of other information about the users to help understand variations in the duty cycle data. In addition to linking monitoring study participants' current data to their own responses in the earlier survey, the survey provides a large comparison group. This group includes 572 respondents who met the same criteria for eligibility in the monitoring study: other staff members, faculty members, and graduate students at the same university who are also primary or sole users of at least one office desktop.

Data collection for the monitoring study was conducted from late March to late June 2014. At the initial research visit to participants' offices, participants filled out a questionnaire updating selected information from the survey. In addition, researchers recorded the current automatic power management settings from the office desktop and installed the monitoring software, Verdiem Surveyor Version 6.

The 125 monitoring study participants include 96 staff members, 19 faculty members, and 10 graduate students. The majority are between 25 and 64 years of age; 57 percent are female. The majority of desktops studied used a Windows operating system (82 percent); 18 percent used a Macintosh operating system. Other operating systems are not supported by the monitoring software.

The Verdiem Surveyor software transmitted usable monitoring data for 119 desktops. The majority of computers supplied 35 days of data; the minimum number of days was 20. Multiple days of data are combined for each participant to produce individual averages: for example, that user's average Monday or average weekday. Three states for the CPU are drawn from the duty cycle data: off (including hibernate), sleep, and on. Time spent in CPU-on mode is divided into user-active, defined as any 15-minute period with mouse or keyboard input, and user-inactive.

Computers in this study spent an average of 16 percent of the day in user-active mode, with higher rates on weekdays (22 percent, or 5.2 hours) than on weekends (2 percent, or 0.4 hours). Participants exhibited lower use of their office desktops if they had reported using multiple computers in the spring 2013 survey, including other office desktops as well as laptops and home desktops. On weekdays, participants with no other computer used their office desktop an average of 59 percent of the period between 8 a.m. and 5 p.m., compared to 42 percent for those who reported using two or more other computers.

Occupational roles make a difference. Staff members exhibit significantly more hours per week of active use on their office desktop (29.8 hours) than faculty members (13.8) or graduate students (18.5). Faculty members and graduate students are also more likely to use other computers, which probably explains some of the difference. The active use hours observed in the monitoring study were very close to the hours of use participants reported in the survey for their primary office desktop.

According to the duty cycle data, most computers are left on for a large percentage of the time they are not being actively used. Overall, computers spend an average of 16 percent of the day off, 7 percent of the day in sleep mode, and 77 percent of the day on. However, computers are only actively used for one-fifth of the time they are on: on average, computers are on and inactive for 61 percent of the day.

Duty cycle results show greater energy efficiency on weekdays than weekends. Computers are on for less time on weekends (79 percent versus 70 percent), but they are used so little that they still show more time in user-inactive mode, that is, on but idle (68 percent versus 57 percent). The percentage of time spent in sleep is about the same: 7 percent for weekends and 6 percent for weekdays.

The average times can mask the fact that most computers are concentrated at one end of each scale rather than being evenly distributed around the mean. The majority of computers (72 percent) are off less than 20 percent of the time, and most of those are off for only a few minutes a day, while 73 percent of computers are never in sleep mode.

The researchers observed the automatic power management settings that were enabled on participants' office desktops at the beginning of the monitoring study. There is no certainty that these settings were not changed during the study period. However, as only eight percent of participants reported that they or someone else changed the PM settings in the since the survey the previous spring, it is likely that most were stable. The PM settings show that 20 percent of computers have sleep or standby enabled, including 2 percent of computers that also have automatic hibernation enabled. However, 30 percent of the computers set to automatically transition to sleep or standby have transition times set at longer than 30 minutes, with three computers set to transition after three hours or longer. Macintosh computers can be set to transition automatically to shutdown at a preset time, but none of the computers in this study had this option enabled. If automatic PM is defined as including automatic transitions to sleep or standby, hibernation, or shutdown, 20 percent of these computers have automatic PM enabled. It is far more common to have low-power modes enabled for monitors (83 percent) and hard disks (54 percent).

