Energy Analysis of Multi-Function Devices in an Office Environment

Rodney A. Martin, PhD **Scott Poll**

ABSTRACT

As part of an effort to monitor electricity usage by plug loads in a new high performance office building, plug load management devices were deployed to enable data collection, analysis, and active control of plug loads. We used a Commercial Off-The-Shelf (COTS) plug load management system to capture relevant data for two different types of multi-function devices (MFDs) in the facility, one of which was tested for use with different power settings. This enabled a quantitative analysis to assess impacts on energy consumption. It was found that a projected 65% reduction in annual energy consumption would result by using a newer, Energy Star compliant model of MFD, and an additional projected 39% reduction in annual energy consumption would result by subsequently changing the time-to-sleep for that MFD. It was also found that it may be beneficial to apply automated analysis with anomaly detection algorithms to detect problems with MFD performance, such as a failure to go to sleep mode or variations in sleep power draw. Furthermore, we observed that energy savings realized by using plug load management devices to de-energize (unplug) MFDs during non-business hours depends on the sleep power draw and time-to-sleep setting. For the MFDs in this study with settings established per the maintenance contract (which were different than factory default values), turning the device off at night and then on in the morning used more energy than leaving it on in sleep mode due to the start-up behavior and excessive time-to-sleep setting of four hours. From this and other assessments, we offer these recommendations to building occupants: reduce MFD time-to-sleep, encourage employees to use the power save button, and apply automated analysis to detect problems with device performance.

INTRODUCTION

A high performance office building was recently occupied at the National Aeronautics and Space Administration (NASA) Ames Research Center campus. The project is one of several sustainability initiatives at NASA as federal agencies strive to meet Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance. This executive order sets a goal that all new Federal buildings in the planning process after 2020 are to be designed to achieve zero-net-energy by 2030. An important aspect of the executive order is continuous improvement towards meeting the goal by evaluating and reporting building performance. A significant factor in the performance of energy efficient buildings is plug loads, also referred to as miscellaneous electrical loads or plug and process loads. Plug loads can account for a large fraction of the energy demand in high performance office buildings as the number and variety of plug loads proliferate while at the same time the lighting and mechanical systems become more efficient. To better understand the role of plug loads, we deployed a plug load management system to the high performance building at Ames, covering approximately one quarter of the building and more than 200 plug load devices. Several different types of devices were monitored, including typical workstation loads (computers, monitors, etc.), break room loads (coffee pot, microwave, etc.), conference room loads (large monitors, speakerphones, etc.) and copy room loads (multi-function device, printer, fax machine, etc.). In this paper, we restrict our attention to just one of the monitored loads – the multi-function device (MFD).

Rodney Martin is a researcher in the Intelligent Systems Division at NASA Ames Research Center. Moffett Field, CA 94035. Scott Poll is the deputy lead for the Diagnostics and Prognostics Group in the Intelligent Systems Division at NASA Ames Research Center. Moffett Field, CA 94035.

(a) MFD Brand X (b) MFD Brand Y

Figure 1 Multi-function device change from older model of Brand X to newer model of Brand Y.

Conveniently, after the initial deployment of the plug load management system, a new contract was competed to replace older MFDs (Brand X) for copying, scanning, and e-mailing with newer MFDs (Brand Y) (see Figure 1). Since the plug load management system was deployed prior to the MFD replacement, we were able to capture energy data from both MFDs and assess the impact of the change. In the following sections we show not only how energy consumption of the Brand X MFD compared to the Brand Y MFD, but also how changing the time-to-sleep from 4 hours (the default setting per the contract) to 20 minutes affected energy consumption. Furthermore, we show that it is possible to identify anomalies which impact energy performance.

