Impact of New Approaches to Address Energy Management Gaps on Total Energy Use in Computer Workstations

Michael J. Klopfer, Joy E. Pixley, Saniya Syed, and G. P. Li

Abstract Power management in computer workstations commonly relies on user behavior, typically involving the continual assessment of keyboard and mouse usage combined with timers to initiate sleep/standby power management actions. Specifically, if the user does not provide input on the keyboard or mouse within the timer period, then the user is not considered to be present, continued computer use is not expected, and the device automatically initiates entering sleep/standby mode. In this indirect manner, the presence of the user is determined, and accordingly, the intent of the user to continue employing the device is inferred. In this study, we investigated the effectiveness of power management in desktops and the impact of alternative sensing and control approaches for workstation power management. This study used a hybrid model approach where the dataset from a 115 subject real-world, observational study was used to seed the behavioral model to evaluate savings potential of traditional power management with different modeled strategies in addition to modeled energy savings obtained by using an independent, USB-based power management motion sensor device. Such a device provides sleep triggers based on a motion sensing and an independent power management timer to determine the presence of the user and trigger initiation of sleep as opposed to using a keyboard/mouse. CalPlug modeled and compared energy management capabilities for both systems. The USB motion sensor device produced between 12% and 67% energy savings with action on two specific mechanisms: (1) elimination of sleep blocking events that prevent normal entrance into sleep states, and (2) prevention of users unintentionally disabling or setting sleep to extended periods and leaving them this way permanently. This sleep blocking effect was observed during 13.5% of all idle periods where sleep would have occurred sooner. Findings from this work highlight the continued concern with sleep blocking affecting the operation of

M. Klopfer (✉) · J. Pixley · G. P. Li
California Plug Load Research Center, University of California, Irvine, CA, USA
e-mail: mklopfer@uci.edu; jpixley@uci.edu; gpli@calit2.uci.edu

S. Syed
California Plug Load Research Center, University of California, Irvine, CA, USA

D+R International, Silver Spring, MD, USA
e-mail: ssyed@drintl.com

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computer power management as well as the need for judicious sleep management settings and the potential for independent systems to improve computer energy management by reducing the impact of sleep blocking events.

1 Introduction

Computer workstations are plug loads that consume significant amounts of energy in both residential and commercial settings. Prior investigations have shown that power management is often enabled by default for users, but these settings can become disabled inadvertently, contributing to a substantial increase in energy usage [1, 2].

Several studies have performed physical setting audits or energy measurements of computers and other electronic office equipment in situ, in commercial and university buildings [2–5]. 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 (e.g., [6–9]). 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 [1, 10, 11]. Similarly, it has been shown that in a number of cases, workstations can experience power management that fails to act as required when it is in an unmanaged state. This may be due to legitimate processes such as updates, backups, virus scans, and actively playing audio/video. In other, illegitimate cases, desktop and similar types of un-required notifications to users from the operating system, un-observed playing media, site contents in open browsers, etc. may cause the countdown timer responsible for activating power management sleep states to be reset. Power management launch issues can also be due to the unwanted action of programs, peripherals or utilities operating on the workstation which prevents sleep modes from being activated.

In this study, we sought to look deeper into the prevalence of sleep blocking and external means that could mediate power management for workstations to augment onboard power management capabilities. In typical implementation, the sleep-state based power management system on workstations involves the use of countdown timers (often referred to as a power management or sleep timer) which are reset via an action, typically a keyboard or mouse movement indicating user input. Timers can be suspended either legitimately or illegitimately to delay entering sleep mode. An example of legitimate sleep blocking would be a video display application that prevents sleep from occurring when a user is watching video. Contrarily, illegitimate sleep blocking would be a hidden tab or peripheral preventing sleep from occurring. This illegitimate sleep blocking also can encompass low-frequency actions of programs or peripherals causing unwanted system wakeups, e.g. frozen or looped tasks, active windows, etc.

Several products exist in the marketplace that use either centrally managed or independent workstation managed approaches to power management. For centrally controlled approaches, an onboard utility daemon and a supervisory system independently tracks activity and mediates the workstation entering sleep in non-activity scenarios. An alternative approach uses a locally placed sensor to identify motion in the workspace to indicate user presence in front of the workstation and, accordingly, manage entering sleep in non-activity scenarios. An example of this type of device is a USB-based motion sensor. Both systems can be used in conjunction with an advanced power strip (APS) to provide behavior mediated shutdown of workstation peripherals (Tier-2 APS type control).

In office settings, promoting power management best practices either by policy or centralized power management control is a component of the problem. Two general classes of approaches have been used: empowering the user to make better decisions or using tools to help improve or retain power management effectiveness without user involvement. Both approaches have been demonstrated as effective [2, 12].

