USB Motion Sensor Computer Energy Management System: Technology Evaluation Report

California Plug Load Research Center

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Preface

The California Plug Load Research Center (CalPlug) was established by the California Energy Commission (CEC) to improve energy efficiency in the use and design of devices and consumer electronic devices. CalPlug focuses on energy efficiency solutions, efficiency evaluations of consumer electronics, standards development, education and public outreach, and user behavior studies. CalPlug is located on the University of California, Irvine campus as a division of the California Institute for Telecommunications and Information Technology (Calit2) organization.

TrickleStar, Inc., founded in 2007, is a manufacturer of energy-saving devices suitable for residential and commercial applications. TrickleStar is incorporated out of Delaware and based in Grand Rapids, Michigan.

Cover Figure: TS1910 USB motion Sensor (top); TS1910 USB Motion Sensor and TS1104 APS (bottom).

Disclaimer

This commissioned report was prepared based on independent testing and analysis. By CalPlug policy circa 2015, background content about a product or manufacturer in such commissioned reports should be unbiased, expository, and informative, but shy away from anything that would be prudently considered to be conveying effusive marketing information.

Executive Summary

Purpose:
Workstation computers are a major contributor to home and commercial loads originating from service outlets (plug loads). In this study, CalPlug evaluated a commercial solution to trigger computer standby without the need for direct user intervention or centralized coordination by using motion as the sensing element for user activity for computer use at a workstation. The sensor itself can be used alone or in combination with a conventional Tier-1 Advanced Power Strip (APS) to produce a solution with Tier-2 APS functionality.

Study Overview:
In this study, we reviewed the energy usage requirements for desktops and laptops of different operating systems and under different usages. In addition, as an extension of prior CalPlug evaluations, we provided an estimate of evaluated energy management setting frequency. From here we were able to present an energy savings potential from devices in the field through an intervention strategy.

CalPlug evaluated the TrickleStar TS1910 USB Motion Sensor and Tier 2 APS solution (the TS1110) combining a TS1910 and a Tier 1 APS to provide operational Tier 2 control. Evaluations and simulations were performed for the TS1910 alone and the TS1110 solution for capability, concept of operation, and simulated performance. Considerations for performance for desktop and laptop applications in addition to computers running Microsoft Windows™ versus MacOSX™ are discussed. The impact of savings on "wildtype" computers in "as-found" state is discussed in addition to the impact with simulated power management (PM) sleep settings and the impact of competing power management schemes. The load controllability and the use of the USB motion controller as a Tier-2 solution was also evaluated for savings impact.

In functional testing, the mode of operation for the USB Motion Sensor was characterized and compared to classic sensing strategies of keyboard and mouse input via a set of comparison studies. Modeling assumed par operation using motion sensing as compared to keyboard/mouse based usage detection for workstations, yet predictions of performance difference were discussed based on limited-scale differential testing. Savings potential was assessed based on a modeling study where a 2014 CalPlug dataset of computer operation was used to model from. This dataset included 115 university staff workstation computers, of which 16 had sleep power management enabled and set. Within this dataset, observed idle periods were acted upon by an algorithmic application of savings by an external device. A baseline calculation was determined based on times from the study in which the studied machines remained in each operational state (On, Off, and Sleep) and the power consumed by these machines.

Results:
For a population of computers across the study with energy management in the as-found state (denoted Wildtype), the energy savings potential for the USB Motion Sensor (which provides whole-minute timer settings of 5, 10, 15, 20, 25, 30) was determined to permit an average savings of between 880 minutes per day (at an intervention setting of 5 minutes) and 782 minutes per day

(at an intervention setting of 30 minutes), see Figure 5. There was a differential of 12.54% of savings between the two settings, see Figure 6. The large population of systems with no power management enabled lead to substantial savings predicted due to the large potential for extended idle times. For a population subset with sleep power management enabled (with various operating system PM timer settings), a savings of between 165 minutes per day (at an intervention setting of 5 minutes) and 97.61 minutes per day (at an intervention setting of 30 minutes) is predicted. A differential savings of 69.57% was predicted between the two settings. The large differential in savings potential for computers with PM enabled is due to a lower overall savings for the idle runtime baseline due to the existence of an operating system provided PM that acts as a backstop for excessive energy usage and extended idle periods.

Runtime reductions are linearly related to overall energy savings. Considering a computer with 40 W of active power use and 2.5 W of standby power use, a reduction of 880 minutes of daily runtime (based on all subjects with a modeled timer setting of 5 minutes) results in a savings of 200.7 kWh/year from a baseline usage of 273.6 kWh/year, corresponding to 73.4% yearly energy usage reduction. For reduction of 782 minutes of daily runtime (all subjects, timer setting of 30 minutes) results in a savings of 178.3 kWh/year from a baseline usage of 273.6 kWh/year, corresponding to 65.3% yearly energy usage reduction. For the population only consisting of a data subset with PM enabled, at 166 minutes of daily runtime (PM subjects only, timer setting of 5 minutes), a savings of 37.5 kWh/year is estimated from a yearly (PM subset) baseline of 85.4 kWh/year. This results in an energy usage that is 43.9% of the baseline. At a reduction of 98 minutes of daily runtime (PM subjects only, timer setting of 30 minutes), a savings of 22.0 kWh/year is estimated from a yearly (PM subset) baseline of 85.4 kWh/year. This results in an energy usage that is 25.8% of the baseline. See Table 1 for a summary of these results. A model for an APS used in conjunction with the motion sensing system is shown in Table2.

Table 1: Summary table of energy reduction calculation results (with margins of error for the mean calculated at the 95% confidence interval shown); see Table 18, Table 19, Table 20, Table 23, and Table 28 for further specific configuration and scenario calculations. In the specific modeled scenario, using the TS1910, a workstation is modeled with 40W active load, 2.5 W standby load and 0.5W SoftOff load. Extended energy savings and baseline energy usage values presented in this table were determined using "**Daily Runtime Reduction (minutes)**" and other model values using the attached Excel calculator.

Settings	**Daily Runtime Reduction (minutes)**	**Energy Reduction Savings (kWh/year)**	**Baseline Energy Usage (kWh/year)**	**Yearly Energy Usage Reduction (%)**
All subjects, timer setting of 5 minutes	880 ± 9.6%	200.7	273.6	73.4
All subjects, timer setting of 30 minutes	782 ± 10.5%	178.3	273.6	65.2
PM subjects only, timer setting of 5 minutes	166 ± 25.8%	37.5	85.4	43.9
PM subjects only, timer setting of 30 minutes	98 ± 57.1%	22.0	85.4	25.8

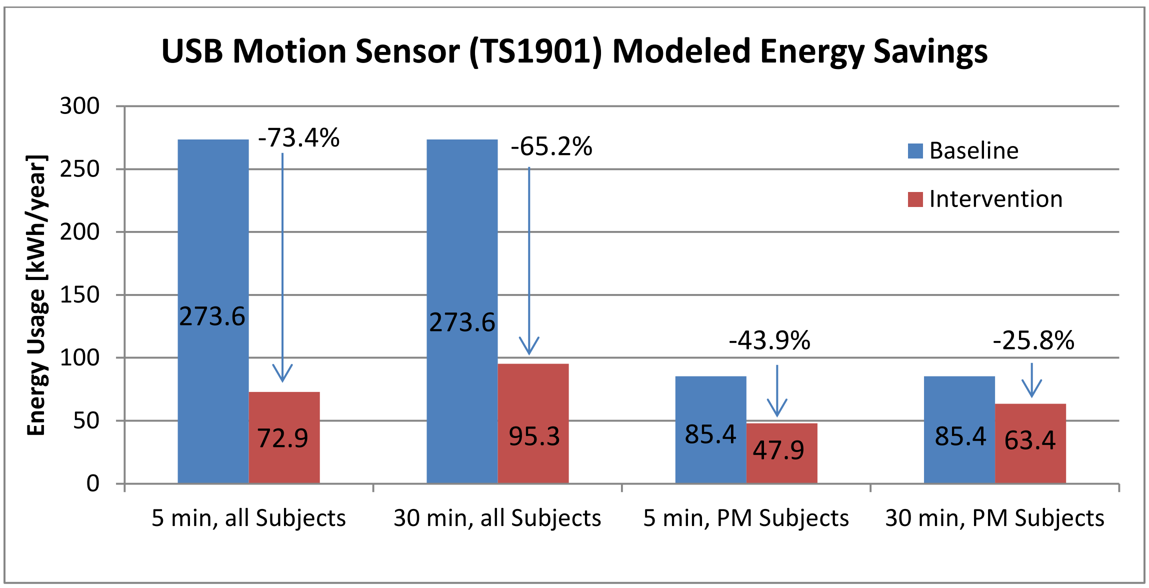

Figure 1: Graphical summary of the data within Table 1 showing percent decrease in energy usage between baseline and intervention cases.

Table 2: Summary table of energy reduction calculation results with the USB motion sensor operating with a Tier 2 configuration using a connected power strip (with margins of error for the mean calculated at the 95% confidence interval shown). In the specific modeled scenario, using the TS1910 in conjunction with the TS1104 APS to provide Tier 2 APS control, a workstation is modeled with 40W active load, 2.5 W standby load and 0.5 W SoftOff loads. The APS as modeled to manage a 40W average load (wasteful active + standby load reduction), and 10 W standby average load (Tier 1-style controlled standby load). Please see Table 27 for other similar configurations.

Settings	**Daily Runtime Reduction (minutes)**	**Energy Reduction Savings (kWh/year)**	**Baseline Energy Usage (kWh/year)**	**Yearly energy Usage Reduction (%)**
All subjects, timer setting of 5 minutes	880 ± 9.6%	412.7	549.9	75.1
All subjects, timer setting of 30 minutes	782 ± 10.5%	366.4	549.9	66.6
PM subjects only, timer setting of 5 minutes	166 ± 25.8%	77.8	171.7	45.3
PM subjects only, timer setting of 30 minutes	98 ± 57.1%	45.7	171.7	26.6

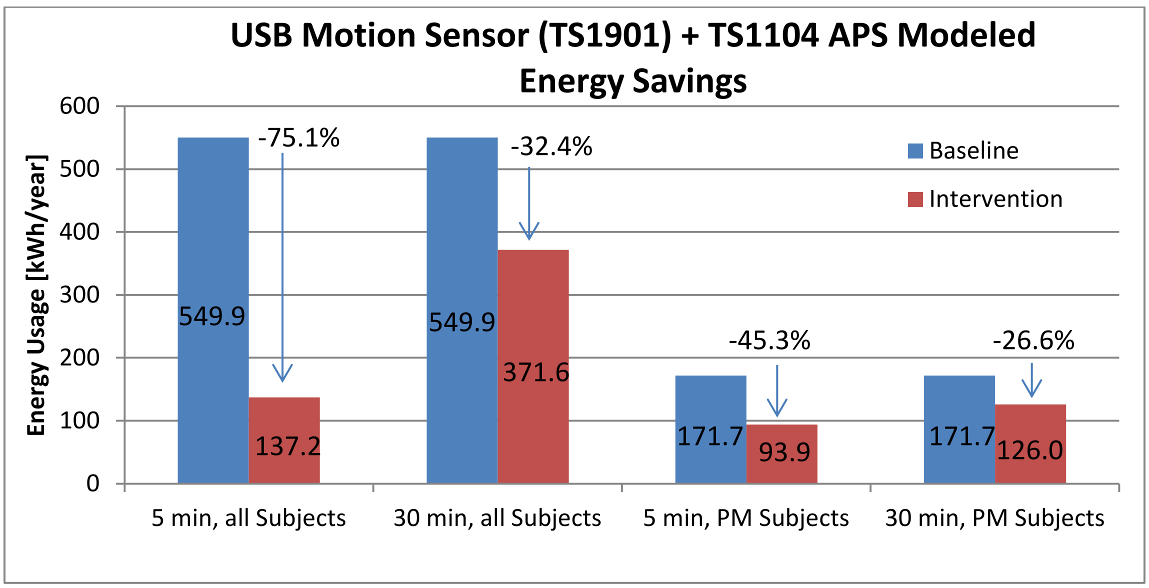

Figure 2: Graphical summary of the data within Table 2 showing percent decrease in energy usage between baseline and intervention cases.

Based on the sampled population, MacOSX workstations were predicted to have 44.56% less runtime savings average across the population with no PM enabled, and 1.39% less savings across a population with PM not enabled (see Figure 37 and Figure 38). Both values consider intervention periods from 5 to 120 minutes in length. It must be stated that a substantially lower population of MacOSX machines were included in the population dataset with unequal proportionality to PCs for having PM enabled and a different proportionality for PM operation. The authors strongly caution that this data set does not have strong statistical power, and the presented differences are likely aberration due to subset sizes. Mechanisms for differential operation, especially in runtime alone are not clear. Follow-up investigation on this point is recommended. Workstations operating with MacOSX are used less frequently in typical office environments than alternative options. Details of this frequency are discussed in the introduction of this report.

The use of the USB Motion Sensor with an computer power draw triggered advanced power strip (as part of a Tier 2 Solution) can provide additional savings by reducing peripheral standby energy consumption and wasteful active energy consumption but at the expense of the control overhead (approximately 4 KWh/year). The savings values shown in Table 1 can be conceptually extended based with this additional control capacity as presented for sample calculation points and scenarios in Table 26, Table 27, and Table 28.

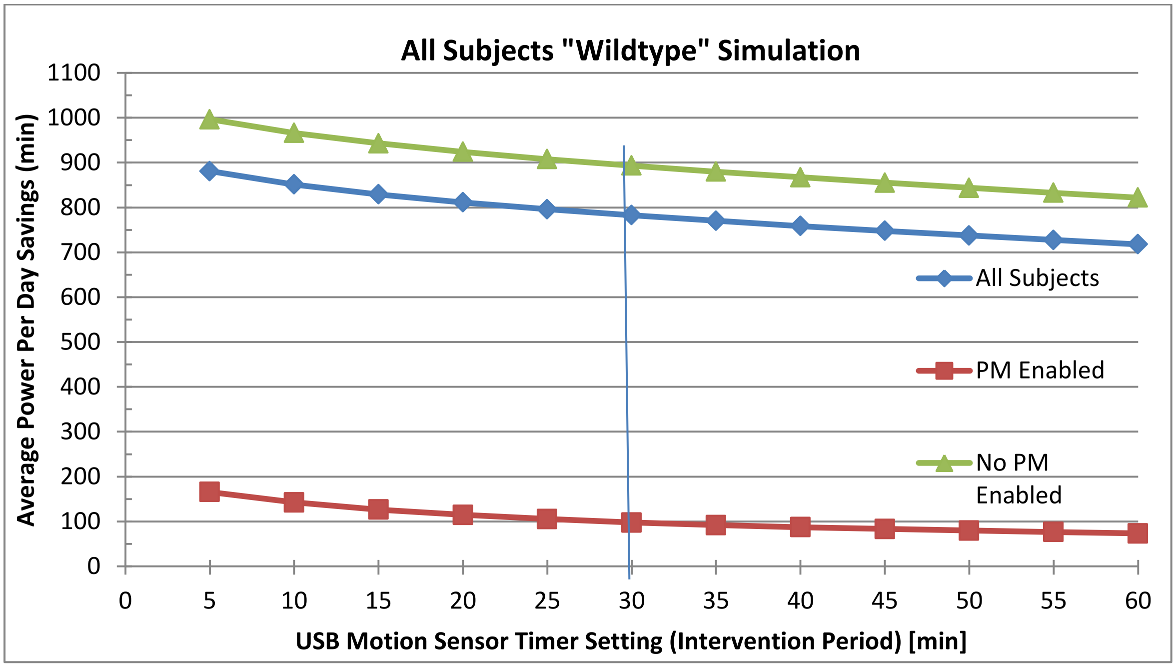

Figure 3: System On state runtime savings for different USB Motion Sensor timer lengths with subject data for all subjects and subsets with power management enabled (various settings) and power management not enabled. A line is drawn on the graph at the maximum timer value setting available on the USB Motion Sensor.

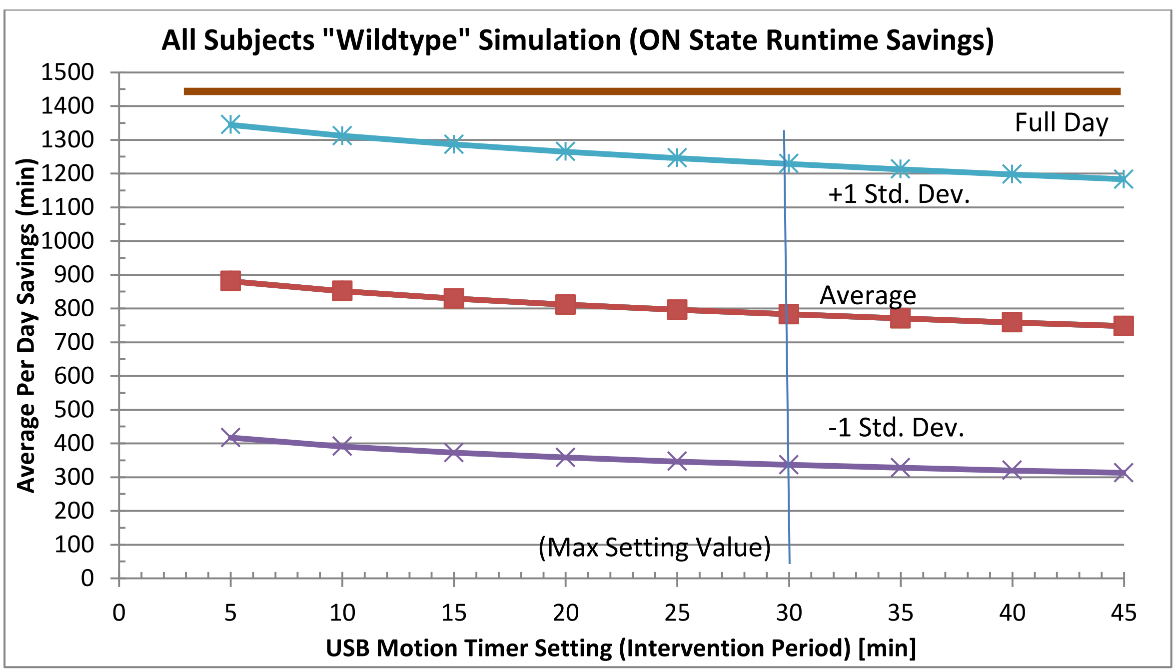

Figure 4: Wildtype system On state runtime savings for different USB Motion Sensor timer lengths. The average and +/- 1 standard deviation values are shown along with the reference for the length off a full day.

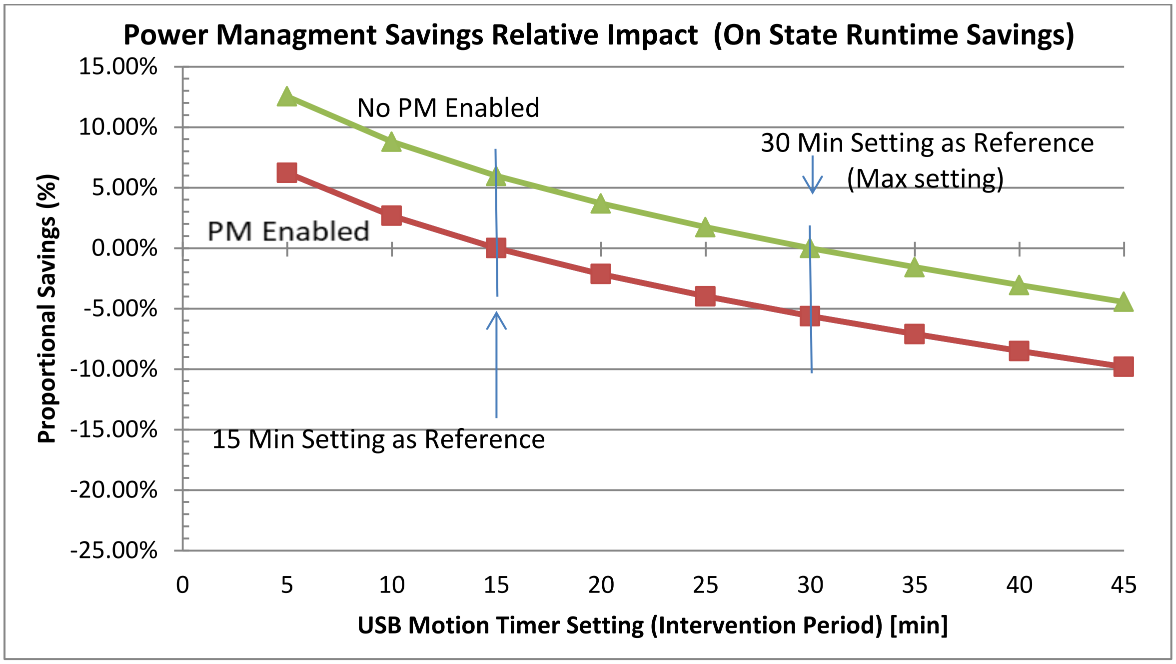

Figure 5: Comparison of predicted per day savings for all subjects. Shown are subjects with sleep PM enabled (bottom line), and subjects with no Sleep PM enabled (top line) for Timer settings modeled up to and beyond the maximum value of 30 minutes (top). The full dataset for all subjects shown with +/-1 standard deviation above and below the mean calculated value for all subjects (below).

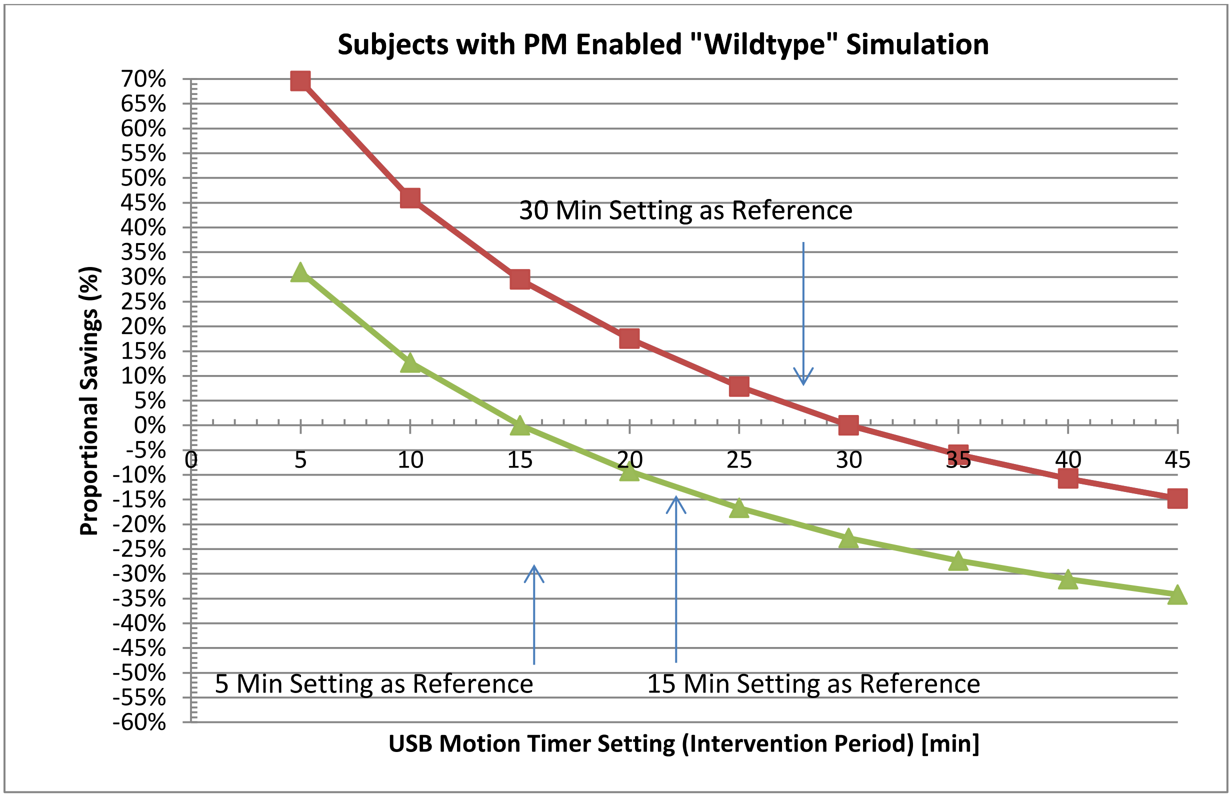

Figure 6: Modeled variance in savings of runtime for all subjects due to change in the timer setting of the USB Motion Sensor from both a 5 minutes (shown as reference), 15, and 30 minute reference for all workstations (top) and for the subset with known sleep PM settings (bottom).

Laptops in stationary use (unmoved alone or in use with docking stations) are expected to have similar performance as desktops for energy savings assuming identical PM settings and distribution as desktops and no screen power management. Laptops typically have a lower baseline energy usage compared to desktops with respect to the computing elements of the system, but the addition of a built-in screen adds to overall active power usage. Laptops in portable configurations are expected to have less savings potential as the period where the laptop is not connected to power and assumed to be in sleep mode – it is assumed that PM settings are enabled for non-externally powered modes of laptop use. CalPlug has discussed power management interface design in a separate report and pertinent summary details are discussed [1]. Use of external screens with laptops under APS control is another potential configuration that lends itself to use with the USB Motion Sensor in combination with an APS. In this configuration, the USB Motion Sensor would stay connected to an external workstation monitor. When both signal and USB are connected to the laptop, the USB Motion Sensor would provide external power management control for the laptop. Through APS control, PM action of the laptop provides controllability of the standby power for the second monitor in addition to any other workstation electronics under management by the APS.

Control of devices by APS is directly linked to total runtime saved. Accordingly, savings can be considered based on this factor in addition to average controlled load and APS operational/standby load (both in units of watts). Considering the ENERGY STAR standby value of 2 W, negligible energy savings (approximately 12 kWh/year) can be achieved with monitor control alone assuming rapid entry into monitor sleep but no entry into computer sleep. Based on CalPlug's 2014 computer monitoring survey, this is a relatively common setting configuration. Significant active load reduction is only available if extended length display sleep settings are used or no monitor sleep settings are used, leading to a picture never disappearing from the display in user absence (no monitor sleep occurring). This configuration may not lead to a tipoff that a sleep event will be occurring. In this scenario, the USB Motion Sensor has a flashing indicator one minute before shutdown that may provide an equivalent warning of eminent shutdown if monitor sleep is not used prior to computer sleep.

Tier-2 type control was directly assessed and simulated based on control operation of the computer as managed by a USB Motion Sensor indirectly through the PC. When operating correctly, in this control scheme, a savings based on the number of connected devices is modeled. For a 10 W constant modeled load, this is 34 kWh per year. Compared to baseline, this is an added annual energy savings of is a 13% that can be yielded additionally by using this control approach. Savings are modeled for multiple loads in addition to this presented value, as well as the general case based on operational minutes. Other connected loads, including desk fans, heaters, printers, lights, and others, can produce substantial savings under APS management if routinely left on by the user when not present. Savings were strongly coupled to controlled load with the savings potential substantially larger when active use was reduced rather than just reduction of device standby load.

The modeling and analysis process used in this study provides a framework of predicting savings potential based on known operating patterns of workplace desktops. While individual habits and distributions of PM settings vary by workplace based on computer operating system, policies, etc., patterns of savings with respect to intervention technique (USB Motion Sensor, USB Motion Sensor + Advanced Power Strip) and Intervention period setting (USB Motion Sensor timer duration) can be understood as to the impact of marginal settings. In this manner, any absolute divergence between the presented model and that of values measured in field trial can additionally extend the current model. Moreover, the absolute change between settings can be applied to a single point of field trial data to predict marginal changes based on adjustment of a USB Motion Sensor timer. Similarly, field trial data which logs user's idle times can be used to generate an extended model based on this population set. The presented analysis comes with some caveats related to the modeling approach and general technique that are discussed in detail in the body of this report.

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Definitions

1. **Personal computer (PC):** This term is commonly used to refer to two specific items. For the purposes of this report, this term is generally limited to desktop or laptop computers used by a single user, as contrasted with a server or stations in a computer lab. The said computer may use any operating system. In specific verbiage use cases, a "PC" may denote a computer operating a Windows or Linux operating system off, historically this lineage was referred to as IBM PC Compatible. The former definition is the typical use. The alternative term use case will be denoted.

2. **Workstation**: For the purposes of this report, a workstation is a static working environment such as an office or cubicle that contains at least one personal computer as well as other office equipment, including monitors, lamps, printers, etc.

3. **Computer states**: Abbreviated from the Advanced Configuration Power Interface (ACPI) standards:

    a. On, or working: Computer is running and can execute instructions. The computer is turned On [ACPI G0(S0)] with one of the following functional (user) states:

        i. User engaged: The user is actively engaged by interacting with personal computer. This is typically via the console, but may also be via remote access. Use of the computer can include a wide range of activities. Information is transferred (or will be imminently transferred) between the user and the computer.

        ii. User absent, active background operation: The user is not engaged with the device, but the system is performing operations in the background, such as automatic backups, diagnostics, or updates. It may also be performing an unattended operation initiated by the user (e.g., a long-running data analysis or download).

        iii. User absent, idle: The user is not engaged with the device. The device may be left operating in idle mode with the user away (or not interacting) with the computer. Non-critical background tasks may be in operation.

    b. Sleep or standby: a low-power mode where RAM remains powered (ACPI system level S3).

    c. Hibernation: a very low-power mode where the main memory is saved to disk and the system is powered down.

    d. Soft Off: the computer is shut down, but is still connected to a power supply and using minimal power.

e. Mechanical Off: the computer is shut down and power is cut off [ACPI G3].

4. **Display (monitor, screen) states:** Abbreviated from the ACPI standards:

   a. On: The display is on and displaying visual content.

   b. Screen saver: The display is on and displaying a continuously updating graphic. This state may provide the user security (e.g., a login screen requiring a password) but does not result in display power savings.

   c. Sleep: The display is dark and in low-power mode, and can be woken by keyboard or mouse activity.

   d. Off: The display is dark and using minimal power; it can be woken only with the power button.

5. **Advanced Power Strip (APS):**

   a. A Tier 1 APS is a power strip with one master outlet and multiple controlled outlets. When the device in the master outlet (e.g., a TV or desktop computer) goes into a low-power or shutdown mode, the APS cuts power to the devices plugged into the controlled outlets (e.g., DVD player or printer).

   b. A Tier 2 APS incorporates engagement sensing to determine when devices are unused, cutting power to all devices without the need for action from a master device. Like a Tier 1 device, the Tier 2 device also only cuts power to those devices in the controlled/switched outlets. Tier 2 devices typically have two always-on outlets.

6. **Universal Serial Bus Human Interface Device (USB HID):** A descriptor of a class of input devices such as keyboards, mice, game controllers and alphanumeric display devices connected via Universal Serial Bus (USB). Some USB HID devices offer control commands and capabilities that can be used to trigger computer power management events.

7. **Countdown Timer**: A timer that is initiated at the last input event. When partially elapsed, a warning may be displayed to the user. Once fully elapsed, a command or action to control power is issued for APS and motion-sensor type devices.

8. **USB Motion Sensor:** A device that uses motion input events to manage computer power states. In this document, this term refers to the TrickleStar TS1910.

Chapter 1: Introduction

Background

Individual computer workstations account for the majority of plug load devices in most office buildings, as they generally outnumber common areas and shared equipment. Computers use a substantial proportion of each workstation's energy use. One study of over three hundred workstations found an average energy consumption of 332 kWh/year, in which computers used an average of 60% for desktop computers and 30% for laptops [2].

Desktop computers are losing sales market share to portable (i.e., laptop or notebook) computers, but their contribution to energy consumption continues to be high in both commercial and residential settings [3, 4]. Even with the introduction of mobile computing devices to both business and residential settings, the long replacement cycles mean these devices still are present to contribute to energy usage. A recent study estimates the installed base of desktop computers in the US to be 72 million, compared to 122 million for portable computers. This same September 2018 report by Net Applications indicated 2.5% Linux (all variants), 9.52% MacOS, and 87.56% Microsoft Windows across all work computers [5]. Similarly browsing statistics for desktops/Laptops indicate 2.76% Linux, 13.49% MacOS, and 81.76% Microsoft Windows [6]. A July 2018 survey by Spiceworks revealed that 68% of surveyed organizations still provide desktops as the primary computing device as opposed to 29% for laptops. The replacement cycle is often much longer with desktops than with laptops. The survey results showed 70% of companies use desktops for five or more years while 24% use them 7 or more years. For laptops, the replacement cycle is faster [7]. Only 48% of companies use laptops for five or more years, while only 8% use laptops for seven or more years. The report detailed hardware failure that drives replacement cycles [7, 8].

Laptops, due to their portable nature, unlike desktops may not always be connected to AC power when not in use. Laptops in nearly stationary usage (always connected with similar power management settings) commonly have similar energy consumption patterns to desktops, but laptops may be disconnected and placed in standby/hibernate power states (placed in a storage state) when not in use. Battery energy would supply any active functionality in this setup. The charger may be left connected or disconnected when the laptop is being moved. This leads to zero direct energy usage when disconnected, although used energy in this state may be added back upon reconnection and subsequent battery recharge. When viewed in aggregate, the estimated annual electricity consumption for desktops is 18 TWh compared to only 5.1 TWh for portable computers across the population of deployed devices [9]. Desktop computers are major contributors of wasted "idle" energy use in homes and businesses [10]. Current ENERGY STAR guidelines estimate average power consumption for desktops at 2.3 watts in Sleep mode compared to 48.1 watts while idle [11]. In one case study, desktops with sleep settings enabled (regardless of delay time) spent an average of 12% of the week idle, compared to 68% for those without sleep enabled [12].

Unfortunately, despite having powerful power management options, most desktops are not benefiting from them. Numerous studies have performed physical audits or measurements of computers and other electronic office equipment in situ, in commercial and 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. With better power management practices substantial energy savings could be possible [13, 14-16]. Multiple studies have shown that in the absence of office policies or IT control of computers, the majority of office desktops have their computer sleep settings disabled [17-19]. Notifications to users not present from the operating system, browsers, or other applications may cause a resetting of the countdown timer to enter power management activated Sleep state.

