Title
Power levels in office equipment: Measurements of new monitors and personal computers

Authors
Roberson, Judy A.
Brown, Richard E.
Nordman, Bruce
et al.

Publication Date
2002-05-14

Power Levels in Office Equipment: Measurements of New Monitors and Personal Computers

Judy A. Roberson
Richard E. Brown
Bruce Nordman
Carrie A. Webber
Gregory K. Homan
Akshay Mahajan
Marla McWhinney
Jonathan G. Koomey
Lawrence Berkeley National Laboratory (LBNL)

ABSTRACT

Electronic office equipment has proliferated rapidly over the last twenty years and is projected to continue growing in the future. Efforts to reduce the growth in office equipment energy use have focused on power management to reduce power consumption of electronic devices when not being used for their primary purpose. The EPA ENERGY STAR® program has been instrumental in gaining widespread support for power management in office equipment, and accurate information about the energy used by office equipment in all power levels is important to improving program design and evaluation.

This paper presents the results of a field study conducted during 2001 to measure the power levels of new monitors and personal computers. We measured *off, on,* and low-power levels in about 60 units manufactured since July 2000. The paper summarizes power data collected, explores differences within the sample (e.g., between CRT and LCD monitors), and discusses some issues that arise in metering office equipment. We also present conclusions to help improve the success of future power management programs.

Our findings include a trend among monitor manufacturers to provide a single very low low-power level, and the need to standardize methods for measuring monitor *on* power, to more accurately estimate the annual energy consumption of office equipment, as well as actual and potential energy savings from power management.

Introduction and Background

The goal of the US EPA's ENERGY STAR Office Equipment program is to reduce office equipment energy consumption by encouraging manufacturers to incorporate available power management technology into their products, which consumers can identify by the ENERGY STAR label. Energy saved by power management of office equipment is currently estimated at 23 TWh/year, with another 17 TWh/year savings possible if power management were present and functional in all office equipment (Kawamoto et al. 2001). Personal computers and monitors currently consume approximately 40% of all energy consumed by office and telecommunications equipment in U.S. commercial buildings (Roth et al. 2002).

Effective use and continued development of power management technology will continue to be an important tool in the overall strategy for reducing energy used by office equipment.

This paper summarizes and discusses the methods and results of measuring the energy consumption and power management capabilities of a sample of new monitors and computers. The research was conducted in support of the ENERGY STAR Office Equipment program; the results will be used to improve estimates of program energy savings and carbon emission reductions, and to inform revisions of the ENERGY STAR criteria for these products.

Our sample consists of 35 monitors and 26 computers manufactured between July 2000 and October 2001. It includes cathode ray tube (CRT) and liquid crystal display (LCD) monitors, desktop and laptop computers, and integrated computer systems, in which power consumption of the computer and monitor cannot be measured separately. For each machine we measured power consumption when *off, on*, and in each intermediate or low-power level.

A more detailed account of this research project is available as Report LBNL-48581 (Roberson et al. 2002).[1]

Estimated Savings from Power Management

The Energy Star program measures its success in terms of energy saved and carbon emissions avoided. Reliably estimating the energy saved by power management for each type of office equipment depends on assessing the following factors as accurately as possible:

- Equipment stock (calculated from estimated annual shipments and equipment lifetime),
- Typical usage patterns (percent of time the equipment spends in each power mode),
- Power management success rates (the percent of equipment in which power management is present, enabled, and functional), and
- Average power consumption in each power mode (off, on, and low power).

The last three factors are combined to yield a typical unit energy consumption (UEC), which when multiplied by equipment stock provides an estimate of total annual energy consumption. Comparing this with estimated energy consumption in the absence of power management provides annual savings from power management (Kawamoto et al. 2001).

Office equipment manufacturers participating in the ENERGY STAR program regularly provide EPA with a list of compliant models (those that meet ENERGY STAR criteria) and their relevant characteristics, including power used in each power mode. EPA uses this information to evaluate progress toward its goals, and complements it with data collected by LBNL, including field surveys of office equipment usage patterns and enabling rates (Webber et al. 2001), and measurements of power consumption (Nordman et al. 1996).

