Energy Use and Power Levels in
New Monitors and Personal Computers

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Abbreviations and Acronyms

As Used in This Report

ACPI   Advanced Configuration and Power Interface

APM   Advanced Power Management

CPU   central processing unit

CRT   cathode ray tube

ICS   integrated computer system

LBNL   Lawrence Berkeley National Laboratory

LCD   liquid crystal display

OS   operating system

PC   personal computer (a generic term that includes laptop computers, desktop computers and integrated computer systems; it includes both Apple and Intel-architecture machines)

PLM   power line meter

PM   power management

UC   University of California

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Abstract

Our research was conducted in support of the EPA ENERGY STAR Office Equipment program, whose goal is to reduce the amount of electricity consumed by office equipment in the U.S. The most energy-efficient models in each office equipment category are eligible for the ENERGY STAR label, which consumers can use to identify and select efficient products. As the efficiency of each category improves over time, the ENERGY STAR criteria need to be revised accordingly.

The purpose of this study was to provide reliable data on the energy consumption of the newest personal computers and monitors that the EPA can use to evaluate revisions to current ENERGY STAR criteria as well as to improve the accuracy of ENERGY STAR program savings estimates. We report the results of measuring the power consumption and power management capabilities of a sample of new monitors and computers. These 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, Macintosh and Intel-architecture computers, 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 low-power level. We identify trends in and opportunities to reduce power consumption in new personal computers and monitors.

Our results include a trend among monitor manufacturers to provide a single very low low-power level, well below the current ENERGY STAR criteria for *sleep* power consumption. These very low *sleep* power results mean that energy consumed when monitors are *off* or in active use has become more important in terms of contribution to the overall unit energy consumption (UEC). Current ENERGY STAR monitor and computer criteria do not specify *off* or *on* power, but our results suggest opportunities for saving energy in these modes. Also, significant differences between CRT and LCD technology, and between field-measured and manufacturer-reported power levels reveal the need for standard methods and metrics for measuring and comparing monitor power consumption.

Introduction

Energy conservation through equipment efficiency is an essential component of international and U.S. efforts to slow global warming and prevent the potentially catastrophic effects of climate change, caused primarily by increased atmospheric carbon dioxide levels that result from burning fossil fuels. In 1992 the U.S. passed the Energy Policy Act and signed the international Earth Summit treaty, both of which committed the federal government to actively reducing greenhouse gas emissions from all major sectors of the economy, including commercial office equipment (EPAct 1992, US EPA 2002b).

The proliferation of personal computers (PCs) and monitors in the 1980s and 1990s prompted the Environmental Protection Agency (EPA) to launch the voluntary ENERGY STAR energy conservation program, which encourages manufacturers of computer hardware and operating system (OS) software to incorporate available power management technology into their products, which consumers can identify by the ENERGY STAR® label.[1] Power management (PM), initially developed to extend the time that portable computers could be used without recharging the battery, is now commonly used to automatically reduce the energy used by office equipment that is *on* but idle, or not in active use (Webber et al. 2001).

Personal computers and monitors currently account for approximately 40% of all energy consumed by office and telecommunications equipment in U.S. commercial buildings (Roth et al. 2002). Energy saved by power management in office equipment is currently estimated at 23 TWh/year, with another 17 TWh/year of savings possible if PM were present and functional in all office equipment (Kawamoto et al. 2001). 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 (Nordman et al. 2000).

This report presents the methods and results of measuring the power management characteristics of a sample of monitors and computers manufactured between July 2000 and October 2001. The sample includes both liquid crystal display (LCD) and cathode ray tube (CRT) monitors, and both Apple and IBM compatible personal computers. For the purposes of this report, the term "personal computer" includes both Apple and Intel-architecture desktop computers, laptop computers, and integrated computer systems (ICSs). An ICS is a computer and monitor - either separate or integrated - that share a single power supply, which makes it very difficult (without sophisticated equipment) to separately measure power consumption of the two components.

For each machine, we measured power consumption when *off, on* and in each low-power level, under typical (as-found) operating conditions, at a single point in time. We then compared measured power levels to current ENERGY STAR power management criteria and manufacturer-reported power levels. Our results will be used to improve Office Equipment program savings estimates, inform revisions of the ENERGY STAR criteria for these products, and identify opportunities for improving ENERGY STAR program development and implementation.

Background

The following information provides additional context in which to interpret the results of our metering.

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[1] The ENERGY STAR® program has since expanded to include other office equipment products, appliances, consumer electronics, building materials and components, HVAC and refrigeration equipment, commercial buildings, and new homes. It is now jointly administered by the U.S. EPA and DOE (http://energystar.gov).

Estimates of Savings from Office Equipment Power Management

For each category of office equipment, reliably estimating the energy saved by power management (PM) depends on assessing the following factors as accurately as possible:
- Total equipment stock (calculated from estimated annual shipments and equipment lifetime),
- Average power consumption in each operating mode (*off, on,* and low power),[2]
- Typical usage patterns (percent of time the equipment spends in each operating mode), and
- PM success rates (the percent of equipment in which PM is present, enabled, and functional).

The last three factors can be 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 PM provides annual savings from PM (Kawamoto et al. 2001, Nordman et al. 2000).

Office equipment manufacturers that participate in the ENERGY STAR program regularly provide EPA with a list of compliant models (i.e., those that meet the criteria and are therefore eligible for the ENERGY STAR label) and their relevant characteristics, including power used in each power mode. This information is compiled in a database used by the government to evaluate program achievements and complemented by data collected by LBNL, including field surveys of office equipment usage patterns and enabling rates (Webber et al. 2001), and field measurements of power consumption (Nordman et al. 1996).

The purpose of this study was to provide reliable data on the energy consumption of new PCs and monitors that EPA can use to evaluate revisions to current ENERGY STAR criteria as well as to improve the accuracy of ENERGY STAR program savings estimates.

Energy Star Criteria

For a given type of office equipment, a particular model is eligible to bear the ENERGY STAR label if its manufacturer participates in the ENERGY STAR program, and it meets ENERGY STAR criteria for energy consumption while in low-power mode (any power level between *off* and *on*). For each category of office equipment (e.g., computers, monitors), the ENERGY STAR criteria are chosen so that the (approximately) 25% most energy-efficient models are eligible for the ENERGY STAR label.[3] To the extent that consumers and purchasers use the ENERGY STAR label to identify and buy energy-efficient products, this provides an incentive for equipment manufacturers to improve the efficiency of their products, and as the energy-efficiency of each equipment category improves over time, the relevant ENERGY STAR criteria need to be revised accordingly. Our tables and charts of our measured power levels includes 25th percentile values, which serve to identify, at least among our sample of new machines, an approximate target for a proposed revision of ENERGY STAR criteria for those products.

In this study we are not concerned with ascertaining whether products that bear the ENERGY STAR label are "compliant" with ENERGY STAR criteria. We are, however, interested in measuring the actual low power levels achieved by both ENERGY STAR and non-ENERGY STAR products. In other words, we want to

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[2] The terms *off, on,* and low-power are defined in a later section of this report.

[3] Original ENERGY STAR product criteria did not include energy consumption while in *off* or *on* mode, but because of the growing proportion of *off* and *on* modes in product UEC, some criteria are being revised to include *off* and *on* power. In these cases, the revised *off, on,* and *sleep* criteria are selected so (approximately) 25% of products on the market meet the combined (as opposed to individual) criteria.

evaluate the impacts of the ENERGY STAR program on the industry as a whole, not to evaluate the degree of individual partner compliance with the program.

Monitors

The ENERGY STAR monitor Memorandum of Understanding (MOU) (US EPA 1999b) defines a monitor as:

> "a cathode-ray tube (CRT), flat panel display (e.g., a liquid crystal display) or other display device and its associated electronics. A monitor may be sold separately or integrated into the computer chassis. This definition is intended primarily to cover standard monitors designed for use with personal computers. The following may also be considered a monitor: mainframe terminals, and physically separate display units".

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

Computers

The ENERGY STAR computer MOU (US EPA 1999a) defines a computer as:

> "a desktop, tower or mini-tower, or portable unit…To qualify the unit must be capable of being powered from a wall outlet, but this does not preclude units that are capable of being powered from a wall outlet and also from a battery…"

The same computer MOU defines integrated computer systems (ICS) 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".

Current ENERGY STAR computer criteria (Version 3.0, Tier 2, effective July 1, 2000) specify a single low-power mode – *sleep* – according to the maximum continuous output rating of the computer's power supply, as seen in Table 1. Guideline A applies to most computers (including all desktop computers in our sample), which are not on a network or whose network connectivity does not interfere with their ability to *sleep*. Guideline B applies to computers whose network connectivity in *sleep* requires involvement of the processor and/or memory (US EPA 1999a)(US EPA 2002a).

Table 1. Key Product Criteria for Energy Star Labeled Computers

	Power Consumption in *Sleep* Mode
Guideline A: Power Supply Output Rating (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)

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[4] Whether Guideline A or B applies to a given computer model is determined by the manufacturer of that computer.

Current criteria for ENERGY STAR integrated computer systems (ICSs) is that they use   35W in *sleep* (US EPA 2002a).

Currently, the EPA considers laptop (a.k.a. mobile, notebook, or portable) computers to be covered by its computer criteria. However, the technology and power characteristics of laptop computer are distinct enough from desktop computers that in this report we will treat desktop computers, laptop computers, and integrated computer systems are separate equipment categories, and refer to them collectively as PCs (personal computers).

Power Management: Technology

Power management introduces one or more power levels that are intermediate between *on* and *off.* In each successive low-power level, more internal hardware devices 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 extensively between hardware and software manufacturers and versions. Efforts are underway to standardize PM terminology (Nordman et al. 2002).

In general, power management in monitors is simpler, more reliable, and more important (in terms of potential energy savings) than in PCs. Though most new monitors are capable of PM, they require that a signal be sent from the PC through the video card before PM can be initiated (Nordman et al. 1997).

Power management in personal computers (PCs) involves effective communication between the BIOS (Basic Input-Output System), hardware (the processor and peripheral devices), and software, primarily the operating system. According to Nordman et al (1997), four conditions must be satisfied in order for PM to be accomplished:

> "The first is to monitor activity levels of the processor, input devices (such as the keyboard and mouse), and communication peripherals (network or modem). The second component is to utilize timers to decide when to initiate the shift to a lower power mode. Third, changes in power management status need to be communicated to the correct device and actually occur. Finally, power management needs to recognize when activity resumes and return to a higher power (or full-power) mode."

Early versions of PM, including APM (Advanced Power Management, which was introduced in 1993), were controlled primarily by the BIOS, with minimal involvement of the operating system. Enabling PM was often difficult because (1) PM settings vary widely between BIOS manufacturer and version, (2) the BIOS is usually only accessible during boot-up, and (3) numerous conditions had to be met in order for PM to function, while a failure of any single condition would prevent PM from occurring.

When Intel introduced ACPI (Advanced Configuration and Power Interface) in 1998, primary control of PM features shifted from the BIOS to the operating system (OS). This change meant that PM settings could be changed during normal computer operation, not just during boot-up. Also, PM interfaces in the OS were simpler than those in the BIOS, although there was still significant variation between OSs. ACPI effectively standardized PM technology among Intel-architecture PCs; Apple PCs employ PM technology that is distinct from but similar to ACPI (Nordman et al. 1996, Nordman et al. 1997).

