Measured Energy Savings and Performance of Power-Managed Personal Computers and Monitors

Bruce Nordman, Mary Ann Piette, and Kris Kinney, Lawrence Berkeley National Laboratory

Personal computers and monitors are estimated to use 14 billion *kWh/year* of electricity, with power management potentially saving $600 million/year by the year 2000. The effort to capture these savings is lea by the U.S. Environmental Protection Agency's *Energy Star* program, which specifies a 30*W* maximum demand for the computer and for the monitor when in a 'sleep' or idle mode. In this paper we discuss measured energy use and estimated savings for power-managed (Energy Star compliant) PCs and monitors.

We collected electricity use measurements of six power-managed PCs and monitors in our office and five from two other research projects. The devices are diverse in machine type, use patterns, and context. The analysis method estimates the time spent in each system operating mode (off, low-, and full-power) and combines these with real power measurements to derive hours of use per mode, energy use, and energy savings. Three schedules are explored in the ''As-operated,'' ''Standardized,'' and ''Maximum'' savings estimates. Energy savings are established by comparing the measurements to a baseline with power management disabled. As-operated energy savings for the eleven PCs and monitors ranged from zero to 75 *kWh/year*. Under the standard operating schedule (on 20% of nights and weekends), the savings are about 200 *kWh/year*.

An audit of power management features and configuration for several dozen Energy Star machines found only 11% of CPUs fully enabled and about two thirds of monitors were successfully power managed. The highest priority for greater power management savings is to enable monitors, as opposed to CPUs, since they are generally easier to configure, less likely to interfere with system operation, and have greater savings. The difficulties in properly configuring Pcs and monitors is the largest current barrier to achieving the savings potential from power management.

INTRODUCTION

Following the proliferation of personal computers and laser printers during the 1980s came recognition of the considerable electrical and space conditioning loads they brought to commercial buildings. It is estimated that personal computers and monitors currently use about 14 *TWh/year*, with Energy Star equipment saving about 4 *TWh/year*; by the year 2000 (Koomey et al. 1995). Properly enabled Energy Star equipment could cut PC electricity use in half, to about 11 *TWh/year* by 2000. Initial studies of the magnitude and trends of these loads led to formation of the Office Technology Efficiency Consortium and in 1992 the U.S. Environmental Protection Agency's (EPA) **Energy Star** program for personal computers and monitors (Johnson & Zoi, 1992). Later that year the ***Energy Policy Act*** (EPACT 1992) was passed and signed into law which intended the implementation of a voluntary information program among manufacturers of office equipment to encourage the marketing and purchasing of more efficient products.

As power-managed office technologies become more widely available, there is a need to understand how well these new technologies work under typical conditions in actual office environments. Questions have arisen regarding how much energy these technologies save in practice and whether they satisfy user needs and expectations. This paper presents results from gathering and analyzing data that document field performance and energy savings of new, energy-efficient personal computers and monitors. We have included data from three sources, representing three PCs, three monitors, and five systems[a] (all Energy Star). We also audited 70 PC systems in a sample office area here at our laboratory to examine the prevalence, characteristics, and status of power management features.

The following section discusses how power management is accomplished and identifies impediments to proper functioning. The third section of the paper reviews the methodology we used to collect and analyze the electricity use and audit data. The fourth section presents the quantitative results of the energy analysis and audit of power management settings. The fifth section discusses the difficulties involved with evaluating power management performance, common reasons for failure (partial or total), outstanding questions, and recommendations to computer managers and policy makers.

A more detailed report on this study can be found in (Nordman, Piette & Kinney 1996).

TECHNOLOGY OVERVIEW

As efforts to improve power management in PC systems proceed, two outstanding issues loom: how to get more systems enabled, used well, and working properly, and how to anticipate the evolution of PC technology that could aid or impede successful power management. Both of these issues can be considered by evaluating how power management is actually accomplished, as described below.

Computers are organized as a hierarchy of layers, from those that the user directly interacts with, to those more connected to the physical control of electrical signals. The layers relevant to power management are the application software, the operating system, the firmware (BIOS, Basic Input/Output System), processor and peripheral hardware. The BIOS and core logic are the interface between the processor, system memory, and peripherals (Easterday 1995). To date, the BIOS has been the primary controlling layer for power management, though more recently, control has been migrating upwards into the operating system. More recently, Advanced Power Management (APM) has been expanded to include I/O buses that control memory, mass data storage, CD-ROM drives, and additional devices. Power management modes defined on the more recent versions of APM are shown in Table 1.

Table 1. *PC Power Management Modes*

Mode	Description
Full-on	No power management occurring.
Enabled	CPU slows down; devices can be powered down individually
Standby	CPU may stop entirely; most devices* are in low-power mode (not off)
Suspend	CPU stopped; most devices are powered down (off)
Off	System turned off; must be rebooted to operate

Source: Intel & Microsoft 1993.
*‘device’ in this context refers to components of the PC such as the hard disk, memory, or cards such as network or video cards.

