

**Metered Energy Consumption and
Analysis of Energy Conservation Techniques
in Desktop PCs and Workstations**

by
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Submitted to the Department of Architecture on May 24, 1996
in partial fulfillment of the requirements for the Degree of
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Abstract

This thesis investigates potential energy savings due to the application of power managed PCs, monitors, and workstations. The basis of this effort includes electric metering of such equipment at six preliminary and one primary location, a large business office in Boston, Massachusetts. Metering there occurred over an 8 week period, using an in-line metering device, and at a resolution of one minute intervals. The results of this study show that many problems exist in the field today which prevent any energy savings from being realized. These include both software and hardware incompatibilities. It was found that either the equipment was not enabled from the beginning; that various problems caused inadvertent disabling of the energy saving features, or that lack of knowledge about specific power management techniques caused the user to intentionally disable the features.

Since this work began, the EPA's Energy Star Computers and Monitors Program updated their requirements such that energy saving features are now enabled when they are shipped from the manufacturer. All computers tested in this investigation were installed before the application of this condition, which was October 1, 1995. However, many problems exist other than those remedied by this requirement, including: computers which disengage from the network environment upon entering the lowest power management levels, various software incompatibilities, problematic methods of achieving power reduction, and little to no training of users or even prior negative experiences with power managed equipment.

There is a need for manufacturers to develop suitable or standard methods of achieving power management. In addition, computer procurement employees or users must be taught about power management methods, and must have an opportunity to voice questions or concerns to manufacturers regarding power managed equipment. More research needs to be focussed on network incompatibilities. Specifically, many computers are disconnected from their network upon engaging the lowest power level. This is due to either unacceptable power management methods or "stand-alone" power manageable computers which are placed on a network. Users purchasing computers intended for network use should be informed about whether the energy saving features are compatible with their type of network.

This thesis is divided into two parts, the first for PCs and the second for workstations. The primary metering site for workstations was the Massachusetts Institute of Technology, which contains both Energy Star compliant and non-compliant machines. Opportunities for energy

conservation in workstations are compared and contrasted to those of desktop PCs and monitors. In addition, current and future trends in workstation manufacturing and their impacts on energy conservation are explored.

Thesis Supervisor: Leslie K. Norford, PhD, P.E.
Title: Professor of Building Technology

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PART I: DESKTOP PCs AND MONITORS

SECTION I: POWER MANAGEMENT

A. Energy Saving Programs

With the continual increase in the number of computers and monitors has come various power management programs designed to reduce consumption of devices during active and idle times. The EPA's Energy Star Program, begun in 1992, is one of the more well-known programs, specifically targeting office equipment idle time power management. EPA estimates that approximately 40% of computers sold in the second half of 1993 and the first half of 1994 are Energy Star compliant¹. This thesis attempts to determine energy savings of installed computers and monitors which have power management capabilities. Since EPA estimates that 5%² of total US commercial electricity consumption is from computers, and 20%³ of computers are left on overnight, there is a great potential to save energy during idle times. To that end, the Energy Star Computers and Monitors program requires each device to power down to less than 30W after a period of idle time.

Other countries have developed similar programs, such as Sweden's NUTEK program for monitors⁴ and Japan's Law Concerning the Rational Use of Energy. The NUTEK program is similar to the Energy Star program for monitors, except that it is a more strict standard, requiring less than 3W in sleep for compliance. Japan's new program targets mini- and mainframe computers and is scheduled to be implemented by the year 2000.

¹ *IEEE Spectrum*, Jan. 1995, p.61

² *IEEE Spectrum*, Jan. 1995 p.36

³ <http://www.epa.gov>

⁴ Dandridge, C.B., p. 24

The EPA Energy Star Computers program has been widely implemented in the US, and was scheduled in 1994 to be adopted by other countries including Japan and the European Community. Its goal is to reduce air pollution caused by power generation through the introduction of energy efficient personal computers and monitors into the computer industry. It is a partnership program where members of the computer industry may voluntarily sign an agreement stating that they intend to manufacture PCs and monitors which can "sleep" during idle times, while consuming less than 30W.

Computers and monitors sleep by powering down all unused components and subsystems while maintaining system memory and other configuration parameters. Thus, manufacturers provide computers with power manageable hardware, such as HDDs, monitors, and CPUs, and the software to allow power management to occur. Two documents define various power levels which, if implemented, will achieve power management:

- the Intel/Microsoft Advanced Power Management BIOS Specification, and
- the VESA Display Power Management Signaling Standard.

