CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

The Power Management User Interface Study

Gavin Newsom, Governor

June 2021 | CEC-500-2021-034

PREPARED BY:

Primary Authors:
Joy E. Pixley
Sabine Kunrath
Sergio Gago Masague
Raquel Fallman
G.P. Li

California Plug Load Research Center
California Institute for Telecommunications and Information Technology
University of California, Irvine
Irvine, CA 92697
(949) 824-9768

Contract Number: EPC-15-022

PREPARED FOR:
California Energy Commission

Bradley Meister
Project Manager

Virginia Lew
Office Manager
ENERGY EFFICIENCY RESEARCH OFFICE

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

ACKNOWLEDGEMENTS

The authors acknowledge important support from several sources. The California Energy Commission provided financial sponsorship, administrative support, and exceptional guidance. The California Institute for Telecommunications and Information Technology (Calit2), at the University of California, Irvine, provided additional financial and administrative support, led by Dr. G.P. Li. Members of the technical advisory committee gave valuable feedback on the design of the software. The Office of Information Technology at University of California, Irvine provided assistance with testing the software application. Within Calit2, important contributions to the design, development, and testing of the software were made by Tina Chau, Keyvan Fatehi, Dr. Elizabeth Gervais, Steven Kuo, Viet Than Ly, and Dr. Gloria Mark

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

The Power Management User Interface Study is the final report for the Power Management User Interface project (Contract Number EPC-15-022) conducted by the California Plug Load Research Center at the University of California, Irvine. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov.

ABSTRACT

Research shows that many desktop computers are left on for long periods when not being used. Getting computers to transition to sleep mode during these periods would save a substantial amount of energy. The research team developed and tested a new software application that manages computer sleep settings, called Power Management User Interface. The goal was to create a user interface that encourages desktop computer users to use the automatic sleep settings already available on computers more efficiently. The design of the user interface was based upon past research on the efficacy of various energy feedback programs to encourage pro-environmental behaviors more generally, and on behavioral theories. A field test of 407 office desktop computers was conducted to test the effectiveness of this software application and to collect data on users' behaviors toward power management. At baseline, only 13 percent of computers had computer sleep settings enabled, but more than 56 percent of subjects reported the settings were enabled. Findings suggest user confusion about settings that is correlated to lack of use and knowledge. Subjects exposed to the Power Management User Interface application were significantly more likely than control subjects to enable their computer sleep settings and to reduce the delay time. Treatment subjects' computers subsequently spent less time idle and more time in sleep mode than control subjects' computers. However, more than half of computers with sleep enabled experienced at least one problem with sleep transitions being blocked, and 27 percent exhibited substantially higher idle time and lower sleep time than expected. These sleep blockers reduced the effects of enabling sleep settings and thus the effects of the Power Management User Interface treatment. However, treatment subjects still saved an average of 23.7 percent more energy than control subjects. These results provide strong evidence for the effectiveness of changing computer users' energy-saving behavior using feedback and encouragement. They also illustrate the importance of solving technical problems that inhibit sleep transitions. California taxpayers will benefit from this software because it will reduce energy use by desktop computers.

Keywords: *computers, software, energy, efficiency, power management, desktops, sleep settings, behavior*

Please use the following citation for this report:

Pixley, Joy E., Sabine Kunrath, Sergio Gago Masague, Raquel Fallman, and G.P. Li. 2021. *The Power Management User Interface Study*. California Energy Commission. Publication Number: CEC-500-2021-034.

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EXECUTIVE SUMMARY

Introduction

A significant amount of plug-load energy goes into the use of computers in residences and businesses. The California Energy Commission (CEC) estimated in 2016 that computers and computer monitors are responsible for up to 3 percent of residential and up to 7 percent of commercial electricity consumption. A study in in California offices estimated that computers and monitors accounted for 66 percent of the office plug load demand. Although desktop computers are now outnumbered by laptop computers, the energy consumed per unit is so much higher for desktops that annual energy consumption (the energy consumption per unit multiplied by the number of units) remains higher than that of laptops. One national study estimated annual energy consumption for residential computers at 18 terawatt-hours (TWh) for desktops and 8.1 TWh for monitors, compared to 5.1 TWh for laptops. In the commercial sector, the annual energy consumption of an estimated 74 million desktop computers was 30 TWh in 2011.

Reducing the energy used by computers and monitors, especially when they are idle, has a great potential to increase energy efficiency and help California reach the aggressive greenhouse gas reduction goals as mandated by the Clean Energy and Pollution Reduction Act (Senate Bill 350, De Léon, Chapter 547, Statutes of 2015). One way to save energy is to shift computer use from desktops to mobile computers. Another method is to make desktop computers more efficient by introducing new efficiency standards such as adopted by the CEC in 2016). Both approaches are promising in the long run, but this project supplements these approaches with a third that is especially useful for those who will continue to use desktops: increasing the efficiency of desktop computers by influencing user behavior toward power management.

All computers are equipped with low-power modes that can save a substantial amount of energy if used efficiently. The most effective method is to engage the automatic sleep settings, which transition computers into sleep mode after a specified delay period of idle, or inactive, time. Most computers are currently shipped with sleep settings already engaged. However, research shows that many desktop computers in the field are left on for long periods and spend little time in sleep mode, indicating that automatic power-management settings have been disabled. At the same time, most users report in surveys that their computers go to sleep when idle.

The disparity between users' self-reports of power management and researchers' observations of inefficient computers seems at least partially due to user confusion. Research suggests that many users do not understand power management or have trouble locating the settings. Extensive public and private efforts encourage computer users to employ power-management settings and explain how to do so, from detailed instructions on the Microsoft and Apple websites to educational campaigns at the state, city, and enterprise levels. However, these efforts do not appear sufficient to engage with users and change their behaviors.

An alternate approach is centralized information technology (IT) control, in which a company's IT department uses a software application or service to remotely control its employees' computers, including their power-management settings. This works well for many companies and can save substantial energy. However, it is not appropriate in many situations, such as residential computer use and small companies with limited IT resources. Also, even where centralized IT control is already used to facilitate updates and backups, a policy of mandatory sleep settings can face resistance from IT personnel and employees. In short, broad educational outreach has proven ineffective at convincing computer users to engage their sleep settings, and external control of those settings is limited.

A third alternative is direct educational engagement with individual users combined with personalized feedback. This approach focuses on feedback-based behavioral interventions for reducing energy use in homes and workplaces. The current project used the results of these prior studies on overall energy use to design a software application that gives specific, actionable, and motivating feedback to users about their computers.

Project Purpose

This project developed and field-tested a software application to increase computer user awareness and understanding of sleep settings, provide feedback on how much time computers spend idle, and encourage users to save energy by reducing idle time through enabling the computer sleep settings. The researchers measured the actual power use of computers in various states to assess the savings from more effective and efficient power management. The goal was to produce a standalone software application that could be distributed freely and used on any desktop, at home or work, as a voluntary and cost-effective alternative to centralized IT control of power management.

The goal was to develop a worthwhile new tool to reduce energy wasted in commercial and residential offices, by promoting the use of sleep settings and other power-management behavior among computer users. The open-access software application would provide an inexpensive and simple way to upgrade existing computers as well as new ones. The energy saved is relatively small on a per-computer basis, however when accumulated across the large number of computers in the state, it is substantial compared to the low cost of the solution.

The main hypothesis of the study was that exposing computer users to feedback with the Power Management User Interface will change their behavior toward more sustainable power-management practices, which in turn will reduce the power use of the computers and monitors. Specifically, compared to the control group, subjects who use the Power Management User Interface were expected to be more likely to enable the sleep settings if not already enabled, or reduce the delay time for the sleep settings if already enabled, resulting in considerable electricity savings.

This report describes whether the Power Management User Interface software succeeded in achieving the intended goals, namely whether subjects who were exposed to the software were more likely to improve their power-management settings than the control group, and whether these subjects were also more likely to reduce their computer-related energy usage than the control group.

Project Approach

The California Plug Load Research Center (CalPlug) designed, programmed, pretested, and field-tested the Power Management User Interface software. Experts in human-computer interaction helped during the design phase. The researchers tested the program on multiple computers with various Windows and Mac operating systems. A laboratory pretest walked 22 subjects through using every feature to assess their comprehension and interpretation. The CalPlug team worked closely with a technical advisory committee of experts from industry, utility, government, and research disciplines. The project team solicited ongoing feedback on the functionality and design of the program from the committee.

The design of Power Management User Interface was based largely on similar efforts to encourage energy-saving behaviors more broadly at home and at work. The software incorporates elements from successful feedback interventions in an appealing, user-friendly way. Power Management User Interface measures and reports the computer's states: specifically, the time it spends off, in sleep mode, on and actively being used, and on but idle. Briefly, the interface compares the computer's observed states with a target profile (goal setting), compares time spent idle during a week versus the previous week (historical comparison), and displays patterns of computer states in connection with sleep settings, which can be shown in different time scales (hourly, half days, full days, weeks, and months).

After developing and internally testing the Power Management User Interface application, the CalPlug team field tested the effectiveness of the interface in changing user behavior. CalPlug recruited more than 400 university staff members to participate. All subjects were the sole users of a desktop computer on campus and controlled the power-management settings on those computers. The research design enabled comparisons between treatment and control groups and between baseline and intervention periods.

The researchers designed the Power Management User Interface to encourage subjects to activate their sleep settings and to decrease their delay times. In practice, the interface also served another function: alerting some subjects that their computers were not transitioning to sleep mode even when sleep settings were activated. The CalPlug research team worked with the subjects' IT managers to help troubleshoot those computers and resolve issues whenever possible.

Project Results

CalPlug field-tested the Power Management User Interface software application on more than 400 office desktop computers from March 2017 to May 2018. The team installed the interface on each computer for a minimum of three months. No security issues or other negative effects were linked to the Power Management User Interface software.

The initial observations of the field test confirmed the prominence of poor power-management practices, finding that only 13 percent of computers had computer sleep settings enabled and of those almost one in three had a delay time of longer than 30 minutes. Display settings were much more efficient: 83 percent of computers had display sleep settings enabled and almost all had delay time settings of 30 minutes or less.

The final field test results strongly support the hypothesis that the Power Management User Interface application positively affected power-management behavior. Of those who had computer sleep settings disabled before the intervention but second research visit, subjects who used the interface application were significantly more likely to enable computer sleep settings than those in the control group (59 percent versus 15 percent).

Results were similar for display sleep, indicating a spillover effect since the Power Management User Interface does not give users feedback on their monitors' states. Of the small group who did not have display sleep settings enabled at the beginning of the study, treatment subjects were significantly more likely to enable display sleep than control subjects (56 percent versus 30 percent). Among those with display settings already enabled, treatment subjects were significantly more likely than control subjects to reduce the delay time for display sleep settings (47 percent versus 13 percent).

Few subjects changed their settings during the baseline period, indicating that simply participating in the study was not a major factor in behavioral change. Rather, positive changes for the control and treatment groups occurred at or after the second research visit. In other words, simply showing the control subjects their standard operating system sleep settings encouraged some of them to improve their sleep settings. However, those who instead saw the Power Management User Interface application were significantly more likely to enable their computer sleep settings right away. The treatment group also continued to show more improvement than the control group between the second intervention and the end of the study, supporting the importance of ongoing feedback from the application.

Comparing the observed sleep settings to the subjects' self-reports helps illuminate a major factor in inefficient power-management behavior: user confusion. This report offers evidence that many subjects were confused about their settings or about power management in general. More than half of subjects (56 percent) reported that their computers automatically transitioned to sleep, but only 21 percent of those subjects were correct. A substantial minority (16 percent) admitted they did not know whether their computers went to sleep; almost all these subjects (96 percent) were observed to have disabled computer sleep settings.

Given the role of misunderstanding in poor power-management behavior, part of the solution would seem to be more effective, targeted education about power management along with gentle nudges toward improving power management behavior. The results of the project show that the Power Management User Interface application is an effective mechanism for both increasing subject awareness and encouraging adoption of more energy efficient behaviors.

Analyses of the time computers spent in idle versus sleep mode, energy consumption, and changes over the course of the study show the predicted effect: Power Management User Interface effectively encouraged treatment subjects to enable their computer sleep settings, which led to more time in sleep mode and less time idle, which in turn led to lower energy consumption.

Knowledge and Technology Transfer

CalPlug presented the Power Management User Interface software and the field test results at various conferences and workshops and held numerous demonstrations directed to academic researchers, scientists, and administrators, and representatives from industry and utilities.

The Power Management User Interface application was developed using open source (free) software to better facilitate distribution to a wide range of users. The software team modified the interface application to be a standalone program and made the software available for free on its webpage on the California Institute for Telecommunications and Information Technology (Calit2) website (https://pmui.calit2.uci.edu/). The beta version currently available was modified to facilitate self-installation and to remove the research module that transmits data to the CalPlug server. It is currently available only for Windows operating systems, until self-installation problems with Mac operating systems can be resolved.

Additional modifications are also in progress. First, while the study version of the software was designed to handle short-term data collection, a new version is being developed that implements optimized data storage and retrieval methods to accommodate long-term use. Second, the software currently cannot record sleep for computers with very short sleep-delay times (less than 5 minutes). In addition, the software must be updated to reflect any subsequent upgrades in operating system or other software. Once the adaptations are complete, the availability of the app will be communicated through Calit2's extensive contact network and beyond, through a planned news release and an article in the Calit2 magazine, *Interface*. CalPlug is also in discussions with the university about the possibility of distributing the software more broadly across the campus, whether in research mode or standalone mode.

The project results were featured in an article in the Calit2 Interface magazine in fall 2019 in an article titled "Ready, Set, Sleep" (page 30). The online version is located at: http://128.195.177.176/wp-content/uploads/2019/11/INTERFACE-Fall-2019.pdf

In late 2019, findings were presented at the 10th International Conference on Energy Efficiency and Domestic Appliances and Lighting (EEDAL), Jinan China, November 6-8, 2019.

A student research group at University of California, Irvine is assessing some of the problems with the previous design and redesigning the "Time Spent Idle" page and general environmental messaging.

For the longer term, CalPlug plans to reach out to Microsoft, Apple, and other computer manufacturers, with the goal of incorporating Power Management User Interface prior to distribution. It is assumed that this will be more effective once the software has been distributed more widely and broad interest has been established. Whatever agents adopt or incorporate the interface, the baseline software remains open source and can continue to be used and updated by others.

Benefits to California

This research shows that a simple, free, standalone software program can effectively save energy by encouraging users to adopt more energy-efficient computer behaviors. The Power Management User Interface software can be used to make existing desktops more efficient rather than requiring ratepayers to purchase new computers. Another benefit is that it is voluntary: overall energy consumption in an enterprise can be reduced without risking pushback from employees who might resist centralized control of their computers.

The interface software was designed to be used on any personal desktop, residential and commercial, thereby expanding its potential reach to California ratepayers. The software can benefit California ratepayers both directly and indirectly. Ratepayers who use the software will learn more about power management and how to efficiently use their computers, and depending on their current settings, could save energy and money. All ratepayers will indirectly benefit from the energy that is saved by others who use the program, through reduced carbon dioxide emissions and reduced demand on the energy grid. At a projected full deployment of 10 percent of California desktops, Power Management User Interface would save 37,323 megawatt hours per year and more than $5.9 million in electricity costs and would reduce carbon dioxide emissions by 26,314 metric tons.

This research also provides valuable insights into user behavior toward power management, helping researchers better understand and improve intervention strategies for saving energy. The research sets the groundwork for additional projects, applying the same behavioral feedback intervention strategies to laptops and to other plug-load devices in homes and offices. Finally, the results quantify the extent to which remote access and sleep blocking reduce the efficacy of computer power management. To the extent that this research encourages new solutions for these two barriers to efficiency, it will facilitate even greater energy savings in the future.

CHAPTER 1: Introduction

Computer Energy Use

A significant amount of plug-load energy goes into the use of computers in both residences and businesses. The California Energy Commission estimated in 2016 that up to 3 percent of residential and up to 7 percent of commercial electricity consumption is generated by computers and computer monitors (California Energy Commission, 2016). The annual consumption of both residential and commercial desktop computers in the U.S. added up to 52 TWh in 2011, second only to televisions among miscellaneous electric loads (Navigant Consulting, 2013). In the commercial sector, the annual energy consumption of an estimated 74 million desktop computers added up to 30 TWh in 2011 (Navigant Consulting, 2013). A study in several offices in California estimated that computers and monitors accounted for 66 percent of the office plug load (Moorefield et al., 2011). A more recent study of consumer electronics estimated the total number of desktop computers in United States homes to be 72 million, the number of monitors 101 million, and the number of portable computers 122 million (Urban et al., 2017). Despite laptops outnumbering desktop computers, desktop computers still use more energy overall: Table 1 shows that desktop computers in homes consumed 18 TWh annually, while portable computers only used 5.1 TWh. Desktop computers exhibited the highest unit energy consumption among household electronics (246 kWh per year, compared to 123 kWh per year for televisions). ENERGY STAR® estimates that up to $50 a year can be saved per computer when computer power-management settings are enabled (ENERGY STAR, 2018a).

Table 1: Energy Use by Desktop Computers, Laptops, and Monitors in US Homes

	Units (millions)	Unit Energy Consumption (kWh/year)	Annual Energy Consumption (TWh)
Desktop Computer	72	246	18
Portable Computer	122	42	5.1
Monitor	101	80	8.1

Source: Energy Consumption of Consumer Electronics in U.S. Homes in 2017 (Urban et al., 2017, p. 14).

Desktop computers are major contributors of wasted idle energy use in homes and businesses (Delforge, Schmidt, & Schmidt, 2015). Current ENERGY STAR guidelines estimate average power consumption for desktops at 2.3 watts in sleep mode compared to 48.1 watts while idle (ENERGY STAR, 2018c), showing the impact on energy consumption for transitioning computers from idle to sleep. In California Plug Load Research Center's (CalPlug's) computer-monitoring study, desktops with sleep settings enabled spent an average of 12 percent of the week idle, compared to 68 percent for those without sleep enabled (Pixley & Ross, 2015).

Numerous studies have performed physical audits or measurements of computers and other electronic office equipment in situ, mostly in commercial or university buildings. These audits and monitoring studies 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 (e.g., Acker et al., 2012; Bensch, Pigg, Koski, & Belshe, 2010a; Chetty et al., 2009; Hackel, Plum, & Carter, 2016; Mercier & Moorefield, 2011; Motta Cabrera & Zareipour, 2011)

Power Management

Definition

All modern desktop computers come equipped with low-power modes. Most manufacturers use an open industry standard for such settings: the Advanced Configuration and Power Interface, or ACPI (UEFI Forum, 2018). In *sleep mode*, the computer reduces power to subsystems that are not needed (ACPI S3, commonly referred to as "sleep, standby, or suspend to RAM"). Random-access memory (RAM) is powered at a minimal level; open programs and files are held in RAM, allowing for a quick revival of recent activity. *Hibernation* (ACPI S4) deactivates almost all computer functions; after storing the current state of processes to the hard disk, the computer powers down. Like sleep, hibernation restores any open programs and files when the computer is reactivated, but it requires more time to reactivate the computer. S*hutdown* or *soft off* (ACPI G2/S5) also powers down the computer, but does not save the current processes and, therefore, all data must be saved and programs must be closed. *Hybrid Sleep* is a relatively new option that combines sleep mode and hibernation. It consumes approximately as much energy as sleep, but it also saves processes to the hard drive for retrieval, which is useful if there is a power loss.

These low-power modes use substantially less energy than idle mode. Urban et al. (2017) estimated that in 2016, desktop computers on average used 56 watts in short-idle mode and 52 watts in long-idle mode, but only 2.1 watts in sleep mode and 0.9 watts when shut down. The ENERGY STAR power-management calculator estimates 48.1 watts for idle mode versus 2.3 watts for sleep mode for average desktop computers or, for ENERGY STAR-compliant computers, 27.1 watts versus 1.8 watts (ENERGY STAR, 2018d). The challenge, then, is to ensure that desktop computers spend as little time as possible turned on when they are not being actively used. In theory, automatic power-management settings, particularly the sleep settings for computer and display, should address this problem. The settings allow the user to control how and when various components transition automatically to various low-power modes. ENERGY STAR-labeled computers have automatic power management enabled when shipped by the manufacturer. The default settings include transitioning the computer to sleep mode after 30 minutes of inactivity (Intel, 2009). Computer users can also use manual power management: that is, shutting down the computer or putting it into sleep or hibernate mode immediately using menu commands.

Implementation

Past research suggests that desktop computers are left on for long periods and spend little time in sleep mode, indicating that automatic power-management settings have been disabled (Acker et al., 2012; Barr et al., 2010; Bensch et al., 2010b; Mercier & Moorefield, 2011; Roberson et al., 2004). At the same time, the majority of users report in surveys that their computers go to sleep when idle (Pixley et al., 2014; Tiedemann et al., 2013; Urban et al., 2017).

Some of the discrepancy between self-reports of enabled sleep settings and observations of idling computers appears to be due to user confusion about what constitutes sleep, such as assuming the computer goes to sleep when the monitor does (1E & Alliance to Save Energy, 2009). Two studies conducted at UC Irvine shed some light on the apparent contradiction by comparing self-reports to researcher observations in the same sample. First, a large survey found that 86 percent of subjects reported that their office desktops automatically transitioned to sleep (Pixley et al., 2014). However, a follow-up study that observed computers of a subset of these subjects found that only 30 percent of subjects who reported that sleep settings were enabled were correct, and that, overall, only 20 percent of computers had any power management enabled (Pixley & Ross, 2014). Some of that discrepancy may be due to social desirability reporting bias. However, subjects who reported incorrectly were more likely to have not changed their settings recently (or ever) and to rate themselves as lower on computer expertise, suggesting that they were confused about whether their computers were going to sleep. Also, most of these users had display-sleep enabled, and may not have been able to discern whether their computers were still on when their monitors went dark. Screen savers can add to the problem, as users might confuse their screen saver with computer and/or monitor sleep. Moorefield et al. (2011) found that screen savers were used often when desktop computers were on during nonworking hours.

Other studies also suggest that users don’t understand power management or have trouble locating the settings. For instance, one survey of over 1,400 United States employees who use computers at work found that 32 percent either did not know what power-scheme settings were (for example, what "Balanced" or "Power saver" schemes mean), did not how to change their power-management settings, or both (1E & Alliance to Save Energy, 2009). An in-depth study of households in Seattle similarly found that many people they interviewed "did not know how to alter their power settings to be more energy efficient” (Chetty et al., 2009 p. 1039). In the UC Irvine monitoring study, those who rated themselves as more knowledgeable about computers were likely to show greater accuracy about their settings. This suggests that informing users about sleep settings may be an important step to saving energy. Despite these computers having their factory-enabled sleep settings disabled, the majority of users had not changed the settings themselves (Pixley et al., 2014), indicating the likely involvement of IT managers, previous users, or other third parties.

Education

Extensive public and private efforts encourage computer users to employ power-management settings and explain how to do so. ENERGY STAR has a set of activation instructions for various operating systems on its website. Households and organizations can pledge to enable their power-management settings and calculate their annual savings resulting from using computer power management. Through the Federal Electronics Challenge, the federal government encouraged federal agencies to enable ENERGY STAR power-management features on 100 percent of eligible computers and monitors. Many universities, cities, and companies have websites, fliers or posters encouraging the use of power-management options and providing instructions (for example, Boston University, 2018; City of Irvine, 2018; Picklum et al., 1999). Instructions to engage sleep settings for each specific operating system can be found on the Microsoft and Apple websites, as well as countless other IT help pages. However, given the research cited earlier that sleep settings are disabled on most desktop computers, these wide-ranging educational efforts do not appear to be effective.

Centralized Power Management

One approach to reducing energy waste by decreasing idle time in computers is third-party control (Korn, Huang, Beavers, Bolioli, & Walker, 2004). Many IT systems on the market enable centralized managers to control the sleep settings of employees' computers under their management, often with the same system used to push software updates and backups. This can be a highly effective strategy for saving energy for many enterprises, but it is not appropriate for everyone. IT managers may be reluctant to implement such systems, facing pushback from higher-status professional employees and those with computer expertise who prefer different settings (Hackel, Plum, & Carter, 2016; Pollard, 2016).

For example, one study faced resistance to centralized power management from IT managers at various study sites, as well as from users who disabled the settings on their own (Hackel, Plum, & Carter, 2016). Pollard (2016) describes how an attempt to establish centralized power management as part of a climate-change mitigation strategy at a university failed because of the strong resistance of staff, particularly administrators and faculty. Some organizations may have so many employees opting out (perhaps because they need to remotely access their desktops) that the savings are not worth the investment of time and resources. Moreover, some IT managers may resist the idea of centralized power management, expecting it to increase their workload through additional troubleshooting, complaints, and issues with the networked environment, such as software distribution, update procedures, security patches, and backup management. Also, power management might be inconvenient to centrally manage because it is connected to the user's account and not to the computer; if the user is logged out of the account the IT manager cannot access the settings. Third-party control may also not work for smaller businesses that lack the personnel and funds to implement and maintain such an IT infrastructure. Furthermore, such an approach is not applicable for residential desktops or for computers used by the self-employed.

When centralized IT control is neither desirable nor an option, individual users should be encouraged to voluntarily enable power-management settings on their computers, by increasing their knowledge, skills, and motivation. The next section looks into feedback as a method to achieve these goals.

Feedback

As outlined earlier, research suggests that one of the reasons computer sleep settings are not enabled is that users are confused about their settings. A similar issue has been found in household energy consumption because modern energy use is abstract and invisible (Darby, 2006; Ehrhardt-Martinez, Donnelly, & Laitner, 2010; Hargreaves, Nye, & Burgess, 2010; Karlin, Zinger, & Ford, 2015). When individuals do not understand how much electricity and gas their household uses, and which applications they should use to track the usage, they cannot make informed decisions about saving energy. It is important to acknowledge that energy usage is not an end in itself but a by-product of people satisfying various needs, such as cooking, lighting, heating, cooling, housekeeping, and entertainment. In most everyday activities, individuals' attention is not focused on energy usage itself, and its effect is not salient enough to trigger conservation measures (Delmas, Fischlein, & Asensio, 2013; Tiefenbeck et al., 2018). People are often not responsible for paying for the energy that they use, such as in the workplace or in rented units, thus lacking a monetary incentive to conserve. Moreover, the potential monetary savings that can be reached through conservation may be too small to be motivating, especially on a per-action or per-day basis.

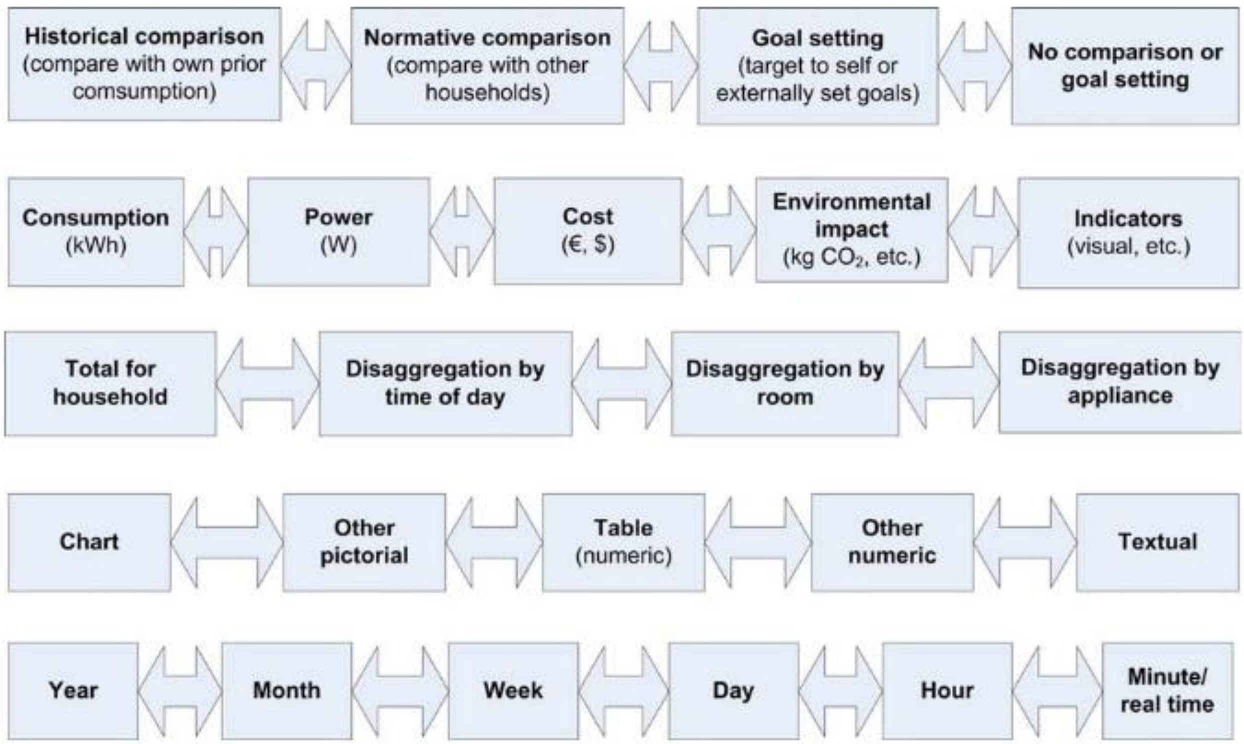
Feedback has been incorporated to make the otherwise hidden energy consumption accessible by directing the users’ attention to the amount of energy consumed. Feedback can offer a learning experience, increase energy-related knowledge, and allow the users to track and monitor their usage. It may instill a sense of control over the usage and point to the relevance of one’s behavior. Feedback can also motivate consumers to use less energy by activating motives like saving money or decreasing the environmental impact of power usage. It can also offer users a convenient way to help fulfill their energy-related goals when coupled with full or partial automatization (Promann & Brunswicker, 2017) or highly personalized recommendations (Froehlich, 2009).

Researchers have been experimenting with giving feedback to households about their energy use since the 1970s. However, technology has only recently advanced enough to offer feedback in real-time to a large audience. Recent meta-analyses (Delmas et al., 2013; Karlin et al., 2015) and reviews (e.g., Abrahamse, Steg, Vlek, & Rothengatter, 2005; Ehrhardt-Martinez et al., 2010; Faruqui, Sergici, & Sharif, 2010; Fischer, 2008; Hermsen et al., 2016) concluded that feedback can be a valuable tool to save energy in households, with potential savings ranging from 1 percent to 20 percent. However, more detailed and rigorous studies are needed about various aspects of feedback, including the persistence of behavior change (EPRI, 2009), which groups benefit most from feedback (Vine, Buys, & Morris, 2013), and unintended consequences of feedback (Buchanan, Russo, & Anderson, 2015).

Effective Strategies in User Feedback

Many types of informational feedback mechanisms have been developed, from web applications displaying utility customers' current and past monthly bills to in-home displays producing real-time data. Feedback can be given through various means (such as paper reports or enhanced bills, software or web platforms, or energy monitors) in various frequencies (including monthly, daily, and real-time), granularity (for example, disaggregated by different devices), and duration. The effects of energy usage can be presented in numerous ways (in terms of carbon emissions or financial savings; comparison with past use and/or with similar users). Karjalainen (2011, p. 459) graphically summarizes several aspects that need to be considered when designing a feedback intervention (see Figure 1). These aspects concern the standards of comparison, the reporting units, the level of disaggregation, the textual and graphical design, and the frequency at which feedback is provided. It is important to note that the options within each aspect group (the horizontal elements in the figure) are not mutually exclusive but can be combined as needed. As described below, studies have shown that certain features are more effective in curtailing use or preferred more by the feedback recipients.

Figure 1: Summary of Options for Presenting Feedback on Household Electricity Consumption



Source: Karjalainen (2011, p. 459)

Feedback is considered a "consequence" strategy that influences behavior by showing users the outcomes of their behaviors (Abrahamse et al., 2005). It may regulate behavior by evaluating and reacting to a comparison of the behavior to a standard derived from historical behavior, normative comparison, or by comparison with internally or externally set goals (Karlin et al., 2015; Kluger & DeNisi, 1996). Savings can be motivated by both historical comparisons and comparisons to similar users; however, the latter may backfire for those who are doing much worse or much better than others (Byrne, Nauze, & Martin, 2018). Studies have shown that many users prefer to compare their current usage to their own historical usage in previous months or years (Canfield, Bruine de Bruin, & Wong-Parodi, 2017; Karjalainen, 2011). Setting or assigning goals can be an integral part of successful feedback, as feedback by itself represents neutral information (McCalley & Midden, 2002).

Energy use can be expressed using physical or monetary reporting units or indicators. The usage should be presented in terms that are meaningful and relevant to the user (Lesic, Bruin, Davis, Krishnamurti, & Azevedo, 2018). Studies revealed that people do not have a good understanding of technical units like kilowatt hours (kWh). Cost is a unit that users can more easily relate to. However, even for people who prefer seeing energy expressed in monetary units, this understanding may not improve outcomes, either for learning about how to save energy (Krishnamurti et al., 2013) or observed energy reductions (Schultz et al., 2015). Furthermore, displaying cost may not be motivating if the computer user is not responsible for paying the electricity bill, for example, for an office computer. Framing the impacts of energy reduction in terms of units of carbon dioxide emissions, which are associated with climate change, can be successful in increasing conservation intentions (Spence et al., 2014).

Feedback can be provided through the aggregate sum of usage or disaggregated by time, location, or device. Users, in general, have trouble understanding how much power specific appliances or other devices use (Froehlich, 2009). Kempton and Montgomery (1982) devised an often-cited thought experiment that parallels aggregated energy bills with a fictional grocery store that does not give prices on individual items, only the total sum of the purchase, thus requiring the customer to use heuristics to understand how a single item affects the total. Technological advances allow more and more for disaggregated feedback on the appliance level, which may help the user identify the causes of high consumption (O. I. Asensio & Delmas, 2015; Vine et al., 2013).