Savings estimates for the ENERGY STAR Office Equipment program have until now been calculated using *on* (or active) power levels reported by manufacturers. *On* power levels are important because they establish the baseline energy consumption from which power management savings are calculated. One purpose of this study was to provide measured data for all (not just low) power levels, to compare with and supplement manufacturer-reported values to improve the accuracy of program savings estimates.

---

[1] LBNL-48381 is available for download at http://enduse.lbl.gov/Projects/PCMonitor.html.

ENERGY STAR Criteria

Another purpose of this study was to provide measured power consumption data for evaluating revisions to ENERGY STAR criteria. In general, the 25% most efficient models in each equipment category are eligible for the ENERGY STAR label, which provides an incentive for manufacturers to improve the efficiency of their products. As the efficiency of each product category improves over time, the relevant ENERGY STAR criteria are revised accordingly.

Current ENERGY STAR monitor and computer criteria specify maximum power use in low-power level(s), but do not specify maximum power use when the equipment is *off* or *on*.

Monitors. Current criteria for ENERGY STAR monitors (Version 3.0, effective July 1, 1999) specify two low-power levels: ≤ 15W in *sleep,* and ≤ 8W in *deep sleep*, regardless of monitor type or size (US EPA 2002). The terms *sleep* and *deep sleep* do not necessarily correspond to terms manufacturers use to describe monitor low-power levels. In effect, *deep sleep* becomes the monitor's lowest low-power level, while *sleep* is a second, higher low-power level, if any is present.

Computers. The ENERGY STAR program has established different power consumption criteria[2] for computers and integrated computer systems. From EPA's current computer MOU (memorandum of understanding) with participating manufacturers, a computer is defined as "…a desktop, tower or mini-tower, or portable unit…" and integrated computer systems are defined as:

> "(s)ystems in which the computer and visual display monitor are combined into a single unit. Such systems must meet all of the following criteria: it is not possible to measure the power consumption of the two components separately; and the system is connected to the wall outlet through a single power cable" (US EPA 1999).

From these definitions, it is not clear whether laptop (or notebook, or portable) computers are to be considered computers, integrated computer systems, or both. In any case, their technology and power characteristics are distinct enough that for the purposes of this report, we consider desktop computers, laptop computers, and integrated computer systems to be separate equipment categories. Of the 26 computers in our sample, there are 14 desktop computers, nine laptop computers, and three integrated computer systems.

Current criteria for ENERGY STAR computers (Version 3.0, Tier 2, effective July 1, 2000) specify a single low-power level, *sleep,* depending on the size of the computer power supply, as seen in Table 1. Guideline A applies to virtually all personal computers, including those in our sample. Current criteria for ENERGY STAR integrated computer systems is that they use ≤ 35W in *sleep* (US EPA 1999).

As with monitors, the term *sleep* seldom corresponds to power management terms that appear in the operating system or user interface. However, because ENERGY STAR criteria specify a single low-power level for computers and integrated computer systems,

[2] The criteria for each Energy Star product are specified in a memorandum of understanding (MOU), which serves as a guideline for participating manufacturers and other program stakeholders.

sleep, in effect, becomes the lowest low-power level exhibited by a computer or integrated system.

Table 1. Criteria for ENERGY STAR Labeled Computers (US EPA 2002)

	Power Consumption in Sleep Mode
Guideline A:	
Power Supply (W)	
≤ 200	≤ 15 W
201-300	≤ 20 W
301-350	≤ 25 W
351-400	≤ 30 W
> 400	≤ 10% of power supply's maximum continuous output rating (W)
OR	
Guideline B:	≤ 15% of power supply's maximum continuous output rating (W)

Power Management Technology and Terminology

Power management introduces one or more low-power levels between *on* and *off*. In each successive low-power level, more internal hardware components are slowed down or turned off, and more time is required for the equipment to recover, or wake up. Terms used to describe low-power levels vary between hardware and software manufacturers and versions, but efforts are underway to standardize power terminology (Nordman et al. 2002).