Power Management: Terminology

Power management is complicated by the confusion of terminology used to describe low-power levels. Manufacturers of hardware, BIOS, and operating systems all provide some PM functionality and use their own terminology in the user interface. Because of the complex and evolving nature of system interaction (e.g., BIOS and OS, computer and monitor), and endless possible equipment combinations, the PM

functionality that actually results in PC-monitor systems is both unpredictable and inconsistent, and there is no consensus on the definitions or use of power management terms.

Consider for example, the seemingly simple terms *on* and *off*. Power used by a PC when *on* depends on the level of processor activity, so it is often useful to distinguish "*on*-active" (when the computer is actually computing) from "*on*-idle" (when computing functions are fully available but not in use, so the processor can be stopped). Similarly, *off* in PCs can be either a "hard *off*," in which the computer consumes no power because the power button is on the high voltage side of the power supply, or "soft *off*," in which the computer consumes some power because the power button is on the low voltage side of the power supply. Associated with "soft *off*," "hibernate" is not a separate power mode but rather a process in which the system state is saved to disk before turning *off*, allowing the computer to be turned *on* without restarting the operating system or applications.

The terms just defined here for PCs can serve to describe their *on* and *off* power levels, but still other terms are needed to describe PC low-power levels (between *on* and *off*). Further complexity is added because the number of *on, off,* and low-power levels varies with each type of office equipment.

Given the lack of any standardized definitions or use of PM terminology, it is all the more important that PM terms be carefully defined and consistently used, at least within each research project or report. In this report, terminology used in a BIOS or OS interface is placed in quotes (e.g., "standby") but we do not attempt to directly correlate the low-power levels that we measured to any of these PM terms. 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 the power used when the equipment is *off* and *on*. In addition, in order to inform EPA's revision of relevant ENERGY STAR criteria, we must also establish some correspondence between measured low-power levels and the criteria for monitors and PCs.

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.

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

	Personal Computers	**Monitors**
Off	The unit is plugged in (powered), the power button is in off position and the power indicator is dark.	
Deep Sleep	Not applicable	The lowest low-power level between *on* and *off*.
Sleep[5]	The lowest power level between *on* and *off*.	The lowest low-power level between *on* and *deep*
On	The power button is in the on position, the power indicator is green. *	The power button is in the on position, the power indicator is green, and the screen display is an "empty desktop" (as-found on bootup)

*Note: Computer *on* power can vary considerably depending on the degree of processor activity. In this report, we measured *on* power when the processor was idle, so our measurements represent minimal computer *on* power.

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[5] Because it is confusing to have two definitions for *sleep*, we considered defining *sleep* as the lowest power level in monitors as well as computers. However, that would require eliminating EPA's term *deep sleep* for monitors and introducing another term (e.g., *light sleep*) for the higher low-power level, introducing an additional element of confusion that we thought would effectively offset any benefit.

Description of Sample

To characterize the energy category, we selected and metered a sample that reflects (but is not necessarily representative of) the range of brands, cost, size, and type of models in the US market. To obtain our sample, we visited local offices and office equipment retailers; from models available to us in those locations, we selectively metered the number and type of units that we estimated to reflect the market, based on available data about market share by equipment manufacturer. We present a statistical analysis of the data, but recognize that because of the small sample size, particularly for the computer categories, our results may not be statistically significant.

Our sample includes only one unit of each model. We did not attempt to evaluate the consistency of power consumption between units of the same model. We did meter duplicate units of one model; the resulting values for each power mode were within 1W; only one set of results is included in our sample.

We report data for 35 monitors and 26 PCs, of which 14 are desktop computers, nine are laptops, and three are integrated computer systems. All units were manufactured between July 2000 and October 2001. For models that did not exhibit a manufacturing date on their nameplate, we estimated the date by subtracting a month from the date purchased (if the unit was metered in an office) or acquired (if metered in a retail showroom). About halfway the through the metering we began recording unit cost (if it was in an office) or retail price (if it was in a showroom). We used this information to ensure the diversity of that sample.

Monitors

Monitor size is measured diagonally and rounded to the nearest inch. For CRT monitors, actual size is usually about an inch less than nominal (manufacturer list) 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 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."

The sample of 35 monitors is characterized as follows:

Type: Nineteen (54%) are cathode ray tube (CRT); sixteen (46%) are liquid crystal display (LCD). [6]

Brand: Acer, Compaq, Dell, Gateway, HP, KDS, Micron, NEC, Philips, Samsung, Sony, ViewSonic.

Price: Of eight CRTs for which we have costs, the range was $270 to $1,000;
of the six LCDs for which we have costs, the range was $380 to $920.

Year: Ten of the monitors were manufactured in 2000; 25 were manufactured in 2001.
Five did not exhibit a manufacturing date; we estimated the date as described above.

Location: Fifteen monitors were metered in retail showrooms, and twenty were metered in offices either at LBNL, the UC Berkeley campus, or the City of Berkeley.

Operating System: Three monitors were used with Macintosh desktop computers; the other 32 were connected to desktop computers with a Windows OS. Of the latter, eight used Windows 98, one used Windows NT, eleven used Windows 2000, five used Windows ME, and seven Windows XP.

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[6] A potential source of confusion is that some new CRT monitors have flat (as opposed to slightly convex) screens and are variously advertised as "flat-screen" or "flat-display" monitors. These flat CRT screens should not be (but are easily) confused with "flat-panel" technology, which includes both LCD and plasma monitors.

Table 3. Distribution of Monitors in Sample, by Type and Size

Size	CRT monitors (nominal size)			LCD monitors		
	Count (n)	% of CRTs	% of Sample	Count (n)	% of LCDs	% of Sample
15"	4	21%	11%	9	56%	26%
17"	5	26%	14%	4	25%	11%
18"	0	-	-	3	19%	9%
19"	6	32%	17%	0	-	-
21"	4	21%	11%	0	-	-
all	19	100%	54%	16	100%	46%

About halfway through the metering period we began recording whether each piece of equipment exhibited an ENERGY STAR label, which when present, is on a nameplate, usually on the back of the unit. Of 19 monitors for which we have this information, 11 did and 8 did not have the ENERGY STAR label.

Figure 1. Monitor Sample by Type and Size
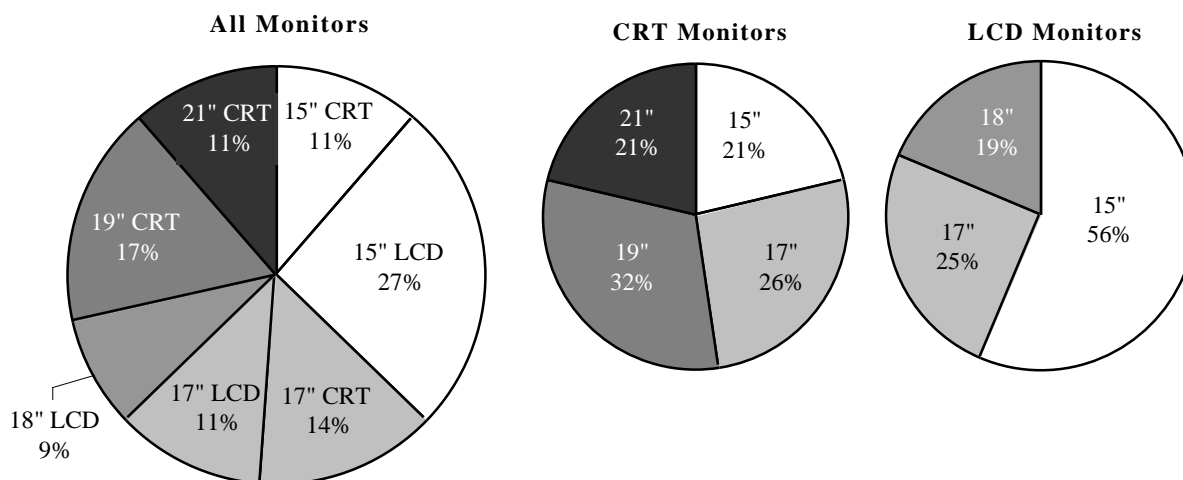
Personal Computers

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 but two (87%) were manufactured in 2001. Seven were metered in retail showrooms; the rest were metered in offices in Berkeley CA. Seven did not exhibit a manufacturing date. Of the eight desktop computers for which we have costs, the range was $750-$1,900. All desktop computers in our sample used a Windows operating system: four had Windows 98, five had Windows 2000, one had Windows ME, and four had Windows XP.

The sample of nine laptop computers consists of Apple, Dell, Fujitsu, HP, IBM, Panasonic, and Toshiba brands. Of the six (66% of) laptops for which we have processor speed, the range was 400-1000 MHz. None of the laptops exhibited a manufacturing date; we estimated that three were manufactured in 2000 and six were manufactured in 2001. Three were metered in retail showrooms; six were metered in LBNL offices. We have costs for all nine laptops; the range was $1,199-$3,134. Four laptops used the Windows 98 OS, four used Windows 2000, and one used the Mac OS X.

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

Of the three ICSs, only one unit (the Apple G4) bore a manufacturing date; their costs ranged from $949 (for the iMac) to $3,308 (for the Apple G4 with Studio Display monitor).

None of the eight PCs for which we looked for an ENERGY STAR label bore the label.

Methodology

Metering Equipment

Six field power line meters (PLMs) were used in our study; three model PLM-1-LP and three model PLM-1-PK. All are from Electronic Product Design, Inc. (EPDI, Springfield OR), which tested and calibrated them in July and August 2000. At the end of our study in December 2001, two of the PLMs were tested at the LBNL Lighting Laboratory against a bench model Voltech PM3000A Universal Power Analyzer. The PLMs accurately measured a no-load at 0W, and measured the "real" power load from a nominal "75W" incandescent lamp at 72.6W and 72.7W, compared to the bench model's measurement of 72.4W; i.e., the PLMs were accurate to within 0.4%.

Field Measurements

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 reading) of the power readout in watts.[7] Refer to <u>Appendix A</u> for a detailed description of our metering protocols.

Power measurements were recorded in tenths of a watt, and the results of our calculations are reported to the nearest watt.

Our measurements of monitor *on* power were made just after the computer booted-up and the display showed an empty (as-found, user-defined) desktop. Monitor *on* power actually varies considerably depending on the image displayed, and this issue is discussed in detail later in this report. Our spot measurements are intended to capture "typical" *on* power, but they are not standardized to a specific display and they do not capture the full range or a full duty-cycle of monitor *on* power consumption.

Because external USB devices (keyboard, mouse, etc.) affect power consumption, power measurements and standard test procedures should account for devices connected to USB ports. For each machine in our sample, we recorded the type of equipment (if any) connected to its USB ports, and for most machines we also recorded the number of USB ports.

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[7] PLM measurements and calculations are updated every second.

Measurements of the time required for a monitor display to recover or wake from (PC or monitor) low-power levels are necessarily subjective and therefore should be considered as rough estimates. Recovery times were estimated to the nearest second, and the minimum recovery time recorded was 1 second, even when a display appeared to recover instantaneously. Recovery timing started with the wake event and ended when there were no further changes in brightness of the display. Recovery times are not available for many units in our sample for a variety of reasons, including the difficulty of immediately ascertaining whether a particular wake event actually initiated a recovery from low-power.