Information should be clearly and simply presented, preferably in graphical form, and multiple formats should be used to appeal to users with different preferences (Fischer, 2008; Murugesan, Hoda, & Salcic, 2015; Roberts & Baker, 2003).

Feedback can be provided at different frequencies. When possible, data should be provided real-time or soon after consumption, so that users can link their behaviors to their outcomes (Abrahamse et al., 2005; Roberts & Baker, 2003; Vine et al., 2013).

Overall, feedback is more likely to change behavior when it is engaging and interactive (Fischer, 2008; Vine et al., 2013) and motivates users to change by appealing to values, norms, or rewards. For example, Schultz, Nolan, Cialdini, Goldstein, and Griskevicius (2007) found that the inclusion of an emoticon (happy or unhappy face) made study participants lower their consumption or, if they were already below average levels, keep it low. Delmas and Kaiser (2014) pre-tested various kinds of messages to see which kind of information would motivate users most to conserve energy. They found that environmental messages (such as higher electricity usage translated to removing trees from the community, increasing carbon dioxide emissions from coal plants, and adding cars to the road) were a top reason to reduce energy use for 70 percent of the pretest-sample. Results from intervention studies show that health-based messages and environmental messages may influence conservation behavior or the motivation to show pro-environmental behavior (O. I. Asensio & Delmas, 2015; Steinhorst & Klöckner, 2017). Users seem to benefit most from a combination of antecedent (such as goal setting) and consequence (feedback, for example) strategies (Abrahamse, Steg, Vlek, & Rothengatter, 2007). Interventions that give feedback, motivate and engage users, and incorporate a goal with frequent well-designed messages seem to be most effective (Bird & Legault, 2018).

Using Feedback to Influence Computer Power-Management Behaviors and Energy Savings

The previous sections show that using computers' power management (PM) has great potential for saving energy in both residential and commercial settings; however, users are confused about whether they have their sleep settings enabled. External technological solutions, such as manufacturers enabling automatic power management as the default or entrusting IT executives with power management in commercial enterprises, have apparently not helped end users effectively apply power-management settings. This suggests that a promising approach would be to give the users feedback about their computers' power-management settings and the computers' states (active, idle, sleep, and off) to address the lack of awareness and to motivate savings.

Previous studies provided feedback to employees about the power consumption of individual workstations, covering a range of plug-load devices (Gulbinas & Taylor, 2014; Mulville, Jones, Huebner, & Powell-Greig, 2017; Murtagh et al., 2013) or at the whole office level (Nilsson, Andersson, & Bergstad, 2015). A few feedback studies focused on computer states and energy use (Kamilaris, Neovino, Kondepudi, & Kalluri, 2015b; Pollard, 2016) or provided users with usage information disaggregated for specific devices (Gandhi & Brager, 2016; Orland et al., 2014).

Few feedback studies have examined user behavior in connection with computer states and power modes. One study measured the power consumption and computer states of 18 desktop computers in a university setting in Singapore (Kamilaris, Neovino, Kondepudi, & Kalluri, 2015a). During the five-week intervention period, the study participants received weekly e-mails with feedback about their computers' energy consumption, coupled with comparisons to colleagues and the entire office, energy savings advice, and a goal that was set by the researchers for the coming week. Participants were exposed to posters and leaflets displaying information about computers' energy usage, advice about how to use computers properly that also addressed concerns users might have regarding low-power modes, and about relevant financial and environmental benefits of low-power modes. During the intervention period, significantly more users powered their computers down after work and during the weekends than in the baseline period; this effect persisted over a 13-week follow-up period. During lunch hour, more users used "hibernate" and "sleep" during the intervention period than in the baseline period; however, over the follow-up period the number of users who used these low-power modes declined. A total of 90 kWh was saved in the intervention period compared to the baseline period by the 18 desktop computers, which was not statistically significant. In the follow-up period, the energy use was 311 kWh less than in the baseline period (statistically significant). The authors speculate that it took some time for the feedback messages to affect the users' behavior and subsequent savings.

Another feedback study (Pollard, 2016) equipped participants with an energy-saving device called Eco-button that was connected to their computers. When users pushed the button, the computer went into sleep mode. When the computer was reactivated, an interface appeared that displayed the actual savings in kWh, dollars, and CO_2 for the current day and since installation. A total of 146 computers were equipped with the Eco-button for eight weeks. The majority of users (62 percent from 143 users that replied to the survey at the un-installation visit) reported that they operated the device at least once a day; only four users reported that they did not press the Eco-button at all. Energy data was received from 137 computers; collectively, these workstations saved 8,462 kWh over a period of eight weeks, with an average of 61 kWh per computer and savings ranging from 0 to 310 kWh.

A third study (Orland et al., 2014) tested the effects of feedback with a "serious-game" (a game used for scientific study) intervention. After a baseline period measuring the energy usage of up to five devices in 57 workstations, 41 participants agreed to play a web-based game called "Energy Chickens." The application showed players their energy use disaggregated for different devices, including their computer. Participants were also exposed to educational posters about the energy consumption of plug loads. Sixteen participants were exposed only to the educational material but did not play the game. After eight weeks of intervention, the posters were removed for all participants. The game participants were able to play "Energy Chickens" for six more weeks. Then the energy usage was measured for eight more weeks. The group playing the game reduced energy consumption by almost 13 percent in the first eight weeks and by 10 percent in the next six weeks, but the savings' effect disappeared in the eight weeks of follow up. The education-only group showed savings of 10 percent in the six weeks after the posters were removed, but not at the other times. The authors concluded that a behavior change in the "game" group, namely switching off devices before non-work days (such as weekends), played an important role in the realized energy savings of this group in comparison to the "no game" group.

Another study used the "Cool Choices" game to achieve a reduction of office plug loads and to encourage general sustainable behaviors at the office and home (Gandhi & Brager, 2016). Thirty players competed in teams, earning points for completing sustainable actions; power usage was measured of 137 desktop computers, monitors, portable computers, and task lights. Unfortunately, due to a data loss limited data was available for users who also participated in the intervention; thus, the energy impact of the intervention could not be determined. Also, most employees had already been engaged in sustainable behaviors before the intervention, limiting the opportunity and reach of behavioral change.

More studies are needed to assess the potential of feedback on influencing computer users' behaviors. Ideally, these studies should have larger sample sizes than the studies mentioned above, feature an experimental design with a randomized control group and a baseline period, and direct measures of the computers' states as well as energy savings.

Project Approach

Building upon earlier work that surveyed more than 2,000 computer users about their power-management behavior and monitored 119 computers at the University of California, Irvine (Pixley & Ross, 2014; Pixley et al., 2014), this project aimed to study whether a carefully designed intervention can help computer users engage with and apply their computer's power-management settings. The project used a three-pronged approach:

1. Design, develop, and test a software application intended to increase computer users' understanding of sleep settings and of how much time their computers spend idle, and to encourage them to save energy by reducing idle time.
2. Assess user behavior toward computer power management and encourage users to apply the energy-efficiency features of their desktop computers.
3. Measure the actual power usage of computers in various states and assess the savings from a more effective and efficient power-management behavior.

CalPlug designed, programmed, pretested, and field-tested the Power Management User Interface (PMUI) software. The design phase was aided by experts in human-computer interaction. At that stage, the program was pretested on multiple computers, with various Windows and Mac operating systems. A laboratory pretest walked 22 subjects through using every feature to assess their comprehension and interpretation. Feedback on the functionality and design of the program was solicited from a Technical Advisory Committee of industry and research experts. All possible revisions based on these suggestions were made before the field-test stage. The software was vetted for security considerations by the university's Office of Information Technology.

The design of PMUI was based largely on similar efforts to encourage energy-saving behaviors more broadly at home and at work. Such programs and devices focus on giving users feedback on their energy usage, clarifying how to improve their behaviors and outcomes, and encouraging and motivating these changes. Research suggests several features that help promote behavior change, including frequent and specific feedback that is clear and easy to understand, engaging graphical representations, and the ability to compare one's current outcomes to prior outcomes, or to a goal or standard. The software incorporates elements from successful feedback interventions in an appealing, user-friendly way. PMUI measures and reports the computer's states: specifically, the time it spends turned off, in sleep mode, on and actively being used, and on but user-idle. Briefly, it compares the computer's observed states with a target profile (goal setting), compares time spent idle this week versus the previous week (historical comparison), and displays patterns of computer states in connection with sleep settings, which can be displayed in different time scales (by the hour, half days, days, weeks, and months).

After developing and internally testing the PMUI application, the CalPlug team conducted a field study with staff members of the University of California, Irvine (UCI), to test the effectiveness of PMUI in changing users' behaviors. The UCI campus employs more than 6,000 staff members on the main campus (UC Regents, 2019). However, not all of the schools and departments are being served by UCI's Office of Information Technology, and instead have their own IT departments with different procedures of managing the computers and the networked environment. As a consequence, the research team had to approach various schools and IT departments to see whether (a) the IT managers were interested in supporting the project, (b) their users were allowed to participate, and (c) their users had full control of their power-management settings. In case of computers storing sensitive information (such as computers at the police department or medical facilities), participation was generally disallowed by the IT staff. Other IT managers were not interested in the study; fears that the software and hardware components of the study would create problems may have come into play. Also, some departments had an explicit or implicit policy that the computers may never be turned off because of the way their networked environment was structured.

CalPlug was able to recruit more than 400 university staff members to participate. All subjects were the sole users of their desktop computers on campus and had control over the power-management settings on those computers. The research design enabled comparisons between treatment and control groups and between baseline and intervention periods. Research participation involved a minimum of three research visits, producing a baseline measurement period of at least four weeks prior to the second visit and an intervention period of at least eight weeks before the third visit. At the first visit, the PMUI software was installed to collect computer-state data, how the application itself was used, and any changes to the computer or display sleep settings (whether through PMUI or through the standard settings). Researchers also installed power strips and plug sensors to measure the energy used by the subjects' computers and monitors. At the second visit, the PMUI was activated for treatment subjects, who were shown how to find it. For control subjects, researchers reminded them how to find their standard sleep settings; the PMUI was not activated. Subjects completed brief surveys at the second and third research visits. The observed behaviors were compared to the subjects' self-reports of behaviors and attitudes in the two surveys and to the computer power usage.

The research team had to overcome various technological barriers that did not manifest themselves during the in-house testing. For example, the software developers had not anticipated users logging off their profiles, creating chunks of unknown data. This and further unexpected glitches, like missing the "unknown" state in several charts and a too-short display of the weekly reminder to check the Usage Report, required the research team to update the software through the course of the study. The research team also had not realized that the plug-meter manufacturer was able to send hardware updates, which reset numerous meters already placed in the field, requiring manual resets of the affected meters. Also, all of the meters had to undergo a hardware upgrade to be in an "always on" state once it was clear that in case of hardware failure the power to the plugged-in computers and monitors was being cut, shutting down the equipment immediately, and thus inconveniencing the user and jeopardizing the willingness for research subjects to participate in the study.

PMUI was designed to encourage subjects to activate their sleep settings and to decrease their delay times. The research team did not anticipate that in practice, it also served another function: alerting some subjects to the fact that their computers were not transitioning to sleep mode even when sleep settings were activated. The CalPlug research team worked with subjects' IT managers to help troubleshoot those computers and resolve issues whenever possible.

In addition to these technological challenges, the research team was managing organizational challenges (such as the scheduled switch-out of computers with newer models and office moves), physical challenges (including problems with outlets that were blocked by furniture or unmarked controlled outlets), and behavioral challenges (such as the plugging in of new or other equipment either by the subjects or IT managers during the course of the study). Working around these issues often required multiple visits to the affected subjects' offices and tight collaboration with the subjects' IT managers.

CHAPTER 2:
Software Design and Development

Design Principles

This section describes the design of the user interface and its features. The goal was to choose a format that gets the users' attention and encourages them to change their behavior. Elements of successful feedback interventions were incorporated in the design of the PMUI. The principle decisions described in this section were based on the research discussed in the previous section.

Presentation of the Outcome Variable

PMUI cannot access the actual energy being used by the computer, and as a standalone program it has no way of accessing the user's utility account or usage rates. Instead, it focuses on reducing computer idle time, which the laboratory pretest showed was meaningful and easy for subjects to understand. Further, the software relates reducing idle time to improvements in environmental indicators, such as "tons fewer carbon dioxide emissions" and “acres of trees planted” as meaningful units.

Frequency of Feedback

Feedback can be provided at a range of frequencies, from plug meters showing current power consumption to summaries of monthly usage that are posted or mailed after the fact. When possible, data should be provided real-time or soon after consumption, so that users can link their behaviors to their outcomes (Abrahamse et al., 2005; Roberts & Baker, 2003; Vine et al., 2013). PMUI shows computer states (active, idle, off, and sleep) both currently and in different temporal resolutions (hourly, half-day, daily, weekly, monthly).

Specificity of Feedback

Feedback is more useful when it provides users with specific, actionable information. For instance, feedback about energy usage for a user's apartment or dorm room is more informative than energy usage for the entire building. Likewise, if feedback is specific to certain energy uses (such as HVAC) or individual appliances, this helps users identify what they could do to save energy (Electric Power Research Institute, 2009; Fischer, 2008; Karjalainen, 2011). This concept motivates personalized recommendations included in home energy audits, appliance-specific metering, and efforts to disaggregate smart meter data to fine-tune home energy reporting (Armel, Gupta, Shrimali, & Albert, 2013; Gupta & Chakravarty, 2013). PMUI provides feedback specific to a single device and offers clear instructions for how to reduce energy use for this device.

Visual Presentation of the Data

Data should be clearly and simply presented, preferably in graphical form rather than tables, and multiple formats should be used to appeal to users with different preferences (Fischer, 2008; Murugesan et al., 2015; Roberts & Baker, 2003). PMUI offers multiple types of graphs for feedback reports (specifically: pie chart, bar chart, interval graph, and line graph), allowing users to check their usage from different perspectives. It also engages users with pictorial representations (including emoticons, trees, exhaust fumes, cars). The sleep settings are also displayed graphically, making them clear and easy to understand.

Historical Comparisons

Savings can be motivated by historical comparisons which display how the user's energy consumption has varied over time; for instance, this month compared to the same month last year (Roberts and Baker, 2003; Darby, 2006). Studies have shown that many users prefer this format, as it can reward improvements (Canfield et al., 2017; Karjalainen, 2011). PMUI allows users to compare their current and past computer states and directly connects past changes in sleep settings with corresponding changes in idle time.

Social Comparisons

Savings can also be motivated by comparisons to similar users. However, this approach may backfire and produce a boomerang effect for those who are doing much better than others (Schultz et al., 2007): those who learn they are much more efficient than their neighbors may feel they can afford to indulge in energy-inefficient behaviors (Buchanan et al., 2015; Byrne et al., 2018). The PMUI application could not employ comparisons to other users due to the competing priority of making the final application capable of standalone use. That is, users will not need to be customers of a particular utility, members of an organization, or signed up along with their neighbors in order to use PMUI. This is intended to expand the scope of users who will be able to download and benefit from the application once it is finalized and available to the public.

Comparisons to a Standard

Goal setting is an important part of successful feedback, as feedback by itself represents neutral information (McCalley & Midden, 2002). Individuals can use feedback to achieve goals by comparing their actual performance to an ideal outcome. Historical and social comparisons are thought to operate by implying goals: that is, by motivating users to improve compared to their own past performance or relative to similar neighbors. A goal can also be derived by comparing one’s performance to an internally or externally set standard (Karlin et al., 2015; Kluger & DeNisi, 1996). PMUI provides an external standard in the form of an "Energy Saver Target Profile" to which it compares the idle time of the user's computer.

Appealing to Values and Norms

Feedback is more likely to change behavior when it motivates users to change by appealing to personal values or social norms. For example, Schultz et al. (2007) found that including an emoticon (happy or sad face) conveying social approval or disapproval made study participants lower their consumption or, if they were already below average levels, keep it low. Delmas and Kaiser (2014) pre-tested various kinds of messages designed to activate users' values, to see which kind of information would motivate users most to conserve energy. They found that environmental messages (such as higher electricity usage translated to removing trees from the community, increasing carbon dioxide emissions from coal plants, and adding cars to the road) were a top reason to reduce energy use for 70 percent of their pretest sample. Results from intervention studies show that health-based messages and environmental messages may influence conservation behavior or the motivation to show pro-environmental behavior (O. I. Asensio & Delmas, 2015; Steinhorst & Klöckner, 2017). The PMUI software rewards low computer idle time with smiley-face emoticons and appeals to environmental values such as reducing pollution.

User Engagement

Finally, feedback only works if users pay attention to it, and keep paying attention over time (Murtagh et al., 2013). To encourage this, feedback should be engaging and interactive (Fischer, 2008; Vine et al., 2013). The PMUI design is interactive, allowing users to engage with their feedback data by zooming in or out to smaller or larger time frames, and back and forth through their own usage history. Multiple types of graphical representation attempt to appeal to a wider range of users. Also, the interface provides hover text messages that give users additional information, rewarding them for engaging with the graphs, charts, and emoticons. Furthermore, to keep users engaged over time, a weekly pop-up reminder was built into the program, to encourage users to check their latest Usage Report.

User Interface

The design of the user interface was chosen based on current research on user behavior intervention studies and best practices in the field of human-computer interaction. The following main features are included in the application's design:

1. The interface is easy to access (while remaining nonintrusive) and easy to use (including focusing only on computer sleep and display sleep).
2. It encourages positive intrinsic motivation for energy efficient behaviors.
3. It provides direct and timely feedback to the user on how their selected settings affect their computer's idle time and energy use.

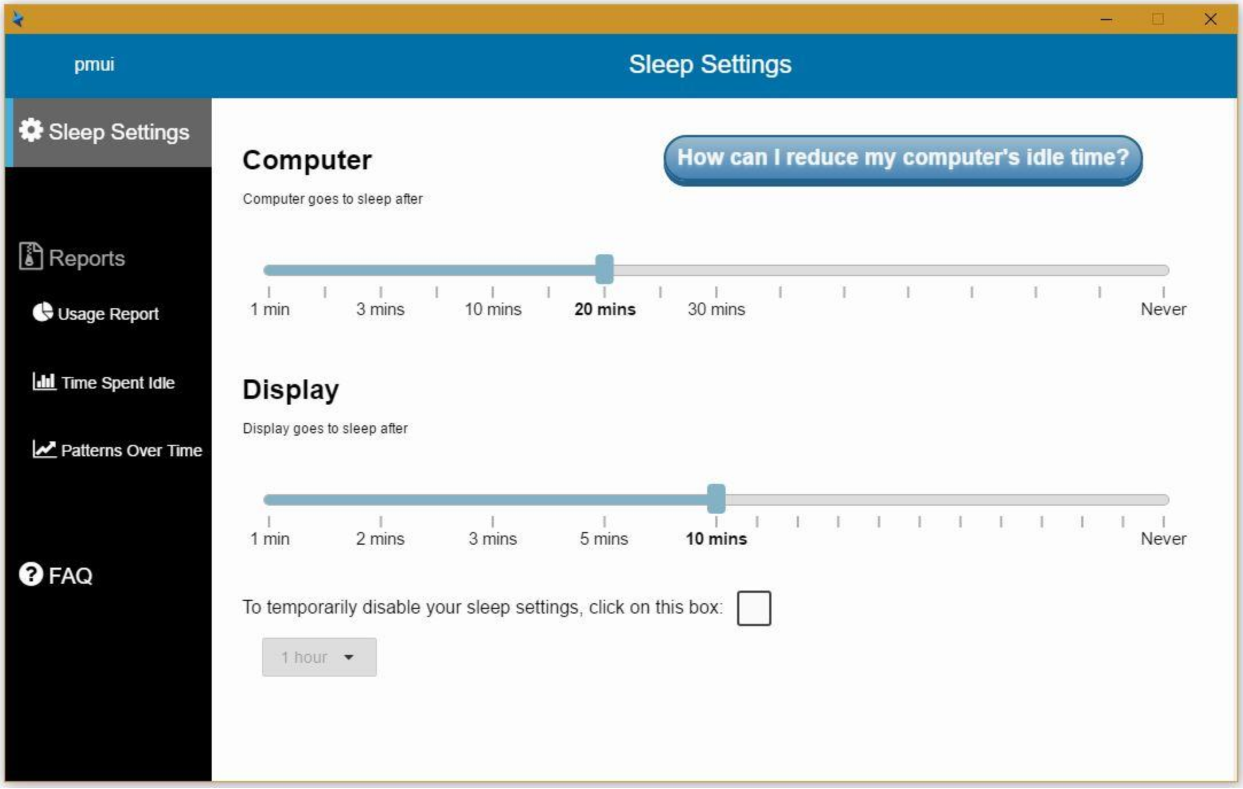
The interface consists of five pages: one page for sleep settings, three pages that report the user's data, and a Frequently Asked Questions page. On the report pages, the data collected by the PMUI app is used to generate charts and graphs as follows:

1. Pie Chart: used to show the percentages of idle, active, sleep, and off time in a given period.
2. Bar Graph: used to display time spent idle on each day of the week compared to the previous week.
3. Interval Graph: used to display the pattern of computer states over a given period.
4. Line graph: used to show the sleep delay time setting over a given period.

Sleep Settings

The *Sleep Settings* page includes three settings users can change: computer sleep settings, display (monitor) sleep settings, and an option for temporarily disabling sleep settings (see Figure 2). The computer and display sleep settings use slide bars, with the selected delay time indicated by a dark marker and a bold-face time. This design was chosen for its ease of understanding and ease of use. The program is linked to the computer system settings, so a change at either interface will appear in the other. The PMUI sleep settings include the same delay time options as the standard sleep settings on the Windows or Mac operating systems. This is necessary to maintain comparability across the two interfaces.

Figure 2: Sleep Settings Page



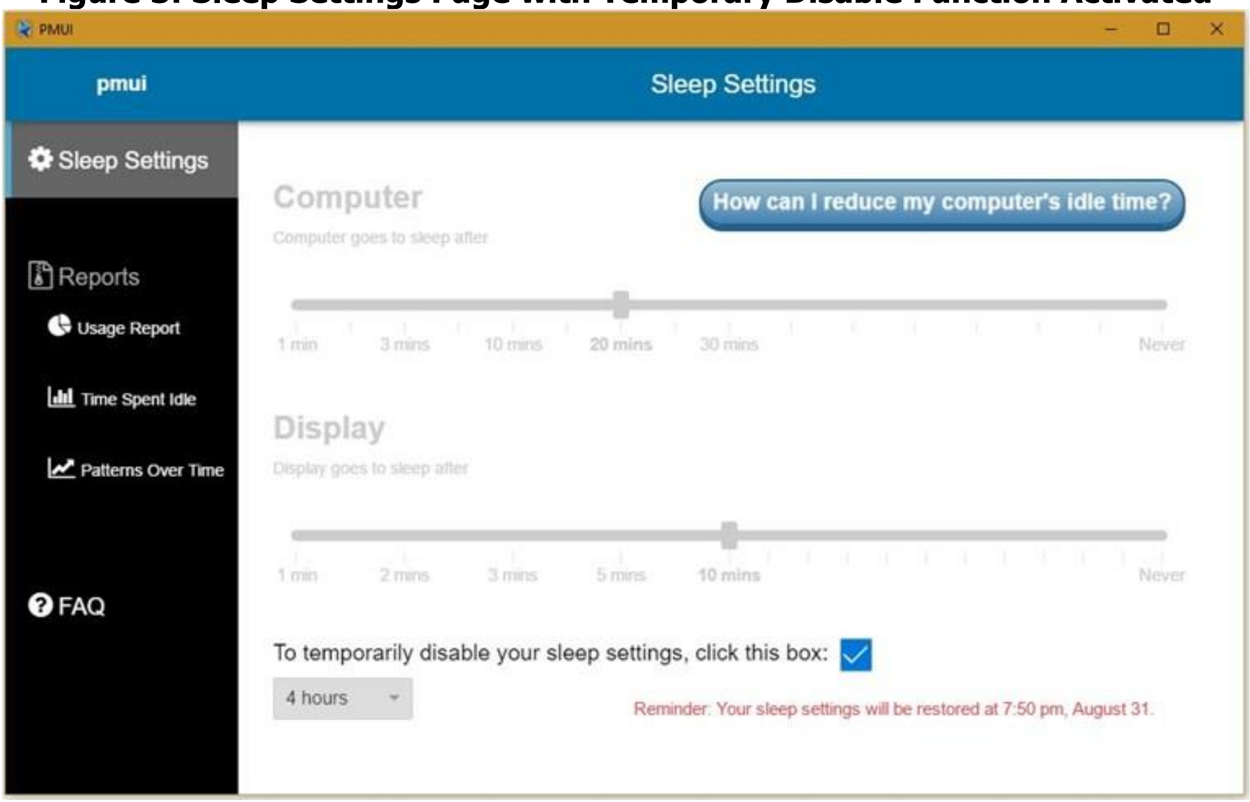
Source: Dr. Joy Pixley et al

The presentation of the sleep setting options in the PMUI program is designed to communicate to the user what the normal or desirable settings are. The normal delay time settings the research team chose to promote (30 minutes for computer, 10 minutes for display) are positioned in the middle of the slide bar. The shorter delay times to the left are visible (suggesting they are preferable options) while the longer delay times to the right are not seen unless the user clicks on them. This design was based on research suggesting that people prefer to think of themselves as normal or average if not better than average, and find it aversive to be worse than average. This echoes a classic effect witnessed in survey research: subjects offered response categories for reporting socially undesirable behavior (how many hours of television do you watch per week) tend to choose the middle or lower answer, regardless of the actual range of answers, in theory because they interpret the middle category to be average (Schwarz, Hippler, Deutsch, & Strack, 1985). Thus, PMUI users should be subtly encouraged to choose the middle (normal) delay time or an even shorter delay time.

Different hover box texts are shown when the user moves the mouse to the button "How can I reduce my computer's idle time?" depending on the current computer sleep settings. If computer sleep settings are disabled, the message reads, "Enabling your computer sleep settings is the best way to reduce computer idle time and save energy. Tip: Try setting the computer's sleep delay to 30 minutes or less." If computer sleep is enabled but the sleep delay is higher than twenty minutes, the message reads: "Lowering the amount of time until your computer goes to sleep will reduce the time your computer is left idle, and thus save energy. Tip: Try reducing the computer's sleep delay to 20 minutes or less." If the computer's sleep delay is set at twenty minutes or lower, the same message is shown except the tip suggests "10 minutes or less."

The Sleep Settings page also allows users to disable sleep settings for a certain time period if they wish to do so. This novel feature is not provided in the native applications of Windows and Mac operating systems. The option for temporarily disabling sleep settings was included based on the notion that users may disable their sleep settings because they are worried their computer will transition to sleep mode while being used, such as while they are giving a presentation, downloading large files, or running a complex analysis. If they disable the sleep settings, they could easily forget to re-enable them later. By putting the option for temporarily disabling the sleep settings on the same page as the settings, this feature should discourage users from disabling the sleep settings in such situations. Instead, they can select a time frame (1 hour, 2 hours, 4 hours, 8 hours, 1 day, 2 day, or 3 days) and click the box. While the settings are disabled, the computer and display settings are grayed out, and a message appears notifying the user of when the settings will resume (Figure 3). The user can unclick the check box to re-engage the sleep settings at any time.

Figure 3: Sleep Settings Page with Temporary Disable Function Activated



Source: Joy Pixley et al

Reports

Three report pages were designed to give users a wide variety of feedback on their usage patterns, and to help keep them get engaged and interact with the program. The program's feedback is limited by the standalone nature of the program: it can only report on data it collects from the computer itself and not, for instance, data on their utility company rates. The PMUI reports use data on the computer states, or more precisely, the combination of computer and user states. The PMUI program records the computer as being on, in sleep mode, or off. Whenever the computer is on, it is recorded as being actively used (mouse or keyboard activity) or idle. There are brief periods of unknown time when the computer turns on or wakes from sleep but cannot yet record user activity, or when the computer state cannot be determined for some other reason. In testing, these periods were usually less than one minute; for the feedback reports, brief periods spent in unknown states are ignored and the prior state is extended to fill the time. Longer periods of unknown are shown in gray, and indicate the need for troubleshooting.

The reports give feedback only on observed usage of the computer, not the display. This decision was deemed reasonable because prior investigation by this research team showed high rates of engagement for display sleep settings. This also simplifies the interface by reducing the number of charts shown by half.

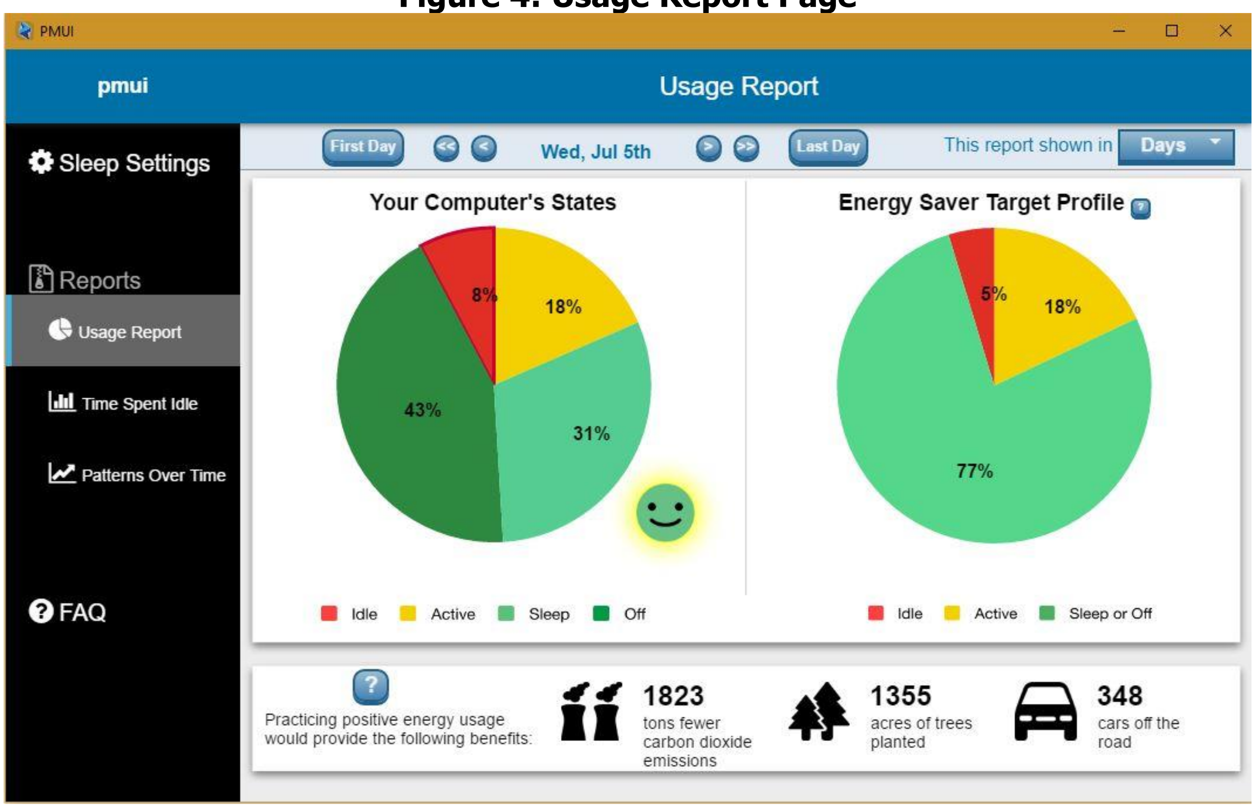
One report shows patterns on a weekly basis, while the other two allow the user to change the units of time shown (days, weeks, months). All three reports allow the user to change which dates are shown to scan backward and forward in time to observe any changes in behavior and outcomes. These features were included to increase possibilities for user interaction with the program and allow the user to compare current and past outcomes.

This section first describes the types of graphs shown in each report page, and then some of the features that are common across the reports.

Usage Report

The Usage Report page shows one pie chart with the user's computer states for a given day, week, or month (Figure 4).

Figure 4: Usage Report Page



Source: Joy Pixley et al

Specifically, it shows the percentage of time the computer spent in the four defined usage states: idle, active, sleep, and off. A second pie chart is labeled "Energy Savings Target

Profile," and serves as a comparison standard. The target profile numbers were generated by simulating the percentages of idle and sleep time that would result, on average, if the computer was set to a sleep delay of 10 minutes and showed the same amount of active time as the user's profile. This target was chosen to be challenging while allowing positive feedback to be reachable for most users. The target profile pie chart combines sleep and off time in one pie wedge to avoid either advocating or penalizing the option of shutting down the computer. An emoticon appears in the left box to indicate the comparison of the user's computer idle time to that of the Energy Saver Target Profile. The rules for showing happy versus sad faces are explained in the "Motivating Energy Savings" section.

Color coding is used to suggest positive or negative valence (intrinsic goodness or badness) for the states shown in the pie charts. The attractive or desirable states (sleep, off, or either) are shown in green, which is associated with "green energy" and also with "go" as a stoplight analogy. Idle time is presented as red, which is associated with "stop" in the stoplight analogy, as well as with red-lining and needing correction.

A hover text box is keyed to the red "idle time" pie wedge which explains that lowering the amount of time until the computer goes to sleep will reduce idle time and offers a link to the Sleep Settings page. Another hover text box appears if the user puts the cursor over the emoticon, which gives additional feedback and offers a link to the Sleep Settings page. These messages are explained in more detail in the next section.

A third hover text box is keyed to a question mark near the Energy Saver Target Profile and reads, "What is this?" Clicking the link takes the user to the relevant FAQ answer.