2 Materials and Methods

2.1 Idle Period Determination and Power Management Classification

The 115 subject 2014 dataset for the CalPlug monitoring study [1] was reanalyzed to identify patterns in regard to the duration of inactivity periods. This dataset was originally collected using Verdiem Surveyor software (Seattle, WA, USA) and, in segments of 15-min-long reporting periods, the data captures computer status including: On (active or idle), Sleep, or Off states. The CalPlug developed the Marginal Intervention Savings of Energy Reporter (MISER) (available at https://github.com/CalPlug/MISER) tool which was used to tabulate the individual contiguous idle periods for each day for all subjects whose computer was active for any period during the day [13]. Making the assumption that power management prevents idle periods longer than the sleep timer duration except in limited cases, the duration of periods longer than the sleep timer duration is subset out of the total idle periods. Cross-referencing this against the workstations with power management enabled (20 subjects) allows the calculation of the following metrics:

1. *Incidence percent (%)*: Ratio of the number of idle periods greater than the sleep timer setting divided by the total number of idle periods for a single subject across all study days. This metric provides the frequency of incidences where idle periods are greater than the timer duration compared to all idle periods. In normal usage this ratio should typically be low.
2. *Period average ratio*: Ratio of the average period length between the idle periods longer than the timer and the average of all idle periods for a single subject across all study days. This metric provides the comparative average duration for

the two sets. This ratio provides a qualitative metric for how distinct the subset of extended idle periods is compared to the full dataset.

3. *Average power management overage period (min/day)*: Average period of time per day for all study days where the workstation was in an idle state longer than the sleep timer duration. This metric can be used to categorize the general effectiveness of the power management settings.

2.2 Marginal Interventional Savings Calculation

The CalPlug MISER tool was used with the same dataset to calculate potential energy savings based on a strictly applied power management timer duration. By varying the "interventional" power management setting, the difference in savings performance between different interventional settings, in addition to onboard power management performance, can be evaluated. This approach allows the calculation of marginal savings performance. Savings is expressed at this state in minutes per period. To calculate energy savings, state energy usage on a per-state (On [Active or Idle], Off, or Sleep) basis provides baseline energy use values (per Eq. 1). Change in states of operation can be considered adding or subtracting time spent in each of these states. Conversion of time spent in On [Idle] to Sleep is considered savings.

$$Energy\ \ Baseline\left[\frac{Wh}{period}\right]=T_{On}\left(P_{On}\right)+T_{Off}\left(P_{Off}\right)+T_{Sleep}\left(P_{Sleep}\right)$$

$$Yearly\ \ Savings\ \ Change\left[\frac{kWh}{year}\right]=\left(S_{idle}*\frac{365.25\ \ days}{year*60\ \ \min}*\frac{P_{On}}{1000}\right)-\left(S_{idle}*\frac{365.25\ \ days}{year*60\ \ \min}*\frac{P_{Sleep}}{1000}\right) \quad (1)$$

The MISER program provides daily usage information and an Excel calculator is used to determine yearly energy usage or savings. As a result of startup delays and limited observed use, only activation of sleep mode was considered; Off was not considered a state valid for savings conversion in this estimation.

The use of a Tier 1 Advanced Power Strip in combination using power sensing to turn off peripherals when an attached computer enters sleep mode can provide Tier-2 type control for device peripherals by eliminating both standby load along with active primary device load. An estimation of peripheral savings can also be calculated by modeling a Tier 2 approach. Estimation of savings requires knowledge of time spent in active versus off/standby for each peripheral. As limited information is available in modeling, an estimation factor was used in calculation to provide the average On versus Off state power.

2.3 Sensing and Occupancy Detection Comparison

Evaluating occupancy sensing as a factor was based on the operational sensing provided by an Onset HOBO UX90-006 motion/light sensor and a HOBO UX120-018 plugload meter (Onset Computer Corp., Bourne, MA). This workstation was using CalPlug's PMUI power management software to provide comparative state transition information [2]. The study was performed in a 10′ × 10′ isolated office with no person traffic except for the test user.