METHODOLOGY

The study was performed over several months using a plug load management system that allows for the metering and automated control of individual electrical plug loads. Control is achieved through schedule-based rules which establish pre-set times at which power to individual plug loads is automatically energized (turned on) or de-energized (turned off). The system includes power ports and bridges, shown in Figures 2a and 2b, respectively. The Power Port is a power strip with four channels (receptacles) that are individually metered and controlled. An independent calibration of the channels was not conducted; the manufacturer's specification sheet states 0.1W resolution and an accuracy of 2.5%. The power ports transmit power draw data once per second to the bridges. The bridges are used to wirelessly communicate data from power ports to a local area network (LAN) using an RJ45 Ethernet port. Once on the LAN, data is sent to the wide area network (WAN) through a locally hosted server, and stored in a cloud-based data service once per minute with the minimum, mean, and maximum power draw over each one minute interval recorded, among other parameters. Following the collection phase, data were downloaded for subsequent analysis.

Table 1. Experimental Configurations

MFD Type	Time-to-sleep	Duration of Experimental Period
Brand X	4 hrs	77 days
Brand Y	4 hrs	134 days
Brand Y	20 min	56 days

Table 1 summarizes the configurations investigated in this study. Brand X was present in the office building when the plug load management system was deployed. The time-to-sleep for the device had been previously set to four hours in accordance with the maintenance contract. A change in the maintenance contract resulted in Brand X being replaced with Brand Y after 77 days of data collection. Note that the Brand Y MFD was plugged into the same channel used to acquire data for Brand X. The new contract also specified a time-to-sleep of four hours. Approximately four months of data were collected in this configuration. Finally, the time-to-sleep setting was changed to the factory default value of 20 minutes for an additional 56 days of data collection. The impacts of these configuration changes are discussed in the next section.

(a) Power Port (b) Bridge

Figure 2 Plug load management equipment.

RESULTS

Table 2 summarizes the projected annual energy consumption and electricity costs for the configurations tested in this study. The first row represents the baseline. The last column in the subsequent rows indicate the percentage savings from the previous row, reflecting the impact of the incrementally applied intervention. For the energy consumption projection, we computed an average daily kWh usage over the relevant period in Table 1 and multiplied it by 365 days. For the electricity cost projection, we assumed $0.12/kWh based on a market assessment of "green" commercial electricity rates. For the results presented in Table 2, we did not track the number of MFD jobs processed in each experimental period and hence do not attempt to normalize energy measurements. However, all configurations were in the same shared work space with the same users.

Table 2. Projected Annual Energy Consumption for Experimental Configurations

MFD Type	Time-to-sleep	Energy Consumption for MFD	Electricity Cost	Reduction
Brand X	4 hrs	~1000 kWh/yr	~$120/yr	--
Brand Y	4 hrs	~360 kWh/yr	~$43/yr	65%
Brand Y	20 min	~220 kWh/yr	~$26/yr	39%

From the data acquired in this study, there is a projected 65% reduction in annual energy consumption and associated electricity cost by changing the MFD from older Brand X to newer Brand Y. This is primarily due to the differences in the sleep and idle mode power draw between the two devices, as is evident from Figures 3 (Brand X) and 4 (Brand Y) in the following section. The differences are not surprising considering the manufacturers' specification sheets, summarized in Table 3. Brand Y meets the Energy Star 2009 guidelines, while the older Brand X did not meet either the 2009 or 2007 guidelines. More generally, it reflects the improvement in technical and energy performance of newer generations of MFDs compared to previous generations. There is more discussion in the following section concerning the discrepancy between sleep mode power measured in this study for Brand Y and the value reported in the specification sheet.

Additionally, there is a 39% reduction in Brand Y energy consumption by changing its time-to-sleep from 4 hours to 20 minutes. The latter value is the factory default setting but the maintenance contract had specified setting time-to-sleep to 4 hours, presumably to minimize user inconvenience of waiting for the device to return to ready-to-use state. However, there were no user complaints after the setting was reduced to 20 minutes, most likely because of its short low power recovery time. It should also be noted that the results presented in Table 2 include certain operational anomalies that are documented in the subsequent section.