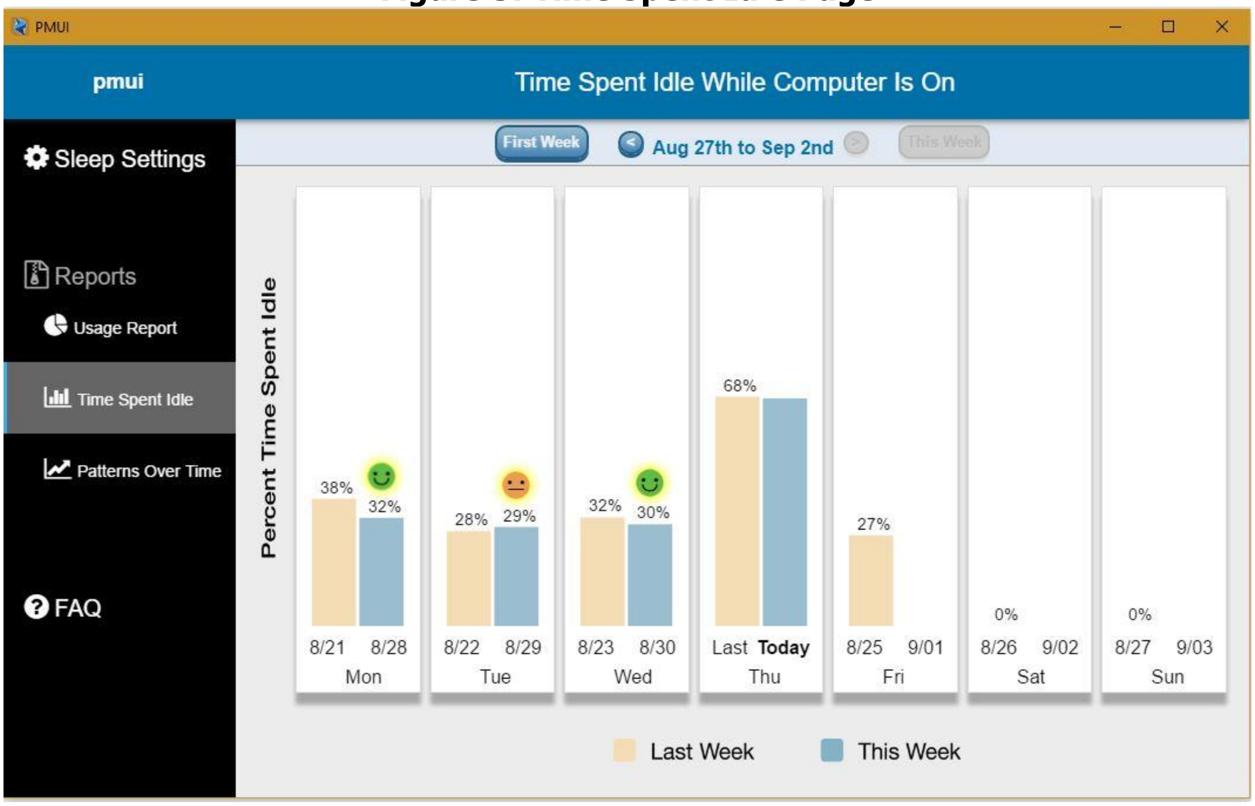
A pull-down menu allows the user to look at these pie charts by day, week, or month. As the pie chart shows a percentage, it must have data for the full period shown, so the most recent full day will be the previous day and the most recent full week will be the previous Monday through Sunday. Navigation arrows and buttons at the top of the page allow the user to move back and forth across the period PMUI has recorded so far. For instance, in "day" mode, the user can return to the first day and then jump back to the last day, use the single arrows to move back and forth one day at a time, or use the double arrows to jump forward or backward one week to compare the same day of the week (such as comparing one Friday to previous Fridays). The double arrows are only available in day mode.

The bottom panel of the Usage Report page displays the social benefits of energy efficiency; this is discussed in the "Motivating Energy Savings" section.

Time Spent Idle

The Time Spent Idle page presents the percentage of time spent idle when the computer is on: that is, how much idle time is exhibited compared to active time (Figure 5). It compares each day in the current week to the same day in the previous week. This report isolates the energy-wasting state the user should be trying to minimize and identifies whether more idle time is accrued (and more energy wasted) on certain days of the week, or in certain weeks. Navigation buttons at the top allow users to move back and forth to compare earlier weeks.

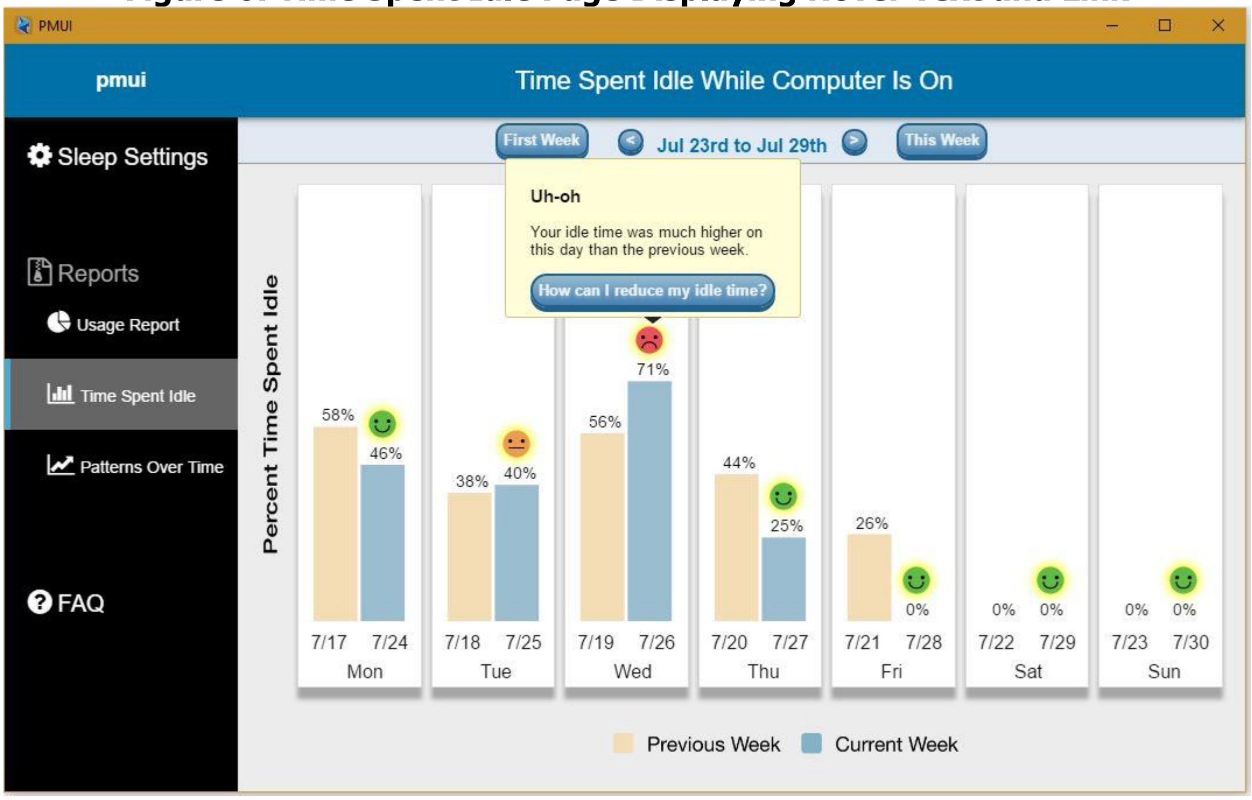
Figure 5: Time Spent Idle Page



Source: Joy Pixley et al

Depending on the comparison to the idle time on that day in the previous week, the page shows one of three emoticons (big smile, neutral, or big frown). Moving the mouse over the emoticon results in a hover box with a value response and a link to the Sleep Settings page, as shown in Figure 6.

Figure 6: Time Spent Idle Page Displaying Hover Text and Link

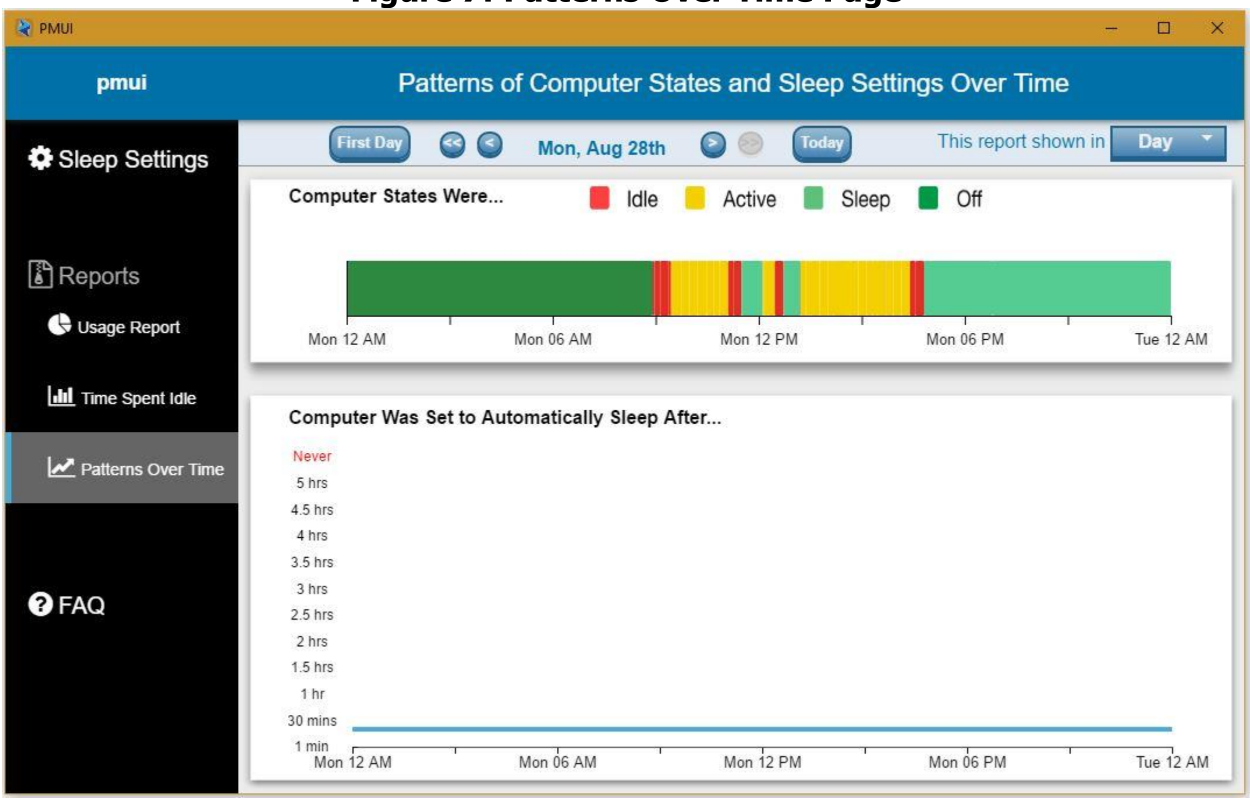


Source: Joy Pixley et al

Patterns Over Time

The Patterns Over Time page has two panels (Figure 7). The computer-states bar is an interval graph showing the periods the computer spent in the four possible states (idle, active, sleep, off) across the time span shown. The sleep settings line graph shows what delay time was set for the computer sleep settings (including "never") at any given time across the same time span. Showing these two graphs together allows users to compare how a prior change in sleep settings affected the pattern of computer states, such as periods spent in idle versus sleep.

Figure 7: Patterns Over Time Page

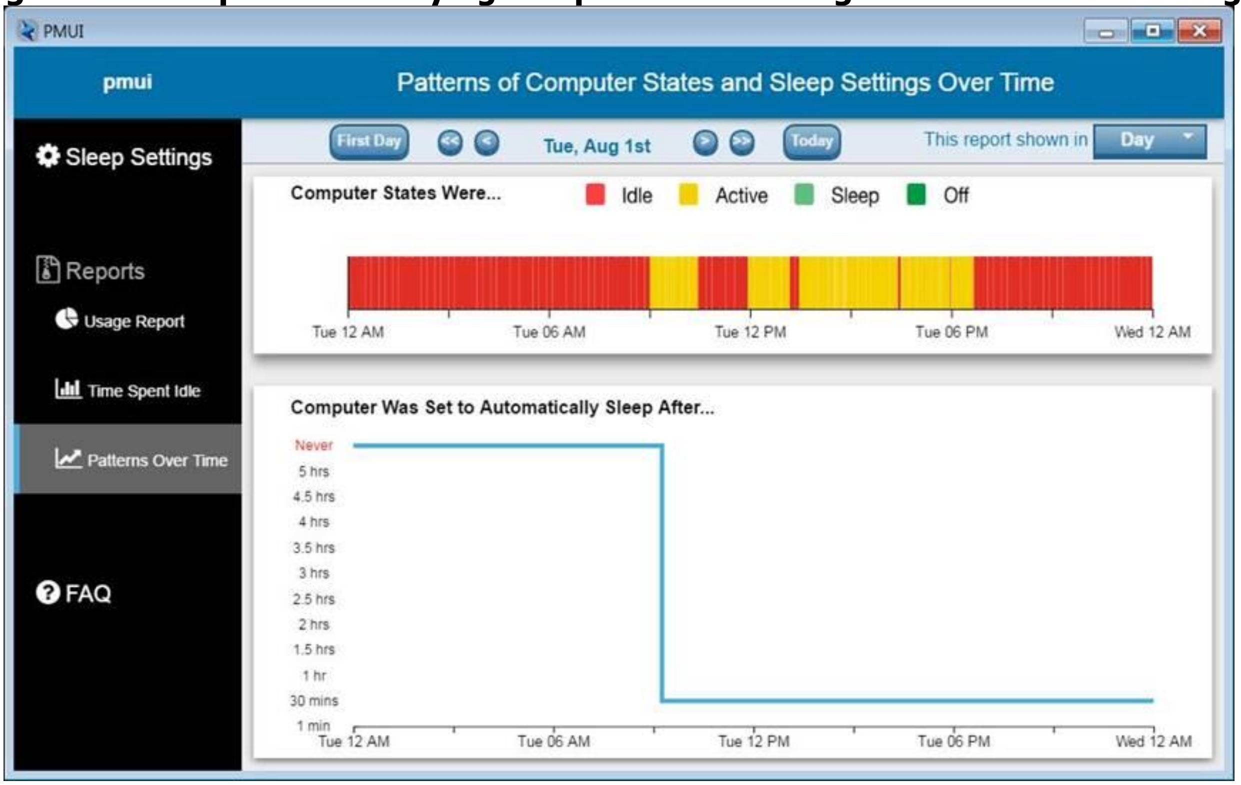


Source: Joy Pixley et al

This graph can be seen at five levels of granularity: month, week, day, half-day, or hour. Clicking at any point on the states bar zooms the view to the next lowest level (from day to half-day) to get a closer look at specific transitions between states. As with the other report graphs, navigation buttons at the top can be used to compare across time periods.

The computer-states bar also helps users identify periods when their computer is not behaving as expected; for instance, if the computer is waking up in the middle of the night for updates and then not returning to sleep mode, or if it never goes to sleep despite having computer sleep settings enabled (Figure 8). The current version of the PMUI program does not suggest any solutions for these problems but providing users with information can spur them to investigate further, or to ask an IT manager for help, as witnessed during the field test.

Figure 8: Example of Identifying Sleep Problems Using Patterns Over Time Page

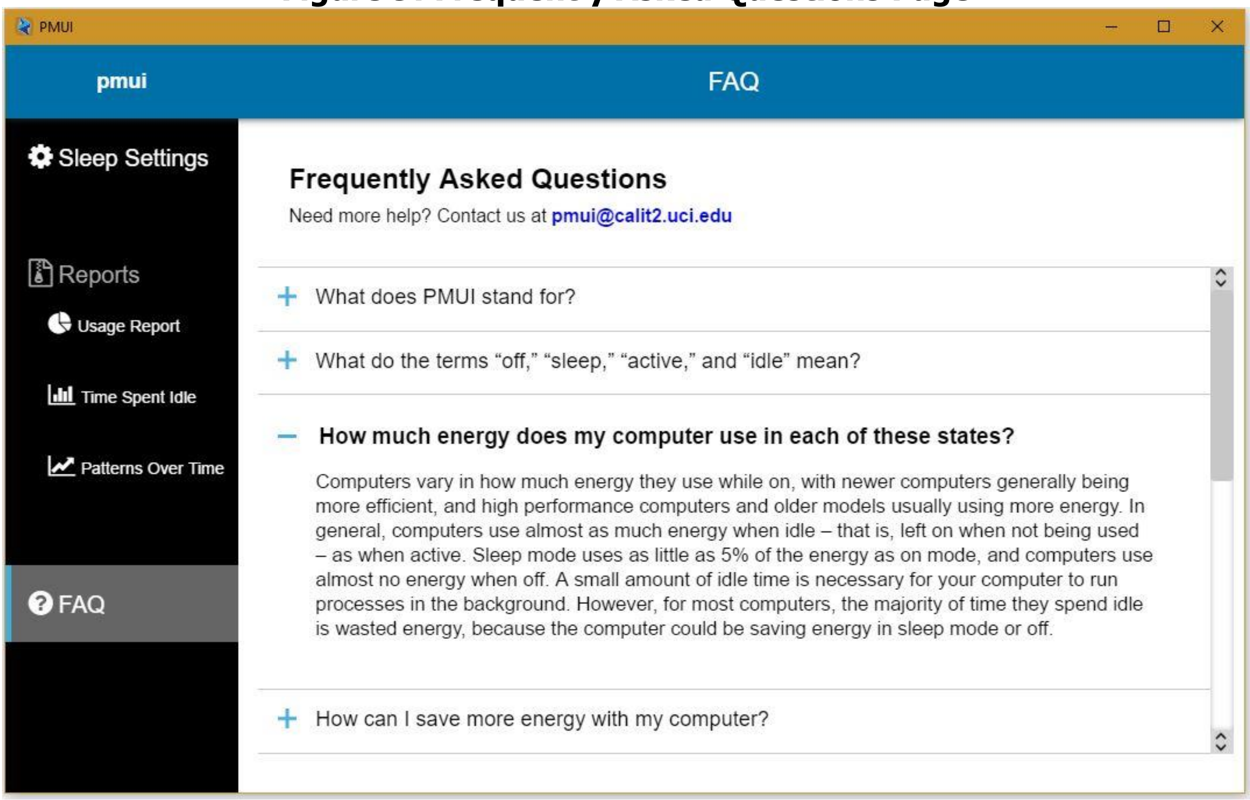


Source: Joy Pixley et al

Frequently Asked Questions

The last page is a help page titled Frequently Asked Questions, or FAQs (Figure 9). This section answers questions about saving energy, provides basic documentation to users to clarify how to use the program, and offers an email for submitting questions or complaints. The full list of FAQs is included in Appendix A.

Figure 9: Frequently Asked Questions Page



Source: Joy Pixley et al

Motivating Energy Savings

Communicating Energy Use

As noted above, the program is limited to presenting information it can collect from the user's computer. As such, it cannot measure and report the computer's actual energy consumption. Instead, the PMUI program focuses on reducing computer idle time, as the computer could potentially be saving energy during these periods by being in a low-power mode. The message that idle time is bad and should be reduced is persistent throughout the user interface. For instance, idle time is represented as red (negative associations), and the Sleep Settings page has a button titled, "How can I reduce my computer's idle time?"

The FAQ page deals more directly with energy savings, including answers to questions such as "How much energy does my computer use in each of these states?" and "How can I save more energy with my computer?"

Emoticons

Two of the report pages use emoticons (happy or sad faces) to readily convey to users whether their computer is spending too much time idle and to encourage more energy-efficient behavior. On the Usage Report page, the emoticon responds to the comparison between the percentage of idle time observed for the time period shown (such as the past week, or a particular day) with the percentage of idle time for the matched Energy Saver Target Profile. There are five levels: a big smile (up to 3 percentage points higher than the target), a small smile (up to 10 percentage points higher), a neutral or flat smile (up to 20 percentage points higher), a small frown (up to 30 percentage points higher), and a big frown (more than 30 percentage points higher than the target). To further communicate the features of the icon, the colors of a stoplight are used, consistent with the use of these colors for the pie chart: the happy faces are green, the sad faces are red, and the neutral face is yellow. In the laboratory pretest, subjects did not always notice the emoticon icon on the page, so the programmers added a halo, or highlighting, effect to make it more conspicuous.

On the Time Spent Idle page, the percentage of idle time for each day is compared to the same day in the prior week. Three levels of emoticons are used, depending on whether idle time is lower or higher: a big smile (same or lower), a neutral or flat smile (1 to 5 percentage points higher), and a big frown (more than 5 percentage points higher). The calculation rounded the difference to a whole number, so there are no values between "same" and 1 percentage point higher.

For both reports, the emoticons have hover boxes that clarify the message. For instance, on the Usage Report page, moving the cursor over the emoticon comparing the user's states with the Energy Saver Target Profile produces the following messages, each followed by a link button labeled "Open Sleep Settings":

- Big green smile or small green smile: "Good job! You're a real Energy Saver! Your idle time is similar to the Energy Saver target."
- Neutral yellow face: "Not bad! Your idle time was still higher than the Energy Saver target, though. You could save more energy by reducing your idle time."
- Small red frown or big red frown: "Uh-oh! Your idle time was higher than the Energy Saver target. You could save energy by reducing your idle time."

On the Time Spent Idle page, moving the cursor over the emoticon comparing the idle time for one day with the same day last week produces the following messages:

- Big green smile: "Good job! Your idle time was the same or lower on this day than the previous week."
- Neutral yellow face: "Not bad! Your idle time was a little higher on this day than the previous week."
- Big red frown: "Uh-oh! Your idle time was much higher on this day than the previous week."

The neutral and frown faces are followed by a link button labeled "How can I reduce my idle time?" which takes the user to the Sleep Settings page.

Broader Social Benefit Messages

Research indicates that people may be motivated to save energy if they believe their actions have a broader environmental or social benefit (Omar Isaac Asensio & Delmas, 2016; Spence, Leygue, Bedwell, & O'Malley, 2014). PMUI mentions three such effects: tons of fewer carbon dioxide emissions, the equivalent of how many acres of trees planted, and the equivalent of how many cars off the road. On the Usage Behavior report, these three effects are shown with easy-to-understand icons (as well as text), with the message: "Practicing positive energy usage would provide the following benefits." A question mark tooltip explains what the numbers mean in more detail: "The perks: Reducing your current idle time to the Energy Saver Target Profile would save energy. If only 10 percent of Californians did the same thing, the energy saved per year would be the equivalent of the benefits listed here. Imagine if even more did! Every computer counts!" This message was designed to invoke both a social responsibility norm and a social comparison norm.

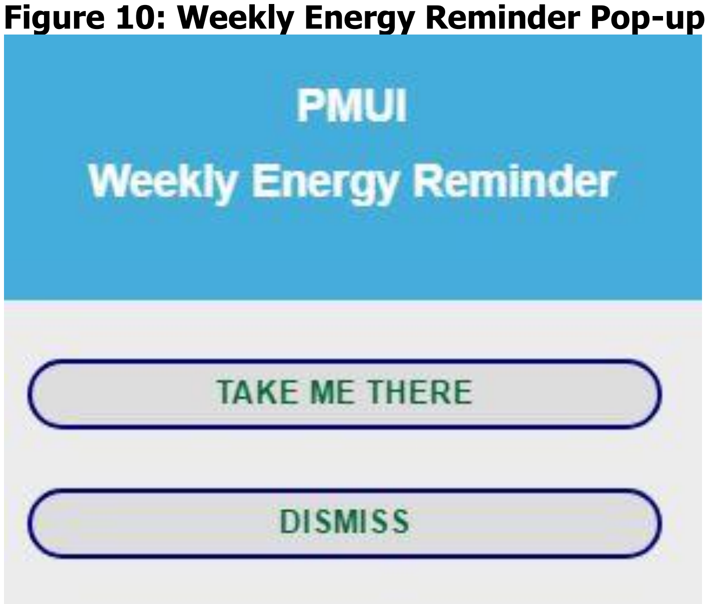
The numbers for the environmental equivalents were based on the ENERGY STAR Computer Power Management Savings Calculator, which links kWh to the three broader social benefits listed above. ENERGY STAR estimates of power consumption in each mode (on/idle, sleep, and off) for typical desktops (not ENERGY STAR-compliant) were used to calculate the estimated kWh for every possible Energy Saver Target Profile, and also for the user's computer states. Using an estimate of 2,900,000 desktop computers in California, 10 percent is 29,000, which is used to multiply the (relatively small) number of kWh saved per year for each computer to illustrate the broader consequences.

Access and Engagement

Users can access the software at any time using the system tray icon or their program menu; these actions open the program to the sleep settings page. This design was intended to simplify the procedure of reaching the sleep settings, compared to multiple clicks needed for the standard settings in Windows operating systems.

Feedback systems designed to change behavior face the challenge of keeping users engaged with the interface over time without interfering or annoying them. A weekly reminder pop-up was used to encourage continued engagement with the program over time (Figure 10).

Figure 10: Weekly Energy Reminder Pop-up



Source: Joy Pixley et al

The pop-up appears Monday mornings at 10:00 a.m. If the user clicks on the "Take Me There" button, PMUI opens to the Usage Report page, set to the previous week (from the previous Monday to Sunday). If the user clicks the "Dismiss" button, the pop-up disappears. The original plan was to have the pop-up automatically disappear after a certain period, but this would mean that users not at their computers at 10:00 a.m. would routinely miss the message. An option for users to turn off the reminder function is included, via a check box in the FAQ item titled, "Can I disable the weekly energy reminder popups?"

Software Development

The software development was constrained by priorities of the research process and the planned final application, and by standard security protocols of the university.

1. PMUI was designed to look and function similarly on both Windows and Mac operating systems, and to include as many older versions as possible. The team programmed PMUI to function on Windows versions 7, 8, and 10, and on Mac versions from OS X Yosemite to macOS Sierra.
2. PMUI used only free or open-source programming components, so that the final version can be more directly distributed and adapted.
3. The research version of PMUI was programmed to transmit data to CalPlug's secure servers; this function can be easily removed for the future, deployable version.
4. The research version of PMUI was programmed to not automatically display the user interface, but to allow the software to collect data in the background during the baseline data collection period, and to continue to do so for the control subjects.
5. The PMUI application was pretested in a human-subjects lab, and changes were made to the interface based on subjects' responses to walk-throughs and comprehension tests.
6. The PMUI team submitted extensive testing results and protocol reports to UCI's Office of Information Technology, which vetted the software before allowing it to be used on university computers.

Data Structure

The PMUI application requires an intensive data-collection framework. The application needs to not only inform users how well they are doing in terms of saving energy, but to report data to the PMUI server that will improve the understanding of the application's performance and the users' habits. The PMUI application collects the following data:

1. Timestamps for when the computer transitions to each state: idle, active, sleep, and off.
2. Any changes in power-management settings (computer sleep and display sleep).
3. Current delay set for computer and display sleep settings (in minutes).
4. When the user runs the app and when it is closed.
5. When specific pages of the PMUI app are accessed by the user.
6. When the user toggles the "Temporarily Disable Sleep Settings" box on the Sleep Settings page.

7. How long the sleep settings were temporarily disabled using the “Temporarily Disable Sleep Settings” feature.
8. Internal processes of the PMUI software, such as when the user interface was activated and whether and when the weekly reminder pop-up was sent.
9. Computer-state data, so that the charts can be generated.

In determining computer states, no distinction is made between short-idle or long-idle. For the purposes of research, idle is measured as any time the computer is on with no keystroke or mouse activity for one minute. Thus, it captures short-idle as well as long-idle, although they are grouped together in the data. For the purposes of calculating and displaying results to the user for the Usage Report and Time Spent Idle pages, idle is measured as no keystroke or mouse activity for ten minutes. This decision was made to provide a cushion so that users did not feel penalized for short-idle time that naturally occurs during active use. For the Patterns Over Time page, periods are presented down to the minute.

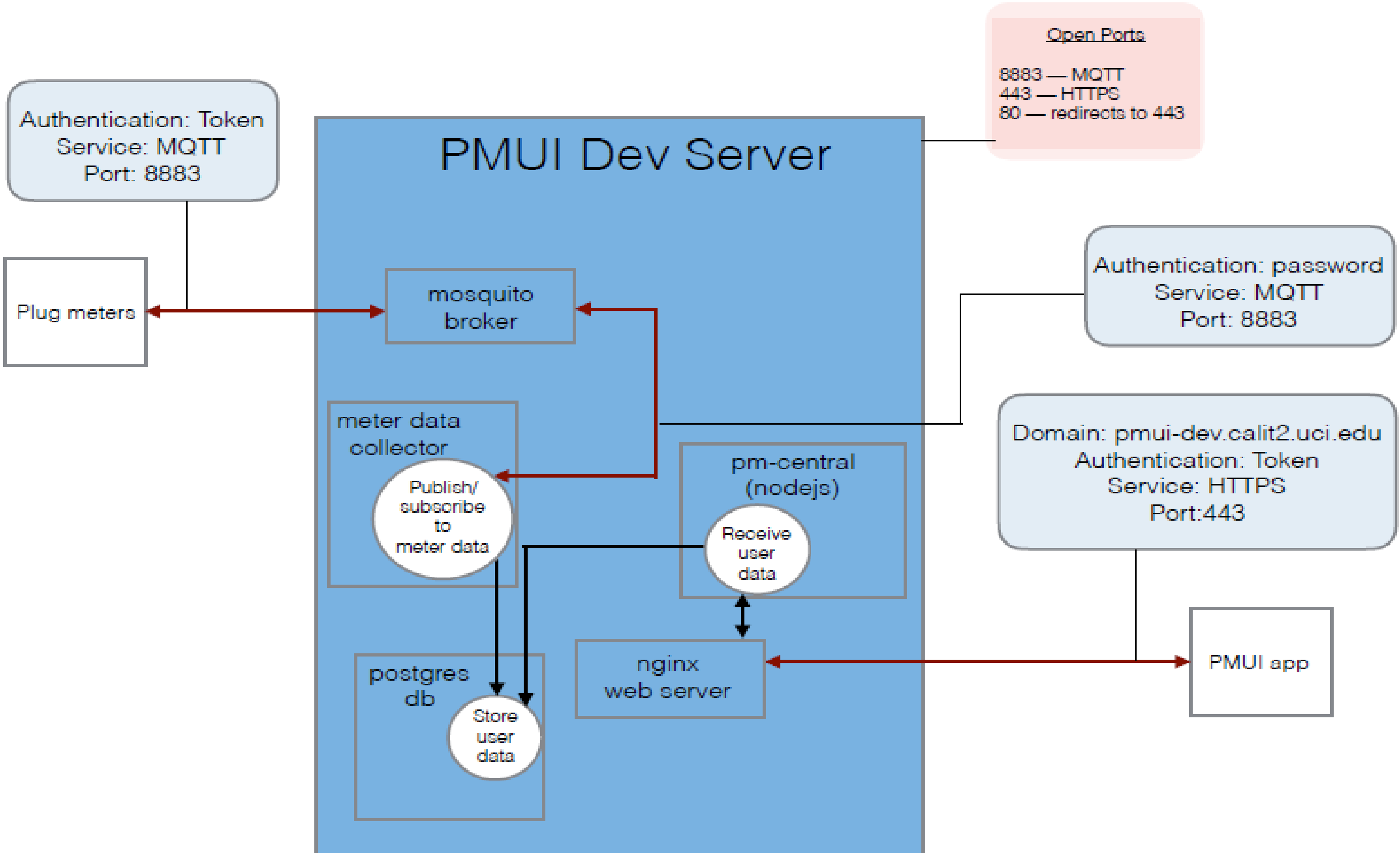
The software also does not distinguish between the various levels of sleep outlined by the standards of the Advanced Configuration and Power Interface (ACPI), counting the initial transition into sleep mode only. Unfortunately, hibernation (ACPI state S4) could not be distinguished from soft off state (ACPI state G2/S5). As energy consumption is similar for those states, the associated plug meter data cannot be used to retroactively infer hibernation.

PMUI also collects data on what programs might prevent the computer from going to sleep if sleep is enabled. In some cases, this may indicate user activity, such as when users are watching a video. In other cases, it may indicate a bug. For Windows OS computers, a command line query asks the Windows OS specifically for what processes are blocking sleep. However, the query requires administrator privileges every time it is run, and thus could not be implemented in the software. Instead, if the computer sleep settings are enabled and yet the computer has been idle longer than the set delay time, the PMUI program records which programs are currently running in Task Manager. For Mac OS computers, PMUI can record which programs are preventing the computer from transitioning to sleep.

Data Flow

The data collected by the software applications and the plug meters is managed by the PMUI central server. The server uses several services and technologies, such as PostgreSQL, MySQL, MQTT, NodeJS, JavaScript and Python, to collect and store the information needed (Figure 11). All data transfers are encrypted through Secure Sockets Layer.

Figure 11: Data Flow



Source: Joy Pixley et al

Software Implementation

The application was developed based on the design of the graphical user interface and the requested features. The application links to the native Windows or Mac operating system's power management in a bi-directional way, so that a settings change made using either interface (native or PMUI) is reflected in the other.

There are two major parts to the PMUI application: the graphical user interface (GUI) and the event listener subprocess. The PMUI GUI was built using Electron, a cross-platform desktop application framework. The main technologies used were HTML, CSS (frontend application), and JavaScript. The PMUI GUI application plays many roles: it administers and communicates with the event listener subprocess, it sends data to the server, and it displays an interactive interface to the user. The interactive interface has five pages: Settings, Usage Report, Time Spent Idle, Patterns Over Time, and FAQs. All of the slider and chart components are built from the D3 (Data-Driven Documents) JavaScript API. The event listener subprocess is a console application, written in C# for Windows and Swift for Mac, that runs in the background to collect computer-state data. The event listener for Windows uses powercfg terminal commands to get and set the user's display and computer sleep settings and to determine what programs are blocking sleep. The event listener for Mac uses the pmset terminal command to get and set the user's display and computer sleep settings and to determine what programs are blocking sleep. Because pmset requires administrator privileges, the PMUI program obtains these permissions during install.

NodeJS and Python libraries were also used for the backend application. For a comprehensive list of libraries used by the PMUI app, see Appendix B.