Wake events vary with the low-power level and type of communication between computer, monitor, and OS. In order of increasing "difficulty," the wake events for both personal computers and monitors are: (1) mouse movement, (2) mouse click, (3) keyboard action (hitting any key), and (4) pressing the PC power button.[8] If in addition to the monitor, the computer has also entered a low-power level, a more "difficult" wake event is usually required, and the time it takes the display to recover will increase by the time it takes the computer to respond to the wake event. Estimated monitor recovery times reported in our data do not include computer recovery times.

Results and Discussion

Monitors: Low-power Levels

The current criteria for ENERGY STAR monitors specifies power consumption in two low-power modes: 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 monitor *deep sleep*. This suggests a clear trend among monitor manufacturers to provide a single very low low-power level.

Table 6 below shows that among monitors in our sample, average *deep sleep* power for CRTs was 7W, but average *deep sleep* power for LCDs was 2W, which is indistinguishable from average LCD *off* power.

As described earlier, two objectives of our metering were to (1) identify and measure all low-power levels (between *off* and *on*), and (2) to establish some correspondence between these and the ENERGY STAR *sleep* and *deep sleep* criteria for monitors. As defined in Table 2, we determined that if a monitor exhibited one low-power level, it corresponded to the ENERGY STAR *deep sleep* level, and if a monitor exhibited two low-power levels, the higher low-power level corresponded to *sleep*.

Based on these definitions, 34 (97% of) monitors in our sample exhibited a *deep sleep* power level, and of these, 32 (94%) met the ENERGY STAR criterion of 8W in *deep sleep*. Thus, 32 of 35 (91% of) monitors in our sample met the ENERGY STAR *deep sleep* criterion. On the other hand, only six (17% of) monitors in our sample exhibited a *sleep* mode. Of these, four (67%) met the ENERGY STAR criterion of 15W; the range was 6W-10W.

Of the three (9% of) monitors that did not meet ENERGY STAR criteria for *sleep* or *deep sleep* power consumption, two were used with computers run by the Windows ME operating system. Both of these exhibited two low-power modes corresponding to *sleep* (69W and 79W) and *deep sleep* (28W and 61W, respectively), all of which are well above the ENERGY STAR *sleep* and *deep sleep* criteria for monitors. The third monitor was used with a computer run by the Windows NT operating system, which does not allow power management; however, this monitor did power manage when the computer was turned *off*.

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[8] In this paper the term "mouse" includes mouse equivalents such as a trackball or touch pad.

To inform EPA's revision of ENERGY STAR criteria for monitor power management, we calculated minimum, maximum, average, median and quartile values for power consumption in each power level. Table 4 and Figure 2 below show the statistical analysis for all monitors in our sample; Figure 2 does not include *sleep* power because so few monitors in our sample exhibited *sleep* mode. The 25th percentile of *deep sleep* power consumption is 2W, which is also the 50th and 75th percentile value. In other words, 75% of monitors in our sample used 2W in *deep sleep*. The 25th percentile of *deep sleep* power is the same (2W) for both CRT and LCD monitors, as seen in Appendix C: Statistical Analysis of Monitor Power Levels, which show results by monitor type and size.

Table 4. Statistical Analysis of All Monitors, All Power Levels

Count (n)	35	34	6	28	35
All Monitors	*Off* **(W)**	*Deep Sleep* **(W)**	*Sleep* **(W)**	**Monitor *On* (W), with PC *Off***	**Monitor *On* (W), with PC *On***
Minimum	0	1	6	1	14
25th percentile	0	2	9	2	33
Median/50th percentile	1	2	10	2	56
Average/Mean	1	5	30	12	55
75th percentile	2	2	54	3	74
Maximum	9	61	79	78	110

Figure 2. Statistical Analysis of All Monitors, Most Power Levels
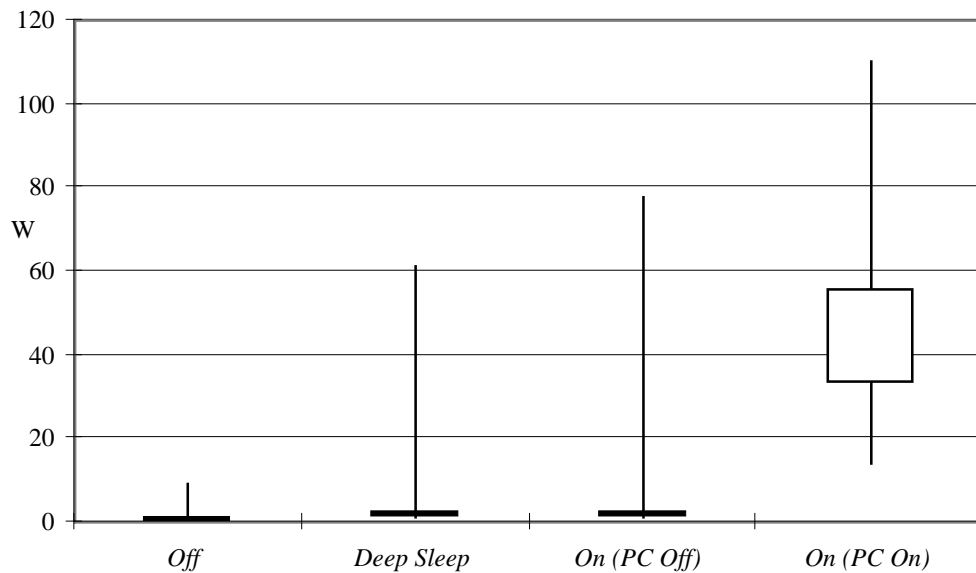
Note: The top and bottom of each box correspond to Mean and 25th percentile values, respectively. The vertical line through each box shows the range (maximum and minimum) of measured values.

Monitors: Recovery Time from Low-Power Levels

A central issue in power management is the time it takes a machine to recover from low-power levels. Therefore, besides recording monitor low-power levels, we recorded the minimal action (wake event) required to initiate recovery from each low-power level, and the estimated time, in seconds, that it took each display to fully recover. Timing of monitor recovery began with the wake event and ended when

there was no apparent change in the brightness of the display, and although some monitors appeared to recover instantaneously, the minimum time we recorded was 1 second. Because these observations are necessarily subjective and approximate, our resulting times should be considered to be rough estimates.

Individual results of estimated monitor recovery times are in Appendix B, Table B1. The range of recovery time from *deep sleep* was 1-12 seconds for CRTs, and 1-3 seconds for LCDs; the median time from *deep sleep* was 8 seconds for CRTs, and 2 seconds for LCDs. Figure 3 presents recovery time from *deep sleep* by monitor type and *deep sleep* power savings (or *on* power minus *deep sleep* power).

Although there is variability within the CRT and LCD samples, in general, the more power that is saved by powering down from *on* to *deep sleep*, the longer it takes a monitor to recover from *deep sleep*; CRTs save more power (relative to *on*) but take more time to recover from *deep sleep* than LCDs. CRTs saved 40-110 W in *deep sleep* and took 3-12 seconds to recovery; LCDs saved 10-40 W and took 1-3 seconds to recover.

Figure 3. Monitor Recovery Time by Monitor Type and **Deep Sleep** *Power Savings (W)*
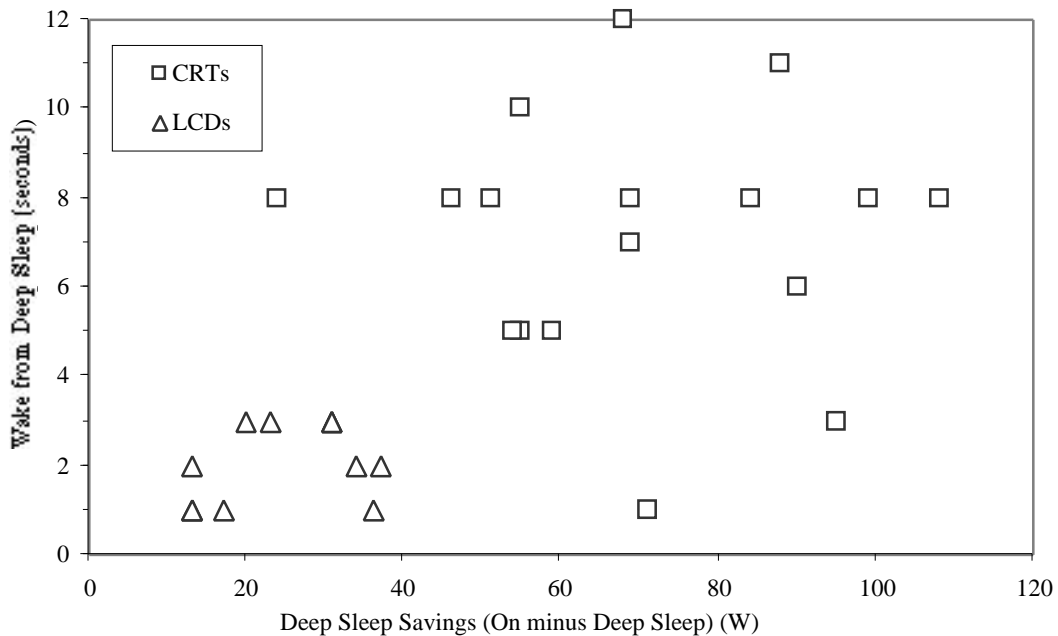
Without exception in our metering, the wake event for the automatic PM level "Turn off monitor" (Windows) and "display sleep" (Macs) was mouse movement; recovery time varied from 1-11 seconds. Although some monitors appeared to recover instantly, the minimum time recorded was "1 second."

Of three monitors in our sample run by a Mac OS, the wake event for "system sleep," both automatic and manual, was the keyboard. However, among monitors connected to desktop computers using a Windows OS, wake events from the "standby" power level varied widely among monitor brands, computer brands, and even depending on whether "standby" was initiated automatically (through the control panel) or manually. We found no correlation between "standby" wake events and monitor brand, computer brand, or Windows OS version. Of 17 desktop computers using with a Windows OS and "hibernate" mode, the computer power button was the wake event for all but one (an LCD monitor used with a computer using Windows 2000), which required only a mouse move. These observations suggest the complexity of interaction between power management features in the hardware and the OS.

Monitors: Effect of Operating System on Low-Power Levels

Monitors depend on the computer to initiate power management (PM) through the video card. For monitors in our sample, we recorded the desktop computer operating system (OS) and the PM features and settings as-found in the appropriate OS control panel. Some operating systems (including Windows NT, as well as some Linux and Unix) do not natively[9] support or allow PM. Among operating systems that do support PM, availability and nomenclature of power management (PM) features varies considerably, although PM features and terms tend to be relatively consistent among different versions of the same OS.

In the Macintosh (Mac) OS, automatic PM settings in the "energy saver" control panel are called "(system) sleep", "display sleep", and "hard disk sleep." "(System) sleep" can also be manually initiated from the "special" menu. In Macintosh PCs the BIOS is not accessible. Windows operating systems usually (but not always) have the same "turn off monitor", "turn off hard disks" and "system standby" automatic PM delay settings available in a control panel that is called "power management" in Windows 98 and "power options" beginning with Windows 2000. The "hibernate" feature, also new in Windows 2000,[10] must be enabled in the "power options" control panel in order for its automatic delay settings to be available in that control panel, or for it to be available for manual selection from the "start" menu.