Table 3. MFD Specification Sheet Comparison

MFD Type	ENERGY STAR Compliance	Sleep Mode Power	Copying Speed	Warm-up / First Use Time	Low Power Recovery Time
Brand X	2009 spec	< 80 W	30 ppm	< 99 sec	< 20 sec
Brand Y	none	< 8 W	36 ppm	< 30 sec	< 4 sec

ANALYSIS AND DISCUSSION

The use of a plug load management system over an extended period of time allowed collection of several interesting events that are worth noting. The first of these observations relates to the fact that there was a period of several days, roughly from 2/29/12 to 3/13/12, when the Brand X MFD did not consistently enter sleep mode. This was also seen with a different copier of the same model in a previous pilot study (Poll and Teubert 2012). This is illustrated in Fig. 3, where it is clear that on a specific day (3/1/12) during this period the MFD was unused but drawing well above sleep power. In contrast, for specific days before (2/25/12) and after (4/1/12) this period the MFD was unused and drawing only sleep power all day. The data provides evidence of a potential problem with the Brand X MFD since the time-to-sleep setting per the maintenance contract was 4 hours. This illustrates that even a very cursory qualitative analysis provides value for the identification of potential anomalies or faults in energy-consuming devices. More automated and statistically rigorous anomaly detection methods can be applied to improve the analysis.

The next observation relates to a period of time in which the Brand Y MFD was turned off using the power strip from 9 pm to 4:30 am for a few days in June, running from approximately 6/14/2012 to 6/21/2012. This period of time is coincident with an experiment that was being conducted to collect data for select nodes with schedule-based rules. The study was intended to demonstrate possible reductions in energy consumption as a result of turning devices off and on at defined times. As is evident from Fig. 4, turning off the Brand Y MFD according to these rules used more energy than leaving it on due to its start-up behavior and time-to-sleep setting of 4 hours. Therefore, in this particular case, the application of the rule was disadvantageous. This was especially true for a day in which there were no copy jobs executed. As can be seen from Figure 4, the MFD operated at idle mode power after an automated power-on was executed according to the rule and subsequently dropped to sleep power after several hours.

The penultimate observation relates to a shift in sleep power draw from 13 watts to 20 watts experienced by the Brand Y MFD that occurred on 7/24/2012. Figure 5 provides illustrative evidence of this anomaly, in which the power draw from 7/23/12 – 7/29/12 is displayed sequentially. It is clear from Fig. 5 that the MFD was going into sleep mode on 7/23, in which the power draw was ~13W. This was immediately followed by a failure to go into sleep mode (after 4 hours, per the setting) on the next day, 7/24. After this point, the baseline power draw for sleep mode shifted from ~13 W to ~20 W, but shifted back to ~13 W on 8/19/12 (not shown in Fig. 5). This same shifting of the sleep power draw between ~13 W and ~20 W appears to recur indefinitely beyond 8/19/12 at various periods. Furthermore, the fact that the measured power draw is greater than the value reported on the manufacturer's specification sheet (< 8 W, see Table 3) is another clue that the anomaly requires further investigation to understand and identify the root cause.

Figure 6 offers another perspective on visualizing the anomaly, where the same days shown sequentially in Fig. 5 are overlaid according to a 24-hour period that begins at midnight. The magnified inset picture more effectively illustrates the shift in sleep power draw. The process of manually identifying anomalies in a qualitative manner can greatly benefit from automation by application of data mining methods. This has been investigated in part in previous work (Teubert & Poll 2012), and will continue in further studies. There are many other advanced algorithmic methods that have been investigated in association with the analysis of energy consumption, e.g. (Kolter & Johnson 2011) which may also be useful in this regard.