In addition to automatic PM settings, users can also save energy by taking manual PM steps: specifically, turning the computer off or manually putting it into sleep or hibernate mode. Although the Surveyor monitoring software did not distinguish between manual and automatic transitions, some inferences about manual PM use can be made. For users who do not have automatic sleep enabled, any time their computers exhibit sleep mode is evidence of manually-activated sleep, a type of manual PM. The same is true for any time the computer is off, for users who do not have automatic hibernate or shutdown enabled. The results show that few users who have automatic sleep disabled are substituting with manual steps; only 13 percent of these computers show any time spent in CPU-sleep mode. The evidence is stronger for manual shutdown or hibernate: at least 25 percent of users are engaging in manual shutdown or manual hibernation that keeps the computer off for at least 20 percent of the time. Indeed, among desktops without automatic shutdown or hibernate enabled, 14 percent are off for at least 50 percent of the time.

The office desktops examined in this monitoring study unnecessarily consume a significant amount of energy while idle instead of conserving power in sleep, hibernate, or shutdown mode. This study underscores other monitoring studies that have found low rates of power management enabling for workplace desktops. Still, some computers do spend time in low-power modes, and the duty cycle data and power management settings tell only part of the story. Additional insights can be gained by looking at these results in the context of other information collected in the monitoring study and in the spring 2013 survey.

5.2 Relationship to Survey Results

Two general topics are important in relating the monitoring study results to the survey results. First, the discrepancy on automatic PM is greater than for most surveys and survey results are in agreement with the monitoring results in many ways, which suggests some other factors are affecting the overreporting of automatic PM in the survey. Second, it is argued here that this discrepancy is due to user confusion about PM settings, which is evident throughout these findings.

5.2.1 Differences between Self-Reports and Observed Measures of Automatic Power Management

The self-reports of PM behavior from the survey do correspond to the observed data from the monitoring study in important ways. For one thing, monitoring study participants were fairly accurate at estimating their manual PM behavior. In the survey, respondents were asked how often, when they left their computer for several hours, they turned it off, left it on, or manually transitioned it to sleep or hibernate. Although participants overestimated how often they turned their computers off, these answers are significantly correlated to the monitoring data collected for their office desktops. Also, as mentioned earlier, participants gave reasonably accurate accounts of the number of hours they actively used their computer, both on a day-of-the-week basis and for the overall week. Even for automatic PM settings, the responses are somewhat related: participants who reported that settings were enabled in the survey were more likely to show automatic PM enabled in the monitoring study than those who did not.

Despite the correlations across studies, the gap between reported automatic PM and observed automatic PM is large, and suggests the possibility that users believe their computers are set to be more energy efficient than they really are.

A more thorough discussion of survey errors may be useful. Studies using surveys must rely on what respondents notice, understand, remember, and decide to report. The power management settings of a respondent's computer may be especially difficult to obtain from surveys due to problems at any one of these steps. In this case, there are two likely reasons for the discrepancy between the survey reports of automatic PM settings and the PM settings observed in the monitoring study.

The first likely reason is a reporting bias, affecting what respondents decide to report: that is, respondents knew that they did not have PM enabled on their computers but reported that they did anyway. This could be due to a social desirability bias, if they wanted to make themselves look better to the researchers, or to survey demand effects, if they wanted to be a "good subject" and say what they believed the researchers wanted to hear.

The second likely reason is respondent observation error or recall error: that is, respondents were truthfully reporting what they believed about their computers, but were incorrect about whether their computers ever automatically transitioned to low-power modes. There are many reasons respondents might believe they are employing energy-saving automatic PM strategies when they are not. Respondents may never have looked up the settings, or may have last seen them so long ago that they cannot remember them. In survey research, saliency—the distinctiveness and importance of an event--is known to increase the chances of respondents having noticed the event and reliably recalling it later. Even if respondents have seen their PM settings, that event was probably not especially salient to them, and much time may have elapsed since then. For this reason, the survey did not ask what the specific PM settings were, but asked respondents to identify states such as sleep or hibernate or off based on how the computer behaves after it has been idle: in particular, whether programs are still open and how long it takes to resume. Although these events are recent and tangible, they may also not be very salient to many respondents. Also, this requires respondents to notice, interpret, and remember many details such as how long it takes the computer to resume operation, and to remember details such as whether programs and files are usually still open. The subjective experience of waiting for the computer to resume may make the time delay seem longer than it is. They may also forget turning their computer off, or not realize that someone else has done so, and therefore believe that their computer is set to automatically transition to hibernate or shutdown mode. Users could similarly confuse times when they manually put their computer into sleep mode as indicating that the computer automatically transitions to sleep mode. In all these examples, respondents would believe they are employing energy-saving automatic PM strategies that they are not.