3 Results

3.1 State Usage Summary

As reported in the original study, only 20 of 115 (17.4%) evaluated university workstations in the study were determined to have power management active by evaluation. The remainder of the evaluated workstations were found without power management enabled. MISER was used to tabulate the average percentage of study time and corresponding standard deviation for each workstation in the study, providing additional granularity beyond previously published results for the monitoring study from which the dataset was sourced. Periods of time where the reporting utility could not determine a state or sub-state are marked as "Unknown". Typically these periods exist in the dataset near transitions or during partially observed study days. During weekdays, the active period of 13.2% is substantially lower than the 33.3% the 24 h day that the 8 h work day corresponds to. Workers are, on average, using their computer actively for a cumulative period much shorter than the 8 h work day (Fig. 1). The time in the Sleep state on average is reduced during the weekend compared to the weekday likely due to workstations being turned off by users during this period. Similarly, the drop in active usage for weekends compared to weekdays does not strongly convert to extended idle or sleep during weekends, but likely is encapsulated in increased workstation presence in the Off state during the weekends. The idle periods are generally short in length with large numbers of small periods and a few large periods corresponding to the length of 1 day (see [1]). Due to the nature of the analysis, contiguous idle periods between the end of one workday and the start of another are broken into subcomponents each of approximately 7–8 h in length (420–480 min). This can be observed in Fig. 2. As this length is longer than any common power management timer setting, this artifact does not impact calculations. Consequently, day breaks of idle periods in calculation can contribute approximately 1.0% error per event (Table 1).

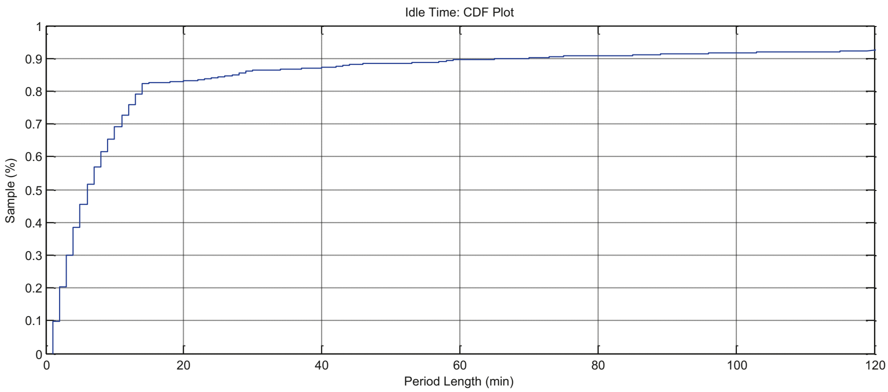

Fig. 1 Cumulative distribution function showing idle periods up to 120 min in length for all study workstations (n = 115). The vast majority of periods are under 20 min in length. At 120 min, only 7% of all samples are still unaccounted

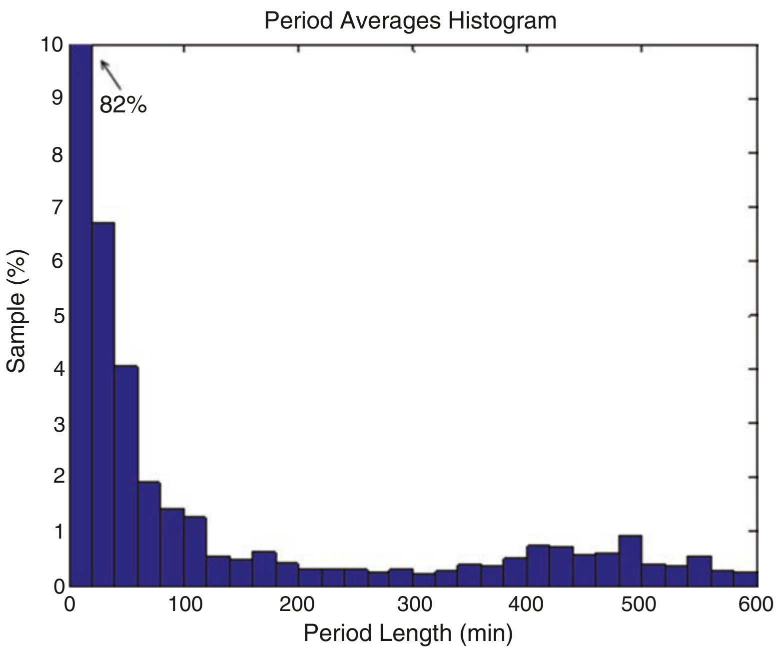

Fig. 2 Idle period length across all days and subjects from lengths 5 to 600 min in 20 min histogram bins. A local maximum exists near 480 min which corresponds to 8 h (evocative of the period of a full work day) but also coincidentally the approximate difference between the start of a day and the start of the workday and the end of the workday and the end of a day, creating an artifact

Table 1 The time spent in each state for the 115 observed office desktops in the monitoring study with sub-states shown

Computer state	Weekday average		Weekend average		Overall average	
	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

3.2 Observed Power Management Performance

Of the 20 workstations with power management enabled, a large disparity exists in observable performance. The averaged sleep power management setting is 14 min while the average overage period in minutes per day for each workstation beyond the power management setting was 258.4 ± 118.4 min (95% confidence interval-CI) (see Table 2). For a hypothetical workstation that consumes 30 W in active mode and 1 W in sleep, this corresponds to a yearly added consumption of 45.6 ± 20.9 kWh (95% CI). A total of 4 of the 20 evaluated workstations in the study (20%) were operational with greater than 700 min (approximately 11.5 h) per day of energy usage beyond the power management setting. As the average number of days evaluated with operation (observed On state) was 54.8, this is clearly an incidence of power management improperly functioning. As extended idle periods were observed throughout the study period for these subjects, this was likely not due to the user changing the power management period mid-study (Fig. 3).