Most computers are now shipped from the manufacturers with their computer and display (monitor) sleep settings enabled. Typically, the monitor will sleep prior to the computer sleep transition. For Windows desktops, the standard default is to set the computer to transition to Sleep mode after 30 minutes of inactivity and set the display to transition to Sleep mode after 10 or 15 minutes. These default power management settings are being changed in many offices, whether by end-users, IT managers, or other third parties. In some cases, users have deliberately disabled the sleep settings, perhaps frustrated with their computers going to sleep while they were reading or doing other non-interactive tasks. In other cases, users may have intended to temporarily disable the settings for a specific task and then never reinstated them. This can include downloading files, use of conferencing/communications programs, video and music players, etc. Programs acting in an irregular manner may cause sleep settings to activate even when properly configured. This may happen consistently or erratically and with or without the user's knowledge. In other cases, power management may be disabled by someone other than the user without their knowledge, even though the user would be amenable to using power management.

In contrast to the research observing computers directly, surveys show high rates of users reporting that their computers automatically go to sleep [20, 21]. Some of the discrepancies between self-reports of enabled sleep settings and observations of idling computers appears to be due to user confusion about sleep settings, such as assuming the computer goes to sleep when the monitor does [22]. One study that linked self-report to research observations for the same subjects found that although 86% of subjects had reported their computer sleep settings enabled, only 30% of those subjects had their settings enabled [23]. Furthermore, those who rated themselves as more knowledgeable about computers were more likely to be accurate about their settings. This suggests that educating 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 [20], indicating the likely involvement of IT managers, previous users, or other third parties.

In short, research suggests that for a range of reasons, personal computers tend to be poorly managed by standard power management settings. In this project, we explore an alternate solution: an external device that puts the computer to sleep after a set period of time when it senses that no user is present. The motion sensor provides a different measure of when the computer is not being used, to either supplement or replace the traditional measure using keyboard and mouse activity. In theory, a motion-sensor based solution can use a shorter delay time than automatic power management settings without decreasing the user's satisfaction, because the computer does not transition to sleep unless the user is absent from the terminal interface. Thus, it could supplement or replace less aggressive PM settings that the user may otherwise not use to overall reduce energy usage or provide a stopgap capability for misunderstood or mismanaged operating system PM settings.

CalPlug evaluated the capability of a system using external, user-sensing energy management control and the potential of this device to provide energy savings for desktop and laptop computers.

Advanced Power Strip (APS) Energy Management

Another type of device for managing energy in office equipment is the Tier 1 Advanced Power Strip (APS). When used alone, it allows energy savings by turning off workstation accessories and surrounding devices when the computer itself is in Sleep or Off modes. In conventional usage, the user connects the workstation itself or the monitor into the master outlet, while accessories to be controlled are plugged into the "controlled" outlets. Per some manufacturer usage instructions, for desktop usage, the monitor is used in place of the computer itself as the master device. This is because monitor sleep power management is often better configured than computer sleep management [1]. This configuration also lends itself to laptop use as well. In this configuration, monitor savings in monitor standby mode (versus unplugged) cannot be counted. When turned off, the APS cuts power to the other devices. Controlled peripherals may include monitors (primary and/or secondary), lamps, speakers, scanners, printers, fans, under-desk heaters, and other near or on desk devices. Previous utility studies have shown between 23 and 89 kWh/year saved based on multiple utility studies of Tier 1 APS performance in office workstations. Likewise, a NREL study showed workstation Tier 1 savings between 4% and 26% [24, 25].

Tier 2 Advanced Power Strips incorporate the ability to sense user engagement (e.g., via a motion sensor), and cut power to devices if no one is present for a set period of time, including the master device (usually a television for Tier 2 APS entertainment applications, but for Tier 2 APS in computer control applications this, correspondingly, is typically a CPU or monitor). Residential applications for Tier 2 APS devices for entertainment applications have a *de facto* set of features that device class members share, yet no such rigorously defined category exists for commercial computer power management [26-28]. CalPlug previously offered guidance on this product category [29]. Elements of the current Tier 2 design for entertainment device control do not align well with computer power management applications. Unlike televisions, a computer cannot have power cuts used for energy control. Instead they should transition into lower-power states through power management commands. Also unlike a residential unit, the workstation Tier 2 APS does not respond to infrared remote control signals. Approaches claiming Tier 2 control for computers use a combination of external input and/or management on top of PC self-managed control.

Similar to Tier 2 APS devices for entertainment uses, Tier 2 APS devices for computer power management *should* provide the following basic functionality. Energy savings potential in Tier 2 APS devices is a combination of what devices are connected and how wastefully they are inherently used, how effective the Tier 2 APS device is at targeting both active and standby waste modes to provide energy savings, and how the design of the device contributes to extended, safe, and unobtrusive usage with little overhead energy usage. A list showing the *de facto* California Investor Owned Utility Qualified Product List (CA Tier 2 - APS QPL) product category guidelines for Tier 2

APS devices [29] with *suggested* functional equivalent capability systems for computer workstations in potential Tier 2 APS solutions are shown:

1. **Use indication of user engagement to manage automatic shutdown**
<u>Residential Entertainment:</u> Use of IR commands to trigger APS device startup. Lack of IR input due to lack of assumed user engagement (in addition to lack of observed motion in some cases) causes the initiation of the shutdown sequence of television and attached accessories.
<u>Computer Workstation:</u> Use of keystrokes or local motion to provide management of computer workstation energy management in a means substantially superior (in aggregate) to onboard operating-system controlled energy management.

2. **Provides persistent energy saving operation**
<u>Residential Entertainment:</u> Permanent installation intended with clear user operation and defined interaction for use. Designed to fail in manner to alert users of simple problems.
<u>Computer Workstation:</u> Design and operation of a device or solution system should consider similar operational points.

3. **Low inherent power usage**
<u>Residential Entertainment:</u> Low inherent power usage in any configuration to provide energy savings solution. Average active/On mode power consumption must not exceed 1.0 watt for Tier 2 devices without external communication capability via a wireless networked connectivity system when controlled devices are active. Average active/On mode power consumption must not exceed 2.0 watts for devices with external communication capability via a wireless networked connectivity system when controlled devices are active.
<u>Computer Workstation:</u> Similar recommendations follow for computer workstation recommendations.

4. **Intelligent power sensing and control**
<u>Residential Entertainment:</u> Use of power sensing with auto-thresholding, Sense total power being consumed by all controlled devices or sense total power consumed by the device plugged into the controlled outlet, Sense true RMS power to determine device usage of AV equipment.
<u>Computer Workstation</u>: Auto thresholding is a feature that should be included, in new generation Tier-2 Solutions for computers. It is typical for Tier-1 solutions to not include auto-thresholding for cost reasons.

5. **Features safe and reliable construction**
<u>Residential Entertainment:</u> features resettable circuit breaker and relay system rated for 100,000 cycles at 15A load, and must comply with the 2016 California Fire Code (605.4), a standardization of the International Fire Code.
<u>Computer Workstation:</u> Similar recommendations follow for computer workstation recommendations.

6. **Provide warning and reasonable countdown timer duration for substantial savings**
<u>Residential Entertainment:</u> Deliver a minimum 10 minute count down Idle Mode warning to avoid nuisance switching and to provide adjustable Idle mode capability with a potential minimum setting of 1 hour.

<u>Computer Workstation:</u> In analogous operation, a warning should be provided prior to shutdown. Since timer durations are much shorter with workstations, a period of 1-5 minutes is reasonable dependent on the total timer duration. For total timer duration, the periods should approximate those provided by modern operating systems with a minimum of approximately 5 minutes up to approximately 1 hour as provided options. Shorter timer durations lead to energy efficient device usage.

7. **Safe Power Switching and control**
   <u>Residential Entertainment:</u> Use of power cuts and in some cases CEC commands can be used to provide safe, effective power control of attached devices.
   <u>Computer Workstation:</u> Power cuts are inappropriate for device control due to risk of data corruption. Use of a software or daemon solution or hardware based command and control to provide operating system mediated shutdown is a best practices approach. The extent as to which such a solution updates or controls inherent operating system power management settings versus providing external control triggers via a connected device or networked solution is dependent on the exact framework of the solution used.

8. **Feature filtering and false signal triggering**
   <u>Residential Entertainment:</u> Hardware and/or software IR filtering technology and firmware to filter out rogue non-AV equipment IR interference from compact fluorescent lights and sunlight.
   <u>Computer Workstation:</u> Best practice of input filtering (keystroke input or ambient sensing—including motion sensing), sensor fusion should sense and filter inputs to avoid unintentional resets of the countdown timer due to irrelevant inputs.

The features suggest that Tier 2 APS for computer workstations are agnostic of the physical configuration or form factor for a Tier 2 solution. In implementation, a Tier 2 solution may be a single part device or a multi part system with both software and hardware components. The control may be centralized or decentralized to meet these operational goals.

Evaluated Devices

This report details a laboratory-based investigation of the energy savings potential of the TrickleStar USB Motion Sensor (Model TS1910) device. The TS1910 plugs into a USB port and uses standard human interface device (HID) protocols to communicate input from the user (in this case, their presence) to the computer. The device uses a passive infrared sensor to determine the presence of a person in front of the computer by changes in thermal energy between zones, indicative of motion. Presence is triggered by activity such as moving a hand on a keyboard or mouse, or the user moving in his or her seat or in the local area. The device can be programmed for multiple individual delay times: 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes. Whenever the countdown timer reaches the delay time without sensing activity, the device puts the connected computer into Sleep mode (ACPI S3). This approach uses HID commands that emulate the keystrokes of a user to initiate sleep. Specifically, the function of the "sleep" keyboard key or the menu-driven action on the part of the user to manually trigger a single session of sleep from the operating system. The button on the side of the TS1910 also provides a rapid "sleep button" that allows direct and immediate initiation of Sleep mode. The TS1910 has a setting based on the position of a slide switch to emulate HID commands compatible of actuating sleep either Apple/Macintosh and Linux (MAC) [positon 1] as well as another setting (PC) for Windows [position 2].

The HID over USB operation of the TS1910 does not require the installation of drivers or control software. There is no central point of control that has to be managed or installed. This reduces a potential barrier to site rollout of the solution, as IT managers frequently prohibit the installation of third-party software on workstation computers. Installation involves the physical positioning of the device, setting of the operating system switch (as MAC or PC), connecting the USB port to an available port, and setting the timer if it is desired to be set at another value other than the default 15 minute value. The device can be installed with or without the machine being turned on and does not typically require administrator privileges or computer restarts in setup, although this may not be true for workstations with stringent security control of attached USB devices. The TS1910 does not interfere with current power management settings, but serves to augment these settings to provide improved energy management by placing the connected workstation in Sleep mode earlier than it otherwise would, if the user is absent. This assumes a smaller timer duration value for the USB Motion Sensor than the operating system power management and par-equivalency of sensing. This device provides a plug-and-play stopgap for energy use management. If onboard sleep settings have a period extended beyond the settings of the TS1910, the device will effectively provide energy management control.

The TrickleStar USB Motion Sensor is also sold together with a Tier 1 APS. In addition to testing the TS1910 alone, it was also tested in combination with this APS (packaged together as Model TS1110). Energy savings for peripheral devices are limited by the efficiency of the controlling computer: poor power management of the master device leads to poor power management of the entire system. By using external motion sensing to mediate sleep control, the combined solution of the USB Motion Sensor and the Tier 1 APS can provide the operational functionality of a Tier 2 APS solution. This solution uses behavior (occupancy) to manage control of both the computer and its connected peripherals to fit within the suggested feature set discussed within this report.

Why develop simulation-based models?

In this report, real-world parameters and verified device operational logic are combined into a simulation to help understand usage in several scenarios. Evaluating the performance of energy savings devices requires an additional level of complexity beyond evaluating the energy performance of a typical end user device. Even limited-scale field trials are costly to generate a representative dataset. Additionally, such field trials can produce non-representative or non-trustworthy results if they are not conducted at a statistically large enough scale or if experimental elements change. Producing a model of operation based on simulation allows a structured, repeatable evaluation to be conducted factoring in the influence of major operational and situational parameters. Real-world values, where available, are used to provide evaluation boundary conditions or inputs. By varying structural parameters of the device operation model in addition to the model inputs, multiple usage conditions can be simulated to provide quantitative boundaries on energy savings performance. Figures of merit and multiple relevant configurations can be evaluated. This can be used to provide planning input to field study development. By focusing on appropriate or relevant usage parameters based on simulation, the field trial work may be streamlined. This can lead to the value of studies being increased by focusing on relevant factors. Additionally, knowing the factors that can lead to experimental non-conclusion results ahead of time can reduce the risk of irrelevant findings or experimental dead ends.

If the model justifies the effort, the performance boundaries determined by the model can provide a basis for extended-scope field trials to confirm model validity. The model can also provide a framework to discuss field trial results for aberrations or benchmarking. Extensions of the model can be used to drive innovation forward by allowing rapid evaluation of device performance using real world data to test how changes in device operation would likely affect real-world performance. In this manner, simulation-based modeling with device evaluation provides a high value asset to justify further testing and a framework to drive continued device innovation.

CalPlug Evaluation Approach

Using data collected from internal testing in conjunction with data from prior research, CalPlug tested the assumptions and estimated the overall power consumption and potential energy savings of the USB Motion Sensor under evaluation. Specifically, we performed the following investigations on the TrickleStar TS1910 and the TrickleStar APS + TS1910 (Model TS1110):

1. Teardown, feature confirmation, and independent device performance review against manufacturer specifications - Evaluation of device operational parameters against manufacturer provided specifications.

2. Evaluation of the device method of operation – Evaluation of general use of motion and HID triggering as a means of energy management and verification of operational parameters relevant in device operational model.

3. Modeled savings evaluation – Develop a best case for operational savings using real-world test data with simulated operational parameters based on observed performance. This establishes an upper bound for performance. Simulated considerations that reflect real-life performance are added on top of this to provide the grounds to approximate expected field trial performance. This approach provides a first-principle examination with granular considerations. For the systems under examination, multiple specific considerations are made.
    a. Review of general model development and relevant parameters for evaluating device operation.
    b. Review of real world data used for evaluation. Parameters that are not explicitly available are justified by corroboratory data to develop boundary values used in evaluation.
    c. Determination of energy usage baselines for the following usage cases:
        i. Desktop computers with a range of settings for standard internal power management.
        ii. Docked laptop computers.
        iii. Desktops and docked laptop computers with controlled desktop accessories.
    d. Determination of energy saving capability and expected boundaries for multiple commercial usage cases.
    e. Discussion of the most relevant factors affecting performance.

The intent of the evaluation is to show the capability of this type of control device to provide effective plug-and-play energy management without the need for software configuration. If the internal power management settings of the computer workstation are set more stringently than the timer on the TS1910, the device will not produce additional power savings. If the computer's power management is disabled or set with a longer sleep delay than the device, the difference in settings leads to energy savings by the TS1910. When a Tier 1 APS is connected, the savings is extended by way of un-powering connected loads when the computer is transitioned to Sleep mode. Simulation will generate a best-case simulation of ideal performance to establish upper performance limits, as well as consider factors likely to affect best-case savings values when applied to real-world results. In totality, this approach provides a granular interpretation framework to extend beyond pure simulation and provide contextual considerations for field-trial performance.

Chapter 2: Device Specification and Operation Evaluation

In this chapter, the operation of the devices under test is evaluated, and used to establish general functionality related to energy savings which is used as the underpinning for the model simulated operational design to calculate saved energy and the baseline of savings.

Device Operation Evaluation

Evaluating the operation of the device against specified operating parameters provides a set of operational values used in modeling in addition to verifying the manufacturer stated specifications against actual operation. Specifically, CalPlug evaluated the sensing, timing, and triggering functions of the TrickleStar TS1910 and the TS1004, the equivalent APS component of the TrickleStar TS1110 combined motion sensor and APS solution.

1. The TS1910 was directly evaluated for the following:

- Standby and operational power consumption
- Comparative motion sensing to an identical system in a repetitive evaluation alongside an independent motion sensing system
- Timing and actuation event triggering accuracy for single motion events
- Triggering compatibility for multiple computer operating systems and platforms and usage scenarios
- Evaluation of energy savings considerations with place-shifting or remote access was not directly evaluated

2. For the TS1104 as an individual device, we evaluated the following considerations:

- Standby and operational power consumption
- Triggering threshold identification

3. For the combination of these two devices (TS1910 and TS1104), which together provide Tier 2 APS control, we evaluated the operation of the TS1104 as triggered via change in operational power when transitioning to Sleep from an On state.

Product Packaging Components

The model TS1910 USB Motion Sensor system comes packaged with a TS3006 mounting bracket and cable kit. In typical usage, this unit is interfaced to a computer and placed on the monitor bezel (with or without the use of an attachment bracket) where it is in a clear sight path to the user.

Table 3: Summary list of TrickleStar products discussed in this report.

Model Number	Product Description	Product Usage
TS1910	USB Motion Sensor device	Provides independent computer power management for triggering the initiation of Sleep state.
TS1104 (equivalent to the APS component of the TS1110)	Tier-1 Advanced Power Strip	Provides Tier-1 control alone and can provide Tier-2 type operation when used in conjunction with (and provided switching control from) a computer managed by a TS1910 motion sensor. Power Strip features a threshold switch with [low, medium, high] settings.
TS1109	Tier-1 Advanced Power Strip (auto-thresholding)	Provides Tier-1 control alone and can provide Tier-2 type operation when used in conjunction with (and provided switching control from) a computer managed by a TS1910 motion sensor. Power Strip is functionally equivalent to the TS1104 but features auto thresholding capability and no threshold switch. TrickleStar indicates this product is designed, tested and UL approved, but not in general sale at the time of this document's publication as a Tier 2 (with the USB Motion Sensor) solution.
TS1110	USB Motion Sensor device and Tier-1 Advanced Power Strip in common OEM packaging	Provides a turn-key solution for Tier-2 type control in a single paired set, unit packaged for sale.
TS4002	Wi-Fi enabled, data logging, Tier 1 advanced power strip is our TS4002 model (Tier 1 equivalent of the TS4001 Tier 2 APS power strip for residential applications)	Used for data collection for energy management and usage studies. The TS1910 paired with a TS4002 provides the functional equivalency of the TS1910 paired with the TS1104.

The TS1110 model provides a sensor (the TS1910 USB Motion Sensor) packaged in conjunction with a Tier 1 APS solution that is functionally equivalent to the TS1104, a stand-alone APS product when used with the TS1910 USB Motion Sensor. The APS in the TS1110 solution is not available for stand-alone sale. The operation of the TS1910 combined with the computer provides control that offers a minimum level of savings of the master device. When operating together, the two devices provide *de facto* Tier 2 type capability as the USB Motion Sensor can cause a connected computer to enter Sleep mode, which in turn will cause the Tier 1 APS to un-power peripherals connected to the power strip.

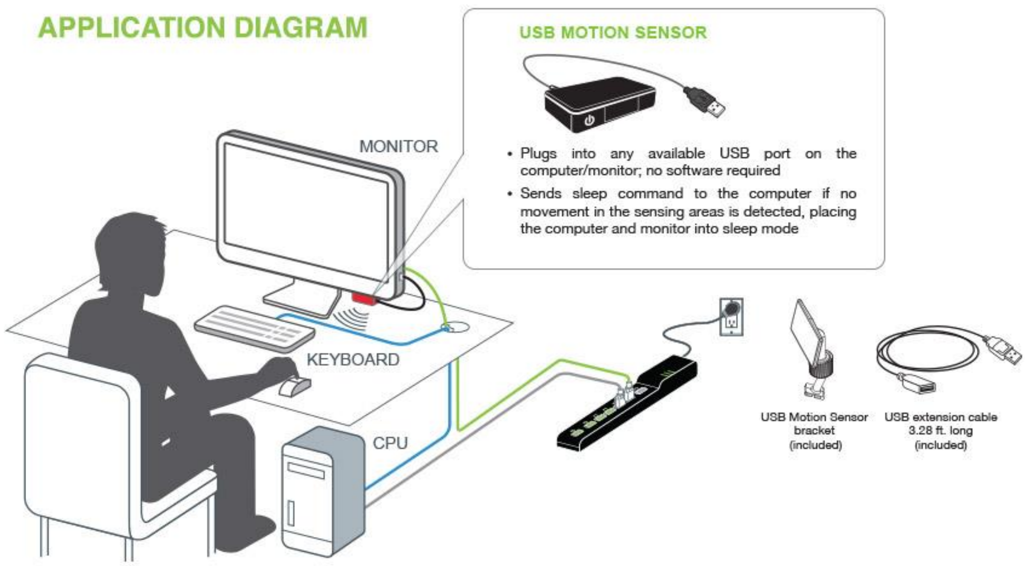


Figure 7: TrickleStar TS1910 USB Motion Sensor with the TS1104 advanced power strip used to provide Tier 2 APS type workstation power management. IMAGE SOURCE: TrickleStar

Solution General Evaluation and Functionality Tests

For the following tests, a TS1910 USB Motion Sensor was connected to a range of computers, except where otherwise noted, and set to the appropriate mode (e.g., "PC" mode for a Windows 10 computer). Power was measured using an Onset HOBO UX120 plug load meter. An Onset HOBO UX90-006 was used to independently monitor motion events during the control period. Keyboard/mouse activity was measured using CalPlug's Power Management User Interface (PMUI) software, which records user activity and computer states. These measures were supplemented by testers' self-reports of behavior.

Device Teardown Evaluation

Both the TS1910 Motion Sensor and the TS1104 APS were evaluated for energy use in all normal states of operation. Internally the TS1910 device uses a Suren™ motion sensor processor and PIR sensing element with a microcontroller handling USB communication. Both operational elements are included on a single PCB. A USB connection is provided to interface with the computer. A side button is used to initiate a manual sleep trigger as well as to enter programming mode. A recessed button provides firmware update capability (per device instructions – this feature was not tested). The device uses sticky pads and an optional mount clip to allow attachment to a desk or monitor, to best aim the motion sensor toward the user's location during normal computer use. A replaceable slide plastic cover rounds off the case and fills the mount slot when the bracket is not in use. The front plastic lens is molded to provide multi-element lensing. The case is held together with four mounting screws.

The TS1104 APS is a 7 port Tier-1 APS that features 2 always-on ports, 1 control port, and 4 switched ports. This model of Tier-1 APS features a resettable breaker and a 3 position threshold switch with settings marked [high, medium, low]. The design and operation is comparable to other non-auto-thresholding TrickleStar Tier-1 APS devices.

Standard Operation Evaluation

All evaluations used one of the listed computers below for device testing. Other workstation computers were evaluated for energy usage only to establish baselines. The tested systems are presented are the three categories of systems used including Windows/PC, Apple OSX, and Linux:

- A Dell desktop computer running Windows 10
- An HP laptop running Windows 10

- An Apple MacBook Pro 2007 era (MAC OSX Snow Leopard)
- An Apple MacBook Pro 2012 era (MAC OSX High Sierra OS) were used for all evaluations described in this section

- An Ubuntu 18.04 Debian Linux (dual boot)

Each machine was evaluated for control capability for a USB Motion Sensor with the sleep timer set to 10 minutes. The motion sensor control switch setting was matched to the operating systems ("PC" for the Windows 10 setups and "MAC" for the OSX and Ubuntu setups).

In all cases, each setup was able to have Sleep mode initialized after the period elapsed on the sleep timer. The laptop running OSX Snow Leopard presented a dialog box (see Figure 8) in several test cases, halting the process of entering Sleep state, as the computer was seeking user input to clarify the intent of the pressing of the power button (the emulated keystroke provided by the USB Motion Sensor). The OSX Snow Leopard version of this dialog box does not appear to feature a countdown and will stick at this point without user action. One method of bypassing this dialog box reported by Apple is the use of the "Option–Command–Power button" sequence versus just the power key [30]. In the test computer case, the system did not respond to further manual HID commands (pressing the manual power trigger button on the side of the TS1910) from the device until the user provided a response or operating system power management resulted in Sleep mode from another trigger. Without re-priming (via a sleep entry or power-cycle), the TS1910 will not issue another sleep command. Only one command was observed for each primed operation cycle. This is likely by design to prevent unwanted wakeups if the sleep command sent again also could be interpreted as a wakeup signal.

Figure 8: Macintosh OSX power button option dialog box which was observed during testing with legacy OSX Snow Leopard.

Standard Operation Evaluation in conjunction with the TS1104 Advanced Power Strip

The tests conducted in the prior Standard Operation Testing section are repeated with the computer plugged into a TS1104 APS. The TS1104 uses a selection switch while the TS1109 uses auto-threshold detection. In this study, we only tested the performance of the TS1104. The power strip was plugged in and the threshold setting checked. The threshold selector switch was set to "low" for the laptops (tested in fully-charged state). On each of the tested laptops, the "medium" state appeared also work properly. The desktop was set to "medium" to allow proper sleep triggering when the desktop was used to provide direct control and "low" when the attached monitor provided control per provided usage instructions. Please refer to previous discussion on computer versus a connected monitor for providing master control.

The term "control" was used as the port to which the devices were connected for one of the TS1104 APS devices (body color white). Another sample of the same model TS1104 equivalent APS from the TS 1110 solution (body color black) has the "control" port labeled "Display". In this labeling scheme, a laptop would be connected to the "display" not the CPU port for control. This scheme provides desktops indirect management of auxiliary devices. The monitor sleep setting is used to control auxiliary devices, providing the trigger to un-power auxiliary devices via APS control. For laptops and docks, the "Control" or "Display" input must be used versus the CPU. Harmonizing logo text and silkscreens with intended and possible use cases between sub-models may improve user setup experience.

For desktops, the advantage of using a monitor for control is that with tighter monitor settings, control can be actualized earlier. The disadvantage is that the standby load form the monitor cannot be managed by the connected Tier-1 APS. In control situations without the TS1910, the former situation is more likely to provide better energy management as monitor sleep settings are typically better controlled by operating system power management settings [19]. When using the TS1910 USB Motion Sensor, the operation of this device may shift potential savings towards control of the monitor rather than using the monitor power signal as a control signal.

Using these settings, laptops in Sleep state and not charging do not trigger the turning on of APS controlled auxiliary devices. When charging (either On or in Sleep), accessories are triggered. For the desktop computer, the On state resulted in a triggering whereas the Sleep state did not cause triggering (or released an active trigger). On the desktop computer, triggering monitor sleep or computer sleep will cause an APS shutdown and a resultant unpowering of attached devices. On the laptop, sometimes a screen blanking would cause an unpowering trigger, but always when sleep was actually triggered (either by the TS1910 or the on-board power management) would the APS un-trigger to shut off connected accessories. With this being said, in alone-usage, there are options that have potentially different performance in different usage scenarios for Tier 1 APS devices. All evaluated Tier 1 Power Strips are only considered Tier 2 solutions when used in conjunction with a USB Motion Sensor to provide persistent, behavioral based control.

The 2016 ENERGY STAR specifications require qualified monitors (displays) to have less than 2 W of power consumption when the monitor is in sleep mode. Monitors quickly leave the active mode when the computer sync is lost. For this discussion we will assume no wasteful active use beyond what is commanded by computer control. If the monitor is placed under Tier 2 control, a ceiling savings value is 17.52 kWh per year is calculated with 100% idle usage (ideal case). This obviously unrealistic model sets the extreme upper bounds. With 30% usage, this amounts to 5.1 kWh savings annually with control. Yet, the overhead of the Tier 2 APS plays a major role in savings potential with low power controlled loads. With just the monitor under control by the APS, a modeled 1.0 W standby power from the APS would reduce actual savings by nearly 50%. Clearly direct APS control of an attached monitor results in savings, but without other attached loads, the savings is impractically low. This situation draws two directions of action for APS Tier 1 controlled systems:

- Use the Tier-1 APS to control the monitor plus other workstation devices as controlled loads with the computer power providing the control signal for the APS. The monitor power can be saved along with other devices when the computer enters standby mode. Computer sleep is often improperly configured for maximum reasonable savings.
- Use the monitor sleep mode to trigger other controlled devices. As monitor sleep is often more likely to be configured more aggressively than computer sleep, this mode offers tighter control. Monitor power management is sacrificed but potentially tighter control is provided to other workstation devices under APS managed control. For illustrative discussion, 60% savings is used as modeled wasteful usage reduction value with aggressive monitor sleep, and 30% is the wasteful reduction usage with computer sleep alone, a difference of 4.95 kWh/year is sacrificed in controlled load due to the monitor in this control scheme. From this same spread of wasteful usage time, 2,628 hours per year of wasteful time that can be controlled is gained by this control scheme. Each watt of controlled load results in 2.63 kWh/year of potentially increased savings in this case as compared to the previous case.

Command Verification Testing

The USB Motion Sensor device transitions the computer to Sleep mode using an HID command. The function was demonstrated on computers with Mac, Windows, and Linux (Ubuntu 16.10) operating systems. The HID USB commands trigger with function codes 0x01, 0x09 [Generic Desktop], 0x82 [SYSTEM SLEEP] (switch position "PC" – for Windows) and 0x66 [KEY-PWR] (switch position "MAC" – for Mac/Linux) were used to trigger the successful entering of standby by tested machines [31]. A KeeLog KeyGrabber TimeKeeper-MCP was used to collect timestamped commands sent by the device. The "MAC" mode key command is keystroke loggable. When used on a Windows computer, an analog of Log Mode Evaluation (LME) can be used to monitor a sleep point prior to onboard power management, providing the actual sleep event which then resets the USB Motion Sensor for future triggers when the computer wakes up from Sleep state. A computer PM setting with 5-10 minutes beyond the USB Motion Sensor was used for this test. A USB power cycling provided by the computer entering sleep appears to need to "re-prime" the USB Motion Sensor to send future commands. The USB Motion Sensor does not appear to reset the timer and try to issue a second command after timer expiration. This is likely by design to prevent wakeups by a repeated power command.

Continued operation requires a power cycle of the USB Motion Sensor, once an initial motion is observed, the device is fully re-primed with the countdown timer started. The recorded, time-stamped keystroke indicates that a sleep command was sent. With a single motion event, this testing approach is used to verify timing accuracy and operation against known timer settings. Overall, this evaluation is used to verify actuation triggering and timing. CalPlug has produced a thorough discussion of the LME evaluation approach as used for Tier 2 APS devices for entertainment applications [32].

Tested timer settings of 5, 10, 15, 20, 25, and 30 minutes were all within 5% of stated time values as measured from the end of a single registered motion event and the initiation of the HID command to trigger a sleep sequence [33]. Note that some prior versions of the instruction manual do not mention the 5 minute setting. In evaluation samples provided, this setting existed even if not referenced in the product literature.

In operation, the warning light will alternate blinking orange and blue three times (dual color, repeated) over the course of a 1 minute period to warn of impending sleep transition prior to the end of the sensor timer period. This pattern and period provides a noticeable alert to the user, if present, to take action to prevent a sleep transition. In our limited tests, the action of reaching toward the device without making contact caused a timer reset and a clearing of the warning. If no motion is registered by the time the one-minute warning expires, the sleep command will be sent over HID.

Solution General Evaluation and Functionality Tests

The action of the USB Motion Sensor was evaluated in multiple ways to assess the capability for detection of motion events in addition to how the representation of motion events by the sensor correlate with triggering power management decisions with similar impact on energy management as the use of keyboard and mouse input to detect user engagement.

Motion Sense Verification Testing: Multiple Sensors

Two USB Motion Sensor devices were connected to an Onset HOBO UX120-017 pulse event logger. The internal test point labeled “DTO” with reference to device ground provided a 3.3 V pulse related to the output of the motion detection circuitry prior to the onboard microcontroller. This connection was only used to verify sensing capability and is not used in normal testing operation. Additionally, an Onset HOBO UX90-006 was used to independently monitor motion events. Motion from a user operating the computer or a single motion event trigger was used during this evaluation. A single motion event is a purposeful motion event followed by a blocking of future events to the sensor by application of IR opaque film. Simultaneous collection of data between both USB Motion Sensor systems is presented in Figure 9. This was compared to CalPlug PMUI software logging of user keyboard and mouse activity and computer operational state information [34]. It should be noted that the loading impedance of the Onset HOBO UX120-017 is not insignificant and can lead to missed motion signaling pulses to the microcontroller. The typical failure mode was failure to register any events by the onboard microcontroller. Thus, HID-based triggering should not be evaluated using this logging configuration.

Both USB Motion Sensors under test were connected to a desktop computer running Windows 10. When the motion sensors are in "MAC" mode, they provide a keystroke command to trigger sleep that is logged, whereas in "PC" mode, they do not. For this reason, the motion sensor was set to "MAC" mode for these tests, even though "PC" mode would be appropriate for normal use. This provided a timestamped logging value without actuating machine Sleep mode, consistent with LME testing operation. In this LME configuration, the KeeLog KeyGrabber TimeKeeper-MCP was connected to one device at a time for logging sent commands. A computer power management setting of 10-20 minutes longer than the timer setting was used to create the reset sequence to "re-prime" the USB Motion Sensor for future logging even after the controlled computer was returned to the On state. As previously mentioned, connection internally to the signal on the DTO bus may lead to the TS1910 providing irregularly timed HID control commands due to an impedance mismatch, resulting in attenuated trigger signals to the microcontroller. For full LME logging of operation, all patchwork to internal connections must be removed and only the timestamps used to indicate points at which HID commands for sleep would have been sent.