B. Advanced Power Management (APM)

The APM BIOS Interface Specification⁵ was written by Intel Corporation and Microsoft Corporation. It defines a method for computers with power manageable hardware to support power management. Power management is coordinated via a software connection between the APM BIOS (Basic Input/Output System) and the APM Driver. In essence, both the APM BIOS and the APM Driver can be thought of as pieces of software which contribute to controlling certain aspects of power management. The specification describes a method for the APM BIOS and the APM Driver to coordinate power management.

An APM BIOS is merely a standard system BIOS which adheres to the APM interface specification. The standard system BIOS is itself a piece of software which is written as the basic methodology for specifying hardware options within the computer. It is accessed during boot-up and sometimes contains pull-down menu screens to facilitate setting the various

⁵ Intel/Microsoft, APM Spec., 1992.

options. An APM BIOS also includes Power Options, and defines APM System Control.

The following power states are defined for APM System Control ("system" here means the entire computer with all devices and peripherals):

- 1) full on: system is not performing any power management
- 2) enabled: the system is operational except for some unused devices which may not be powered
- 3) standby: low power state with some power savings; most devices in low power mode; CPU clock may be stopped; system returns quickly to the APM enabled state; prior operation resumes after returning to the APM enabled state.
- 4) suspend: system is not working; low power state with maximum power savings; most power managed devices are not powered; CPU clock is stopped; CPU core is in its minimum power state; system returns slowly; prior operation resumes after returning to the APM enabled state.
- 5) off: system is not working; the power supply is off; system resets and initializes when transitioning to the full on state.

The APM specification is very generalized in that it does not define exactly which hardware must be affected in each power state, nor how much consumption should define each power level. Thus, it is possible that each manufacturer complies with the specification in a different way.

Please take note of the defined APM suspend mode where the CPU core, which consists of the CPU clock, cache, system bus, and system timers, is placed in its minimum power state. This is the state where many users are finding difficulty maintaining their network connection. Placing the CPU core in its minimum state may or may not include cutting the power to the system bus. If this occurs, then the network card will not have any power, and the network connection will be lost. Similarly, if the computer is connected to a server via modem, then power to the modem must be maintained to retain the connection after powering down.

The APM Driver defines APM Device Control. There is some overlap between the System Control and the Device Control because some devices (including the monitor) can be power managed through either the system BIOS or the operating system. The original equipment manufacturer is responsible for defining the relationship between the Device modes and the System states such that there is no conflict; they are coordinated to achieve power management. APM Device modes are defined as on, power managed, low power, and off:

- 1) on: device is fully powered and able to perform work; all device features are available.
- 2) power managed: device is working; some features may be off or at reduced performance levels; power is maintained.
- 3) low power: device is not working; power is maintained.
- 4) off: device is not working; power is not maintained.

The APM specification also discusses methods to control the CPU Core. It is managed differently than other devices because the core itself is required to perform system power state changes. In the APM System "enabled" state, the CPU clock can be turned on and off as needed; in the APM System "standby" state, the CPU clock is stopped; and in the APM System "suspend state", the CPU clock is stopped and the CPU core is in its minimum power state. The CPU Core Modes include:

- 1) full on: full speed operation, high power consumption, and high performance level.
- 2) slow clock: reduced speed operation, reduced power consumption, reduced performance level; restoration near instantaneous.
- 3) stop: only a hardware interrupt can restart the clock; restoration near instantaneous.

Typically, the differentiation between the CPU's standby and suspend modes is whether the clock is slowed or stopped. The significance of this is that the clock can be slowed during idle or active times, but it can only be stopped during idle times.

C. Display Power Management Signaling (DPMS) Standard⁶

This document defines a standardized method in which the display controller sends a signal to the display, enabling it to enter various power management states. DPMS defines the method of power management, but makes no requirements of required consumption in each power level. It defines power management states based on the APM power states; thus, the standard recommends usage of APM as well. However, usage of APM is not required to comply with this standard. The power states for DPMS are on, standby, suspend, and off:

- 1) on: both the horizontal and vertical synchronization signals from the display controller are active; the display is active.
- 2) standby: only vertical sync active; display is blanked; minimal power savings; short recovery time.
- 3) suspend: only horizontal sync active; display is blanked; substantial power savings; longer recovery time.
- 4) off: neither horizontal nor vertical sync is active; display is blanked; maximum power savings; recovery time depends on the type of system.

Although four power states exist, to be compliant with the DPMS standard the only mandatory states are on, suspend, and off.

D. Power Consumption and Computer Organization

There are wide variations in computer power consumption, caused by differences in organization and architecture. In general, a computer with more data storage devices, more I/O devices, wider buses, more powerful CPUs, and additional processors (such as math and graphics coprocessors) will have a higher energy consumption. CPUs with wider data buses can transfer more data in the same amount of time as those with narrow data buses. Thus, a CPU which has a 64-bit bus width will consume more energy than one with 32-bit bus width. This is one reason that the 64-bit Sun UltraSPARC-I CPU consumes more energy than the 32-bit Sun SuperSPARC-I CPU.