Excluding these four grossly underperforming workstations, the updated average per day overage is 26.0 ± 20.4 min (95% CI). A large standard deviation can be observed as performance within this group was divergent and overage periods ranged from 0 to 555 min/day. Using the same computer state values as before in calculation, this corresponds to 4.6 ± 3.6 kWh (95% CI) per year. The disparity shows energy usage has a strong correlation with power management performance. Furthermore, substantial failures, when they do occur, can be severe and contribute to substantially high energy usage. Omitting the systems with observed substantial overages due to catastrophic power management dysfunction, sleep blocking (both legitimate and illegitimate) contributes to (on average) 1.8% of added daily operation time due to delays in sleep. The set time for the power management sleep timer did not appear to strongly correlate with general performance of overage period average number per day or length.

Table 2 Numerical comparison of a subset of 20 subjects with power management enabled in the 2014 monitoring study

	Subject 42	Subject 83	Subject 52	Subject 71	Subject 43	Subject 29	Subject 79	Subject 11	Subject 66	Subject 3	Subject 107
Computer PM setting	9	9	9	9	10	10	11	11	11	25	30
Overage average period (min)	310.06	11.15	2.11	20.55	2.39	4.53	46.62	365.12	318.20	336.41	6.00
Number of overages	161.00	125.00	53.00	295.00	18.00	19.00	455.00	214.00	152.00	148.00	1.00
Incidence%	36.10%	21.89%	15.32%	21.63%	5.90%	18.63%	21.18%	42.71%	27.59%	8.88%	1.09%
Average period ratio	2.64	3.72	0.38	2.14	0.49	0.75	2.90	2.23	3.38	9.07	0.65
Overage per day (min)	1062.13	58.08	4.31	110.22	1.87	6.62	275.45	1240.24	1179.68	732.18	0.43
Idle periods per day	9.49	23.79	12.81	24.80	12.71	7.85	27.54	7.95	13.44	0.01	6.57
Overage periods per day	3.43	5.21	1.96	5.36	0.75	1.46	5.83	3.40	3.71	2.18	0.07
On-state days	47	24	27	55	24	13	78	63	41	68	14
Total study days	51	37	39	78	68	71	98	63	41	70	38
Workstation type	Win.	Win.	Win.	Win.	Win.	Win.	Mac.	Win.	Win.	Win	Win.

Subject 30	Subject 61	Subject 101	Subject 21	Subject 97	Subject 86	Subject 90	Subject 35	Subject 46	Average	Std. dev.	Median
30	30	30	60	60	120	180	180	240	53.70	69.37	27.50
48.12	20.20	28.79	26.33	176.63	6.67	0.00	16.00	0.00	87.29	131.79	20.37
78.00	5.00	29.00	12.00	160.00	3.00	1.00	2.00	1.00	96.60	120.52	41.00
4.19%	0.93%	2.98%	2.34%	16.16%	0.37%	0.18%	0.38%	0.19%	12.43%	12.94%	7.39%
4.57	2.38	2.26	2.85	3.42	1.11	0.00	0.51	0.00	2.27	2.10	2.25
68.24	3.37	15.46	15.80	392.50	0.67	0.00	0.76	0.00	258.40	429.77	15.63
33.82	17.83	18.00	25.60	13.75	26.83	15.49	12.67	18.52	16.47	8.49	14.62
1.42	0.17	0.54	0.60	2.22	0.10	0.00	0.05	0.00	1.92	1.95	1.44
55	30	54	20	72	30	35	42	29	41.05	19.59	38.00
55	39	76	34	89	43	49	68	52	57.95	18.71	53.50
Win.	Win.	Win.	Win.	Win.	Win.	Win.	Win.	Win.	N/A	N/A	N/A