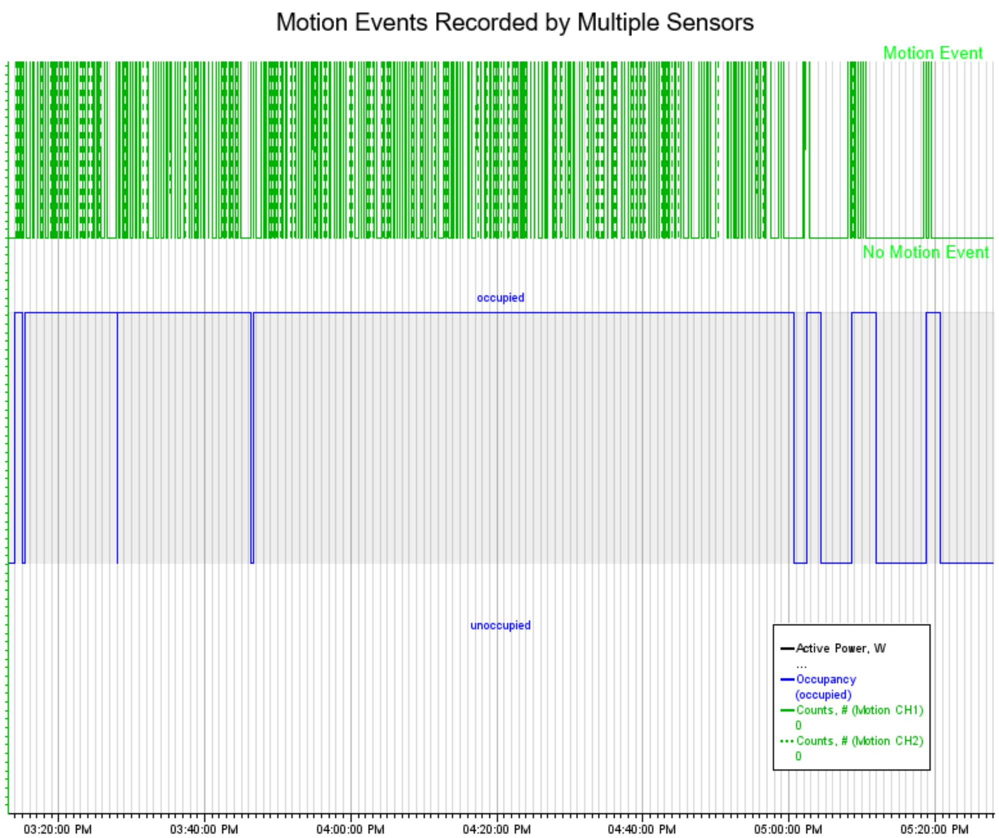


Figure 9: Motion events recorded by two TS1910 units and occupancy recorded by a HOBO UX90-006 occupancy/light sensor. Note the delay in the HOBO UX90-006 data.

Operation of the device was validated by the use of concurrent measurements of a motion event within a 10 second window or an external motion sensor in addition to the TS1910. A single motion event was measured by both devices. In a 2 hour period, there was a 93% gross identification equivalency between both sensors. The total number of events detected by each system varied by 7%. There was a 6.5% synchronicity mismatch in that both sensors for all measured time points within a particular common 10 second measurement integration window. Restricted to total measured points with an event the synchronicity match is 50.7% and 47.6% in reference to either the first or second device under analysis. A 1.4% maximum false trigger error was observed for all triggered events. This is recorded as a situation where the HOBO UX90-006 motion/light sensor did not detect motion while either of the USB Motion Sensors did. In this evaluation, the authors did not directly analyze light sensor data collected, but CalPlug has shown contextual information provided by correlate light and motion events for energy management that may be a point of consideration for future motion sensor development designs [35]. When discriminated for a 30 second period around transitions recorded by the HOBO UX90-006 motion/light sensor, this value falls to 0.4%. Based on analyses of data collected from both sensors, on average, the “occupied” state reported by the HOBO UX90-006 persisted for 65 seconds longer than the last reported motion detection event by the TS1910.

Motion Sense Verification Testing: Keyboard / Motion Input Comparison and Power in Idle and Active Workstation Operation

Indirect sensing of motion events using a HOBO UX90-006 motion/light sensor and indirect evidence of OS power management was used in evaluating the comparable equivalency of approaches. In this same test configuration as the previous evaluation, a savings-delta evaluation was conducted using a desktop computer in a single occupant 10’x10’ office. The data for one sensor at a time was used in evaluation. Over the course of one day, the correlation between keyboard or mouse input and motion was evaluated as equivalent user activity proxies. This evaluation was not intended to be exhaustive, but rather illustrative to the observed modes of action for these two methods. The use of keyboard or mouse activity assesses user input to the computer, while the use of motion assesses user occupancy. It is hypothesized these two approaches provide equivalent sensing for power management control with perspective to enabling behavior based energy management. With this being said, each method likely provides different indications of engagement with different patterns and modes for false positives and negatives for use in controlling energy management, a detailed breakdown is forthcoming in this report.

A preliminary test with the aforementioned desktop computer using the HOBO UX90-006 motion/light sensor and the plug load meter was used to assess the relationship between PM control and motion. No USB Motion Sensor was used at this stage of the evaluation. Initially, computer PM settings were disabled and motion events were recorded alone without any PM control. Energy usage from the computer during times of usage and non-usage were also recorded. At a point during the study an operating system PM setting of 30 minutes was enabled (labeled in Figure 10). For two periods where sleep occurred, sensor common periods were noted.

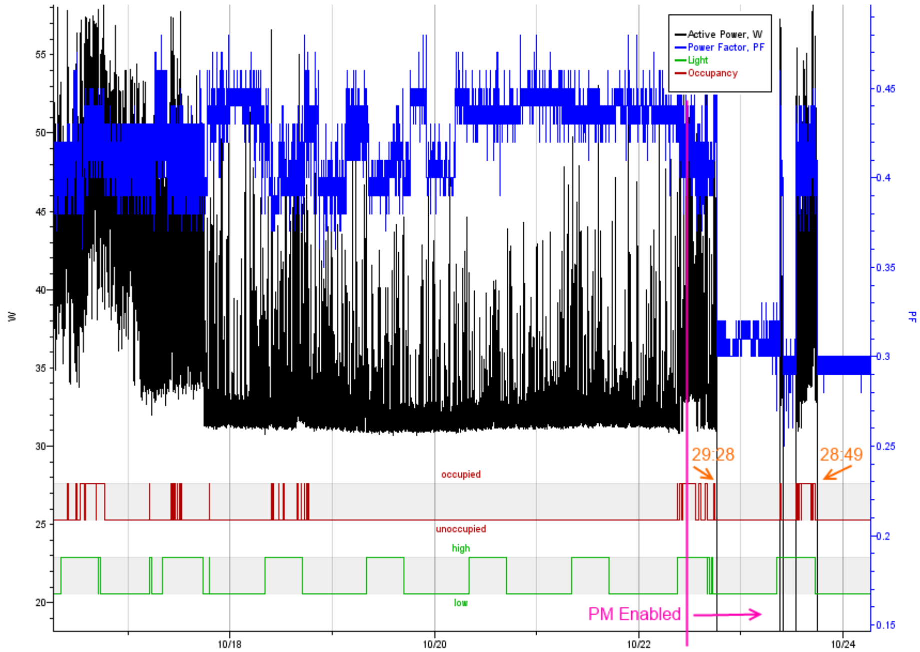


Figure 10: Evaluation of motion as an indicator for power management

Two specific points are illustrated in Figure 10; firstly, the link between direct user activity and energy use is not strong. For periods when clearly no user activity was present, varied actions of system background tasks caused changing power usage that on a threshold based level is within the same band as active use power. With this being observed (both in and beyond what is illustrated in Figure 10), active and idle use power are modeled as a common energy usage value. Secondly, as power management and an external motion sensor are shown for once power management is re-enabled, the delay after a shutdown event by the OS (timed by keystrokes) at 30 minutes lines up with the observed period between the last recorded "occupancy" condition and the shutdown. For the two presented cases, this was 29:28 and 28:49. For the HOBO UX90-006, an average of 65 second period of occupancy is maintained per our observations beyond the last recorded motion event. In all tested cases, 97% of single motion events were recorded within a 5 minute window from keyboard events in these tests. It must be noted that this test was performed in a controlled environment where non-user motion triggers were prevented. In an environment with background motion, it is strongly possible, that the figure presented would decrease in a manner strongly situationally dependent on the configuration of the workstation and the level of background person traffic.

Motion Sense Verification Testing: Keyboard / Motion Input Comparison, Sensor Detection Evaluation

Direct observation of the motion events using the USB Motion Sensor in LME configuration was used along with direct measurement of time from last keystroke to the actuated shutdown was measured. The CalPlug PMUI software provided the record of last keystroke observed. For this test, the actual USB Motion Sensor was used with a setting of 25 minutes while the computer power management was set to 15 minutes. This unusual timing was used to ensure no motion time expiration trigger would be sent during test operation. Motion events were recorded from the sensor directly using pulse logging. In all tested cases (6 total periods), the last measured signal from the USB Motion Sensor (pulse) was provided within 10 seconds of the last keystroke as evidenced by the PMUI system. All final motion events occurred after the last keyboard/mouse input event.

Motion Sense Verification Testing: Keyboard / Motion Input Comparison, Live Operation to LME Evaluation

Evaluation of triggering was compared between a live operation evaluation and a LME test to show equivalency between evaluation methods. In the same setup room as the previous evaluation, a live test was performed. A windows machine was used (as with the previous tests in this section), hence the "PC" setting on the USB Motion Sensor was used. The computer was set with a sleep setting of 20 minutes, while the USB Motion Sensor was set with a sleep timer of 15 minutes. The PMUI idle period was compared to the evidenced shutdown period for a total of evaluation runs. A HOBO UX100 plug load power meter was also used on the workstation under evaluation. The CalPlug PMUI software was used to evidence shutdown points and last points of keyboard/mouse input. In this test, an independent HOBO UX90-006 witnessed motion events for tracking comparison. The timing diagram for this evaluation is shown in Figure 11.

1. The time from the last motion event to the initiation of the motion sensor initiated shutdown is the motion sensor timer period (denoted in Figure 11 as X, and referred to in text as T_{STP}).
2. The period of time between when the shutdown occurs and when the shutdown would have occurred is the Sensor Delta Period. This is the period that is counted as savings between when the shutdown would have occurred and when it did occur (denoted in Figure 11 as Y, and referred to in text as T_{SDP}).
3. The time period that triggered initiation of PM sleep (virtual if the motion sensor triggers sleep first) from last keyboard/mouse input event is the operating system PM timer period (denoted in Figure 11 as Z, and referred to in text as T_{PMP}).
4. T_{PMP} - T_{STP} is the duration between the sensing of the last keyboard stroke and the final motion event, this is equivalent to T_{SDP} due to period symmetry. T_{SDP} would be equaled to zero if sensors were of equivalent length and triggered simultaneously. A positive T_{SDP} assumes a triggering of a motion event following the last keyboard/mouse event with a motion sensor timer period (T_{STP}) shorter than the PM timer duration (T_{PMP}).
5. The Normalized Sensor Delta Period (NORMT_{SDP}) is a derivative calculated figure used to represent the delayed time for shutdown when considering timers of unequal length. In calculation, with respect to the USB Motion Sensor (the intervention case), the PM timer is assumed to be of equal length for the sake of the calculation (typically shortened). The time difference between when the PM timer would have expired and the Motion sensor shutdown occurred is presented as a positive time value figure for reporting a delay. In this calculation, an assumption is made that no events past the timer period would have aborted the process of the timer where the value was shortened in calculation.

For 10 evaluated periods, a NORMT_{SDP} of less than 3 minutes was observed for all cases. In all evaluation runs, the USB Motion Sensor triggered a shutdown prior to the operating system PM triggering a shutdown as expected with normal operation. When the USB Motion Sensor was disabled, the computer's automatic sleep PM activated at 20 minutes +/-20 seconds in all cases, as shown by the PMUI data and confirmed by the power meter/logger unit to provide a negative control case. In all cases, the last motion event occurred after the last keyboard/mouse event.

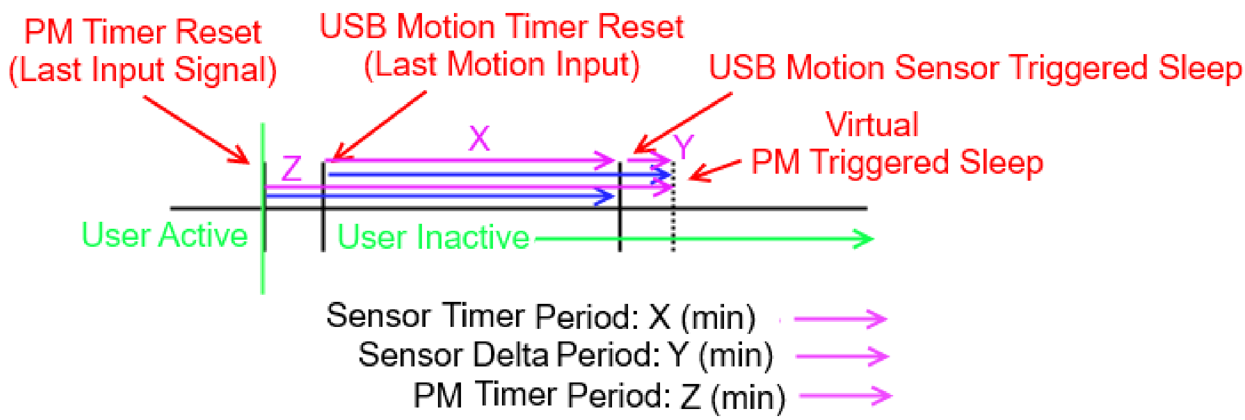


Figure 11: Timing diagram for sensor operational evaluation

An additional extended live evaluation was used to observe the impact of specific activities on the impact of motion versus keyboard/mouse used as an indicator for engagement and to assess the impact of daily activities on energy savings. In this test, as in previous evaluations, no background motion was permitted to be observed other than the computer user. Using the same setup configuration as the prior live test during a 5 day period, the user logged activities that were performed. During this test, the USB Motion Sensor timer was set to 15 minutes, while the PM timer was set to 30 minutes. Table 4 outlines observed scenarios that may extend the period of the motion sensor timer and reduce savings. This is due to the fact the user may linger in the area in front of the workstation after the last keystroke is pressed, accordingly the timer based on motion is expected to always start after the timer based on keystrokes and mouse motion. The sensor delta period value was normalized down to a common 15 minute period such that the T_{SDP} value shown, NORMT_{SDP}. A test was shown in Table 4 where multiple logged actions were compared to effects on the start of the sensor timer as described in Figure 11, showing the delay between the start of the motion sensor timer from the start of the keystroke/mouse event based timer. In this manner, in one instance, a 14:28 minute delay was observed because the user never left the area but did not continue to use the workstation. The result of this was a delayed timer start and reduced comparative savings to a keystroke/mouse event based power management timer. If this period of continued motion is long enough into the idle time, potentially power management would never be triggered for this idle event. In all likelihood, this is a relatively low-frequency scenario compared to the action possible for the majority of idle periods where users are truly absent from their workstation.

Table 4: Summary of sensor common periods and deltas for the test period.

Sensor Delta Period NORMTSDP (min:sec)	User Activity (Comments)
2:02	User left workspace area
1:50	User left workspace area
0:39	User left workspace area
0:18	User left workspace area
6:09	User left, workspace area, someone entered the workspace to leave a note on the desk in front of sensor
4:38	User cleaned up then left workspace area
1:35	User left workspace area
14:38	User conducted meeting near computer area but not using the computer during the period. User continued to trigger resets of the motion timer but not the PM timer.

In addition to the observations outlined in Table 4, we observed several circumstances to take note of during testing. In cubicle environments, the background motion events prolonged the timer duration substantially. The impact of background traffic extending the USB Motion Sensor timer is highly dependent on device usage configuration and was not tested extensively as part of this evaluation.

In the second test, an LME approach was used. The motion sensor "MAC" setting was used to provide energy triggering events recorded by the keylogger without the actual workstation PM triggered by the USB Motion Sensor being evaluated. In this test versus the prior LME test using pulse data from the sensor, the HID trigger command was recorded versus individual detection events. The timer duration on the USB Motion Sensor was set to 15 minutes. The PM duration was set to 20 minutes. Due to the LME approach, a record of when a Sleep event should have occurred is recorded as a timestamped entry on the keylogger rather than an actual trigger event. When the PM eventually causes a Sleep event, the workstation enters sleep. Awaking from this Sleep state will result in a re-priming of the USB Motion Sensor to enable the recording of another event.

Motion Sensing Verification Testing: Operational Evaluation

In a live evaluation configuration, the transition time test was directly assessed over a 6 hour experimental period during one day where the user continuously used the desktop computer for 10 minutes followed by no usage or motion in the vicinity for 40 minutes. The motion sensor timer was set for 30 minutes. In all cases, the machine was asleep after each test period indicating proper timer operation within the 40 minute window.

Motion Sensing Verification Testing: Operational Evaluation with user Feedback

A limited scale test was used to collect feedback from users for operation detrimental to their workflow. The USB Motion Sensor timer was set to 10 minutes and observed for a period of five days in a single occupant 10’x10’ office with a Windows 10 desktop. No false triggers (0%) were observed in this period. In one instance the one-minute warning sequence was displayed. When the user moved, the timer reset and the light returned to the normal active blue state. The user commented that the “power button” on the device provided an easy means to trigger Sleep mode as this user’s keyboard did not have a Sleep button. On the third night of the test period, a single update instance of Microsoft Windows 10 occurred. This caused a computer wakeup as recorded by the PMUI software and the plug meter logger. There was no evidenced interference in this process by the USB Motion Sensor as the lack of priming presented action from the USB Motion Sensor. The system logs indicate the update occurred successfully. After the update, the computer was found in a Sleep state but logged off from the user’s account the following morning.

APS Verification of internal connected device power usage reporting capability

When the USB Motion Sensor is used with a Tier 1 advanced power strip, Tier-2 type control is produced. The TS4002 logging Tier 1 Advanced Power Strip can be used to log energy usage to provide telemetry information on studies in progress for Tier 2 solution effectiveness for energy savings. The TS4002 was also evaluated for power measurement accuracy against a reference Chroma 6420 power analyzer supplied by a Chroma 6620 reference power source. Both devices have been evaluated against NIST traceable references and performed within measurement standards (see Appendix 1). Both Reference instruments were certified for calibration within 1 year of use in this study. Qualification of this measurement device was performed using resistive static reference loads comprised of incandescent light bulbs with nominal markings of 7W, 15W, and 60W, no variance was observed between the measured value and the reference value to the nearest 0.1 watt.

Table 5. Controlled socket measured power consumption for standardized loads for four representative evaluated samples of the TS4002 APS unit.

	Average Device Measured Power (W)			
Load Power Consumption (W)	**Device 1**	**Device 2**	**Device 3**	**Device 4**
15.17	15.1	15.1	15.1	15.1
61.36	61.2	61.2	61.2	61.2
7.33	7.3	7.3	7.3	7.3
15.12	15.1	15.1	15.1	15.1

Operational considerations and functionality

The intention of both computer PM settings and the USB Motion Sensor is to trigger the computer to spend as much time in Sleep mode as possible while minimizing interference with functionality. Using motion sensing rather than keyboard or mouse activity may be a more accurate assessment of whether Sleep mode is desirable in some instances, and less accurate in others.

As defined at the beginning of this report, there are three possible operational states when the computer is on: user engaged, user absent with programs or background operations running, and user absent and idle. In the last state, when there is no engagement from the user or other operations, transitioning to a low-power mode is desirable. In the other two states, transitioning to a low-power mode would interrupt ongoing processes, and would be undesirable. The challenge, then, is to distinguish these three states.

Keyboard and mouse activity clearly indicate that the user is engaging with the computer. However, the user may be engaged even without such activity: for instance, while reading or watching a video. Current operating systems are programmed with a range of processes that will prevent automatic transition to sleep, such as an active video or download, but they cannot tell when a user is passively reading the screen, which could result in an inappropriate transition to sleep. By contrast, the motion sensor approach considers all time the user is near the computer as active time (assuming the user is moving). This reduces false Sleep events but could overestimate active usage and miss periods of user idle.

Another potential problem identified with the motion sensor approach is that the sensor may not be properly placed to register all true motions of the user. This could be due to improper installation or, as observed in our tests, to accidentally nudging the sensor when moving the monitor to show the screen to a colleague, or when moving items on the desk. If the motion sensor misses some of the user's movements, it may trigger sleep inappropriately. If the motion sensor misses all the user's movements, it would not trigger sleep at all because the sensor is only “primed” to provide sleep commands after motion is observed.

If no motion is observed at sensor power up, then it is assumed the computer either powered up automatically to update or the sensor is in a position incapable of measuring activity. This allows the machine to be restarted for automatic updates and backups, but does not prevent the machine from being put into sleep during operations that begin when the user is not present. At this point sleep is only resumed by the control of onboard power management or with the return of a user to prime the action of the motion sensor.

More challenging situations require the temporary suspension of power management saving: this can include extended processing operations or downloads. From our testing, the sleep command will interrupt running processes. If the motion sensor is primed and a user leaves the area, as of now there is no way to halt the shutdown process other than disconnecting it. If these sleep commands are observed during the operation of the process, then the process will be interrupted. A related issue is the problem of remote access, which requires the computer to be on rather than in Sleep mode. This is a problem for both the motion sensor and standard automatic PM settings, as they result in the computer being in Sleep mode when the user is in a remote location. In some circumstances, “wake-on-LAN” protocols can be used to take a computer out of Sleep mode so that remote desktop control could be used, but the process is limited and problematic.

In future designs, the logic of this control could be extended to recognize usage patterns to improve usability while reducing the potential for user frustration and mitigating the total impact on savings. A semi-flexible or programmable control may yield greater functionality than a single setting option. Another idea is self-learning via reinforcement: for instance, if a given pattern that triggers Sleep state results in the user quickly restoring the computer to operational mode, this would suggest inappropriate sleep transitions that could be avoided in the future. This may extend the delay period in some usage circumstances while allowing it to be shorter in others. The desired effect is an overall net shorter delay period permitted by the user.

Chapter 3: Computer Energy Usage Baseline and Calculation Figure Determination

Prior to estimating savings resulting from using the TS1910, baselines must be established for computers used with the USB Motion Sensor. A combination of the device and how it is used determines energy savings potential. CalPlug collected data from two studies to provide the requisite factors to enable a simulation for potential savings for use of the USB Motion Sensor.

Computer Operational Observations

Addressing both the population and usage of the target device is critical to establish the possible savings that could be achieved by increasing sleep time and thus reducing computer idle time. To establish this baseline, we use data from two earlier CalPlug studies of university desktop computers. As described earlier, CalPlug's PMUI software was used to log computer states in test case computers. CalPlug recently completed a field test of whether PMUI effectively encouraged users to enable their sleep settings. The software was installed on over four hundred desktop computers of university staff members [34]. Preliminary data from this study can be used to provide a baseline of observed computer and user behaviors. In the earlier 2014 Monitoring Study, CalPlug used Verdiem Surveyor software to monitor the computer states of 115 office desktop computers for two months [1]. These two studies offer supplementary views of desktop computer usage and power management settings. The preliminary PMUI data can add context to the well-reported Monitoring Study data. In comparison, this dataset is more stable in current state for the simulation based analyses conducted in this study. With this being said, the user idle times and power management settings are largely congruent with the initial results of the PMUI data still being processed. These datasets offer insights into the periods of idle time that can be converted into sleep as well the settings for computers “in the wild”. The settings of these computers, referred to henceforth as “wildtype” settings, can be used as the basis for calculation of potential savings with an intervention strategy such as the USB Motion Sensor.

In addition to providing analysis data, the presented studies provide an assessment of how aware users are of computer power management settings for desktop computers as well as provide an assessment of how willing users are to change them provided actionable steps. Without an external mandate to implement and follow computer energy usage guidelines, computer usage in a work environment presents an incentivizing problem. As users themselves are not paying for electricity or computer maintenance, a better method is to activate intrinsic motivations to be good resource stewards or follow target goals. The balance between user inconvenience/annoyance and power savings is always a balance that must be considered on a use case basis.

In the PMUI field test, the program recorded users' sleep settings. In the PMUI study the sleep settings are constantly recorded whereas in the monitoring study, only the starting settings for power management are recorded. Table 6 shows the sleep settings at the beginning of the intervention, which is a reasonable baseline measure of settings in an office environment. While most users had their display sleep settings enabled, only a minority were observed to have their computer sleep settings enabled. Of those who did, the most common delay time was 30 minutes, which is the standard to which desktops are set by the manufacturer. For those whose computer sleep settings had changed, a similar percentage of computers had delay settings longer than 30 minutes (30%) as delay settings shorter than 30 minutes (28%) as shown in Table 6.

Table 6: Observed sleep settings for university office desktops from 2017-2018 CalPlug PMUI study.

	Computer		Display	
Sleep delay	**All**	**% of enabled**	**All**	**% of enabled**
never	86%		17%	
5	1%	7%	1%	2%
10	2%	15%	12%	15%
15	0%	2%	3%	4%
20	0%	2%	1%	1%
25	0%	2%	1%	1%
30	6%	41%	60%	72%
45	0%	2%	0%	0%
60	2%	14%	3%	3%
120	1%	7%	0%	0%
180	0%	2%	0%	0%
240	1%	5%	0%	0%
N	407	58	407	339

The distributions of delay settings for computer sleep and display sleep are shown in graphical form in Figure 12, emphasizing the prevalence of settings at 30 minutes and, for display only, 10 minutes. Display sleep settings are substantially more likely to be enabled than computer sleep settings. This is an important point of consideration for Tier 1 APS usage linked to display state triggering.

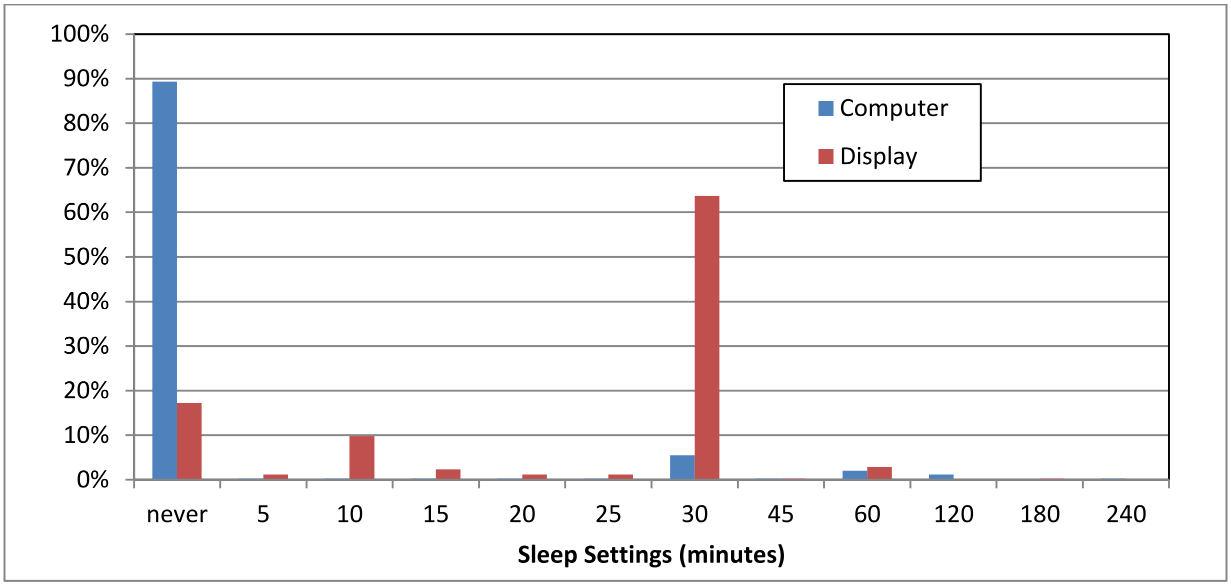


Figure 12: Observed sleep settings for university office desktops from CalPlug PMUI study.

In the Monitoring Study, researchers directly observed and recorded the power management settings at the beginning and end of the study period. The rate of enabling computer sleep and display sleep was almost exactly the same for the Monitoring Study subjects as for the PMUI subjects (Figure 13). Again, display sleep was much more likely to be enabled than computer sleep.

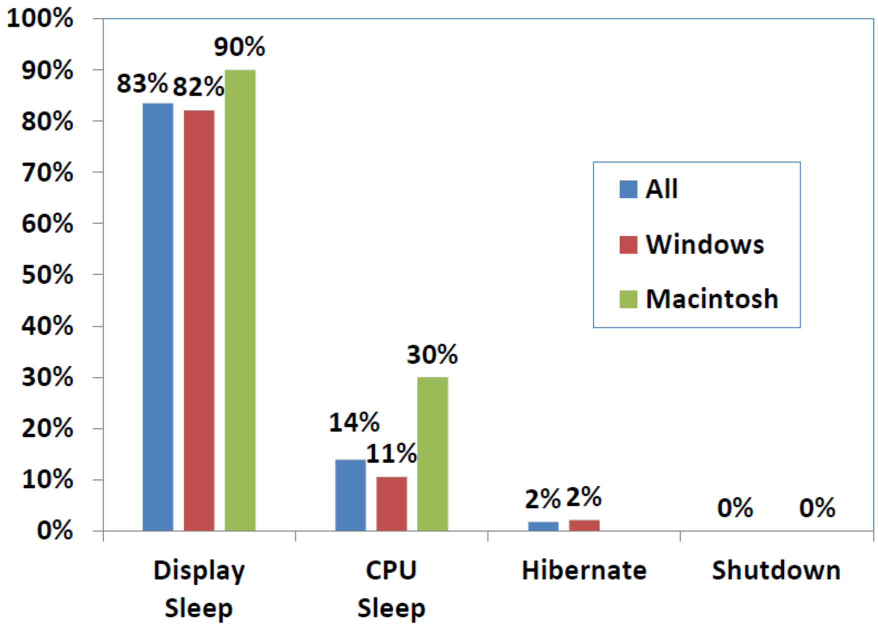


Figure 13: Prevalence of enabled settings for Macintosh (OSX) and Windows computers in the Monitoring Study

Time Spent Idle

The previous sections have treated computers as having an average profile depending on whether or not sleep is enabled. However, computers can vary substantially in the amount of time they spend idle—and thus the amount of energy that can be saved by putting them to sleep—even within each of those groups. Thus, another approach is to consider the time computers spend in each state.

For both PMUI and Verdiem Survey, the computer states are recorded as On, Off, Sleep, and unknown. Most computers recorded only brief unknown periods for the computer state, usually when transitioning to or from shutdown or hibernation (which could not be distinguished). User states included active, idle, and unknown; whenever the computer was in a state other than On, the user state was recorded as unknown, so we consider the user states as a subset of computer on. This produces five states:

- User Active (Computer On)
- User Idle (Computer On)
- Computer Sleep
- Computer Off
- Computer or User Unknown

Any given sleep setting, or lack thereof, can lead to varied amounts of time spent idle depending on other factors, such as how many days the computer is used and how often the user manually turns the computer off or puts it into a hibernate or Sleep state. Figure 14 presents a visualization for how enabling sleep settings affects the percentage of time in sleep versus idle in the PMUI study. The first bars represent the first three weeks after research visit 1 (RV1), which was the beginning of the baseline period. Computers with sleep enabled spent 32% of the time idle during this period, compared to 66% of the time for computers that did not have sleep enabled. The last three bars represent the last three weeks before the final research visit (RV3), at the end of the experimental period. Although many computers shifted from the sleep disabled group to the sleep enabled group, the overall averages within each group remained fairly stable compared to the baseline measurement.

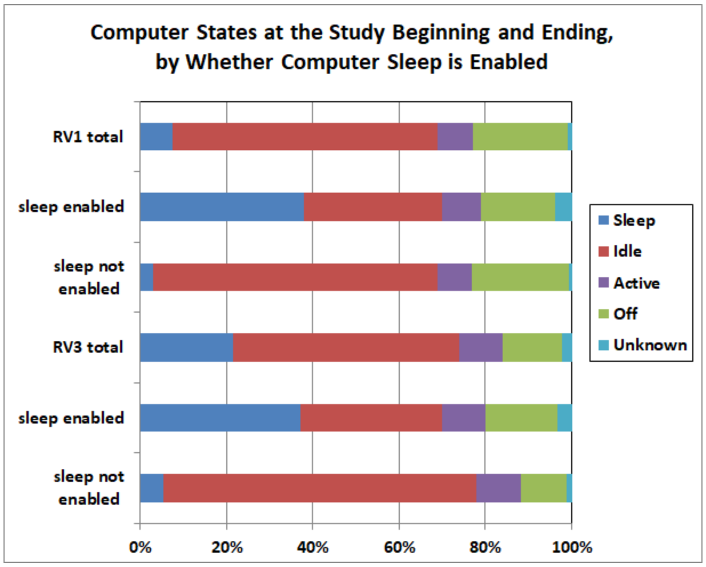


Figure 14: Percent of time computers spend in each state at the beginning and end of the PMUI study.

Total idle time is not enough information required to calculate savings using an outside interventional solution (such as the USB Motion Sensor). The length of each idle period is required to calculate how much savings could have been enacted using an alternate interventional savings approach.

In the Monitoring Study, data on computer states was recorded as the number of minutes in each 15-minute block spent in each state. When consecutive 15-minute periods showed all minutes having the same state (e.g., idle or sleep), it was clear that the state was continuous. Other patterns can also be inferred, such as one 15-minute period showing only idle and the next period showing some idle and some sleep; or the reverse, where a long period of sleep or idle is ended by a period that includes active use. However, minutes of user active are usually interspersed with minutes of user idle; this reflects the natural way that users interact with computers, pausing to read, watch, think between typing or moving the mouse. Thus, assumptions had to be made in order to estimate how long periods of idle were, based on this data.

We investigated and used block splitting and interpolation as a means to correct data artifacts that can affect simulations. Assuming monolithic or single-split 15 minute blocks only, an interpolator was used to estimate minute-by-minute states of operation. A time period with no state changes is assumed to be monolithic (the block has none or only a single state change – multiple state changes are lumped in a single block). A period with one state change during a 15 minute time block is assumed to be a single split period. Multi split time blocks, where a state changes, reverts, and then changes again is assumed to be a single split with regard to analysis. There is also an issue of a period extending between two blocks being cleaved into two smaller periods. In modeling, this situation can cause larger periods to be represented by more numerous smaller periods as an artifact. We used a sliding-window style algorithm that combined blocks based on likelihood of fit between adjacent blocks. In this manner we were able to mitigate this artifact's effect in simulation.