Early versions of power management, including Advanced Power Management (APM), were controlled primarily by the BIOS (Basic Input-Output System), with minimal involvement of the operating system. With Advanced Configuration and Power Interface (ACPI, introduced in 1998), primary control of power management shifted from the BIOS to the operating system, and power management interfaces became simpler, though varied. ACPI effectively standardized power management technology among Intel processor-based computers; Apple computers use technology that is distinct from but similar to ACPI (Nordman et al. 1996).

In general, power management in monitors has been simpler, more reliable, and more important – in terms of potential energy savings – than in computers (although that could change). Most new monitors are capable of power management, but require that a signal be sent from the computer through the video card before power management can be initiated (Nordman et al. 1997).

Given the lack of standard definitions for power management terminology, it is important that terms be carefully defined and consistently used. In this report, terminology used by an operating system interface is quoted (e.g., "standby"); we do not attempt to establish a correlation between these terms and measured power levels. Rather, we are primarily concerned with measuring the power consumed in all available low-power levels, and comparing the power used at each level to power used when the equipment is *off* and *on*. In addition, to inform EPA's revision of relevant ENERGY STAR criteria, we also tried to establish some correspondence between measured low-power levels and current ENERGY STAR criteria for monitors, computers, and integrated computer systems.

Therefore, for purposes of this report, we use the italicized terms *off, on, sleep,* and *deep sleep* to refer to measured power levels. *Sleep* and *deep sleep* are based on terms used in the ENERGY STAR criteria. Table 2 provides our definitions. Unfortunately, some confusion is inherent in these definitions, because the lowest low-power level in computers is called *sleep*, while the lowest low-power level in monitors is called *deep sleep.*

Table 2. Definition of Power Management Terms As Used in this Report

	Desktop and Laptop Computers and Integrated Computer Systems	**Monitors**
Off	The unit is plugged in (powered), the power button is in *off* position, and the power indicator is dark.	
On	The power button is in the *on* position, the power indicator is green, and the processor is idle.	The power button is in the *on* position, the power indicator is green, and the screen displays an 'empty' desktop; no application windows are open.
Low-power Levels		
Sleep	The lowest power level between *on* and *off.*	The lowest low-power level between *on* and *deep sleep*.
Deep Sleep	Not applicable	The lowest low-power level between *on* and *off.*

Methodology

Description of Sample

To characterize the energy use of new models of each equipment type, we metered a sample of the range of brands, cost, size, and type of models on the market, based on available data about market share by equipment manufacturer. We report data for 35 monitors, 14 desktop computers, nine laptop computers, and three integrated computer systems. All were manufactured between July 2000 and October 2001.[3] Although we present a statistical analysis of the data, we acknowledge that our sample size, particularly for the computer categories, is small and thus may not be statistically significant.

Monitors. Monitor size is measured diagonally and rounded to the nearest inch. For CRT (cathode ray tube) monitors, actual size is usually about an inch less than nominal (listed) size because the visible area of the tube is reduced when surrounded by (set into) the housing. Unless otherwise noted, this report describes CRT monitors by their nominal size. For LCD (liquid crystal display) monitors there is no distinction between actual and nominal size. Our sample includes four CRT sizes: 15", 17", 19", 21"; and three LCD sizes: 15", 17", and 18".

Three monitors were connected to Macintosh computers; the rest were connected to computers with a Windows operating system. The following brands are represented in our monitor sample: Acer, Compaq, Dell, Gateway, HP, KDS, Micron, NEC, Philips, Samsung, Sony, and ViewSonic.

---

[3] For models that did not exhibit a manufacturing date, we estimated the date by subtracting a month from the date purchased (if the unit was metered in an office) or acquired (if it was metered in a retail showroom).