Both sources of reporting error—biased responses and recall errors -- probably affected the survey results. The bias argument is tempting: from the perspective of trying to encourage more enabling of automatic PM settings, it would be reassuring to find that respondents over-report automatic PM use because they perceive it as socially desirable. However, there is reason to believe that reporting error may be more problematic than reporting bias. The wording of the survey questions and the introductory materials was deliberately designed to be neutral in tone, to reduce demand effects and other biases. Social desirability bias and demand effects are most problematic in face-to-face interviews, and least problematic in self-administrated surveys. The 2013 survey was online, self-administered, private, and confidential. These factors all reduce the likelihood of reporting biases, as they remove the social interaction with the interviewer and reduce the risks of reporting socially undesirable behaviors. However, especially for anonymous online surveys, self-serving biases can result from respondents' own skewed self-perceptions: that is, they honestly believe that they behave better than they actually do.

Although there are no established estimates for how strongly social desirability might affect reporting of computer PM, the level of discrepancy for automatic PM reports seen in this study far exceeds the effect of social desirability found for reporting other pro-social activities, suggesting alternate explanations. For instance, there is a well-known bias in over-reporting voting, but even those accuracy rates are calculated to be much higher than those seen here (for example, 80 percent accuracy found by Belli et al 1999).

5.2.2 Knowledge and Confusion about Power Management

One factor that may affect use of power management is users' control over their office desktops. Among the 572 survey respondents eligible for the monitoring study (a group used as a comparison for the 125 monitoring study participants), just under half reported having control over the automatic PM settings on their primary desktops; 21 percent said they had no control and 30 percent didn't know. Staff members were much less likely to report controlling their settings than were faculty members or graduate students. Respondents who controlled their settings in the absence of any office policy were the most likely to report changing the PM settings (55 percent), followed by those who controlled the settings but followed a policy (32 percent), while only 5 percent of those reporting they did not have control had ever changed the settings. Similar results were found in the survey for the subsample of monitoring study participants.

In the monitoring data, participants who had reported changing the PM settings on their primary office desktops displayed significantly higher rates of CPU-sleep, lower rates of CPU-on, and lower rates of user-inactive. That is, on average, users who controlled their settings used their computers more efficiently. Unfortunately, the majority of office desktop users at the university are staff, and staff members are least likely to report having control over their PM settings. It is not clear who does control these settings, although it is probably a supervisor or IT managers. In the 2013 survey, 19 percent of eligible respondents reported that someone else had changed or may have changed the settings on their primary office desktop, which might refer to IT managers or to others who share the computer. However, it was much more common for respondents to report that nobody had changed the settings (35 percent) or that they didn't know (21 percent).

Users' confusion over automatic PM settings seems to extend beyond not knowing whether they have control or who might have changed the settings; many also seem confused about whether any PM settings are enabled at all, and if so, which ones. The 2013 survey asked respondents to report on whether their computers ever transitioned into sleep, hibernate, or shutdown modes, based on descriptions of how the computer acts when awaking from each mode. As noted earlier, the majority of respondents reported that some automatic PM setting was enabled. Among monitoring study participants, 84 percent reported at least one setting enabled on their primary office desktops, with 76 percent reporting sleep or standby. The spring 2013 survey reports thus provided a substantially higher estimate of the automatic PM enabling rate than what was shown from the automatic PM settings observed in the monitoring study. This discrepancy mirrors many other studies in the literature, where direct monitoring of computers often shows low enabling rates (for example, Barr et al. 2010; Roberson et al. 2004) while surveys can suggest moderate or even high levels of enabling (Tiedemann et al. 2013). The benefit of the current research design is that it is possible to compare self-reports and observations from the same people—and in many cases, for the same computers—to try to better understand when and why these sources of data can differ. Self-reports represent, after all, the users' perspectives and knowledge, which help explain the users' behaviors, which in turn produce the duty cycle results.