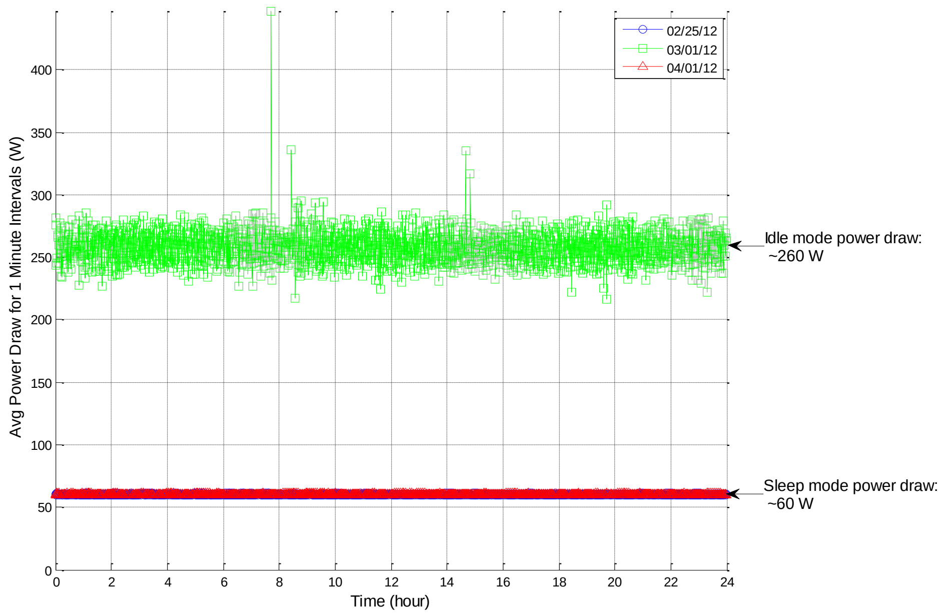

Figure 3 Brand X MFD fails to enter sleep mode.

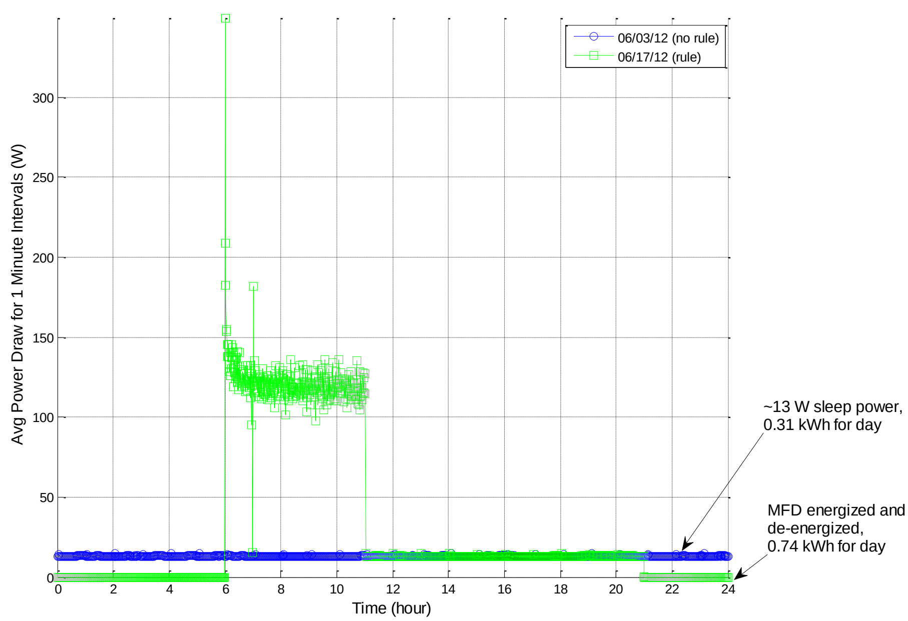

Figure 4 De-energizing Brand Y MFD with 4 hr time-to-sleep uses more energy than leaving it on.

The final observation shows a comparison of low power modes of operation for the Brand Y MFD. A user can push a power save button on the control panel, which causes the unit to enter a low power state which uses only slightly more energy than sleep mode. In Figure 7, the power save mode is entered on two separate occasions, as is shown to occur on 8/1 and 8/3. The magnified inset picture more clearly illustrates the power save events. The main plot on the left of Figure 7 shows the average power draw for each day of the week from Mon, 7/30 – Sun, 8/4. Recall that after 7/24 the sleep power draw established a new baseline of ~20 W. Evidently, operation in power save mode draws ~30 W, which is only 10 watts more than when in sleep mode.