While power management systems vary considerably in many respects, they usually share some common characteristics. Often there is one master control that when turned off disables all power management features. Low-power modes usually begin after a timer indicates a certain period of low- or in-activity has passed. Usually, what controls the timer is fixed but the length of time it is set for can be changed (within a range). Power management configuration systems differ with the manufacturer of the BIOS hardware, the processor, and the core hardware (motherboard). The configuration and processor speed also dictate power management options. The number and character of the timers varies considerably among machines. Some power management controls are found in system set-up screens available only on system boot-up. Others can be changed through a software control panel accessible at any time. Existing set-up screens range from those with just one power management option to control all features to complex screens that allow a different delay time for each device and allow the user to specify what events bring the specific device (or all devices) back to active mode.

The most common method for accomplishing monitor power management is Display Power Management Signalling (DPMS). With DPMS, the PC (through the video card), indicates to compliant monitors when they should begin the power management sequence, with either the monitor or the PC triggering further steps. More intelligent ‘‘Universal’’ monitors can be used with CPUs that do not support power management because they initiate power management using a blank screen saver setting, or they can be triggered by DPMS signals. Some PCs have monitor outlets that can be switched off after a pre-set time of inactivity; these switched outlets can accomplish power management on monitors not originally designed with this feature. In the case of DPMS, both devices must usually be designed to use DPMS and the PC must be properly enabled in order to send the correct signals. (There are a variety of PC and monitor aftermarket controlling devices that turn off the machine by sensing key strokes or room occupancy, but these devices are beyond the scope of this study.)

METHODOLOGY

This project involved analyzing data on PC and monitor energy use of Energy Star compliant devices, from both our own measurements at LBNL, and from three other sites. Data from other case study sites extend the number and diversity of devices in the database. The most common measurement basis among the studies is average power drawn over 15-minute periods. Fifteen-minute data are a practical minimum resolution to confidently capture the power-management performance of current systems. This analysis only captures direct electricity savings and not other

possible impacts such as reduced peak demand charges or changes in space conditioning loads.

Terms, Definitions, and Methods

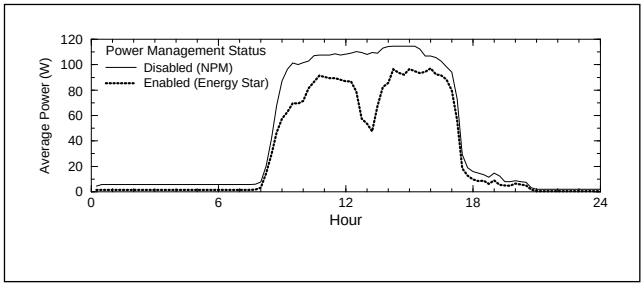
We use the term *PC* for PC devices powered by the main power cord, which include internal cards. This does not include the switched AC plug common on many PCs (which some monitors plug into), nor devices such as external hard disks, modems, or scanners that are separately powered. The *monitor* is a single display unit that is usually, but not always, a video monitor (cathode ray tube). A *device* is a PC or a monitor; the combination of a PC and a monitor is a *system*.

In order to evaluate PC energy use and savings from power management, we measure:

Power Levels	The power (in *W*) used by the device (on average) in each operating ***mode.***
Operating Patterns	The distribution of time (in *%* of a period of time) spent in each mode by day type.

We define the primary operating modes below. Operating patterns are the result of the computing habits of the user, the system's power-management configuration, and the computing environment to which both belong. The configuration follows from the user's needs, the computing environment, and the system's power-management capabilities. While we can check the configuration at any specific point in time, the other factors cannot be measured directly or rigorously, hence our reliance on the operating pattern. The Energy Star and *Non-Power-Managed (NPM)* operating patterns differ in that all low-power time in the Energy Star pattern is shifted to full-on time for the NPM pattern. Figure 1 shows the loadshape for both operating patterns for one system. All power levels are from specific device measurements, rather than manufacturer's ratings or reported values.

Figure 1. *Hourly Average Energy Use with Power Management Enabled and Disabled; Weekday As-operated Energy Use: System S1, by Hour of Day*



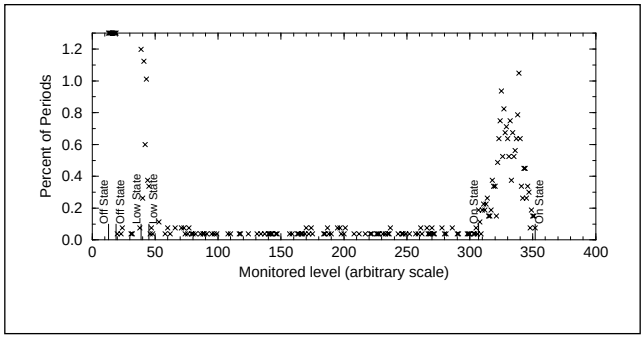
The most basic metric of electricity use in PCs and monitors is the **annual energy use**, which is the amount of electricity (typically in *kWh/year*) used by a device. The **annual energy savings** (also typically in *kWh/year*) reflects the benefit of enabling power management. The savings estimates are of three types (each with an Energy Star and NPM operating pattern):

As-operated	Measured power levels and operating patterns.
Standard Operation	The power levels are based on the measured Energy Star system, but the operating pattern is a single, standard, pattern (defined later in this section).
Maximum Savings	The power levels are based on the Energy Star system, and the operating pattern is adapted from 'standard operation, but the system is always on.