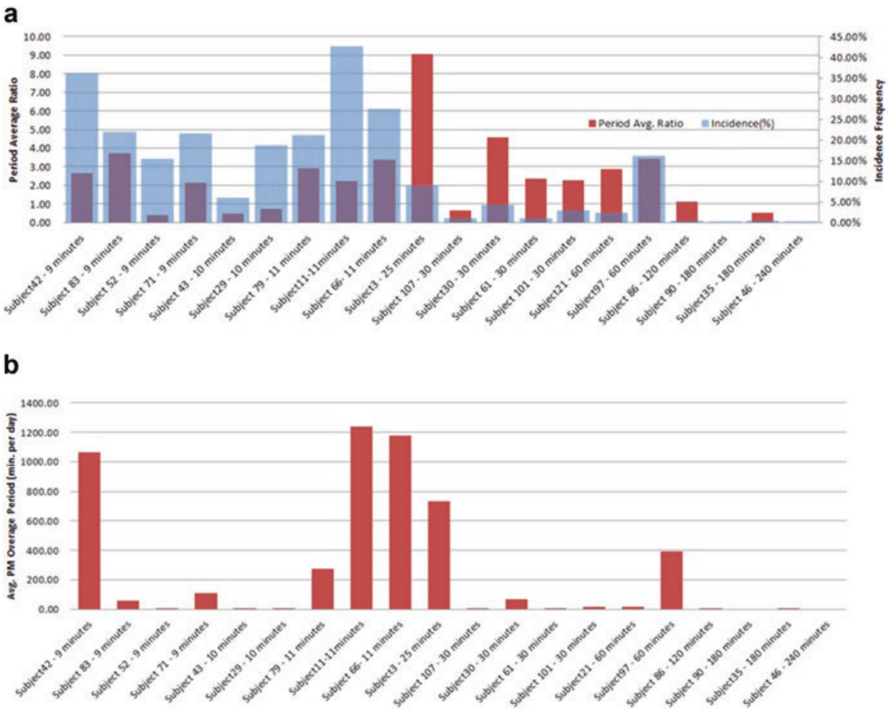

Fig. 3 (**a**, **b**) Graphical comparison of a subset of 20 subjects with power management enabled in the 2014 monitoring study

3.3 Interventional Savings in All Study and PM Subset Workstations

Considering all workstations (with power management and without) in a single set, a marginal savings calculation was performed for simulated sleep settings ranging between 5 and 300 min. With a sleep setting of 5 min, a savings of 880.8 ± 84.7 min (95% CI) could be realized (Table 3 and Fig. 4). Because of the total length of a day and the potential for carry-over to the next day, the potential for power management with even relatively long delay periods can produce substantial savings. In Fig. 5 this is further illustrated as even consistent simulated long power management sleep timer settings lead to savings greater than 40% as compared to the average of all study workstations. This fact highlights the general importance of power management even if with longer settings.

As the majority of observed idle periods are short in duration, increased savings is available due to short timer lengths. This can be observed visually in the representing figure as an inflection between approximately 5 and 60 min modeled intervention period length for weekdays but not for weekends where short idle periods are generally nonexistent due to lack of user presence at the workstation.

Table 3 Summary of calculated minutes per day period estimated power savings (for a subset of all study days) due to the action of simulated power management

Intervention period (min)	Average savings (min/day)	Standard deviation (min/day)	Average energy savings (kWh/year)
5	880.8	463.6	156.8
30	782.6	446.1	138.1
60	717.9	424.2	126.7
120	623.4	384.2	110.0
300	414.2	274.5	73.1

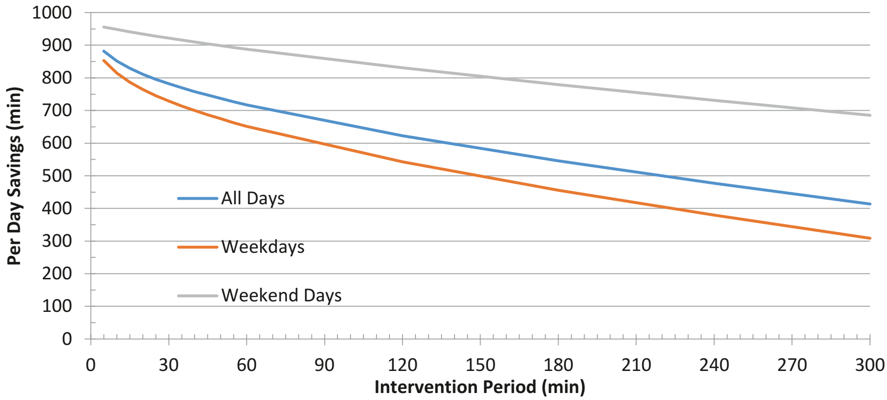

Fig. 4 Study-average estimated savings due to simulated change in power management sleep timer setting considering weekday versus weekend evaluation periods