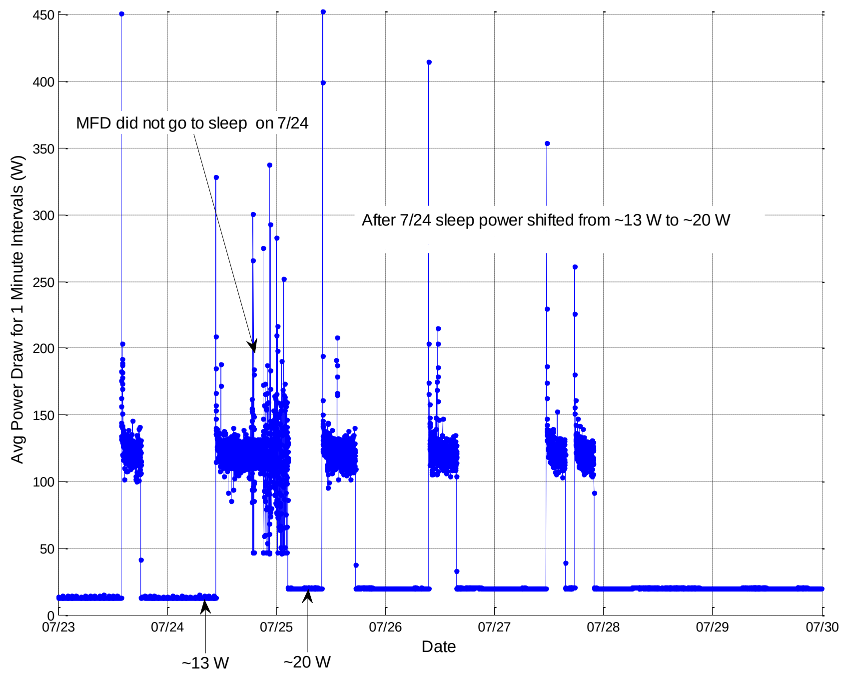

Figure 5 Brand Y MFD sleep power draw shift shown sequentially.

CONCLUSION: FINDINGS & RECOMMENDATIONS

This study confirms the expectation that replacing older MFDs with newer ones which meet Energy Star specifications can save a significant amount of energy; a projected 65% reduction in energy consumption was observed between two different generations and brands of MFDs with the same time-to-sleep setting. The primary reason for the reduced energy consumption in the newer MFD was due to lower sleep and idle mode power draws. To minimize capital expense, equipment refreshes should coincide with contract renewals. The maintenance contracts should specify a time-to-sleep which is no more than the factory default, which represents a reasonable balance between user convenience and energy savings. A projected 39% decrease in energy consumption was obtained by changing the time-to-sleep from contractually specified 4 hours to factory default 20 minutes.

Examination of the recorded data informed a policy recommendation to encourage employees to use the power save button. This may be another beneficial energy mitigating intervention, which can be further quantified in future investigations. Furthermore, it was found that it may be useful to apply an automated analysis with an anomaly detection algorithm to detect problems with MFD performance, e.g., a failure to go to sleep mode or unexplained variations in sleep power draw.

Finally, we identified that energy savings realized by using schedule-based rules to de-energize MFDs overnight depends on the time-to-sleep setting. We found that turning off the Brand Y MFD according to such rules used more energy than leaving it on due to the MFD start-up behavior and time-to-sleep setting of 4 hours. Consequently, depending on device characteristics, application of a schedule-based rule can be disadvantageous compared to operating without it.