The PMUI application uses a few of the standard JavaScript community tools for debugging and testing, and for code quality. The current repositories of the applications are stored in a UCI OIT GitHub at: https://github.oit.uci.edu/ETAD/pm-shell that contains the user side of the PMUI application, and https://github.oit.uci.edu/ETAD/pmcentral, which contains the server side of the PMUI framework.

Software Issues and Fixes

Charts did not represent the "unknown" state

The initial build did not account for displaying "unknown" state data, as it was assumed that such periods would be very brief and could be subsumed into the prior state for display purposes. However, large periods of "unknown" time were observed for some subjects, resulting in confusing charts. The software developers added "unknown" to the pie chart. They also added "unknown" bars to the Time Spent Idle charts because the users' idle time was not being represented correctly if they had had a period of unknown time during the day. Further, the "unknown" state had been broken on the Patterns Over Time chart and showed up black instead of gray, which was also fixed in a software update.

Missing data when logged out

Testing the PMUI software on a wide range of computers and operating systems produced only brief periods of time (usually less than one minute) when the computer state was unknown, such as when the computer had just been turned on. However, none of the tests were performed on computers where users logged in with a user profile. The software must be installed on the user's profile in order to access the power-management settings. However, when users logged off for the evening, PMUI was unable to access the computer to collect state data. This issue went unnoticed until the first round of treatment subjects had their user interface activated and later reported seeing long periods of gray (unknown) in their reports. The software team updated the software to read the system events from the OS system logs retroactively every time PMUI is launched, to fill in the missing sleep, off, and idle events.

Weekly reminder pop-ups

The reminders were intended to appear every Monday morning and to encourage subjects to click on the button to open the Energy Report page. They could instead click on a button to dismiss the message. Some of the first wave of subjects, faced with questions in the RV3 survey about various features of the software, reported that they had never seen the weekly reminder pop-up. Other subjects reported that the pop-up appeared for only a few seconds and then disappeared before they could click on it. This was determined to be an artifact of using the native operating system notifications. An updated version of the software used custom-built notification to overcome this issue.

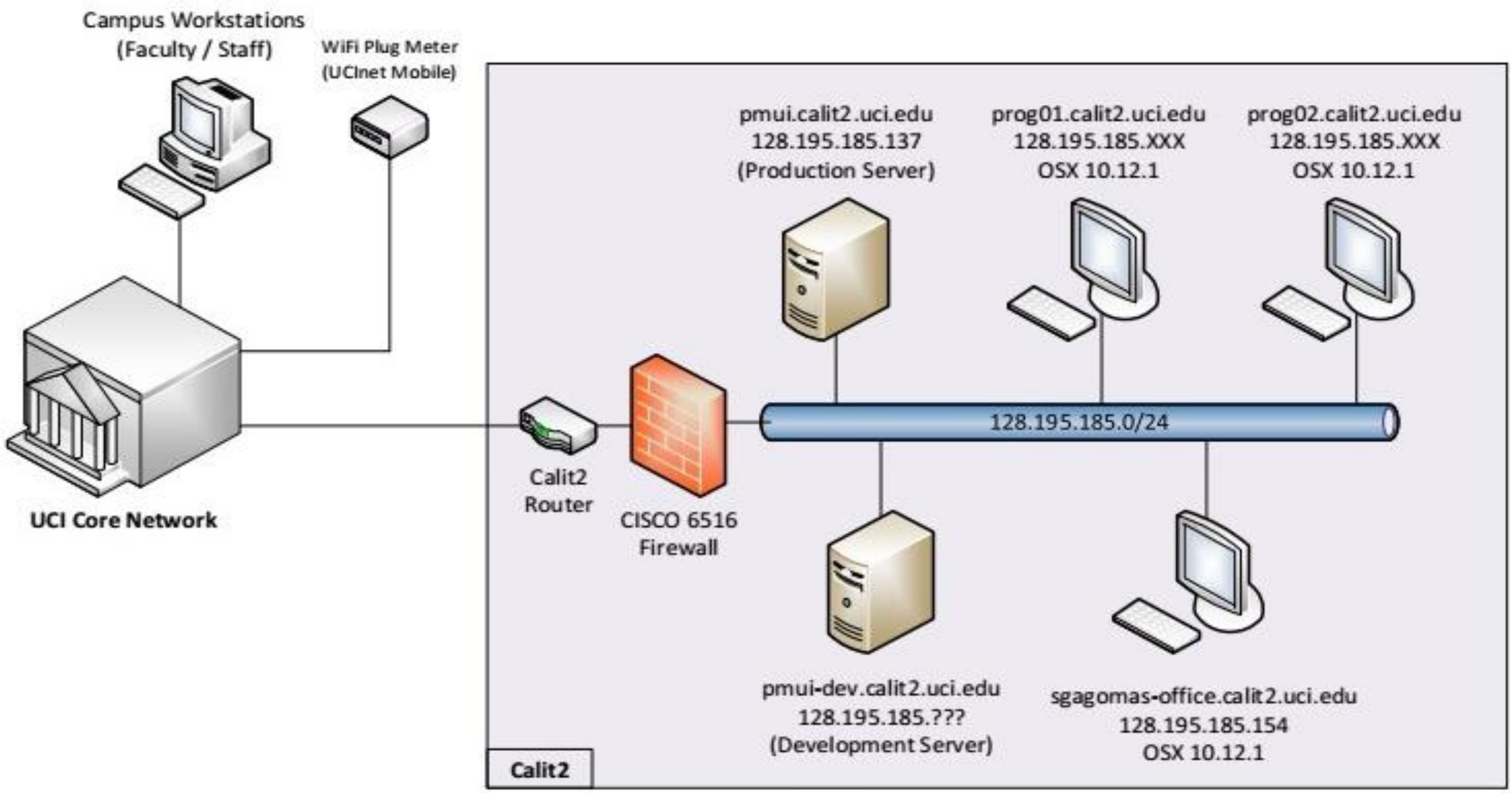
False idle periods

Some subjects reported observing idle periods in the Pattern Over Time page when they should have seen sleep periods. These proved difficult to diagnose, because some supposedly false idle periods were indeed idle periods, caused by computers that did not transition to sleep when they were supposed to. However, other false idle periods should have been coded as sleep; these were traced to sleep and idle events with the same timestamp, leading to PMUI miscoding the result. An updated version of the software addressed this by ignoring a false idle event if it occurred at the same time as a sleep event.

PMUI Network

The data network for PMUI that was used in the current study is shown in Figure 12. The data collected from the PMUI app and plug meters was transmitted to the PMUI central server in a secure and encrypted network. All data transmission occurred within the UCI Network. The PMUI server was located in the Calit2 building, in a server room. VMWare virtualization was used to run two servers, one for development and one for production. Images were stored in a secure network server. The PMUI servers were Linux-based.

Figure 12: PMUI Network



Source: Joy Pixley et al

Summary of Software Development

To summarize, the PMUI software design was based on current research about usage feedback and developed using free or open-source programming components. The software was thoroughly vetted by UCI's Office of Information Technology for security and functionality. After extensive testing before the field test, as well as with continual improvements during the field test, the software is fully functional as a research platform. However, some changes are necessary prior to distribution and further use:

- As with any software application, before further testing or distribution, PMUI must be updated to reflect any external changes since the last version, such as updates to Windows or Mac protocols.
- The data collection and report generation features functioned well during the field test. A few researchers retained the software on their own computers, providing a test period substantially longer than the three to four months of most subjects. The field test version of the PMUI software was only designed to accumulate and process up to six months of data. Although the program is still operating on several computers after more than two years, it exhibits long delays on opening and occasional grayed-out reports. A public version of PMUI would require implementing optimized data storage and retrieval methods to accommodate long-term use.
- To analyze the effectiveness of the user interface during the planned field-test study, the current version of the software was designed to transmit data on computer states and user activity to a secure server managed by the research team. For any non-research deployment, PMUI must first be modified to remove this research mode.
- One bug was identified toward the end of the field test that the software development team has not been able to solve. When computers have very short delay times before transitioning to sleep (less than five minutes), PMUI shuts down before registering the sleep event, and subsequent time is recorded as idle. This does not affect many computers, but it should be addressed.

Other modifications or additions are optional but recommended by the research team. Field test subjects were asked for feedback about the various functions and pages of the user interface, and the program collected data about how often the application's functions and pages were used. The research team also made its own observations of the functionality of the interface and received valuable suggestions from the Technical Advisory Committee that could not be incorporated into the current version in its current scope. Based on this information, CalPlug recommends the following revisions of the user interface that could more fully engage and encourage users:

- Program the frequency of the weekly reminders to be dynamic, responding to whether the user has recently looked at the PMUI program and whether the sleep settings are enabled; this should reduce the chance that users are annoyed by frequent reminders even when their sleep settings are already efficient. Consider also flexible timing, as some users may prefer reminders on other days of the week.
- Rethink the Time Spent Idle page. Users may not understand presenting the percentage of time idle as a function of the amount of time on. Also, as usage and idle

times vary day by day and the comparison criteria is narrow, this page often presents neutral or sad emoticons even when overall usage is efficient.

- Consider the Technical Advisory Committee's suggestion of adding predictive feedback on settings: for example, predictions of how idle time would change depending on various sleep setting delay times the user is considering.
- Rethink how the environmental impact rewards on the Usage Report page are communicated. In the current version, the numbers represent the benefits users could make if they reduced their idle time, but this means the benefits appear greatest to the most inefficient users and disappear when users are already efficient. An alternate approach could reward users if they are meeting the Energy Saver Target profile goal by presenting higher environmental benefits.
- Give users actionable information on troubleshooting and solving problems with computer sleep. The Patterns Over Time page can identify problem periods when the computer is not sleeping even though sleep settings are enabled. It may be possible for PMUI to tell the user which background process is keeping the computer from transitioning to sleep.

The current version is designed for desktop computers, which were the focus of the field test. The same interface could be adapted for laptop computers with minor modifications to the sleep-settings page, to distinguish settings while plugged in versus while on battery power. However, user behavior for laptop computers is expected to differ enough from that of desktop computers that additional field testing would be recommended to estimate energy savings.

The intended end product of the required changes is a standalone application that can be distributed freely and used in a wide range of residential and enterprise settings. As with any application, it would require a dedicated team to maintain the integrity of the software, adapting it against new security threats, and keeping it compatible with operating system and other upgrades.

CHAPTER 3:
Field Test Methods

Recruitment

At UC Irvine, the Office of Information Technology (OIT) manages the computers of several administrative buildings and units. Other schools, centers, and units have their own IT management, leading to a variety of IT set-ups across campus. As the OIT had been working with the CalPlug team from the beginning, recruitment began with the employees under their management. Recruitment of other units involved contacting the IT managers and unit heads and asking for their cooperation. The final sample included administrative, research, facilities, and academic units.

Subjects were eligible if they met the following criteria: a university staff person 18 years or older, who was currently working on campus (not on leave) and was the sole user of a desktop computer on campus, and who had control over the power management of that computer. The original recruitment criteria also included faculty members, but it was difficult to establish a comparable baseline and experimental periods for that group, given the changes in work they experience across quarters. Control over power-management settings was screened ahead of time through discussions with the department head and/or IT manager. Participation was also limited to the operating systems the PMUI software functioned on, which eliminated all Linux users and anyone using systems prior to Windows 7 or Mac OS X Yosemite. The research team identified staff members affiliated with the selected department or unit through the university directory; some unit contacts assisted by providing a list of current emails for their staff.

Recruitment of subjects was conducted in waves, to stagger the use of research equipment and the scheduling of research assistants. First, the IT manager or department head was asked to send a standardized email to their staff members to let them know that they would be contacted about the study, that the study was legitimate and not a scam, and that participation was completely voluntary. Within days, CalPlug emailed the same potential subjects. A series of reminder emails were sent to non-responders.

The email explained the study and invited the potential subject to fill out an online scheduling survey to establish eligibility and facilitate scheduling. The project lead or the project coordinator contacted each potential subject to answer any additional questions and schedule the first appointment.

Procedures

Subjects were assigned a study-identification number, which was referenced throughout the study.

Research participation involved a minimum of three research visits, producing a baseline period of at least four weeks between the first and second visit and an intervention period of at least eight weeks prior to the third visit. Subjects were asked to report times when they were away from work for vacation or sick leave; those days were removed from the total count (and from the resulting data set), and the next research visit delayed as necessary.

University holidays were also not counted as valid days. For one subject, additional days removed after the fact reduced the number of valid baseline days to 27 (instead of 28). Three subjects had to leave the study early (changing jobs) and completed fewer than 56 days of intervention period (minimum of 35 days). The median number of valid study days was 37 for the baseline period and 68 for the intervention period.

At the first research visit (RV1), the research assistant handed the subject the informed consent form to read, clarify any questions, and sign. The research assistant asked the subject to close all programs on their computer, then installed the PMUI software on the computer. (In some units, the IT manager remotely installed the PMUI software instead.) At this point the PMUI software interface was not activated, so the subject could not access the software. The informed consent form explained the PMUI software using the following language:

> "The software will record the power states of your computer (active, idle, off, sleep) and power management settings during the study period. The software will record whether the computer is being actively used by you (any mouse or keyboard activity) or by other processes (for example, backups or security updates). It will not observe what you type, what web pages you visit, what files you open, or other potentially private information."

The research assistant shut down the computer to install the study hardware: a dedicated power strip to which the computer and its monitor(s) were plugged into, plugged in turn into a plug meter that measured energy consumption. At the end of RV1, as at the other two research visits, the research assistant gave the subject an Amazon gift card for $25.

Before the second research visit (RV2), subjects were assigned to treatment or control groups. The list of cases was divided into Windows and Mac lists and each was sorted by date of RV1; every fourth case was designated as a control case (producing three treatment subjects for every control subject). When new unassigned cases were added to the list, the pattern from the previous (assigned) list was continued. This quasi-randomization procedure was disrupted twice by the fact that a subject who would have been assigned to the control group worked closely with a treatment group subject and was thus switched to the treatment group as well.

At RV2, the research assistant handed the subject a tablet to fill out an online survey. For privacy, the research assistant asked the subject to close any programs on their computer before accessing it. For the treatment subjects, the research assistant activated the PMUI, and handed the subject an "updated Study information sheet" that explained this new aspect of the study. The document explained that the subjects could use the PMUI or not, "as you please." It also asked the treatment subjects not to discuss the interface with their coworkers, as they might be in the "comparison, or control group" and knowing about the interface might change their behavior.

To make the control group experience as similar as possible, at RV2 those subjects were shown how to access their regular sleep settings. Research assistants were specially trained to deal with the potentially awkward interaction, if subjects insisted they already knew and did not have to be shown, but no research assistants reported frustrated responses from subjects. As with the treatment subjects, if control subjects asked if they were supposed to change or use their sleep settings, the research assistants were trained to say, "You can if you want to, but you don't have to."

At the third and final research visit (RV3), research assistants again handed the subjects a tablet to fill out an online survey. They also uninstalled the PMUI hardware and PMUI software (or exited it, in cases where the IT manager had to uninstall it remotely after the visit).

As described below, additional visits between RV1 and RV3 were necessary for many subjects, for troubleshooting software or hardware problems or for re-installations when subjects moved offices or changed computers; in total, 159 of such "other" visits were scheduled. The next section describes the problems and issues during data collection in more detail.

Data Collection

Observational data

Two sources of observational data exist: data collected by the PMUI software and data collected by the plug meters.

The PMUI software collected on a continuous basis and transmitted to the CalPlug server the following types of data:

- The states of the computer (off, sleep, on and being actively used, on but user-idle)
- The current sleep settings (and any changes) for computer sleep and display sleep
- If the computer was set to go to sleep, but it was still idle:
    - For Windows, the processes that were currently running
    - For Macs, the processes that were specifically preventing sleep
- The subject's usage of the PMUI application

To supplement data collected by the software during the field test, researchers used study-specific power strips and plug meters to capture energy consumption. It was not feasible to measure energy use by the desktop computer and monitors separately. The study team decided to measure the combined energy consumption of the computer and any monitors controlled by it to capture the full impact of power-management settings. The plug meters collected and transmitted energy consumption data to the CalPlug server. It is important to clarify that energy-consumption data was collected independently of the PMUI app and was not reported to subjects as part of their feedback.

Self-Reported data

As described in the Procedures section, subjects filled out three surveys. For the wording of the survey questions used in the current report, see Appendix A.

The scheduling survey established eligibility criteria (age, university employment status, sole user of a desktop computer, computer operating system). Subjects were also asked for their office address, their IT manager, whether they thought they had administrative privileges on their computer, and a few possible times to schedule the first appointment.

Questions about power-management behaviors were not asked until the second research visit to avoid contaminating the baseline data. The RV2 survey reprised a series of questions about the subject's computer behavior that were originally tested and used in the Computer Power Management User Survey, conducted by CalPlug for an earlier project funded by the Energy

Commission (Pixley et al., 2014). These questions included what the subjects thought their computer's sleep settings were, whether they had ever changed their power-management settings, how often they turned their computers off or manually put them to sleep, and their reasons for doing so. The survey also asked for demographic information on gender, education, race and ethnicity, and occupation.

The RV3 survey asked subjects to rate the user-friendliness of the normal sleep settings on their computer. It also asked whether subjects had changed their sleep settings or their manual power-management behaviors (turning the computer off or putting it to sleep) during the study period and, if so, why. Many questions were asked only of the treatment group, and consisted of standardized scales and items for rating the PMUI. The control group was also asked whether they had figured out if they were in the control group before the end of the study, and if so, when.

Additional information was volunteered by the subjects over the course of the study, through emails to the study staff and in discussions with the research assistants (who were trained to write notes about any questions or comments from the subjects on the research visit interaction forms). The original informed consent form did not mention these statements as being usable data; partway through the study, the right to quote the subject was added to the informed consent form and required a separate signature. Almost all of the 118 subjects given the revised consent form agreed to be quoted (98 percent). The university's Institutional Review Board required CalPlug to send the prior 289 subjects a follow-up email asking for consent to quote or paraphrase their statements. Of those who responded, 97 percent agreed to be quoted, but 26 percent never replied and were treated as not giving permission to quote. Some of the subjects had finished the study months earlier and others were no longer working for the university, which reduced the response rate. In all, a subsample of 323 agreed to be quoted, or 79 percent of the total sample.

Data Collection Issues

During the first wave of the study the research team was confronted with unexpected software and hardware issues that led to several delays.

Software Data

As described in the software development section, the initial software version did not account for any "unknown" state data. This software glitch was found approximately one month after the first subjects' applications were installed; eight treatment subjects were potentially affected by this omission before it was fixed in the software. While waiting for this improved version to be completed, some treatment subjects' RV2 visits were delayed, so that the new version could be installed at that visit. All treatment subjects installed at that time (n=142) received a software update at their second research visit and new subjects received the updated version.

The initial version of the software was unable to collect data while users were logged off from their user profiles. In the first wave, 198 subjects were affected by this problem, which led to large amounts of missing state data for some of them, mostly for the evenings and weekends. All subjects experienced some unknown state data whenever the PMUI program was not running or could not collect state data from the computer. This ranged from a few seconds a day during routine restarts to hours or longer, such as when subjects accidentally exited the

PMUI program instead of closing it, or when PMUI was erroneously not installed into the startup folder, and did not start automatically upon restarting the computer. Energy data from the plug meters was used to infer whether the computers were idle, off, or in sleep mode during the unknown periods, by comparing the power consumption to periods where the state data was known. Unfortunately, whenever missing state data overlapped with missing plug-meter data, state data could not be recovered. In the original data, subjects showed an average of 29.9 percent unknown-state data; after interpolating based on energy data, there remained an average of 4.4 percent unknown-state data. Individual days of data for each subject were removed from state analyses if they included 5 percent or more unknown state. In the baseline period, 29 percent of subjects lost up to ten days of state data for this reason and another 8 percent lost more than that. In the experimental period, 15 percent of subjects lost up to 10 days of state data for this reason and another 10 percent lost more than that. The primary state data analyses require three weeks' worth of data from the baseline and three weeks' worth from the experimental period; 94 percent of subjects had sufficient valid data for the baseline period and 98 percent for the experimental period.

Also in the initial version, the weekly pop-up reminder automatically disappeared after a short period, meaning that many research subjects failed to notice it (if they were away from their desks at the time). Fifteen subjects wrote to the research team or mentioned it at the last research visit that they never saw a pop-up reminder, and five users of the initial version mentioned that they had seen it once or more. The second version of the software solved this problem by keeping the reminder on the screen until the subject dismissed it, however, two subjects that had this version mentioned at their last research visit that they had not seen the pop-up, which can most likely be attributed to subject inattention. For treatment subjects who were already in the experimental period, weekly reminder emails were sent in lieu of the weekly reminder popups.

Subjects using the initial version also had to deal with false idle periods where the software thought the computer was idle if the "idle" and "sleep" event were emitted at the same time, leading to a misrepresentation of sleep as idle on the subjects' reports. Less than 2 percent of subjects seem to have had this problem based on e-mail conversations and the inspection of the subjects' sleep profiles. This was fixed in the second version of the software by having the software ignore the "idle" event in case of a simultaneous emission of a "sleep" event. Another problem was that the software had trouble recognizing sleep if computer sleep was set to less than five minutes because the PMUI application shut down before the event could be read; this problem could not be fixed. This issue affected eight subjects. In one instance, the software did not pick up any "active" events and in another instance, no idle time was recorded; the cause for these problems on these computers could not be determined.

During the study, 28 subjects contacted the research team to complain that their usage reports did not always show sleep time even thought they had enabled their sleep settings. In about half the cases, the computer was actually sleeping but one of the other problems mentioned here interfered with the reports. In the remaining 17, the computer was not transitioning to sleep as expected. The team tried to find a solution with the subjects and/or their IT managers to the problem. This issue seemed to be caused by myriad causes, such as update settings and processes, wireless devices, network properties, and cloud applications. The research team did not realize until much later that many more computers were also not consistently sleeping; this problem is discussed in more detail in the results section.

As can be expected with any software, the app occasionally crashed, leading to the program not sending data to the server. In other instances, subjects exited the software by accident, also leading to a period of missing PMUI data. There was one case where the software was uninstalled unbeknownst to the researchers by an IT manager who thought that the software was causing problems to the subject; the software was re-installed after this incidence. In total, 40 subjects had interruptions in their software transmissions that were not due to vacation or other time off.

Plug Meter Data

Before deploying the meters in the field, each meter was configured to transmit to the CalPlug server and tested. However, when installed in the field, some meters failed to send data due to hardware problems. These meters had to be collected and exchanged and were sent back to the manufacturer for testing and repair. In total, 33 meters that were installed in the field had to be exchanged. The plug meters used in the study were originally designed to enable cutting power to plugged-in devices. This became problematic when various glitches occurred in the plug meters, because not only did they stop sending data, but they also cut power to the subjects' computers. After this had happened to three subjects, the research team asked the manufacturer to perform a hardware refurbishment that would allow power to flow through, even if it was broken, to avoid any unexpected shutdowns for the research subjects. Plug meters were either switched out at regular research visits or at visits that were scheduled for a plug-meter upgrade.

An unanticipated software update from the plug-meter manufacturer in the first wave of data collection reset all 117 plug meters that were deployed in the field. Those meters needed to be retrieved and manually reconfigured to transmit to the CalPlug server. This led to substantial periods of missing data for those subjects. Also, there were two subjects whose offices were not covered by the university wi-fi system and had missing plug-meter data for the entire time. One subject opted to remove the plug meter after a series of unwanted computer shutdowns, which were later traced to a defective graphics card. Five meters sent faulty data that could not be used. Many meters transmitted inconsistently, leading to missing data for one or more days. Unfortunately, during the study the research team was only able to check whether the server was receiving data and not the quality of the incoming transmissions. In two instances, the plug meter was not configured correctly or the meter's MAC address was not stored correctly, leading to a loss of data.

Some offices on campus are equipped with controlled outlets; these use a motion sensor and/or a timer to cut power to any plugged-in devices when the offices are unoccupied. The research assistants were instructed to use "always on" power outlets for the experimental set-up wherever such controlled outlets were present. However, in many instances these outlets were not marked or were ambiguously marked, and the current office occupants were unaware of them. In fact, the research team was unable to locate anyone in these buildings who knew which outlets were controlled, what their settings were, or how to modify them. This posed another unexpected challenge that threatened the validity of the data for six subjects for the period that the set-up was plugged into such an outlet. In most cases the issue was resolved within a few days, in some cases this problem was not discovered until a few weeks into the research.

The validity of the plug-meter data was compromised if equipment was changed, or if different or additional equipment got plugged into the study power strip during the course of the study. Seventeen subjects changed computers during the study, and five subjects ended up having different office equipment plugged in, such as printers, lamps, or chargers, despite the researchers' instructions and precautions. Two subjects downsized their number of monitors from two to one, in one of these two cases the existing monitor was also switched out with a new one. Six subjects had an additional monitor plugged in for part of the time, due either to getting a new monitor or to research assistant error.

Also, 12 subjects moved to a new office location, creating a source of interruption and possibility for compromising the set-up; for example, in two cases the power strip was not plugged in for one or two days, respectively, until the set-up was corrected by a research assistant. In six instances, research assistants discovered at the second research visit or later that the Central Processing Unit was not plugged into the power strip and plug meter. This was fixed by the research assistants or study subjects on site. After the field test, inspection of the data revealed eight instances where energy consumption was so low that it was assumed the Central Processing Unit had not been plugged in.

In total, energy data was excluded for 44 cases, including 17 subjects who changed computers during the study and 27 whose data was corrupted by plug-meter problems or by having incorrect or inconsistent devices plugged into the study power strip. Another 67 cases were missing most or all of their energy data.

Survey Data

Surveys at RV2 and RV3 were conducted on a tablet the research assistant brought to the session. If the tablet was forgotten, would not work, or could not connect to the university Wi-Fi, subjects were e-mailed the survey after the research visit. This carried a risk of the subjects not answering the survey. One subject did not fill out an online survey for the last research visit. In one case, the research assistant gave the RV3 treatment-group survey to a control-group subject.

CHAPTER 4: User Behavior Results

Overview

This section focuses on subjects' power-management behaviors and describes the sample used in the field test. The main results are presented first: specifically, what sleep settings were observed in the baseline period and whether subjects exposed to the PMUI application were more likely than control subjects to improve their sleep settings by the end of the intervention period. The second part of this section looks at explanations for users' behaviors, using subjects' self-reports of their own power-management behaviors, knowledge, and rationales to better understand the main results. Wherever possible, the participants' subjective self-reports of their behavior or their computer's behavior are compared to objective observations of that behavior (such as whether computer sleep settings are enabled) to identify areas of apparent confusion. The third part of this section summarizes barriers to using power management that were reported or observed over the course of the study.

Sample

The research team sent 1,784 invitations to participate in the research study; 1,482 employees received one follow-up e-mail, 1,109 three, 175 four, and 112 five. Seven subjects approached the research team after learning about the study from an IT manager or co-worker; they were determined to be eligible but had been missed because the directory did not reflect the most recent employees. Of those subjects who filled out the scheduling survey or otherwise contacted the research team, 187 were ineligible because they were not using desktop computers or they were sharing their computers, 68 employees refused participation, and 32 did not get back to the research team after initially displaying interest.

Altogether, 419 subjects completed the first research visit, resulting in a response rate of 26 percent calculated from 1,604 eligible invitees (1,784 original invitees plus 7 new, minus the known 187 ineligible). It is important to note that this response rate gives a conservative estimate as there may be many people who did not respond because they knew they did not meet the eligibility criteria. Of these 419 subjects, 415 completed the second research visit and 410 the third, resulting in a completion rate of almost 98 percent from the first through the last research visit. Seven of the subjects who dropped out either left UCI or moved to a department not involved in the study, one subject replaced his desktop computer with a laptop, and one subject was rarely on campus and was not able to participate anymore. Given the low attrition rate and nonstudy related reasons for dropping out, the research team does not expect a biased sample. Three subjects were faculty members who were installed in the first month of the study, prior to the research team deciding to exclude faculty; they were kept in the study as a courtesy, but their data was excluded.

The final sample consisted of 407 subjects, all university staff, including research and administrative staff and post-doctoral scholars, but no faculty or students. The majority were women (68 percent). Almost half (45 percent) of the subjects identified as white, with 28 percent identified as Asian or Pacific Islander, 11 percent identified as Hispanic or Latino, 8 percent identified as multiracial, and less than 5 percent identified with any other group.

Compared to census estimates for California, the sample is less white (versus 72.4 percent), less Hispanic (versus 37.2 percent) and more Asian (versus 15.2 percent). However, the state race and ethnicity data is for people of all ages and education, whereas staff members who use computers at a university (and at other similar enterprises) are likely to be of working age and more highly educated than average. Indeed, all but 11 percent of the sample are college-educated: 53 percent have a bachelor's degree, 28 percent have a master's degree, 1 percent have a different professional degree, and 6 percent have a doctorate. By contrast, the census shows that for the overall population in the state, only 32 percent of persons 25 and older have a bachelor’s degree or higher. Subjects were asked to identify which official census occupation category fit them best. The majority are professionals, administrative support, or higher-level administrators (see Table 2). Almost all (98 percent) report working full time, defined as at least 30 hours per week, or a 75 percent appointment. These demographic differences from the overall state averages are to be expected with a sample focused on office workers in administrative and professional settings, who comprise most users of office desktop computers.

Table 2: Occupations

Occupation	Percent
Professional (instructor, engineer, scientist, physician, pharmacist, librarian, computer programmer, HR specialist, accountant, financial analyst, athletic coach)	44%
Administrative support (office manager, library technician, secretary, payroll clerk, accounting assistant)	34%
Manager or official (executive officer, mid-level manager)	18%
Technician	2%
Operative	1%
Commercial or sales support	1%
Other	1%
Craft worker	0.3%
Security support	0.3%
N, sample size	407

Source: Joy Pixley et al

The majority of desktops in the study (92 percent) used the Windows operating system, with most using Windows 7 (77 percent of the sample) or Windows 10 (15 percent of the sample). The other 8 percent used Mac operating systems, primarily the most recent build at the time, macOS Sierra (19 of the 31 Mac computers, and 5 percent of the sample).

Multiple monitors were common: at the beginning of the study, 37 percent of subjects had one monitor, 62 percent had two monitors, and six subjects (less than 2 percent) had three or four. Seven subjects changed the number of monitors they had over the course of the study, but the percentages in each group stayed the same. Twenty-five desktops (6 percent) were all-in-one computers; these were all Apple computers, although two of them were running

Windows operating systems. All-in-one computers were coded as having one monitor; nine of them were also connected to a second monitor.

As planned, three in four subjects were in the treatment group (303, or 74.5 percent). The treatment and control groups did not differ significantly on any of the demographic characteristics measured, nor on the operating system of their computer or the number of monitors.

The sample was limited to subjects who used a desktop computer on campus. The usage of other computers as well may have indicated greater familiarity with computers and their various settings. One question on the RV2 survey asked what other types of computers the subject used "regularly – that is, at least three hours a week." The types of other computers reported by subjects is shown in Table 3. Laptop or notebook computers are most commonly mentioned; it is not clear how many of these are personally owned and how many were issued by the university. Almost half the subjects also use a tablet, while one in three use a desktop at home. Summarizing types within subject, 41 percent use only one other type of computer, while 38 percent use two, 11 percent use three, and 3 percent use four or more. Of these computer types, home desktops and laptops are most likely to give subjects additional experience with power management: 82 percent of subjects use one or both of these types of computers.

Table 3: Other Computers that Subjects Regularly Use

Type of Computer	Percent
Another desktop(s) on campus	9%
Desktop(s) at an open computer lab	1%
Desktop(s) at home	35%
Desktop(s) somewhere else	2%
Laptop or notebook computer(s)	65%
Tablet(s)	48%
No other computers	8%
N, sample size	407

Source: Joy Pixley et al

Initial Sleep Setting Rates

The PMUI software observed and recorded the computer and display sleep settings throughout the study period. Observed computer sleep settings are shown in Table 4 for the beginning and end of the baseline period. Specifically, these report the first observations of sleep settings when the software was installed at RV1 (before the subject resumed use of the computer) and the sleep setting at the end of the day prior to RV2 (as changes during that day could be during the visit itself). At the beginning of the baseline period, 14 percent of subjects' desktop computers had the computer sleep setting enabled. Of those computers, the most common sleep delay time was 30 minutes (the default), with almost equal proportions of others exhibiting higher and lower delay times. The 29 percent of subjects with delay times over 30 minutes, especially those with delay time of two hours or more, represent possible gains in efficiency even among those with enabled settings.

During the baseline period, four subjects enabled their computer sleep settings period and two subjects disabled them, which resulted in about the same proportion enabled at the end of the baseline. Most of the changes in computer sleep delay times were due to these six subjects, but two other subjects increased their computer sleep delay times. The small number of subjects who changed their settings during the baseline, and the fact that they changed in both directions, suggests that subjects' power-management behavior was not significantly affected by a Hawthorne effect, meaning that they were not influenced by participating in the study.

Table 4: Observed Computer Sleep Settings at Beginning and End of Baseline Period

Computer Delay Time (minutes)	RV1			Day before RV2		
	Number	Percent of All	Percent of Enabled	Number	Percent of All	Percent of Enabled
Never	350	86%		348	86%	
1	4	1%	7%	4	1%	7%
10	9	2%	15%	9	2%	15%
15	1	0%	2%	2	0%	3%
20	1	0%	2%	1	0%	2%
25	1	0%	2%	1	0%	2%
30	24	6%	41%	21	5%	36%
45	1	0%	2%	1	0%	2%
60	8	2%	14%	9	2%	15%
120	4	1%	7%	1	0%	2%
180	1	0%	2%	6	1%	10%
240	3	1%	5%	1	0%	2%
N	407	407	58	407	407	59

Source: Joy Pixley et al

Far more computers had display sleep settings enabled at baseline (see Table 5). Almost all of them had delay times set at 30 minutes or less, with a substantial minority at 15 minutes or less. As with computer sleep, few changes occurred during the baseline period for display sleep settings. Between the first and second research visit, two subjects disabled display sleep while another two enabled display sleep. Three others changed their delay time for display sleep. In short, no consequential changes were seen during the baseline period for either computer or sleep settings.