⁶ VESA DPMS Standard, 1993.

Processor energy consumption is dependent on processing speed, the number of transistors on the chip, and the energy required to switch each transistor⁷. The energy to switch each transistor is dependent on the operating voltage. The typical operating voltage on chips is very small, around 3 to 5 Volts; this scales with circuit size, around a micron (one micro-meter) or less. In fact, as circuit sizes continue to decrease, they will require even lower voltages. A few years ago the standard operating voltage dropped from 5 V to 3.3 V; today, it is not uncommon to see 2.5 V or even 1.8 V for certain chips. The benefits of lower voltage is that the logic gates switch faster, leading to higher CPU speeds; at the same time, power is reduced since it is proportional to the square of the voltage⁸. It is possible that eventually, operating voltages may be lost in background electrical "noise". However, even using today's technologies, computer circuits can operate at as low as a few millivolts⁸.

Different logic families offer varying levels of power dissipation, speed, and packing density. Today the most common logic family is the MOS technology, specifically CMOS devices. They consume low power in active time, and are particularly low consumers in power management modes. One report listed the power management for equivalent sizes of different technologies as follows⁹:

- CMOS, 1mW
- MOS, 500mW active and 100mW standby
- ROM (bipolar), 800mW

CPU technology greatly affects CPU energy consumption, and in particular affects its power management capabilities. Fully static CMOS drives are capable of not only slowing the CPU clock, but stopping it to reduce power consumption. Partial CMOS chips require a minimum clock frequency to maintain internal register contents. These chips are typically found as a CPU subsystem or in architectures which attempt to put all of the CPU on a single chip. One manufacturer produces both fully static all CMOS chips used in Energy Star compliant computers, and partial CMOS chips which are used in non-compliant computers.

⁷ Dandridge, C.B., p. 41.

⁸ Raskin p. 72

⁹ Tomek, p. 396

E. Methods of Power Reduction

Common power reduction techniques include:

- allowing the HDD to spin down when not in use
- stopping the horizontal, vertical, or both synchronization signals to the display
- slowing or stopping the CPU clock
- reducing power to video and graphics boards
- cutting power to fax/modem and network cards
- cutting power to speakers, unused memory cards, CD-ROM drives, cameras

Microprocessors

CPUs are capable of conserving energy during idle and active times. The most common method is to stop the CPU clock thus reducing CPU power to only the memory and initialization. In addition, during active times Performance on Demand is possible. In this technique, the clock speed of the processor is reduced for non-critical tasks, such as waiting for input, and operates at full speed during normal program execution¹⁰. Specifically, if the CPU is under-utilized, by using word processing on a Pentium, for example, the CPU clock can slow down to save energy in the active mode. Although saving in the active mode is far from the norm, one manufacturer's CPU has an automatic power-down capability wherein it does not consume any power unless RAM is accessed.

Slowing the CPU clock affects not only processing speeds, but also the speed of all other devices. A CPU's clock allows synchronous timing, where the occurrence of events is determined by the clock. The clock defines equal-width time slots, and events begin only at the beginning of a time slot. A time slot is the length of time to transmit a 1 and then a 0. This 1-0 sequence is continuous and occurs on its own "clock line" of the bus. All other devices on the bus read the clock line and begin their events at the start of the clock cycle. Thus if the clock cycle is slower, all events will occur at a slower rate.

Monitors

When the PC is not transmitting a signal to the display, the video controller tells the display to

¹⁰ *BYTE*, Nov. 1989 p.115

power down. This means that either the horizontal, vertical, or both synchronous signals are removed. If the monitor is found to be in a power saving mode, this is an indication that either the PC has been turned off at the switch, the connection between the CPU and monitor has been broken, or the PC is engaging power saving options. The benefit of monitor power down in this manner is that if users turn their computer off at the switch without turning off the monitor at the switch, the monitor will automatically enter a low power mode with the loss of signals.

Some machines base their CPU and HDD power saving functions on the action of the monitor. The CPU or HDD power saving capability activates when the monitor engages low power mode. This technique presents problems for computer functions which do not require the use of the monitor. On the other hand, some monitor and CPU power saving functions require a specific screensaver to be used in order for the power saving functions to be enabled. Both of these problems will be discussed more fully in Section II.A.

Currently there are no standard power reduction technologies for many I/O Devices, including: fax/modem cards, floppy disk drives, sound cards, video cards, graphics cards, CD-ROM drives, or speakers. Some manufacturers simply cut power to these devices, but without a standardized method to do so, initialization may be lost.