Several findings from the monitoring study, especially in conjunction with the earlier survey results, are consistent with the idea that users are confused by automatic PM and may not realize that their automatic PM settings are as inefficient as they are. There are problems with user interfaces and power plans, as well as variation in PM use by computer knowledge. These ideas build on the few earlier studies that address behavioral issues: for example, 1E and the Alliance to Save Energy (1E 2009) found that one-third of their U.S. respondents did not know how to change their power settings, and Chetty et al. (2009) also found user confusion about power management in the households they studied.

In current and recent Windows operating systems, the user interface for changing PM settings involves various power plans (also called power schemes or power profiles). Power plans could affect user PM behaviors, but have been little studied by other researchers on this topic. The presentation of power plans to users seems intended to facilitate power management, by offering users an easy choice between two or more pre-set bundles of automatic PM settings. However, this approach may not have the desired outcomes. The research team does not have access to the specific default settings for every power plan included in this study, but presumably most or all the default plans involve enabling sleep mode. Clearly, many default power plans have been modified, given that only 20 percent of office desktops in the monitoring study have sleep mode enabled. Having selected a power plan with a name like "balanced" or "energy saver" may mislead users into thinking their settings are more energy efficient than they are, even after modification.

Some power plans or PM interfaces seem to do better than others. There is little variation across computers using a range of Windows power plans in the small amount of CPU-sleep time and high amount of user-inactive time observed. However, the “Dell” plan shows the lowest level of user-inactive tie and highest level of sleep time, followed closely by Macintosh computers. A further examination of how these power plans or user interfaces differ may help give insight into these differences.

Another confusing aspect of the user interface for automatic PM settings is which settings are available, and the extent to which available settings are easy to access and notice. Sleep (or for Windows XP, standby) is universally available, and in most cases is the easiest setting to locate, along with the setting for putting the display or monitor to sleep. However, automatic transitions into hibernate or shutdown, which would result in greater energy savings than sleep mode, are not available on many operating systems. Further, even when those settings are available, they are usually buried within an “advanced settings” menu containing many other settings and options that most users would not understand and that may be intimidating.

Conducting the monitoring study revealed how difficult some of these settings are to find. The interviewers had extensive training on looking up and recording PM settings on all the relevant operating systems, and were tested on this skill prior to collecting any data. Even so, the interviewers were unable to locate the hibernate settings on 26 percent of computers or the shutdown settings on 18 percent of computers, and incorrectly marked those settings as unavailable. Most average users would probably give up searching for a setting on their computer before these trained interviewers, suggesting that many users may not realize these settings are available options.

Additional research into how users interact with PM setting menus may help to develop interfaces that are easier to use, and encourage the use of lower-power automatic modes, especially hibernation for Windows computers and shutdown for Macintosh computers. Realistically, if users have to search online for directions on how to find and engage their settings, they are unlikely to engage them. Many users may not be sufficiently interested in or knowledgeable about automatic hibernate or shutdown to actively seek out those options. However, putting them on the main menu of the power plan window and including them as default settings may convince users that engaging such settings is normal and expected, instead of a complex task best left to the experts.

Another result supporting the idea that users are confused by their automatic PM settings is the relationship between PM settings, PM reporting, and computer knowledge. In the 2013 survey, respondents were asked to rate their knowledge of computers overall and their knowledge of PM, both using a scale from 0 to 10. In the survey results, respondents who rated themselves more highly on expertise were less likely to report engaging automatic PM. Looking only at the survey data, it seemed that computer experts might be prioritizing performance over energy saving.

In the monitoring study, the relationship between expertise and PM engagement is the reverse of what was seen in the 2013 survey. When their desktops were observed in 2014, participants who had rated themselves highly on PM knowledge in the survey were more likely to have automatic PM settings enabled than those who rated themselves lower on the scale. They are also somewhat more likely to have a match between whether they reported that sleep was enabled in the survey and whether sleep was observed to be enabled on their desktop in the monitoring study; in this small sample, though, this finding only approaches statistical significance. The same types of differences were seen for self-rated general computer knowledge, although they were not large enough to be statistically significant. Furthermore, according to the duty cycle data, the computers of more knowledgeable users spend more time in sleep mode, less time in CPU-on mode, and less time in user-inactive mode. Overall, this suggests that more expert users are not only more likely to enable automatic PM settings, but to report their use more accurately.