Table 5: Observed Display Sleep Settings at Beginning and End of Baseline Period

Display Delay Time (minutes)	RV1			Day before RV2		
	Number	Percent of All	Percent of Enabled	Number	Percent of All	Percent of Enabled
Never	68	17%		68	17%	
3	1	0%	0%	2	0%	1%
5	6	1%	2%	6	1%	2%
10	50	12%	15%	49	12%	14%
15	14	3%	4%	14	3%	4%
20	5	1%	1%	5	1%	1%
25	4	1%	1%	4	1%	1%
30	245	60%	72%	242	59%	71%
45	1	0%	0%	1	0%	0%
60	11	3%	3%	13	3%	4%
120	1	0%	0%	2	0%	1%
180	1	0%	0%	1	0%	0%
N	407	407	339	407	407	339

Source: Joy Pixley et al

Observed Sleep Settings Changes

As reported earlier, 14 percent of the sampled computers had their computer sleep settings enabled at the end of the baseline period, before the intervention at the second research visit. Prior to RV2, subjects were divided into control and treatment groups. The control group had a slightly higher proportion of computers with computer sleep enabled and a slightly lower proportion with display sleep enabled (see Table 6), but neither difference was statistically significant.

Table 6: Sleep Settings at End of Baseline, by Condition

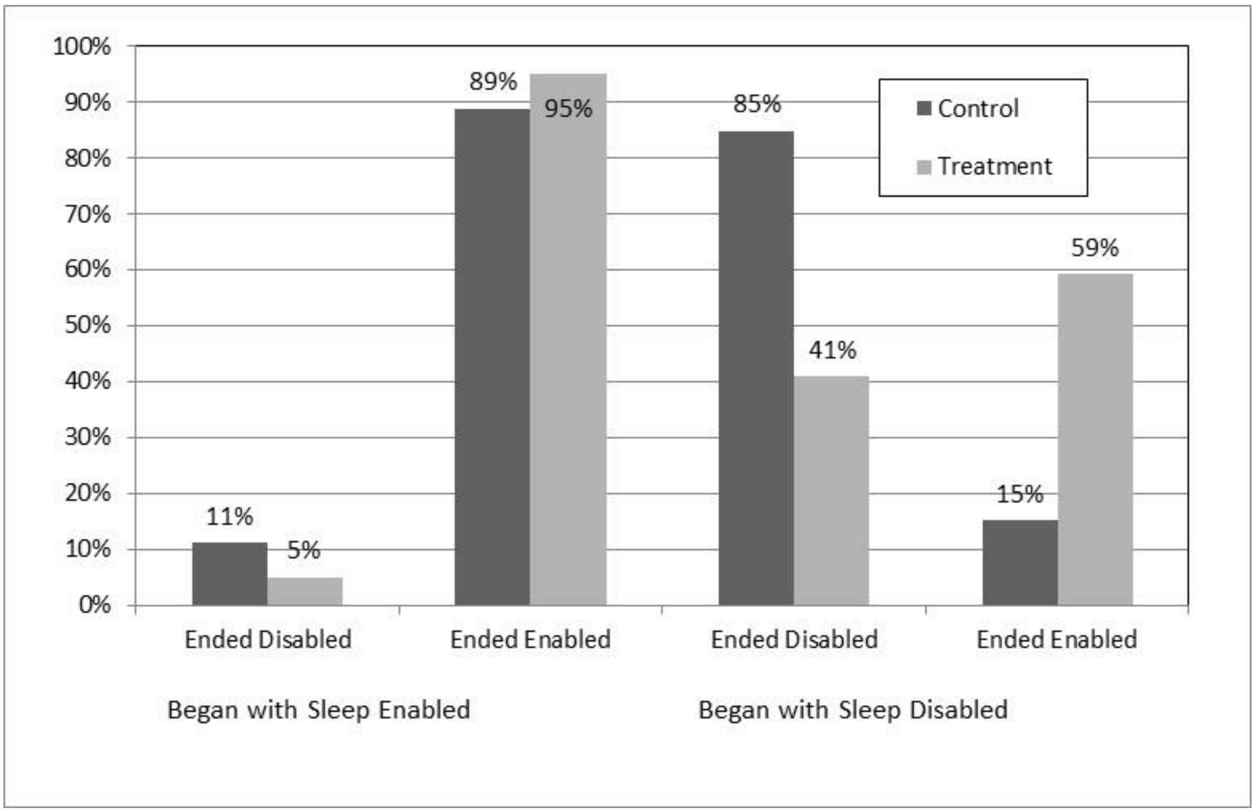
	N	Computer Sleep Enabled Before Intervention Period		Display Sleep Enabled Before Intervention Period	
		Number	Percent	Number	Percent
Control	104	18	17.3%	84	80.8%
Treatment	303	41	13.5%	255	84.2%
Overall	407	59	14.5%	339	83.3%
p value			.3453		.4240

Source: Joy Pixley et al

Changes in Computer Sleep Settings

As the intended purpose of PMUI is to encourage users with disabled sleep settings to enable them, the most important analysis in this report is whether subjects in the treatment group were more likely to enable their sleep settings than those in the control group. These findings are shown in Figure 13. Of those who began the intervention period with computer sleep enabled, the majority retained their sleep settings. There was no significant difference by treatment condition. Of those who began the intervention period with computer sleep disabled, subjects in the treatment group were significantly more likely to have their sleep settings enabled at the end of the intervention period (59 percent versus 15 percent, $p < 0.0001$).

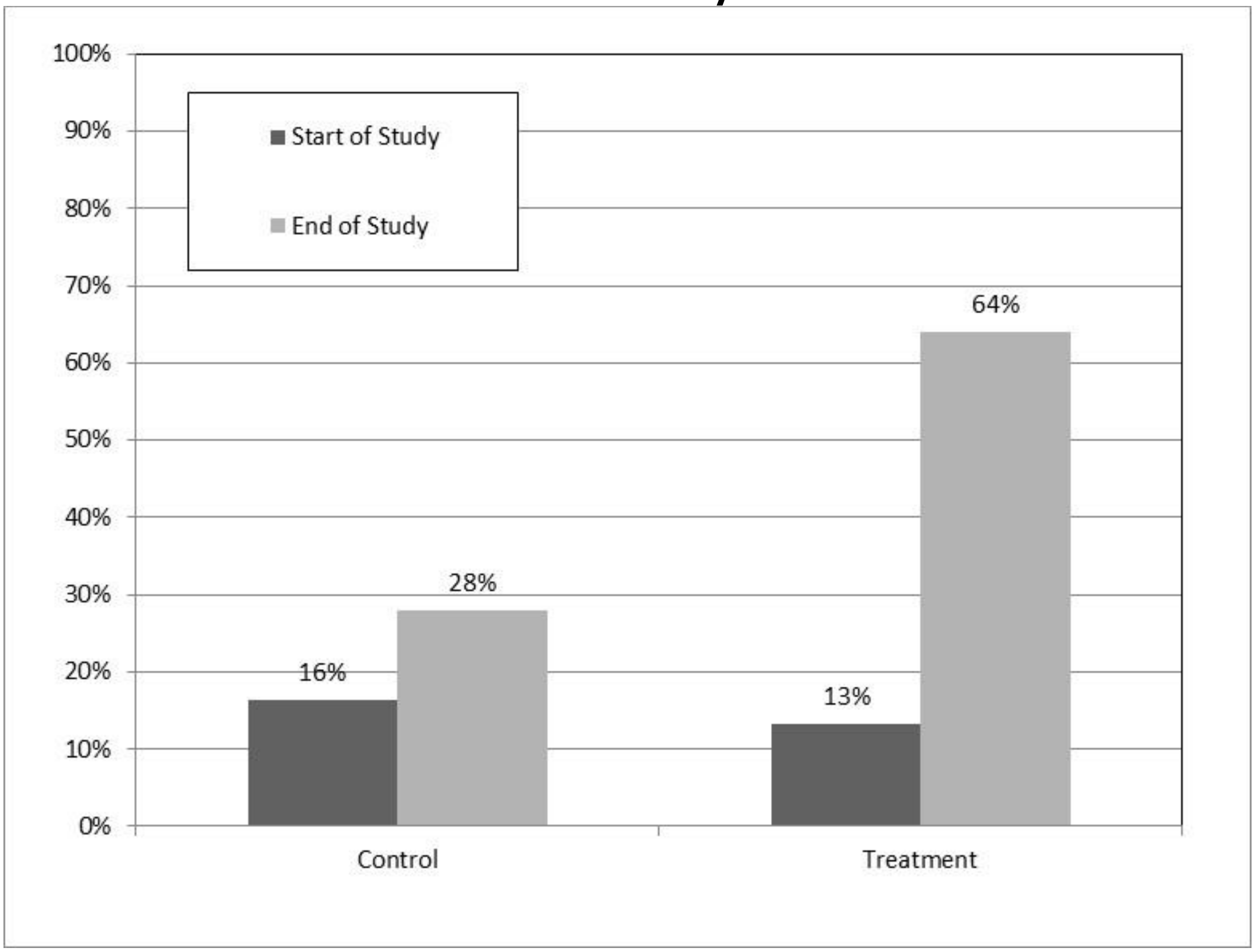
Figure 13: Change in Computer Sleep Setting Over Intervention Period, by Condition



Source: Joy Pixley et al

Another way to look at this is how much the total percent of computers with computer sleep enabled changed across the course of the study (Figure 14). There is no significant difference by condition in likelihood of having display sleep enabled at the beginning of the study and, as noted before, the rate of enabling begins quite high. By the end of the study, treatment group computers are significantly more likely ($p < 0.0001$) to have their computer sleep settings enabled, going from 13 percent to 64 percent.

Figure 14: Change in Percentage of Computers with Computer Sleep Enabled Across Study



Source: Joy Pixley et al

So far, the analyses have focused on the final outcome at the end of the study, at least two months after the initial intervention at RV2. It is useful to ask how much of this improvement took place immediately after the intervention, versus developing over time. As it is possible that the subject experimented with changing during or shortly after RV2 and then reverted to the previous settings, here the focus is on the change in status (if any) from the end of the day prior to RV2 to the end of the day after RV2 occurred. The possible subject actions following the intervention at RV2 depend on whether the computer sleep settings were already enabled; they are listed in Table 7. Among subjects who had computer sleep disabled prior to RV2, subjects in the treatment group were significantly more likely to enable sleep than those in the control group (29 percent versus 17 percent, $p = .0342$). Among subjects who had computer sleep already enabled, a larger proportion of treatment subjects decreased (that is, improved) the sleep delay (22 percent versus 6 percent), but this is not statistically significant, likely because of the small sample size. Overall, this suggests that subjects were more motivated to improve their sleep settings by looking at the PMUI program than by looking at their standard settings, even though the two interfaces displayed the same basic information.

Table 7: Change in Computer Sleep Settings after Initial Intervention, by Condition

Status at RV2	Change at RV2	Control Group		Treatment Group	
		Number	Percent	Number	Percent
Disabled	No change	71	83%	186	71%
	Enabled sleep	15	17%	76	29%
	N	86		262	
Enabled	No change	16	89%	31	76%
	Disabled sleep	0	0%	1	2%
	Increased sleep delay	1	6%	0	0%
	Decreased sleep delay	1	6%	9	22%
	N	18		41	
N		104		303	

Source: Joy Pixley et al

The next analysis asks how much the subjects' initial response at RV2 is related to the eventual outcome, that is, whether the computer sleep settings are enabled at the end of the intervention period at RV3 (Table 8). For the control group subjects who began with disabled settings, those who did not change them during RV2 were highly unlikely to change them later in the study (only 1 percent), while 20 percent of those who enabled their sleep settings during RV2 had disabled them again by the end of the study. By contrast, of the treatment group subjects who did not enable their settings during RV2, almost half (45 percent) enabled their computer settings later in the intervention period and kept them enabled until RV3. Also, almost all of the treatment group subjects who enabled their settings at RV2 still had them enabled at the end of the study (95 percent). All the treatment group subjects with enabled sleep settings who did not change them at RV2 still had them enabled at RV3; the other cells in the table are too small to produce reliable percentages. To summarize, the continued positive changes for the treatment group after the change at RV2 suggests the effectiveness of the ongoing intervention of the PMUI feedback.

Table 8: Relationship of Change in Computer Sleep Settings after Initial Intervention to Outcome at End of Study, by Condition

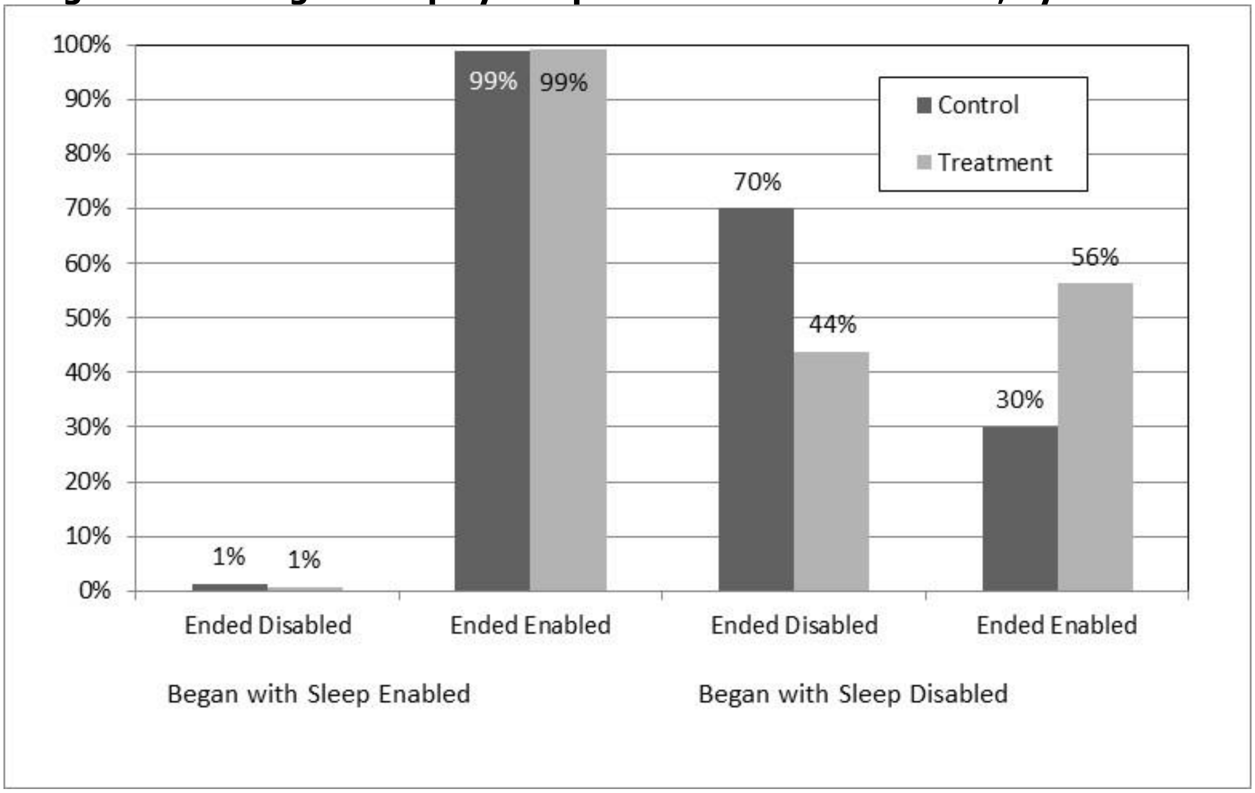
Status at RV2	Change at RV2	Control Group			Treatment Group		
		Number	Sleep Disabled at RV3	Sleep Enabled at RV3	Number	Sleep Disabled at RV3	Sleep Enabled at RV3
Disabled	No change	71	99%	1%	186	55%	45%
	Enabled sleep	15	20%	80%	76	5%	95%
Enabled	No change	16	13%	88%	31	0%	100%
	Disabled sleep	0			1	0%	100%
	Increased sleep delay	1	0%	100%	0		
	Decreased sleep delay	1	0%	100%	9	22%	78%
N		104			303		

Source: Joy Pixley et al

Changes in Display Sleep Settings

As shown in Table 6, the majority of computers began the intervention period with enabled display sleep settings. The PMUI program did not present feedback about display idle time, although displays are mentioned as a factor in energy waste in the FAQs. Nonetheless, using the PMUI program is associated with improved efficiency for display settings as well as computer settings. As shown in Figure 15, subjects in the treatment group whose display settings were disabled were significantly more likely to enable them than those in the control group (56 percent versus 30 percent, p = .0484).

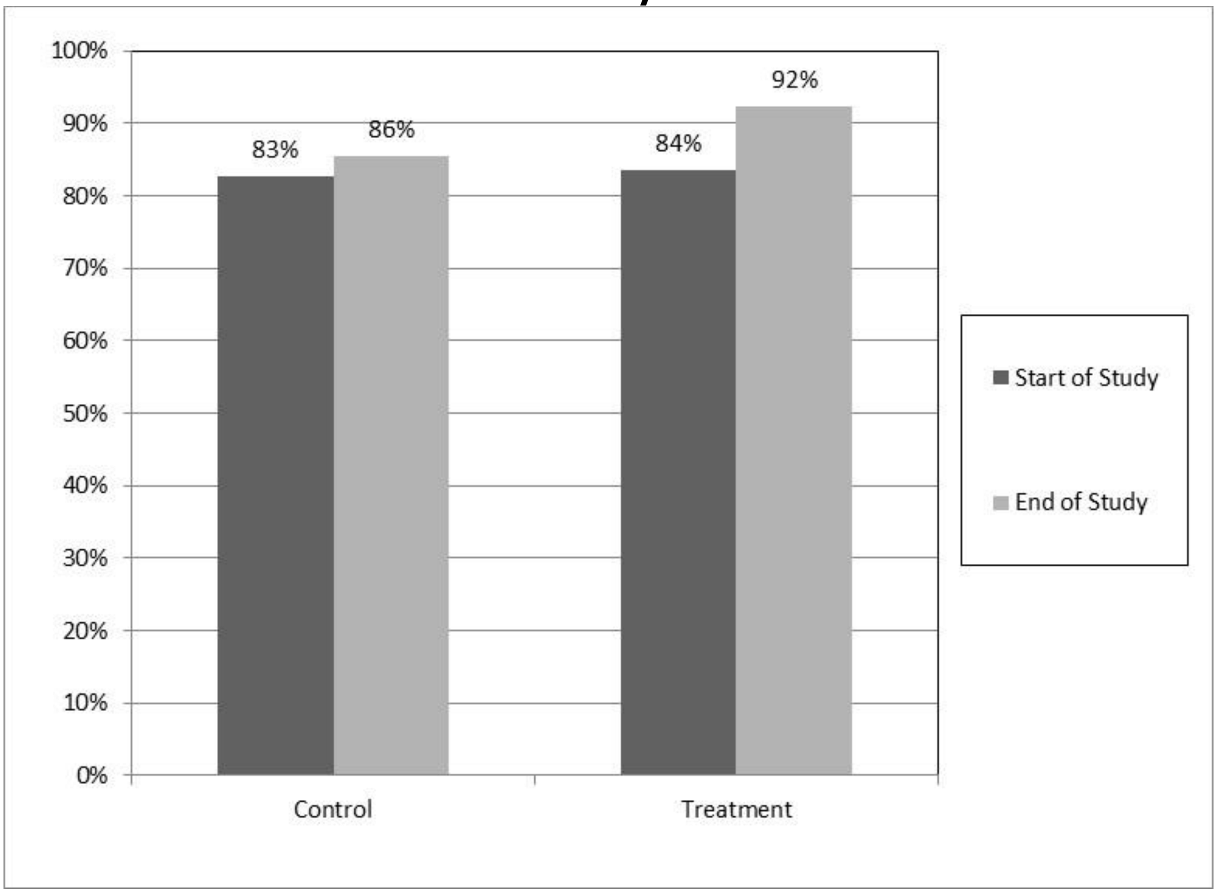
Figure 15: Change in Display Sleep over Intervention Period, by Condition



Source: Joy Pixley et al

Another way to look at this is how much the total percent of computers with display sleep enabled changed across the course of the study (see Figure 16). There is no significant difference by condition in likelihood of having display sleep enabled at the beginning of the study and, as noted before, the rate of enabling begins quite high. By the end of the study, treatment group computers are significantly more likely (p = .0388) to have their display sleep settings enabled, going from 84 percent to 92 percent.

Figure 16: Change in Percentage of Computers with Display Sleep Enabled Across Study



Source: Joy Pixley et al

As with changes in computer sleep, the next question is how many subjects changed their display sleep settings as an immediate response to the intervention at RV2 (see Table 9). The observed relationship is in the expected direction, with more subjects in the treatment group than in the control group enabling display sleep or decreasing the delay time.

Table 9: Change in Display Sleep Settings after Initial Intervention, by Condition

		Control Group		Treatment Group	
Status at RV2	**Change at RV2**	**Number**	**Percent**	**Number**	**Percent**
Disabled	No change	16	80%	30	63%
	Enabled sleep	4	20%	18	38%
	N	20		48	
Enabled	No change	74	88%	208	82%
	Disabled sleep	0	0%	1	0%
	Increased sleep delay	0	0%	1	0%
	Decreased sleep delay	10	12%	45	18%
	N	84		255	
N		104		303	

Source: Joy Pixley et al

The next analysis examines the connection between changes made at the intervention visit (RV2) and the status at the end of study for display sleep settings (see Table 10). As most subjects had their display sleep settings enabled for the entire study, there are not many differences by condition to report. In both control and treatment groups, all of the subjects who already had display sleep enabled and made no change at RV2 still had display sleep enabled at the end of the study, as did most of the subjects who enabled display sleep at RV2. Among subjects with disabled settings who did not enable them at RV2, treatment subjects were more likely than control subjects to later enable them, but this relationship is not statistically significant. A small number of subjects who decreased the display delay time at RV2 later disabled display sleep.

Table 10: Relationship of Change in Display Sleep Settings after Initial Intervention to Outcome at End of Study, by Condition

Status at RV2	Change at RV2	Control Group			Treatment Group		
		Number	Sleep Disabled at RV3	Sleep Enabled at RV3	Number	Sleep Disabled at RV3	Sleep Enabled at RV3
Disabled	No change	16	88%	13%	30	67%	33%
	Enabled sleep	4	0%	100%	18	6%	94%
Enabled	No change	74	0%	100%	208	0%	100%
	Disabled sleep	0			1	0%	100%
	Increased sleep delay	0			1	0%	100%
	Decreased sleep delay	10	10%	90%	45	2%	98%
N		104			303		

Source: Joy Pixley et al

Changes in Delay Times for Computer and Display

Although enabling sleep settings has the largest impact on how much time the computer or monitor spends idle, reducing the delay time for the sleep settings also saves energy. Table 11 shows the proportion of subjects in each group who already had sleep settings enabled before the intervention at RV2 who either increased or decreased their delay time. Subjects in the treatment group were somewhat more likely than control subjects to reduce the delay time for their computer sleep settings, but this relationship only approached the level of significance (39 percent versus 11 percent, $p = .0532$). The difference for the larger number of subjects who began with display sleep settings is more pronounced, with 47 percent of treatment subjects reducing their display delay time compared to 13 percent of control subjects ($p <. 0001$).

Table 11: Change in Delay Times over Intervention Period, by Condition

	Control Group		Treatment Group	
	Number	**Percent**	**Number**	**Percent**
Computer				
Enabled before RV2	18		41	
Delay Time at RV3:				
Same	13	72%	23	56%
Shorter	2	11%	16	39%
Longer	1	6%	0	0%
Disabled	2	11%	2	5%
Display				
Enabled before RV2	84		255	
Delay Time at RV3:				
Same	71	85%	122	48%
Shorter	11	13%	120	47%
Longer	1	1%	11	4%
Disabled	1	1%	2	1%

Source: Joy Pixley et al

Self-Reported Power-Management Behavior

Self-Reports at Baseline

Subjects were not asked about their sleep settings or power-management behavior until the second research visit, after the baseline period. This was done deliberately to limit the effect of study participation on the baseline measures. The first question read, "Does the monitor (or, display) for this desktop automatically go to sleep (that is, go dark) when you haven't used the computer for a while?" If yes, a follow-up question asked, "How long do you think it takes the monitor (or, display) to go to sleep after you stop actively using the computer? Please think carefully, and make your best guess." The next question asked, "Does the computer itself automatically go to sleep when you haven't used it for a while?" If yes, the same follow-up question about delay time was asked.

Self-reports of whether the monitor goes to sleep are shown in the first columns of Table 12. The majority of subjects reported that display sleep was enabled. The right-hand columns compare self-reports to observed settings. Of those who reported that their monitors automatically transitioned to sleep, almost all of them (93 percent) were correct, and of those who didn't know, one in three had display sleep enabled. Perhaps more surprising is the 43 percent of subjects who said their monitors did not transition to sleep, but whose display sleep settings were enabled. Overall, 84 percent of subjects were correct about whether their display sleep settings were enabled.

Table 12: Comparing Reported and Observed Display Sleep Settings at End of Baseline

Self-Report		Observed			
		Enabled		Disabled	
Enabled	330	307	93%	23	7%
	81%				
Disabled	58	25	43%	33	57%
	14%				
Don't know	19	7	37%	12	63%
	5%				
N	407	339	83%	68	17%

Source: Joy Pixley et al

Subjects who reported that their monitors automatically transitioned to sleep were offered a set of response options with a range of delay times (Table 13). More than four in five subjects believed the delay time was less than 30 minutes; this is also true for the smaller number whose sleep settings were observed to be enabled. However, the observed display sleep delay times were substantially longer than subjects believed, with the majority set at 30 minutes or longer. Additional analyses (not shown) compared observed display sleep delay times to self-reported delay times for those who offered one (excluding "don't know" and "no answer"). Among these 296 subjects, 76 percent reported their monitors going to sleep sooner than they actually did, 20 percent were accurate about the delay time, and the remaining 4 percent overestimated the delay time.

Table 13: Comparing Reported and Observed Display Sleep Delay Times at End of Baseline

Display Sleep Delay Time	Self-Reported	Self-Reported, Sleep Enabled	Observed
Less than 10 min	31%	31%	3%
10 to less than 30	52%	53%	22%
30 to less than 60	10%	10%	71%
1 hour or more	4%	3%	4%
Don't know	3%	3%	
No answer	0.3%	0%	
N	330	307	307

Source: Joy Pixley et al

Self-reports of whether the computer goes to sleep are shown in the first columns of Table 14. More than half of the subjects reported that computer sleep was enabled, while one in four said it was not, and one in six didn't know. The right-hand columns in Table 14 compare self-reports to observed settings. Of those who reported that their computers automatically transitioned to sleep, only 21 percent were correct, and of those who didn't know, only 4 percent had computer sleep enabled. For a small number of subjects who said their computers did not transition to sleep, PMUI recorded that their computer sleep settings were enabled. While there were a few instances of computers in the study not transitioning to sleep even though the sleep settings were enabled, these computers were not exhibiting that problem. Put another way, of the 348 computers where computer sleep was disabled, half (52 percent) of the subjects incorrectly reported that it was enabled. Overall, only 37 percent of subjects were correct about whether their computer sleep settings were enabled.

Table 14: Comparing Reported and Observed Computer Sleep Settings at End of Baseline

Self-Report		Observed			
		Enabled		Disabled	
Enabled	229	48	21%	181	79%
	56%				
Disabled	111	8	7%	103	93%
	27%				
Don't know	67	3	4%	64	96%
	16%				
N	407	59	14%	348	86%

Source: Joy Pixley et al

Subjects who reported that their computers automatically transitioned to sleep were offered a set of response options with a range of delay times (see Table 15). Almost two-thirds believed the delay time was less than 30 minutes; this is also true for the smaller number whose sleep settings were observed to be enabled. However, the observed computer sleep delay times were substantially longer than subjects believed. Additional analyses (not shown) compared observed computer sleep delay times to self-reported delay times for those who offered one (excluding five who said "don't know"). Among these 43 subjects, 58 percent reported their computers going to sleep sooner than they actually did, while 35 percent were correct about the range and 7 percent gave a longer delay time than observed.

Table 15: Comparing Reported and Observed Computer Sleep Delay Times at End of Baseline

Computer Sleep Delay Time	Self-Reported	Self-Reported, Sleep Enabled	Observed
Less than 10 min	21%	27%	8%
10 to less than 30	43%	40%	23%
30 to less than 60	20%	15%	40%
1 hour or more	8%	8%	29%
Don't know	8%	10%	
No answer	0.4%	0%	
N	229	48	48

Source: Joy Pixley et al

Part of the discrepancies between self-reported and observed sleep settings could be due to subjects' confusion about or unfamiliarity with their computer's sleep settings. The survey conducted at RV2 asked subjects about their experiences with computers. Given the greater discrepancies for computer sleep settings, this section focuses on how accurate subjects were about whether their computer settings were enabled.

Two questions taken from the previous UCI Survey of Computer Energy Use asked subjects to rate their knowledge of computers overall and their knowledge of power management on a scale from 0 to 10, where 0 is a beginner, 5 is average, and 10 is an expert. Responses are shown in Table 16. Self-rated knowledge is somewhat higher for both measures in the current study than among the staff who participated in the prior UCI survey, whose average knowledge rating was 6.8 for computers and 6.2 for power management (Pixley et al., 2014). However, the same pattern is shown, in which subjects are more confident about computers in general than about power management more specifically.

Table 16: Reported Computer Knowledge and Relationship to Power Management Accuracy

	All		Incorrect about Computer Sleep Setting		Correct about Computer Sleep Setting		
	Mean	SD	Mean	SD	Mean	SD	*p* value
Knowledge of computers in general	7.4	(1.5)	7.4	(1.5)	7.3	(1.3)	.8317
Knowledge of power management	6.9	(2.2)	6.6	(2.2)	7.5	(2.2)	<.0001

Source: Joy Pixley et al

In a monitoring study that followed up on select subjects of the UCI Survey of Computer Energy Use, self-reported knowledge about power management was significantly correlated to whether subjects reported correctly about whether their sleep settings were enabled, but knowledge about computers more generally was not significantly related (Pixley & Ross, 2014). As such, these analyses are run again here, and the same results hold true. Accuracy about whether computer sleep is enabled is significantly related to knowledge of power management, but not to knowledge of computers in general. Note that self-reported knowledge about power management was not significantly related to whether computer sleep settings were enabled at the beginning of the study, nor at the end of the study (results not shown).

Another measure of how comfortable subjects are with computers was assessed by asking, if the subject were to get a new computer at home for personal use, "who would probably install the software and manage the settings." The percent who chose each response options was: I would do it myself (54 percent); I would do it, but might need a little help (24 percent); I would do it, but would probably need a lot of help (4 percent); and I would ask someone else to do the set-up for me, like a friend or a tech support service (18 percent). The small number of subjects in the third category makes a cross-tabulation (chi-square) test with power-management accuracy unadvisable. However, collapsing all of the "help" categories into one category reveals a clear relationship: subjects who would set up their own computers are significantly more likely to report their computer sleep settings accurately.

Table 17: Whether Subject Would Set Up New Computer and Its Relationship to Power Management Accuracy

	All	Percent of All	Percent of Row Correct About Computer Sleep Setting
Would do it myself	220	54%	43%
Would need help	187	46%	30%
	407		37%
p value			.0108

Source: Joy Pixley et al

Another possible factor in whether subjects know their power-management settings and thus can report accurately is whether they have changed their settings and, indeed, whether they even believe they have control. Subjects were asked, "Do you currently have control over the power-management settings on this desktop computer? That is, can you change the settings for whether and when it goes to sleep?" The response options were: I don't have control over the power-management settings; I control the settings, and there is a formal or informal policy about what they should be; and I control the settings, and there is no policy about what they should be. Note that only staff members who had control over their sleep settings without any specific policy were eligible for this study, and this was verified with their IT manager ahead of time. However, as shown in Table 18, less than one third of subjects knew that they had control of their settings. Almost half didn't know, 7 percent thought there was a policy, and 16 percent thought they were not allowed to change their settings. (The research assistants were trained to reassure any subject who asked that they did have control over the settings, after showing them either the PMUI program or their standard sleep settings.)

Table 18: Reported Control of Power Management Settings and Relationship to Power Management Accuracy

	All	Percent of All	Percent of Row Correct About Computer Sleep Setting
I control	118	29%	49%
Control with policy	29	7%	38%
Don't control	64	16%	36%
Don't know	195	48%	30%
	406		37%
p value			.0102

Source: Joy Pixley et al

Subjects who knew that they controlled their computer's power management were significantly more likely to be correct when reporting whether their computer sleep settings were enabled, while those who said they didn't know were especially likely to be incorrect. Logically, this would follow if subjects who believed they had control over their settings were more likely to change those settings, and thus to be aware of them.

Another question asked, "Computers come with default settings for power management, such as whether the computer goes into sleep mode after a period of inactivity. Have you or anyone else changed any of the default power-management settings on this computer?" The percent of subjects who gave each response is in the first row of Table 19. Relatively few subjects report changing their own power-management settings (16 percent), while most of the other subjects are evenly split between thinking that nobody changed them (26 percent), maybe someone else changed them (28 percent), or they don't know whether they were changed (25 percent).

Table 19: Likelihood of Changing Power Management Settings by Perceived Control

Control over PM Settings		Who Changed PM Settings				
		Nobody	Me	Someone Else	Maybe Someone	Don't Know
All	406	26%	16%	5%	28%	25%
I control	118	21%	40%	4%	19%	15%
Control with policy	29	24%	38%	7%	21%	10%
Don't control	64	44%	5%	16%	16%	20%
Don't know	195	24%	2%	3%	37%	34%

Source: Joy Pixley et al

The remainder of Table 19 assesses the relationship between whether subjects know they control the power-management settings of their desktops and whether they changed those settings. The results are consistent with expectations: subjects who control their settings (with or without a policy) are substantially more likely (40 percent and 38 percent, respectively) to report changing the settings. However, a substantial proportion of those who realize they control their settings have not changed them and are not sure whether someone else did.