Computers. The sample of 14 desktop computers consists of Compaq, Dell, Gateway, HP, Micron, and Sony brands. Processor speeds ranged from 733 to 1800 MHz. All used a Windows operating system; four had Windows 98, five Windows 2000, one Windows ME, and four Windows XP.

The sample of nine laptop computers consists of Apple, Dell, Fujitsu, HP, IBM, Panasonic, and Toshiba brands. Of the six laptops for which we have processor speed, the range was 400-1000 MHz. All except the Apple, which used Mac OS X, had a Windows operating system; four had Windows 98 and four Windows 2000.

The three integrated computer systems in our sample are (1) an Apple iMac, in which a computer and CRT monitor are integrated into the same housing, (2) a Gateway Profile, in which a computer and LCD monitor are integrated in the same housing, and (3) an Apple G4 computer power-linked to an Apple Studio Display LCD monitor, in which the computer and monitor are connected by a single cable that carries all video, USB, and power signals (the monitor cannot be plugged into an outlet, and the components cannot be metered separately).

Metering Protocol

In this study we used power line meters (PLMs) manufactured by Electronic Product Design, Inc. (EPDI, Springfield OR). The meters were calibrated by the manufacturer before the study. Subsequent to the study, we compared two of the PLMs to a laboratory-grade power analyzer at LBNL and found the PLMs to be accurate (0W) for no-load measurements, and to within 0.4% for "real" power measurement.

Power measurement was conducted by "spot metering," in which each machine is plugged into a power meter and "real RMS" power consumption in watts (W) is measured for each power level at a single point in time. Whenever a machine entered a new power level, we waited at least 15 seconds for the power to stabilize, observed the readout for 30 seconds, and recorded the range and mode (most frequent number) of the power readout (PLM measurements and calculations are updated every second). Watt values were recorded and averaged in tenths of a watt, and reported to the nearest watt.

Monitors. Monitor *on* power was measured first with the (desktop) computer *off*, and again after the computer booted up and displayed the user-defined desktop, with no applications or other windows open. Because we were trying to capture the effect of user settings in the field, we did not adjust contrast, brightness, refresh rate, or resolution settings.

Computers. Unlike desktop computer *on* power measurements, laptop and integrated computer system *on* power measurements include power required to illuminate the display. All *on* power measurements were made when the processor was idle. Laptop batteries were fully charged before measurement to exclude the effect of battery charging.[4]

Results

[4] Our measurements of laptop power do not include battery charging, and so are not a duty-cycle average.

Our results include quantitative (numerical) findings as well as more qualitative observations. Each topic is introduced with an explanation of the context of our investigation and analysis.

Monitors

Table 3 shows power consumption in all power levels by monitor type and size.

Table 3. Average Monitor Power Consumption by Monitor Type and Size

Monitor Type	Size	Count (n)	Off (W)	Deep Sleep (W)	On (W)
All Monitors	**All**	35	1	5	55
CRT	**15"**	4	1	2	58
	17"	5	1	2	61
	19"	5	2	14	85
	21"	5	1	7	95
LCD	**15"**	9	2	2	20
	17"	4	2	2	35
	18"	3	2	3	54

Note: Values for the ENERGY STAR *sleep* level are not shown here because only 17% of monitors in our sample exhibited more than one low-power level.

Monitor type and size. The power consumed by a monitor when *on* is primarily a function of its type (CRT, LCD), size, and the nature of the displayed image. LCD monitors use less power when *on* than CRT monitors of similar size. The larger the screen, the more power a monitor uses when *on*; this applies to both CRT and LCD monitors. Displayed image is primarily a function of the user's color settings and desktop graphics, and the size of any open application windows.[5] More power is required to display a lighter than a darker screen.

LCDs are available in different sizes than CRTs, whose actual diagonal size is about one inch less than the nominal (listed) size. Because CRT and LCD monitors use different technology and are sized differently, we need a metric other than diagonal screen size to compare them. In this paper we calculate approximate display area in square inches[6] and compare power consumption per square inch. We expect significant differences between CRT and LCD monitors, but not within each type.