F. Potential Conflicts

The intent in computer energy conservation is to power down all unused components and subsystems while maintaining system memory and other configuration parameters.

Manufacturers are not told how this goal should be achieved, however. Unfortunately, many of the resulting energy conservation techniques are incompatible with system software or hardware, rendering them unusable. For example, one manufacturer powered down I/O devices by cutting power to the I/O controller which maintains device configurations. Upon exiting sleep mode, the CPU is no longer aware of the existence of these devices, rendering them unusable. This problem is discussed more fully in Section II.A.

Another issue is a potential conflict between HDD spin down and the use of virtual memory.

Virtual memory is used when more memory is needed than that which is available as RAM. When a system has virtual memory, active program segments are stored in main memory while remaining segments are stored on the HDD. Virtual RAM operates with the CPU as if it were in fact primary storage. Many laptops, PCs, and workstations have this capability, however it is more energy intensive. In fact, laptop manufacturers recommend that the virtual memory capability be disabled to conserve energy. Virtual memory is more energy intensive because the HDD is constantly active and does not power down; also, CPU access to virtual memory is more time-intensive than accessing cache or physical memory. Another related conflict exists between HDDs that spin down based on keyboard or mouse inactivity and an active CPU which requires the HDD for virtual memory access.

One problem which has been found in some systems concerns energy saving techniques that are incompatible with networks. This incompatibility can come in two forms: either the server's periodic polling of the client will prevent CPU power down, or the CPU power down mode will result in a lost network connection. In this study, the former problem was not seen. One manufacturer replied that with periodic polling, the server is communicating directly with the network card, not the CPU; thus, there should be no problem when the CPU engages its low power mode. The latter problem occurred at Site C and is discussed below.

Another potential conflict concerns possible wear and tear on computer hardware due to energy saving techniques. Only a few studies have been done which address this issue; the problems include failure of mechanical hardware and failure due to thermal shock. Only one manufacturer is known which takes these issues into account in its power saving hardware, but only in servers, where usage is more sporadic and failure more threatening.

G. Problems Discovered by Manufacturers

Both Novell and Apple provide technical information at their WWW sites.¹¹ The information is presented in a question and answer format such that users can search for specific problems they may have; employees answer these questions and provide interested users with solutions.

¹¹ <http://corp.novell.com> and webmaster@info.apple.com

The following six problems were found at both Web sites and are directly related to power management techniques. They are intended to demonstrate the types of problems that users are encountering¹².

1) Using Novell network's Netware 4.01, one user reported problems with an idle workstation connected to an Energy Star compliant server. Apparently, when the power saving screen saver engaged, the screen saver's image on the screen would move about wildly, and CPU utilization would climb from 0% to 75%. Once the user disabled the energy-saving functions, the problem was solved. [TID014827]

2) The energy saving features of one computer engaged whenever the screensaver was active. The system would stop processing when the screen blanked, and printing and other background functions would cease. The solution is to disable the energy saving features until the manufacturer could produce an enhancement to correct the problem. [TID655098]

3) One screensaver did not recognize mouse movement as non-idle usage. Thus, if a worker is using only the mouse and not the keyboard, the screensaver activated. The recommended solution was to disable the "Save In Graphics Mode" option ("graphics" meaning "mouse-only" usage). [Document ID: TID603959]

4) Another screensaver caused print jobs to be interrupted when it activated. The reason is that the screensaver is part of an energy saving utility which caused operations to be suspended, including print jobs. The solution offered was to disable the screen saving -- and thus power saving -- ability through the "Don't Sleep" function. [Document ID: TID600662]

5) Certain file servers were receiving such errors as "Incomplete Packets" or "Abend:...On Polling" from power saving computers. The recorded cause was due to power cut from the CPU during sleep mode; the suggested solution was to disable the sleep function. [Document ID: TID250377]

6) One user requested information about setting the CPU power saving option such that when a telephone call came through, the modem would wake the system. Unfortunately, the type of power saving capability on this particular system simply shut the computer off at a specified period, rather than keeping it partially awake¹³.

¹² Novell's disclaimer states the following: "The origin of this information may be internal or external to Novell. Novell makes every effort within its means to verify this information. However, the information provided in this document is for your information only. Novell makes no explicit or implied claims to the validity of this information."