The single (17" CRT) monitor connected to a desktop computer using Windows NT (which does not allow PM), did not *sleep* (power manage) when the computer was *on;* however, this monitor powered down to 1W when the computer was *off.* (When the computer and monitor were both *off*, the monitor used 0W.) In this case, the Windows NT OS clearly prevents PM in a monitor that is otherwise capable of PM. Other than this discussion, this monitor's *deep sleep* PM level is excluded from our results and analysis, which are concerned with monitor power levels measured when the computer to which it is connected is not *off.*

One desktop computer that used the Windows 98 OS could also be booted up using a Linux 6.2 OS. We metered its 21" CRT monitor using both operating systems and found identical power levels (including a 2W *deep sleep*) except *on*, which measured 110W with Windows 98 and 118W with Linux. This 8W difference can be attributed to differences in color between the desktop displays of each OS. Although this monitor was metered twice (once with each OS), we used one set of results (those corresponding to the Windows 98 OS) in our subsequent analysis.

Only two (6% of) monitors – a 19" CRT and a 21" CRT – failed to achieve ENERGY STAR power levels; both were connected to computers using Windows ME. In response to PM settings in the control panel, both monitors exhibited two successive power levels between *on* and *off*, but neither level was 15W. *Sleep* and *deep sleep* were 69W and 61W in the 19" CRT, and 79W and 28W in the 21" CRT monitor.

In our monitor sample, we found one Windows 2000 and two Windows 98 desktop computers for which "standby" settings were not available in the control panel. Although their monitors could *sleep*, these computers were unable to automatically or manually enter "standby" mode. In one 17" LCD monitor connected to a Windows 98 desktop computer, we manipulated BIOS PM settings in an unsuccessful attempt to enable "standby" settings in the OS control panel. In three other monitors connected to desktop computer using various Windows OSs, "standby" was available wither manually or automatically, but not both. These observations reflect the inconsistency and unpredictability of PM.

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[9] For Windows NT, add-on software is available that enables monitor power management.

[10] Before 2000, proprietary software was available to enable some laptop computers to "hibernate."

Monitors: *Off* Power

In our sample, two-thirds (68%) of CRTs used 0W when *off*, compared to only 12% of LCD monitors. On average, CRT monitors in our sample used 1W when *off,* while LCD monitors used 2W when *off.* These results agree with those of Groot and Siderius (2000), who found that while some CRT and LCD monitors used 0W when *off,* CRTs use 1.2W on average and LCDs use 2.5W on average when *off.* However, for all monitors in our sample, including CRTs and LCDs, the 25th percentile of *off* power was 0W.[11] These results indicate an opportunity to reduce *off* power consumption, particularly in LCDs.

In discussing monitor *off* power, it is important to note that our results are reported to the nearest watt. On closer inspection of the measurements, which were recorded in tenths of a watt (according to the PLM readout), almost half (9) of the 19 CRTs measured 0.0W when *off,* but none of the 16 LCDs did.

These differences between CRT and LCD *off* power are attributable not to their display technology, but rather to the location of the power switch relative to the power supply. A power supply receives high (~115V) voltage from the power main and sends low(er) voltage to the electronic components of the monitor; the monitor power switch (or button) is located either on the "high" or "low" side of the power supply. If the monitor power switch is on the high (wall) side of the power supply, the monitor is said to have a "hard *off*" feature because it draws no power (0.0W with our metering protocol) when switched *off.* If the switch is on the low side, the power supply is said to have a "soft *off*" feature because is draws some power (0.1W with our protocol) from the wall outlet even when the switch is *off.* The power supply of CRTs is internal (within the monitor housing) but to reduce the weight and size of LCDs, their power supply is often external, with the power supply incorporated into either the plug or the power cord. Monitors with an internal power supply (e.g., CRTs) can have either a "hard *off"* or "soft *off*" switch, while monitors with an external power supply (most LCDs) use power when *off* because their switch is a "soft *off*." The amount of *off* power used by monitors with external power supplies depends on the efficiency or quality of their external power supply, which varies considerably.

The nine CRT monitors in our sample that measured 0.0W when *off* clearly had a "hard *off*" feature. Table 5 compares *off* power of the remaining 26 monitors (10 CRTs, 16 LCDs) that had measurable (0.1W) *off* power consumption, i.e., those monitors whose switch is on the low side of the power supply.

Table 5. Comparison of *Off* Power for Monitors that Consume Power when *Off*

Monitor type	Count	*Off* Power Consumption (W)		
		Range	Average	Median
CRT	10	0.2-9.3	2.1	1.7
LCD	16	0.1-3.6	1.8	1.8

When CRTs and LCDs whose power switch is on the low side of the power supply are compared, their *off* power consumption is similar; both average and median values for CRTs and LCDs round to 2W.

Off power consumption is eliminated by placing the power switch on the high side of the power supply, which requires an internal power supply. Although most LCDs currently have external power supplies, it is possible to incorporate internal power supplies, particularly in larger LCDs. Even among LCDs with external power supplies in our sample, the wide range of *off* power (0.1-3.6W) indicates that some external

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

power supplies use much less *off* power than others; this indicates an opportunity to reduce *off* power consumption in LCD with external power supplies by installing more efficient power supplies.

Monitors: *On* Power

Current ENERGY STAR monitor criteria do not specify power consumption in *off* or *on* mode, but to the extent that monitor size (and percent time *on*) continue to increase, reducing monitor *on* power consumption becomes more important in efforts to reduce office equipment energy use (Groot & Siderius 2000).

The amount of power consumed by a monitor when *on* is primarily a function of its type (CRT, LCD), screen size, and the image displayed. LCD monitors use less energy when *on* than CRT monitors of similar size. The larger the screen size, the more power a monitor uses when *on*; this applies to both CRT and LCD monitors (Nordman et al. 1997). Image displayed is primarily a function of the user's color settings and desktop graphics, as well as the color and size of open application windows; a given monitor requires more power to display a white (or light) screen than a black (or dark) screen. Displayed image affects *on* power more in CRTs than LCDs, as discussed in detail below. However, brightness and contrast (which can be adjusted using controls on the front of the monitor), as well as refresh rate and resolution settings (which can be changed in the computer's OS control panels) also affect the amount of power a monitor uses when *on*. (These factors are further discussed below, in the section **Monitors: Revised *On* Power Estimates**.)

Comparing the energy use of monitors on the basis of screen size is problematic for several reasons. First, the actual diagonal size of the display on a nominal 19" CRT monitor is closer to 18" than 19", but the difference (whether absolute or relative) between actual and nominal CRT size is not consistent, so the only way to accurately determine the diagonal size of a CRT's actual display is to measure each CRT monitor. Second, LCD sizes do not always correspond to actual CRT sizes; e.g., our sample consists of 15", 17", and 18" LCDs, while actual sizes of CRTs in our sample are approximately 14", 16", 18", and 20" (nominal sizes 15", 17", 19", and 21", respectively); i.e., LCDs and CRTs don't always have the same diagonal sizes. Third, a given diagonal screen size has several possible aspect ratios, or height and width combinations, each with a slightly different display area. Fourth, for a given display area, there are many possible combinations of brightness, contrast, and resolution settings, all of which affect *on* power consumption.

Clearly, accurate comparison of monitor *on* power consumption requires a better metric than diagonal size; the ideal metric would normalize monitor *on* power consumption by unit display area. In a recent report to EPA, ECOS Consulting (Callwell & Reeder 2002) recommends normalizing monitor *on* power (W) using pixel count, which is the product of horizontal and vertical resolution. " Pixels per watt" has several advantages as a basis for normalizing *monitor on* power consumption; besides being able to make comparisons between monitor technology and size, incongruities in resolution or aspect ratio also become irrelevant.

Unfortunately, in this study we did not record resolution settings, and so we do not have pixel counts for monitors in our sample. Nor did we record horizontal and vertical screen measurements of the actual display of each CRT, which would provide the accurate screen areas. Therefore, we instead calculate an approximate display area based on the nominal diagonal size of the monitors, assuming each monitor has an aspect ratio of 3:4 (height:width) and that CRT actual size is one inch less that its nominal size.

Table 6a presents monitor *on* power as a function of approximate display area in square inches, and Table 6b presents monitor *on* power as a function of approximate display area in square centimeters. Figures 4 and 5 display these results graphically.

*Figure 4. Average Monitor **On** Power Consumption (W per Approximate Display Area)*
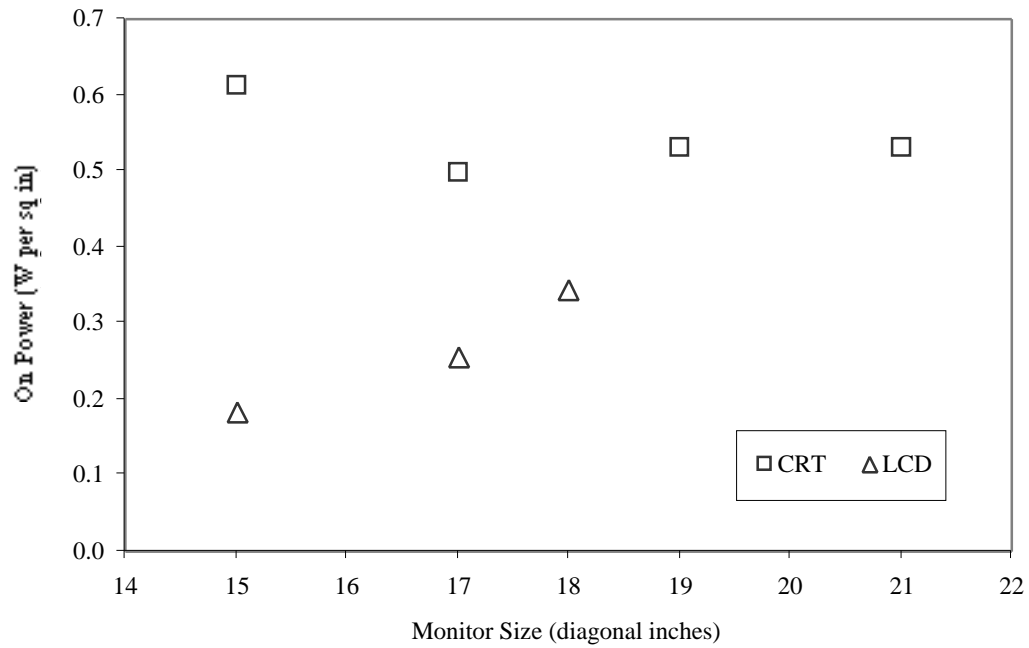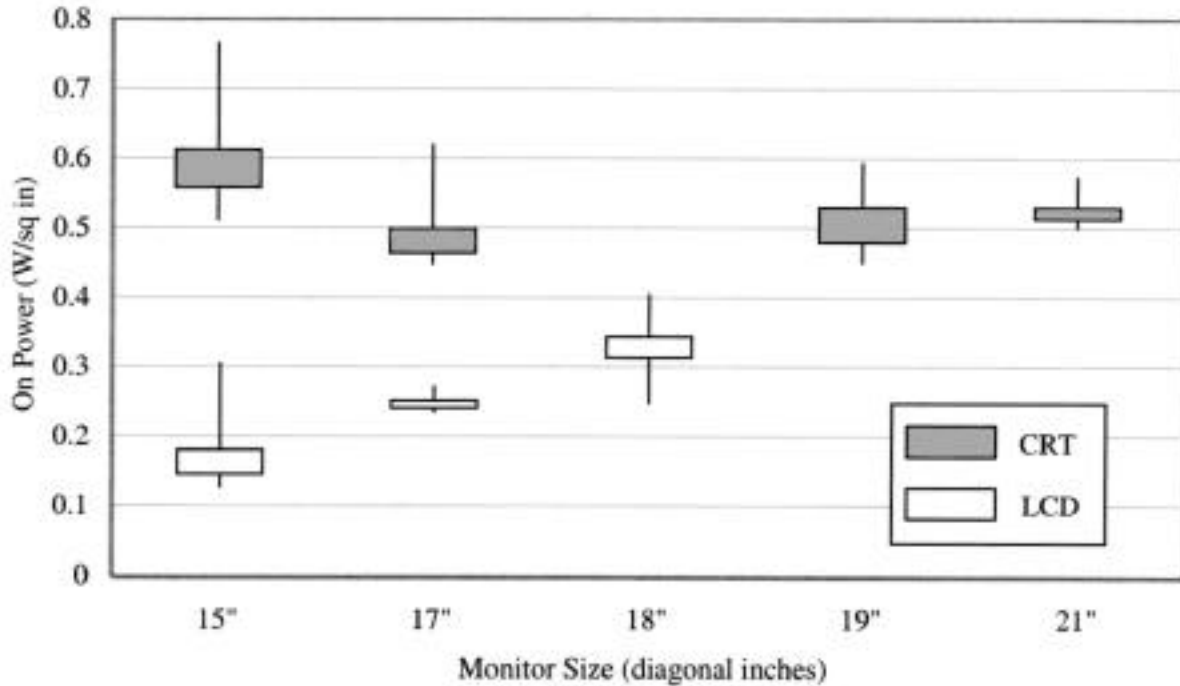