The results in Table 4 confirm that LCDs use less energy than CRTs, but also indicate that among LCD monitors, power use *per square inch display area* increases with monitor size. The latter finding suggests that the difference between CRT and LCD *on* power decreases as monitor size increases, and also that there are opportunities for reducing the energy consumption of large LCD monitors, which should use no more power per unit display area than smaller LCD monitors.

Table 4. Average Monitor *On* Power (W) per (approximate) Square Inch Display Area

Diagonal Size (in)	15	17	18	19	21	All sizes
CRT	0.611	0.498	-	0.529	0.529	0.538
LCD	0.183	0.254	0.345	-	-	0.231

[5] Brightness, contrast, refresh rate, and resolution settings also affect the power a monitor uses when *on.*

[6] In our metering we did not record horizontal and vertical screen dimensions (i.e., aspect ratio), so we use the diagonal dimension (rounded to the nearest inch) and assume each monitor has an aspect ratio of 3:4 (height to width). Our calculations of monitor display area are therefore approximate.

Another potential metric for comparing CRT and LCD monitors is number of pixels, which is determined from the resolution. Pixel count has several advantages as a basis for normalizing monitor energy consumption; besides being able to make comparisons between monitor technology and size, incongruities in resolution or aspect ratio also become irrelevant. We did not record monitor resolution in this study, and so cannot determine their pixel count.

Monitor *off* power. Two-thirds (68%) of CRT monitors in our sample used 0W when *off,* compared to 12% of the LCD monitors.[7] The 19 CRTs in our sample used an average of 1W when *off,* compared to the 16 LCDs, which used an average of 2W when *off*. These results agree with those of Groot and Siderius (Groot & Siderius 2000), who found that on average, LCD monitors use 2.5W when *off,* and CRT monitors use 1.2W when *off*. These results are attributable to the fact that in most (if not all) LCD monitors the power supply is external, and therefore uses some power even when the monitor is switched *off*. However, the range of *off* power consumption (0-9W for CRTs, 0-4W for LCDs) suggests opportunities for reducing *off* power consumption in monitors, perhaps by including an *off* power specification in the revised ENERGY STAR criteria.

Monitor low power. Current ENERGY STAR monitor criteria specify power consumption in two low-power levels: ≤ 15W in *sleep*, and ≤ 8W in *deep sleep.* However, 83% of monitors in our sample exhibited only one low-power level, 94% of which were low enough to meet ENERGY STAR criteria for *deep sleep*. This indicates a trend among monitor manufacturers to provide a single very low low-power level.[8] We suggest that a revision of monitor criteria specify one low-power level, and that it be described by the term *sleep* instead of *deep sleep.*

The 25th percentile[9] for power use in *deep sleep* was 2W, whether calculated for the entire monitor sample, CRTs only, or LCDs only. Note that, at least among our sample, power used by new LCD monitors in *deep sleep* is equivalent to their power usage when *off.*

Monitor *on* power. Based on the results of this study, we estimate that the average monitor sold in 2001 has an *on* power of 65W (using data on shipments by type and size to weight the power levels resulting from this study). Previously, ENERGY STAR program savings estimates were based on an *on* value of 85W, which is a simple average of *on* power levels reported by participating manufacturers. The lower *on* power derived from this study would have a considerable impact on program savings estimates, which led us to investigate the discrepancy between measured and manufacturer-reported *on* power.