The As-operated operating pattern is derived from continuous measurements of either electrical current or true power. We use the monitored data to measure the fraction of time spent in each mode. Annual energy use estimates are based on the modal distribution for the entire monitoring period combined with one-time power measurements for each mode.[b]

The device is assumed to have three distinct **primary** operating modes, **Full**-on, **Low**-power, and **Off.** If intermediary modes become common this definition will need to be adjusted. Some devices may have **secondary**, intermediate modes, that are temporary states in a sequence that ends with the Low mode. For each operating mode, a **modal power range** (minimum and maximum) is defined that covers the variation within that mode, so that power levels outside of these ranges are assumed to reflect combinations of several modes during a single monitoring period. Figure 2 presents the distribution of monitored current levels by 15-minute period (for one device).

Figure 2. *Modal Power Values: Monitor M1, Weekdays Only*



The horizontal scale is a multiple of the measured current (averaged over fifteen minutes). It could be converted to milliamps, but this is not necessary as these data are only used to determine the combination of modes present in the period and the amount of time in each. The vertical scale is the frequency that a particular level occurs in the monitored data, in percent of data points. Points that would be off the graph are moved to appear at the top. Monitored levels near zero (''Off'') are examples of this, as rather than occurring just over 1%, several of the points are over 10%. The boundaries of the modal ranges are shown, with points in between reflecting combinations of modes. These data are used to determine the ranges of the operating modes.

In defining **day types**, we first distinguish between **weekdays** and **weekend** days, with the latter including *only* Saturdays and Sundays. Then, any weekday which has less than half an hour of on-time (Full- or Low-power) is considered an **absence** day; the rest of the weekdays are **workdays**.

Disaggregating data by day type is important for several reasons. A principal reason is that because the monitoring periods are relatively short (i.e. two to four weeks), they may contain a distribution of day types different than found over the course of a typical year. In addition, the disaggregation helps construct explanations of why use patterns have their current (and possible future) mode distribution. We were unable to evaluate how representative each monitoring period is with user's long-run operating pattern, such as the percentages of absence days. Using the concept of absence days in daytyping avoids the need to identify or interpret holidays or separate them from vacations.

An **operating pattern** is the distribution of time spent in each mode, by day type, plus the frequency of each day type (as implied by the absence day rate). An operating pattern can be defined by only five numbers: the percentage of time for workdays and weekend days in full-on and low-power modes, and the absence day percentage. The off times (by day type), are simply the time not spent in the other two modes. Our analysis algorithm extracts the as-operated operating pattern from the monitored data.

We defined a **standard operating pattern** to evaluate energy savings from power management under typical or standard operating conditions. The pattern is intended to reflect the average operating pattern and therefore the average energy consumption of PC systems. Our definition of the standard operating pattern is based on that developed by LBNL in an earlier study to estimate electricity use by office equipment in commercial buildings (Piette et al. 1995). Piette et al., estimate that 76% of PC systems are turned on for some portion of the average weekday based on work by Szydlowski and Chvala (1994) and by Tiller and Newsham (1993). These studies contain the most reliable estimates of PC operating patterns, with the largest samples of individual monitored PCs representing several hundred systems.

The standard operating regime from Piette et al. specifies that a workday is 9.5 hours long, with a typical PC system in Full (''Active'') mode for four hours and Low (''Suspend'') for 5.5 hours. While only 76% of PC systems are on on any given weekday, 18% are left on all night for 14.5 hours, and 20% left on all weekend. The resulting percentages are shown in Table 2. We also defined a ''Maximum Savings'' operating pattern that takes the Full mode time from the Standard Operating Pattern with all other time in Low mode. This pattern indicates the upper bound of the possible electricity savings from current power management technologies with systems left on 24 hours/day.

Audit Methodology

To better characterize a population of computer systems and their hardware and operational characteristics, we conducted an audit of the machines in a sample office area at LBNL. A total of 70 computer systems were evaluated.

In the course of the project, we employed three levels of system audits. The simplest involves observing brand and model information by visual inspection of the outside of the case, without relying on the machine being on. The second level of audit examines configuration settings in any appropriate BIOS screens and control panels, observing the presence and configuration of any relevant software (such as screensavers or video or network card drivers), and potentially contacting the manufacturer for any power manage-

Table 2. *Standard Percentage of Time in Each Mode by Day Type, by Operating Pattern*

	Full	Low	On	Off
Standard Operating Pattern				
Workday	17	35	52	48
Weekend Day	0	20	20	80
Absence Day	0	20	20	80
Weekday Average	13	32	45	55
All Days Average	10	26	35	65
Maximum Savings Pattern				
All Days Average	10	90	100	0

Absence Rate: 20%

ment information they can provide. The third level adds measurement of the power drawn by the device over enough time to observe all important power management modes that occur, recording the amount of time between mode changes and the power level at each mode.

RESULTS

In this section we present information about the sources of data we used in the quantitative analysis of eleven devices, the power levels and operating patterns we observed, the energy use and energy savings values we calculated from the observations, and the economic implications of these. Further, we report the results from our audit of a larger sample of 70 PCs and 70 monitors.

Source Notes

Table 3 presents key information about our three data sources, and the following discussion reviews these and other aspects of the projects and resulting monitored data.