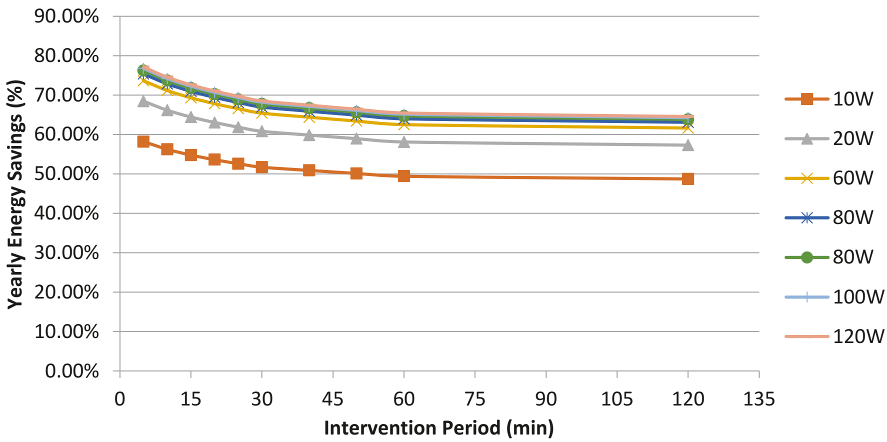

Fig. 5 Baselined yearly savings for different modeled On/Active state power loads with a high modeled Sleep state power load of 2.5 W for multiple intervention period settings for all study computers (n = 115)

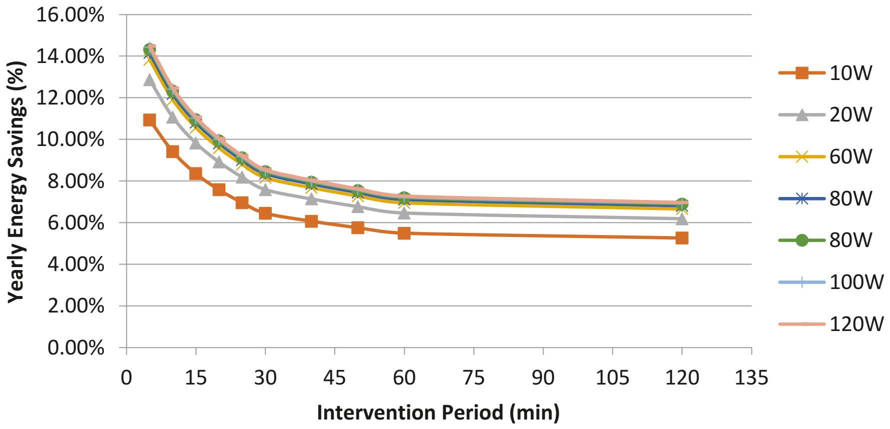

Fig. 6 Baselined yearly savings for different modeled On/Active state power loads with a modeled sleep state power load of 2.5 W for multiple intervention period settings for study computers as found with PM enabled excluding workstations with gross power management operational issues (n = 17)

Considering the study subset with power management enabled (17 subjects, excluding the 4 specified cases) the energy savings potential is substantially less than presented in Fig. 5 as no extended events contribute to multi-day idle periods (Fig. 6).

3.4 *Marginal Interventional Savings*

The distribution of idle periods can be used to seed a simulation to estimate the difference in savings between two ideal case operations. This is essentially the On time that can be saved considering an ideal operation between two intervention period settings. In this manner the marginal benefit can be estimated and compared against the potential marginal cost related to potential user interruption. The details of how different settings can produce savings is presented in Fig. 7.

3.5 *Sensing and Occupancy Detection Comparison*

A weak correlation between active usage versus idle for energy usage was observed. This is indirectly observed in Fig. 7 where extended period of use (as evidenced by a time correlated occupied signal from the motion detector) is not strongly correlated to a unique increase in energy usage (Fig. 8).

An extended live evaluation was used to observe the effect of specific activities on the impact of motion versus keyboard/mouse used as an indicator for