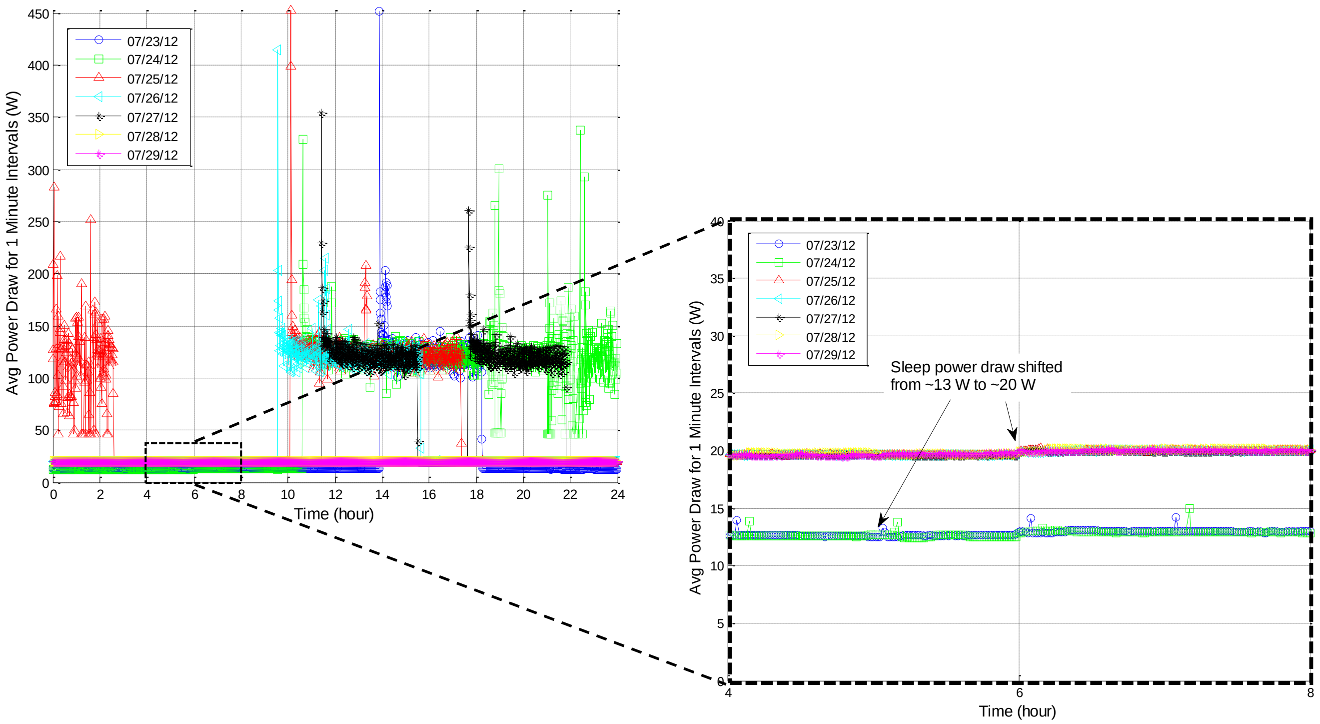

Figure 6 Brand Y MFD sleep power draw shift shown as an overlay.