We first verified that our measurement techniques were generating accurate and reproducible results. As discussed earlier, the meters we used were tested to be accurate within 1% of the measured power level. Moreover, repeat metering of several machines yielded results that were very close to our original values. We therefore concluded that our measurement results accurately represent the real power levels under the conditions that we metered the sample equipment. We then looked at the nature of the data reported by

---

7 Note that because of rounding, "0W" means 0.0-0.4W, "1W" means 0.5-1.4W, and "2W" means 1.5-2.4W.

8 Since Windows 95, Windows operating systems have supported only the lowest monitor low-power level.

9 In a sample, 75% of values are greater than or equal to, and 25% are less than or equal to the 25th percentile.

manufacturers. We identified 15 monitor models in our sample that are also on EPA's list of ENERGY STAR monitors, and for which there are manufacturer-reported data. This subset of monitors includes CRTs and LCDs of all sizes. Without exception, reported *on* power was higher than our measured value, indicating a consistent difference in the way that manufacturers were either measuring or reporting their power data.

To determine the source of this bias, we contacted five monitor manufacturers, three of whom responded with information. Although each manufacturer used a different method to measure monitor power, in all cases the values reported to EPA were based on a "worst case scenario;" in the case of *on* power, this means maximum brightness and resolution, and a white screen. Also, manufacturers that tested multiple units of a given model reported the highest individual measurement. While manufacturers made a good faith effort to provide accurate data, the absence of a standard protocol for measuring and reporting data meant that each had to develop their own method, and each reported their worst case results for a variety of practical reasons.

By comparison, LBNL's measured values are intended to reflect typical rather than worst case operating conditions for monitor use. Because typical operating conditions are more representative of how equipment is actually used in the field, LBNL's measured power values are now being used to estimate ENERGY STAR program energy savings.

The process of resolving the discrepancy between measured and reported *on* power revealed some opportunities for improving ENERGY STAR program design and implementation. These include developing standard methods for manufacturers to use to measure product data, and continuing to supplement reported values with independent measurements of power consumed under typical operating conditions.

Computers

Table 5 shows power consumption in all power levels by type of computer. Table 6 shows a statistical (though not necessarily statistically significant) analysis of desktop and laptop power levels.

Table 5. Average Power Consumption by Type of Computer

Computer Type	Processor Type	Speed Range (MHz)	Count (n)	Off (W)	Sleep (W)	On (W)
Desktop	All	733-1800	14	3	9	70
	AMD Athlon	1000-1400	4	3	15	104
	Intel Pentium 3	733-1000	4	3	13	38
	Intel Pentium 4	1300-1800	6	3	3	67
Laptop	All	400-1000	9	2	3	19
Integrated System	All	600-870	3	6	15	91

Table 6. Statistical Analysis of Desktop and Laptop Computer Power Levels

	Desktop Computers (n=14)			Laptop Computers (n=9)		
	Off (W)	*On* (W)	*Sleep* (W)	*Off* (W)	*On* (W)	*Sleep* (W)
Minimum	1	28	2	1	14	1
Maximum	4	117	49	3	25	8
Average/mean	3	70	9	2	19	3
25^{th} percentile	2	50	3	1	15	2
Median	3	63	4	2	19	3

Desktop computers. Of 14 desktop computers in our sample, none used 0W when *off*. The range of *off* power was 1-4W, the average was 3W, and the 25th percentile 2W.

Current criteria for ENERGY STAR computers specify a single low-power level – *sleep* – depending on the type of network connectivity (if any) and size (W) of the computer power supply. Even if we assume that Guideline A of the MOU applies to all desktop computers in our sample, it is difficult in practice to assess the size of a computer's rated power supply without opening the computer housing, which was beyond the scope of our field protocol. Based on external visual indicators, we were unable to determine the power supply for any computers in our sample; therefore, discussion of our results in relation to ENERGY STAR criteria is limited to a suggestion that revisions of the computer criteria be based on attributes that are more readily apparent.

Desktop computers in our sample used 2-48W in *sleep* (the lowest low-power level); the average was 9W, and the 25th percentile 3W. However, 50% of the 14 computers in our sample exhibited at least two low-power levels, and one exhibited three low-power levels. This suggests that many computers spend time in low-power levels that are higher than the current ENERGY STAR *sleep* criteria. When revising the computer criteria, EPA might consider specifying power consumption in a second, higher low-power level, in addition to *sleep*.