Of the three Energy Star PCs we monitored at LBNL, only two were enabled and one of these not optimally. The LBNL measurements were based on ''as-found'' operation; we did not modify the power management configuration. In the other projects the systems were enabled, if necessary, before monitoring. The FSEC project was designed to estimate the savings attained by properly enabled systems. Initially, a standard, non-Energy Star computer system and printer were monitored (not reported here), followed by monitoring of one properly enabled Energy Star compliant model of each (Lapujade & Parker 1994). Researchers at MIT measured four PC systems at one office site (Norford & Bosko 1995). Power management was enabled on four systems (it had been disabled previously) and monitored data were collected for each system.

Operating Patterns, Energy Use, and Savings

The results for our analysis of the operating profiles and energy use of the individual devices and systems are shown in Tables 4 and 5 and Figures 3 and 4. With the low number of devices currently in the database, the average statistics are not statistically significant.

Table 4 reports the operating patterns for six individual devices and five systems. Two of the devices (one PC and one monitor) had no Low-power time, as their power management features had been disabled. Seven of the devices were never left on overnight; none of the other four were left overnight on more than 20% of the time (usually much less).[c] None of these devices achieved even half of the Low-power time that the standard pattern specifies for nights or weekends. The Full-On time is higher than the standard operating pattern in six of the eleven cases. However, the total on-time is lower than standard in all cases due to much less time in Low mode than the standard case. While on average the absence rates are higher for this sample than for the 20% standard, this is a particularly difficult factor to draw conclusions about, particularly with many of the measurement periods being only three weeks in length.

Table 5 presents measured power levels. PC full-on power, averages 47 *W*, just over half the large monitor power, in contrast to the conventional wisdom that PCs and monitors require similar amounts of electricity. The 30 *W* Energy Star standard applies to a base model of the machine, though many PCs (perhaps most) will have additional components such as add-on cards or more memory that will raise the total demand over the 30 *W* threshold; P1 is probably an example of this effect. The 2 *W* for Low-power for P2 is the power used when the system is completely off (it lacks a true suspend mode as discussed later); a more recent model from the same manufacturer has true low-power operating

Table 3. *Power-Managed PC Monitoring Studies*

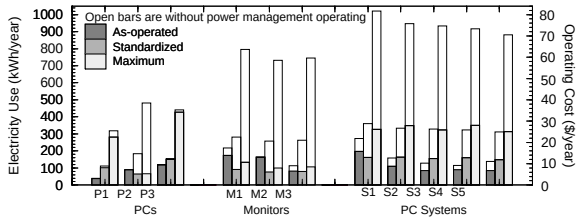
Source Code	Name	Monitored PCs	Monitored Monitors	Systems	Devices	Length *(weeks)*
LBNL	Lawrence Berkeley National Laboratory	3	3		P1, P2, P3; M1, M2, M3	2-10
FSEC	Florida Solar Energy Center			1	S1	12
MIT	Massachusetts Institute of Technology			4	S2, S3, S4, S5	4

Table 4. *Operating Pattern—Percent of Time by Daytype*

Code/Source	Workdays On	Workdays Low	Workdays Off	Weekend Days On	Weekend Days Low	Weekend Days Off	All Days On	All Days Low	All Days Off	Absence Rate %
PCs										
P1 / LBNL	17	7	76	0	0	100	9	3	88	29
P2 / LBNL	31	0	69	0	0	100	15	0	85	32
P3 / LBNL	24	14	62	3	6	91	16	11	73	8
Monitors										
M1 / LBNL	28	8	64	10	3	88	21	6	73	7
M2 / LBNL	38	0	62	2	0	98	22	0	78	22
M3 / LBNL	22	9	69	0	0	100	11	4	85	32
Systems										
S1 / FSEC	24	13	63	0	2	98	17	10	73	0
S2 / MIT	20	16	64	0	0	100	9	8	83	35
S3 / MIT	15	14	70	0	0	100	7	7	86	35
S4 / MIT	27	12	61	0	0	100	9	4	88	55
S5 / MIT	14	17	69	0	0	100	7	9	84	30
Average (n = 11)	*24*	*10*	*66*	*1*	*1*	*98*	*13*	*6*	*81*	*26*
Standard Operating Pattern	*17*	*35*	*48*	*0*	*20*	*80*	*10*	*26*	*65*	*20*
Maximum (Always On)	*17*	*83*	*0*	*0*	*100*	*0*	*10*	*90*	*0*	*20*

modes. P2 is also the only device that consumed electricity when nominally off. The Low power for P3, 49 *W*, is considerably above the 30 *W* Energy Star standard, and reflects the operation of only one PC power management method, spinning down the hard disk. The monitors in this table use just 5 *W* on average in their low-power mode, contrasting sharply with the PC systems that generally fall close to the 30 *W* threshold (the low-power mode for the monitors in S2-S4 are reported as zero).

Figure 3. *Annual Energy Use, with and without Power Management*



The operating patterns and power levels are combined to produce annual energy use values, as shown in Figure 3. The As-Operated values range from 37 to 273 *kWh/year*. For some devices, the standardized values are considerably higher than the as-operated; P1, for example has just a third the total on-time of the standard. For the power-managed scenarios, most devices rose from As-Operated to Standardized due to the higher low-power times in the standard scenario; only when the As-Operated Full-on time was particularly high was the standard value lower than the as-operated value. For the non-power-managed (NPM) estimates, the standard energy use is larger than the as-operated in all cases, since none of these devices had total on-time as high as that in the standard case. Not surprisingly, the standard energy use values are considerably more consistent within each device type than are the as-operated values.