Accuracy rates in reporting power management settings—that is, whether the self-reports in the survey matched the observed settings in the monitoring study— were also higher for participants who had reported in the survey that they had control over the power settings of their primary office desktop compared to those who did not. Accuracy rates were also higher for those who had changed the power settings on their primary office desktop in the survey, or reported having done so since the survey.

The findings for computer knowledge and control over power settings help shed light on some other differences in PM reporting and behavior. In the survey, women reported much higher rates of automatic PM than men did, whereas there was no gender difference in actual power settings or computer states observed in the monitoring study. If anything, men's rates of enabling sleep and time spent in CPU-sleep mode were a little higher than those for women (if not significantly so). This gender difference may be at least partially explained by the fact that women rate themselves lower in computer knowledge and PM knowledge, on average. Women in this sample are also more likely to be staff members, who on average reported less control over their computers, while men make up a larger proportion of the faculty members and graduate students.

The over-reporting of automatic PM points to problems beyond the low use of automatic settings. If users believe their automatic PM settings are engaged when they actually are not, they may be less responsive to campaigns to encourage or educate them about power management, believing they have already addressed the problem. Such users may also be less likely to pay attention to manual PM steps. Indeed, the most common reason respondents gave in the survey for leaving their office desktops on was that their desktops were set to automatically transition to a low-power mode anyway.

At the same time, these participants' erroneous belief that their power settings are enabled could be seen as an opportunity, as they represent a large group of computer users who are apparently willing to use automatic PM but currently are not doing so. In the 2013 survey, over half of respondents who reported changing their PM settings gave "to save energy" as one of the reasons for doing so. This suggests that users value the goal of saving energy. Even a cynical interpretation that this answer was affected by social desirability bias suggests that these users view saving energy as socially desirable.

5.3 Overall

The monitoring study results show a low rate of enabling for automatic power management, along with inefficient duty cycle, suggesting low rates of manual power management as well. The low rate for automatic power management observed in the 2014 monitoring study contrasts with a much higher rate reported by the same respondents in the 2013 survey. The reasons for the over-reporting have been addressed. Comparing the monitoring results to the survey results was enhanced by the fact that the survey provided much more information about the users than the monitoring study itself could have.

The tentative conclusion from the monitoring study and survey, taken together, is that differences between self-reported automatic PM settings and observed PM outcome suggest a substantial amount of user confusion about power management, related to real and perceived problems of complexity, control, and competence. Many respondents have little control over the PM settings on their office desktops, have never changed them, and do not feel they know much about power management or computers more generally.

There are two interrelated challenges.

First, users with less knowledge about computers or power management exhibit less efficient power management behaviors. More efforts at education might help. However, making automatic and manual power management options intuitive and easy to use may be even more useful: the current complexity of the user interfaces and the great variety across systems makes it harder for users to save energy, not easier.

Second, even those users who are knowledgeable about power management and have control over their own settings have enabling rates that are wasteful. The reasons respondents gave in the 2013 survey may help explain why knowledgeable users may deliberately disengage power management, and thus which technical problems to solve to change their minds: slow restart times, problems with remote access while in low-power modes, and problems with automatic backups and updates in low-power modes.

Based on the results of these two studies of user behavior, both of these problems may be substantially improved by providing smart power management options that increase ease of use for confused users and allow more flexibility of use for experts.

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GLOSSARY

Term	Definition
AC	alternating current, typically 110-120 volts
ACEEE	American Council for an Energy-Efficient Economy
ACPI	Advanced Configuration and Power Interface, an industry-wide open standard for managing computer devices and components, including power management
CA	California
CEA	Consumer Electronics Association, the leading national trade organization for consumer electronics
CEC	California Energy Commission
CPU	central processing unit
DK	don't know, as an answer to a survey question
DOE	U.S. Department of Energy
EIA	Energy Information Administration, in the U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
HD	home desktop(s)
HP	primary home computer(s)
IEEE	The Institute of Electrical and Electronic Engineers
IT	information technology
NRDC	Natural Resources Defense Council
OIT	Office of Information Technology, a unit at UCI
OD	office desktop(s)
OP	primary office desktop(s)
OS	operating system
PM	power management, including both automatic power management settings and manual power management actions
R	The respondent or subject in a study