Desktop computer *on* power ranged from 28-117W; the 25th percentile was 50W. In an attempt to correlate power consumption with a computer characteristic besides the power supply, we noticed that PC *on* power appear to be more closely correlated with processor make and model than with processor speed. Table 5 shows desktop computer *on* power by processor make, model, and speed. In our sample, the computers with Intel Pentium 3 processors averaged 38W when *on*, compared to an average 67W for those with Intel Pentium 4 processors, and an average 104W for those with AMD Athlon processors.

Laptop computers. The nine laptop computers in our sample used 1-3W when *off*; the average was 2W and the 25th percentile 1W.

Laptops used 1-8W in *sleep*, the average was 3W, and the 25th percentile 2W. Most (89%) of the laptops exhibited at least two low-power levels. Laptop *on* power consumption ranged from 14-25W; the average was 19W and the 25th percentile 15W.

Table 5 indicates that laptops had lower average power levels, in both *on* and *sleep* modes, compared to desktop computers. This finding is not unexpected, given that computer manufacturers go to great lengths to design laptops for low-power consumption, in order to extend battery run-time. We believe, however, that this discrepancy in power levels between laptop and desktop computers indicates significant technical potential still remains for reducing the power consumption in desktop computers. While some of these reductions may not be cost-effective, we suspect that others may be achievable at little to no cost (using the experience of consumer electronics as a guide, where reductions in standby power were achieved with essentially no increased cost to consumers).

Integrated computer systems. Though this sample is too small for statistical analysis, the *off* power range was 4-8W, *sleep* power range was 4-31W, and *on* power range was 54-

131W. All three met the ENERGY STAR (≤ 35W in *sleep*) criteria for integrated computer systems.

Conclusions and Recommendations

Many of our conclusions specifically address the ENERGY STAR Office Equipment program, but some are relevant to identifying and resolving broader issues in government and industry.

Consistent terminology. In the absence of any industry consensus on the definition and use of power management terms, the ENERGY STAR program can facilitate energy savings and minimize stakeholder confusion by more clearly defining and consistently using its own terms, both among the various documents produced for each labeled product, and to the extent possible, between products. The need for clear and consistent terminology extends – but is not limited – to products (e.g., "workstation") as well as power levels (e.g., *off* and *on).*

Consider the following example. In computers *sleep* is the lowest low-power level but in monitors *deep sleep* is the lowest low-power level, and *sleep* is a higher low-power level. We suggest that revision of product criteria is an opportunity to eliminate confusion by defining *sleep* as the lowest low-power mode among all categories of office equipment. When necessary to define a higher low-power level, use a compatible term, such as *light sleep.*

Standard methods. Manufacturers participating in the Energy Star program are making a good faith effort to comply with the relevant MOUs. EPA can improve program success by clarifying for each product the data that it needs and the methods to be used for collecting it. This recommendation extends and depends on the clear definition and consistent use of terms.

The obvious case described in this paper is that of monitor *on* power. The term *on* appears simple enough, but is manifested in a broad range of power consumption in monitors. Revisions to the criteria need to unambiguously define *on* and clearly specify the conditions (e.g., resolution, displayed image) under which *on* (and every other power level) is to be measured and reported.

***On* and o*ff* power.** Until now, efforts to reduce energy consumption of office equipment have focused on ensuring that idle equipment automatically undergoes power management. In the future, improved energy savings may depend on minimizing energy used when *on* and *off.* A recent study estimates that monitors, on average and on an annual basis, are *on* 37.4% of the time, in low-power mode 34.0% of the time, and *off* 28.6% of the time (Roth et al. 2002).

Our results for monitors, particularly LCDs, suggest opportunities for reducing *on* and *off* power levels, and revision of ENERGY STAR monitor criteria to include *on* and *off* power could ensure additional savings from this emerging technology. Inclusion of *on* power criteria will not only require a standard test procedure for measuring *on* power, but also a consistent method for normalizing power consumption to screen size (e.g., based on pixel-count).