The filter does not affect the total period in idle per day, just the length of each idle period. Our preliminary findings showed this granularity is really only significant for analyzing very short time durations, otherwise the gaps had a negligible effect on data output in simulation – for this reason, we did not use block splitting for the final analysis. The final calculation of usage statistics and simulated savings was performed using the following approach:

1. Average idle state calculations were performed as an aggregate for all subjects for all days.
2. The Idle time periods were separated out on a per-day basis for each user to generate lists of idle periods and length of these periods.
    a. An XOR/AND mask was applied to the idle state information as an optional safety check (only states showing both On and Not-Active, and Idle state are considered as an Idle state period. Idle periods are separated on a per-day basis. Daily continuation of idle periods is divided into two periods in calculation.
    b. Days of the week were classified and simulations run for each analysis scoped period: weekdays, weekend days, and an aggregate grouping of both for each subject for each day. Summary statistics for all times spent in each state are presented on a per day and an aggregate basis.
    c. For a given scoped period, a sliding window algorithm was used to re-combine likely separated blocks of idle time due to the 15 minute sampling period, this is performed in two iterations to recombine separated periods. Without this step, the number of short periods is substantially overrepresented in simulation.
    d. A 1440 minute binary mask is used to represent idle periods, an edge filter applied to this mask was used to calculate and summarize idle periods blocks on a per day, per subject basis.
3. Using the idle periods per-day, per subject, and within each scoped period, a simulation was applied to estimate savings potential by the application of an intervention device with a setting defined in minutes. The results of this simulation on a mixed group of workstations as found will produce a "wildtype" summary of energy usage.
    a. Periods determined to have savings potential had this potential applied and summed on a day by day basis.
    b. Savings potential presented as an average across multiple time scopes including all days, an average for weekdays (computer assumed to be placed in standby for the weekends), or uniform across all weekdays with full power savings for weekend days (computer assumed to be idle all weekend and the whole period can be converted to savings with the use of intervention).
    c. Idle periods are calculated in time, energy usage is calculated by applying power usage to determined time.
4. Savings due to uniform power management can be simulated by the application of strict power management control. The known power management sleep setting (PM Setting) for subjects with PM enabled is presented in Table 7. This simulation is accomplished by subtracting the total PM period from the idle period on a period by period basis for each day. If the remainder value for each period is greater than zero, the intervention simulation is applied and the result is presented for multiple time scopes. This simulated PM evaluation can be applied on computers within three specific sets for different analysis goals. Firstly, computers with no power management can be simulated to operate with strict power management. Mixed groups of computers with power management can be

simulated to operate at a harmonized setting. Secondly, computers with high PM values can be simulated to have a common PM value, or a group of computers with mixed PM settings can be simulated to operate at a harmonized setting. Thirdly, a PM setting matching the PM setting for a single or monolithic group of computers can be used to identify the difference in savings between a strict implementation of the PM and the actual real-world PM operation. In this case, differences can be due to show PM performance or real world scenarios that (rightly or wrongly) impact PM performance from the ideal case which is simulated.

Table 7: Summary of subject Power Management (sleep) settings and corresponding operating systems for the 2014 Monitoring Study.

Index #	Operating System	Analysis Sample #	PM Setting (min)
1	Win7	3	60
2	OSX10-9	10	10
3	Win8	21	30
4	OSX10-9	29	180
5	Win7	30	240
6	Win7	35	30
7	OSX10-8	43	10
8	Win7	46	120
9	Win7	48	25
10	OSX10-9	51	10
11	OSX10-9	60	180
12	OSX10-8	82	10
13	Win7	85	60
14	Win7	89	30
15	Win7	100	30
16	XP	105	60

Analysis shortcomings are known, and a prepared list of issues and mitigation strategies are presented.

a. The data format used in the monitoring study does not explicitly show the actions <u>within</u> a 15 minute reporting block. Accordingly, assumptions must be made to pre-process data for usage. The original dataset has data collected in 15 minute blocks with a tally of time spent in each state during this period. For the 1440 minutes in a day, 95 blocks are used. Multiple internal periods of idle (block non-homogeneities) within a 15 minute timespan cannot be determined as this cannot be represented by a summary value. Internal state period non-homogeneities are shifted to block edges and combined into a single period. The effect on simulation as the forced concatenation of smaller blocks of sub 15 minute periods to larger periods toward 15 minutes. Shifting to the edges can extend the legitimate length of a state that extends beyond a single 15 minute reporting period. An illustrative example of this problem is highlighted in red in Table 8.

b. The data format used in the monitoring study does not explicitly show the actions between 15 minute reporting blocks. Similarly, to the previous issue, a non-homogenous period that extends to the next block produces an ambiguously represented situation where the carried over state may extend between blocks. If the period carries between blocks on both sides, the orientation of the periods is ambiguous. An illustrative example of this problem is highlighted in blue in Table 8. In this example, the reported values for Block 2 could represent multiple situations where edges are reversed or there is a single non-homogeneity versus two non-homogeneities. Only a single non-homogeneity can be represented, leading to partial mitigation with the effect in combining small state period durations to larger ones within the 15 minute period, thereby trending toward larger periods. The dual-edge concern cannot be fully mitigated. A block with a double non-homogeneity on the edges must be combined to a single discontinuity on one edge (as previously stated). The issue then follows as to which block the non-homogeneity aligns with. This problem is mitigated partially by comparing both situations and conceptually "rotating" each block to produce the maximum value for each edge fit. The largest value is selected as the final orientation. This can be accomplished with a single or a multiple pass approach. The multiple (double) pass approach was used ultimately for the major analysis in this project. The over-combination of periods can lead to extended savings potential. In evaluation, less than 1.5% difference was noted between the original and both the single and multiple pass approaches. The performance for a wildtype analysis across all subjects is shown in Figure 15. The major impact not combining blocks in this approach is poor performance and major underrepresentation of energy savings with studies involving forced PM simulation.

c. The data format used in the monitoring study with a 15 minute reporting period generates sampling artifacts in the data and can be observed in histogram plots of idle periods. This is due to non-homogeneities and periods split between blocks. The artifact presents itself as periodic pattern that is evocative of a sub-Nyquist frequency sampling of periodic signals.

d. The simulation in the current version treats each day as independent of every other day. Idle periods that carry over from a previous day are treated as starting during this day. This leads to a phantom intervention period applied at the start of the first idle period adding to that period saved even if the idle period was the whole day and there was zero savings. Compared to all other modes of error, this one is relatively minor and the estimation of savings potential accepted. When plotting histograms of idle periods across populations, artifacts can develop. Overnight artifacts appear as split periods. The time between the end of the workday to the end of the day (nominally 5pm to 12am, 7 hours/420 minutes), and the time between the start of the day and the start of the workday (nominally 12am to 8am, 7 hours/420 minutes) are two periods of substantial impact.

e. The simulation approach treats operational states as a binary option between On and Sleep/Standby. The Off state saves even more energy than Sleep, but must be user initiated. When the dataset is unsure of the state, an Unknown is presented. This is currently uncategorized and ignored. As less than 3% of total study time has this state, the impact was assumed negligible.

Table 8: Example of three 15 minute periods of computer usage and the representation of these periods by the reporting format used in the Monitoring Study.

		Block 1	Block 2	Block 2
15 Minute Blocks (Verdiem Format)	On	15	15	10
	Idle	12	11	9
	Active	3	4	1
	Standby/Sleep	0	0	5
	Off	0	0	0
Explicit (Shown in binary mask format)	On	1,1,1,1,1,1,1,1,1,1,1,1,1,1,1	1,1,1,1,1,1,1,1,1,1,1,1,1,1,1	1,1,1,1,1,1,1,1,1,1,0,0,0,0,0
	Idle	1,1,1,1,1,0,1,1,1,1,1,1,1,0,0	0,1,1,1,1,1,1,1,1,1,1,1,0,0,0	0,1,1,1,1,1,1,1,1,1,0,0,0,0,0
	Active	0,0,0,0,0,1,0,0,0,0,0,0,0,1,1	1,0,0,0,0,0,0,0,0,0,0,0,1,1,1	1,0,0,0,0,0,0,0,0,0,0,0,0,0,0
	Standby/Sleep	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0,1,1,1,1,1
	Off	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0	0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

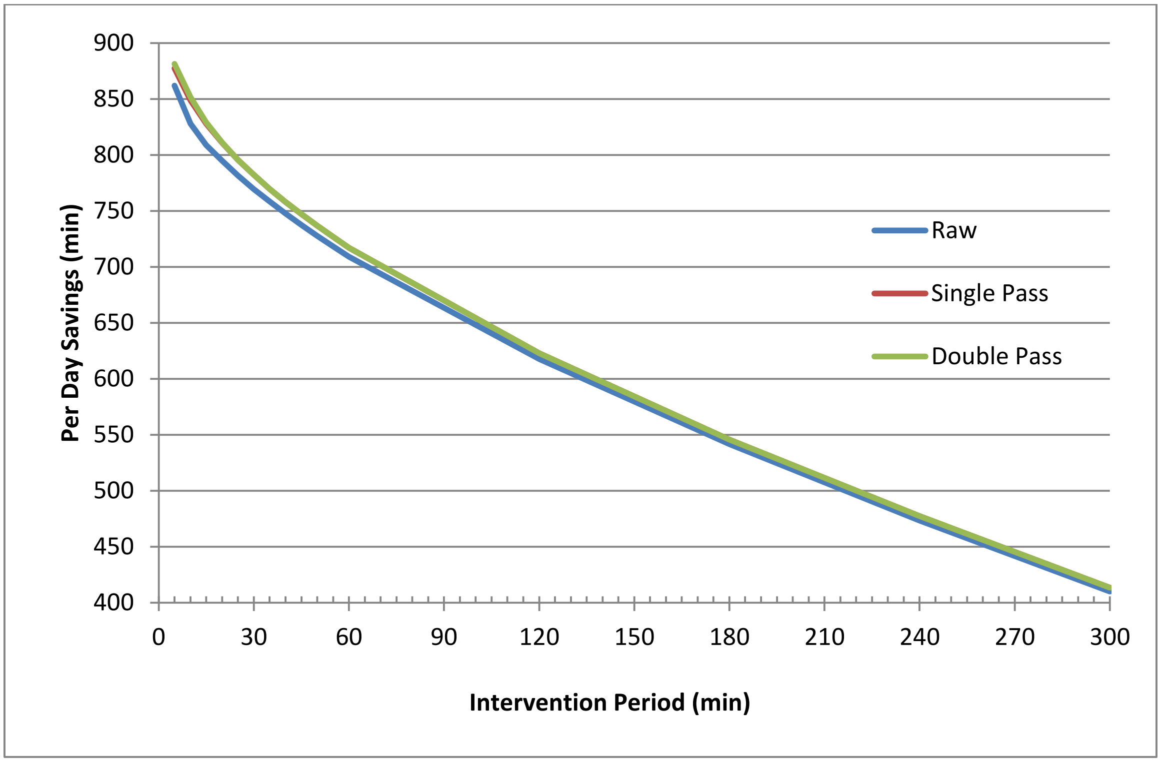


Figure 15: Evaluation of a single and a multiple (double) block combination algorithm for the "wildtype" case for all subjects across a scope of all days.

Further details of the simulation will be discussed later in this report, after the discussion of behavior in this section. The results for percent time spent in each state for the Monitoring Study are presented in Table 9. As described above, the computer has four possible states (On, Sleep, Off, and CPU-unknown). The user states (active, idle, and User-unknown) are only valid when the computer is on. Two unknown states exist, the CPU version is shown when the computer operational state is unknown, and the User-unknown is shown when the computer is in the On state, but if during this period active versus idle is unknown. Overall, the 115 evaluated computers spent an average of 64.6% of the day on and user idle. There was an insignificant difference between the subset of Mac computers evaluated compared to the total population with this subset having a per day idle time of 51.85% (s.d.=37.5, n=13). On the weekends, more computers are turned off, increasing the average percent time off, but the low active time (0.5%) results in the average idle time across computers being almost as high as during the week (64.7%). Extended periods of idle time during evenings and weekends provide potential savings opportunities.

Table 9: The time spent in each state for the 115 observed office desktops in the Monitoring Study with sub-states shown

	Weekday Average		Weekend Average		Overall Average	
Computer State	**Percent**	**s.d.**	**Percent**	**s.d.**	**Percent**	**s.d.**
On	77.7%	31.0%	68.7%	41.7%	75.1%	34.6%
User active	*13.2%*	*7.4%*	*1.0%*	*3.3%*	*9.7%*	*8.5%*
User Idle	*64.0%*	*31.3%*	*66.3%*	*42.4%*	*64.6%*	*34.9%*
User Unknown	*0.5%*	*3.6%*	*1.5%*	*2.3%*	*0.8%*	*1.8%*
Sleep	8.2%	20.0%	6.9%	21.8%	7.8%	20.6%
Off	11.8%	22.3%	21.0%	36.1%	14.4%	27.3%
Unknown	2.2%	10.1%	3.4%	14.0%	2.64	11.4%

The average time in each state shown in Table 9 includes all subjects, regardless of power management settings. The results are much different when desktops with computer sleep settings enabled are separated from those with sleep settings disabled, as shown in Figure 16. As expected, computers with sleep settings enabled spend more time in Sleep mode. However, these computers also spend more time Off (or in hibernate mode), both during the week and over the weekend.

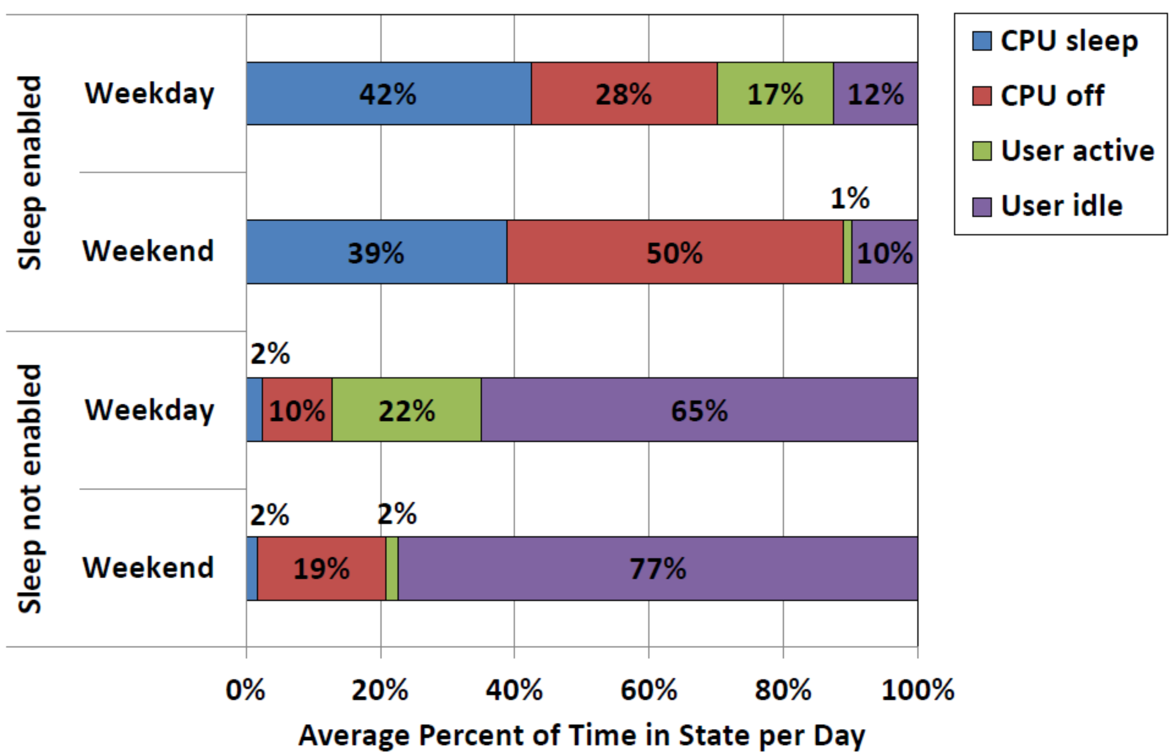


Figure 16: Time spent in each state for Monitoring Study desktops by PM enabling and time of week

It must be noted that the sleep delay timer setting cannot be used to calculate the total time spent in idle although correlation can be observed. Computers with short delay times will tend to have reduced idle time compared to computers with computer sleep enabled with longer delay times, but the amount of time the user is active and the pattern of that usage will also affect idle time. Another factor is whether computer sleep takes place when expected. Computer programs or processes may block the activation of sleep either legitimately or illegitimately (referred to in Table 10 as "Inconsistent Transitions"). Legitimate temporary blocking activities include the playing of movies, virus scanners, running backups, watching of videos, software updates, etc. where no action on the part of the user is typically but sleep is held off. Illegitimate actions include software or hardware preventing sleep but providing no utility during this period.

Table 10: Details of the 16 study subject workstations with sleep PM enabled. The PM setting (sleep delay) is show along with study time spent in each state.

		Time spent in each state				
	Sleep delay	User idle	CPU sleep	CPU off	User active	Inconsistent transitions
A	10	1%	3%	91%	6%	
B	10	1%	98%	0%	2%	
C	10*	10%	22%	60%	8%	
D	10	15%	29%	39%	16%	Yes
E	25	50%	25%	2%	23%	Yes
F	30	1%	97%	0%	2%	
G	30	3%	84%	0%	13%	
H	30	3%	7%	80%	10%	
I	30	11%	62%	0%	26%	Yes
J	60	2%	64%	27%	7%	
K	60	4%	3%	77%	17%	
L	60	25%	22%	27%	25%	Yes
M	120	4%	41%	36%	19%	
N	180	19%	73%	0%	8%	
O	180	36%	32%	22%	11%	
P	240	5%	0%	84%	11%	
* Delay increases to 15 minutes midway through study						

Number and length of idle periods

The overall amount of time a computer spends in idle depends on the PM setting and length of each idle period. This is important for any analysis of power management, as each transition to idle represents a potential opportunity to intervene and trigger sleep, and the length of that idle period represents the potential savings. However, as typical use of a computer involves constantly alternating between active interaction with the computer and minutes of idle time, not every idle transition is a true sleep opportunity.

In practical usage, computer idle time is reduced by the action of power management, but the correlation is not strong with regard to the power management setting itself. In Figure 17, a large number of the "No PM Enabled" data subset forms a "zero-sum" line where only active use offsets idle usage on a per day basis. Computers where users manually turned them Off or triggered Sleep states caused the data point to drop below this line on Figure 17. In this figure, computers with PM active lie significantly below this line, indicating power management operation. The PM setting for time until sleep does not correlate well with idle time. This is due to multiple factors.

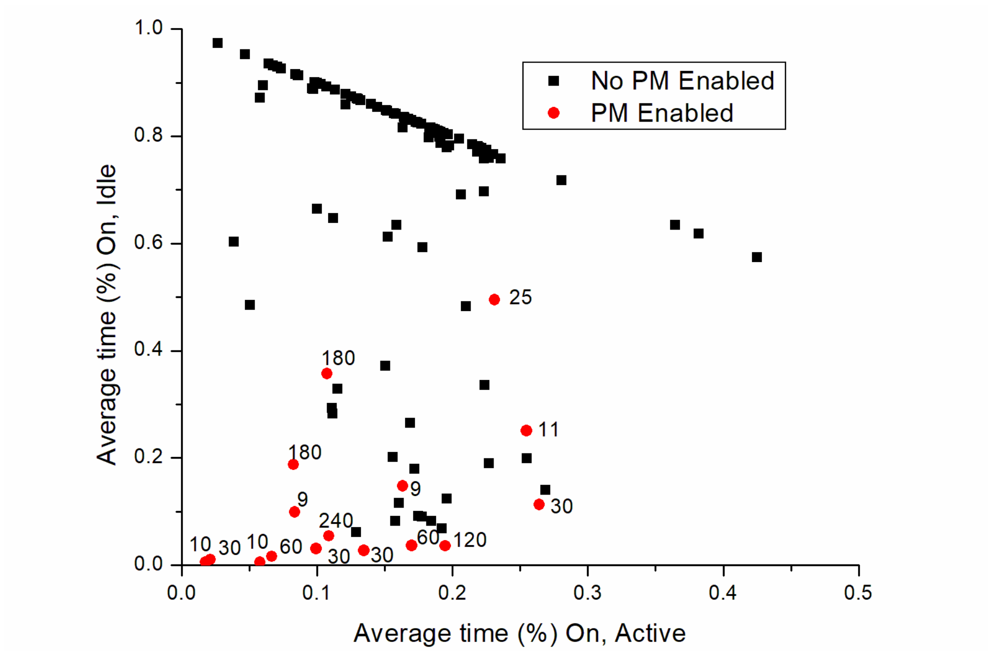


Figure 17: Comparison of idle versus active time for computers with PM enabled and non-enabled. Time (in min) until sleep is activated is shown next to relevant points. The cluster of points forming a downward slowing "zero-sum" line represents computers that only were in Active or Idle without Sleep or Off states (see Table 7).

This point is shown clearer in Figure 19. Looking at the time spent by workstations in Off, On, Idle and Sleep state, there is no strong correlation with power management settings. Inspecting individual idle time blocks, it is apparent there are a number larger than the total idle period. In Figure 18, a large overlap exists between computers with PM enabled and those with PM not enabled with idle time, yet few computers with PM not enabled have substantial sleep time, indicating most machines are left on with no user intervention to trigger sleep manually.

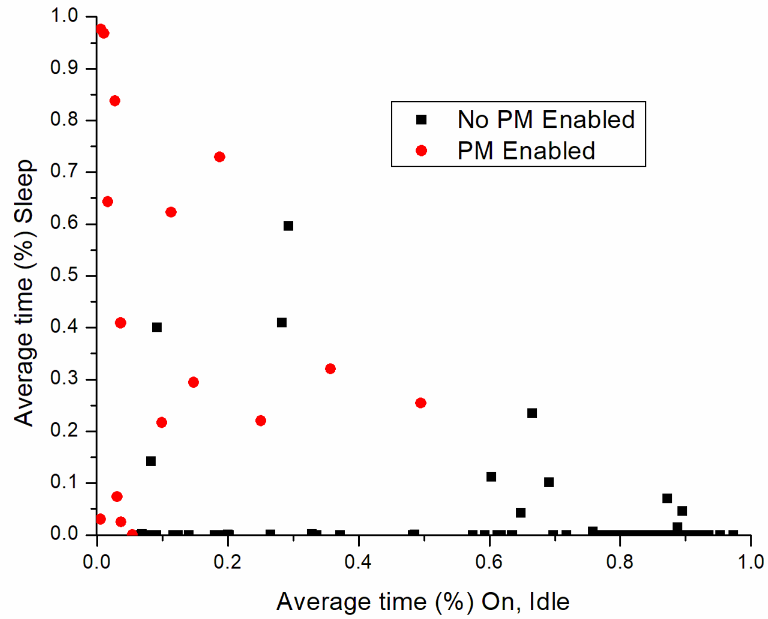


Figure 18: Comparison between computers with time spent in On, Idle versus Sleep for groups with PM enabled and PM not enabled.

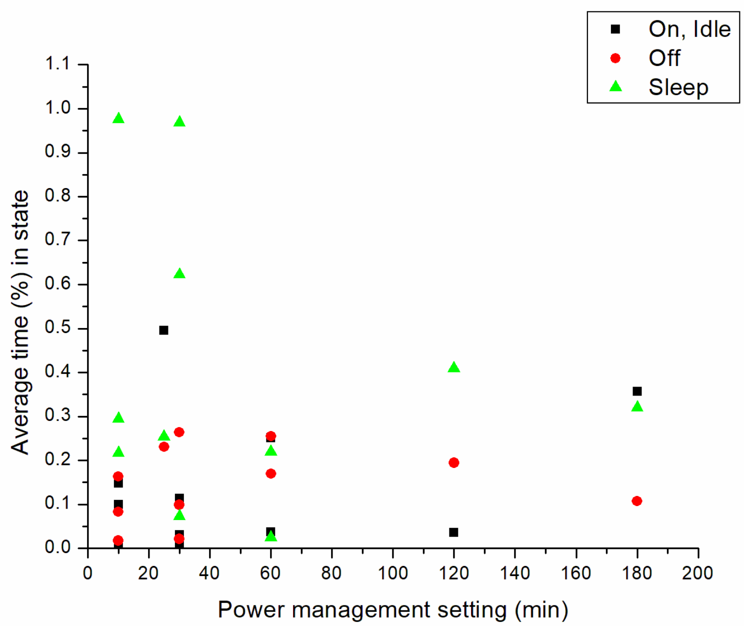


Figure 19: Comparison of the time spent in Off, On, Idle, and Sleep states with respect to the power management setting for PM enabled computers.

The length of the idle periods for a combination of all computers for all subjects is used to gain a perspective of the distribution of idle periods in a general population of workstations. The number of idle periods is larger for smaller period duration. A summary of idle periods for mixed subjects, subjects with PM enabled and subjects without PM enabled is shown in Table 11. For all subjects in a combined set, a summary histogram is presented in Figure 20. When separated out into individual sets of computers with and without PM enabled, substantially fewer long idle periods exist for the workstations without power management enabled.

Table 11: Histogram summary comparing remaining data points beyond specified idle period lengths in addition to the frequency of full day idles within the normalized idle periods.

Idle Period Length	All Subjects (n=115)	No PM Enabled (n=99)	PM Enabled (n=16)
Periods>15min	40.41%	41.37%	32.11%
Periods>30min	26.64%	27.90%	15.75%
Periods>60min	19.43%	20.90%	6.70%
Periods>120min	14.37%	15.64%	3.30%
All Day	2.00%	2.21%	0.26%

Many or even most of these idle periods are probably occurring during what users would qualify as "active" use—that is, brief periods of not interacting with the computer while reading, thinking, or otherwise temporarily pausing. As even aggressive power management is rarely set to put the computer to sleep with less than a 15-minute delay, these periods are not subject to reductions and related energy saving. Increased period time leads to proportionately increased savings considering the same active power usage. A substantial difference exists in the number of Idle periods between computers with and without PM enabled. A cumulative distribution function (CDF) of the three cases (Figure 21) shows a substantial distinction between the distributions for daily idle periods. A pronounced increase in period length and the total number of full day idle periods is present for computers without PM enabled. This is in part due to the action of the PM itself. Idle periods over the PM setting are reduced in number, causing a distribution shift toward shorter period. In Figure 22 and Figure 23 differences in idle lengths and total number of days fully idle are presented as comparably scaled histograms. It is important to note that a previously discussed aliasing artifact is prominently present in Figure 23 in addition to a period length artifact where split weekdays can present non-contiguous idle periods. This is observed as a local maxima that exists near 480 minutes which corresponds to 8 hours. This is an artifact of the measurement, which is restricted to the events occurring within a 24-hour day. That is, the first idle period of the day "begins" at midnight and the last one "ends" at midnight. Given that many people begin their work day approximately 8 to 9 hours past midnight or end their work day approximately 5 to 7 hours before midnight, these results are expected.

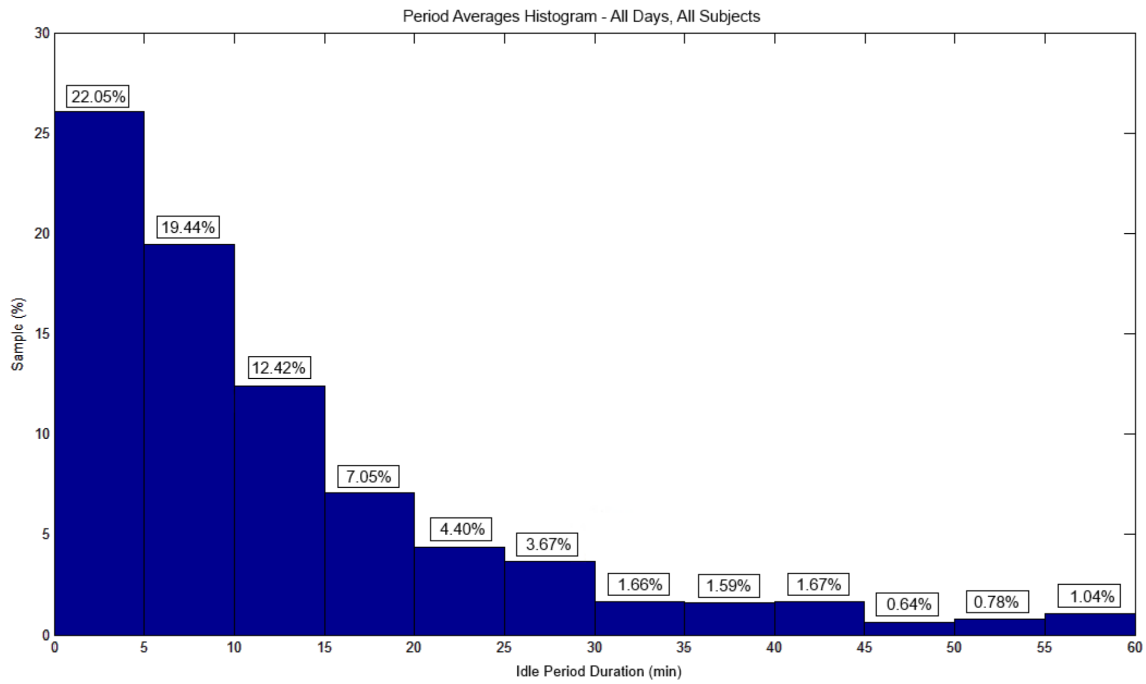


Figure 20: Histogram with 5-minute binning of idle periods for all days for all subjects

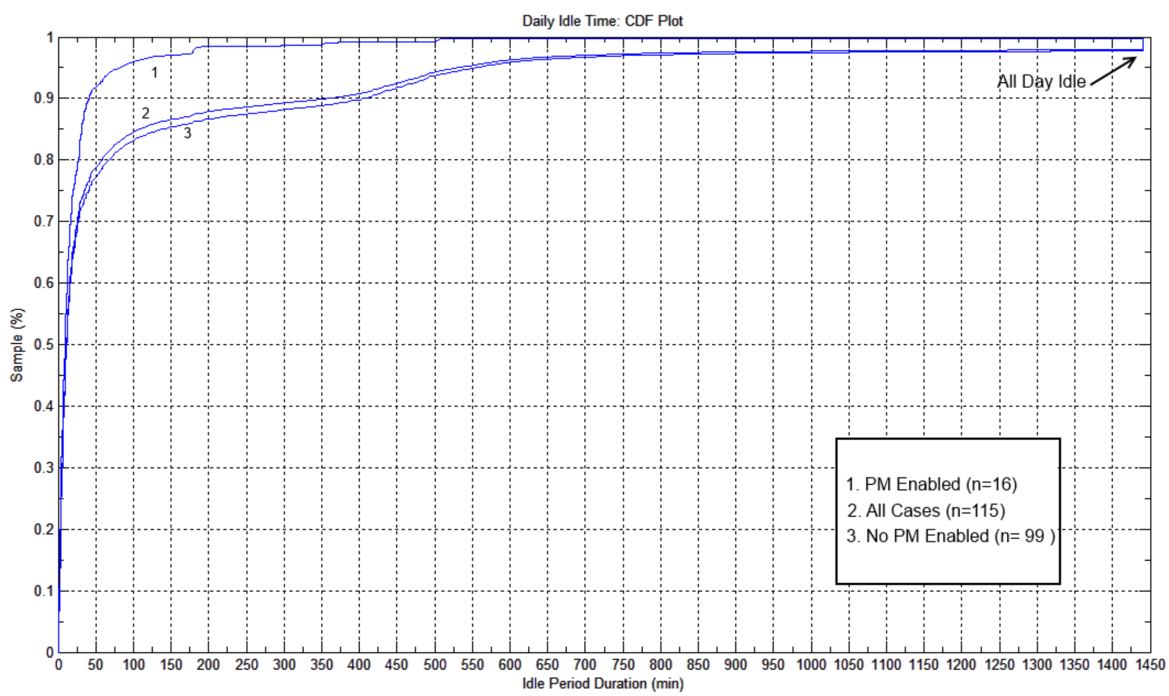


Figure 21: Cumulative distribution function showing idle periods up to 1440 minutes (a full day) for three specific data subsets

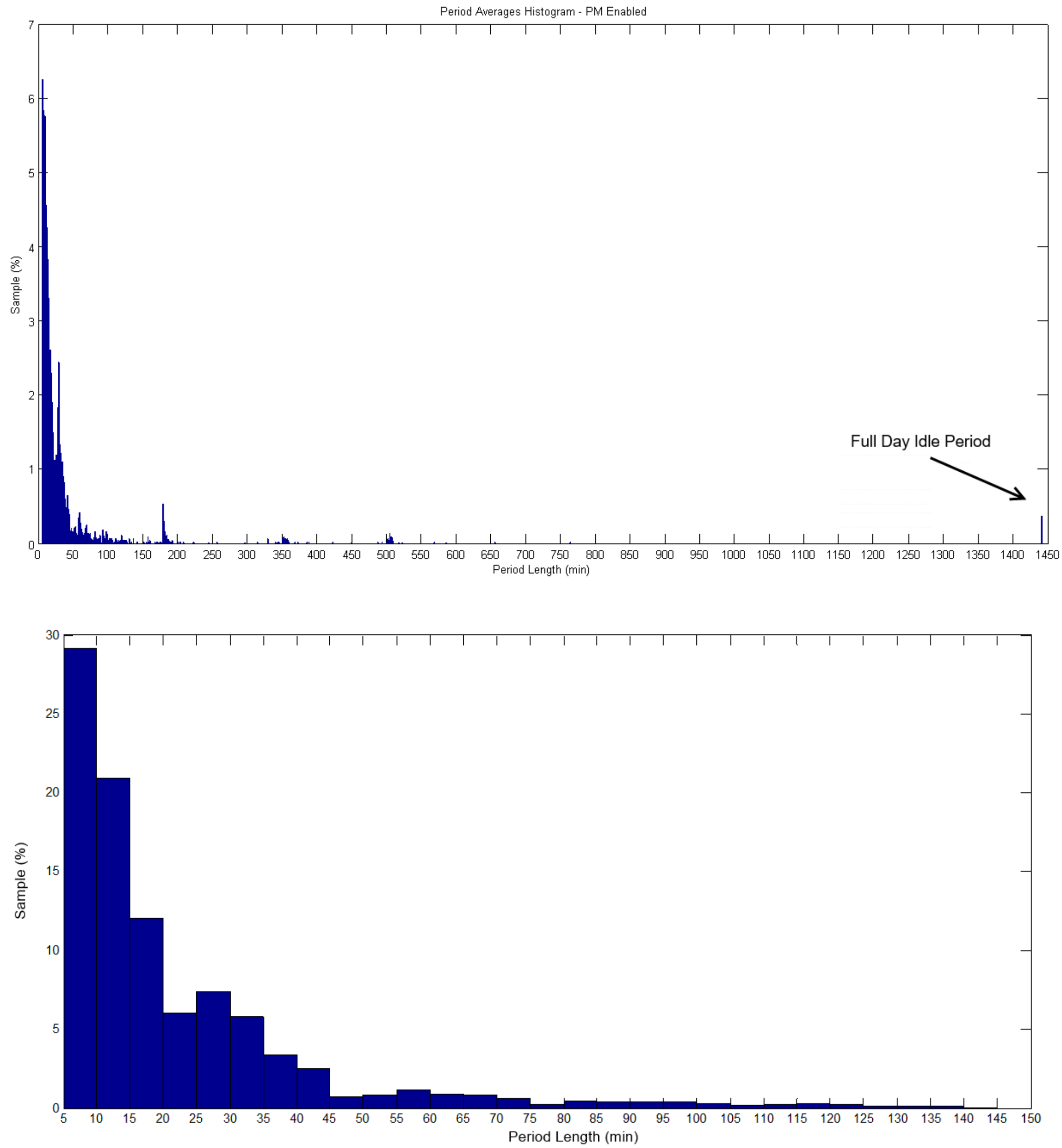


Figure 22 (top and bottom): Histogram showing idle periods for all subjects with PM enabled for a full day period with 1-minute binning for a full day (top) and with 5-minute binning for a total range of 150 minutes (bottom)

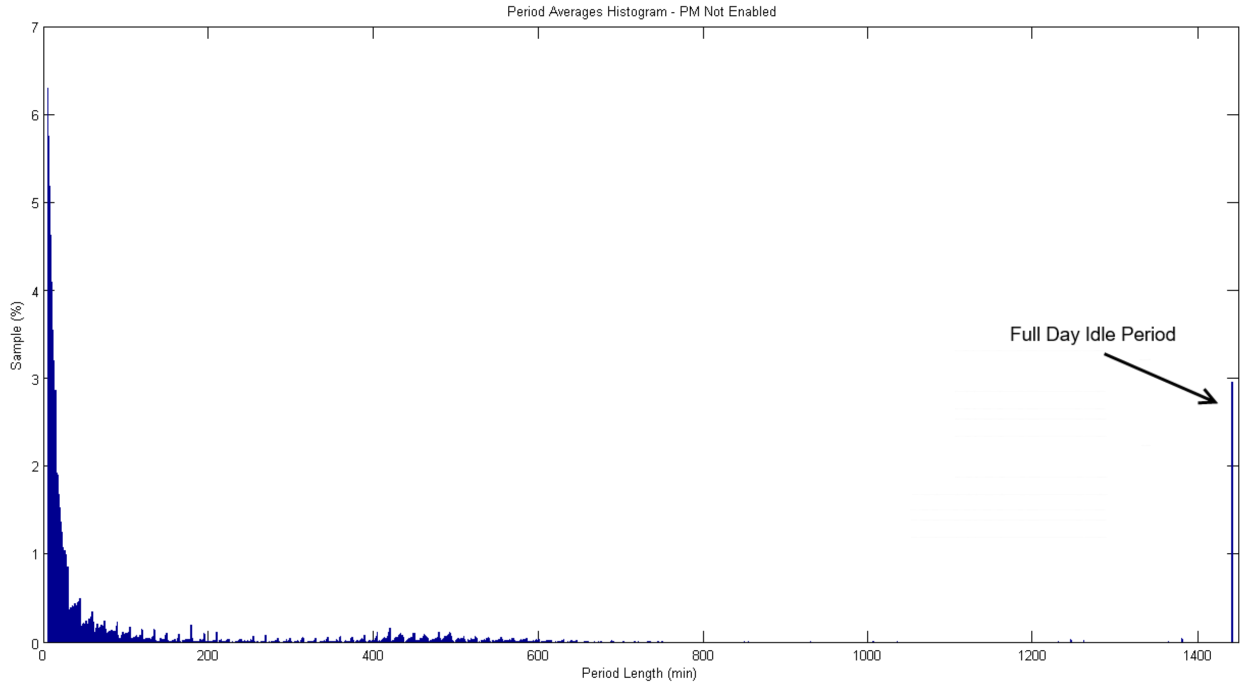


Figure 23: Histogram of idle periods for all days with subjects with PM disabled. Note artifacts due to sampling.