*Figure 5. Statistical Monitor **On** Power Consumption by Type and Size*

Note: The top and bottom of each box correspond to Mean and 25th percentile values, respectively. The vertical lines through each box show the range (maximum and minimum) of measured values.

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Table 6a. Average Monitor *On* Power per Unit Display Area (W/in^2, approximate)

Nominal Diagonal Size (in)	15"	17"	18"	19"	21"	All sizes
CRT *On* Power (W/in^2)	0.61	0.50	-	0.53	0.53	0.54
LCD *On* Power (W/in^2)	0.18	0.25	0.34	-	-	0.23
LCD (W/in^2) ÷ CRT (W/in^2) (%)	30%	51%	-	-	-	43%

Table 6b. Average Monitor *On* Power per Unit Display Area (W/cm^2, approximate)

Nominal Diagonal Size (in)	15"	17"	18"	19"	21"	All sizes
CRT *On* Power (W/cm^2)	0.10	0.08	-	0.08	0.08	0.08
LCD *On* Power (W/cm^2)	0.03	0.04	0.05	-	-	0.04
LCD (W/cm^2) ÷ CRT (W/cm^2) (%)	30%	51%	-	-	-	43%

Even with the uncertainties involved in our calculation of display areas, the differences between CRT and LCD *on* power are robust enough to confirm that LCDs consume significantly less power when *on* than CRTs of similar size. On average, for monitors in our sample, 15" LCDs consume 30% as much power when *on* as 15" CRTs, and 17" LCDs consume 51% as much power when *on* as 17" CRTs.

The data also suggest that LCD *on* power per unit display area increases slightly with LCD size; in other words, that the difference between CRT and LCD *on* power decreases as monitors get larger. Based on approximate display areas for monitors in our sample, and on average, 18" LCDs used 36% more *on* power per unit area than 17" LCDs, and 88% more *on* power per unit area than 15" LCDs. A possible explanation for these results is that larger LCDs have higher resolution as well as smaller pixels (higher pixel density), which require more backlighting to achieve the same level of brightness (Callwell 2002). In any case, further investigation is needed to determine if these results are borne out with a larger sample size.

Table 6 above shows average monitor *on* power consumption by approximate size of the display area. Table 7 shows median *off, on,* and *deep sleep* power consumption by monitor type and nominal size. Median (instead of average) values are used to exclude the outlying *deep sleep* power values of the two CRT monitors that did not power manage. To measure *on* power, we turned both the monitor and desktop computer *on* and waited until bootup was complete before measuring monitor *on* power according to the procedure detailed in Appendix A.

Table 7. Median Monitor Power Consumption by Monitor Type and Size

Monitor Type	Size	Count (n)	*Off* (W)	*Deep Sleep* (W)	*On* (W/in^2)
All Monitors	All	35	1	2	0.45
CRTs	15"	4	0	3	0.58
	17"	5	0	2	0.47
	19"	5	0	2	0.55
	21"	5	0	2	0.52
	All	19	0	2	0.53
LCDs	15"	9	2	2	0.17
	17"	4	2	2	0.25
	18"	3	1	2	0.38
	All	16	2	2	0.23

For 28 (80% of) monitors in our sample we also measured *on* power when the monitor was *on* but the desktop computer was still *off*. For 23 of these, monitor *on* power with the computer *off* was within 3W of monitor *off* power use. The other five (18% of) monitors used 24W-78W when the monitor was *on* but the computer was *off*; these values represent 78-100% of the power used by the monitor when both monitor and

computer are *on*. The results (listed in <u>Appendix B, Table B.1 Monitor Metering Results</u>) suggest that some monitors left *on* are unable to power manage when the computer to which they are connected is *off*. The significance of this observation is uncertain, however, because it is possible that some of these monitors would have powered down given more time than we allowed (about a minute); some monitors take up to 15 minutes to respond to the absence of a signal from the computer.

Monitors: Revised *On* Power Estimates

Monitors and PCs were the first products labeled by the ENERGY STAR Office Equipment program, and energy saved by power management of monitors has been and remains important to program success. As described above, the ENERGY STAR program evaluates its success by calculating the energy saved by power management of office equipment, and reliable estimates of energy savings depend in large part on accurate assessments of the power used by each product in each power level.

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

First we verified that our measurement techniques were generating accurate and reproducible results. As discussed earlier, our meters were tested to be accurate within 1% of the measured power level. Moreover, repeat measurement of several machines yielded results very close to our original values. We therefore concluded that our measurements accurately represent real power levels in the conditions in which we metered. Next we looked at the nature of the data reported to EPA by the 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 includes CRTs and LCDs of a range of sizes. Without exception, manufacturer-reported *on* power was higher than our measured value, indicating a consistent difference in the way manufacturers either measured or reported the power data.

To determine the source of this bias, we contacted five major monitor manufacturers, three of whom responded with information. Each manufacturer used a different method to measure monitor power, but in all cases the values reported to EPA were based on a "worst case scenario;" which in the case of *on* power means maximum brightness and resolution, and a white screen. Also, of the manufacturers that tested multiple units of a given model, all decided to report their highest individual measurement.

We performed more detailed measurements with a limited number of monitors in our sample to determine the range of *on* power and the relative impact of various factors affecting monitor *on* power. First, without changing the as-found monitor settings, we compared *on* power of four displays: an empty desktop, a maximized application window (Microsoft Excel, if available, or Microsoft Word), a black screen, and a white screen. We then varied the resolution and refresh rate settings and measured *on* power with an empty desktop, black screen, and white screen. Not all measurements were made for each monitor. <u>Table 8</u> shows the results for selected, representative monitors, The combination of white screen and maximum resolution approximates the test procedure reported by manufacturers.

Table 8. Variation in Monitor *On* Power (W), for Selected Monitors

| Display Resolution | Monitor *On* Power (W) | | | | | | | | Ratio of max to min *On* W (%) |
| | Desktop | Application | Black | White | Desktop | | Black | White | |
	As-found				Min	Max	Min	Max	
CRT 15"	63	66	62	66	58		57	67	118
15"	56		48	57					119
17"	86	97	75	93	82	86	74	96	131
17"	96	104	74	104					140
19"	90		86	103					120
19"	91	99	69	97	82	99	59	111	188
21"	118	123	103	128	116	125			124
21"	99		93	111					119
LCD 15"	17		16	16					106
15"	33		32	33	33				103
18"	59		57	59					104
18"	40		37	40	40		37		108

The data in <u>Table 8</u> seem to indicate that *on* power is more variable in CRTs than LCDs (the ratio of maximum to minimum *on* power ranges from 118-188% in CRTs, compared to 103-108% in LCDs. Among CRTs, maximum *on* power appears to be associated with a white display, or a maximum-sized application window (which approximates a white display). Among the few LCD monitors in the table, the power used to display a white screen is indistinguishable from power used to display the desktop. Thus, it appears that display color is a significant determinant of *on* power for CRTs, but not for LCDs.

However, we did not measure the full effect of brightness and contrast settings on monitor *on* power. Another researcher observed that these settings (whose controls are on the front of each monitor), have a greater impact on the range of LCD *on* power than do resolution or screen color, because a brighter LCD requires more backlighting, the most energy-intensive component of LCDs (Callwell 2002).   More thorough testing is needed to characterize and quantify the effect of all these variables (monitor brightness, contrast, refresh rate, resolution, and screen color) on the range of CRT and LCD *on* power.

In summary, manufacturers made a good faith effort to provide accurate data to EPA, but the absence of a standard protocol for measuring and reporting power data meant that each manufacturer had to develop their own method, and each reported their worst case results for a variety of practical reasons. (Worst-case conditions are routinely used for purposes of documenting product functionality, liability, and consumer protection.)

By comparison, LBNL's metering protocols were designed to reflect typical operating conditions, on which ENERGY STAR program savings estimates are supposed to be based. As a result of our investigation into the discrepancy between measured and reported power, LBNL's measured values have replaced manufacturer-reported values for use in estimating overall energy savings from ENERGY STAR monitors.

Although the ENERGY STAR program intended to use the manufacturer-reported data to evaluate its own success in terms of energy savings, manufacturers (understandably) assumed that information they reported would or could be used to evaluate their own "compliance" with the ENERGY STAR program.[13] Clearly, there is a need to more effectively communicate the program's data collection goals to participating manufacturers.

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[13] ENERGY STAR is a voluntary - not regulatory - program.

Desktop Computers

Our computer sample consists of 14 desktops, nine laptops, and three integrated computer systems. While such small sample sizes may not be statistically significant, but their analysis may nevertheless provide useful insights into power use and trends among the newest generation of personal computers.

Table 9 and Figure 6 present a statistical analysis of measured power levels and estimated low-power recovery (or wake) times for desktop computers in our sample. Appendix B, Table B.2 lists the results in detail. The term *light sleep* is defined below in the section **Desktop Computers: Low-power Levels**.