Monitors. Although current ENERGY STAR criteria specify two low-power levels in monitors, only 13% of monitors in our sample exhibited two low-power levels. Given the trend among monitor manufacturers and Windows operating systems to support a single low-power level, we suggest that the ENERGY STAR monitor criteria be revised to specify a single *sleep* level.

Computers. Current ENERGY STAR computer criteria specify *sleep* power consumption according to the size of the computer power supply, which cannot be ascertained in the field. We therefore suggest that a revision of the criteria either include a requirement that the rated power supply be clearly and externally evident on each machine, or that *sleep* power be based on a computer characteristic that is more readily apparent.

Industry Trends. Continued success and improvement of the ENERGY STAR program depends on identifying new opportunities for energy savings, which requires continuing field measurements to characterize emerging power trends and supplement manufacturer data.

For both monitors and computers, trends in technology and usage patterns are having offsetting effects on the energy-savings of power management. For monitors, the increasing use of LCD display technology and lower low-power levels reduce energy use, but external power supplies increase *off* power consumption and larger screen sizes are driving up *on* power consumption. For desktop computers, improved controls and cooperation between hardware and operating systems may be improving power management success rates, but newer generations of processors appear to be increasing *on* power consumption. Increased reliance on laptop computers may reduce reliance on desktop computers and monitors, but there is also evidence the latter remain *on* more often than in the past. The aggregate effect of these competing trends will be borne out over time as we conduct further field metering and the ENERGY STAR program revises its aggregate impact estimates accordingly.

References

Groot, M.I., and P.J.S. Siderius. 2000. *Monitors Statistical Analysis: on-mode power consumption*. Delft, Netherlands: Van Holsteijn en Kemna BV, on behalf of Novem BV.

Kawamoto, Kaoru, Jonathan Koomey, Mike Ting, Bruce Nordman, Richard E. Brown, Mary Ann Piette, and Alan Meier. 2001. *Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed Report and Appendices.* Berkeley CA: Lawrence Berkeley National Laboratory.

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

Nordman, Bruce, Mary Ann Piette, Kris Kinney, Carrie Webber. 1997. *User Guide to Power Management for PCs and Monitors.* LBNL-39466. Berkeley CA: Lawrence Berkeley National Laboratory.

Nordman, Bruce, Alan Meier, Don Aumann. 2002. "Even Electronics Deserve a Good Night's Sleep: Toward Standard Power User Interface Elements." In *Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings* (in press). Washington DC: American Council for an Energy Efficient Economy.

Roberson, Judy A., Gregory K. Homan, Akshay Mahajan, Bruce Nordman, Carrie A. Webber, Richard E. Brown, Marla McWhinney, and Jonathan G. Koomey. 2002. *Energy Use and Power Levels in New Monitors and Personal Computers.* LBNL-48581. Berkeley CA: Lawrence Berkeley National Laboratory.

Roth, Kurt, Fred Goldstein, Jonathan Kleinman. 2002. *Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings - Volume I: Energy Consumption Baseline*. Washington DC: prepared by Arthur D. Little for the U.S. Department of Energy.

U.S. EPA. 1999. *Computer Memorandum of Understanding (Version 3.0)*. Washington DC: U.S. Environmental Protection Agency, Climate Protection Partnerships Division.

U.S. EPA. 2002. *Key Product Criteria: Monitors, Computers, and Integrated Computer Systems*. Washington D.C.: U.S. Environmental Protection Agency, Climate Protection Partnerships Division website: http://www.epa.gov/nrgystar/purchasing/6a_c&m.html#specs_cm

Webber, Carrie A., Judy A. Roberson, Richard E. Brown, Christopher T. Payne, Bruce Nordman, Jonathan G. Koomey. 2001. *Field Surveys of Office Equipment Operating Patterns.* LBNL-46930. Berkeley CA: Lawrence Berkeley National Laboratory.