RECS	Residential Energy Consumption Survey, produced by the U.S. Department of Energy
REF	prefer not to answer, or refuse, as an answer to a survey question
UCI or UC-Irvine	University of California, Irvine
XP	Windows XP®, a computer operating system for some desktops and laptops

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APPENDIX B: THE MONITORING STUDY QUESTIONNAIRE

This questionnaire was self-administered by monitoring study participants during the initial research interview, at the same time the monitoring software was installed. The text shown in blue was pre-printed on each participant's questionnaire, using data from the spring 2013 survey. The text shown here is a fabricated example; it is not from an actual participant. The supplementary lists of response options were given to the participant as a laminated handout, to assist in making any changes to the responses in question 1.

MPID# MP1234

IWER# _______

UCI Computer Use Study, Phase II

Follow-up questions

If you have any questions about how to fill out this brief questionnaire, please ask the researcher to help you.

1. In the Spring 2013 survey you told us the information shown below. If this information is correct and is the same now, check the "same/correct" box. If this information has changed (or was incorrect), please write the new answer in the right-hand column.

	If same/correct, check this box	If changed or incorrect, enter new information here.
UCI NetID: jmjones		
Age: 47		
Gender: Female		
Primary role at UCI: Administrative or Management Staff		[See list A for response options, enter the number here.]
Occupation category at UCI: Administrative support		[See list B for response options, enter the number here.]
Work status at UCI Full-time (at least 30 hours per week / 75% appointment)		[See list C for response options, enter the number here.]
UCI school or work unit: School of Medicine		[See list D for response options, enter the number here.]

2. Since you did the spring survey, on JUNE 6, 2013, have you changed when you work <u>on campus</u> in any of the following ways? Note that "campus" includes the main campus, North Campus, Research Park, the Health Sciences campus, and the UCI Medical Center in Orange. (Circle the number of any answers that apply.)

   I work on campus….

   1. More hours on weekends
   2. Fewer hours on weekends
   3. More hours on weekdays
   4. Fewer hours on weekdays
   5. About the same as before
   6. Don't know

3. In the Spring 2013 survey, you told us about the desktop(s) you use on campus, and your answers are shown in the table below. If your current primary computer is one of these, check the "current desktop" box for that computer, and correct any errors or note any changes. If your current primary computer is not listed here, please fill out the last column for your current desktop.

	Desktop 1	Desktop 2	Desktop 3	Desktop 4	New/different desktop
Which one is your **current desktop?**	[ ]	[ ]	[ ]	[ ]	[ ]
Name you gave the computer:	"personal"	"front office"	"lab"		
Operating system:	Windows Vista	Windows 7 or 8	Max OS X version 10.8		
Year this computer was made:	2008	2009	2012		
Who uses this computer? If changed, enter the number from the right-hand column for the new status.	I am the only user [ ] same [ ] changed New:	I use it most often [ ] same [ ] changed New:	I share it [ ] same [ ] changed New:		1. I am the only user 2. I use it most often, but one or more others also use it 3. I share it about equally with someone else 4. Someone else uses it more often than me

4. Computers come with default settings for power management, such as whether the computer goes into sleep mode after a period of inactivity. <u>Since you took the spring survey</u>, have you or anyone else changed any of the power management settings on your current desktop computer? If the settings were changed multiple times, answer for the most recent change. If this is a new computer for you, think about what has happened since you got the computer. (Think only about changes to the power management settings in the computer software, not about whether you manually turn the computer off or put it to sleep.)

   1. I changed the settings
   2. Someone else changed them
   3. I did not change them but maybe someone else did
   4. Nobody has changed the settings
   5. Don't know

5. If you changed the power management settings, which of the following best describes how they changed?

   [ ] Does not apply – I did not change the settings

Automatic <u>sleep</u> was:	Automatic <u>hibernate</u> was:	Automatic <u>shut down</u> was:
1. Not changed	1. Not changed	1. Not changed
2. Off, and I turned it on	2. Off, and I turned it on	2. Off, and I turned it on
3. On, and I set it to go on faster	3. On, and I set it to go on faster	3. On, and I set it to go on faster
4. On, and I set it to go on slower	4. On, and I set it to go on slower	4. On, and I set it to go on slower
5. On, and I turned it off	5. On, and I turned it off	5. On, and I turned it off
6. Don't know	6. Don't know	6. Don't know

Thank you! Please hand your survey back to the researcher when you are finished.