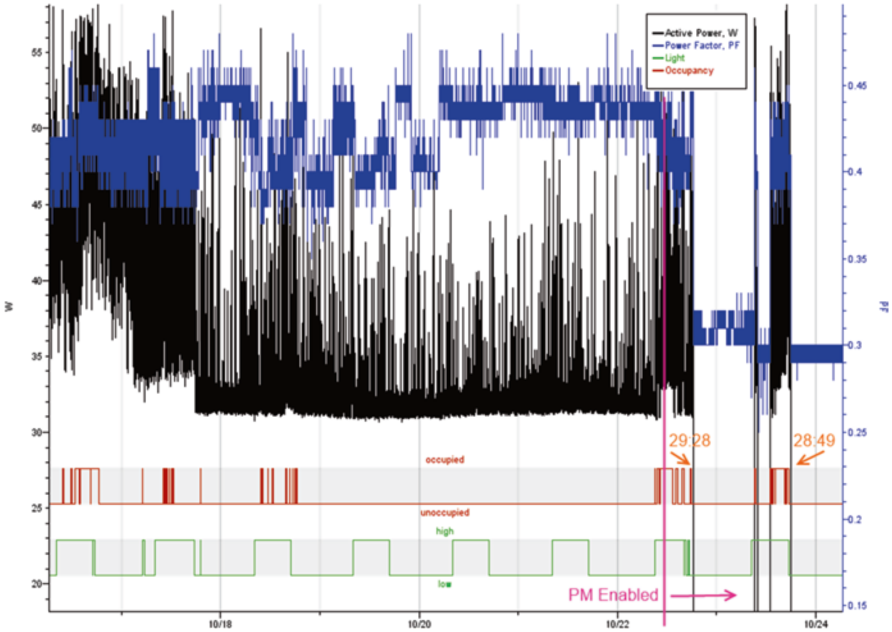

Fig. 7 Evaluation of motion as an indicator for power management

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 based on the configuration of the evaluation space. 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 computer PM timer was set to 30 min. Actuation of sleep was compared to time points of measured motion. The time of the last motion event is compared to the timer duration (listed in Table 4 as sensor delta period). The duration between when sleep was expected to happen and the last motion event is presented. In all cases a motion shutdown would have occurred yet a short timer delay occurred likely due to residual motion following the last keystroke.

4 Discussion

Improving the effectiveness of computer power management can lead to massive savings. Within just the context of the monitoring study, a majority of computers were shown to operate without effective power management set up or in cases where power management was active, catastrophic failures were observed, resulting in loss of substantial savings opportunities. Clearly getting power management to

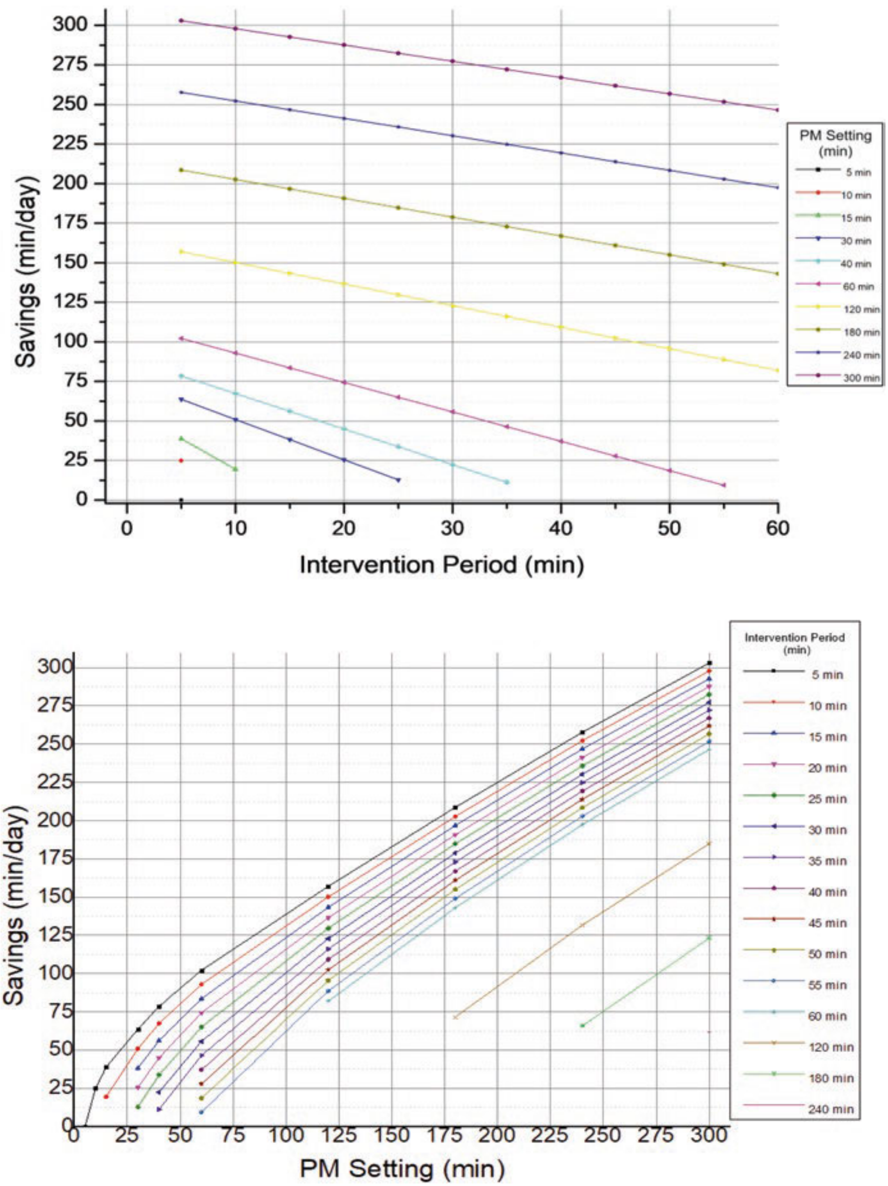

Fig. 8 (**a**, **b**) Savings for all subjects (with and without PM enabled) as a function of simulated PM period compared to the action of an alternative choice of time power management sleep timer duration (denoted as Intervention Period (min))