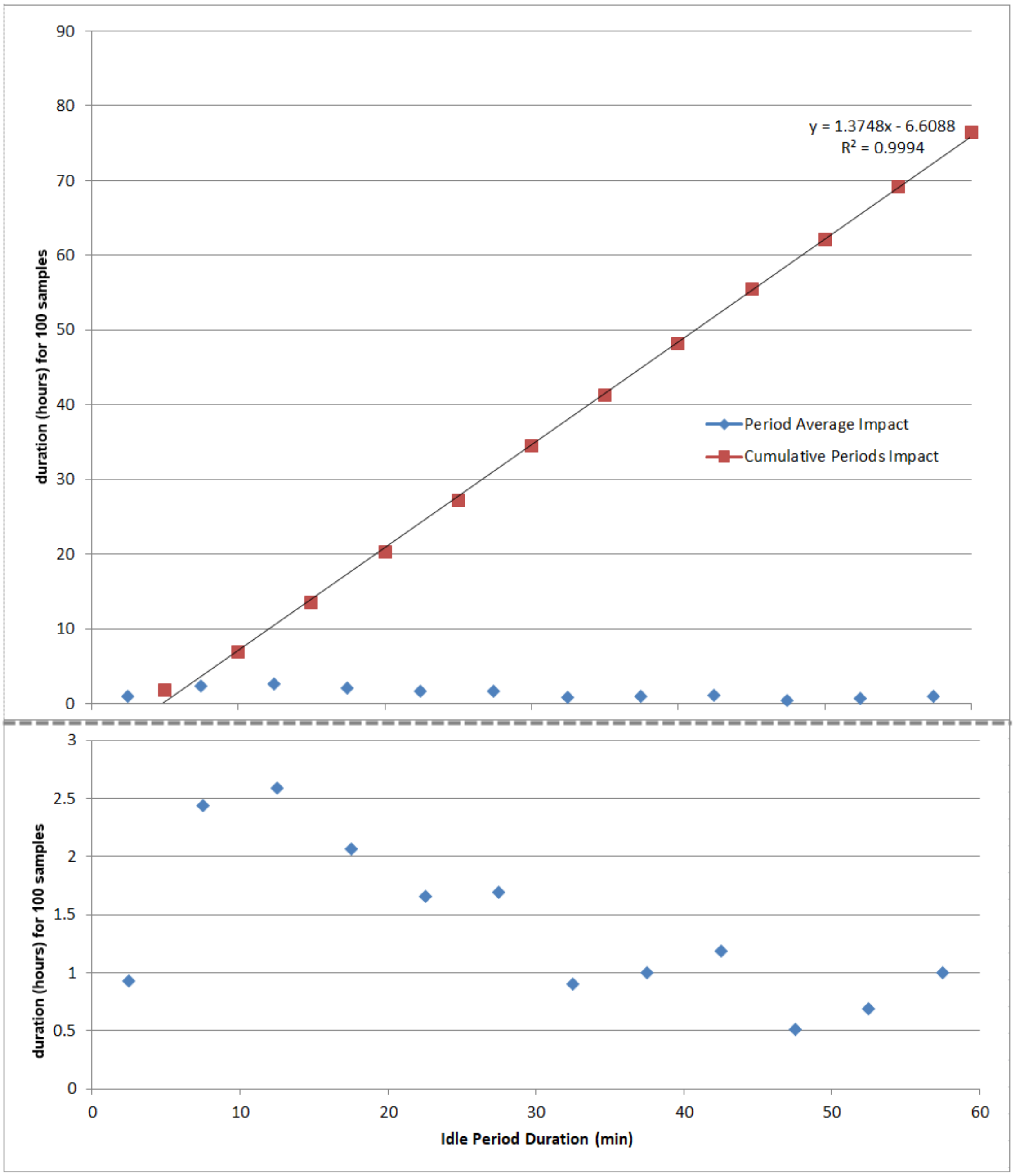


Figure 24: Idle period summary histogram for idle periods across all days up to 30 minutes in 5 minute binning (top). Calculation of hourly time (normalized for all days in a full year) spent in idle across a distribution-normalized total of 100 samples from the top sub-figure is presented in further details. This is a precursor factor (hours/100 total samples) is used to calculate total power consumed when multiplied by wattage and normalized to evaluated sample size.

Clearly, based on the usage data, savings opportunity exists by targeting multiple periods of idle time, sourced by different mechanisms and with varying impacts on both the user and total wasteful energy use. The periods are categorized here as very short term (less than 5 minutes), short term (5 to 15 minutes), mid-term (15 to 300 minutes), mid-long term, (300 to 600 minutes) and the long term (600 to the daily 1400 minutes or beyond). Setting PM to a very short time or applying an intervention strategy to these very short periods can result in small savings and a high likelihood of user frustration. When looking at the contribution to energy savings from histogram data, as the population drops off of individual periods (for longer periods), these periods simultaneously become more contributory to energy use. The result is a seemingly linear appearing relationship for the normalized plotted data in Figure 24 for the range of the plot. This data was directly calculated from period population distribution and length rather than a tabulated simulation. The following key points can be drawn from idle period length analysis and the impact of idle periods on energy use:

1. Most very short term periods (less than 5 minutes) probably occur during the course of active usage, when the user pauses keyboard or mouse activity temporarily but is still engaged with the computer. A sleep transition during these periods would interrupt the user and lead to frustration.
2. Short term periods (5 to 15 minutes) are likely generated when users may have stepped away from their workstation or participated in other short-term activities such as talking to a coworker or talking on the phone. In very short periods monitor sleep may be more beneficial than computer sleep to avoid waiting for the computer to return to usable state. The large number of these periods leaves substantial opportunity for some users to become frustrated with delays with only short, punctuated periods for savings.
3. For mid-term periods (15 to 300 minutes), users likely have stepped away from their desk. In most cases improved PM action can lead to substantial reduction in energy use without substantial user impact, with the exception of cases where the user could be using a computer to play music or provide a ready link for chat programs in which potential savings may cause issues.
4. For mid-long term periods (300 to 600 minutes), there are at least two likely possibilities. The first is users that start their computer at the beginning of the day then turn it off at the end with little to no use. Legitimate savings is likely possible in most cases for this scenario. The other possibility is a data artifact. The logging and analysis software uses 12AM as the delineation point for a single day. If a computer is idle overnight, the period from 12AM until 8AM (8 hours) and the period between the end of the day at 5PM and 11:59PM (~7 hours) can count in this period of time. Legitimate savings is possible in most cases for this scenario as well.
5. For long-term periods (600 to the daily 1400 minutes or beyond), this typically includes computers left on for multiple days or left on over the weekend. Legitimate savings is likely possible in most cases for this scenario. Similar to the data artifact issue of the previous case, a single full day of idle would be represented as a record for 1440 minutes, even though the total idle period would actually be longer, continuing from the previous day and extending into the next.

Energy Usage Baseline Evaluation

Baseline evaluation covers generation of calculation figures as a hybrid of cited data and measured devices onsite and as part of PMUI as well as generalized usage schedules. Details of how different factors contribute to measured energy savings and approaches for the calculation of baselines for different usage scenarios are discussed in this section.

TS1910 Energy Usage Baseline

The authors measured the power consumption of the USB Motion Sensor. In operational mode, the sensor draws 0.0355W, in standby (power applied), the sensor draws 0.0028 W (average, n=4) from a 5V DC input provided by the USB port. A fully active user offers an entire year (overestimation) that would result in 0.31 kWh/year direct energy usage due to the operation of the TS1910 Motion Sensor. Considering the baseline energy usage for a typical computer is greater than two orders of magnitude, the energy usage of this device is negligible in calculation. This factor must be subtracted from total savings when calculating energy usage to properly account for this overhead burden. This burden is only present in the active state. Because the value is so small, a calculation simplification can be made to use baseline runtime as the period of operation for the sensor rather than linking it to actual runtime with intervention (see Excel based calculator in the Appendix).

APS Energy Usage Baseline

The TS1104 and the TS4002 are two options for APS units to provide Tier 2 control. The TS1104 is both a residential and commercial solution. In the home, the TS1104 is used in both TV systems (entertainment) and home office applications. The TS1104 is also deployed into commercial workspace applications, the TS4002 is an APS equivalent in functionality to the TS1104 but with energy usage and state logging capability. The TS1104 consumed 0.469 W in standby and 0.966 W in the active (triggered state). Correspondingly the baseline bounds for 0% usage (no triggers) and 100% usage (always triggered) is 4.10 kWh/year and 8.46 kWh/year, respectively. The TS4002 consumed 1.013 W in standby and 1.663 W in the active (triggered state) assuming a network connection active for remote logging. Correspondingly the baseline bounds for 0% usage (no triggers) and 100% usage (always triggered) is 8.87 kWh/year and 14.57 kWh/year, respectively.

Desktop Computer Energy Usage Baseline

For desktops, we present the ENERGY STAR guidelines. This data is identical to the computer energy state period and energy values contained in Table 12. Information for laptops is not provided. To verify the representativeness of this data against the population of desktop and laptop computers that could possibly benefit from the TS1910 we independently spot tested several sample desktops and laptops for comparison against the example values in Table 12.

Table 12: ENERGY STAR Estimates for Desktop Energy Use (in watts)

Device State	Energy Consumption (W): Average desktops	Energy Consumption (W): ENERGY STAR compliant desktops
Sleep	2.3	1.8
Idle	48.1	27.1
(Active)	48.1	27.1
Off	1	0.8

Applying the ENERGY STAR estimates for energy use per state to the observed percent time in state from the PMUI baseline measures (see Figure 14) produces the calculations presented in Table 13.

Table 13: Computer states of use, frequency of use and energy use per state

Desktop computers			Sleep enabled		Sleep not enabled	
		Watts	% time/day	kWh/day	% time/day	kWh/day
Average desktops	Sleep	2.3	38%	0.021	3%	0.002
	Idle	48.1	32%	0.368	66%	0.760
	(Active)	48.1	9%	0.103	8%	0.093
	Off	1.0	17%	0.004	23%	0.005
	Total			**0.496**		**0.860**
Energy Star compliant	Sleep	1.8	38%	0.016	3%	0.001
	Idle	27.1	32%	0.207	66%	0.428
	(Active)	27.1	9%	0.058	8%	0.053
	Off	0.8	17%	0.003	23%	0.004
	Total			**0.285**		**0.486**
Watts per state taken from Energy Star power management calculator estimates.						

However, the energy usage in active versus idle mode was a consideration. This is typically assumed to be the same. We spot evaluated this conclusion. While some differences in activities between active and idle mode generate discrepancies, there is substantial variance to allow clear, separable divisibility based on power data alone. An example of variability during and extended idle period is shown in Figure 25.

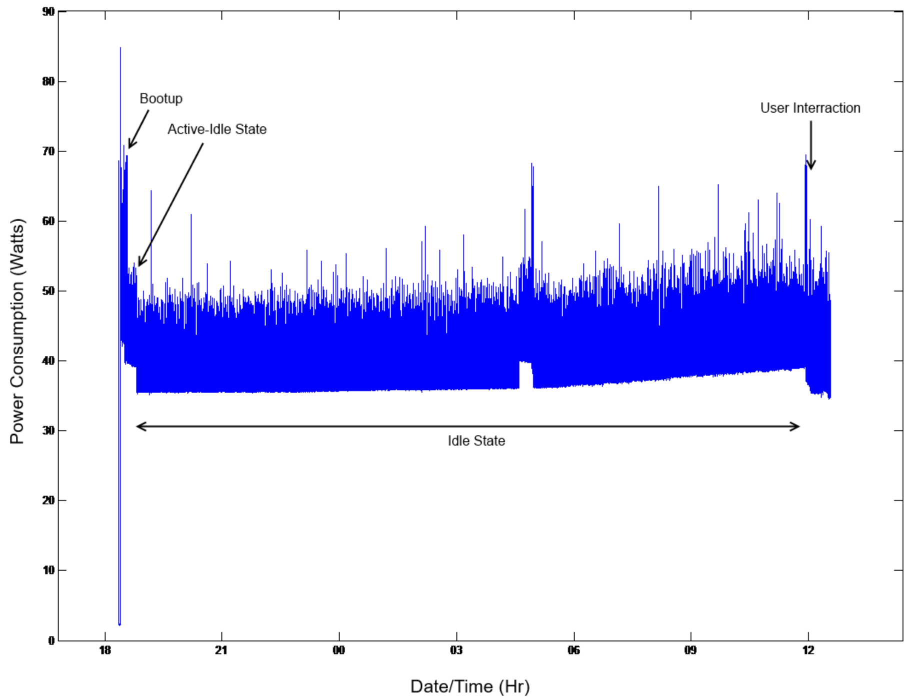


Figure 25: Energy use in an extended idle period for a desktop computer.

Based on the test of six modern desktop computers from four manufacturers we observed a divergence in state energy consumption. See Table 12 versus

Table 14 for different desktop energy usage values summarized from literature and testing by CalPlug. Generation of representative values was produced by running the computer for 4 hours in multiple states of operation including off, standby, and active. For the active state the boot state was measured as well as post bootup at a desktop screen. Roughly based on the usage, 1/2 of the total time in the on state included bootup and idle at a desktop, ¼ surfing the web with multiple tabs open in a web browser, and ¼ running a system benchmark in Novabench™ computer benchmarking software. This is intended to provide a repeatable and justifiably representative active usage profile for energy consumption in the On state by providing synthetic load to simulate user actions. The collected data was sorted by energy versus time to verify data integrity (an example shown in Figure 26) with experimental logs. The data is then resorted in increasing energy usage order to produce a state chart (annotated example shown in Figure 26).

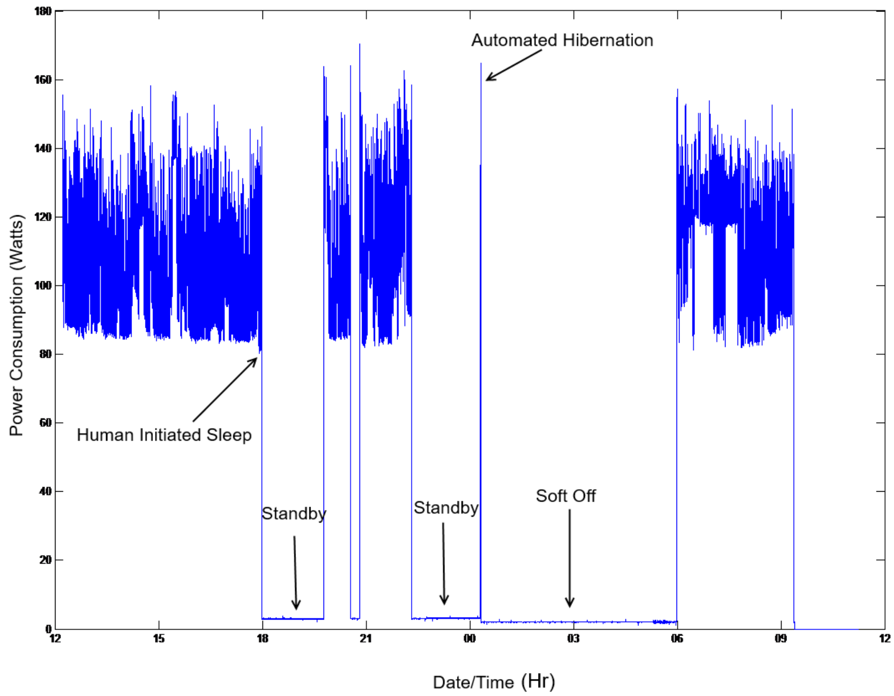


Figure 26: Example Desktop Computer power consumption with respect to time with annotations for states of operation and known user initiated or observed triggers or states. The x-axis labels show local time in daily hours.

A k-means segmentation is applied in MATLAB to determine state breaks in the presented data. Averages on a state-by-state basis were performed once the state boundaries were established. In Figure 27, an annotated k-means segmentation is shown with representative states highlighted. Based on the test of six modern desktop computers from four manufacturers we observed a divergence in state energy consumption. See Table 12 versus

Table 14.

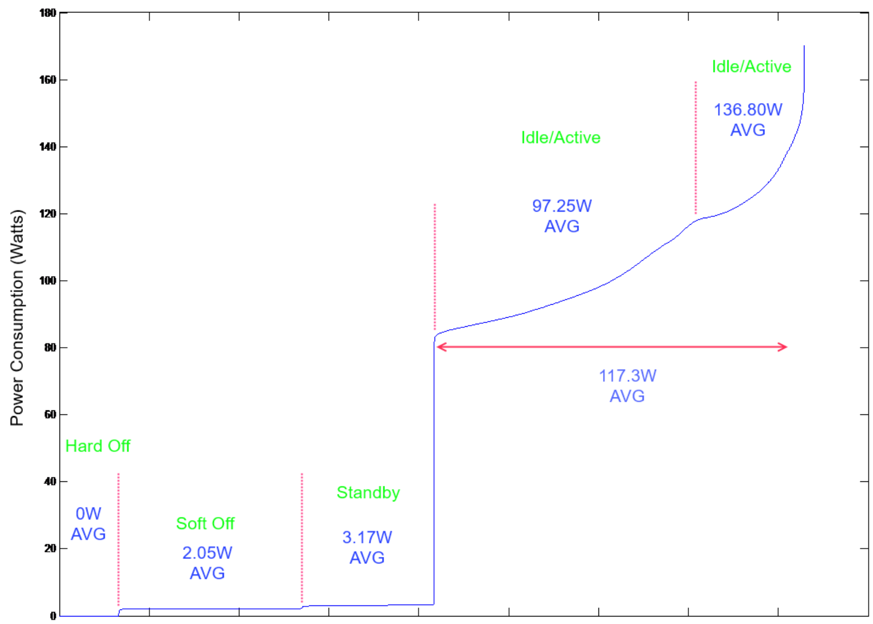


Figure 27: Example high-end desktop computer power consumption (from Figure 26) sorted with respect to magnitude with annotations for states of operation and power consumption in these states.

Table 14: Desktop computer measured energy usage in multiple operational states

Desktop Computer Energy Usage		-	Power Consumption (W) in Operational States			
Manufacturer	**Description**	**Model**	**Off (Case Switch)**	**Soft Off Avg**	**Standby Avg**	**Active Avg**
Manufacturer 1	Model 1	Small form factor desktop computer -Intel i3	N/A	0.42	1.924	43.5
	Model 2	Small form factor desktop computer - Intel i3	N/A	1.24	2.23	63.5
	Model 3	Mid-size Desktop computer - Intel i3	0	1.74	2.27	42.7
Manufacturer 2	Model 1	Full form factor Gaming COMPUTER - AMD P2x4 Clone	0	2.05	3.17	117.3
Manufacturer 3	Model 1	Mid-size Desktop computer - Intel i5 Clone	N/A	0.68	1.87	46.2
Manufacturer 4 (HP)	Model 1	Mid-size Desktop computer - AMD A10 Clone	N/A	0.29	1.22	110.4
		Average:		**1.07**	**2.114**	**70.6**

The wide variability between the results presented in Table 12 versus

Table 14 led us to present multiple values to use in simulation. Accordingly, the values presented in these tables are used to establish the upper and lower simulation bounds for the On (active and idle), Standby, and Off states.

Laptop Computers

Similarly, laptop computers have similar power consumption profiles although with more operational states as compared to desktop computers. These additional states are related to behavior when charging overlaid on-top of the operational energy usage in addition to screen power consumption being included in total energy usage. In contrast, for desktop computers, the monitor power is not included in the reported CPU energy usage reported total. In Figure 28 the power use profile of a laptop being used during charging is presented. In this figure, a laptop with multiple distinct active use periods is shown. Clearly charging has a substantial impact on the presentation of the states.

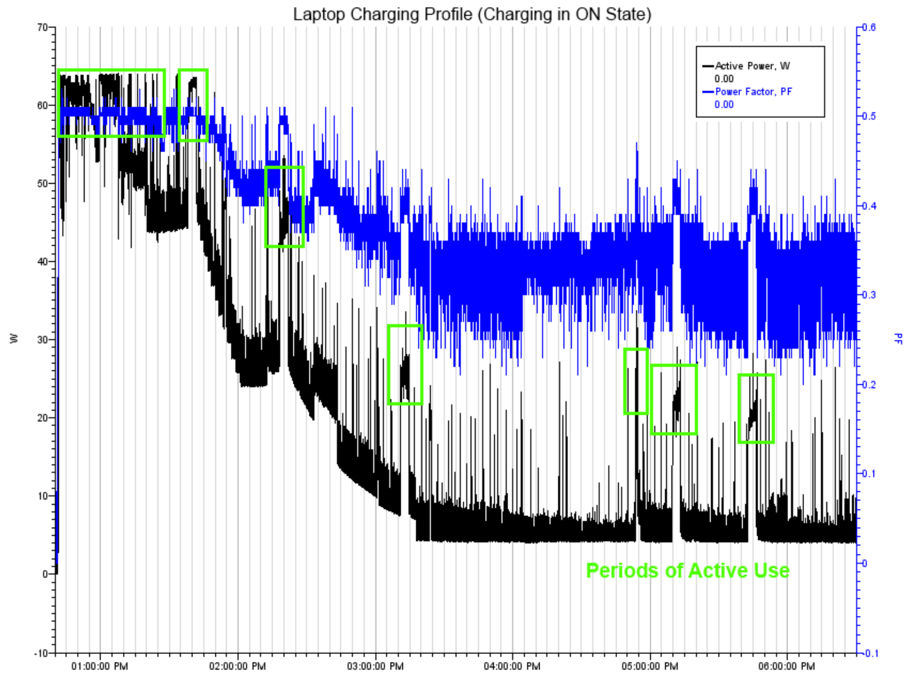


Figure 28: Laptop energy usage related to charging duration and state of charge. Observe changing energy use due to charging as well as noted operational state changes.

When a laptop is on Off state, the power consumption due to just the charging process can be individually assessed. This consumption is visualized in Figure 29 for the same laptop as data was presented for in Figure 28.

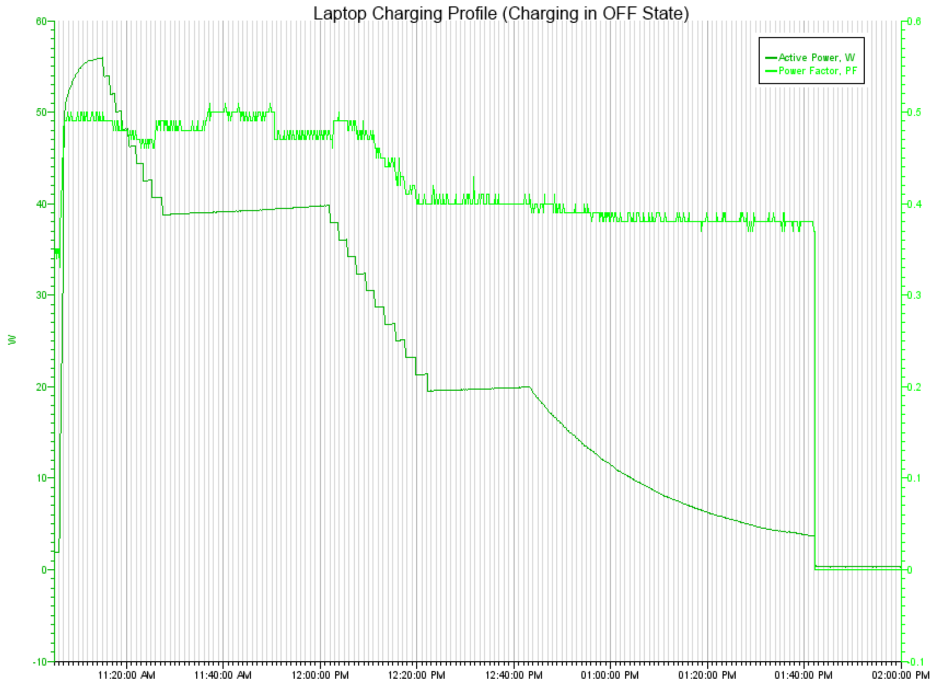


Figure 29: Laptop energy usage related to charging duration and state of charge – Example of charging in a SoftOff state of operation.

The method used to determine the energy consumption state-wise for desktops was also applied to evaluated laptop computers. The results are presented in a state-wise split table for operational states in charging (data was collected at between 40% and 60% battery state of charge during analysis in the charging state) both components of the split table are presented in Table 15. The OEM external power supply for the laptop is also tested in unconnected state in the "Charger Alone" category.

Table 15: Laptop computer power consumption (W) measured in multiple operational states

Laptop Computer Energy Usage - Power Consumption (W) while Charging in Operational States -

Manufacturer	Description	Model	Charger Alone	Charging: Soft Off	Charging: Standby Avg	Charging: Active Avg
Manufacturer 1	Model 1	13" Laptop - 2014 era	0.0072	31.06	37.5	47.52
	Model 2	13" Laptop - 2010 era	0.008	28.22	26.24	41.35
	Model 3	13" Laptop - 2015 era	0.0037	66.18	79.07	80.67
	Model 4	13" Laptop - 2015 era	0.968	62.52	45.23	42.62
Manufacturer 2	Model 1	15 inch laptop - 2014 era	0.281	49.6	49.59	49.55
	Model 2	15 inch laptop - 2014 era	0.127	53	90	95
Manufacturer 3	Model 1	15 inch laptop - 2014 era	0.0588	23.75	30.55	44.15
Manufacturer 4	Model 1	15 inch laptop - 2014 era	0.0407	44.968	49.406	49.24
Manufacturer 5	Model 1	15 inch laptop - 2014 era	0.0175	50.054	52.1	52.07
		Average:	**0.168**	**0.151**	**51.077**	**55.797**

Power Consumption (W) in Operational States (Charged) CHARGING VALUES

Manufacturer	Description	Model	Charged: Soft Off	Charged: Standby Avg	Charged: Active Avg
Manufacturer 1	Model 1	13" Laptop - 2012 era	1.31	1.91	35.387
	Model 2	13" Laptop - 2016 era	0.52	0.85	41.45
	Model 3	13" Laptop - 2010 era	0.71	0.75	63.5
	Model 4	13" Laptop - 2015 era	0.85	0.82	20
Manufacturer 2	Model 1	15 inch laptop - 2014 era	1.52	1.52	39.08
	Model 2	15 inch laptop - 2014 era	4.21	1.21	32
Manufacturer 3	Model 1	15 inch laptop - 2014 era	0.56	2.31	18.51
Manufacturer 4	Model 1	15 inch laptop - 2014 era	1.51	3.42	28.608
Manufacturer 5	Model 1	15 inch laptop - 2014 era	0.31		27.24
		Average:	**1.28**	**1.60**	**34.82**

Energy Usage Basis Values

Using the known states per day for all 115 test computers, the energy usage was calculated for multiple energy consumption values. The relationship to calculate the energy usage baseline as a function of individual state power consumption is presented in (Eqn. 1. Considering the test period is representative of a year, individual contributory expressions must be expressed in hours per year for state use (see Excel Calculator in Appendix). From the study data, each subset of the data has a different baseline value (all systems, systems with PM enabled, systems without PM enabled, etc.). Each baseline must be used in appropriate calculations. Although the authors present desktop and laptop data from testing, because large variances occur in test subjects, rounded values are presented as load representations for calculations. These rounded values make it easier for readers to estimate intermediate values if desired.

$$EnergyBaseline\left[\frac{kWh}{year}\right] = E_{On}(P_{On}) + E_{Standby}(P_{Standby}) + E_{Sleep}(P_{Sleep}) \qquad \text{(Eqn. 1)}$$

Table 16: Baseline energy use calculation figures for state use for desktop computers obtained by state time averages of all 115 subjects from CalPlug 2014 dataset regardless of power management settings (see Appendix 2 for extended table of factors used in tabulating these presented values).

Computer State Power Consumption (Off, Sleep/Standby, On-Active/Idle)	**Resulting Annual Usage Baseline (kWh)**
0.5W, 2.5W, 20W	133.4533
0.5W, 2.5W, 40W	266.1585
0.5W, 2.5W, 50W	330.1612
0.5W, 2.5W, 60W	398.8991
0.5W, 2.5W, 80W	624.8757
0.5W, 2.5W, 100W	693.1667
0.5W, 2.5W, 120W	923.1901
0.5W, 2.5W, 150W	1133.582

Peripherals and Control Devices

Attached peripherals can include under desk heaters, desk fans, printers, desk lamps, or multiple monitors. Whether a single monitor is used for triggering or used as a control device is configuration dependent. CalPlug modeled values of 0, 5, 10, 20, 50, 100, 500 watt loads as static input loads for model evaluation with values of 10, 20, and 50 presented. The triggering of the APS was assumed to be concurrent with the initiation of Sleep state. In this section, peripherals were modeled as a total operational average load. Tier-2 Advanced Power Strips save energy as both a sum of active energy and standby energy. In this model, a static energy use value is modeled to represent all plugged in devices. This model simplifies the difference of power used when connected devices are active versus are in standby. Peripherals were abstracted as a an average controlled load. When calculating percent savings against a background, the average standby load must also be determined. This value is likely to be components of standby load (standby when controlled peripherals are manually turned off) and active load. Because the active and standby loads are convolved in Tier 2 APS use, approximations for these two factors must be made. The average energy use rate (in watts) assumed to have been used without Tier 2 APS control is a mixture of wasteful active use and standby use. This value affects the baseline directly as it is required to estimate savings percentage against a baseline energy usage. Likely this average value is less than the active controlled load values. Similarly, the average controlled load is expected to be the value that is saved (in full) during the time when the USB Motion Sensor simultaneously saves computer active use and peripheral active use. This two part simplification provides a more streamlined input for the model system for calculation but requires situational estimates for accurate prediction. Please see the Excel based calculator in the Appendix section of this document for the applied usage of these factors.