Table 9. Statistical Analysis of Desktop Computer Power Levels

Count (n)	14	14	13	7	7	14
All Desktop Computers	*Off* (W)	*Sleep* (W)	**Wake from** *Sleep* (sec)	*Light Sleep* (W)	**Wake from** *Light Sleep* (sec)	*On* (W)
Minimum	1	2	5	29	2	28
25th percentile	2	3	9	34	3	50
50th percentile/Median	3	4	12	52	4	63
Average/Mean	3	9	13	49	5	70
75th percentile	4	5	14	54	6	94
Maximum	4	48	24	90	11	117

Figure 6. Statistical Analysis of Desktop Computer Power Levels
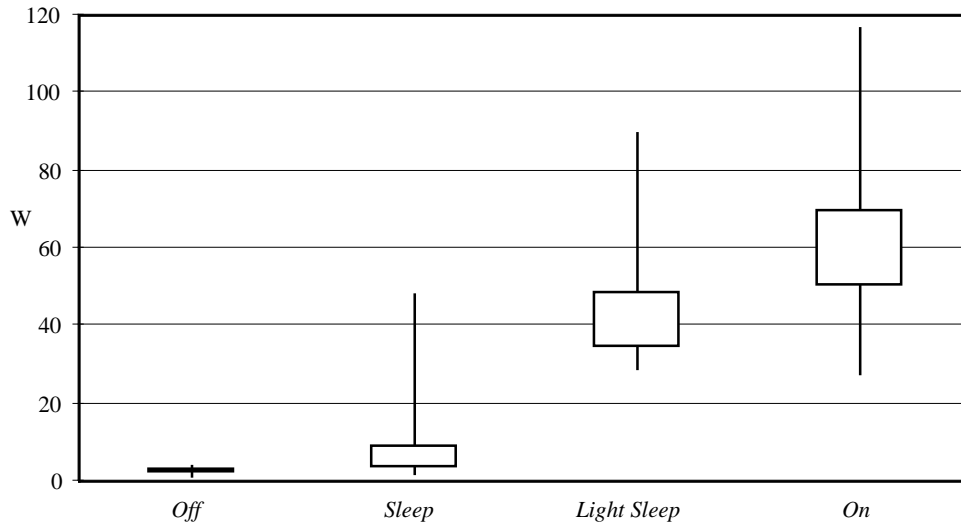
Note: The top and bottom of each box correspond to Mean and 25th percentile values, respectively. The vertical lines through each box show the range (maximum and minimum) of measured values.

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Desktop Computers: *Off* & *On* Power

None of the desktop computers used 0W when *off*; the range of *off* power was 1-4W, the average and median were 3W, and the 25th percentile was 2W.

Desktop computer *on* power ranged from 28-117W; the 25th percentile was 50W. Table B2, which is sorted by *on* W, suggests desktop computer *on* power is more closely correlated with CPU make and model than with CPU speed. Although the two desktop computers with the slowest CPUs (733 MHz) also had the lowest *on* power (28W and 36W), *on* power of the two computers with the fastest CPUs (1800 MHz) were 63W and 94W; these values correspond to the 50th and 75th percentile, respectively, but are not among the highest *on* values, which are over 100W.

Table 10 and Figure 7 show the relationship between desktop computer *on* power and CPU make, model, and speed. In our sample, desktop computers with Intel Pentium 3 CPUs averaged 38W when *on*, compared to an average 67W for desktop computers with Intel Pentium 4 CPUs, and an average of 104W for desktop computers with AMD Athlon CPUs. However, these results are not necessarily a complete indicator of processor efficiency, because CPU performance is affected by factors other than processor speed (MHz).

Table 10. Measured Desktop Computer *On* Power by CPU Brand, Model, and Speed

	CPU		Measured *On* Power (W)	
Count (n)	Brand, Model	Speed Range	Range	Average
4	Intel Pentium 3	733-1000 MHz	28-47	38
6	Intel Pentium 4	1300-1800 MHz	59-94	67
4	AMD Athlon	1000-1400 MHz	93-117	104

*Figure 7. Measured Desktop Computer **On** Power by CPU Brand, Model, and Speed*
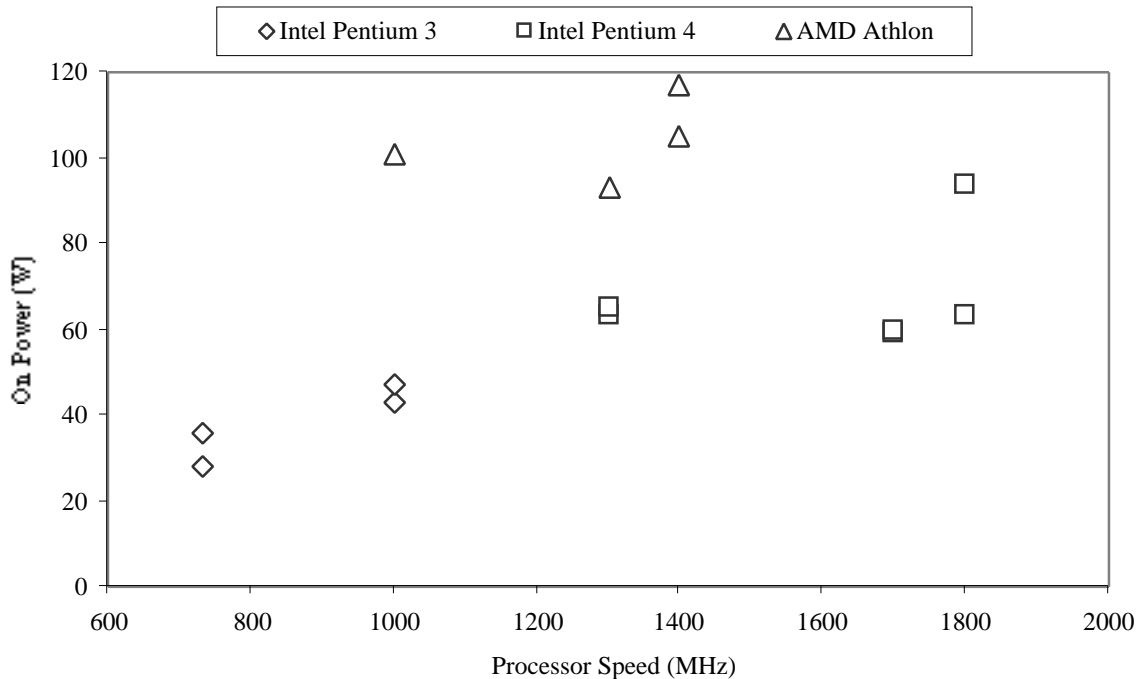
Desktop Computers: Low-power Levels

As seen in Table 1, the current criteria for ENERGY STAR computers specifies a single low-power level – *sleep* – depending on the rated output of the power supply, in watts. In practice, is very difficult to identify the size of the rated power supply of a given computer without opening the computer housing, which was beyond the scope of our field metering protocol. We were therefore unable to determine the size of the power supply for any of the desktop computers in our sample, and discussion of our metering results in relation to ENERGY STAR computer criteria is necessarily limited to a suggestion that revisions of the computer criteria be based on a computer specification that is more readily apparent.

As with monitors, we needed to correlate measured desktop computer low-power levels with ENERGY STAR'S *sleep* mode, which we defined as the lowest low-power level between *off* and *on*. However, seven (50% of) our sample exhibited at least two low-power levels, and one exhibited three low-power levels. Therefore, for the purpose of this discussion, we define a second, higher low-power level – *light sleep.*

Based on this definition, *sleep* power consumption among all 14 desktop computers in our sample (regardless of the size of their power supplies, which we could not ascertain) ranged from 2-48W. Average *sleep* power was 9W, the median 4W, and the 25th percentile was 3W, which is far below the lowest ENERGY STAR *sleep* criterion in Table 1 (15W for computers whose power supply is 200W). This indicates that the ENERGY STAR criteria for computer *sleep* power needs to be revised downward.

In an attempt to correlate *sleep* power with a computer characteristic other than power supply, we looked for a correlation between *sleep* power levels and CPU brand and speed (MHz), but found none. In our sample, the range of CPU speed was 733-1800 MHz, but the two desktop computers that used the least power (2W) in *sleep* both had 1700 MHz CPUs, while two of the three desktop computers that used the most power in *sleep* had 733 MHz CPUs.

Based on our definition of *light sleep*, the seven desktop computers that exhibited a *light sleep* mode used from 29-90W in *light sleep*, and the 25th percentile for power consumption in *light sleep* was 34W.

Of 13 desktop computers for which we estimated recovery time from *sleep*, the range was 5-24 seconds, the average 13 seconds, and the 25th percentile 9 seconds. Of the seven desktops for which we estimated recovery time from *light sleep*, the range was 2-11 seconds, the average 5 seconds, and the 25th percentile 3 seconds.

Laptop Computers

We measured the power consumption of nine laptop computers, all of which had a fully charged battery at the time of our measurement. Four laptops used the Windows 98 OS, four used Windows 2000, and one used Mac OS X. Table 11 and Figure 8 present the statistical analysis of laptop power levels and Appendix B, Table B3 lists the laptop results in detail.

Laptops in our sample used 1-3W when *off*; average *off* power was 2W and the 25th percentile was 1W. *On* power consumption ranged from 14-25W; the average was 19W and the 25th percentile was 15W.

Eight of the nine laptops exhibited at least two low-power levels so, as with desktop computers and for the purpose of this analysis and discussion, we define a second, higher low-power level – *light sleep.* The range of power used in *sleep* was 1-8W, the average 3W, and the 25th percentile 2W. The range of power used in *light sleep* was 2-19W; the average 11W, and the 25th percentile 8W.

Figure 8. Statistical Analysis of Laptop Computer Power Levels
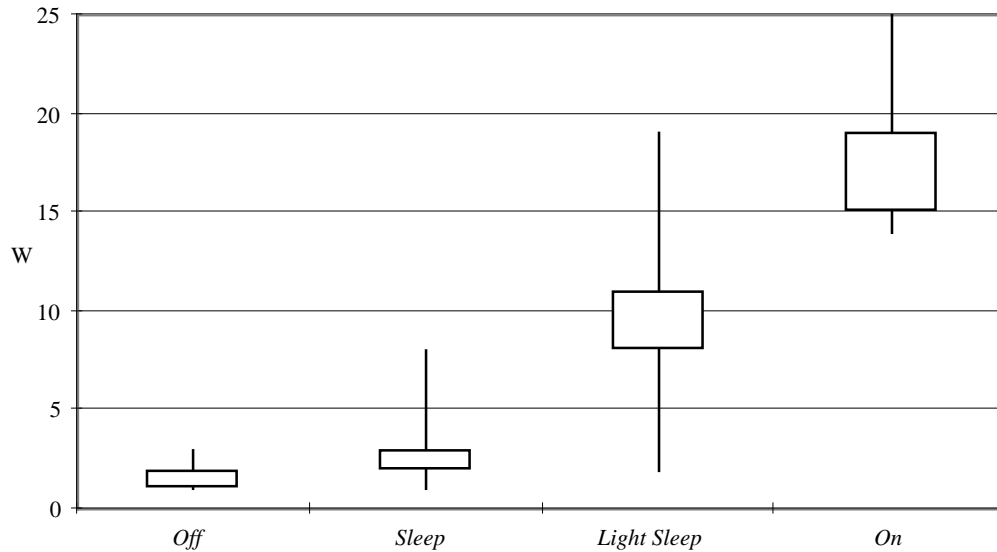
Note: The top and bottom of each box correspond to Mean and 25th percentile values, respectively. The vertical line through each box indicate the range (maximum and minimum) of measured values.