Table 4 Summary of sensor common periods and time deltas for the evaluation test period

Sensor delta period (min:s)	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

operate (and remain operational based on retained settings), then operate correctly to provide consistent transitions into sleep are two major considerations. The results of the 2014 monitoring study highlighted the low incidence of power management present on university workstations while simultaneously confirming screen power management as prevalent. This suggests users may be confused between screen blanking (screen power management) and computer power management. As none of these systems were centrally managed for power management nor did a centralized IT infrastructure or policies exist, the findings of this study are likely applicable to similar office desktop deployment scenarios. Based on presented observations, it is clear that even when enabled, sleep blocking, background tasks, and wakeups negate some power management effectiveness, both legitimate and illegitimate. As a large variability exists in the length of recorded idle periods, this suggests multiple contributing pathways in some or all of these factors contributing to abnormal, likely illegitimate power management override and excessive energy usage. The use of presence sensing may provide a means to negate illegitimate energy usage; however, application usage must take into consideration that such a device will cause a system to go into sleep even if a legitimate process is continuing when the user leaves the area. Best practices for browser code execution and media playing as well as improved general operating systems API controls to override power management should be considered to improve continued judicious power management controls and encourage both users and developers to build within constraints to reduce energy use. Luckily the continued shift of development toward mobile applications inherently requires judicious power management. The mobile-inspired design of current operating systems considers energy usage as a function of battery life. While inherent design trends may implicitly draw attention to improved energy management, the authors have independently observed illegitimate sleep blocking occurring on both mobile and desktop workstations at the date of publication of this work. Browsers with open video tabs often prevent sleep along with cloud service sync in addition to backups and updates. While design is improving, sleep blocking may potentially be a growing problem due to more content-rich websites and advertisements that can prevent computer power management from taking effect. The current incidence of sleep blocking is a worthy investigation. Although the 2014 CalPlug monitoring study dataset was used for the current research study, the CalPlug's 2018 PMUI study dataset (finalized immediately following the submission of this manuscript) [2] may provide deeper and more up-to-date insight into the prevalence of sleep blocking and the real impact on energy usage. Further evaluation of more modern datasets can help determine the rate of sleep blocking and common root causes. From here a plan can be developed with potential mitigation actions for stakeholders.

The use of alternative detection of occupancy other than keyboard/mouse activity, especially employed as an external device to allow independent triggering, has the potential to reduce the effects of extended sleep blocking and users with misconfigured settings. Motion events in lighting and HVAC controls have shown the potential to reduce usage by improved occupancy determination. Improved integration of different systems using motion from various sources as well as alternative passive sensing methods are a major potential focus of continued investigation with wide potential applications to energy management. From this study, motion events specifically were well correlated with power management triggering in a known working configuration. Compared to scenarios where power management is not configured or is operating incorrectly, even limited power management provides substantial energy savings. An example of this is a 1 h sleep timer: while a long period itself, this can prevent potentially 7 h of wasteful overnight operation, leading to nearly 30% savings directly preventing just overnight operation. As observed with Tier 2 APS devices for entertainment applications, extraneous or irrelevant background motion can lead to unwanted resetting of the countdown timer. When compared to no power management, using motion sensing is likely an improvement. Such a system can ensure consistent power management implementation when plugged in, as the operation of this device cannot be as easily changed as operating system settings. However, in a situation in which power management is functioning efficiently, the probability of chance motion canceling sleep requests is potentially high, limiting the ability to eke out additional savings. As power management was largely misconfigured across evaluated systems, such external devices would substantially improve savings as they would provide a stopgap measure. There are specific challenges to using external signaling including not precluding legitimate actions that may suspend sleep such as backup processes and video viewing. Continued development of such devices to reduce interference in legitimate tasks by Operating System (OS) communication is a step to improving the applicability of these devices to a wider audience. Proving the effectiveness of such devices paves the way for integration of motion sensors into monitors and keyboards to reduce total user peripherals while adding consistent energy management functionality. Continued evaluation of specific implementations of solutions based on this approach can be used to further develop a model to advance practical alternative sensing for computer power management.

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