¹³ Apple Technical Information Library, webmaster@info.apple.com

SECTION II: METERED ENERGY CONSUMPTION

A. Descriptions of Test Sites

Throughout the course of this project, seven sites were investigated. The sites include office building individual workstations, university public computer clusters, computer consultant offices, and researcher computer clusters. Each investigation included interviews with computer procurement and installation employees, interviews with users, electrical metering of Energy Star compliant equipment, and hands-on analysis of equipment content and hardware settings. The following pages detail discoveries at each site including the performance of installed Energy Star equipment; in addition, a brief discussion follows which describes an overall picture of computer sites in general.

SITE A

Site A is a computer consultant office where the employees assist computer users in troubleshooting their systems. This site has only seen minimal savings due to the Energy Star program for several reasons. First, the nature of the work performed there requires a very high level of computer activity, nearing 90% of the day in use. Second, of the 8 CPUs and 8 monitors in this office, only 1 CPU and 2 monitors are compliant; the other components are older, non-compliant pieces of equipment. Each computer is left "on" at night such that employees can access them remotely. Potential energy savings at this site are from CPU and HDD power management only since the monitors are turned off after working hours.

There were no reported difficulties for any machine¹⁴ to engage in the low power modes. However, there was a discrepancy between reported "Watts in Sleep" from the manufacturer and the measured Wattage. One monitor's consumption in low power mode was 50% higher than reported, and one was 25% lower than reported; still, both monitors were less than the 30W maximum allowance and were therefore compliant.

SITE B

Site B is a computer cluster where machines are left on for 24 hours per day. This cluster has

¹⁴ The term "machine" is used to represent a PC and monitor combination.

5 compliant machines plus two additional compliant monitors. Unfortunately, all of the compliant equipment has been disabled. The 5 compliant machines were initially enabled but then disabled due to software incompatibilities. The problem lies in the fact that their CPU clock slows after a period of mouse and/or keyboard inactivity. However, these machines are used for complex simulations, each of which requires several hours of computations with no user input. When the CPU timer expired after no user interaction, the CPU clock slowed and each simulation required about 12 instead of 2 computing hours. Upon discovery that the problem occurred due to one of the energy saving features, *all* features on all machines were subsequently disabled (including those which caused no problems, such as the monitor energy saving features).

SITE C

Site C is an office building with approximately 250 compliant machines; about 710 of the former non-compliant machines were retained. The compliant machines had been purchased only about 8 months before we entered the site, but none of the energy saving features were enabled. Initially, we thought that they were not operational merely because the default from the manufacturer was not ON. However, after enabling the machines and working with computer procurement employees and the manufacturer's technical support staff for 6 hours, we were still unable to see any power savings. This site is a classic example of the difficulty which some users experience while trying to enable energy saving computers and achieve energy savings.

The first problem was that operation of the monitor energy saving features requires the user to employ only the screen saver which accompanies the machine. Unfortunately, all of the users had chosen either their own personal screen savers or those available from their LAN; in doing so, they inadvertently disabled these energy saving features. This requirement was listed in the manual that accompanied the computer, however the computer procurement employees had not read the manual's information about the energy saving features.

The second problem was that the energy saving features are incompatible with the LAN version of Windows which their office uses. During the process of initializing the new Energy

Star compliant computers, the factory-installed PC version of Windows was erased from the hard disk and the LAN version was loaded. Apparently, this version was created and installed before the Energy Star program began; thus, it did not include any method to set or enable the energy saving features. To witness the operation of the energy saving features, the LAN version of Windows had to be erased and the PC version re-installed. This is a classic case where a computer with energy saving features was intended to be a "stand-alone" computer, but was installed on a network.

The third difficulty which occurred was more difficult to unravel, and is as of yet not fully understood. We eliminated the first two problems from three of the machines to determine whether it was possible to enable their energy saving features. Initially, the CPU energy saving feature would not engage, despite the insistence from the manufacturer's technical support staff that it should engage. Then, we discovered that the problem stemmed from a network incompatibility which caused the CPU energy saver not to engage; if it *did* engage, the machine subsequently lost its network connection. One reason that computers lose their network connection when entering CPU sleep mode is that power has been cut to the network card or the memory which retains CPU initialization. It is uncertain which of these problems occurred.

SITE D

Site D is also an office building, with 3 compliant machines and approximately 100 older, non-compliant machines. All of the compliant machines were disabled. There were no problems with the monitor energy saving feature, but there *were* problems with the CPU energy saving feature. These include the following:

- Occasionally, the machine would "crash" or "freeze up" after the sleep mode was engaged; these occurrences were seemingly random and could not be anticipated. The machine had to be rebooted to be usable again.
- The mouse was no longer usable once the CPU has returned from the sleep mode; to regain use of the mouse, the machine must be rebooted.

When these problems arose, *all* of the energy saving features were disabled, including those which did not cause any problems, such as the monitor energy saving features. The origin of

the first problem is uncertain, however it is possible that the CPU was no longer initialized, i.e., that the computer was no longer aware of its components, software, hardware, or capabilities.