Configuration Considerations

The final stage of estimating the effects of any sleep-related intervention depends upon the percent of computers that can reasonably be shifted from the "not enabled" to "sleep enabled" condition. Three scenarios are presented in Table 17, depending on the percentage of computers that shift to sleep enabled: half, 75%, or all. This figure is based on the 2018-collected PMUI dataset [36]. This is used to consider the stability of the baseline condition when considering the TS1910 motion sensor solution. Considering the potential cost of solutions (monetary, time, etc.), understanding the likelihood of adjustment without hardware intervention is important. Obviously, the most savings are achieved when all computers are transitioned to sleep, but this is not a realistic goal, given the technical and organizational barriers to computer sleep that still exist for many office workers.

Table 17: Scenarios estimating energy savings for enabling sleep settings

		Baseline		**Scenarios**					
	kWh/day (1)	**%**	**kWh/day (100)**	**50%**	**kWh/day (100)**	**75%**	**kWh/day (100)**	**100 %**	**kWh/day (100)**
Average desktops									
Sleep enabled	0.496	13%	6.452	57%	28.040	78%	38.834	100 %	49.628
Sleep not enabled	0.860	87%	74.809	44%	37.404	22%	18.702	0%	0.000
Total			81.261		65.444		57.536		49.628
Savings					**15.816**		**23.725**		**31.633**
ENERGY STAR compliant									
Sleep enabled	0.285	13%	3.707	57%	16.112	78%	22.314	100 %	28.517
Sleep not enabled	0.486	87%	42.292	44%	21.146	22%	10.573	0%	0.000
Total			46.000		37.258		32.887		28.517
Savings					**8.741**		**13.112**		**17.483**
Scenarios describe the percent of "sleep not enabled" computers that are changed to "sleep enabled" as part of the intervention.									
Savings are represented as kWh/day for 100 computers.									

Chapter 4: Energy Savings Evaluation

Energy Savings Model and Approach method

CalPlug uses a granular approach to demonstrate the savings potential of implemented energy management devices. The relationships presented are implicitly considered in the simulation calculations. Savings contributed by the USB Motion Sensor system ($\boldsymbol{E_{USB\_PM}}$) augments onboard computer power management ($\boldsymbol{E_{PC\_PM}}$) savings where applicable. When a Tier 1 APS solution is used (as in the TS1104 solution), Tier 2 APS type control for peripherals can produce savings ($\boldsymbol{E_{Periph\_PM}}$) when the control device is the computer under control and the USB Motion Sensor in turn is used to provide augmented energy management control for the computer. The net savings is considered after subtracting the solution implementation energy burden ($\boldsymbol{E_{overhead}}$). This relationship in general form is described in the following relationship:

$$\boldsymbol{E_{SavingsTotal} = E_{PC\_PM} + E_{USB\_PM} + E_{Periph_{PM}} - E_{overhead}} \text{ (Eqn. 2)}$$

Considering only the interaction of the TS1910 and the computer (no peripherals), energy savings will only occur when the USB Motion Sensor provides the potential to act upon savings opportunities missed by the onboard computer power management, such that:

$$\boldsymbol{E_{SavingsTotal} = E_{PC_{PM}} + E_{USB_{PM}} - E_{overhead}} \text{ (Eqn. 3)}$$
$$\boldsymbol{E_{USB_{PM}} = 0 \ when \ T_{PC_{PM}} < T_{PC_{PM}}}$$

When considering the savings provided by just the APS solution alone, both internal computer power management and the USB solution contribute to the control of the peripherals. Determining the solution savings benefit here requires considering two general factors in Tier 1 APS models:

When considering the savings provided by just the APS solution alone, both internal computer power management and the USB solution contribute to the control of the peripherals. Determining the solution savings benefit here requires considering two general factors in Tier 1 APS models:

1. Standby power consumption consumed by peripherals
2. Reduction in active use by linking a master control device (in this case, the computer) to the control wasteful active usage of peripheral devices.

The equations to determine the energy usage change (in kilowatt hours per year - kWh/year) due to savings by using a Tier 1 APS to control workstation peripherals is explained below. To calculate an estimated savings, the energy savings in standby mode is calculated and the time a peripheral is in standby mode is subtracted from the time that the master product is in either Standby or Off mode. Any remaining time that the peripheral is in Off mode is then determined and the savings while in Off mode is calculated. The savings from standby and Off modes are then added together to determine a total savings. When plugged into a Tier 1 APS, the power consumption of peripherals plugged into controlled outlets will be shut off and draw zero watts of power each in this new usage configuration. The resulting equation to determine the kWh savings for a typical household or for any given household using the calculation is provided by the general relationship:

$$\frac{\Delta kWh_e}{Year} = \sum_m (SDW_{e,m} \times \frac{SDHrs_{i,m}}{Day} \times \frac{kW_e}{1000W_e} \times \frac{365\ Days}{Year}) \quad \text{(Eqn. 4)}$$

$where$:
$e\ =\ peripheral\ device\ designator$
$i\ =\ conrol\ device\ (computer)\ designator\ (\ master\ control\ outlet)$
$m\ =\ shutdown\ mode\ designator\ (typicaly\ standby\ or\ off)$

$SDWe,m\ =\ shutdown\ watts, the\ watts\ drawn\ by\ e\ in\ shutdown\ mode\ m$
$SDHrsi,m\ =\ number\ of\ hours\ i\ is\ in\ shutdown\ mode\ m;\ =\ 24\ -\ number\ of\ operating\ hrs$

It is important to considering that in most commercial settings, there are distinct differences in use between weekdays and weekends for devices. In most cases, the device usage is similar during weekdays and is typically different during weekend-days. Accordingly, a simplification of the prior relationship can be used for calculating savings assuming binary operation as On (active or idle) or standby states.

The energy saved for each device is calculated per year as follows:

$$E_{saved\_year\_Wh} = \left(\left(P_{on} \times \frac{T_{on}\%}{100}\right) + \left(P_{standby} \times \left(\frac{1 - T_{on}\%}{100}\right)\right)\right) \times \frac{\left(\left(24\ Hr - H_{week\_day}\right) \times 5 + \left(24\ Hr - H_{weekend\_day}\right) \times 2\right)}{7} \times 365.25$$

$where$:
$P_{on}, P_{standby}\ =\ Aggregate\ power\ consumption\ for\ all\ peripherals\ in\ both\ ON\ and\ STANDBY\ operational\ modes.$
$T_{on}\%\ =\ Percentage\ of\ time\ of\ user\ unengaged\ device\ operation\ (wasteful\ use)$
$H_{week_{day}}, H_{weekend_{day}}\ =\ Hours\ of\ master\ device\ (computer)\ usage\ per\ daily\ period\ of\ either\ weekdays\ or\ weekend\ days.$

(Eqn. 5)

Peripheral control requires devices that can be safely unpowered and upon repowering enter an operational state that does not cause user disruption. The savings for peripheral control are maximized under the following circumstances:

1. High standby load – Reducing standby load is a primary effect of APS usage.

2. High potential to be left on unintentionally beyond the period of the master device (computer) – APS mediated unpowering of control devices reduces both standby and active load contributions to baseline energy usage.

There is a strong likelihood of peripheral use during master device usage. Use of the master device should be linked logically to the use of the peripheral. An example of this is a scanner connected to a computer. Without the computer in use, the scanner serves no function. A questionable link may be a lamp or a fan. In some cases, the use of these devices may not be directly linked in all cases to nearby computer engagement. Perversely, a master device may be activated to temporarily use a peripheral device or the system may be disconnected or reconnected in a less efficient means to provide temporary access to peripherals that are not activated. Peripherals that turn on automatically due to the APS that are typically not in use (a printer that is rarely used, for example) may end up using more energy under APS control due to unintentional activation.

The use of the monitor as a controlled or a control device is a potential concern. In some setups (typically not using a TS1910) the monitor is used to actuate a setup attached Tier 2 APS. The reason for this is typically the monitor sleep settings are more stringent than CPU sleep settings. This was observed in the field and believe to be the case as users clearly see feedback from monitor sleep. CPU sleep is less obvious to the users. For this reason, it is common to connect the monitor to the Tier 2 APS to provide control. The downside of this configuration is the standby power used by the monitor cannot be controlled by APS switching as a control device is supplied power to allow switching functionality.

Population Simulation - Materials and Methods

From the study data from the 2014 Monitoring Study dataset, the workstation state data was combined with estimated energy consumption to model energy usage based upon the previously discussed algorithm. A custom analysis suite, CalPlug PLSim (PlugLoad Simulator) and CalPlug MISER (Marginal Intervention Savings of Energy Reporter) tools were used for energy usage tabulation for this study (MISER: *https://github.com/CalPlug/MISER* and PLSIM: *https://github.com/CalPlug/PlugLoad Simulator-PLSim*). These utilities were used for data analysis and energy usage modeling. An overview of the analysis was presented in a previous section along with the algorithmic process for the simulation. Summary data and the calculator used to transform this data into the formats presented in the results section below can be found in the spreadsheet attached to this document in the document Appendix section.

This information is helpful to assess real energy wasted, but also strongly couples the behavior impact of usage of a specific computer to total energy usage rather than providing an open-parameter model where a range of energy usage levels can be simulated. An assumption is made that the energy used in active and idle mode are identical. As previously discussed, this is not always true, but this assumption provides a safe upper boundary for energy usage calculation and a framework to calculate energy use on that is forward facing and extendable.

Population Simulation - Results

Simulated Computer Energy Savings with the TS1910 on "Wildtype" Desktop Computers

The operation of the TS1910 was modeled by simulating savings periods from the computer population dataset. Assuming ideal operation, the following is calculated for use of the TS1910 for computers with the PM settings found without intervention. This will be referred to in this report as "Wildtype" settings. By the application of the intervention (for multiple periods) for each idle period for each subject for each day, a total number of per-day savings time can be determined based on each intervention period setting (in minutes) of the USB Motion Sensor. Periods beyond what is capable for the USB Motion Sensor were modeled to verify trending. The result provides an ideal operation scenario or upper-bounds of savings potential. No capability for legitimately extended idle periods is accounted for. The savings potential for all devices with granular breakdown for weekdays, all days and weekend days is presented in Figure 30. The per day savings value is used to calculate the total energy savings based upon the relationship is presented in (Eqn. 6. The total saved time from a higher use state is multiplied by power consumption to yield period energy consumption. To produce a savings value, the energy usage for the new state must then be subtracted from runtime values (see Table 18). Accordingly, per day saved period is an intermediate to calculate savings and is easy to present as a universal calculation value. As the period of Idle that can be converted increases, more savings is available for each converted period. Energy calculation of savings based on runtime in On and Sleep states is presented in(Eqn. 6 showing the savings potential by converting the On state to the Sleep state. This same relationship can be applied equivalantly for APS control burden in different operational states. The soft-off state is not considered an active conversion target and hence a target for conversion.

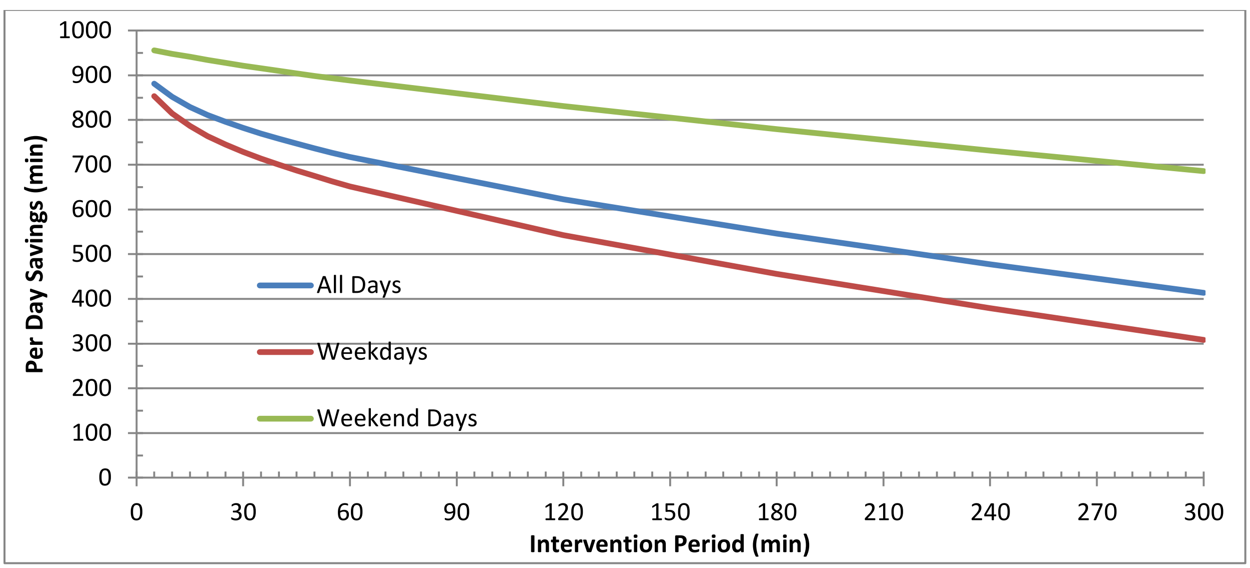


Figure 30: Savings for Wildtype data with respect to different savings value options.

$$YearlySavingsChange\left[\frac{kWh}{year}\right] = \left(S_{idle} * \frac{365days}{year * 60min} * \frac{P_{On}}{1000}\right) - \left(S_{idle} * \frac{365days}{year * 60min} * \frac{P_{Sleep}}{1000}\right)$$

$S_{idle} = modeled\ minutes\ average\ saved\ per\ day$
$P_{On} = Average\ power\ consumption\ (in\ Watts)\ when\ computer\ is\ in\ the\ On\ state$
$P_{Sleep} = Average\ power\ consumption\ (in\ Watts)\ when\ computer\ is\ in\ the\ Sleep\ state$

(Eqn. 6)

To calculate the total savings rather than just the change in energy usage, a baseline of energy use must be initially established and this change compared to it (see Table 16). State operating time provides a universal calculation intermediate for comparison of savings potential due to the action of intervention mechanisms designed to reduce wasteful runtime. This runtime conversion and the known power usage and time spent in each state of operation is used to calculate the baseline and the savings of energy from the baseline usage. In Figure 24 a summary is shown for the potential yearly maximum savings from baseline values considering ideal operation to exactly provide user engagement identification with different On/Active state loads. The values in this table are shown for extreme operating load cases with 20 W at the low end and 150 W at the high end of On state energy usage. This is used to show expected savings potential considering exceptionally large and small On state loads across a range of intervention period lengths. Additional values can be calculated using the Excel spreadsheet including the summarized model data and an included calculator tool attached in the report Appendix. The runtime values are reported along with standard deviation values calculated from the model based on the differences in idle periods for savings. Where possible, the calculation of runtime standard deviation values is carried into energy savings. It must be noted that the large variability between different subjects led to a large standard deviation for all systems. In some cases, one standard deviation of savings added to a mean will result in savings that is larger than the baseline. This large variability must be considered when interpreting results. As an example of an applied calculation, from the values in Table 18, a baseline of 342 kWh/year is a possibility modeling the runtime and average energy draw in each state (see Table 16 and Table A1). Resulting from this a daily reduction of 880 minutes would correspond to a savings of 342 kWh/year for a timer setting value of 5 minutes. This solution was determined using the attached Excel calculator.

In Figure 24, a graphical representation of savings is applied to the values presented in the idle period histogram in Figure 20. Because of the large savings opportunities for computers workstations without power management enabled, there is high savings potential for Wildtype computers where the population is dominated by computer workstations operating without power management, as only 14% of the total subject population has power management enabled. All subject computers were modeled with as found power settings for both Macintosh and Windows machines. Accordingly, much of the savings observed was during long periods before and after the working hours of workdays and on weekends. The runtime savings potential between weekdays and weekends is expressed in Figure 30.

Table 18: Model output for a year period (all days), Wildtype systems, for a workstation with a USB Motion Sensor in use alone and no loads under Tier-2 APS control. The results are presented in minutes per day savings for a given intervention setting (USB Motion Sensor timer duration) and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	Average Runtime Saved per day (min)	Std.Dev of Average Runtime Saved per day (min)
5	880.8 ± 84.7	463.6
10	851.4 ± 84.1	460.4
15	829.2 ± 83.5	456.9
20	811.4 ± 82.9	453.3
25	796.1 ± 82.2	449.6
30	782.6 ± 81.5	446.1
35	770.3 ± 80.9	442.4
40	758.7 ± 80.2	438.6
45	747.8 ± 79.5	434.9
50	737.5 ± 78.8	431.3
55	727.5 ± 78.2	427.7
60	717.9 ± 77.5	424.2
120	623.4 ± 70.2	384.2
180	546.4 ± 63.3	346.1
240	477.9 ± 56.5	309.3
300	414.2 ± 50.2	274.5

Table 19: Yearly percent energy saved comparing baseline energy usage to saved energy in Wildtype computer workstations (n=115) with no controlled loads. Highlighted values are available options for the USB Motion Sensor.

Intervention Setting (min)	Savings (%) with 20 W Active Computer Load	Savings (%) with 120 W Active Computer Load
5	68.42%	77.08%
10	66.14%	74.51%
15	64.41%	72.57%
20	63.03%	71.01%
25	61.84%	69.67%
30	60.79%	68.49%
40	59.84%	67.41%
50	58.93%	66.40%
60	58.09%	65.45%
120	57.29%	64.54%

Table 20: Model output for a year period (all days), Wildtype systems, for both 20 W, 40 W, and 100 W active loads (two extremes of modeled load), presented as kWh/year, savings (n=115), and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	AVG. Energy Savings kWh/year (100W)	Std. Dev. Energy Savings kWh/year (100W)	AVG. Energy Savings kWh/year (40W)	Std. Dev. Energy Savings kWh/year (40W)	AVG. Energy Savings kWh/year (20W)	Std. Dev. Energy Savings kWh/year (20W)
5	522.4 ± 50.3	275.0	200.9 ± 36.7	200.9	93.8 ± 9.0	49.4
10	505.0 ± 49.9	273.1	194.2 ± 35.5	194.2	90.6 ± 9.0	49.0
15	491.8 ± 49.5	271.0	189.2 ± 34.6	189.2	88.3 ± 8.9	48.6
20	481.3 ± 49.1	268.8	185.1 ± 33.8	185.1	86.4 ± 8.8	48.3
25	472.2± 48.7	266.7	181.6 ± 33.2	181.6	84.8 ± 8.8	47.9
30	464.2 ± 48.4	264.6	178.5 ± 32.6	178.5	83.3 ± 8.7	47.5
35	456.9 ± 48.0	262.4	175.7 ± 32.1	175.7	82.0 ± 8.6	47.1
40	450.0 ± 47.6	260.2	173.1 ± 31.6	173.1	80.8 ± 8.5	46.7
45	443.5 ± 47.2	258.0	170.6 ± 31.2	170.6	79.6 ± 8.5	46.3
50	437.4 ± 46.8	255.8	168.2 ± 30.7	168.2	78.5 ± 8.4	45.9
55	431.5 ± 46.4	253.7	166.0 ± 30.3	166.0	77.4 ± 8.3	45.5
60	425.8 ± 46.0	251.6	163.8 ± 29.9	163.8	76.4 ± 8.3	45.2
120	369.7 ± 41.7	227.9	142.2 ± 26.0	142.2	66.4 ± 7.5	40.9

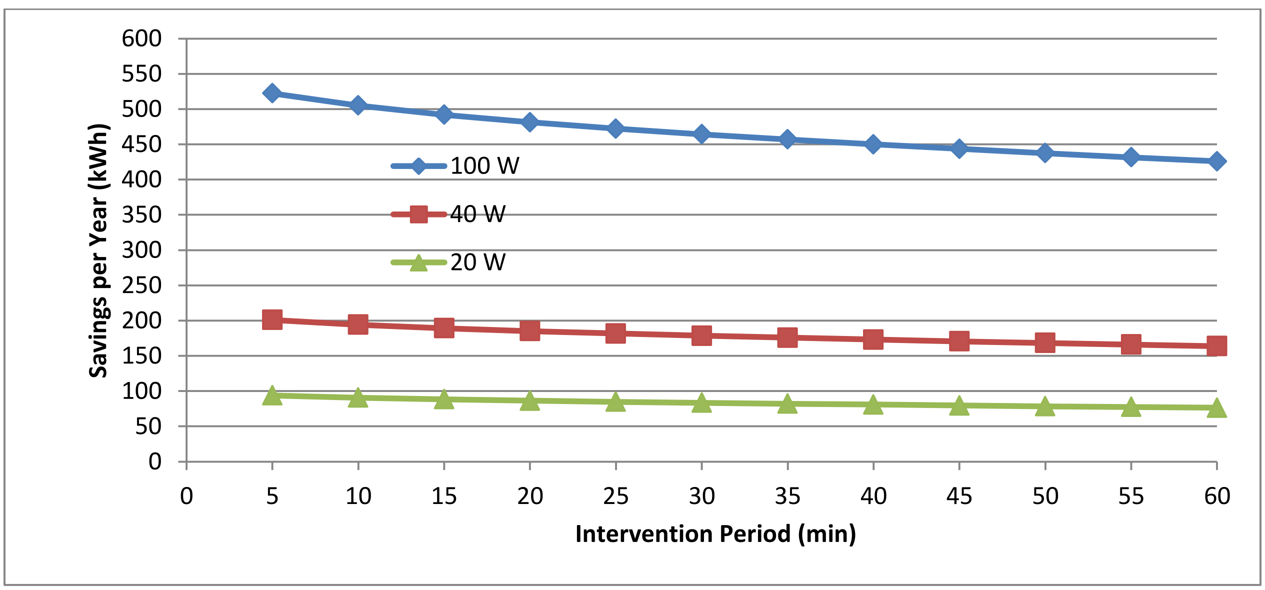


Figure 31: Summary of yearly energy savings for Wildtype subject computers with for multiple intervention period lengths and with different On state energy consumption values.

Considering the lengths of all possible idle periods that could be converted into savings for Wildtype machines, savings can occur only when the intervention setting (timer duration of the USB Motion Sensor is shorter than the idle period. The maximum value for this device is 30 minutes. When comparing the average savings relative to a 30 minute intervention period, the small baseline results in a relative large change for a low magnitude of total kWh saved (see Figure 36). When comparing the baseline against savings for similar time periods of reduced usage for workstations requiring similar loads, a pseudo-normalization occurs. This is because the value of active energy is so much larger than the energy used in sleep mode for both states, and the reason why the yearly percent energy saved against the baseline for 20 W and 150 W (the two modeled extremes) are so similar in savings potential for a given On/Active energy usage value (see Table 20 and Figure 32). A graphical display of the data in Table 20 is shown in Figure 31. The change in savings for shorter duration timer settings is shown relative to the 30 minute maximum value allowed by the USB Motion Sensor (see Figure 33). Per the discussion in the Executive Summary section of this report, a relative savings potential exists by reducing the USB Motion Sensor to have smaller set timer values in operational use. The authors of this report have calculated the absolute savings values (in kWh) from the data and presented this, but strongly hypothesize that a relative pattern exists that follows the percent reduction based on a shifting baseline of usage. In this manner, a relative savings in percent applied to a new case baseline provides a general pattern for savings with varied settings of the USB Motion Sensor. Accordingly, as shown in Figure 33, a savings of ~12% additional savings would be hypothesized for a USB Motion Sensor set at 5 minutes versus 30 minutes with the relative usage data in this study representing the usage of a new user population with representative PM settings values and frequencies of use in the new population as compared to this study population in this report. Confirmation of this trend with follow-up field studies would be required to confirm this pattern.

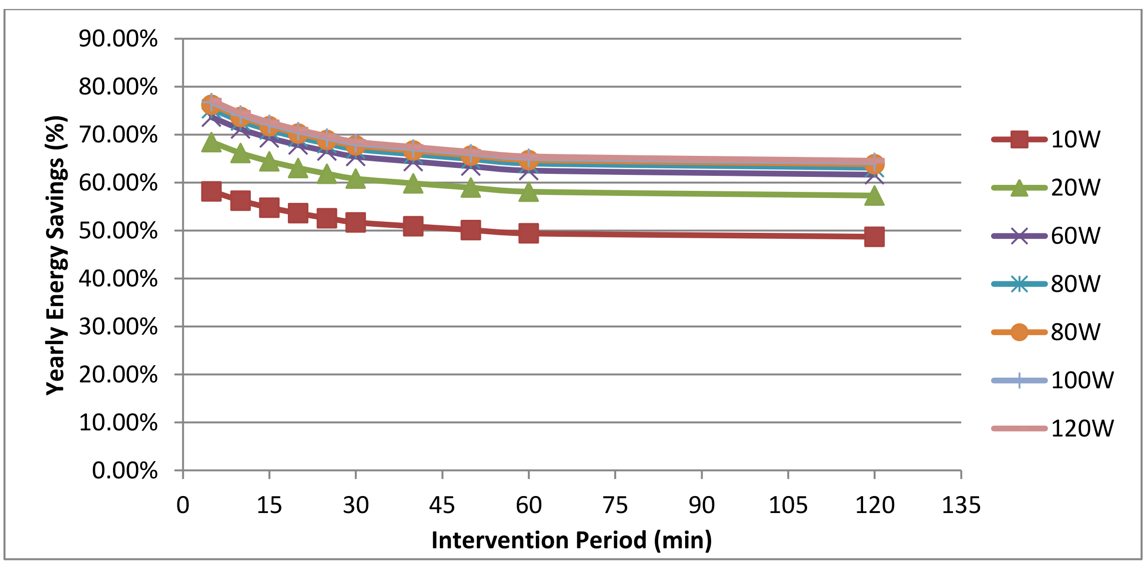


Figure 32: Baselined yearly savings for different modeled On/Active state power loads with a modeled Sleep state power load of 2.5 W for multiple Intervention period settings for study Wildtype computers.

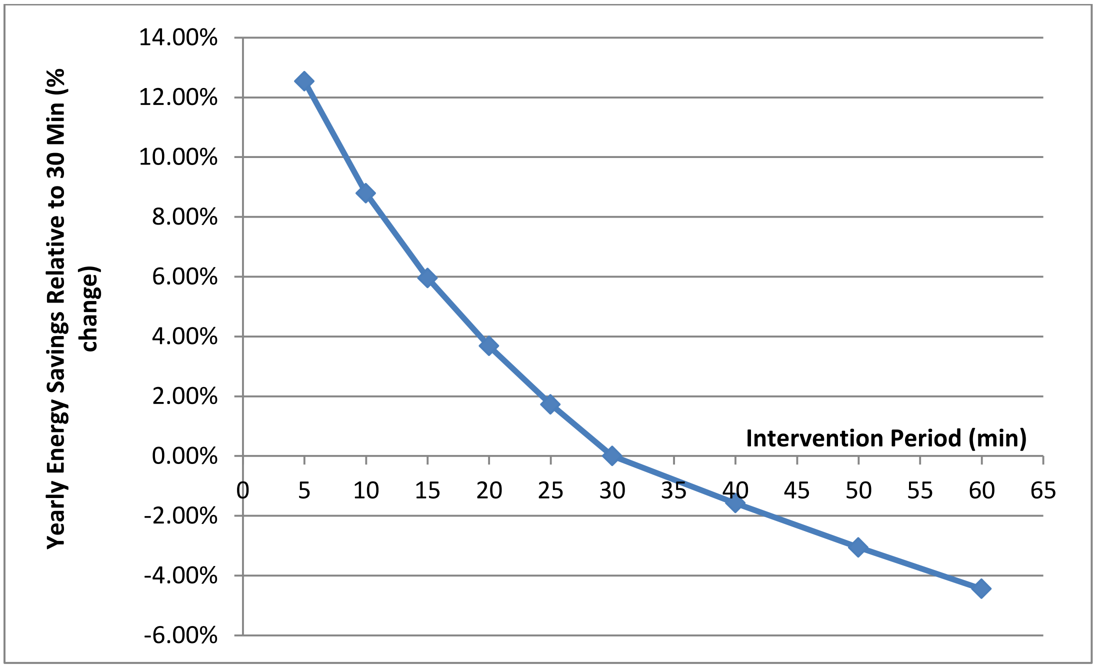


Figure 33: Change in baselined yearly savings for a modeled 40 W On/Active state load for multiple intervention periods as compared to the savings produced by a 30 minute intervention period for study Wildtype computers (n=85).

Computer Energy Savings with the TS1910 on Desktop Computers with Power Management Enabled

A subset of the systems where PM was enabled (with various operating system timer length settings are summarized in Figure 17) are shown in

Table 22 where only systems with PM enabled are modeled. This table shows the savings potential between two extreme ends of On/Active state energy usage that could be saved. The savings potential is proportional to increasing idle period length. With power management, the length of that idle period is typically the operating system power management setting for system sleep/standby.

Table 22 contains the values for savings for systems with power management enabled as compared to Table 19, which contains the values for all Wildtype systems. Equivalently, in Table 23, a summary for energy use is presented with parameters identical to the data presented in Table 20, except with power management enabled for all of the subjects summarized in Table 23 and graphically shown in Figure 34. As with the Wildtype example presented in Table 20, standard deviation values are calculated and presented. As the power management timer settings substantially vary between all reported systems with power management enabled, the resulting standard deviations can be greater than the averages themselves. Accordingly, the authors emphasize that the presented data has a wide margin for error due to the wide variety of operating system power management timer settings represented in this common data set and the relatively small number of systems with power management enabled. For systems with power management enabled, a substantial decrease in energy usage is observed as extended idle periods *should* not exist due to the action of the onboard operating system power management that will cause the sleep state to be entered after the sleep timer for this power management system expires.

As the total baseline energy is reduced for the systems with power management enabled. A <15% savings is predicted from this set of subjects even with a 5 minute USB Motion Sensor setting (Figure 35). The percent savings increases substantially due to a diminished baseline as shown Figure 36. The overrepresentation of the systems with power management in this study segment and the values used for PM settings are a segment of the total study population. This subset is illustrative of the continued impact that external power management control can have to reduce energy usage even with operating system power management enabled.

Table 21: Model output for a year period (all days), Power Management enabled systems (n=16), for a workstation with a USB Motion Sensor in use alone and no loads under Tier-2 APS control. The results are presented in minutes per day savings for a given intervention setting (USB Motion Sensor timer duration), and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	Average Runtime Saved per day (min)	Std.Dev of Average Runtime Saved per day (min)
5	165.52 ± 95.0	193.88
10	142.429 ± 90.9	185.46
15	126.399 ± 87.9	179.36
20	114.699 ± 85.6	174.75
25	105.289 ± 83.8	170.96
30	97.619 ± 82.3	167.95
35	91.83 ± 80.9	165.03
40	87.11 ± 79.5	162.28
45	83.15 ± 78.4	159.90
50	79.63 ± 77.3	157.74
55	76.34 ± 76.3	155.73
60	73.31 ± 66.2	153.88
120	51.32 ± 24.7	135.05

Table 22: Yearly percent energy saved comparing baseline energy usage to saved energy in computers with PM enabled (n=16) with no controlled loads under APS management. Highlighted values are available options for the USB Motion Sensor.

Intervention Setting (min)	Savings (%) with 20 W Active Computer Load	Savings (%) with 120 W Active Computer Load
5	12.86%	14.49%
10	11.06%	12.46%
15	9.82%	11.06%
20	8.91%	10.04%
25	8.18%	9.21%
30	7.58%	8.54%
40	7.13%	8.04%
50	6.77%	7.62%
60	6.46%	7.28%
120	6.19%	6.97%

Table 23: Model output for a year period (all days), PM Enabled systems(n=16), for both 20 W, 40 W, and 100 W active loads (two extremes of modeled load), presented as savings in kWh/year, and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	AVG. Energy Savings kWh/year (100W)	Std. Dev. Energy Savings kWh/year (100W)	AVG. Energy Savings kWh/year (40W)	Std. Dev. Energy Savings kWh/year (40W)	AVG. Energy Savings kWh/year (20W)	Std. Dev. Energy Savings kWh/year (20W)
5	98.2 ± 56.4	115.0	37.8 ± 21.7	44.2	17.6 ± 10.1	20.6
10	84.5 ± 53.9	110.0	32.5 ± 20.7	42.3	15.2 ± 9.7	19.7
15	75.0 ± 52.1	106.4	28.8 ± 20.0	40.9	13.5 ± 9.4	19.1
20	68.0 ± 50.8	103.6	26.2 ± 19.6	39.9	12.2 ± 9.1	18.6
25	62.4 ± 49.7	101.4	24.0 ± 19.1	39.0	11.2 ± 8.9	18.2
30	57.9 ± 48.8	99.6	22.3 ± 18.8	38.3	10.4 ± 8.8	17.9
35	54.5 ± 48.0	97.9	20.9 ± 18.4	37.6	9.8 ± 8.6	17.6
40	51.7 ± 47.2	96.3	19.9 ± 18.1	37.0	9.3 ± 8.5	17.3
45	49.3 ± 46.5	94.8	19.0 ± 17.9	36.5	8.9 ± 8.3	17.0
50	47.2 ± 45.9	93.6	18.2 ± 17.6	36.0	8.5 ± 8.2	16.8
55	45.3 ± 45.3	92.4	17.4 ± 17.4	35.5	8.1 ± 8.1	16.6
60	43.5 ± 44.7	91.3	16.7 ± 17.2	35.1	7.8 ± 8.0	16.4
120	30.4 ± 39.2	80.1	11.7 ± 15.1	30.8	5.5 ± 7.1	14.4

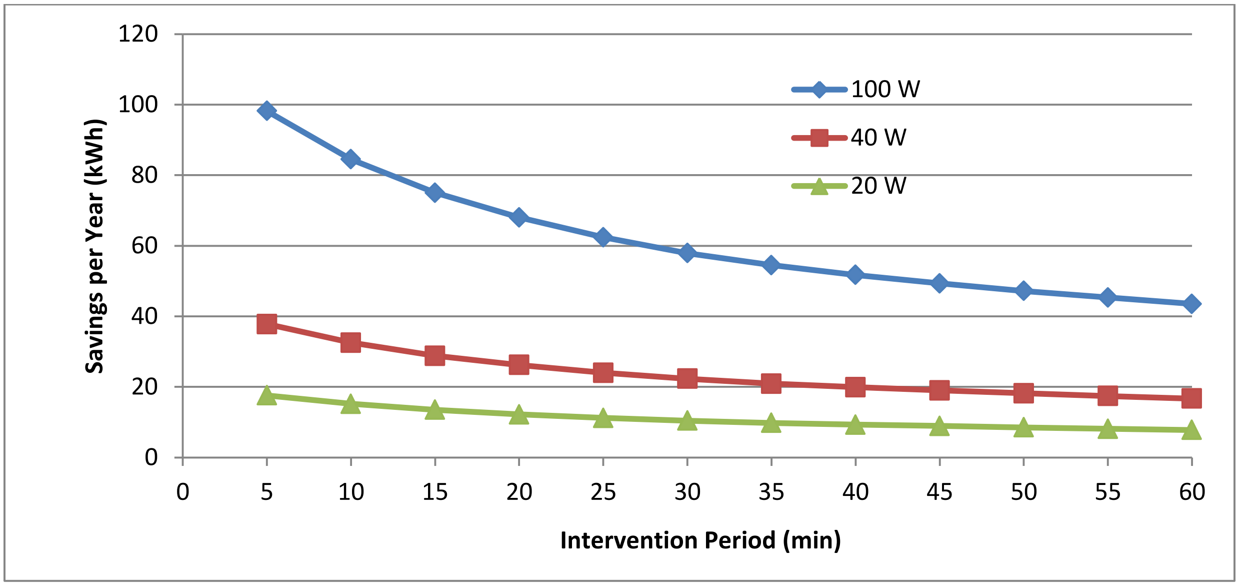


Figure 34: Summary of yearly energy savings for subject computers with power management enabled for multiple intervention period lengths and with different On state energy consumption values.