Estimated recovery time from *sleep* ranged from 2-16 seconds; the average was 10 seconds and the 25th percentile 5 seconds. Estimated recovery time from *light sleep* ranged from 1-4 seconds; the average was 2 seconds and the 25th percentile 1 second.

Table 11. Statistical Analysis of Laptop Computer Power Levels

Count (n)	9	9	7	8	7	9
Laptop Computers	*Off* (W)	*Sleep* (W)	**Wake from** *Sleep* **(sec)**	*Light Sleep* (W)	**Wake from** *Light Sleep* **(seconds)**	*On* (W)
Minimum	1	1	2	2	1	14
25th percentile	1	2	5	8	1	15
50th percentile/Median	2	3	14	11	1	19
Average/Mean	2	3	10	11	2	19
75th percentile	2	3	16	14	2	20
Maximum	3	8	16	19	4	25

Integrated Computer Systems

The three ICSs (integrated computer systems) in our sample are an Apple iMac, in which a computer and CRT monitor share the same housing, a Gateway Profile, in which a computer and LCD monitor share the same housing, and an Apple G4 PC power-linked to an Apple Studio Display LCD monitor, in which the computer and monitor are connected by a single cable carrying all video, USB, and power signals. The iMac used the Mac OS 9.2, the Profile used Windows ME, and the G4 used Mac OS X. Appendix B, Table B4 lists our ICS results in detail. There is no quartile analysis on this small sample.

Among the three ICSs, power used in *off* ranged from 4-8W; power used in *on* ranged from 54-131W.

As with desktop and laptop computers, we define *sleep* in ICSs as the lowest low-power level between *off* and *on*, and we also, for purposes of this analysis and discussion, define a second, higher low-power level – *light sleep*. The range of *sleep* power in ICSs was 4-31W; the range of *light sleep* power was 25-102W. Current criteria for ENERGY STAR integrated computer systems is that they use 35W in *sleep*. Based on our definition of *sleep,* all ICSs in our sample met the ENERGY STAR criteria. ICS recovery from *sleep* ranged from 7-16 seconds; recovery from *light sleep* ranged from 1-4 seconds.

Conclusions and Future Work

Continued improvement of the ENERGY STAR Office Equipment program depends on identifying new opportunities for saving energy, which requires ongoing field measurements to supplement data reported by manufacturers and to characterize emerging power trends as they relate to ENERGY STAR criteria. Summarized below are the primary observations resulting from our latest field measurements.

ENERGY STAR criteria have been so effective at reducing energy use by monitors and PCs that are *on* but idle that the energy consumed when they are *off* or in active use (*on*) has become more important in terms of contribution to the typical unit energy consumption (UEC). Current ENERGY STAR criteria do not specify *off* or *on* power, but our results suggest opportunities for saving energy in these modes.

Monitors

Trends in the monitor market are toward larger screen sizes (because they are easier to read and can display more information) and LCD monitors, which (although more expensive) require less space, use less energy for display, and recover from low-power levels more quickly than CRT monitors. Based on our sample, CRTs predominate among monitors larger than 17", while LCDs predominate within the 15" size category.

Our results reveal a clear trend among monitor manufacturers to provide a single very low low-power level. In our sample of 35 CRTs and LCDs, both the median and the 25th percentile were 2W – well below the current ENERGY STAR monitor criterion of 8W in *deep sleep*. Among LCD monitors, average *deep sleep* power was indistinguishable from *off*. We suggest the current monitor criteria (which specifies two low-power levels) be revised to specify a single low-power level – *sleep*, which is the term used to describe the single low-power level in other ENERGY STAR office equipment products.

Our difficulty in measuring recovery times from low-power levels highlights the fact that – to the extent that recovery time is considered as an element in future product criteria – the ENERGY STAR program needs to establish clear and consistent methods for measuring recovery time for any given product category.

On average, LCD monitors in our sample use 1W more when *off* than CRT monitors. Although 1W per monitor may seem insignificant, the cumulative impact on the UEC of this product category is not. Because the 25th percentile of *off* power consumption in our sample was 0W, we suggest that the revised ENERGY STAR monitor specification include a 0W *off* power criterion. This would provide monitor manufacturers with an incentive to install more efficient power supplies or use internal power supplies.

Regarding *on* power, our results confirm that LCDs consume less power per unit area than CRT monitors, but they also suggest that LCD *on* power consumption per unit area increases slightly with LCD size. Considering the uncertainties in our calculation of monitor display areas and the small size of our sample, the latter result is far from conclusive. We suggest that *on* power in LCDs merits further investigation.

Our difficulty in comparing *on* power consumption among monitors in our sample highlights the need for a metric capable of normalizing *on* power consumption across all monitor types and sizes. We suggest the ENERGY STAR program continue to develop the proposed "pixels per watt" metric for monitor *on* power.

The process of resolving the discrepancy between measured and reported monitor *on* power revealed opportunities for improving ENERGY STAR Office Equipment program design and implementation. As a result, the EPA is now working with researchers and manufacturers to develop standard methods for testing and reporting typical (not worst-case) power consumption of new monitors in all power modes. When these procedures have been agreed upon, participating manufacturers will use them to generate reliable data, which EPA will use to establish criteria for the revised ENERGY STAR monitor specification.

Personal Computers

Current ENERGY STAR computer criteria specify *sleep* power according to the power supply's maximum continuous output rating, which, besides being difficult to determine, says nothing about actual power use. We suggest that revisions to the computer criteria be based on a more appropriate and identifiable metric.

When the data for all desktop computers in our sample was analyzed as a whole, the results indicate that actual desktop computer *sleep* power levels are far below even the lowest ENERGY STAR *sleep* criteria (based on the maximum continuous output rating of the computer's power supply), which therefore need to be revised downward if they are to apply only to the 25% most energy-efficient models on the market.

Half of the desktop computers in our sample exhibited a second, higher low-power level. To the extent that computers spend time in low-power levels other than the lowest (*sleep*) level, it may be worthwhile to specify a second, higher ENERGY STAR low-power level called, for example, *light sleep*. We do not, however, have an estimate of the percentage of time computers spend in intermediate low-power levels.

The range of *off* power consumption among desktop computers in our sample was small (1-4W), and does not suggest a need for an *off* power criteria for ENERGY STAR computers. Desktop *on* power consumption ranged widely, but appeared to be more closely associated with processor brand than with processor speed. We suggest that the trend toward increasing desktop computer *on* power be investigated with regard to minimizing computer *on* power without affecting functionality.

Integrated computer systems exist in a variety of configurations, but as yet are relatively few in number, although we can expect that to change. All three ICSs in our sample met the ENERGY STAR ICS criteria of 35W in *sleep*, suggesting that the current criteria may eventually need to be revised downward. We suggest that more data needs to be collected on this category of computers as it continues to evolve.

By necessity and design, laptops are already much more energy-efficient than their desktop counterparts. However, because the power used by laptops includes that of the display as well as the computer processor, it is more appropriate to compare laptops to integrated computer systems. The 25th percentile of *sleep* power among laptops in our sample was 2W, compared to the ENERGY STAR ICS *sleep* criteria of 35W. We suggest laptops deserve further investigation, not as much in regard to reducing laptop power use as in applying laptop technology to minimizing the power used by desktops and integrated computer systems.

In summary, we propose continued metering of new personal computers, both to improve the size and robustness of the sample, and to identify and evaluate the factors that affect energy use in all power modes, with the goal of identifying savings opportunities and informing revisions to the ENERGY STAR criteria.

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Appendix A: Metering Protocol

General (applies to all monitors and personal computers)

After getting permission of the primary user or retailer, meter the equipment when it is not being used. Record the brand, model number, date of manufacture, and whether it exhibits an ENERGY STAR label (this information is usually found on a metal nameplate on the back or underside of the equipment). In a retail setting, record the price (with and without any discount); if in an office, inquire of its cost. For each piece of equipment, record the number of USB ports and any devices connected to them.

Record the power state in which the equipment is found, based on the power indicator, which is usually dark when *off*, green when *on*, and amber and/or blinking when in low power.

With the equipment *on*, record the PC operating system (OS) type and version (e.g., Windows 2000), as well as any automatic power management (PM) features and settings found in the OS control panel. Restore these settings when metering is complete. Record any unusual circumstances about the equipment or setup that could affect its power consumption or measurement.

Plug the power line meter (PLM) into an outlet and verify that the baseline power readout is zero watts; (if it isn't zero, subtract this measurement from subsequent measurements).

Now you are ready to measure *on, off,* and low-power levels, using the following guidelines. Whenever the equipment enters a new power level, wait at least 15 seconds for the reading to stabilize, then observe the readout for 30 seconds. Record the range and mode (most frequent number) to 0.1 W.

For each low-power level measured, record the following:
*   Whether the low-power level is activated automatically (via delay settings in the control panel) or manually (requiring that the user select the low-power level from a menu). Low-power levels that can be activated either manually or automatically (e.g., "Standby" in Windows) should be initiated and measured both ways.
*   Appearance of the power indicator while the unit is in the low-power level (i.e., whether the light is green or amber, and whether it is flashing).
*   The minimum level of action required to wake the unit up from its low-power level, tried in this sequence: mouse move, mouse click, keyboard action, or pushing a hard power button, and
*   The measured time (in seconds) it takes the equipment to fully recover from the low-power level.

Monitors

In addition to the data described above, record actual screen size (measured diagonally) to the nearest inch, and the brand of desktop computer with which the monitor is being used.

If the monitor and computer are not already *off*, turn them both *off*. Plug the monitor into the PLM and measure monitor *off* power. Turn the monitor *on* and record monitor *on* power with the computer *off*. Turn the computer *on*; during boot-up record the OS and version. When boot-up is complete and the monitor displays the normal user-defined desktop, record monitor *on* power with the computer *on*.

In the power control panel, enable any PM options that are not already enabled (e.g., with the Windows 2000 OS, "Hibernate" is enabled via a checkbox). If you aren't sure whether a given low-power level affects the monitor, initiate the low-power level and measure monitor power consumption to find out.

For each monitor low-power level, select the minimum delay setting (e.g. "1 min") so the monitor automatically enters that low-power level as soon as possible after cessation of user activity. Wait for the monitor to enter the low-power level and measure monitor power as described above. Record the appearance of the monitor power indicator, then initiate and record the wake event and recovery time.

After measuring each automatic low-power level, initiate and measure any manual low-power level(s) (e.g., in Windows, selecting "Suspend" from the "Start" menu). After measuring all power levels, monitor metering is complete. Restore as-found PM settings in the control panel. Turn the monitor *off*, unplug it from the PLM, and reconnect it to its power source.

Personal Computers

Record the data described above under **General**. If the PC is a laptop or ICS, record the actual screen size, measured diagonally, to the nearest inch. If it is an ICS, record the monitor type (CRT or LCD).