As expected, subjects who changed the power-management settings on their office desktops were most likely to be accurate about their current computer sleep setting at RV2 (see Table 20). However, it is notable that even in this group, only 55 percent knew whether their computer sleep settings were enabled, suggesting that confusion about power-management settings is pervasive.

Table 20: Relationship between Report of Who Changed Power Management Settings and Power Management Accuracy

	All	Percent of All	Percent of Row Correct about Computer Sleep Setting
Nobody	107	26%	33%
Me	65	16%	55%
Someone else	22	5%	45%
Maybe someone else	113	28%	30%
Don't know	100	25%	36%
	407		37%
p value			.0100

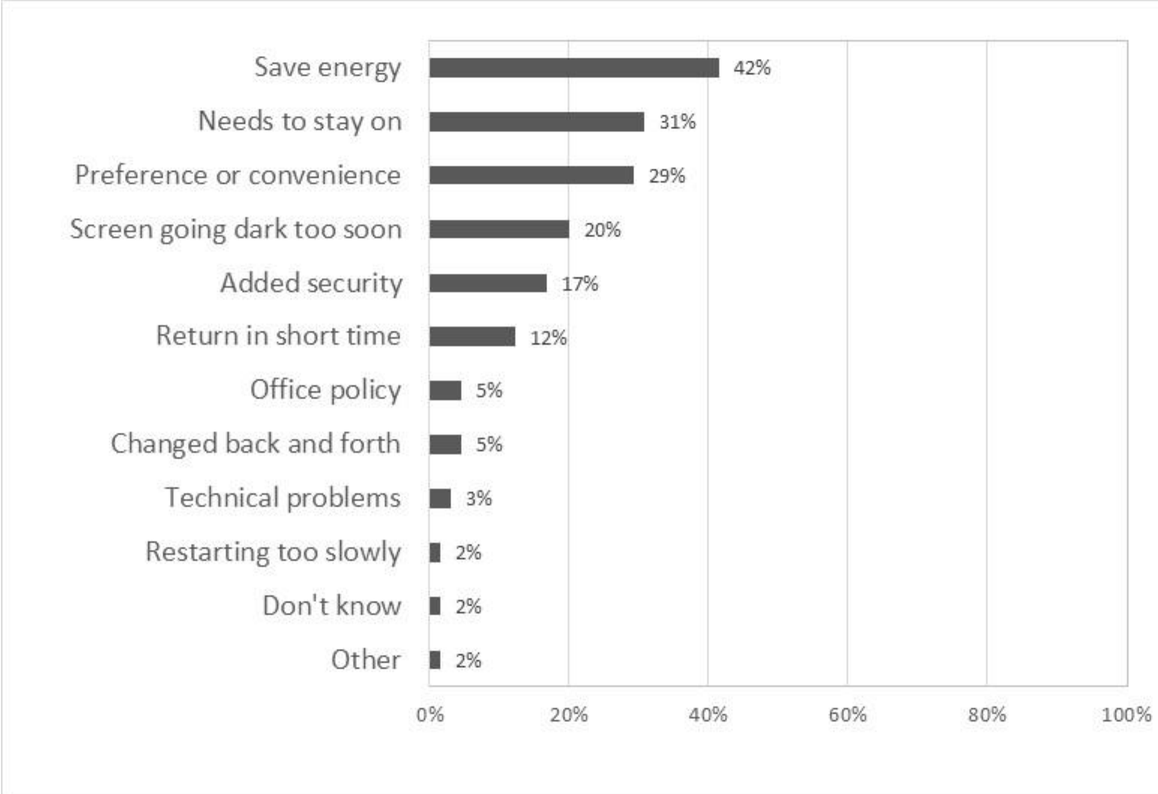
Source: Joy Pixley et al

A follow-up question for subjects who reported changing their power-management settings asked when they had last changed the settings. Of the 65 subjects, half (51 percent) chose the last category more than a year ago. Only three subjects reported changing the settings in the past week, with another two within the past month and 12 within the last six months. This provides too small a sample to compare statistically to the observed changes from the PMUI data. One of the three subjects claiming to have changed their settings in the past week did not in fact change them during the baseline period (a minimum of 28 days), and one subject saying the most recent change was more than six months ago actually changed their settings during the baseline period. The majority (89 percent) made no changes to any of their settings during the baseline period, including all of those who said the most recent change was more than a year ago.

Subjects were not asked exactly what they changed about their power-management settings, in part because they might have made multiple changes (such as disabling and later re-enabling display sleep) and in part because of the difficulty in recalling details of such changes over what might have been a long time period. However, a follow-up question asked for the subject’s reason(s) for changing the settings, and these reasons can be used to infer whether sleep settings were made more or less efficient.

The reasons for changing power-management settings, ordered by frequency of selection, are shown in Figure 17.

Figure 17: Reasons Given at RV2 for Changing Power Management Settings



Source: Joy Pixley et al

The most commonly cited reason is to save energy (42 percent), which clearly indicates a move toward more efficient settings. A second reason assumed to mean more efficient settings is "for added security," as computers can be set to require a password to resume from sleep (cited by 17 percent of subjects). Four reasons are considered to imply less efficient settings or disabling settings: the computer needs to stay on for backups, remote access, or recharging devices, which is the second most-cited reason (31 percent), the screen was going dark too soon (20 percent), the subject would usually return to the computer shortly (12 percent), and technical problems (3 percent). The third most-cited reason is "preference or convenience" (29 percent), which could mean either more or less aggressive sleep settings. Along with the remaining options, this is considered unknown in its efficiency effects.

Of the 65 subjects who reported changing their settings, over half (54 percent) chose only one reason, about one in three (34 percent) chose two, and the remainder chose three or more. It is possible that subjects changed their settings in multiple ways, at multiple times, for different reasons, or that subjects gave multiple reasons for changing their settings in a single way. Of the 36 subjects who gave only one reason, an equal number (11, or 31 percent) said they changed their settings to save energy or because the computer needed to stay on. Combinations of one or more reasons were assessed for whether they indicated consistent directions: 43 percent of subjects gave only "greater energy efficiency" reasons, 42 percent gave only "lower energy efficiency" reasons, 6 percent gave at least one of both types of reasons, and 9 percent gave only reasons that have an unknown relationship to efficiency. This analysis suggests that most subjects were only thinking about one direction of settings change, and that approximately equal numbers made their settings less efficient as made them more efficient.

Self-Reports at the End of the Study

The survey at the end of the study asked subjects whether they had made changes to their computer sleep settings over the course of the study. The four types of changes included both increasing energy efficiency (enabling sleep or decreasing the delay time) and decreasing energy efficiency (disabling sleep or increasing the delay time). Subjects were instructed to mark every option that applied. Results are shown in Table 21. About half the subjects (48 percent) reported at least one type of change. In terms of effects on energy efficiency, many more subjects reported positive changes (enabling sleep or decreasing delay time) than negative changes (disabling sleep or increasing delay time). Subjects in the treatment group were significantly more likely than those in the control group to report any change, and specifically to report enabling sleep or decreasing delay time; they were also more likely to report increasing delay time.

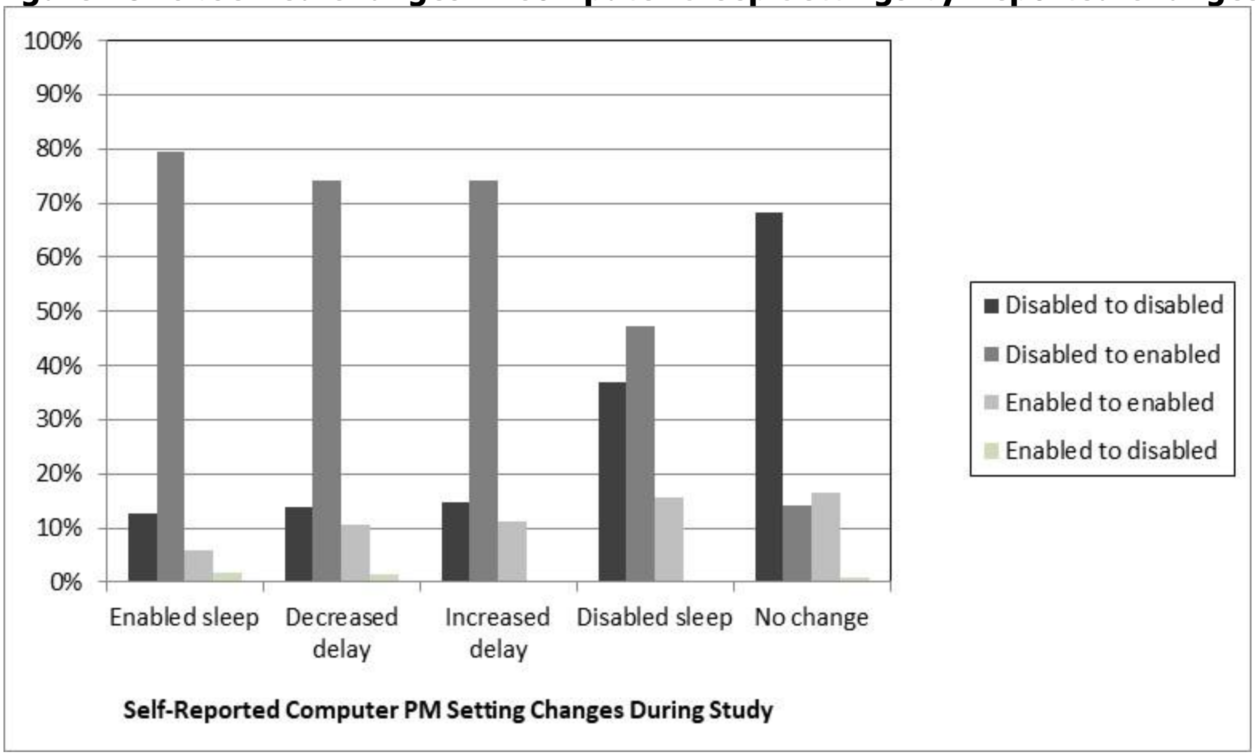
Table 21: Reported Change in Computer Sleep Settings at RV3

	All	Control	Treatment	*p* value
Enabled sleep	29%	9%	36%	< .0001
Decreased delay time	37%	12%	46%	< .0001
Increased delay time	7%	2%	8%	.0245
Disabled sleep	5%	2%	6%	.1215
One or more change	48%	21%	57%	< .0001
No changes	45%	70%	37%	< .0001
Don't know	7%	9%	6%	.4171
N	405	104	301	

Source: Joy Pixley et al

The changes listed here are not mutually exclusive: subjects could have enabled sleep and then later disabled it, or both increased and decreased the delay time. Comparing across changes for the 193 subjects who made one or more, most (82 percent) reported only positive changes, while 5 percent reported only negative changes and 13 percent reported at least one of each type. Since any type of change could be reversed, it is important to look at the end result of what could be multiple changes. Figure 18 shows the observed change in computer sleep settings from RV1 to RV3, by whether the subject reported ever making positive or negative changes to the computer sleep settings. Subjects reporting positive changes (enabling sleep or decreasing the delay time) are very likely to have gone from disabled to enabled computer sleep settings, as expected. However, so are subjects reporting that they increased the delay setting, suggesting that in many of these cases, this change could have been a course correction after decreasing the delay time lower than preferred. Also note that a substantial minority of subjects who made positive changes nonetheless ended the study with their computer sleep settings disabled. By far the most likely groups to end the study with disabled sleep settings are those who reported disabling sleep during the study (presumably after enabling it and changing their minds) and those who made no changes to these settings. However, the subsamples of subjects who reported increasing the sleep delay or disabling sleep are both small, so these results should be interpreted with caution. Overall, this analysis suggests that some subjects experimented with enabled or disabled settings, or higher or lower delay times, before settling on an acceptable combination.

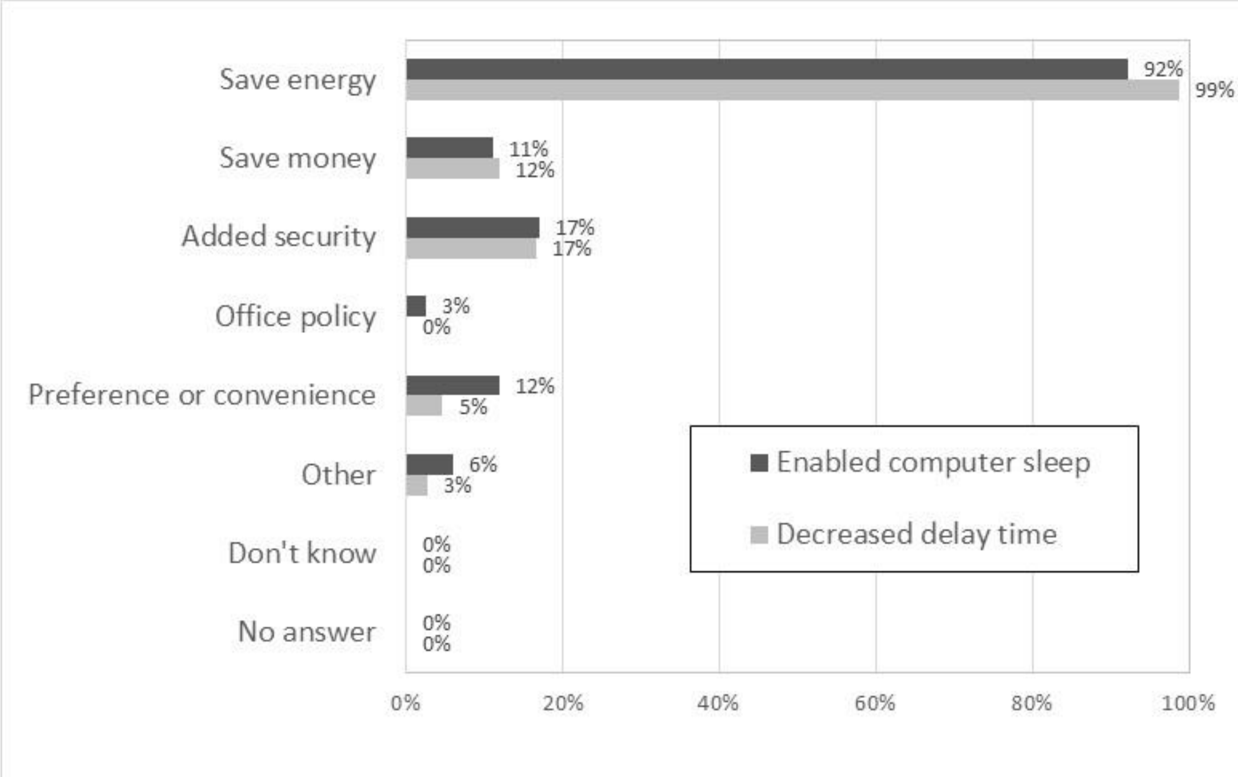
Figure 18: Observed Changes in Computer Sleep Settings by Reported Changes



Source: Joy Pixley et al

If subjects reported any of these four changes to their computer sleep settings reported in Table 21, the survey directed them to a list of reasons why they made that change; the question instructed them to mark all that applied. Reasons given for making changes that improved the energy efficiency of the computer sleep settings are shown in Figure 19. The most common reason given for both enabling computer sleep settings (N= 117) and decreasing delay time for computer sleep (N = 151) is to save energy, cited by almost all subjects who reported these behaviors. Added security was cited by 17 percent of both groups; although computer sleep itself does not confer security, these subjects' computers may require a password to resume functioning after transitioning to sleep.

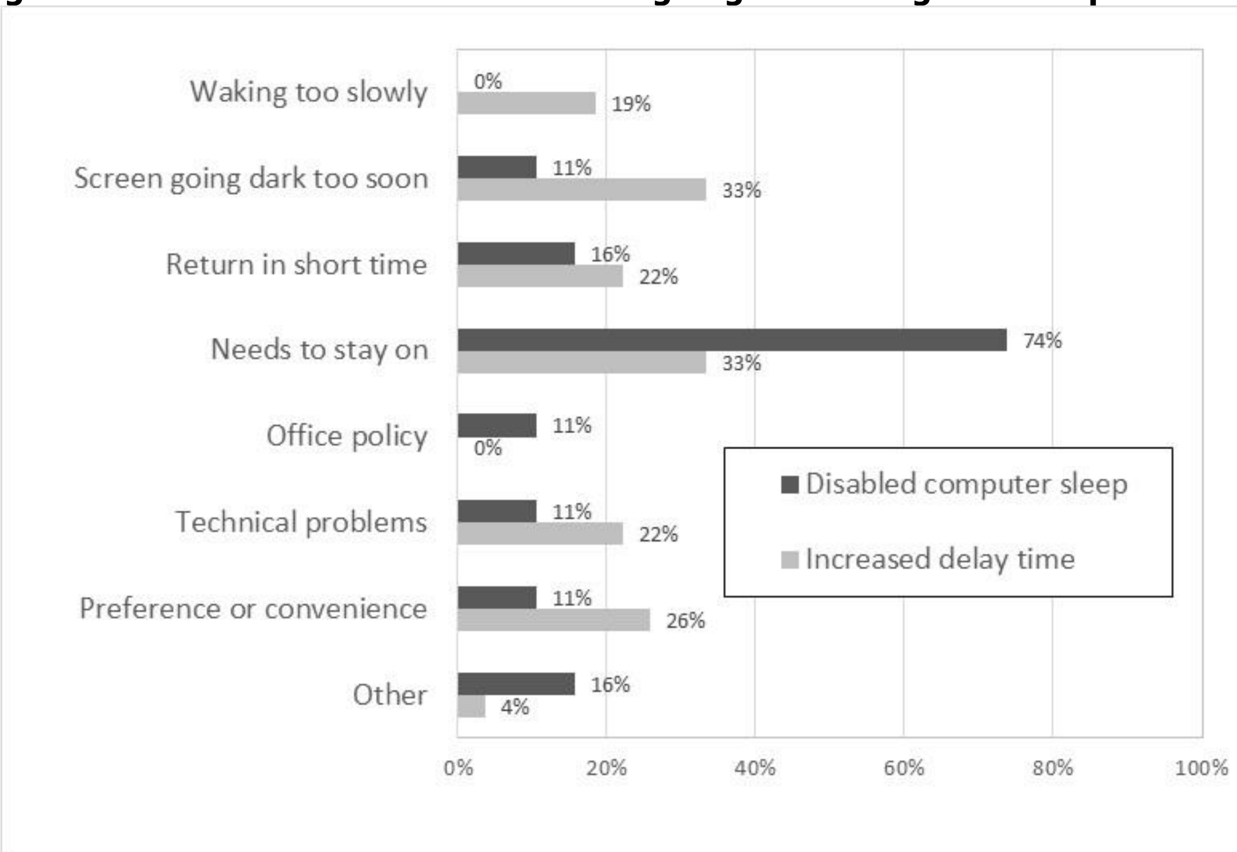
Figure 19: Reasons Given at RV3 for Making Positive Changes to Computer Sleep



Source: Joy Pixley et al

Reasons given for making changes that decreased the energy efficiency of the computer sleep settings are shown in Figure 20. These percentages should be interpreted cautiously, given the small number of subjects who reported disabling computer sleep (N = 19) or increasing the delay time for computer sleep (N =27). One result stands out, however: 74 percent of subjects who disabled computer sleep did so because their computer needs to stay on for backups, remote access, recharging, or another reason.

Figure 20: Reasons Given at RV3 for Making Negative Changes to Computer Sleep



Source: Joy Pixley et al

Regrettably, the question about sleep-setting changes did not ask subjects only for changes since the second research visit, although it is doubtful that subjects would have remembered that distinction. Also unfortunately, the comparable questions for changing display sleep were not asked.

Comparing Computer and Display Delay Times

So far the evidence suggests that subjects are confused about whether their power-management settings are enabled. Another aspect of power management they may be confused by is how to set the delay times for their computer and display in order to maximize energy savings while preventing unnecessary interruptions to their normal use of the computer. Desktop computers generally consume more energy than monitors, but monitors consume a substantial amount and many subjects have multiple monitors connected to the same desktop. Thus, the most efficient power-management strategy involves enabling sleep for both computer and display, and setting the delay as low as possible without annoying the user with too many instances of “false” sleeps – that is, when the device transitions to a low-power mode while in use or if the user was just about to return to it. This raises an important factor to remember: computers take substantially longer to wake from sleep mode than monitors do, suggesting that false sleep events for computers would lead to greater disruption and worse user satisfaction than false sleep events for monitors. If a monitor transitions to sleep mode while the user is present, the user can use keyboard or mouse activity to immediately wake the monitor and restart the delay time clock for both monitor and computer. Thus, the logical choice is to use a delay time for computer sleep that is longer than the delay time for monitor sleep. The question of how much longer is beyond the current focus, as it involves many considerations, such as how many times per day the user is willing to wake the computer from sleep, and how long the user is usually away from the computer before returning.

Table 22 shows the percent of these cases where the display is set to sleep before the computer, at the same time as the computer, or after the computer. The majority of subjects' settings follow the expected pattern of earlier display delay times, but in a substantial minority of cases, the two settings use the same delay time or the computer delay time is shorted. Comparing delay times for computer sleep and display sleep can only be done for subjects with both settings enabled, a proportion of the sample that more than tripled over the course of the study. The proportion of cases who followed the ideal pattern dropped by the end of the study compared to the beginning of the study, with more using the same delay setting and fewer using shorter delay settings for the display. This could indicate that people who newly engaged their sleep settings are less likely to understand the rationale for putting the display to sleep first and may potentially be more likely to become frustrated.

Table 22: Relative Delay Times for Computer and Display Sleep

	N	Display Delay Shorter	Same Delay Setting	Computer Delay Shorter
Beginning of study	57	70%	21%	9%
Before intervention	59	66%	25%	8%
End of study	221	61%	31%	8%

Source: Joy Pixley et al

If setting a lower delay time for the display than the computer is ideal, this approach should be seen more frequently from those with computer expertise. The analyses in Table 23 assess this relationship by asking whether those who use the strategy rate themselves as more knowledgeable of power management. At the beginning of the study, relatively few subjects had computer sleep enabled, so the sample sizes were small. More subjects selected a display delay shorter than the computer delay (40 of the 57) than longer (17 of the 57), and there is no difference across these groups on self-reported knowledge of power management. Results are similar at the end of the baseline period, at RV2. By the end of the study, more subjects had enabled their computer sleep settings, and a larger proportion had selected longer display times (39 percent at the end of the study compared to 30 percent at the beginning). There is a significant positive relationship between knowledge of power management and a shorter display delay time. It is not clear whether the difference in significance is due to a more accurate assessment of the underlying pattern given the larger sample size, or to a change in the characteristics of subjects who had both computer and display settings enabled. Taken as a whole, these results are mixed, and show only tentative support for the hypothesized relationship.

Table 23: Knowledge of Power Management by Relative Delay Times for Computer and Display Sleep

Knowledge of PM	Display Delay Shorter than Computer Delay			Display Delay Same or Longer than Computer Delay			*p value*
	N	Mean	SD	N	Mean	SD	
Beginning of study	40	7.33	(2.1)	17	7.24	(1.0)	.8646
Before intervention	39	7.26	(2.1)	20	7.50	(1.1)	.6262
End of study	134	7.10	(2.1)	86	6.50	(2.0)	.0355

Source: Joy Pixley et al

In any case, it is clear that many subjects did not realize that setting the display sleep delay shorter than the computer sleep delay can greatly reduce unwanted computer sleep events. This strategy for reducing one source of annoyance about computer sleep should be considered in future educational and behavioral campaigns.

Manual Power Management

The amount of time a computer spends idle is affected not only by automatic power-management settings, but also by manual power management (such as when users shut down the computer, or immediately put it into a low-power mode using a menu command). Manual power management can decrease inefficient idle time over that of automatic power management, if users manually shutdown, or put their computer to sleep, as soon as they are finished. If automatic sleep settings are not engaged, manual power management can make the difference between computers being idle all night or weekend; or being shutdown (or in a low-power mode) during those long unused periods.

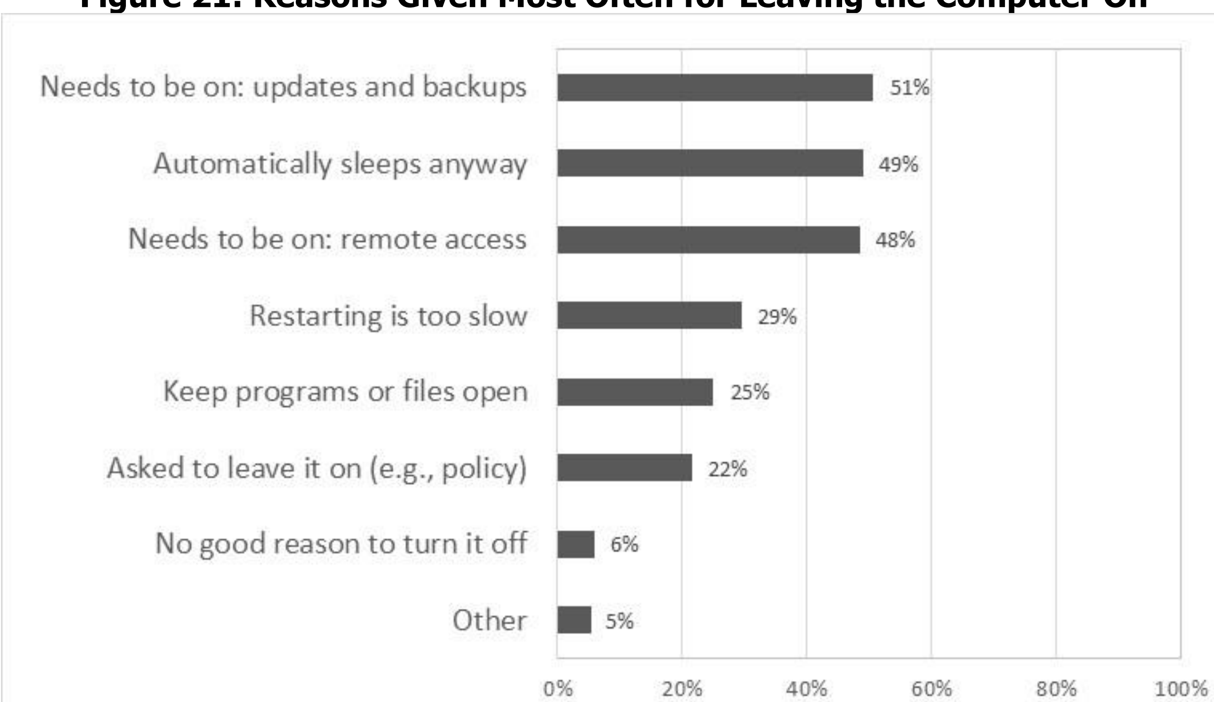
One question not fully explored in past research is whether users balance manual and automatic power management by *substituting* or *supplementing* (Pixley & Ross, 2014). The substitution hypothesis predicts that users with sleep settings enabled would be less likely to use manual power management, such as shutting down their computers at night, whereas users who prefer to use manual power management would be less likely to use automatic sleep settings. This would be expected if users are satisfied that the type of power management they prefer is sufficient and the other is not needed; it also could result when users are not motivated to put their computers to sleep manually and are unaware that their computer sleep settings are engaged. The supplementation hypothesis predicts that the people who use automatic sleep settings are more likely to also use manual power management. This would be expected if both types of power-management behaviors are motivated by the same desire to save energy, but also if the user has reasons for keeping the computer out of sleep mode.

Manual Power Management at Baseline

Another question included in the RV2 survey asked subjects, "In the past two weeks, when you knew you wouldn't be using this computer for several hours or more, what percentage of the time did you do each of the following?" Subjects were offered three possible behaviors: "Turned it off/shut it down completely," "Put it into sleep or hibernate mode manually, using menu options," and "Left it on (may or may not go into a sleep or hibernate mode automatically)." For each behavior, they slide a bar to indicate a number between 0 and 100 percent of the time. The survey program asked for a correction if the three did not add to 100 percent. Nine subjects said they did not know or gave no answer. On average, subjects report leaving their computers on 61 percent of the time they stop using them, manually putting them to sleep 25 percent of the time, and shutting them down 14 percent of the time. It is important to distinguish the percentage of occurrences when the subject uses manual power management from the proportion of the day that the behavior affects. The most likely situation in which the subjects would be away from their computers for several hours is at the end of the work day, meaning that a behavior that happens one time that day (whether they leave the computer on or use manual power management) affects the state of the computer all night or all weekend long.

If subjects reported ever leaving their computers on when they would be gone for several hours, they were asked why, and instructed to mark all the reasons that applied to them. The reasons selected by at least five percent of the subjects are shown in Figure 21 (n=316). The three most commonly selected reasons, each noted by about half of the subjects, are that the computer needs to stay on for automatic updates or backups, it needs to stay on for remote access, or that it will automatically transition to sleep anyway. About one in five subjects reported that they were told to leave the computer on by an IT manager, for instance. As mentioned earlier, to be eligible for participation, subjects could not be limited by any office or IT policy that prohibited them from putting their computers to sleep. However, it is possible that some IT managers advised staff not to shut down their computers to avoid problems with scheduled updates and backups or with remote access. Of the 68 subjects who said they were asked to leave their computers on, 50 (74 percent) also said the computer needed to stay on for automatic updating or backups; 21 of those subjects plus another 5 (7 percent) said the computer needed to stay on for remote access, for a total of 81 percent.

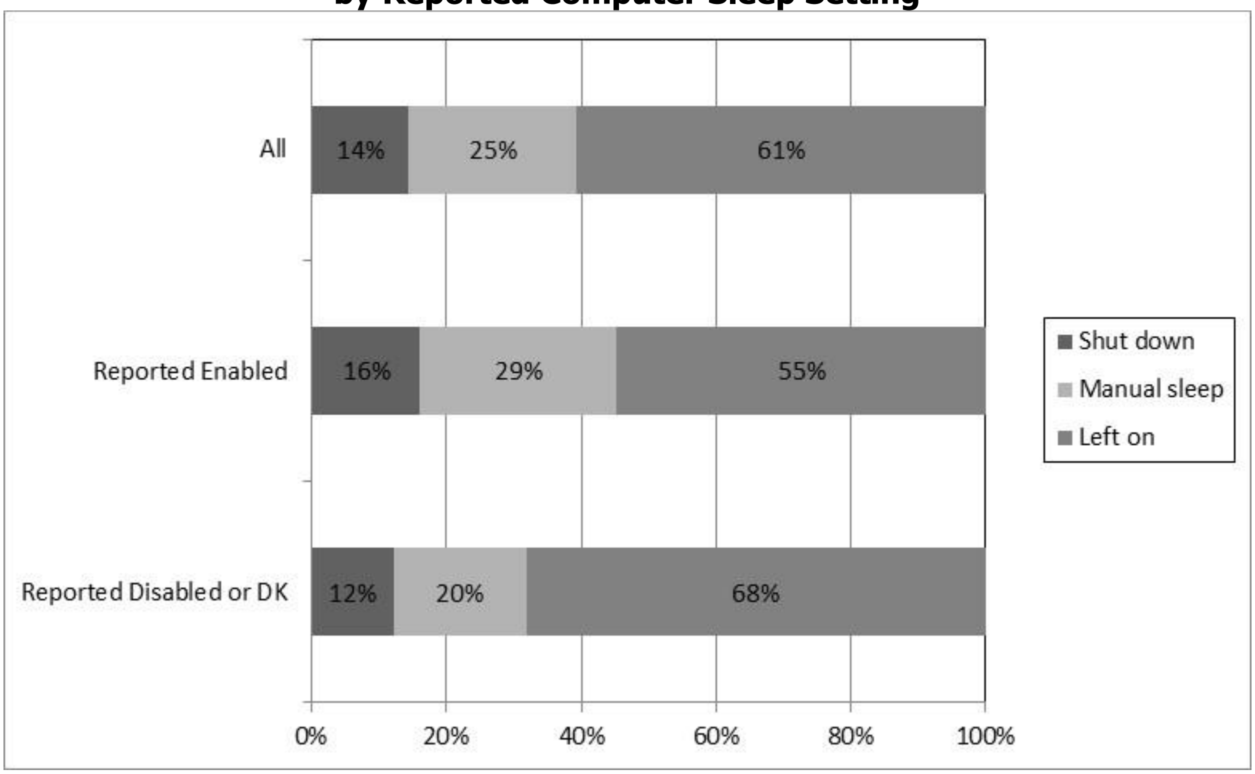
Figure 21: Reasons Given Most Often for Leaving the Computer On



Source: Joy Pixley et al

Among subjects who keep the computer on when they leave it, about half said they do so because it will automatically transition to sleep mode anyway. This is consistent with the hypothesis that users tend to substitute manual for automatic power management: if so, subjects who believe their computer sleep settings are enabled would use manual power management less often. The bottom two bars in Figure 22 test this by comparing the average percentage of time subjects left the computer in each state to whether the subject reported their computer sleep settings to be enabled, compared to subjects who said their settings were disabled or that they did not know (DK). The observed correlation is the opposite of that predicted by a substitution hypothesis. Subjects who believe their computers will automatically transition to sleep are actually less likely to leave them on than those who think they will not (or who are not sure) (55 percent versus 68 percent, p = .0015). Those who believe their computer sleep settings are enabled exhibit no significantly higher likelihood of shutting down their computers; the difference is in their greater (reported) likelihood to manually put their computers to sleep (29 percent versus 20 percent, p = .0088).

Figure 22: Percentage of Times Subjects Report Using Manual Power Management, by Reported Computer Sleep Setting



Source: Joy Pixley et al

The average percentage of times subjects overall use manual power management masks important variation: in particular, the proportion of subjects who report never or always leaving their computer in each of these three states. The percentage of answers for the manual power-management behaviors are collapsed into categories and presented in Table 24. Overall, 62 percent of subjects report that they never shut down their computers, 57 percent never manually put them to sleep, and 41 percent always leave them on. A total of 14 percent of subjects report either always shutting down the computer (5 percent) or always manually putting it to sleep (9 percent). As 21 percent of subjects report never leaving the computer on, the remaining 7 percent use a combination of shut down and manual sleep to do this.