Supplementary Lists of Response Options

List A: UCI position

1. Undergraduate student
2. Graduate or professional student
3. Postdoctoral scholar
4. Research staff (e.g., Researcher, Specialist, Project scientist, Lab technician)
5. Administrative or management staff
6. Faculty (including Lecturers and Instructors)
7. Physician
8. Medical staff (e.g., Residents, Fellows, Nurses, Interns, Technicians)
9. Staff, all other
10. Retired faculty
11. Retired staff member
97. Other (please describe)

List B: UCI occupation code

1. Laborer or helper (examples: grounds maintenance worker, construction laborer)
2. Operative (examples: machine operator, parking lot attendant, bus driver)
3. Craft worker (examples: electrician, plumber, construction worker, painter)
4. Service worker (examples: cook, food preparation worker, custodian)
5. Security support (examples: police officer, security guard)
6. Commercial/sales support (examples: sales supervisor, cashier, travel agent)
7. Medical support (examples: medical assistant, healthcare worker)
8. Administrative support (e.g., office manager, library technician, secretary, payroll clerk, accounting assistant)
9. Technician (examples: laboratory technician, LPN, diagnostic related technologist)
10. Professional (examples: instructor, engineer, scientist, physician, pharmacist, registered nurse, librarian, computer programmer, HR specialist, accountant, financial analyst, athletic coach)
11. Manager or official (executive officer, mid-level manager)
97. Other (please describe)

List C: Work Status

1. Working full-time (at least 30 hours per week/75% appointment)
2. Working part-time (less than 30 hours per week/75% appointment)
3. On medical leave or family leave
4. On sabbatical, but located locally
7. Other (please describe)

List D: UCI school or work unit

1. School of the Arts
2. School of Biological Sciences
3. School of Business
4. School of Education
5. School of Engineering
6. School of Humanities
7. School of Information & Computer Science
8. School of Law
9. School of Medicine
10. School of Physical Sciences
11. School of Social Ecology
12. School of Social Sciences
13. Accounting & Fiscal Services
14. Administrative & Business Affairs
15. Administrative & Business Services – Other (Office of the Vice Chancellor for Administrative & Business Services, Design & Construction Services, Internal Audit, Material & Risk Management, Administrative Policies & Records, Environmental Planning & Sustainability)
16. Campus Recreation
17. Chancellor's Office and Chancellor's Office – Other (Campus Counsel, Chief Executive Roundtable, Alumni Association, Strategic Communications)
18. Division of Undergraduate Education
19. Enrollment Services (Admissions & Relations with Schools, Registrar's Office, Center for Educational Partnerships, Financial Aid & Scholarships, Enrollment Services)
20. Environmental Health and Safety
21. EVC/Provost/Academic Affairs – Other (Office of the Executive Vice Chancellor and Provost, Academic Senate, Academic Personnel, Academic Planning, ADVANCE Program, Office of Equal Opportunity & Diversity, Ombuds Office, University Editor, Whistleblower Coordinator)
22. Facilities Management
23. Graduate Division
24. Health Sciences (Nursing, Pharmaceutical Sciences, Public Health)
25. Hospitality and Dining Services
26. Housing
27. Human Resources
28. Intercollegiate Athletics
29. Libraries
30. Medical Center or Gottschalk Plaza
31. Office of Information Technology
32. Office of Research (including institutes and centers under this office)
33. Planning and Budget
34. Police
35. Student Affairs
36. Student Affairs – Other (Office of the Vice Chancellor for Student Affairs, Student Affairs Budget Office, Student Affairs Communications Office, Student Affairs Research and Evaluation, Child Care Services, Student Affairs Human Resources & Staff Development, Student Affairs IT Strategic Planning, Student Government)
37. Student Center & Event Services/Bookstore
38. Student Life & Leadership
39. Transportation & Distribution Services
40. University Advancement
41. University Extension and Summer Session
42. Wellness, Health & Counseling Services (CARE, Career Center, Student Health, Health Education, Counseling Center, Disability Services Center)
97. Other (please describe)