If the PC is not *off*, turn it *off*. If it is a laptop, the battery should be either fully charged, removed, or disconnected in order to prevent the power consumption measurements from including power used to recharge the battery. Plug the PC into the PLM and measure PC *off* power.

Turn the PC and monitor *on*. During boot-up, record the OS and version, CPU make and speed (in MHz), RAM size (in MB), and hard disk size (in GB). When the desktop is displayed, record *on* power.

In the power control panel, enable any PM options that are not already enabled (e.g., with the Windows 2000 OS, "Hibernate" is enabled via a checkbox). If you aren't sure whether a given low-power level affects the PC, initiate the low-power level and measure PC power consumption to find out.

For each PC low-power level, select the minimum time delay setting so the PC automatically enters that low-power level as soon as possible after cessation of user activity. Wait for the PC to enter the low-power level and measure PC power consumption as described above under **General**. Record the appearance of the PC power indicator, then initiate and record the wake event and recovery time. Also record if the PC does not enter a low-power level after the specified time. As with monitors**,** low-power levels that can be induced manually or automatically (e.g., "Suspend" in Windows 2000) should be initiated and measured both ways.

After measuring each automatic PC low-power level, initiate and measure any manual low-power level (e.g., "Suspend" from the "Start" menu). After measuring all power levels, PC metering is complete. Restore the as-found PM settings in the control panel. Turn the PC *off*, unplug it from the PLM, and reconnect it to its power source.

Appendix B: Metering Results (Blank fields either do not apply or are not available.)

Table B-1. Monitor Metering Results, Sorted by Monitor Type & Size

Monitor ID No.	Mfr Date (*estimate)	Cost/Price $	Type	Size (in)	Monitor Off (W), PC Off	Monitor On (W), PC Off	Monitor On (W), PC On	*Sleep* (W)	Wake from *Sleep* (sec)	*Deep Sleep* (W)	Wake from *Deep Sleep* (sec)	Computer OS
7	2000-Nov		CRT	15	3		54			3	8	Windows ME
11	2000-Nov	200	CRT	15	0	2	48			2	8	Windows 98
14	2001-Apr		CRT	15	0	3	72			3	7	Windows 00
15	2001-Feb		CRT	15	0	1	56			1	5	Windows 98
16	2001-Jun		CRT	17	0	2	57			2		Windows 98
20	2001-Jun*		CRT	17	0	1	76					Windows NT
22	2000-Nov		CRT	17	0	1	55			1	5	Windows 00
27	2000-Oct	400	CRT	17	1	1	60			1	5	Windows XP
29	2000-Nov	450	CRT	17	3	3	58	6	2	3	10	Windows XP
9	2001-Jan	270	CRT	19	9		85	69	4	61	8	Windows ME
10	2001-Jan	300	CRT	19	0		71			2	8	Windows ME
13	2001-May		CRT	19	0	74	90			2	11	Windows 98
26	2001-Jun		CRT	19	0	1	86			2	8	Windows 00
30	2001-Jan	500	CRT	19	0	1	92			2	6	Windows XP
33	2001-Apr	450	CRT	19	2	2	70	9	1	2	12	Windows XP
6	2000-Jul		CRT	21	2	2	110			2	8	Windows 98
12	2001-Mar	1,000	CRT	21	0	78	99	79	2	28	1	Windows ME
23	2000-Oct		CRT	21	0	2	101			2	8	Windows 00
25	2001-Oct		CRT	21	0	75	96			1	3	Windows 00
1	2000-Jul*		LCD	15	2	2	33	10		2	3	Windows 00
2	2001-Mar		LCD	15	2		18			2		Windows 00
5	2001-Apr		LCD	15	2		17			2		Windows 00
8	2001-Jun	450	LCD	15	3	24	24			1	3	Windows ME
17	2001-Aug		LCD	15	2	2	19			2	1	Windows 98
21	2001-Mar		LCD	15	4	3	16			3	1	Windows 98
31	2001-Aug		LCD	15	1	2	22			2	3	Windows XP
32	2001-Sep	650	LCD	15	2	2	15			2	1	Windows XP
35	2001-Oct*	380	LCD	15	1	1	14			1	2	Mac OS 8.6
18	2001-Jul	920	LCD	17	0	36	38			2	1	Windows 00
24	2001-Aug		LCD	17	3	4	34			3	3	Windows 98
28	2001-Jul*	900	LCD	17	1	2	36			2	2	Windows XP
34	2001-Oct	750	LCD	17	2	2	33			2	3	Windows 00
3	2000-Nov		LCD	18	1		59			2		Mac OS 9.1
4	2000-Nov*		LCD	18	4		63	9		4		Mac OS 8.1
19	2001-Sep		LCD	18	0	2	39			2	2	Windows 00

Appendix B: Metering Results (Cont.) (Blank fields do not apply or are not available)

Table B-2. Desktop Computer Metering Results (Sorted by *On* Power)

PC ID No.	Mfr Date (*estimate)	Cost/ Price $	Type	CPU Make, Version	CPU speed (MHz)	Off (W)	On (W)	*Light Sleep* (W)	Wake from *Light Sleep* (sec)	*Sleep* (W)	Wake from *Sleep* (sec)	Computer OS
7	2001-Jul*		desktop	Intel P3	733	2	28			20	5	Windows 98
2	2000-Sep	1,650	desktop	Intel P3	733	4	36	29	6	24	12	Windows 98
6	2001-Jul*		desktop	Intel P3	1000	2	43			3	14	Windows 2000
8	2001-Jun*	1,400	desktop	Intel P3	1000	4	47	36	3	5	14	Windows 98
12	2001-Jul*	1,200	desktop	Intel P4	1700	2	59	52	6	2	16	Windows XP
14	2001-Jul*	1,200	desktop	Intel P4	1700	1	60			2	14	Windows XP
1	2001-Jun	1,900	desktop	Intel P4	1300	4	63			4		Windows 2000
11	2001-Aug		desktop	Intel P4	1800	2	63	54	3	3	9	Windows XP
4	2001-May		desktop	Intel P4	1300	3	65	53	11	5	24	Windows 98
13	2001-Jul*	750	desktop	AMD Athlon	1300	3	93	32	2	3	12	Windows XP
9	2001-Oct		desktop	Intel P4	1800	3	94	90	4	4	10	Windows 2000
3	2001-Jun	1,430	desktop	AMD Athlon	1000	4	101			4	8	Windows 2000
5	2001-Jun		desktop	AMD Athlon	1400	2	105			48	8	Windows ME
10	2001-Oct	1,800	desktop	AMD Athlon	1400	4	117			5	19	Windows 2000

Table B-3. Laptop Computer Metering Results (Sorted by *On* Power)

Laptop ID No.	Mfr Date (*estimate)	Cost/ Price $	Type	CPU Make, Version	CPU speed (MHz)	Off (W)	On (W)	*Light Sleep* (W)	Wake from *Light Sleep* (sec)	*Sleep* (W)	Wake from *Sleep* (sec)	Computer OS
3	2000-Oct*	1,800	Laptop	Celeron	600	1	14	6	2	4	4	Windows 2000
7	2000-Aug*	1,990	Laptop	Celeron		1	14	8	1	1		Windows 98
9	2000-Jun*	1,800	Laptop	Intel P2		2	15	18	1	2	16	Windows 98
4	2001-Jul*	2,070	Laptop	Mac G4	400	2	17	10	1	2	2	Mac OS X
2	2001-Mar*	2,500	Laptop	Intel P3	600	2	19	12	1	3	14	Windows 2000
6	2001-Jul*	1,200	Laptop	Celeron	800	1	19	2	4	1	15	Windows 98
1	2001-Mar*	2,700	Laptop			2	20	12		3		Windows 2000
5	2001-Jul*	2,190	Laptop	Intel P3	900	3	25			3	16	Windows 98
8	2001-Jun*	3,130	Laptop	Intel P3	1000	1	25	19	1	8	6	Windows 2000

Table B-4. Integrated Computer System Metering Results (Sorted by *On* Power)

ICS ID No.	Mfr Date (*estimate)	Cost/ Price $	Type	CPU Make, Version	CPU speed (MHz)	Off (W)	On (W)	*Light Sleep* (W)	Wake from *Light Sleep* (sec)	*Sleep* (W)	Wake from *Sleep* (sec)	Computer OS
1	2001-Jul*	1,900	integral PC-LCD	Intel P3	867	6	54	24	1	16	14	Windows ME
3	2001-Jul*	950	integral PC-CRT	Mac G3	600	4	88	78	1	31	16	Mac OS 9.2
2	2001-Aug	3,310	power-linked PC-LCD	Mac G4	867	8	131	102	4	10	7	Mac OS X

Appendix C: Statistical Analysis of Monitor Power Levels, by Type & Size

Table C1. **Monitor *Off* Power (W), by Monitor Type & Size**

Type	CRT					LCD			
Size	**All**	**15"**	**17"**	**19"**	**21"**	**All**	**15"**	**17"**	**18"**
Count	19	4	5	5	5	16	9	4	3
Monitor *Off* Power (W), with PC *Off*									
Min	0	0	0	0	0	0	1	0	0
Max	9	3	3	9	2	4	4	3	4
Average/Mean	1	1	1	2	1	2	2	2	2
25th percentile	0	0	0	0	0	1	2	1	1
Median	0	0	0	0	0	2	2	2	1
75th percentile	2	1	1	0	2	2	2	2	3

Table C2. **Monitor *On* Power (with PC *Off*), by Monitor Type & Size**

Type	CRT					LCD			
Size	All	15"	17"	19"	21"	All	15"	17"	18"
Count	16	3	5	3	5	12	7	4	1
Monitor *On* Power (W), with PC *Off*									
Min	1	1	1	1	2	1	1	2	2
Max	78	3	3	74	78	36	24	36	2
Average/Mean	16	2	2	25	32	7	5	11	2
25th percentile	1	2	1	1	2	2	2	2	2
Median	2	2	1	1	2	2	2	3	2
75th percentile	3	3	2	38	75	3	3	12	2

Table C3. **Monitor *On* Power (with PC *On*), by Monitor Type & Size**

Type	CRT					LCD			
Size	All	15"	17"	19"	21"	All	15"	17"	18"
Count	19	4	5	5	5	16	9	4	3
Monitor *On* Power (W), with PC *On*									
Min	48	48	55	71	70	14	14	33	39
Max	110	72	76	92	110	63	33	38	63
Average/Mean	76	58	61	85	95	30	20	35	54
25th percentile	58	53	57	85	96	18	16	34	49
Median	72	55	58	86	99	29	18	35	59
75th percentile	91	60	60	90	101	37	22	37	61

Table C4. **Monitor *Deep Sleep* Power, by Monitor Type & Size**

Type	CRT					LCD			
Size	All	15"	17"	19"	21"	All	15"	17"	18"
Count	18	4	4	5	5	16	9	4	3
Monitor *Deep Sleep* Power (W)									
Min	1	1	1	2	1	1	1	2	2
Max	61	3	3	61	28	4	3	3	4
Average/Mean	7	2	2	14	7	2	2	2	3
25th percentile	2	2	1	2	2	2	2	2	2
Median	2	3	2	2	2	2	2	2	2
75th percentile	3	3	2	2	2	2	2	2	3