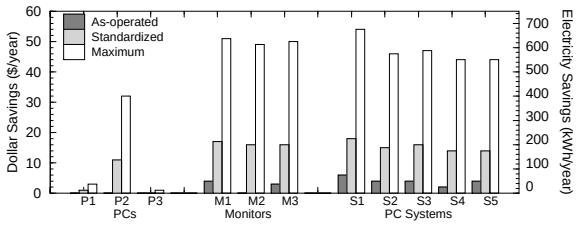
Table 5. *Power Levels and Monitoring Period Length*

Code	Monitor Size *(inches)*	Power Levels *(W)* On	Low	Off	Weeks of Data
P1		36	32	0	2
P2*		55	2	2	4
P3		50	49	0	10
M1	17	91	7	0	4
M2*	17	84	3	0	6
M3	17	85	4	0	4
S1	17	117	29	0	12
S2	14	108	32	0	4
S3	14	107	29	0	4
S4	14	105	33	0	4
S5	14	101	29	0	4
Averages					
PCs		47	28	1	5
Monitors	17	87	6	0	5
Systems	15	108	30	0	6

*Power management not enabled during monitoring of these devices.

Figure 4 shows the estimated annual energy savings for each of the three scenarios. The estimated energy savings for two of the PCs (P1 and P3) are small due to relatively low difference in power level between Full-on and Low and smaller low-power time. The other PC (P2) has high savings

Figure 4. *Annual Energy Savings*



but at the cost of not having a true suspend mode. It turns itself off instead, so that recovery requires rebooting the machine (dissuading all but the most dedicated user from enabling it). The monitors save considerably more, particularly when enabled, due to higher differences between low and full-on power levels. Standard monitor savings are also more similar across different devices. For S1, the power savings for the PC (6 *W*) is only 7% of the power savings from the whole system (the rest being the monitor). If the amount of low-power time was the same for both devices, the standardized savings would be about 15 *kWh/year* for the PC and 205 *kWh/year* for that monitor. From one-time power measurements, we know that the MIT (S2-S5) systems also have higher monitor than PC power savings, approximately four times as much. The individual monitors are larger than those in the combined systems which is part of why they tend to save more energy in the standardized and maximum scenarios.

FSEC developed additional annual energy savings estimates for System S1 using a different methodology. The estimated savings of 75 *kWh/year* by our method contrasts with the 44 *kWh/year* of savings shown in the FSEC report. Our estimate used the same system as the baseline, but with power management disabled. The FSEC estimate was a retrofit study, comparing the Energy Star system with a different non-Energy Star baseline PC and monitor. The active power on the non-Energy Star PCs and monitor was 17 *W* less than the Energy Star system.

For the PCs, the energy savings are meager in two of the cases due to the small power savings that power management accomplishes. For those monitors and systems successfully saving energy, the percentage savings are similar. For the as-operated case, the savings range by a factor of two, from 32 to 75 *kWh/year* (about 20% to 39% of the non-power-managed use). The maximum savings range from 570 to 690 *kWh/year* (from 62% to 86%).

Economics

The results presented here are for devices with built-in power management features so that there is no extra hardware cost for accomplishing power management. The primary cost to achieve savings from power management is the labor for the user or computer specialist to understand enough of how power management works to successfully configure the system. Many companies will need to believe that the dollar savings from power management will pay for this labor cost within a year or two to consider that enabling machines is a worthwhile investment. The dollar savings shown in Figure 4 are based on $0.0775/*kWh*, which is the average electricity price in the United States (EIA 95). We don't consider the potential for peak demand savings or cooling benefits.

The as-operated savings are minimal, with the highest savings being $6/*year* and $4/*year* more typical. This reflects the low occurrence of night and weekend use in this sample, as it is during those times that many hours of energy-saving low power mode can typically occur. For organizations with many PCs, particularly with many of the same or similar model, investing computer management personnel time in enabling power management can be cost-effective. Standard savings are about $15/*year*. The maximum savings are multiple of (just over three times) the standardized savings.

Audit Results—PCs

We conducted the audit to determine the degree to which Energy Star compliant equipment had penetrated the sample population (70 PCs and 70 monitors), the system characteristics, the degree to which power management appeared to be enabled, and the portion of these that were successfully entering low-power modes. As an audit, this did not include metering of operation by the user, but did include one-time power measurements of some devices.

Twenty-eight of the 70 audited PCs appear to be capable of power management as envisioned by the Energy Star program, but only ten appear on the Energy Star list. Of these 28, 24 were found to have a ''main switch'' for turning power management on and off (in most cases with additional switches for controlling individual devices). Of these, five were set 'off' so that no power management would occur, and of the remaining 19, four had all subsidiary switches off, with most of the rest on a 'Low' setting. Thus, the fact that a main power management switch is on should not be taken as an indication that power management is fully or substantially enabled. The machines that lack a 'main switch' utilize additional software (not part of the BIOS) to turn the machine off entirely; none of these machines are presently configured to operate this way. As percentages of the auditable machines, 11% were enabled for maximum power management, 41% were enabled for some, and 48% were disabled. We found the hard disk spin down specifically enabled on five machines and disabled on 16 machines; on the rest it is controlled by other switches. Whether the machines are actually entering low-power modes is another matter which can only be determined with direct metering. Only 7 of 12 enabled machines (2 additional ones could not be tested) actually reduced their power use, ranging from 1.8 to 16.5 *W*, with an average of 6.6 *W*.