Table 24: Percentage of Subjects Who Always or Never Use Manual Power Management, by Reported Computer Sleep Setting

Computer State	Self-Reported Computer Sleep Setting	N	How Often Subject Leaves Computer in that State for Several Hours or More				
			Never	1%–50%	50%–99%	Always	*p* value
Shut down	All	398	62%	25%	8%	5%	
	Reported Disabled or DK (didn't know)	177	67%	23%	7%	3%	
	Reported Enabled	221	59%	27%	9%	5%	.4100
Manual sleep	All	398	57%	17%	17%	9%	
	Reported Disabled or DK	177	63%	16%	13%	7%	
	Reported Enabled	221	52%	17%	21%	10%	.1098
Left on	All	398	21%	16%	22%	41%	
	Reported Disabled or DK	177	16%	12%	24%	48%	
	Reported Enabled	221	24%	20%	21%	35%	.0122

Source: Joy Pixley et al

As before, the reported manual power-management behaviors are compared to whether subjects reported their computer sleep settings were enabled (versus disabled or the subject did not know). The same pattern seen earlier is represented here, although the chi-square results for the full table are only significant for whether subjects leave the computer on. That is, subjects who believe their computers will automatically go to sleep are still less likely to always leave them on. Additional analyses (not shown) collapsed the categories further into the least efficient versus all others: specifically, never shut down versus ever, never put into manual sleep versus ever, and always left on versus not always. This showed a significant relationship for manual sleep: those who reported their computer sleep settings were enabled were more likely than those who didn't to report ever using manual sleep (48 percent versus 37 percent, p = .0306). The same analyses showed a significant difference for leaving the computer on, but not for shutting the computer down.

Manual Power Management during Intervention Period

The survey at RV3 also asked subjects if they had changed their manual power-management behaviors over the course of the study. The majority of subjects (60 percent) reported no such change in behavior. As expected, treatment subjects were significantly more likely than control subjects to report shutting down more often and manually putting the computer into a low-power mode more often. They are also slightly more likely to shut down their computers less often, although this is significant only at the trend level. This would not indicate reduced efficiency if these same subjects also enabled computer sleep settings, but this correlation is not supported by the data.

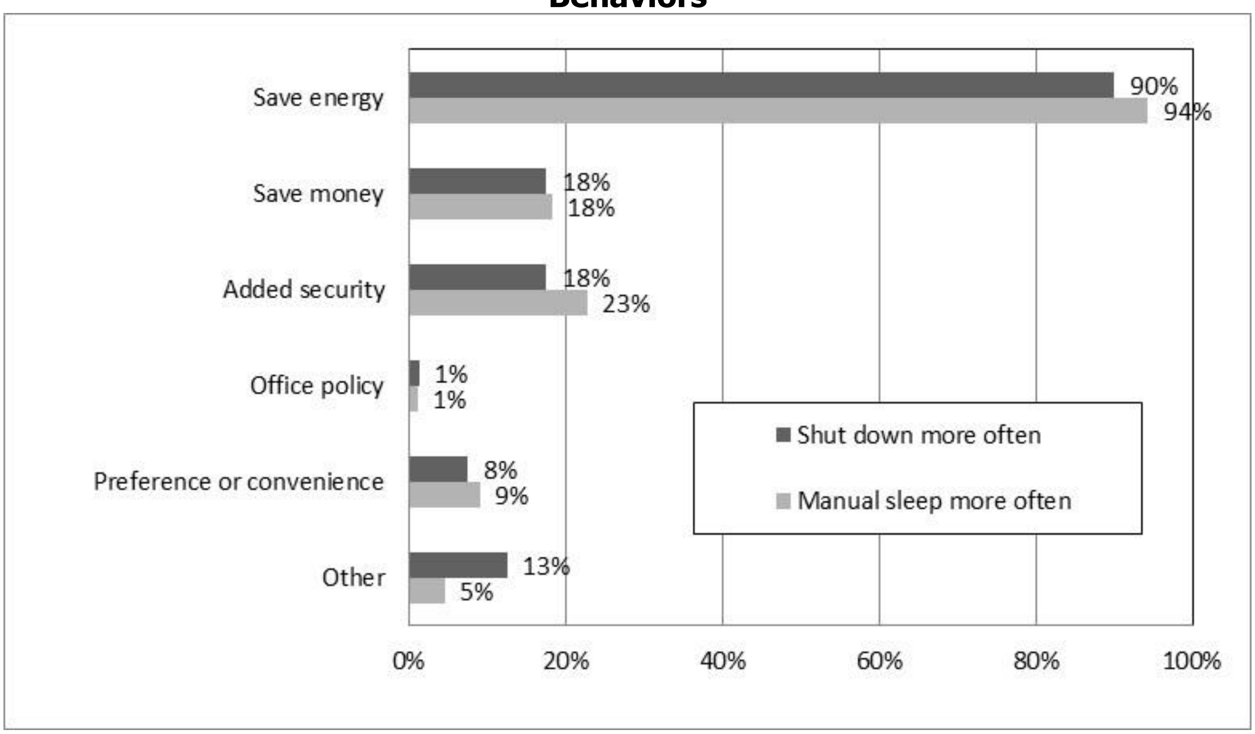
If subjects reported any of the changes in manual power-management behavior shown in Figure 22, they were given a list of reasons for that behavior, matching the reasons given for positive or negative changes to their sleep settings. Subjects were instructed to select all the responses that applied. Too few subjects reported fewer manual power-management behaviors to present those results. The reasons given for engaging in more manual power-management behaviors are shown in Figure 23. By far the most common response was to save energy.

Table 25: Reported Change in Manual Power Management Behavior at RV3

Change	All	Control	Treatment	*p* value
Shut down more often	21%	13%	23%	.0337
Shut down less often	4%	1%	5%	.0563
Manual sleep or hibernate more often	22%	8%	27%	< .0001
Manual sleep or hibernate less often	1%	0%	2%	.1469
None	60%	80%	53%	< .0001
Don't know	2%	1%	3%	.2505
No answer	0%	0%	0%	.5562
N	405	104	301	

Source: Joy Pixley et al

Figure 23: Reasons Given at RV3 for Engaging in More Manual Power Management Behaviors



Source: Joy Pixley et al

Barriers to Effective Power Management

The current study gives insight into why users do not always utilize effective computer power management. Part of the problem is, as expected, user confusion. For instance, the majority of subjects who thought their computer sleep settings were already enabled were incorrect (79 percent). Another problem is perceived lack of agency: only 29 percent of subjects knew that they had control over their own power-management settings.

However, some users deliberately avoid using computer power-management options. Understanding their reasons may facilitate improvements in future technology or policy. Subjects were asked at the end of the baseline period (if relevant) why they changed their power-management settings and why they left their computers on (rather than shutting them down or manually putting them to sleep). At the end of the study they were asked why they changed their power-management settings during the study and why they increased or decreased use of manual power-management options.

By far the most often cited reason for disabling computer sleep and leaving the computer on was that the computer needed to stay on. In some questions the reason it needs to stay on combines "backups, remote access, recharging devices, etc." while another question finds similarly high rates for remote access as for automatic updates and backups. It is important to note that allowing the computers in this study to enter sleep mode, whether through automatic settings or manual transitions, would not have interfered with automatic updates and backups, although shutting them off would have. However, remote access poses a serious barrier to effective power management, one that deserves greater attention.

Remote Access

Remotely accessing a computer requires that the computer be on and active. Various wake-on-LAN protocols exist for waking a computer from sleep mode so it can be remotely accessed. However, these protocols are complex to administer and not always effective (Chetty et al., 2009; Hackel, Plum, Colburn, et al., 2016). The easiest solution for problems with remote access is to leave the computer on and disable the sleep settings.

At RV3, subjects were asked how frequently they remotely accessed their desktop computer during the course of the study, and given a set of response categories. The majority (58 percent) reported never using remote access during the study, 16 percent reported using it one to three times, 25 percent reported using it four or more times, and 1 percent said they didn't know.

This section discusses how use of remote access affects power-management behaviors. The current analyses compare subjects who never used remote access to "regular" users (four or more times). The same analyses were conducted comparing all three groups, and comparing nonusers to users; results for the moderate group (one to three times) fall between the nonusers and regular users.

Table 26 shows the relationship between subjects' reports of using remote access and of ever leaving the computer on (the sample size is reduced due to missing or "don't know" responses). Subjects who regularly use remote access are significantly more likely to leave their computers on and to cite remote access as a reason for doing so. It is not clear why 17 percent of the 166 subjects who leave their computers on but report no remote access would cite remote access as a reason. As subjects were asked about leaving the computer on and the reasons for doing so at RV2, it is possible that they had forgotten about earlier remote access use when asked about that in RV3.

Table 26: Leaving Computer On at RV2 and Remote Access Reports at RV3

	#	Ever Leaves Computer on		Cites Remote Access as Reason
		#	%	
No remote access use	229	166	72%	17%
1 to 3 times	63	54	86%	65%
Regular use (4 or more times)	100	91	91%	95%
N	392	311		
***p* value**			< .0001	< .0001

Source: Joy Pixley et al

Unless the subject has an effective wake-on-LAN protocol, using remote access will also require keeping the computer from going to sleep. Table 27 compares whether the subject reported using remote access at the end of the study to the subject's self-reported and observed sleep settings over the course of the study. To simplify the results, remote access use is collapsed into two groups: no use reported and regular use (four or more times). Subjects who report regularly using remote access were more likely to report that their computer settings were disabled at RV2. Although the observed rate of enabled computer sleep settings at RV2 was much lower, the relationship remained the same. By the end of the study, many more subjects had enabled sleep settings, and yet those who used remote access remained significantly less likely to do so than those who did not.

Table 27: Whether Computer Sleep Settings Are Enabled, by Remote Access Use

	N	Computer Sleep Enabled			*p* value
		Yes	No	Don't know	
Self-reported sleep at end of baseline:					
No remote access	234	60%	22%	18%	.0050
Regular remote access	100	46%	39%	15%	
Observed sleep at end of baseline:					
No remote access	234	18%	82%		.0243
Regular remote access	100	8%	92%		
Observed sleep at end of study:					
No remote access	234	61%	39%		.0007
Regular remote access	100	41%	59%		

Source: Joy Pixley et al

Compared to subjects in the control group, those in the treatment group got more encouragement to enable their sleep settings through the PMUI app. The relationships shown in Table 27 are separated out by conditions in Table 28. Among control subjects, those who used remote access were less likely to have computer sleep enabled both before and after the intervention period, but the difference was not large enough to be statistically significant. Among treatment subjects, the difference in computer sleep enabling rates by remote access is significant even prior to the intervention period and got even larger by the end of the study. Although a substantial number of treatment subjects who used remote access enabled their sleep settings, PMUI was more effective at changing behavior for subjects who did not use remote access. Specifically, the proportion of treatment subjects with initially disabled computer sleep settings who later enabled them was 63 percent for those not using remote access, compared to 47 percent for those using remote access at least four times. Given the difficulties of combining automatic sleep with remote access, it is not clear how these subjects managed to do so; an exploration of anecdotal evidence from emails and other contacts may shed light on this, but it is beyond the scope of the current report.

Table 28: Whether Computer Sleep Settings Are Enabled, by Remote Access Use and Condition

	N	Computer Sleep Enabled: Yes	No	Don't know	*p* value
Control group					
Observed sleep at end of baseline:					
No remote access	54	20%	80%		.4197
Regular remote access	30	13%	87%		
Observed sleep at end of study:					
No remote access	54	35%	65%		.1447
Regular remote access	30	20%	80%		
Treatment group					
Observed sleep at end of baseline:					
No remote access	180	17%	83%		.0233
Regular remote access	70	6%	94%		
Observed sleep at end of study:					
No remote access	180	69%	31%		.0053
Regular remote access	70	50%	50%		

Source: Joy Pixley et al

Given the reported problems with combining automatic sleep settings and remote access, subjects might employ a substitution strategy, in which they employ manual power management on those evenings or weekends when they know they won't need to remotely access their desktops. As shown in Table 29, the opposite is found for the current subjects. Compared to those who never use remote access, those who used it at least four times were significantly more likely to always leave their computers on, and significantly less likely to ever shut them down or manually put them into sleep mode.

Table 29: How Often Subjects Use Manual Power Management, by Remote Access Use

	Never	1–49%	50–99%	Always	N	*p* value
Shut down:						
No remote access	54%	28%	11%	7%	229	< .0001
Regular remote access	82%	15%	2%	1%	100	
Manual sleep:						
No remote access	49%	18%	23%	9%	229	.0279
Regular remote access	67%	13%	13%	7%	100	
Left on:						
No remote access	28%	21%	20%	32%	229	< .0001
Regular remote access	9%	12%	21%	58%	100	Co

Source: Joy Pixley et al

CHAPTER 6: Settings, Computer States, and Energy Use

The results thus far show that the user feedback provided in PMUI encourages subjects to change their behavior: specifically, to enable their computer sleep settings and improve the delay time for their display settings. Energy savings, however, do not depend upon sleep settings but on the computer's resulting states: that is, whether the computer actually spends more time in sleep mode that it would otherwise have spent idle.

As described earlier, various technical and practical issues arose that rendered certain days of data unusable for specific subjects, and other days were removed from analysis when subjects were on vacation or traveling. This complicates comparisons across subjects for specific periods, as some subjects are missing data for some or all of any particular week. The analyses in this section refer to the first three weeks of the baseline period (starting with the day after RV1) and the last three weeks of the experimental period (ending with the day before RV3). As these periods use only valid study days (e.g., not vacations) with valid data (e.g., not missing, not corrupted), they do not always correspond exactly to the first and last three weeks. Subjects with fewer than 21 days' worth of valid data are not included in the analyses; this occurred more often in the baseline period, as the minimum number of study days was 28. This also occurred more often for energy data than for state data, because missing state data could often be inferred for days that had valid energy data, whereas missing energy data could not be inferred in the opposite circumstance. In total, state data is insufficient for 26 subjects in period 1 and 15 subjects in period 2, and energy data is insufficient for 91 subjects in period 1 and 33 subjects in period 2. About half the subjects missing state data in period 1 are also missing it in period 2, and about one in three subjects missing energy data in period 1 are also missing it in period 2. A total of 104 subjects are affected at one or more type-period points, leaving 303 cases with complete data of both types for both periods; four subjects are missing at all four points, excluding them from these analyses.

The earlier analyses of sleep setting changes focused on the settings on specific days, such as the first day and last day of the study. The analyses in this section cover the first three weeks and last three weeks of valid data, so changes to computer sleep settings during this period must be assessed. One subject enabled their computer sleep settings in the first three weeks; that subject is removed from the relevant analyses. In the last three weeks, 32 subjects with enabled settings changed the delay time; they remain in the analyses. However, six subjects disabled their settings within the last three weeks, while twenty enabled their settings during that period; these are removed from these analyses. This removes more treatment subjects than control subjects, as treatment subjects were more likely to change their settings overall and also in the last three weeks (18 percent versus 5 percent). Of the 303 cases with otherwise valid and complete state and energy data for both periods, last-minute changes of sleep settings removes another 18 cases, for a total of 285.

Computer States by Whether Computer Sleep is Enabled

The premise of encouraging subjects to enable computer sleep settings is that sleep-enabled computers will spend most of the time they are not used in sleep mode rather than remaining idle. An important question is how well this works in real-life usage: that is, how much time do sleep-enabled computers spend idle compared to those with sleep settings disabled?

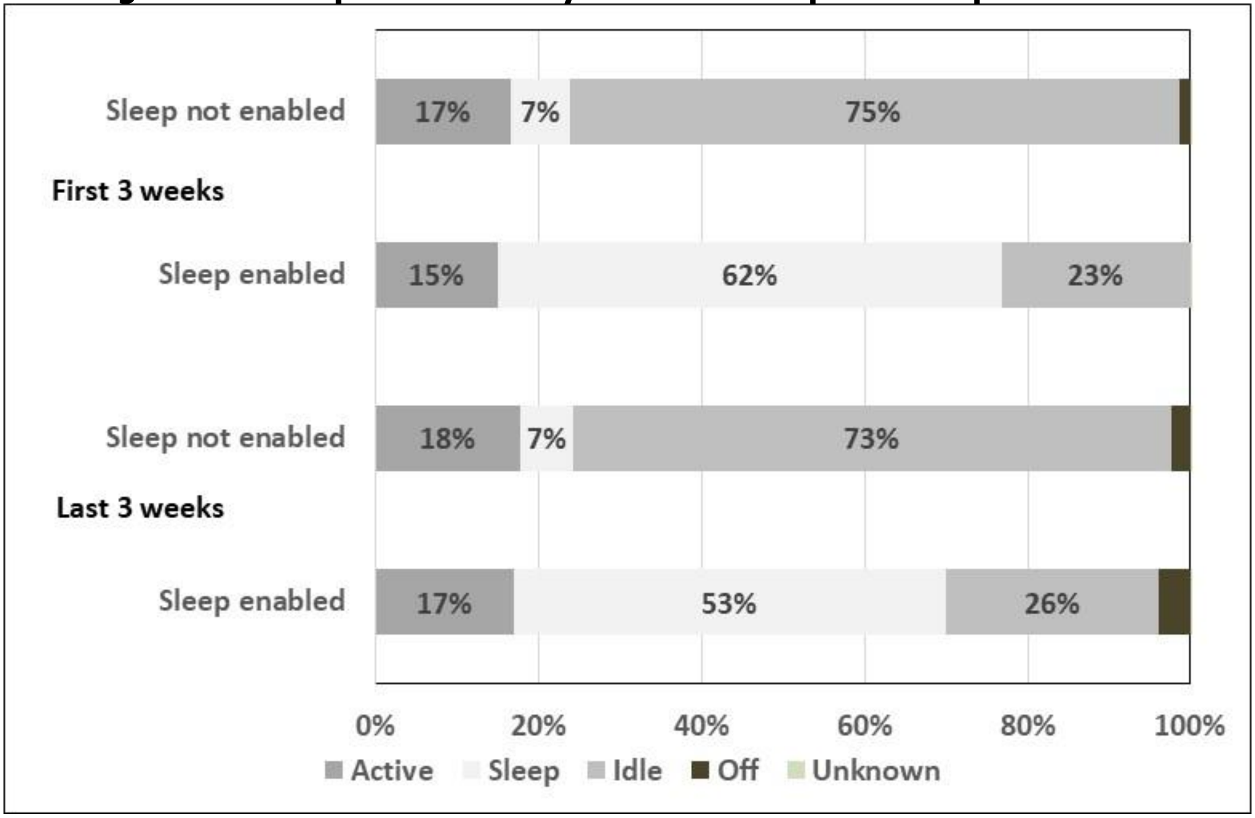
Figure 24 shows the average percentage of time computers spent in each state by whether they had computer sleep enabled at the beginning of the study (n = 379) versus at the end of the study (n = 391). The primary expectation is fulfilled: sleep-enabled computers spent more time on average in sleep mode and less in idle mode than sleep-disabled computers, both at the beginning of the study and at the end (when many more subjects had enabled their settings).

Sleep-disabled computers spent an average of 7 percent of the day in sleep mode in both periods. In the absence of automatic sleep settings, these sleep periods must be attributed to subjects manually putting their computers to sleep. Most of the computers without settings enabled (71 percent) spent no time in sleep mode; among those that did, the average time in sleep mode was 25 percent for the first three weeks of period 1 and 32 percent for the last three weeks of period 2.

On the other hand, there is evidence for manual shutting down behavior in the second period, which is slightly more common among subjects with computer sleep enabled. Small amounts of off time can be attributed to periodic restarts, but the 4 percent of off time found for this group indicates deliberate shutdowns. Again, averages can be misleading: 88 percent of subjects with sleep enabled at the end of period 2 exhibited minimal off time, but the rest show higher amounts, consistent with deliberate shutdowns. Specifically, 6 percent of subjects show 5 to 24 percent time off, 3 percent show up to 49 percent, and 3 percent shut their computers down for half the time or more.

One interesting finding is that sleep-enabled computers spent less time in sleep mode in the last three weeks of period 2 than in the first three weeks of period 1 (53 percent versus 61 percent, $p < 0.0001$). The possible reasons for this will be further explored below.

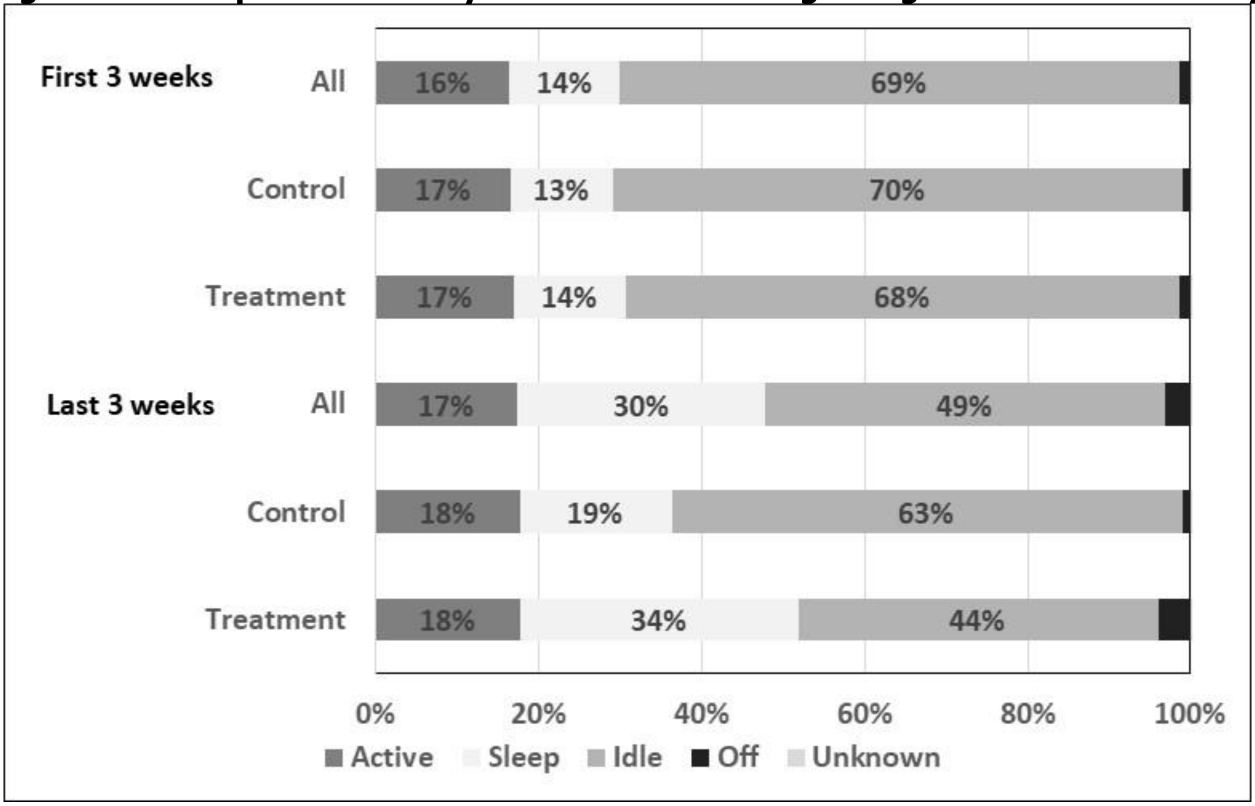
Figure 24: Computer States by Whether Computer Sleep is Enabled



Source: Joy Pixley et al

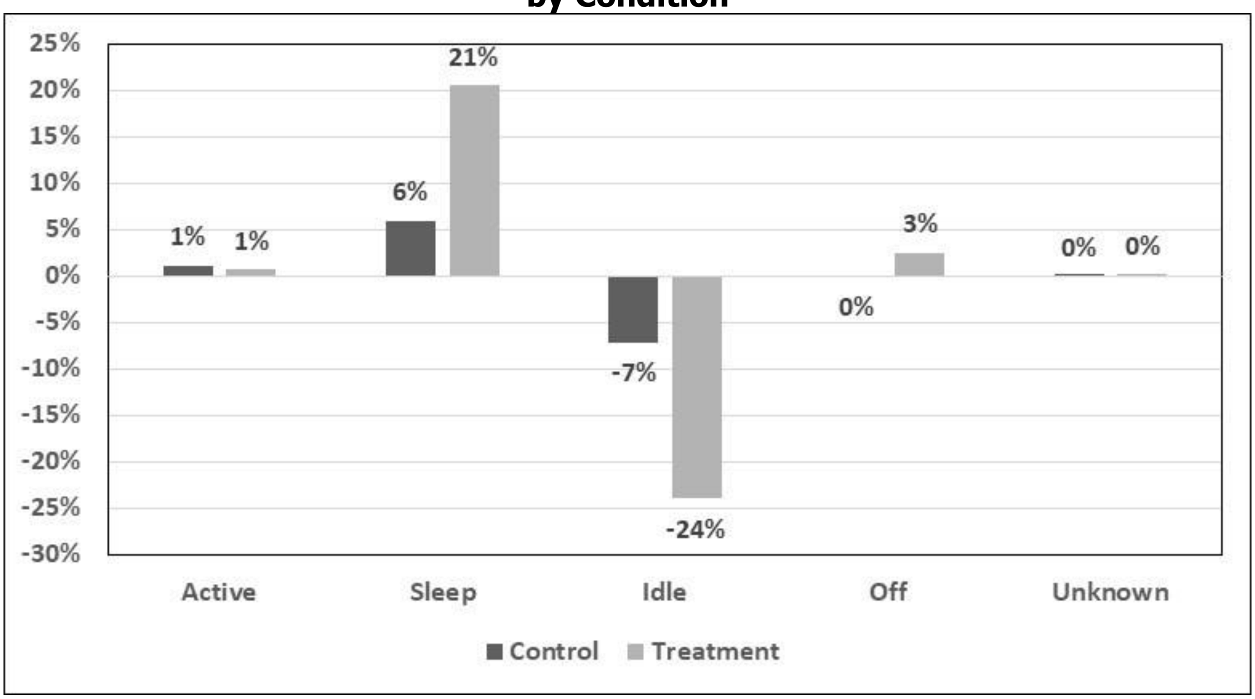
Figure 25 shows how average computer state time varies by condition across the study. At the beginning of the baseline period, computer states do not differ across groups. In the last three weeks of the experimental period, treatment subjects' computers spent significantly more time in sleep mode (34 percent versus 19 percent, $p < 0.0001$) and significantly less time idle (44 percent versus 63 percent, $p < 0.0001$) than those of control subjects. This difference is strong, but not as strong as might be expected, given the much larger difference between computers with enabled versus disabled sleep settings; this is partially due to the fact that some control subjects also enabled their computer sleep settings while some treatment subjects did not. This is reflected in the percentage in state changes for the two groups. On average, treatment subjects increased the time spent in sleep mode by 21 percentage points and decreased the time spent in idle mode by 24 percentage points (see Figure 26). The improvements made by control subjects reduced the relative effect size for the treatment group. However, the control subjects also experienced an intervention, in being shown their normal sleep settings during the second research visit, which explains their improved power-management behavior.

Figure 25: Computer States by Condition at the Beginning and End of the Study



Source: Joy Pixley et al

Figure 26: Change in Computer State Percentage from Beginning to End of Study, by Condition

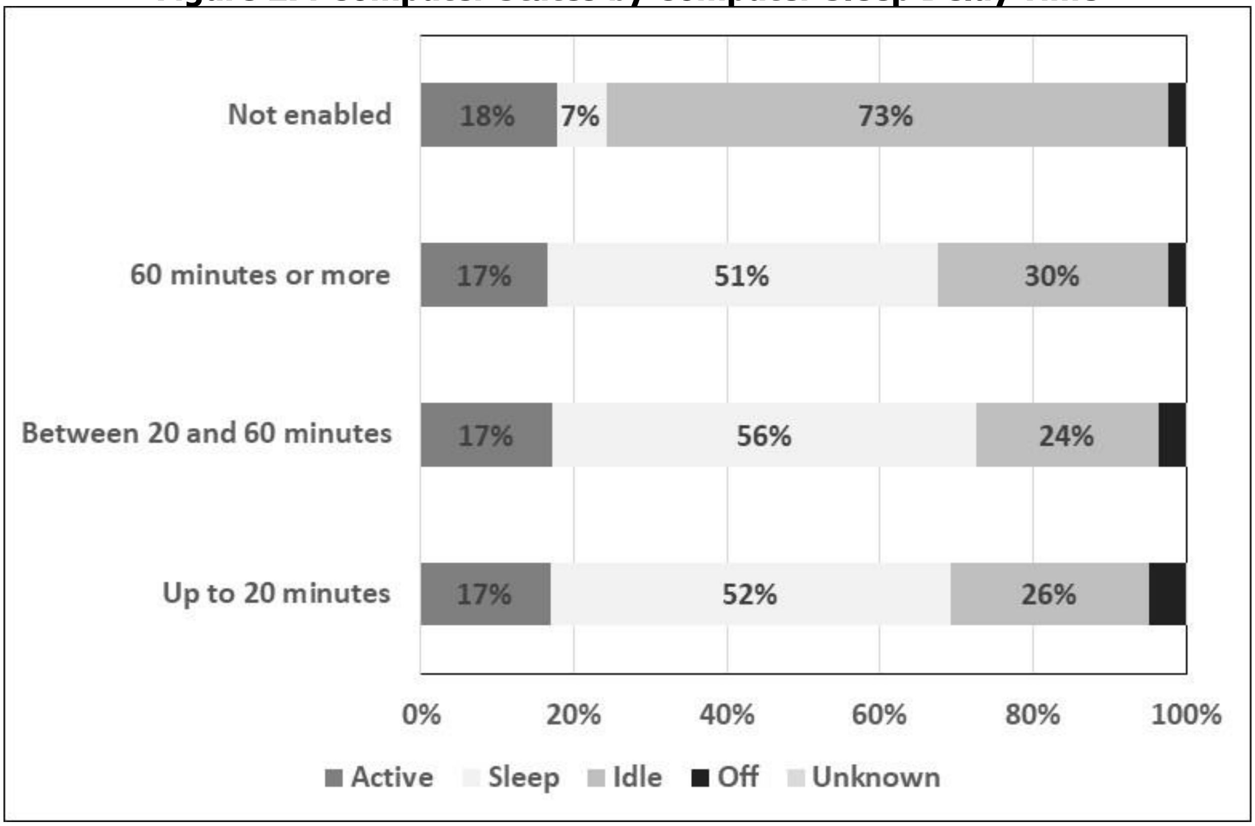


Source: Joy Pixley et al

The Effect of Delay Times on Computer States

Setting a lower delay time for computer sleep settings means the computer transitions to sleep sooner. This should result in more sleep time and less idle time for shorter delays than for longer delays. However, in the current data there are no significant differences in average time spent in sleep or idle across categories of delay time (see Figure 27). This result remains non-significant when any combination of delay categories is used.

Figure 27: Computer States by Computer Sleep Delay Time



Source: Joy Pixley et al

One possible explanation is that perhaps sleep delay does not affect idle and sleep times dramatically: as the majority of unused time for office desktops is overnight and on weekends, the amount of time it takes to transition from idle to sleep each evening is small by comparison. To explore this concept, a series of possible usage profiles were constructed to calculate the expected percent time spent in idle and sleep for each one. The profiles all assumed a five-day work week, and work hours that ranged between 7 and 10 hours per work day. The profiles differed by the number of periods the computer was left inactive for 15 minutes, 30 minutes, 1 hour, or 3 hours at a time. Results of this quasi-simulation showed that indeed, the majority of sleep time occurs in off-work hours, but that idle time still varies by sleep delay settings. It also showed that expected idle time is substantially lower than the means in the current sample. To illustrate, one hypothetical profile of a working day of computer usage is presented in Table 30: the person is at work for a total of 9 hours, takes a one-hour lunch, and is away from their desk or otherwise not using the computer for several periods of 15 or 30 minutes. The calculations for the number and percentage of idle minutes are shown on the table; results for sleep minutes are also included for comparison. Naturally, the difference in idle time for the transitioning to sleep at night is the difference in the sleep delay setting. However, shorter delay times also mean less idle time during the day: in this particular profile, the difference between the longest and shortest delay settings in idle time saved during the day (165 minutes) is even greater than that saved in the evening (115 minutes). Because of this, a hypothetical (albeit unrealistic) workday with zero inactive periods of 15 minutes or longer would produce the smallest difference between settings: a 5-percentage point gap between 5 minutes and 2 hours, and even smaller differences between the delay settings in between. However, such a workday would be highly unusual, and cannot explain the current results. As the observed idle times in this sample range from 27 to 31 percent, profiles were created to maximize idle time in an attempt to reproduce such high figures, with idle periods added for during off-hours for periodic backups and updates. The highest-idle profiles required either nonstop cycling of use (7 minutes active, then leaving the computer idle for 15 minutes, 22 times in a row for ten hours) or infrequent use at long intervals (10 minutes active, then leaving the computer idle for three hours, three times during the work day), which only produced high idle times for the highest sleep delay. Based on these calculations, a cutoff point of 25 percent idle time was chosen, as an estimate beyond which the idle time is excessive compared to expectations, indicating problems with sleep transitions. This is an especially conservative estimate for sleep delays less than 1 hour, which are predicted to have substantially lower idle times in most reasonable scenarios. Further examination is warranted, to establish lower cutoff points for each delay setting; for the current report, 25 percent is used for all delay settings.