The second problem was most likely due to cutting the power to the I/O Device Controller instead of the I/O Device. I/O devices, including FDD, HDD, printer, CD-ROM, keyboard, and mouse, are controlled by one or more I/O controllers which provide an interface between the device and the system bus, control the operation of the devices, and store the device configuration. Thus, if power is cut between the I/O Device and the I/O Controller, the device configuration is not lost. However, if power is cut to the I/O Controller, then upon awakening the CPU must be re-initialized (and thus re-booted) to learn again the device configurations.

SITE E

This site is a public computer cluster for researchers, with 5 non-compliant machines, 3 compliant machines, and 24 hour per day operation. When the computers were purchased, and before any problems occurred, the computer procurement employee not only disabled, but permanently erased from the hard drive all software which was intended to provide energy saving features. This person had extensive knowledge of computers and erased the capabilities to increase the productivity of the researchers. The given justification was that the energy saving software would continuously "listen" for keyboard or mouse activity, causing a decrease in performance of the computer due to an additional loop.

In addition, this employee did not believe any significant amount of energy would be saved due to the Energy Star program. He indicated his belief that the newer machines did not consume much more energy than machines which were a few years older, and that in comparison to the decades-old, energy intensive mainframe he recently removed (about 10 feet x 10 feet by 6 feet in size), the total energy consumption of the cluster is minimal.

In a sense, this employee is correct, since the mainframe consumed a great deal of energy. Despite this fact, there still exists a great energy saving potential in the cluster since the machines are on all night and idle. In addition, it is not known that application of energy saving features causes a computer to operate more slowly. In this case, education of the

computer procurement employee about the exact method of power management would have been beneficial.

SITE F

This site is an office building where the employers recently purchased 26 compliant machines and retained approximately 74 of its non-compliant machines. The computer procurement employee disabled all of the energy saving features on all of the machines after receiving various user complaints. Some of the problems were similar to those of Site D, where the machine would crash when in the low power mode. Another problem was that the low power mode of this particular machine would engage after a period of keyboard idle time, *not* both keyboard and mouse idle time. There were several instances where the user was installing software by using only the hard drive and mouse, and the screen blanked in mid-procedure. The final problem was that sometimes after the low power mode engaged, the original condition in which the PC was left was not intact.

SITE G

This site has approximately 100 compliant DEC machines and several hundred non-compliant machines in three different locations within the Boston area. This is the site which was used for the in-depth analysis. Upon entering the site, all of the compliant machines were disabled. These machines were disabled because the default is not "enabled" from the manufacturer, and because there was a perceived incompatibility between the energy saving features and the network. The computer procurement employee had problems in the past with similar energy saving features of laptop computers. Apparently, these features were incompatible with the network and were disconnected upon engaging the low power mode. This problem was found to be true through testing of some laptops connected to a network via network card or modem. These laptops lost their network connection during the deepest sleep mode.

Thus, when the option of enabling the new DEC machines arose, the decision was made to *not* enable them. When we enabled several of these machines, we found only one problem, that the CPU energy saver would not engage. As described further in Section II.B., the reason for this problem is still unknown. However, this problem is not due to periodic polling of the network, as this feature does not engage even when disconnected from the network. EPA's

compliant product database lists the DEC Celebris 590 as one PC which is Novell network tested and approved. This should mean that there is no incompatibility between the power management capabilities and the Novell network. And in fact, there was found to be no incompatibility (i.e., the network connections were not lost); thus, the computer installation employees agreed to enable a few machines for the purpose of this study.

The DEC machines were not enabled due to a perceived incompatibility which simply does not exist. They probably would have been enabled if the computer procurement employee was educated about the methodology of achieving power savings. The manual accompanying the computer briefly discusses the energy saving features, but not in enough detail to reassure the employee that there would be no problems. Specifically, no information was given about "system" energy saving, which is CPU power down, the power saving technology which causes the most problems in network environments.

The percent saturation of Energy Star compliant PCs and monitors at each site¹⁵ are summarized in Table 1.

Table 1
Saturation of Energy Star Compliant Machines

Site	Number of Compliant Monitors	Number of Compliant PCs	Total Compliant Equipment	Total Non-Compliant Equipment	Percent Saturation (%)
A	2	1	3	16	19
B	7	5	12	48	25
C	250	250	500	1420	35
D	3	3	6	200	3
E	3	3	6	10	60
F	26	26	52	148	35
G	100	100	200	500	40

The following table summarizes the sites visited, the status of the compliant machines upon entering the site, and the problems encountered. Please note that Site G would most likely

¹⁵ EPA-estimated saturation of Energy Star compliant computers and monitors for 1995 was 40%.

have all of its computers enabled and operational if the default was "enabled" from the manufacturer. Future problems of this nature will not occur due to the newer version of the MOU (October 1995).