Audit Results—Monitors

The monitors are considerably more successful than are PCs in power management. Thirty-four apparently meet the Energy Star requirements. Twenty are ''Universal'' and accept either a DPMS signal, *or* a blank screen generated by screen-saver (or other) software; the 14 other monitors are triggered only by DPMS signals.

Sixteen of the compliant monitors (and 30 of the entire set) were left on at the time of the audit, of which 12 were in a suspend mode. For the non-compliant monitors, one was in suspend, five were running screensavers, and the other eight were fully operational. Of the 12 monitors in suspend, eight were attached to PCs that were off, and in only one case were both the monitor and PC in suspend. Of the 22 PCs left on at the time of audit, ten had their monitor turned off; of the remaining 12, three were fully operational, five were running screen-savers, and four were in suspend mode. For the compliant monitors, 12 were attached to PCs on at the time of the audit, and of these, six were off, four in suspend, and one each in screensaver mode or fully operational. Thus, the fraction that are accomplishing power management of these are one third of all monitors and two thirds of compliant ones.

DISCUSSION

In this section we review what we learned from the data collection and audit activities. While some of these findings derive from direct observations, others are based on anecdotes of experiences with power management. There is no substitute for the metered case study data, since laboratory tests don't reveal the variety and subtlety of actual person-machine interaction. We identified many obstacles to identifying devices that are Energy Star compliant and saving energy, and reasons why potential power management savings usually don't materialize. We also outline outstanding research issues, and our recommendations for policy and future research.

Difficulties in Examining Performance of Energy Star Computers

It is often difficult to identify which devices are in fact Energy Star compliant, which are enabled, and which are successfully saving energy. The problems are due to difficulty in equipment identification and mis-identification, system complexity and assembly, software and hardware barriers, and lack of feedback. For some computer models, only a portion of the devices carrying the identical model number are compliant. Sometimes, compliant and non-compliant devices have distinct, but similar, model numbers. Many compliant models are not on the Energy Star list, and may have no obvious indication of their compliance. The user of the machine may not have the hardware manuals that came with the system or even know where they are. Many if not most users are unaware of, or misinformed about, the power management capabilities of their system. PCs and monitors have an increasing number of components that can

affect power management, and they can interact in unexpected ways. These components include basic and add-on hardware and software, and many will have been added after assembly by the primary manufacturer.

An audit beyond the first level can be stymied by the auditor not knowing required passwords. Without these, the BIOS configuration may be hidden, the system may not boot-up, a screensaver may not terminate, or a Local Area Network (LAN) connection may not be made, changing the system's power management behavior. Checking BIOS settings can require rebooting, which would interrupt any active applications, risking loss of data or the LAN connection. Some elements, such as the network and video cards are not visible at all externally, making it difficult to identify the manufacturer and model. Serial numbers can be hard to find or read, since they are generally found on the back of the device, often under cables.

When a monitor accomplishes power management, the screen will dim or go blank, letting the user or auditor know that it is occurring. When a hard disk audibly spins down, or delays the appearance of keystrokes when spinning up, it indicates that the PC is accomplishing some power management. Other than that, it is difficult to know when a PC is accomplishing any further power management.

Reasons Why Power Management is Usually Defeated

Once a system has been identified as capable of power management, there are still many reasons why energy savings may not occur. We have categorized these as general problems, reasons why power management is not initially enabled, why it is specifically disabled, or why savings do not occur despite proper enabling. These problems are not mutually exclusive; many problems have several root causes.

General Problems. Energy efficiency in office equipment is not a high priority for most people. As mentioned, many have no idea whether their PC and monitor are capable of power management, and often don't even know what power management does or why. At least one person in our monitoring sample thought his CPU was Energy Star-compliant though in fact it isn't. Often the person who 'sets up' and maintains a computer system is not the person who is its primary user. Power management information known by MIS personnel may not get passed along to the ultimate user, particularly when there are so many other, more pressing, details to relate at the same time. Aside from monitor blanking and disk spin-down, most users will be unaware of power management succeeding. As power management becomes more effective, it may be less apparent, unless user feedback is designed into the system. People may believe that they are saving energy when they are not (as with screensavers), or even when it is not possible. A final category of interference is hardware limitations introduced by particular power management strategies. Some PCs use less than 30 W when fully active, achieved in part by limiting the capacity for additional cards.

Devices Not Enabled. There are many reasons why people may not understand the need for, methods to, or subtleties of, enabling power management, or be dissuaded from doing so. The presence of an Energy Star logo on the box a device is shipped in, on the hardware itself, or on the screen during system startup, can suggest that energy savings are inherent. As power management gains more options and subtleties, users may not understand them or recognize to what extent they are valuable or even operating. Some systems require more than a modest amount of time and knowledge to set up (presuming the user realizes that it needs the setup). With power management configuration part of general system setup operations, there is the danger that a user may unknowingly change some unrelated configuration option that causes the system (or part of it) to malfunction.