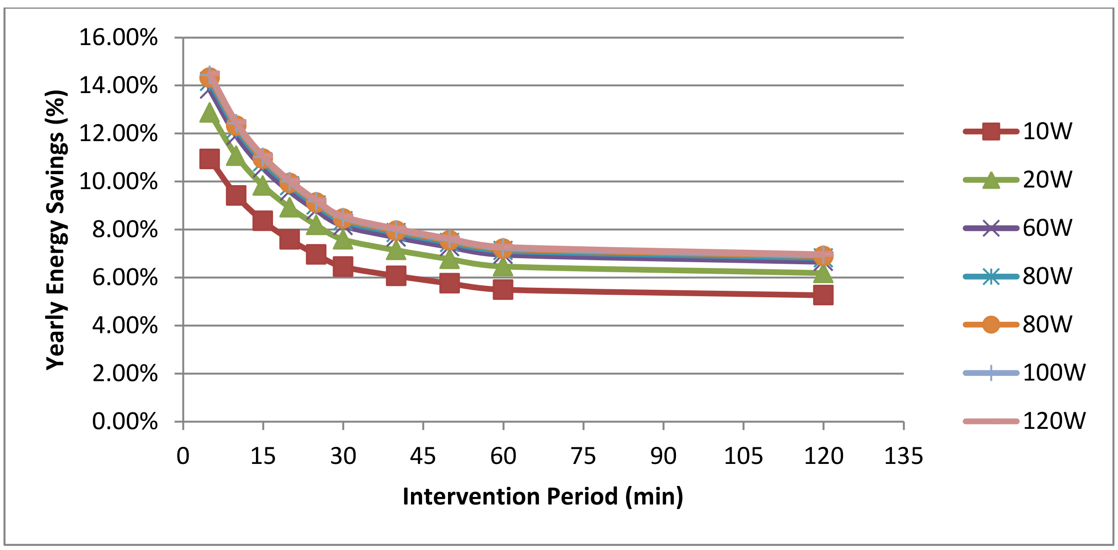


Figure 35: Baselined yearly savings for different modeled Active state power loads with a modeled Sleep state power load of 2.5W for multiple Intervention period settings for study computers as found with PM enabled.

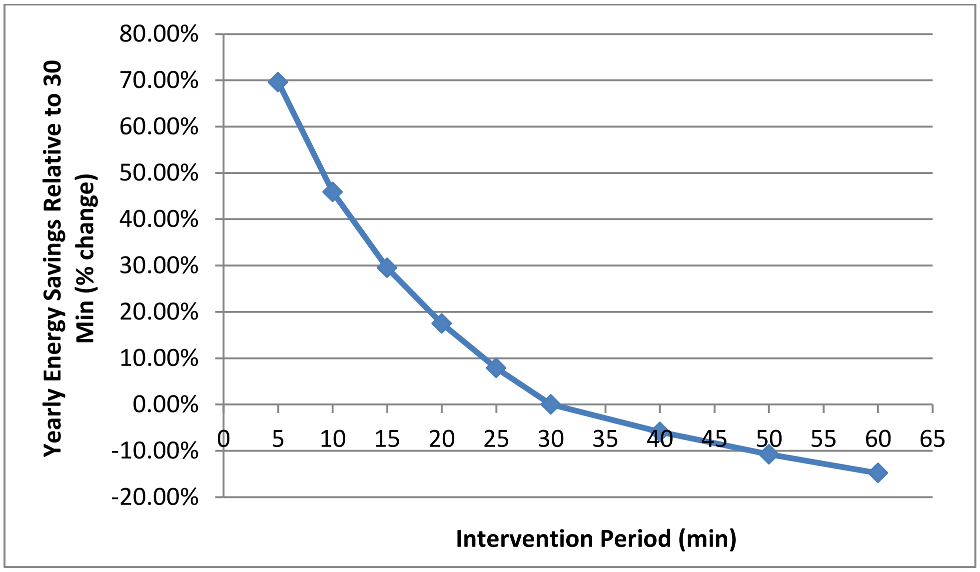


Figure 36: Change in baselined yearly savings for a modeled 40 W On/Active state load for multiple intervention periods as compared to the savings produced by a 30 minute intervention period for study computers as found with PM enabled.

Computer Energy Savings with the TS1910 on Desktop Computers with Different Operating Systems and Form Factors

In addition to comparing subjects based on PM setting, the operating system in use is a major distinguishing characteristic that was evaluated. The impact of the operating system for the subjects with the PM values that were in use were considered. Comparing Windows (denoted as "PC" in Figure 37 and Figure 38) and MacOSX systems shows minor differences based on the limited sample size to compare all cases of OS type and PM status (and setting). What is observed is a clear albeit weak trend in potential per-day savings in MacOSX systems where no PM is enabled. Across a range of intervention values, the difference varies from 0% at 45 minutes of intervention time to 10% difference at an intervention time of 300 minutes. This shows Windows machines in this study have slightly lower savings potential (based on runtime reduction) at large timer values compared to MacOSX. This analysis does not consider power usage which is linearly proportional to energy savings which is based on the time that the On state is active in a wasteful capacity versus a sleep state. Per-day savings subsets of subject data for all systems, systems with PM enabled or disabled for each MAC and Windows (PC) workstations is shows against intervention period in Figure 37. In all cases the MAC desktop computers resulted in less per-day savings potential for all periods less than 30 minutes. The total operating system power management timer settings were on average equivalent between both systems types. The discrepancy could be due to variability due to small sample size for this subset or possibly due to a comparatively better operating system power management system or settings for this system that reduces the total long contiguous periods of idle time that could be converted into savings. Further investigation is required to better determine differences. Considering all subjects alone, the MAC users had a substantial reduction in per-day savings time available. Whether this effect was due to the user or the system itself is unclear with the present data set.

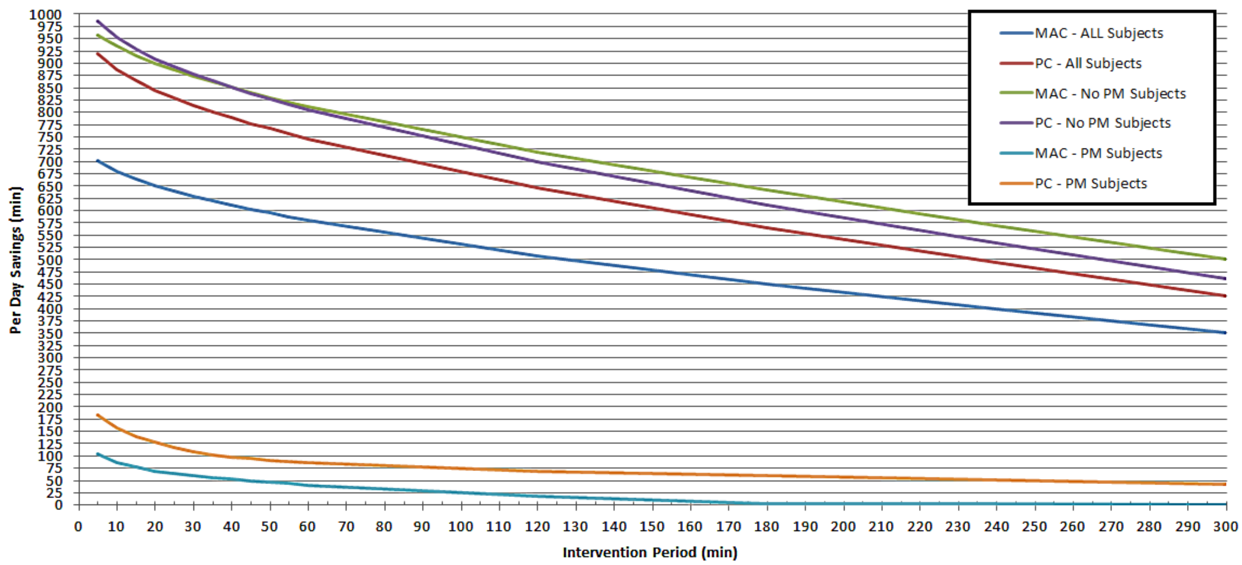


Figure 37: Per-day savings (min) for multiple populations comparing with MAC (n= 21) and PC (n=94) of the total study (n=115) computers for savings potential.

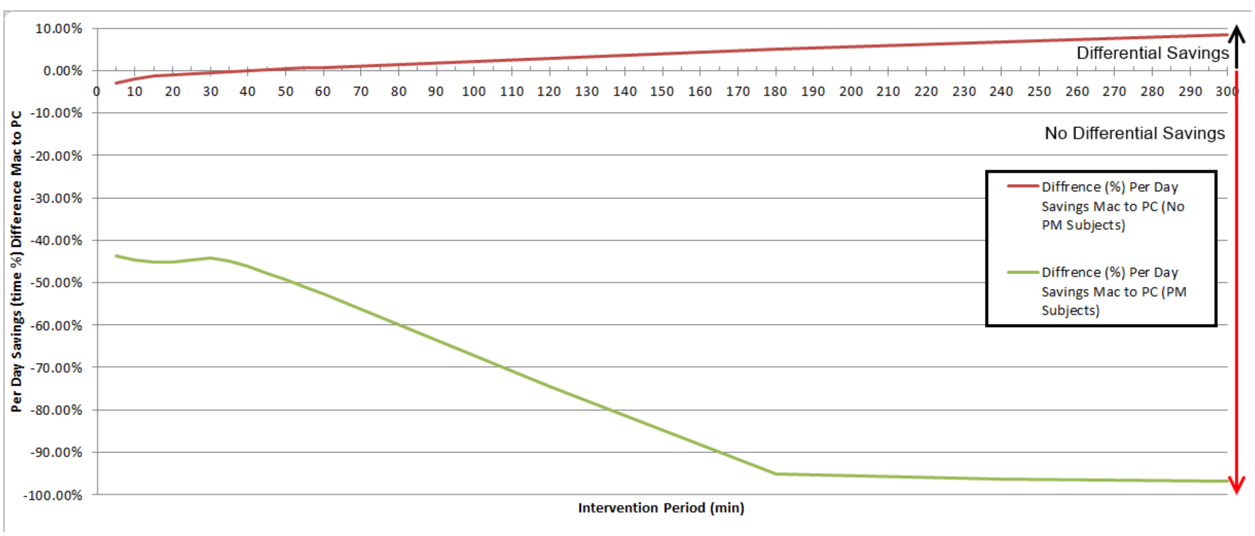


Figure 38: Differential savings (in time %) with MAC (n= 20) compared to PC (n=95) computers compared to subjects with PM enabled (MAC, n=6; PC, n=9) and PM not-enabled (MAC, n=14; PC, n=86).

While the operating system is a large component of the potential power savings potential for a system, the form factor also can be considered for discussion. On average, desktops are more power consuming than laptops (see

Table 14 and Table 15), but both form factors use equivalent operating systems to their alternative form factor brethren (be it OSX or Windows) and use identical power management rules albeit with likely different settings. As this study did not investigate portable systems specifically, conclusions can apply to laptops used in scenarios as desktops. For example, docked laptops or those kept on desks and connected to external monitors may fulfill the same role as desktops, but with inherently mobile hardware. These usage cases are applicable to intervention using devices like the USB Motion Sensor with or without added APS control. Accordingly, assuming equivalence, appropriate state energy use values used in the generated model outputs can be used to extend conclusions to laptops provided the aforementioned caveats related to equivalency of use are true. More investigation is needed to clearly show the direct impact for portable systems in stationary use where external power management control interfaced via a dock or a USB port on an external monitor can provide a consistent desktop-like control approach.

Computer Energy Savings with the TS1910 on Desktop Computers with Simulated Power Management settings: with and without APS Control

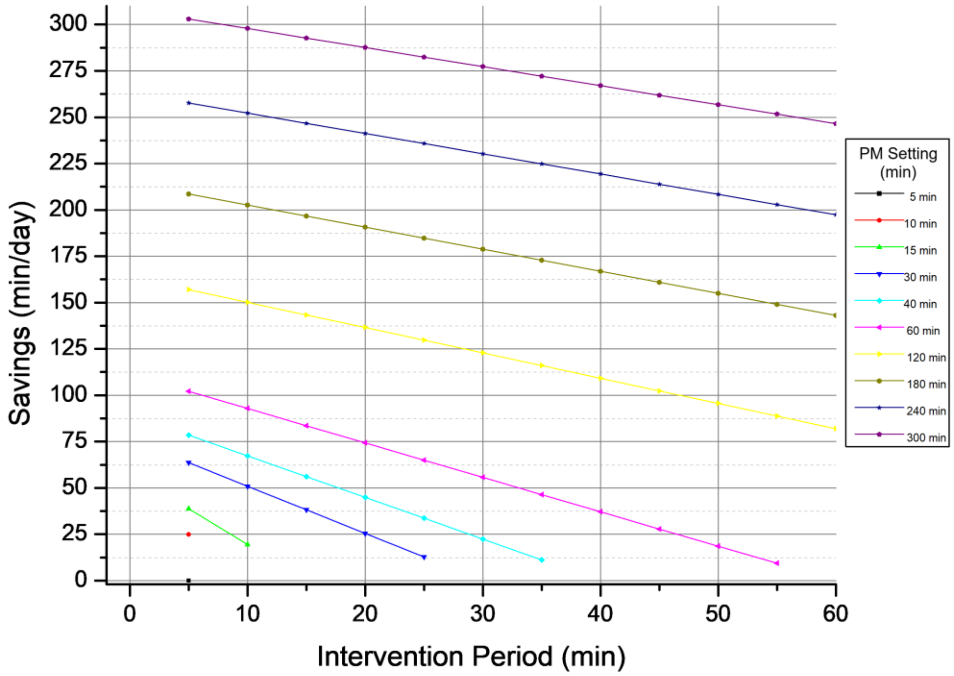
Beyond "Wildtype" and evaluations of PM enabled computers, the impact of uniform PM settings can be assessed by the application of a strict PM scheme on idle periods prior to the application of the intervention period simulation. This provides a strict application of simulated computer operating system PM with the simulated USB Motion Sensor acting upon computers in this control scheme.

For periods where the intervention setting is equaled to the PM, zero savings results in simulated power management. Details of this simulation approach were previously discussed. This approach was modeled for two specific reasons. Firstly, while the dataset collected is intended to be representative of all computers in a similar environment, the balance of computer workstations may change with respect to the number with power management enabled and the specific timer durations for the computers with power management enabled. Secondly, operating system based power management can be overridden by actions of running programs. Browsers, utilities, presentation and communication software all have been shown for some specific software and use cases to inhibit operating system based power management. With these intentional actions, simulated power management will over-predict savings. Assuming intentional actions are at a minimum, by showing the savings potential, the effect of unintentional actions can be assessed as a gap between predicted and actual savings. The USB Motion Sensor can address this gap by providing secondary control that may override unintentional causes for power management not properly acting.

In Figure 39 variable thresholds (PM Setting) values were tested against variable lengths for different Intervention periods lengths resulting in saved runtime values that can be used to calculate energy savings (Table 24). Tabular energy savings values are shown for simulated 60 min and 30 min periods (Table 25 and Table 26). Comparisons for both 60 minutes and 30 minutes are shown for a 40 W On state load in Figure 42. The savings is substantially less than the mixed population values presented in the previous section. As power management is strict with no exceptions permitted, no savings will be available whenever the power management duration is equaled to that of the intervention period.

Table 24: Model output for a year period (all days), simulated Power Management on systems (with 60 minute setting and two example loads), for a workstation with a USB Motion Sensor in use alone and no loads under Tier-2 APS control. The results are presented in minutes per day savings for a given intervention setting (USB Motion Sensor timer duration), and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	AVG. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 40 W computer active load) – 1	Std. Dev. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 40 W computer active load)	AVG. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 20 W computer active load) - 2	Std. Dev. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 20 W computer active load)
5	102.05 ± 10.1	55.22	63.19 ± 6.4	34.76
10	92.77 ± 9.2	50.20	50.55 ± 5.1	27.81
15	83.49 ± 8.3	45.18	37.91 ± 3.8	20.86
20	74.22 ± 7.3	40.16	25.27 ± 2.5	13.90
25	64.94 ± 6.4	35.14	12.64 ± 1.3	6.95
30	55.66 ± 5.5	30.12	0.00	--
35	46.38 ± 4.6	25.10	0.00	--
40	37.11± 3.7	20.08	0.00	--
45	27.83 ± 2.8	15.06	0.00	--
50	18.55 ± 1.8	10.04	0.00	--
55	9.28 ± 0.9	5.02	0.00	--
60	0.00	--	0.00	--



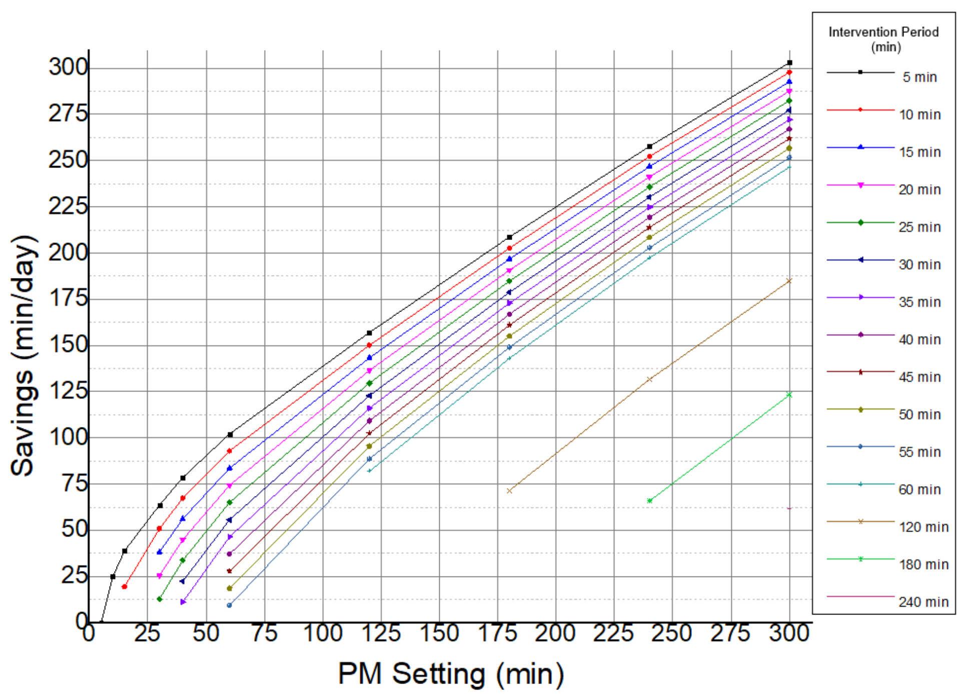


Figure 39 (top and bottom): Savings for all subjects (with and without PM enabled) as a function of simulated PM period or simulated USB Motion Sensor timing (denoted as Intervention Period (min)).

Table 25: Model output for a year period (all days), Simulated PM at 60 minutes, for both 20 W, 40 W, and 100 W active loads (two extremes of modeled load), presented as savings in kWh/year, and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	AVG. Energy Savings kWh/year (100 W)	Std. Dev. Energy Savings kWh/year (100 W)	AVG. Energy Savings kWh/year (40 W)	Std. Dev. Energy Savings kWh/year (40 W)	AVG. Energy Savings kWh/year (20 W)	Std. Dev. Energy Savings kWh/year (20 W)
5	60.5 ± 6.0	32.8	23.3 ± 2.3	12.6	10.9 ± 1.1	5.9
10	55.0 ± 5.4	29.8	21.2 ± 2.1	11.5	9.9 ± 1.0	5.3
15	49.5 ± 4.9	26.8	19.0 ± 1.9	10.3	8.9 ± 0.9	4.8
20	44.0 ± 4.3	23.8	16.9 ± 1.7	9.2	7.9 ± 0.8	4.3
25	38.5 ± 3.8	20.8	14.8 ± 1.5	8.0	6.9 ± 0.7	3.7
30	33.0 ± 3.3	17.9	12.7 ± 1.3	6.9	5.9 ± 0.6	3.2
35	27.5 ± 2.7	14.9	10.6 ± 1.0	5.7	4.9 ± 0.5	2.7
40	22.0 ± 2.2	11.9	8.5 ± 0.8	4.6	4.0 ± 0.4	2.1
45	16.5 ± 1.6	8.9	6.3 ± 0.6	3.4	3.0 ± 0.3	1.6
50	11.0 ± 1.1	6.0	4.2 ± 0.4	2.3	2.0 ± 0.2	1.1
55	5.5 ± 0.5	3.0	2.1 ± 0.2	1.1	1.0 ± 0.1	0.5
60	0.0	--	0.0	--	0.0	--

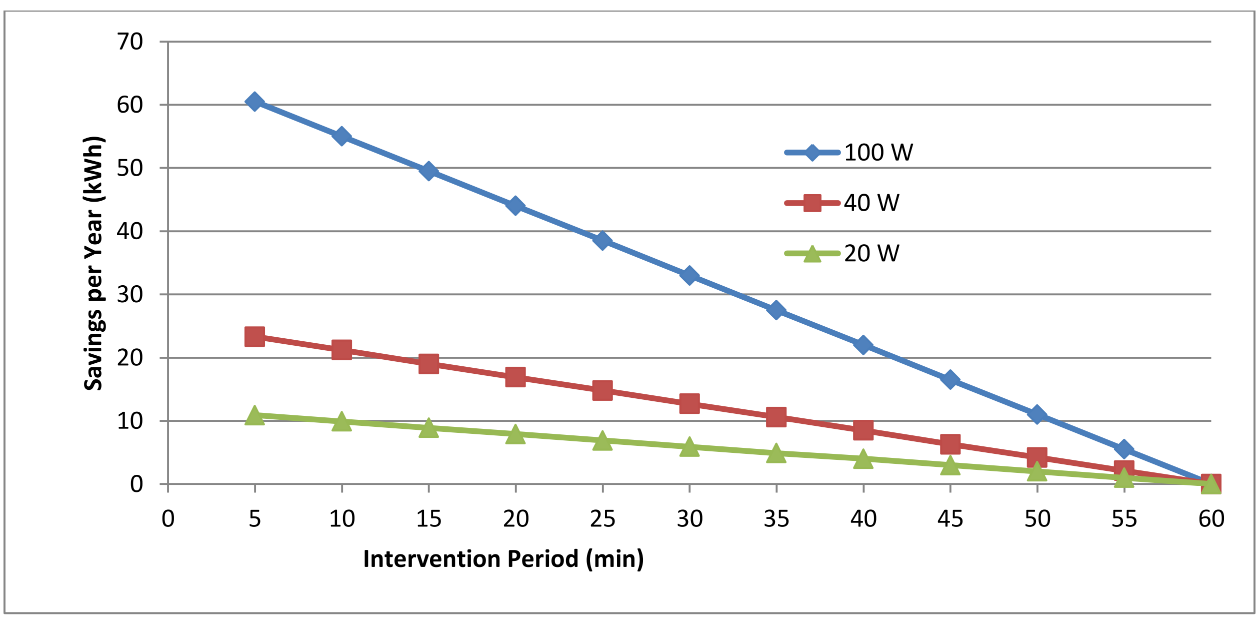


Figure 40: Summary of yearly energy savings as modeled by a 60 minute simulated power management timer for multiple intervention period lengths for different active load values.

Table 26: Model output for a year period (all days), Simulated PM at 30 minutes, for both 20 W, 40 W, and 100 W active loads (two extremes of modeled load), presented as savings in kWh/year, and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	AVG. Energy Savings kWh/year (100 W)	Std. Dev. Energy Savings kWh/year (100 W)	AVG. Energy Savings kWh/year (40 W)	Std. Dev. Energy Savings kWh/year (40 W)	AVG. Energy Savings kWh/year (20 W)	Std. Dev. Energy Savings kWh/year (20 W)
5	37.5 ± 3.8	20.6	14.4 ± 1.4	7.9	8.6 ± 0.3	1.8
10	30.0 ± 3.0	16.5	11.5 ± 1.2	6.3	6.9 ± 0.3	1.4
15	22.5 ± 2.3	12.4	8.6 ± 0.9	4.8	5.2 ± 0.2	1.1
20	15.0 ± 1.5	8.2	5.8 ± 0.6	3.2	3.5 ± 0.1	0.7
25	7.5± 0.7	4.1	2.9 ± 0.3	1.6	1.7 ± 0.1	0.4
30	0.0	--	0.0	--	0.0	--

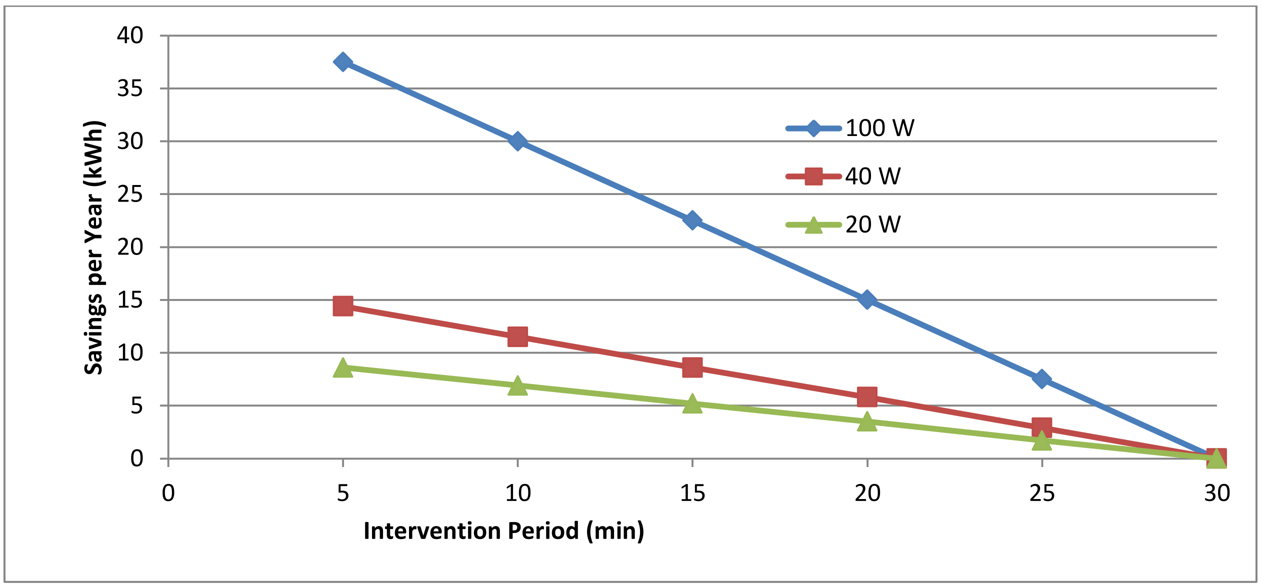


Figure 41: Summary of yearly energy savings as modeled by a 30 minute simulated power management timer for multiple intervention period lengths for different active load values.

Clearly, with power management uniformly enabled at either 30 minutes or 60 minutes on a population of systems, savings potential for intervention will be reduced as compared to the data set subsection with PM enabled. This is due to two specific factors. Firstly, the consistent power management control likely outperforms what actual savings power management. Secondly, the values of 30 or 60 minutes do not match up to the variability of the power management settings for the 21 systems with power management enabled in the study. Although the average time was 54 minutes, the standard deviation of this average was larger than the average itself at 66 minutes. Similarly, the median was 30 minutes with a minimum of 9 minutes and a maximum of 240 minutes. Although the average of all settings was 54 minutes, a consistent 60 minute control applied to all workstations is substantially different than an averaged value from workstations with very different power management timer settings.

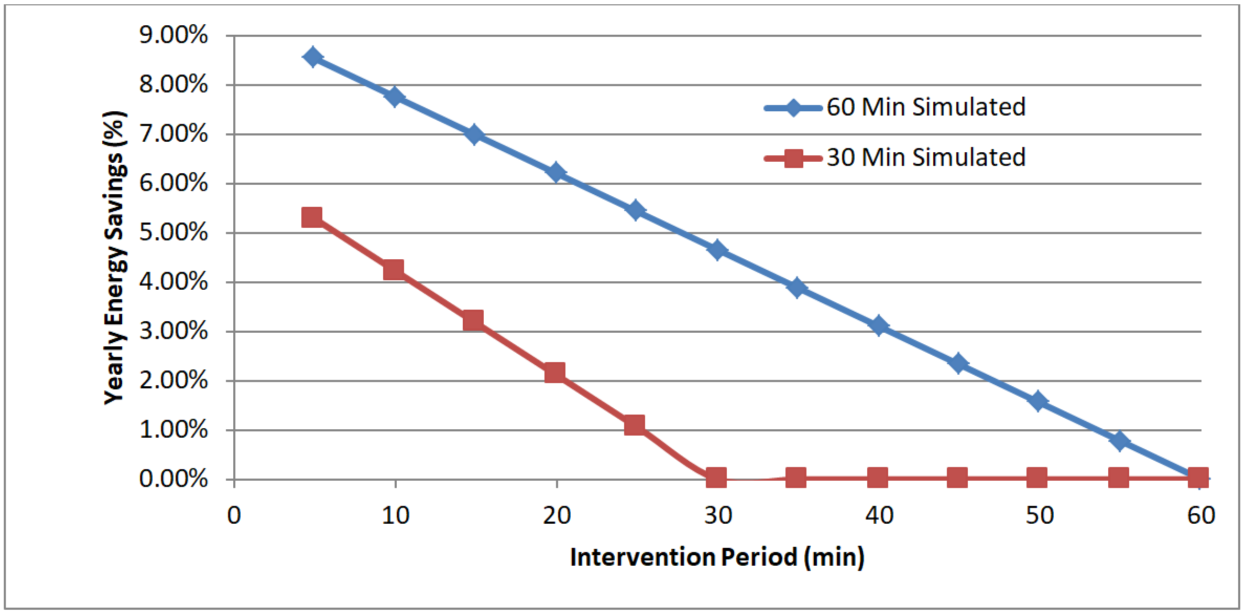


Figure 42: Baselined yearly savings for 40 W On state loads for 60 minute and 30 minute simulated savings applied to different modeled Active state power loads with a modeled Sleep state power load of 2.5 W for multiple Intervention period settings for study computers as found with PM enabled.

As “wildtype” machine make up the dataset used that PM settings were applied on top of for simulation, the authors have not attempted to tease out what the operating system energy settings (and actual performance of the settings) are for individual operating systems under this control scheme.

Simulated Computer Energy Savings with the TS1910 on “Wildtype” and Power Management Enabled Desktop Computers with APS control

In combined operation with an APS, the operation of the TS1910 can trigger loads under APS management acting as a Tier-2 APS type solution. The use of active operating system power management in combination with the TS1910 and an attached Tier 2 APS was also modeled as a combination of the prior considered factors. The relationship in this model is superpositional–values can be added in component states rather than computational factors folded in during the general calculation process. The modeled reduction in idle time reduction that the TS1910 can produce beyond the operating system timer setting is used as the factor to calculate APS savings potential. The control burden for this energy management is 4.10 kWh/year in APS standby and 8.46 kWh/year with the APS in triggered mode as modeled for the entire period. The actual value is based upon the ratio of active to inactive time which is derived as a combination of baseline values and energy saved values. The energy saved by a Tier-2 APS control is a combination of standby load and active load. This is considered coupled to the operation of the computer in this model. When the computer is On, the attached APS load is On. When the computer is in Sleep or Off, the load is disconnected. In this model, the controlled APS load was model as a single averaged value "controlled value". In this model, these two states are time averaged into a single representative figure of control overhead (the energy required to enact control) which was 0.5 W. As many situations can be tested for APS based management, a summary of several situational cases in Table 27 and Table 28. The relationship shown in Eqn. 2 allows the use of saved runtime to be used. Accordingly, the savings due to APS control of an attached load can be determined by knowledge of the runtime saved (available in Table 18- Wildtype and Table 21- PM Enabled) as well as knowledge of the load values controlled and the control burden values for active and inactive APS operation. Presented in Table 27 are savings values of a combined Tier 2 solution (APS savings combined with computer savings) for multiple computer loads with a consistent 10 W controlled load. The direct APS controlled load savings separated from computer workstation controlled savings is shown in Figure 45.