Table 2
Summary of Sites

Site	Number of Compliant PCs	Number of Compliant Monitors	Status	Reason for Disabling
A	1	2	Enabled	N/A
B	5	7	Disabled	Software Incompatibilities
C	250	250	Disabled	Default screensaver Default is not "enabled" Network problems Older version of Windows for LAN
D	3	3	Disabled	Crashed in low power modes Lost initializations
E	3	3	Disabled	Ignorance Potential software incompatibilities
F	26	26	Disabled	Crashed in low power modes Software incompatibilities
G	100	100	Disabled	Default is not "enabled" Ignorance Lost initializations

Power management capabilities should be configured such that there are no user or software incompatibilities. It is possible that manufacturers are not aware of these incompatibilities; they even advertise energy savings through techniques which cause the type of problems listed above. One manufacturer advertised power saving capabilities which engage when the screen saver activates. This may be a good technique if the all components are idle, but for some users this is not the case. Someone who purchases a computer with energy saving features needs to be aware of techniques which are incompatible with their software or usage patterns. Another issue that this technique raises is that there is no opportunity for energy conservation in the active mode, such as CPU clock slowing or HDD spinning down.

The problem at Sites B and F was that the absence of keyboard and mouse activity caused the

monitor, HDD, and CPU to enter power management mode. In both of these cases, the computer was in use: either by the CPU only with time-intensive software, or by the HDD and CPU during software installation. The recommendation to the manufacturer is that power saving features be engaged based on inactivity of the hardware which will be powered down: the monitor should power down with a lack of keyboard and mouse activity; the CPU clock should slow only with no CPU and system bus activity; and the HDD should stop spinning only with no HDD activity.

Another problem occurred with computers that engaged the suspend mode and were disconnected from the network. It is common for standby mode to include monitor, HDD, and CPU energy savings, and for suspend mode to include removal of power from network cards, fax/modem cards, ports, and buses. As soon as power is cut to the network card, the network connection is lost and the machine must be re-booted to connect again. This usually occurs when the energy management features are configured for a stand-alone computer as opposed to a network computer. Some network manufacturers recommend that to maintain network reliability, computers should only engage in standby mode. It is possible to employ automatic re-connection to the network system such that re-booting is not necessary. This is a valuable option in the short term, however the best option would be to not lose the network connection in the first place.

There were several occasions where the use of a screensaver other than the default caused the energy saving capabilities to be disabled. Given that there are thousands of screensavers available to computer users, it is quite possible that many Energy Star compliant computers will be disabled in this fashion. In one case, the default screensaver was basically an advertisement for the manufacturer, with its name moving across the screen. Because of this, *all* of the users implemented personal screensavers.

A basic incompatibility may exist in some network systems combining both new and old computers. Site C is an example where new Energy Star compliant computers were added to the network system which already contained three times as many non-compliant machines. The network employees configured the newer machines to conform with the rest of the network system. Unfortunately, this older method of configuration was inadequate for the new

energy saving features. The LAN version of Windows which was traditionally copied to all new computers was created years before the Energy Star program even began. By replacing the factory-installed stand-alone PC version of Windows with the LAN version of Windows, the network operator inadvertently disabled the energy saving features. To ensure that the Energy Star compliant machines are not disabled upon installation, the manufacturer must consider the PC as a candidate for network use; very often, company policy permits the computer installation employee to purchase only a specific computer, whether or not the manufacturer has configured the energy saving features for network use. At this particular site, the manufacturer would have had to provide LAN upgrades for Windows which take into account new energy saving features.

When suspended, a system must power down all unused components and subsystems while maintaining system memory and other configuration parameters, such as the video display mode and mouse initialization. At Site D, the mouse was no longer usable after engaging suspend mode. This is most likely due to cutting power to the I/O Device Controller instead of the I/O Device. The manufacturer did not succeed to retain device initialization after the sleep mode engaged.

Many of the problems found at these sites were due to inadequate education of computer installation employees. They are technically minded people who understand the intimate operation of computers and their interaction with networks. Standard manufacturer information typically found in computer manuals is not adequate to explain the physical process involved during sleep modes. Perhaps a small paper describing energy saving techniques could be included in the packaging of each compliant machine; this would allow the user and computer procurement employee to fully understand the methodology and to be reassured.