Devices Actively Disabled. Even when initially enabled, some circumstances lead to it being subsequently disabled. Some combinations of hardware and software lead to power management that causes operational failure such as system freezing or dropped network connections. Some power management methods introduce delays that are considered 'excessive' by users. Few people will accept PC power management that turns the system off entirely (though this can be satisfactory for monitors). Some users were aggravated by early Energy Star models due to the minimal number of options or time settings. People may act on early bad experiences with power management that they themselves experienced, or were told to them by others, even when no longer applicable.

Devices Enabled but Not Powering Down. Even when properly configured, power management may still fail to operate. LAN cards often keep a machine active that would otherwise enter low-power modes. Simply removing the network connection often does not alleviate this; the LAN card must be physically removed, replaced, or the BIOS reconfigured. System ''accelerators'' (such as for graphics) take over some tasks from the processor, often operating directly on the system memory, potentially interfering with System Management Mode (SMM) signals. Upgraded processors and application or network software can also interfere with proper operation of power management; conversely, power management can cause problems for some applications or network connections. Some applications may not operate properly when the processor speed is reduced. Many people enjoy having 'screen art' from screensavers on their monitor while they are doing other work nearby. CD-ROMs

playing music could keep the computer awake, and perhaps even the monitor.

Monitor Cords

Another power management strategy for monitors is for the PC to completely power it down with the monitor plugged into the switched convenience outlet present on some PCs; this is a compliance alternative for Energy Star PCs. This allows energy savings from monitors without built-in power management capability. This strategy does cause monitors to take longer to recover from ''off'' than do those that utilize a true sleep mode. Many monitors come with power cords that don't match the convenience outlet.

Switched outlets also cut power to the monitor when the PC is turned off. If a PC is shut off (and the screen goes blank) the monitor sees this as simply a blank screen and doesn't know that the PC is off. An enabled Energy Star monitor that has begun the power management sequence will continue it, eventually getting to suspend via its internal timer. If the monitor had been active, it will usually go to sleep, but not necessarily to suspend.

Adaptor cords exist that facilitate plugging more monitors into the switched outlet on the PC, avoiding monitor power use while the PC is off. The cords can be bought for as little as $3.00; to pay for this at $0.0775/*kWh* requires saving about 40 *kWh* of electricity. For a monitor drawing 10 *W* in suspend mode, it would take about 4,000 hours to recover the investment. At a weekly average 65% PC off time, it would take 8.5 months to pay for the cord, with savings after that accruing at $4.50/*year* (assuming it was never switched off).

Outstanding Questions

A number of issues remain unanswered or can be expected to change over time. These affect estimates of the amount of energy saved by power management, and how much more could be saved if particular technologies or policies were adopted. The questions include the percent compliant, percent enabled, and degree successful; uncertainties in use patterns; a blurring of the line between power-managed and not and between enabled and not; and use beyond offices.

A key issue for the near term is to determine if, and by how much, the fraction of machines enabled and saving energy rises, distinguishing among new machines and the existing stock and between PCs and monitors. At this point in time, there are not enough data on the present situation to confidently compare it with future estimates. To track the compliance and enabling rates, it will be necessary to collect more audit and monitored data to have large enough samples to warrant statistical summaries.

Night and weekend use is the most important factor for measuring total energy use and potential savings from power management. For daytime energy use, the potential savings from slowing the processor clock may be significant; reawakening appears to cause no delay, so could be used with very short delay times. Daytime energy savings can contribute to peak demand and air conditioning reduction, further increasing the dollar value of the energy savings. It seems likely that most office work patterns and computer use will become more irregular with trends in the workplace such as flextime and telecommuting. These use patterns complicate analysis and make estimates more uncertain, particularly for absence days.

For purposes of analyzing the current and potential savings from power management in PCs, it is typical to divide devices into those that are power managed (Energy Star compliant) and those that are not, and for the power managed set, to those that are enabled and those disabled. However, we are seeing more machines with some power management features but that are not Energy Star compliant, so that one cannot assume that non-compliant devices have no power management savings. Since Energy Star addresses low-power modes only, reductions in active power are outside the scope of the program, but still a source of energy savings. Many PCs have only some of their power management features enabled, and for any power managed PC, only some of features may actually be working on a regular basis. Thus, the presence, enabling, and success of power management are more matters of degree than simply of presence or absence on individual devices.

Energy performance of personal computers should be measured in non-traditional settings such as homes, home offices, or industrial or 'non-personal' use. As people become more accustomed to, and dependent on, office technology, they will increasingly want to have similar functionality in their home computer setup. This will lead to more and more home machines on continuously, but with low active times, such that the need for and savings from power management will be large.

CONCLUSIONS AND RECOMMENDATIONS

Based on the technology evaluation, the results from monitoring, and from the audit, several key conclusions emerge.