Table 27: Savings for controlled loads due to attached devices for workstations of both Wildtype and with PM enabled. Inherent APS energy use was modeled as an averaged constant of 0.5 W. Energy savings with computer and APS total combined savings is presented in kWh/year for specified controlled setup parameters, and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	AVG. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 40 W computer active load) - 1	Std. Dev. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 40 W computer active load)	AVG. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 20 W computer active load) - 2	Std. Dev. Energy Savings kWh/year (Wildtype, 10 W APS controlled, 20 W computer active load)	AVG. Energy Savings kWh/year (PM Enabled, 10 W APS controlled, 40 W computer active load) - 3	Std. Dev. Energy Savings kWh/year (PM Enabled, 60 min, 10 W APS controlled, 40 W computer active load)
5	250.1 ± 24.5	134.0	143.0 ± 14.2	77.6	43.4 ± 27.4	56.0
10	241.6 ± 24.3	133.0	138.1 ± 14.1	77.0	36.8 ± 26.3	53.6
15	235.2 ± 24.1	132.0	134.3 ± 14.0	76.4	32.1 ± 25.4	51.8
20	230.1 ± 23.9	131.0	131.4 ± 13.9	75.8	28.8 ± 24.7	50.5
25	225.7 ± 23.7	129.9	128.8 ± 13.7	75.2	26.0 ± 24.2	49.4
30	221.8 ± 23.6	128.9	126.5 ± 13.6	74.6	23.8 ± 23.8	48.5
35	218.2 ± 23.4	127.8	124.5 ± 13.5	74.0	22.2 ± 23.4	47.7
40	214.8 ± 23.2	126.7	122.5 ± 13.4	73.4	20.8 ± 23.0	46.9
45	211.7 ± 23.0	125.7	120.7 ± 13.3	72.8	19.6 ± 22.6	46.2
50	208.7 ± 22.8	124.6	119.0 ± 13.2	72.2	18.6 ± 22.3	45.6
55	205.8 ± 22.6	123.6	117.3 ± 13.2	71.6	17.7 ± 22.1	45.0
60	203.1 ± 22.4	122.6	115.7 ± 13.1	71.0	16.8 ± 21.8	44.5
120	175.8 ± 20.3	111.0	99.9 ± 13.0	64.3	10.4 ± 19.1	39.0

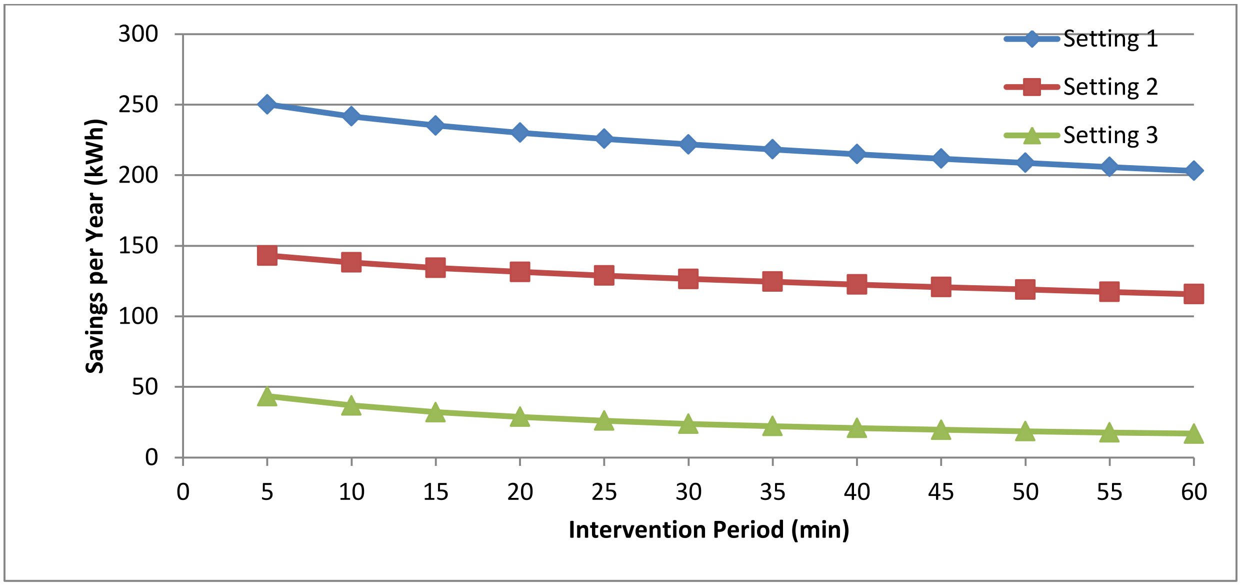


Figure 43: Summary of yearly energy savings as modeled the denoted settings (1, 2, or 3) in Table 27.

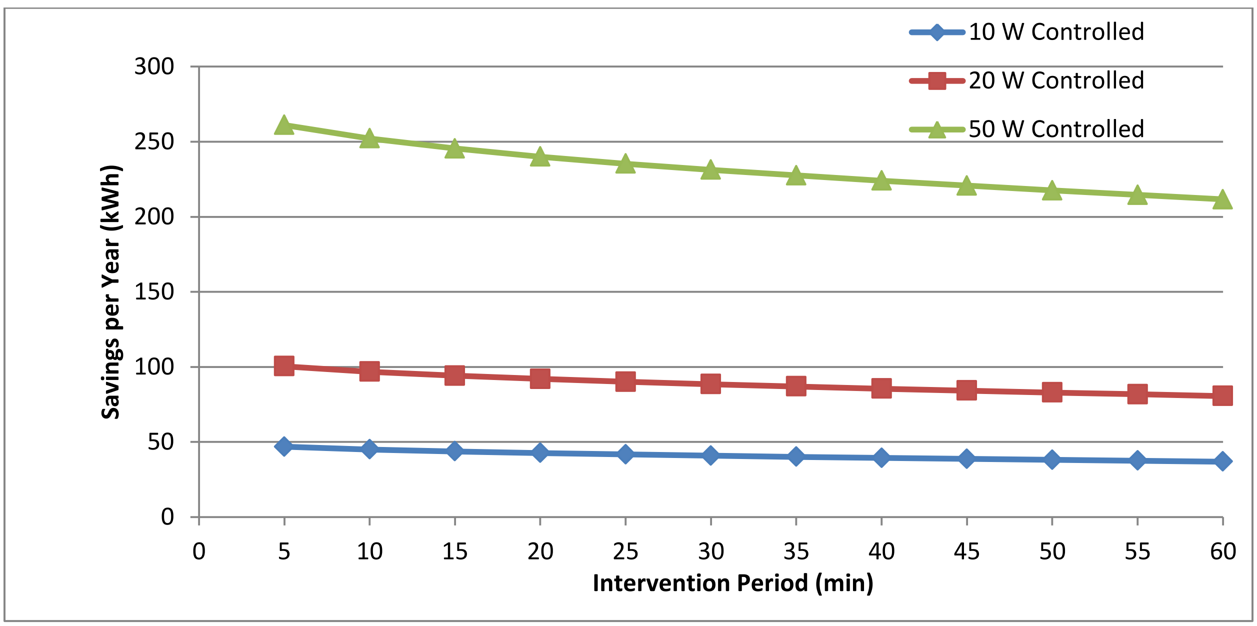


Figure 44: Controlled load savings per year for multiple load values for different intervention period lengths for loads under APS control for Wildtype modeled systems.

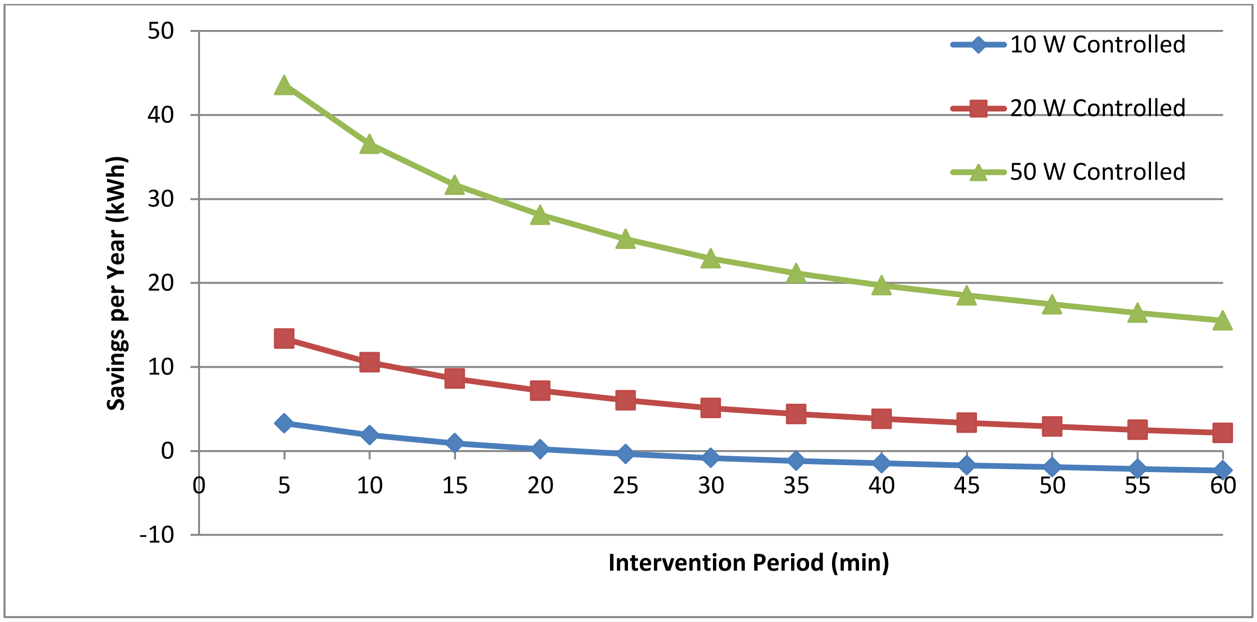


Figure 45: Controlled load savings per year for multiple load values for different intervention period lengths for loads under APS control for systems with power management enabled.

Simulated Computer Energy Savings with the TS1910 on Desktop Computers with enabled power management and APS Control

Energy savings calculations with APS can also be accomplished using simulated power management techniques to determine saved runtime for control. In Table 28 values are presented for energy savings with 3 specific configurations with 30 and 60 minute simulated power management used for calculation. This approach applies the previously discussed benefits from simulated power management settings, but now the runtime savings can be applied to APS control to determine savings potential for controlled loads. The resulting savings values for both 60 minutes and 30 minutes are shown in Table 28, while the graphical representation of these values are presented in Figure 46. The direct APS controlled load savings separated from computer workstation controlled savings is shown in Figure 47.

Table 28: Calculated savings potential for APS controlled loads for three defined settings, and presented with the margin of error at the 95% confidence interval (CI).

Intervention Setting (min)	AVG. Energy Savings kWh/year (SimulatedPM-60 min, 10 W APS controlled, 40 W computer active load) - 1	Std. Dev. Energy Savings kWh/year (SimulatedPM-60 min, 10 W APS controlled, 40 W computer active load)	AVG. Energy Savings kWh/year (SimulatedPM-60, 10 W APS controlled, 20 W computer active load) - 2	Std. Dev. Energy Savings kWh/year (SimulatedPM-60, 10 W APS controlled, 20 W computer active load)	AVG. Energy Savings kWh/year (SimulatedPM-30 min, 10 W APS controlled, 40 W computer active load) - 3	Std. Dev. Energy Savings kWh/year (SimulatedPM-30 min, 10 W APS controlled, 40 W computer active load)
5	25.1 ± 7.8	16.0	12.7 ± 4.5	9.2	13.9 ± 4.9	10.0
10	22.4 ± 7.1	14.5	11.1 ± 4.1	8.4	10.2 ± 3.9	8.0
15	19.7 ± 6.4	13.1	9.6 ± 3.7	7.6	6.6 ± 2.9	6.0
20	17.1 ± 5.7	11.6	8.0 ± 3.3	6.7	2.9 ± 2.0	4.0
25	14.4 ± 5.0	10.2	6.5 ± 2.9	5.9	-0.7 ± 1.0	2.0
30	11.7 ± 4.3	8.7	4.9 ± 2.5	5.0	-4.4	--
35	9.0 ± 3.6	7.3	3.4 ± 2.1	4.2	-4.4	--
40	6.3 ± 2.8	5.8	1.8 ± 1.7	3.4	-4.4	--
45	3.7 ± 2.2	4.4	0.3 ± 1.2	2.5	-4.4	--
50	1.0 ± 1.4	2.9	-1.3 ± 0.8	1.7	-4.4	--
55	-1.7 ± 0.7	1.5	-2.8 ± 0.4	0.8	-4.4	--
60	-4.4	--	-4.4	--	-4.4	--
120	-4.4	--	-4.4	--	-4.4	--

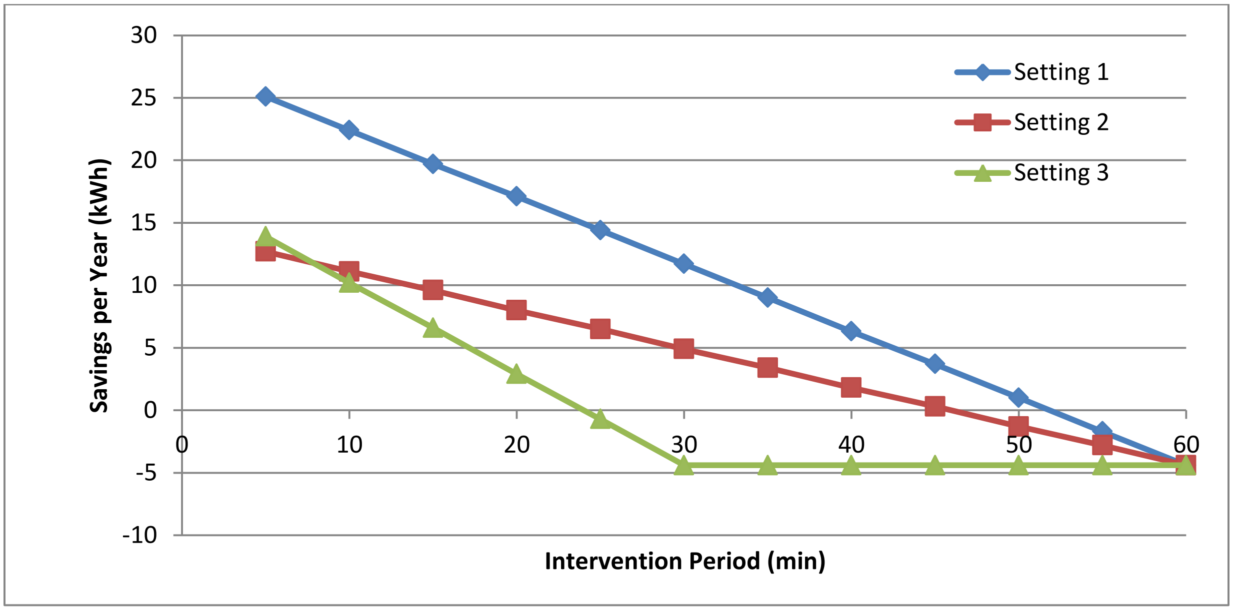


Figure 46: Summary of yearly energy savings as modeled the denoted settings (1, 2, or 3) in Table 28.

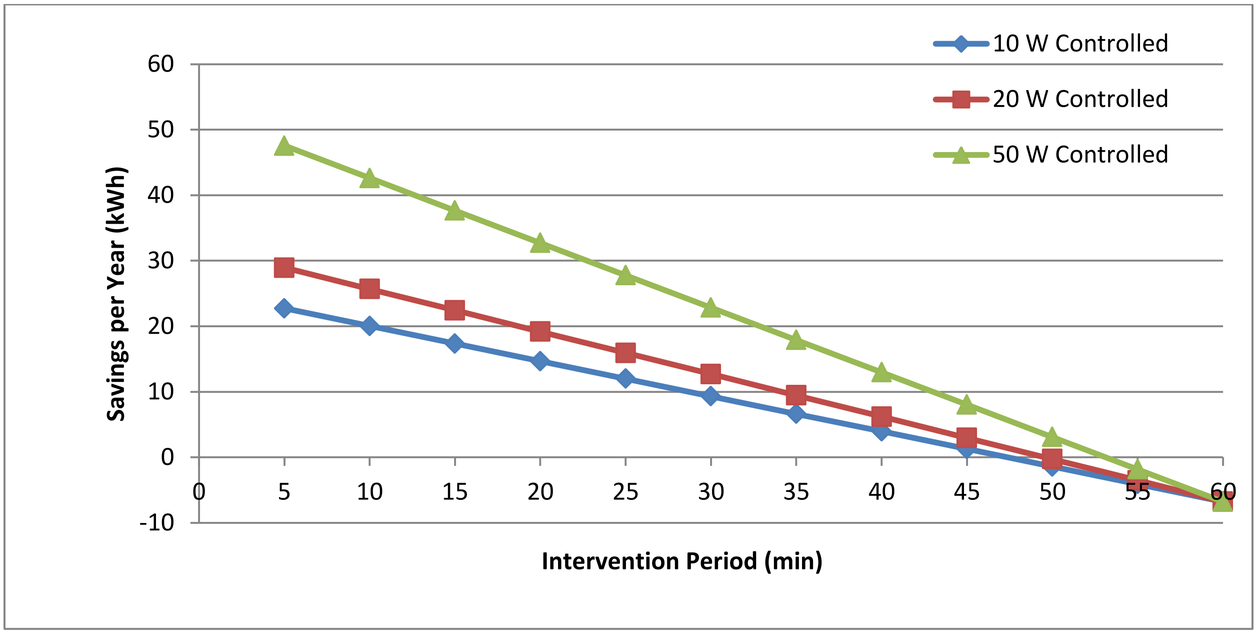


Figure 47: Controlled load savings per year for multiple load values for different intervention period lengths for loads under APS control for systems with simulated power management of 60 minutes performed on Wildtype systems.

Chapter 5: Conclusions

Summary of Test Results

Based on CalPlug's California Energy Commission supported findings [19, 36], there is substantial confusion among users about energy management settings. This confusion may lead users to mistake monitor sleep for system sleep, leading to substantial energy usage. The TS1910 provides a stopgap solution to mandate energy management to not allow extended periods of use to occur despite what power management settings are enabled on the system itself. As long periods of idle time in which savings could be claimed is the most common source of energy usage. The TS1910 itself draws insignificant power in use and in standby operation.

Energy savings is calculated based on the ability to convert blocks of idle time into savings periods. This impact is assessed by calculating the change in state values for power draw between the previous and the new states and multiplying this by the time spent in the new state. After subtracting overhead components, the values are presented. Baselines are calculated using known state power consumption values and time durations. The savings values from the first calculations compared to the final calculations are used to assess energy percent saved. The use of a Tier 2 solution (the TS1110, combined motion sensor and Tier 1 APS) provides control of external loads by coupling them to the usage of the connected computer. Use of a Tier 2 APS to manage accessory loads requires accessories to be in use. Savings is a function of both control provided by accessories by onboard power management and manual user power management (typical Tier 1 APS usage) in addition to the savings provided by Tier 2 functionality enabled by the action of the TS1910. APS savings assessment uses a similar process where converted blocks are used to determine the savings time a device is now spending in a disconnected state versus an active or standby one. Because active and standby loads are controlled by a Tier 2 APS, these factors must be accounted for in simulation. Similarly, control overhead must be subtracted from savings. Baseline values with Tier 2 APS control are tricky to assess due to the issue with active versus standby states. The standby state is easy to assess for the connected devices, but the contribution of active load that the user would manually control without APS intervention is highly variant and a semi-justified approximation used in the model.

Because of the myriad of possible configurations that can be tested, the results presented are not exhaustive, but rather exemplary and provide a framework for further calculations. Simulation model values and an Excel calculation tool are provided in the Appendix to allow further calculation of savings values for situations other than these discussed. Through the use of the CalPlug PLSIM and MISER utilities, one can use new collected study data to completely re-run the entire outlined simulation under different conditions to expand different use conditions. The authors present a framework in this report that can be extended with TS1910 field trial data to provide improved model representation for performance in different usage conditions.

Investigation Limitations

As with almost any energy-saving solution, the TS1910 would be more applicable in some situations and less applicable in others. Most notably, it would produce no savings for users who have deliberately disabled their computer sleep settings for technical reasons, such as being unable to use remote desktop when the computer is in sleep mode. Users who have deliberately disabled sleep settings because of the length of time it takes their computers to wake from sleep are also unlikely to be satisfied with this solution. Similarly, users performing extended simulations or using computers for notifications may also run into situations with contraindications for usage. Establishing the frequency of those situations in the average work environment is beyond the scope of this work, but pertinent in the discussion. However, a recent study asked over one thousand users of office desktops at a university how often they left their computers on when they would be gone for several hours (rather than manually shut down or put them into sleep mode); the average percent of time computers were left on is just over half the time. Although the most frequently cited reason for leaving the computer on was that the computer was set to automatically sleep anyway (or so the user believed), almost as many said that restarting was too slow (33%) or that the computer needed to stay on for updates and backups (30%) or for remote access (31%) [19]. Over two hundred subjects in that same study reported changing the power management settings of their office desktops (whether to enable or disable settings). When asked the main reasons for doing so, 33 percent reported that their computers needed to stay on and 10 percent said that restarting was too slow. Such results suggest that users' perception that sleep settings will interfere with their work computers would lead to resistance for any approach that pushed putting computers into sleep mode.

The energy savings estimates in this report compare installing the TS1910 in an office environment to an initial baseline. The baseline, based on past research, assumes a large proportion of computers have inefficient power management settings. However, it is important not to fall into a false dichotomy of assuming that the only two options are maintaining prior bad habits or installing the TS1910. If office managers, IT managers, or individual users are motivated to improve the energy efficiency of their computers, the question must be, what are the advantages of buying and installing the TS1910 or the TS1100 rather than enabling the computer's existing automatic sleep settings for free? It is certainly plausible that some users who are not willing to use standard sleep settings would be reassured that their computers will not go to sleep while they're present, and would therefore be more willing to embrace the motion sensor approach. However, this question is outside the scope of this testing project.

Another factor in assessing the motion sensor approach as an alternative to standard sleep settings (rather than as an adjunct) is the amount of time that users spend in their offices while they are not using their computers: e.g., having meetings, reading, or using a second device such as a laptop or tablet. Standard sleep settings would put the computer to sleep in the absence of keyboard or mouse activity, whereas a motion sensor approach used alone would not transition the computer to sleep as long as the desk is occupied. With no data on how often computer users spend at or near their desks, this factor could not be incorporated into the estimates in the current report. A similar problem arises for users whose desks are in frequently trafficked areas, where the motion sensor might pick up movement from people standing or passing by the desk who are not using it. Again, this could not be assessed in the current study.

For use as a Tier 2 APS solution, workstations with limited peripherals would not benefit from this type of control. The management of a monitor alone as a single control device may only provide savings if the monitor itself has a standby load that is larger than that of the controlling APS. Provided ENERGY STAR displays specification (version 7.0, 2017) and monitors specification (version 5.0, 2005), a robust effort has been made to reduce standby energy usage with 0.5 W (interactive displays) and <= 2 W (ES Tier 2 monitor) cited as the standby power maximum for standard compliance. The standby power for the APS itself not insignificant in operation or standby. It must be considered in total savings calculations. Although not insignificant, this standby load is justified in many correct usage situations as substantially more energy can be saved than is used.

Use Case Considerations

Simulations provide best-case operation calculations, as they assume that all savings periods can be acted on. Adapting this to realistic assumptions is required to produce accurate calculations, and is challenging as it relies upon verification with external studies. The effectiveness of onboard power management is dependent on both the setting on time and the computer usage. By understanding the general pattern of power savings with respect to specific marginal settings, ground of the model with known field trial data can allow prediction of marginal savings based on percent relative change rather than absolute savings values. In this manner, the expected savings in percentage can be predicted based on marginal change while the actual saved baseline value is brought into the model from field-test results. This scenario is immediately applicable once field trial results are available to extend the power of the results. As the simulation algorithms from this study are available for future use, new data allows calculation based on different usage data models. Continued refinements to the outlined methods are possible with cross validation from field trial data. In this manner simulation and testing can work hand in hand to extend the value when used in combination.

Appendix 1: Standard Test Procedures

The following test considerations and compliances were in use for energy management evaluation for device consumption values using a calibrated Chroma 6420 reference AC source and a Chroma 6620 power analyzer setup. Both devices were calibrated within 1 year to NIST traceable source. Operational energy consumption (where noted) was provided by an Onset HOBO UX120 plug load logger verified to be within CEA-2043 accuracy bounds as assessed via a calibration procedure using static reference loads.

Considered Test requirements and procedures

IEC (International Electrotechnical Commission)

- Use of a stable power supply (<2% harmonics).
- Stable ambient test room conditions.
- Digital power meter with fundamental active power accuracy of 0.5% or better – capable of measurements of 0.01 W or better, capable of including components up 49th harmonic (2.5 kHz) strongly recommended.
- Calibrate the power meter using the IEC 62301 software.
- Data logging capability recommended.

ENERGY STAR®

Average power shall be measured from the AC power source to the equipment being tested.

1. **General:** Unless otherwise specified, measurements shall be made under test conditions and with equipment specified below.
2. **Test room:** The tests shall be carried out in a room that has an air speed close to the UUT of ≤ 0.5 m/s, and the ambient temperature shall be maintained at 23°C ± 5°C throughout the test. The UUT shall be tested on a thermally non-conductive surface.
3. **Test voltage:** An AC power source shall be used to provide input voltage and frequency of 115± 1% at 60 Hz to the UUT. (The Total Harmonic Distortion (THD) of the supply voltage when supplying the UUT in the specified mode shall not exceed 2%, up to and including the 13th harmonic. The peak value of the test voltage shall be within 1.34 and 1.49 times its RMS value).

Test leads: All leads used in the test set-up shall be of a sufficient gauge and length in order to avoid the introduction of errors in the testing process. Note: For further guidance see Table B.2, “Commonly used values for wire gages and related voltage drops” in IEEE 1515.

CEA-2043

<u>Accuracy</u>

Power measurements of 0.5 W or greater shall be made with an uncertainty of less than or equal to 2% at the 95% confidence level. Power measurements of less than 0.5 W shall be made with an uncertainty of less than or equal to 0.01 W at the 95% confidence level. The power measurement instrument shall have a resolution that is

a. 0.01 W or better for power measurements of 10 W or less;
b. 0.1 W or better for power measurements greater than 10 W and less than 100 W;
c. 1 W or better for power measurements greater than 100 W.

For equipment connected to more than one phase, the power measurement instrument shall be equipped to measure the total power of all of the phases connected.

Test voltage

An AC power source shall be used to provide the UUT with an input voltage of 115V ± 1% and a frequency of 60Hz ± 1%. The total harmonic distortion of the supply voltage when supplying the UUT in the specified mode shall not exceed 2%, up to and including the 13th harmonic. The peak value of the test voltage shall be between 1.34 and 1.49 times its root-mean-square (RMS) value.

Test equipment

The following should be considered when selecting test equipment:

1. An oscilloscope with a current probe for AC current waveform, amplitude, and frequency.
2. A true RMS voltmeter to verify voltage at the input of the UUT.
3. A frequency counter to verify frequency at the input of the UUT.

Note: Items (1) and (2) may be considered optional when the AC source output has sufficient accuracy.

Calibration

Test instruments shall be calibrated annually to traceable national standards to ensure that the limits of error in measurement are not greater than ± 0.5% of the measured value over the required bandwidth of the output.

True RMS power wattmeter

Crest factor

A true RMS power wattmeter shall be used and shall have:

1. Accuracy and resolution in accordance with previous section.
2. Sufficient bandwidth.
3. A crest factor rating that is appropriate for the waveforms being measured and capable of reading the available current waveform without clipping the waveform. The peak of the current waveform measured during Sleep and On modes for the UUT shall be used to determine the crest factor rating and the current range setting. The full-scale value of the selected current range

multiplied by the crest factor for that range shall be at least 15% greater than the peak current to prevent measurement error.

Bandwidth

The current and voltage signal shall be analyzed to determine the highest frequency component (i.e., harmonic) with a magnitude greater than 1% of the fundamental frequency under the test conditions. The minimum bandwidth of the test instruments shall be determined by the highest frequency component of the signal.

Frequency response

A wattmeter with a frequency response of at least 3 kHz shall be used in order to account for harmonics up to the 50th harmonic.

Sampling Interval

The power analyzer (wattmeter) shall be capable of sampling at intervals less than or equal to 1s.

Appendix 2: Extended Results

Table A1: Extended granular baseline energy values for all evaluated desktop computers

Note: Table presents the yearly energy consumption averaged on a per day duration basis for each operational state other than the ON state for multiple presented consumption values. This information is used as a calculation component to determine a device energy usage baseline. This was calculated based on the modeled consumption for all 115 subjects. Energy baseline values are presented on a per year basis for the total number of days comprising each scope (weekdays, weekend days, or all days in a year).

State	Assumed Value - Power(W)	Scoped Period	Energy Usage per Year(KWh)
Off	0.1	Weekdays	0.07
Off	0.1	Weekend Days	0.05
Off	0.1	All Days	0.13
Off	0.5	Weekdays	0.37
Off	0.5	Weekend Days	0.26
Off	0.5	All Days	0.63
Off	1.5	Weekdays	1.11
Off	1.5	Weekend Days	0.78
Off	1.5	All Days	1.89
Standby	1	Weekdays	0.51
Standby	1	Weekend Days	0.17
Standby	1	All Days	0.69
Standby	2.5	Weekdays	1.28
Standby	2.5	Weekend Days	0.43
Standby	2.5	All Days	1.71
Standby	5	Weekdays	2.56
Standby	5	Weekend Days	0.87
Standby	5	All Days	3.43

Table A2: Extended Energy Model (see attached spreadsheet)

Note: The table presents simulated savings values from the MISER model output for use of the TS1910 alone and in conjunction with device control for an attached APS for multiple attached accessory load values. The following summary table explains the data columns in the attached file in the simulation results.

Column Name	Description
Controlled devices(W)	Averaged total power consumption of controlled accessory devices (power under APS managed control). Value is 0 if no APS is used along with flag "No Controlled Devices". Rows with a "Control Devices" are a repetitive "row flag" used to designate data blocks with controlled devices used and the power controlled. This value is a model input/parameter.
Scope (reporting type)	Consideration of All Days, Weekdays, or Weekends in calculation. This value is a model input/parameter.
PM Setting(min)	Applied simulated power management setting by the computer operating system. (Wildtype denotes no use of simulated power management). This value is a model input/parameter.
ComputerDeltaPower(W)	Simulated average power consumption of the computer (computer only, not separate monitor). Value used in the calculation of "AVG_totaldaysYearlyEstimate". Note: there is no input for the power used in the alternative state (the one entered for savings to occur) - see note in the Description for "AVG_totaldaysYearlyEstimate" for details. This value is a model input/parameter.
Intervention Setting (min)	Simulated TS1910 timer control setting. This value is a model input/parameter.

AVG_Idle_Percent	Percentage of time system spent in idle state compared to total time in the on state - averaged on a per day basis. This value is a model output/result value.
STDEV_Idle_Percent	Standard deviation of former column value. This value is a model output/result value.
AVG_total_day idle percent	Percentage of time system spent in idle state compared to total time in the day (in all states) - averaged on a per day basis. This value is a model output/result value.
STDEV_total_day idle percent	Standard deviation of former column value. This value is a model output/result value.
AVG_runtimesavedperday [min]	Total ON state time that can be converted into Sleep state time by action of the simulated TS1910 timer control setting. This value is a model output/result value.
STDEV_runtimesavedperday [min]	Standard deviation of former column value. This value is a model output/result value.
AVG_TotalYearHrsSaved[yearlyhoursforscope]	Total hours saved per day for the selected scope. For example, total hours saved per weekend day if the “weekend days” scope is selected for this record.
STDEV_TotalYearHrsSaved[yearlyhoursforscope]	Total hours saved per year for the selected scope. For example, total hours saved per year with just the component of all weekend days if the “weekend days” scope is selected for this record.

AVG_dayEstimateKWh[dailykWh]	Daily savings for the selected scope on a per day basis in kWh. This calculation is based on the standby energy (typically modeled as zero in the general case and added in from baseline data). This value is the savings projected that would be subtracted from the baseline energy usage with the intervention parameters applied.
STDEV_dayEstimateKWh[dailykWh]	Standard deviation value of the aforementioned value for the selected data.
AVG_totaldaysYearlyEstimate (kWh/year)	Energy consumption considering all days in the year for a given scope (options for a sum of all Weekdays, sum of All Days, or sum of all Weekend days in a year is provided). This value is only savings delta for a given operational period. The granular savings must be calculated from the baseline values in Table A1. The saved minutes value must be added to the time spent in an alternate state (using baseline values in Table A1) and this value added to energy usage totals. This value is a model output/result value.
STDEV_totaldaysYearlyEstimate (kWh/year)	Standard deviation of former column value. This value is a model output/result value.
********Notes********	Subset data for computers within the general data set are presented as well as calculations for subsets including computers with PM operating, MAC versus Windows/PC computers, or different BLOCKOPT options (none, 1, or 2). Each scoping parameter may be applied alone or with other scoping parameters included as denoted. The BLOCKOPT options (none, 1, or 2) parameter is the setting for the block alignment parameter. All datasets in this report use OPT2 unless otherwise noted, but data for each block option is provided for testing and qualification purposes.

Analysis Dataset:

Note: Attached project file includes summarized simulation outputs, a summary of baseline energy use values, and a calculator to use minutes of saved runtime with added situational parameters to calculate yearly percent savings and kWh savings.

SimulationSummary1.2.xlsx

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