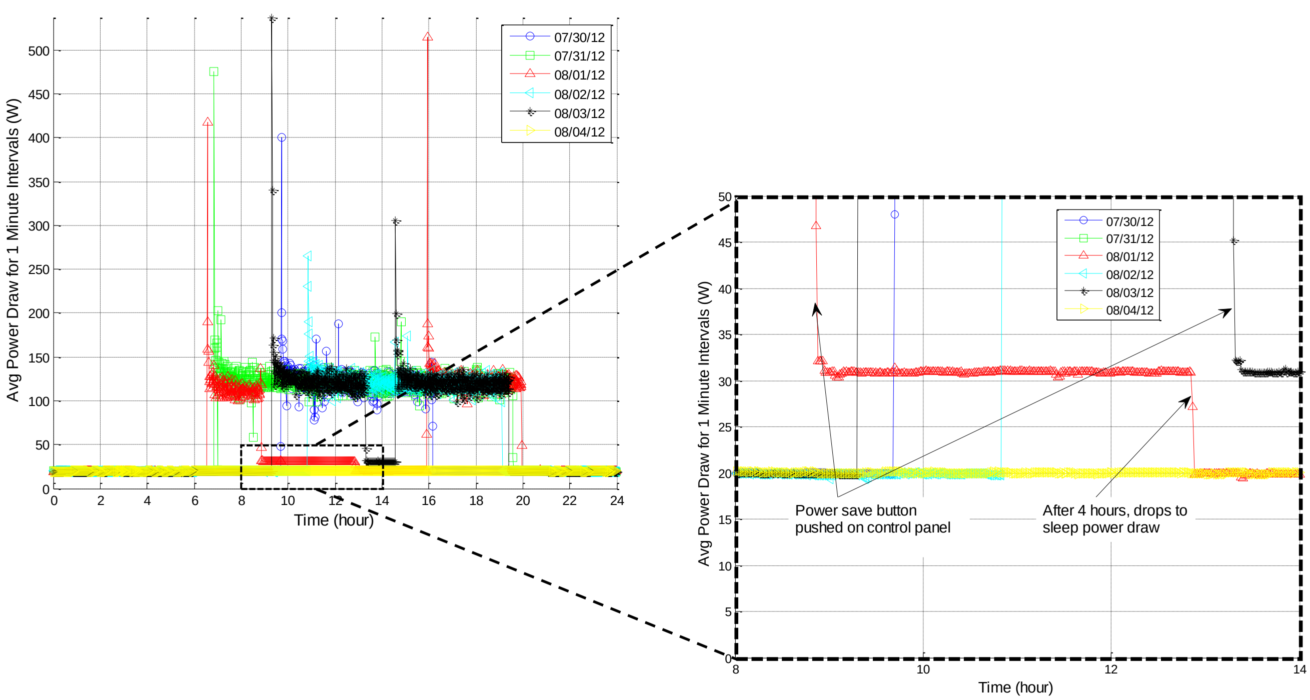

Figure 7 Manually initiated power save events vs. sleep power draw for Brand Y MFD.

Reducing the time-to-sleep would offset the additional power consumed during start-up, possibly making it advantageous to apply schedule-based rules to power off the MFD. Determining the expected savings requires analysis of the start-up power profile, time-to-sleep, sleep power draw, and time in the off state.

The broader message from this paper is that monitoring plug load data may help facility managers to gain insight into equipment malfunctions or additional energy saving measures that would otherwise have gone undiscovered. Doing so would almost certainly help to inform maintenance actions or policy changes that would beneficial to facility managers in the management of their energy costs.

REFERENCES

Poll, S. and C. Teubert. April 2012. "Pilot Study of a Plug Load Management System: Preparing for Sustainability Base," *2012 IEEE Green Technologies Conference,* pp.1-6.

Teubert, C. and S. Poll. September 2012. "Application of Inductive Monitoring System to Plug Load Anomaly Detection," *2012 Proceedings of the Annual Conference of the Prognostics and Health Management Society,* pp. 9-16.

Pless, S., and Torcellini, P., 2012. "Controlling Capital Costs in High Performance Office Buildings: A Review of Best Practices for Overcoming Cost Barriers," *ACEEE Summer Study on Energy Efficiency in Buildings Conference*, NREL, Pacific Grove, CA.

Moran, M., and Berman, M., 2008. "6 Steps to Successful Facility Energy Management," *ASHRAE Journal*, Vol. 50, No. 1, April, pp. 32-34, 36-38.

Weng, T., and Agarwal, Y., 2012. "From Buildings to Smart Buildings—Sensing and Actuation to Improve Energy Efficiency," *Design & Test of Computers*, IEEE, Vol. 29, No. 4, August, pp. 36-44.

Lobato, C., Pless, S., Sheppy M. and P. Torcellini. 2011. Reducing plug and process loads for a large scale, low energy office building: NREL's research support facility. Report NREL/CP-5500-49002. National Renewable Energy Laboratory.

Kolter, J. Z., M. J. Johnson. August 2011. "REDD: A Public Data Set for Energy Disaggregation Research," *In Workshop on Data Mining Applications in Sustainability (SIGKDD)*, San Diego, CA.