Energy Savings Modest but Worth Achieving. For PCs with power management capability present and enabled, we found savings of about 40 *kWh/year* for the systems as-operated. Under a standard scenario that we believe more closely reflects typical use, savings are about 200 *kWh/year*, with most savings in the monitor. Including cooling energy

benefits, this translates to annual savings of $4 and $20 per year per system. Our analysis provides a rough estimate of the energy savings from power management. The number of devices analyzed precludes any statistical conclusions, but, bolstered by our audits, we observed both successful power management and many barriers to it. Better tracking of the percent of devices that are properly enabled and successfully saving energy requires wider audit sampling of the most detailed type described in the report (that is, including direct power measurements to observe the fact and magnitude of power reductions). With the rapid evolution of computing technology generally, new opportunities and impediments continually arise, requiring ongoing attention to gain the electricity savings available.

Focus on Getting Monitors Enabled. Power management is more successful (at saving energy) in monitors than in PCs, due to higher rates of successful enabling/use, and the larger power difference between active and low-power use.[d]

Improve Power Management in PCs. It is better to have power management options configurable through a control panel than through setup screens. Rebooting the machine is an inconvenient method to check or change the power management configuration. Control panels should provide for immediate testing of power management modes, so that the user can verify that they actually work (e.g. that the screen dims, suspends, or sleeps, or that the hard disk spins down), and that the system recovers from sleep modes while maintaining all running applications and network connections. As the number and variety of power management configuration options increases, there is greater need for interactive software that is easy to use and hides details overly complex for the typical user.

Plug Monitors into PCs. In some cases, energy can be saved on monitors that are not turned off when the PC they are connected to is powered down. When this is observed, a short, inexpensive, adaptor cord can be used to plug the monitor into the PC's switched outlet.

Improve Usage Patterns. Encouraging people to turn off their PC when little or no changes have been made to their disk during the day can avoid what can be considered ''unnecessary'' backups. This can be particularly valuable over a weekend.

ACKNOWLEDGMENTS

Prepared for the U.S. Department of Energy, Office of Building Technologies. This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

ENDNOTES

a. We use the term 'device' to refer to a monitor or a PC CPU; the combination is referred to as a 'system'.

b The 'modal distribution' is the portion of time in each primary operating mode (e.g. 30% Full-on and 70% Low-power). In this instance, it refers to each 15-minute period, though in other cases it refers to the distribution across an operating pattern (e.g. three weeks), which is then extrapolated to a full year.

c. For the lab as a whole, however, a survey of over 500 users revealed that nearly half never turn off their monitor.

d. On the other hand, some people are accustomed to turning off their monitor as they leave, but leave the PC on for backup, remote access, or to avoid lengthy rebooting, so the potential hours of low-power time may be much larger for PCs than monitors.

REFERENCES

Blackwood, Jonathan, and Michael Penwarden. 1994. ''Lean, Green Windows Machines.''*Windows Magazine*. May.

Energy Information Administration. 1995. ''Monthly Energy Review, September 1995,'' U.S. Department of Energy.

Easterday, Mark. 1995. ''A System Level Overview of Power Management.'' *In the Proceedings of The 1995 Silicon Valley Personal Computer Design Conference and Exposition*, Phoenix Technologies, August.

EPACT. 1992. ''Energy Policy Act of 1992,'' report 102-1018, 102d Congress, 2nd Session.

FSEC. 1995. ''Work in Progress,'' *BDAC energy files*, p. 8, Florida Solar Energy Center, Vol. 3, No. 1.

Intel/Microsoft. 1993. ''Advanced Power Management (APM): BIOS Interface Specification,'' Revision 1.1, prepared by Intel Corporation and Microsoft Corporation, September.

Johnson, Brian and Catherine R. Zoi. 1992. ''EPA Energy Star Computers: The Next Generation of Office Equipment,'' *in Proceedings of the 1992 ACEEE Summer Study on Energy-Efficiency in Buildings*, Washington, D.C.: American Council for an Energy Efficiency Economy.

Koomey, Jonathan, Michael Cramer, Mary Ann Piette, and Joseph Eto. 1995a. *Efficiency Improvements in U.S. Office Equipment: Expected Policy Impacts and Uncertainties (Draft)*. LBNL Report Number LBL-37383. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Lapujade, Phillipe. and Danny Parker. 1994. ''Measured Energy Savings of an Energy-Efficient Office Computer System,'' *in the Proceedings of the ACEEE 1994 Summer Study on Energy-Efficiency in Buildings.* Washington, D.C.: American Council for an Energy Efficiency Economy.

Nordman, Bruce, and Mary Ann Piette and Kris Kinney. 1996. *Measured Energy Savings and Performance of Power-Managed Personal Computers and Monitors.* LBNL Report Number LBL-38057. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Norford, L.K., and K.L. Bosko. 1995. *Performance of Energy Star Compliant Personal Computers and Monitors.* Massachusetts Institute of Technology, Department of Architecture, Building Technology Group. September.

Piette, Mary Ann, Mike Cramer, Joe Eto, and Jonathan Koomey. 1995. *Office Technology Energy Use And Savings Potential In New York.* LBNL Report Number LBNL-36752. Berkeley, Calif.: Lawrence Berkeley Laboratory.

Szydlowski, R.F. and W.D. Chvala, Jr. 1994. *Energy Consumption of Personal Computer Workstations*. PNL Report Number-9061. Richland, Washington: Pacific Northwest Laboratory.

VESA. 1993. ''Display Power Management Signaling (DPMSP Standard.'' Version: 1.0, Video Electronics Standards Association, August.