Table 30: Predicted Sleep Time for Hypothetical Usage Profile, by Sleep Delay Times

Profile	#	Idle minutes by delay time				
		5 minutes	20 minutes	30 minutes	1 hour	2 hours
# of 15-minute inactive periods	6	6	30	90	90	90
# of 30-minute inactive periods	2	2	10	40	60	60
# of 1-hour inactive periods	1	1	5	20	30	60
# of 3-hour inactive periods	0					
Hours spent not at work	15	5	20	30	60	120
Number of idle minutes		50	170	210	270	330
Percent idle per workday		3%	12%	15%	19%	23%
Percent idle per week		2%	8%	10%	13%	16%
Number of sleep minutes		1060	940	900	840	780
Percent sleep per workday		74%	65%	63%	58%	54%
Percent sleep per week		81%	75%	73%	70%	67%

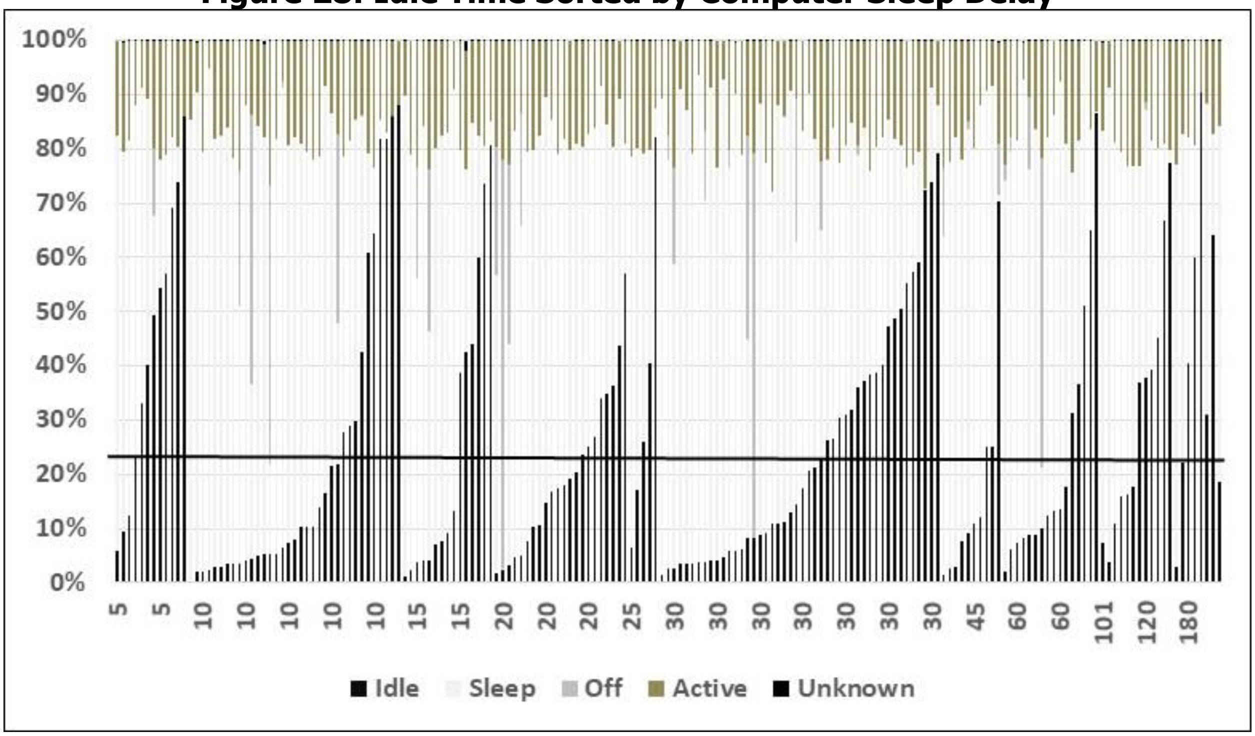
Source: Joy Pixley et al

When Computers Fail to Sleep

In the previous section it was posited that sleep-enabled computers should spend less than 25 percent of the time idle except, perhaps, under extreme conditions for computers with very long delay settings. This forces a new examination of the state times shown in 8, in which the *average* idle time across all sleep-enabled computers.

Figure 24 is 23 percent in period 1 and 26 percent in period 2. This suggests that many computers are failing to transition to sleep even when they are enabled. The extent of the problem is illustrated in Figure 28: cases are sorted by computer sleep delay and then by percent time idle (the dark columns at the bottom) for the last three weeks of period 2. Some variation within subjects who have the same sleep delay is expected, depending on how often they leave their computers inactive and for how long; however, the expected pattern would show very low ranges at the shorter delay times of 5 or 10 minutes, with increasingly higher ranges with longer delay times. Instead, the pattern revealed is that in every sleep delay time category, some computers show very little idle time (as expected, if sleep is functioning normally) and some are idle for one-third or even one-half of the time over the three-week period. The horizontal line is set at 25 percent to help identify cases over this threshold. This pattern of results strongly suggests the prevalence of processes, programs, or hardware interfering with sleep transitions, unrelated to sleep delay settings.

Figure 28: Idle Time Sorted by Computer Sleep Delay



Source: Joy Pixley et al

The PMUI application was programmed to record instances when a computer with sleep settings enabled remained idle when it was supposed to transition to sleep. As a buffer to account for legitimate background processing, the program allotted 20 extra minutes past the delay time before recording a "sleep block" event. PMUI recorded over one in three sleep-enabled computers (39 percent) as experiencing at least one sleep block event; of these, most were blocked no more than three times (67 percent), one in four were blocked four to ten times, and a few were blocked more often, including one outlier with 71 sleep block events and another with 204. A spot check of these sleep block events shows them to be legitimate points at which sleep-enabled computers did not transition to sleep. However sleep block events were only identified for one in three (37 percent) sleep-enabled computers that spent 25 percent or more time in idle mode. For most of those computers, only one to three sleep block events were recorded, which would not be sufficient to cause the high idle rates observed over a three-week period. During the interruptions to PMUI data recording when users logged off (described earlier), PMUI also missed sleep block events. However, it seems that many other sleep block events were missed as well, for subjects who did not suffer from the logging off data problem. Among cases with one or more sleep block events, 40 percent do not show more than 25 percent idle (which is only measured for those with sleep enabled in either the first or last three weeks), so they are not captured by that measure. By definition, these have lower idle times in the periods examined. However, the presence of a sleep block event indicates that other events may also have occurred, possibly in between the first and last three weeks, and that overall, their idle rates may be higher than they should be, given their actual pattern of use. A preliminary examination of the program has not yet identified why the sleep block function recorded so few sleep block events despite evidence that computers did not transition to sleep. The current interpretation is that many more sleep block events occurred and were missed.

In total, of the 201 computers with valid state data that had computer sleep enabled at either period 1 or period 2, 42 percent met the criteria of exhibiting 25 percent idle time or more while sleep enabled. Another 23 percent were recorded as experiencing sleep block events, for a total of 65 percent of sleep-enabled computers affected.

One of the advantages of the PMUI program is that it offers feedback to users about how much time their computer is spending idle and in sleep mode. As three-quarters of subjects were in the treatment group, and they were more likely to enable sleep settings, it is not surprising that most subjects with sleep block problems were treatment subjects (86 percent). For several subjects, PMUI acted as a valuable resource for identifying and troubleshooting sleep block problems. The subjects noticed their computers were spending too much time idle and contacted the research staff, who worked with the subjects and their IT managers to identify the source of the block. Sources included devices (such as a wireless mouse), programs (such as Google drive), or in one case, that the subject's computer was a network hub. However, only seventeen subjects reported this specific issue to the research staff. It is likely that many other subjects whose computers were not sleeping were not checking their PMUI reports often enough and didn't notice. Others may have checked their reports and noticed an increase in sleep and decrease in idle after enabling their settings, and not realized that the difference should have been much greater. Future versions of the PMUI program could benefit by giving clearer instructions on this issue, so that users would recognize the problem when it arose and could choose to pursue a solution.

Energy Consumption

Baseline Measures Across Computers

A computer's energy consumption depends on many factors, including the computer's components, the amount of time it spends active and idle versus in sleep mode or off, what programs and processes it runs, and any auxiliary devices it powers (e.g., speakers, backup drives). In the current study, the energy consumption measures also include any monitor attached to the computer. The basic energy consumption results shown in Table 31 separate computers by whether sleep is enabled (a proxy for less time spent idle) and the number of monitors. There are too few all-in-one computers or computers with three or four monitors to include separately in these results; they were omitted.

The main results conform to expectations: computers with computer sleep disabled use more energy, overall, than those with computer sleep enabled. Among desktops with computer sleep enabled, those with a second monitor use slightly more energy on average, but not significantly so. However, having a second monitor significantly increases energy use for desktops with computer sleep disabled. It is possible that sleep-enabled computers show less energy impact of a second monitor because any attached monitor sleeps whenever the computer does; however, given the high rate of display sleep settings, this seems unlikely. The result may partly be an artifact of the small sample size for the computer sleep enabled computers in the first three weeks, as the differences are not starkly greater for the sleep disabled computers. In almost all subgroups, the standard deviations are quite high relative to the means: that is, there is great variation within groups in energy consumption.

Table 31: Energy Consumption for Workstations by Number of Monitors and Computer Sleep Setting

	First three weeks			Last three weeks		
	N	**Mean kWh/day**	**SD**	**N**	**Mean kWh/day**	**SD**
Computer sleep enabled:						
All	42	0.789	0.496	197	0.941	0.712
1 monitor	12	0.730	0.394	75	0.833	0.888
2 monitors	23	0.967	0.531	112	1.005	0.586
p value		.1841			.1127	
Computer sleep not enabled:						
All	258	1.642	0.934	156	1.705	1.173
1 monitor	104	1.481	0.975	67	1.357	0.842
2 monitors	156	1.736	0.870	95	1.852	1.166
p value		.0283			.0034	

Source: Joy Pixley et al

Another possible source of variance in energy consumption is the brand of computer and the operating system. However, the manufacturer of the computer was not recorded in this study, only whether the operating system was Mac or Windows (which required different versions of the PMUI software), and at least a few computers manufactured by Apple were running Windows software. Desktops running Mac operating systems were much more likely than those running Windows to be all-in-ones (and possibly all of the all-in-ones were Apple computers) and much less likely to have two or more monitors. However, with only 31 desktops running Mac operating systems in the study, dividing them into number of monitors and whether sleep is enabled, produces subsample sizes that are too small for analysis.

Energy Savings

Earlier results showed that the subjects in the treatment group were more likely to enable computer sleep settings, and that computers with sleep settings engaged did indeed spend more time in sleep mode and less time in idle (albeit not as much as expected). The third and final test is the extent to which engaging with the PMUI app reduced energy consumption. Overall means show no difference in energy consumption by experimental condition in the first three weeks of the baseline period, whereas by the end of the study, energy consumption is significantly lower for treatment subjects than for control subjects (see Table 32). Comparing the last three weeks to the first three weeks, control subjects used slightly more energy, while treatment subjects used substantially less. The percentage differences are influenced by the initial energy consumption, which show a wide range; the savings are 17.6 percent for treatment subjects, while control subjects have negative savings (that is, an increase) of 9.3 percent. However, these figures should be considered raw differences, as they do not account for other factors which could affect both baseline energy consumption and savings.

Table 32: Energy Consumption and Savings for Workstations by Condition

	All		Control		Treatment		
	Mean	SD	Mean	SD	Mean	SD	*p*
Average kWh/day first three weeks	1.52	0.95	1.45	0.72	1.54	1.02	.4928
Average kWh/day last three weeks	1.27	1.05	1.50	1.07	1.19	1.04	.0280
Savings (last – first)	–0.24	0.74	0.05	0.62	–0.35	0.76	<.0001
Percent savings (raw)	–0.10	0.50	0.09	0.66	–0.18	0.40	<.0001

Source: Joy Pixley et al

A multivariate analysis is needed to account for these other factors and thus narrow down the independent effect of the experimental condition. The OLS regression results are shown in four nested models to better illustrate the relative impact of the included factors (see Table 32). The dependent variable being predicted is the percent different in energy consumption from the first three weeks of the baseline period (period 1) to the last three weeks of the experimental period (period 2). Model 1 shows the independent effect of experimental condition with no other factors included. This is the "raw" difference relied upon in many other analyses of intervention effects. Model 2 includes the effects of all baseline factors that were determined to be significant predictors when run independently, but excludes the experimental condition. The baseline factors are those that are unrelated to experimental condition but could reasonably predict energy consumption in period 2. These include the energy consumption in period 1 and whether the computer and display sleep settings were enabled at the beginning of the study. It also includes the percent of time the subject spent actively using the computer in both time periods: this controls for any difference in usage across the baseline and experimental periods that could lead to differences in energy consumption. Model 3 combines the baseline factors and experimental condition, to see whether experimental condition still matters once other factors are considered. Finally, Model 4 adds the two mechanisms by which the treatment is expected to operate: whether computer and display sleep settings are enabled at the end of the study.

Consistent with the means shown in Table 32, the regression in Model 1 shows that the treatment group is predicted to save about 28 percent more energy than the control group.

Model 2 shows that percentage of savings was greater for Windows computers and those using more energy at the beginning of the study. Computers that already had computer sleep enabled at the beginning of the study saved less than those who did not; initial display sleep settings had no effect. The baseline factors tested in Model 2 were all significant predictors when run separately; when included in the same regression model, factors that overlap in their effect on the dependent variable may be rendered non-significant, even if they are contributing to the model. For example, active time in period 1 is highly correlated to that in period 2, which helps explain why one of the coefficients is not significant. The pattern of these two coefficients is consistent across all models, and controls for the fact that computers would "save" more energy in the second period if they used the computer less (and vice versa). The R^2 statistic shows the percentage of variance in the dependent variable explained by the independent variables in the model, while the adjusted R^2 is corrected for the extent to which variables have been added to the model that do not add sufficient new information. The adjusted R^2 is always lower than the R^2; if the difference is too large, it indicates that extraneous variables should be removed.

Model 3 shows that being in the treatment group still has an independent effect on energy saving after considering all these baseline factors. This is the moderated or "true" effect size of the experimental condition: those in the treatment group saved an average of 23.5 percent more energy than those in the control group, after controlling for all baseline factors. The coefficients (effects) of the other variables in the model remain similar to those in Model 2, and the adjusted R^2 increases by almost as much as the adjusted R^2 of Model 1, which confirm that the experimental condition has a strong, independent effect on savings.

Finally, Model 4 incorporates variables for whether computer and display sleep settings are enabled at the end of the study. As expected, these have a strong, significant effect on using less energy in the second period. The coefficient for the experimental condition reduces and becomes non-significant at the $p < 0.05$ level: this confirms that its primary effect on energy savings is that subjects in the treatment group are more likely to enable their sleep settings. If the experimental condition had still been a substantial predictor in Model 4, that would suggest some unknown mechanism affecting treatment group subjects besides the intended effect (potentially a bias in the study). The larger coefficients for the settings variables compared to the coefficient for treatment in the previous model is to be expected, as many people in the treatment group did not enable their settings.

The next set of nested regressions follow the same logic, but predict absolute change in energy consumption between the first three weeks and the last three weeks rather than percent difference. The dependent variable is the average kWh per day difference from the first three-week period to the last, so a negative coefficient indicates a decrease, or savings. The results follow the same pattern as the percentage difference in energy savings: the raw treatment effect in Model 1 is somewhat reduced by controlling for other factors in Model 3 and disappears in Model 4 when the mechanism (enabling sleep settings) are included. The resulting estimate of treatment effect size is substantial and significant: treatment subjects saved an average of 0.353 kWh per day, comparing the last three weeks of the experimental period to the first three weeks of the baseline period. This corresponds to a projected 129 kWh per year.

The effects of the treatment group versus the control group provide strong evidence that using PMUI results in more energy savings than would be achieved by simply showing computer users their standard sleep settings and reminding them that they have control over changing them. However, this is probably a smaller effect than would be seen if PMUI had also been compared to a second control group who were given no intervention at all (which was beyond the scope of the current study). To partially approximate that effect, the final set of regressions examines the effects of enabling sleep settings, for those computers that began the study with their computer settings disabled. Results are shown in Table 32. Model A1 regresses the dependent variable of average kWh savings per day (first three weeks to last three weeks) on the same factors used in the earlier tables, and Model B1 does the same for the dependent variable of percent difference in kWh. In both cases, after controlling for other factors, a large and significant savings effect is found for enabling computer sleep settings. A large and significant savings effect is also seen for enabling display settings; this is lower for those who had display sleep enabled at the beginning of the study, but they still averaged additional savings, presumably through lowering their sleep delay times. As expected, for both models, a variable for treatment condition added to the second model is not significant, consistent with the idea that enabling sleep settings is the mechanism through which the treatment condition operates. Since this variable does not improve the model fit, the effect sizes for enabling computer sleep in the first models are used. Specifically, the estimated effect of enabling computer settings is to save 0.586 kWh per day (or 214 kWh per year), at an average savings of 35.2 percent.

LIST OF ACRONYMS AND GLOSSARY

Term/Acronym	Definition
ACPI	Advanced Configuration and Power Interface, an industry-wide open standard for managing computer devices and components, including power management
All-in-one computer	A desktop computer that integrates the display and the system's internal components into a single unit. Current models feature flat-panel monitors that resemble typical desktop monitors with a compact built-in system case.
Calit2	California Institute of Telecommunications and Information Technology, a unit at the University of California, Irvine
CalPlug	The California Plug Load Research Center, at the University of California, Irvine
CEC	California Energy Commission
Computer, desktop	Unless otherwise noted, the term "computer" refers to desktop computers, including all-in-one models, and including both Windows and Mac computers. The term "desktop" is used rather than the term "PC" to avoid implications about the operating system in use.
Display	Every computer has some form of visual content display, such as a monitor (for desktops and all-in-ones) or a built-in screen (for laptops). The type of display has implications both for energy usage and for user behavior. Thus the more universal term "display" is used for sleep settings, while the more specific term "monitor" is used for the monitors controlled by the display settings for these computers.
DK	Standard abbreviation for a "Don't know" response on a survey.
EPIC (Electric Program Investment Charge)	The Electric Program Investment Charge, created by the California Public Utilities Commission in December 2011, supports investments in clean energy technologies that benefit electricity ratepayers of Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas & Electric Company.
IT	Information Technology
Monitor	See "Display."
MAC	Media Access Control
N	Standard statistical notation for sample or subsample size represented in a table.
OIT	Office of Information Technology, a unit at the University of California, Irvine
OS	Operating System

Term/Acronym	Definition
p-value	A measure of the probability of the observed results if the null hypothesis (e.g., no difference between two groups) were true. In this paper results with a *p*-value less than .05 are considered to be statistically significant, while those with a *p*-value less than .10 are interpreted as suggesting a trend toward significance.
Power management, PM	Power management refers to a range of features that transition the computer, specific components, or the monitor into low power states. This includes basic automatic settings that transition the computer or monitor into sleep mode after a set delay period and advanced automatic settings such as those that transition the computer to hibernate or turn off the hard disk after a set delay period. It also includes manual power-management options, in which the user directly transitions the computer to sleep, hibernate, shutdown, or some other low-power mode through menu or keyboard commands.
PMUI	Power Management User Interface, the working title for the software developed in the current project.
RV1, RV2, RV3	Abbreviations for Research Visits 1, 2, and 3 in the PMUI study.
SD	Standard deviation, a measure used to quantify the amount of variation or dispersal of a set of data values within a sample; a smaller standard deviation indicates that values are clustered more tightly around the mean.
UCI or UC Irvine	University of California, Irvine
User	The subject who uses the computer in question (who may or may not be the owner).
User interface	The part of the PMUI software application that the user can see and interact with.

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APPENDIX A: Survey Questions

This appendix provides the text of selected questions whose responses are used in the analyses shown in this report. The scheduling survey was self-administered by the subjects online. The RV2 And RV3 surveys were self-administered by the subjects during the research visit, on a tablet provided by the research assistant.

Scheduling Survey

A1. First, we need some basic information to be sure you are eligible for the study.

How old are you?

A1_TEXT_________ YEARS OLD

1. [if R enters age in text field]
8. Don't know → GO TO A1A
9. Prefer not to answer → GO TO A1A

IF A1_TEXT < 18, GO TO A1B
IF A1_TEXT >= 18, GO TO A2

A1A. What is your age group?

1. Under 18
2. 18 to 24
3. 25 to 34
4. 35 to 44
5. 45 to 54
6. 55 to 64
7. 65 to 74
8. 75 or older
9. 18 or older, not further specified
98. Don't know → GO TO A1C
99. Prefer not to answer → GO TO A1C

(IF A1 < 18)
A1B. Unfortunately, this study is only for people who are 18 or older. Thank you for your willingness to fill out this form, we appreciate it. Click on the "Next" button below to exit.

[END SURVEY]

A1C. Unfortunately, this study is only for people who are 18 or older. We cannot verify that you are eligible if you do not report an age. Thank you for your willingness to fill out this form, we appreciate it. Click on the "Next" button below to exit.

[END SURVEY]

A4. Who uses this desktop computer?

1. I am the only user → GO TO B1
2. I use it most often, but one or more others also use it
3. Someone else uses it more often than me
4. I share it about equally with someone else
8. Don't know

9. Prefer not to answer

A4A. Unfortunately, this study is only for people who are the sole users of the desktop. Thank you for your willingness to fill out this form, we appreciate it. Click on the "Next" button below to exit.

[END SURVEY]

Survey at Research Visit 2 (RV2)

C1. How would you rate your knowledge of computers in general?

Think of a scale from 0 to 10, where 0 means a beginner (say, someone who needs help using email or playing simple games) and 10 means an expert (say, someone who could do advanced programming or teach college classes in computer science).

0	1	2	3	4	5	6	7	8	9	10
Beginner					Average					Expert

98. Don't know
99. Prefer not to answer

C2. Power-management settings allow you to reduce the energy your computer uses. These settings can put your computer into a low-power mode, like sleep or hibernate, if you don't touch the keyboard or mouse for a while. These settings can turn off your hard disk and dim or turn off your monitor after a period of inactivity. They can also be set to shut down your computer at a particular time.

On the same scale as above, how would you rate your knowledge of power-management settings?

0	1	2	3	4	5	6	7	8	9	10
Beginner					Average					Expert

98. Don't know
99. Prefer not to answer

C3. If you got a new computer at home for your personal use, who would probably install the software and manage the settings?

1. I would do it myself
2. I would do it, but might need a little help
3. I would do it, but would probably need a lot of help
4. I would ask someone else to do the set-up for me, like a friend or a tech support service
8. Don't know
9. Prefer not to answer

C4. Besides the desktop computer in this office, what other computers do you use regularly—that is, at least three hours a week? Please include any computers you use for your own work or leisure, whether the computer is owned by you, by UCI, or by someone else. Do not include computers that you maintain primarily for others, like in a lab, or that monitor lab equipment or building functions.

Place your cursor over the colored phrases to see the help text [not available in this document].

(Mark all that apply.)

1. Another desktop computer(s) on the UCI campus in an office
2. Desktop computer(s) on the UCI campus in an open computer lab
3. Desktop computer(s) at home
4. Desktop computer(s) somewhere else (examples: at an off-campus job or someone else's home)
5. Laptop or notebook computer(s) (include netbooks and convertible tablet computers)
6. Tablet(s) (examples: Apple iPad, Google Nexus, Kindle Fire)
7. None
9. Prefer not to answer

Help for "desktop computer": Desktop computers are personal computers designed to stay in a single location (unlike laptops). Standard desktop computers have a "tower" or "box" and a separate monitor, keyboard, and mouse. "All-in-one" personal computers combine the tower and monitor; count these as desktops. Do not count servers.

Help for "an office": This is not limited to your own office. Include any computers you use in the office of a research advisor or colleagues, or any shared computers that are available only to certain people, such as a work team, research team, or students of a particular professor.

Help for "campus": Throughout this survey, "campus" refers to all parts of UCI campus, including the Medical Center, North Campus, and Research Park.

Help for "open computer lab": An open computer lab is open to all UCI students, staff, and faculty, or to anyone in a particular department, such as student labs and library computers. If you use a computer lab that is limited to your research team, or to students of a particular professor, consider this a desktop in an office on campus.

Help for "home": "Home is your primary residence; that is, the place where you spent the most time during this (Spring) quarter.

Help for "convertible tablet computers" or "tablet": A convertible tablet computer has a built-in keyboard; typical screen size at least 10 inches diagonally; and uses Windows or Linux operating systems (examples: Lenovo IdeaPad Yoga, Sony Duo 11, ThinkPad Twist). By contrast, tablet has no built-in keyboard; typical screen size 7 to 10 inches diagonally; and uses iOS (Apple) or Android operating systems. Do not count basic readers, such as a Kindle or Nook.

C5. The next questions are about the desktop computer being used for this study.

Does the <u>monitor</u> (or, display) for this desktop automatically go to sleep (that is, go dark) when you haven't used the computer for a while?

Note that a screen saver, where an image continues to move on the screen, does not count as sleep mode.

1. Yes
2. No
8. Don't know
9. Prefer not to answer

IF C5 = 1:

C5a. How long do you think it takes the monitor (or, display) to go to sleep after you stop actively using the computer? Please think carefully, and make your best guess.

1. Less than 10 minutes
2. 10 minutes to less than 30 minutes
3. 30 minutes to less than 1 hour
4. 1 hour or more
8. Don't know
9. Prefer not to answer

C6. Does the <u>computer</u> itself automatically go to sleep when you haven't used it for a while?

1. Yes
2. No
8. Don't know
9. Prefer not to answer

IF C6 = 1:

C6a. How long do you think it takes the computer to go to sleep after you stop actively using it? Please think carefully, and make your best guess.

1. Less than 10 minutes
2. 10 minutes to less than 30 minutes
3. 30 minutes to less than 1 hour
4. 1 hour or more
8. Don't know
9. Prefer not to answer

C7. Computers come with default settings for power management, such as whether the computer goes into sleep mode after a period of inactivity. Have you or anyone else changed any of the default power-management settings on this computer?

1. Nobody has changed the settings

2. I changed them → GO TO C8
3. I did not change them but I know someone else did
4. I did not change them but maybe someone else did
8. Don't know
9. Prefer not to answer

GO TO C9

(IF C7 = 2, R CHANGED SETTINGS)

C8. When was the last time you changed the power-management settings on this computer?

1. Within the last week
2. More than a week ago but within the last month
3. More than a month ago but within the last six months
4. More than six months ago but within the last year
5. More than a year ago
8. Don’t know
9. Prefer not to answer

C8A. Why did you change the power-management settings? (Mark all that apply.)

1. Computer was restarting too slowly
2. For added security
3. Screen was going dark too soon while I was using the computer
4. I usually return to the computer in a short time
5. To save more energy
6. Computer needs to stay on (for backups, remote access, recharging devices, etc.)
7. Office policy
8. Technical problems
9. Preference or convenience
10. Change settings back and forth in different circumstances
97. Other reason (please describe) [______________________]
98. Don't remember / Don't know
99. Prefer not to answer

C9. In the past two weeks, when you knew you wouldn't be using this computer for several hours or more, what percentage of the time did you do each of the following? (Must total to 100%.)

A. Turned it off / shut it down completely:

Never Half the time Always
0% -- 100%

B. Put it into a sleep or hibernate mode manually, using menu options:

Never Half the time Always
0% --- 100%

C. Left it on (may or may not go into a sleep or hibernate mode automatically):

Never Half the time Always
0% --- 100%

998. Don't know
999. Prefer not to answer

IF C9C (LEFT ON) = 0% → GO TO C11

C10. People have many reasons for leaving their computer on when they will not be using it for several hours. Which of the following reasons are true for you? (Mark all that apply.)

1. Others may need to use it
2. Restarting it is too slow; I want it to be ready when I need it
3. Needs to be on for automatic updating or backups, or for moving large files
4. Needs to be on so it can be accessed remotely
5. Needs to be on to recharge a USB device
6. Computer will automatically go into sleep or other low-power mode anyway
7. Concern that rebooting causes wear and tear to the computer
8. Asked to leave it on by someone else (e.g., IT policy at work)
9. There's no good reason to turn the computer off
10. To keep programs running or files open
11. Technical problems
97. Other (please describe) [________________________________]
98. Don't know
99. Prefer not to answer

C11. Do you currently have control over the power-management settings on this desktop computer? That is, can you change the settings for whether and when it goes to sleep?

1. I don’t have control over the power-management settings
2. I control the settings, and there is a formal or informal policy about what they should be
3. I control the settings, and there is no policy about what they should be
8. Don't know
9. Prefer not to answer

D1. The last few questions are about you.

What is your gender?

1. Male

2. Female
7. Other (please describe) [____________________]
9. Prefer not to answer

D2. What is your race or ethnicity? (Mark all that apply.)

1. African American, Black
2. American Indian, Native American, Alaskan Native
3. Asian, Pacific Islander
4. Hispanic, Latino
5. Middle Eastern, Arab, North African
6. White, Caucasian
7. Other (please describe) [____________________]
8. Don't know
9. Prefer not to answer

D3. What is the highest level of education you have completed?

1. Less than high school
2. High school graduate (or equivalent)
3. Some college (1-4 years, no degree)
4. Associate's degree (including occupational or academic degrees)
5. Bachelor's degree (BA, BS, AB, etc.)
6. Master's degree (MA, MS, MENG, MSW, etc.)
7. Professional school degree (MD, DDC, JD, etc.)
8. Doctorate degree (PhD, EdD., etc.)
98. Don't know
99. Prefer not to answer

IF P2 = 1 OR 3 (FACULTY OR GRAD STUDENT) → GO TO D5

D4. Below is a list of official Census occupation categories. Which of the following best describes the type of work you do at UCI?

If you aren't sure which category to choose, please describe your work in the "Other" category.

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) [____________________]
98. Don't know
99. Prefer not to answer

D5. Which of the following best describes your current work status?

Note that "campus" refers to all parts of UCI campus, including the Medical Center, North Campus, and Research Park.

1. Working full-time on campus (at least 30 hours per week/75% appointment)
2. Working part-time on campus (less than 30 hours per week/75% appointment)
3. On medical leave or family leave
4. On sabbatical, but located locally
5. Away from UCI/Irvine for work (e.g., research, sabbatical)
6. Away from UCI/Irvine for another reason (please describe) [____________________]
7. Other (please describe) [____________________]
8. Don't know
9. Prefer not to answer

Survey at Research Visit 3 (RV3)

E6. Did you change the sleep settings on this computer in any of the following ways during the study period? (Mark all that apply.)

1. Enabled your sleep settings (that is, go from "never" to a time delay)
2. Decreased the delay time, so that your computer went to sleep faster than before
3. Increased the delay time, so that your computer went to sleep later than before
4. Disabled your sleep settings (that is, switch to "never")
5. None of these
8. Don't know
9. Prefer not to answer

[IF E6 = 1]

E7A. Why did you enable your sleep settings? (Mark all that apply.)

1. To save energy
2. To save money
3. For added security
4. Office policy
5. Preference or convenience
97. Other reason (please describe) [______________________]
98. Don't know
99. Prefer not to answer

[IF E6 = 2]

E7B. Why did you decrease the delay time (meaning the computer went to sleep faster than before)? (Mark all that apply.)

1. To save energy
2. To save money
3. For added security
4. Office policy
5. Preference or convenience
97. Other reason (please describe) [______________________]
98. Don't know
99. Prefer not to answer

[IF E6 = 3]

E8A. Why did you disable your sleep settings? (Mark all that apply.)

1. Computer was waking up too slowly from sleep mode
2. Screen was going dark too soon while I was using the computer
3. I usually return to the computer in a short time
4. Computer needs to stay on (for backups, remote access, recharging devices, etc.)

5. Office policy
6. Technical problems
7. Preference or convenience
97. Other reason (please describe) [________________________]
98. Don't know
99. Prefer not to answer

[IF E6 = 4]

E8B. Why did you increase the delay time (meaning the computer went to sleep later than before)? (Mark all that apply.)

1. Computer was restarting too slowly from sleep mode
2. Screen was going dark too soon while I was using the computer
3. I usually return to the computer in a short time
4. Computer needs to stay on (for backups, remote access, recharging devices, etc.)
5. Office policy
6. Technical problems
7. Preference or convenience
97. Other reason (please describe) [________________________]
98. Don't know
99. Prefer not to answer

E9. Did you do any of the following things to this computer during the study period? (Mark all that apply.)

1. Turn it off (shut it down) *more* often
2. Turn it off (shut it down) *less* often
3. Manually put it into sleep or hibernate mode more often
4. Manually put it into sleep or hibernate mode less often
5. None of these
8. Don't know
9. Prefer not to answer

[IF E9 = 1]

E10A. Why did you turn it off (shut it down) more often? (Mark all that apply.)

1. To save energy
2. To save money
3. For added security
4. Office policy
5. Preference or convenience
97. Other reason (please describe) [________________________]
98. Don't remember / Don't know
99. Prefer not to answer

[IF E9 = 2]

E10B. Why did you turn it off (shut it down) less often? (Mark all that apply.)

1. Computer was waking up too slowly from sleep mode
2. Screen was going dark too soon while I was using the computer
3. I usually return to the computer in a short time
4. Computer needs to stay on (for backups, remote access, recharging devices, etc.)
5. Office policy
6. Technical problems
7. Preference or convenience
97. Other reason (please describe) [________________________]
98. Don't know
99. Prefer not to answer

[IF E9 = 3]

E11A. Why did you manually put it into sleep or hibernate mode more often? (Mark all that apply.)

1. To save energy
2. To save money
3. For added security
4. Office policy
5. Preference or convenience
97. Other reason (please describe) [________________________]
98. Don't know
99. Prefer not to answer

[IF E9 = 4]

E11B. Why did you manually put it into sleep or hibernate mode less often? (Mark all that apply.)

1. Computer was waking up too slowly from sleep mode
2. Screen was going dark too soon while I was using the computer
3. I usually return to the computer in a short time
4. Computer needs to stay on (for backups, remote access, recharging devices, etc.)
5. Office policy
6. Technical problems
7. Preference, convenience
97. Other reason (please describe) [________________________]
98. Don't know
99. Prefer not to answer

E12. Some users remotely access their office desktops from home or while traveling. During the period your computer was monitored for this study, on how many days did you remotely access your office desktop?

1. Never
2. 1 to 3 days
3. 4 or more days
8. Don’t know
9. Prefer not to answer