In most of the sites visited, computer users had no knowledge of energy saving capabilities of their computer. They had heard of Energy Star due to the logo on their machine, but had no idea what the logo signified. In most cases, computer procurement and installation employees determined whether the machines would be enabled or disabled; thus, educating these people about exactly how the energy saving hardware operates would be beneficial. Without this

education, they are simply "afraid" of the Energy Star Program -- they don't want to risk the instability of their systems.

B. Detailed Discussion of Primary Site

The primary site chosen for the in-depth desktop PC investigation was a business office in Boston, Massachusetts. In 1994, they began to convert its computer system over to a typical server/client network by purchasing Energy Star compliant DEC machines containing Pentium processors. Prior to the installation of these computers, each employee had a dumb terminal. This is essentially a monitor with keyboard and/or mouse; it accesses a larger computer/server for program files, user files, and processing. Although this system offered some advantages including less maintenance and low power consumption, it was much slower than the current system.

The new system increases worker productivity by increased speed from local processing, better graphics from a higher resolution color monitor, and faster operation of programs that require large amounts of memory. However, in general this system may be under-utilized. Since the work performed at this site consists mainly of word processing, spreadsheets, and internal email, the high-powered CPU is not utilized to its full capability. In addition, there is still a network server to store software and user files, and the 540 Mbyte hard drive provided with each of the DEC Celebris 590's is virtually unused. The demand of a DEC Celebris 590 is approximately 50W in active mode plus 60W for the monitor. Thus by converting the office from dumb terminals to desktop PCs, worker productivity was increased at a price of PC first cost plus an additional demand of 80W per PC.

The in-depth investigation and main metering effort for this project occurred at Site G, a private office complex with three locations within the greater Boston area. As recently as 8 months before the initial consultation, this organization purchased 100 Energy Star compliant PCs and monitors, all from the same manufacturer. They have four different types of compliant machines including those with 486 and Pentium processors. These machines are used mainly for simple spreadsheet, word processing, and email tasks, plus they rely heavily on a Novell network.

The DEC Celebris 590 is listed as Energy Star compliant in the Energy Star Computers Compliant Product Database (June 1, 1995 version). According to the description, power consumption in the "sleep" mode equals 20W, it controls monitor power management via DPMS, and is Novell Network tested (and approved). The computer procurement employees have paired two different monitors with the DEC Celebris 590: the Sony Multiscan 17SE and the DEC PCXBV-PX; both are 14" color monitors. The Sony monitors are listed in the Database with "Watts in Sleep" of 25W. The DEC monitors are *not* listed, but are still compliant. The product literature states that the consumption in the sleep mode is less than 15W. All of the machines metered were DEC machines with DEC monitors. Later in this report, you will see these numbers compared with the measured values; generally though, both computer and monitor achieve the 30W limit set by the Program.

The employees there work on a fairly inflexible schedule from 8am to 5pm. They turn their machines on at the beginning of the day, off at the end of the day, and off for the evenings and weekends. There were a few exceptions, such as an employee who worked for some weekend days and another employee who forgot to turn his machine off at night; generally, though, the usage patterns were relatively stable. The following table summarizes the average distribution of computer usage hours for each machine (PC plus monitor) over the course of the 8 week study; the days included in this calculation are those which have computer usage, whether weekday or weekend.

Table 3
Average Time Machine is ON per Day

Status	Average Hours Machine is ON per Day			
	Machine 1	Machine 2	Machine 3	Machine 4
ON	8.3	7.8	9.0	9.8
OFF	15.7	16.2	15.0	14.2

We discovered that the employees were not aware of the significance of the Energy Star program, although they did recognize the name due to the logo on their machine. When we enabled the energy saving features on their machines, and discussed the energy saving benefits of such a machine, they seemed to have a positive attitude and were willing to assist the metering effort. We were permitted to enable four of their compliant machines for the 8 week

period. After two weeks of working with enabled machines, 2 of the 4 users expressed mild dissatisfaction with the energy saving features. One person expressed disappointment that the length of the monitor suspend timer was so short (5 min), even though the recovery time is only about 2 to 3 seconds; the other person wanted to understand exactly why his computer was behaving differently, and what mechanically was occurring.

Each of the four machines metered at the primary site (Site G) were Energy Star compliant (although disabled) DEC Celebris 590s. They are all "identical" machines with the following components:

Pentium processor	1M Video RAM
90 MHz	8M RAM
3.5" FDD	14" DEC color monitor, plugged into the PC
540 M HDD	

However, as will be seen from the "data analysis" subsection, the energy consumed at full power and at each low power level varies from machine to machine. The variation in energy consumption was approximately 10% to 20% for identical monitors and 5 to 10% for identical PCs.

C. Power Options of the DEC Celebris 590

The manual which accompanies the DEC Celebris 590 mentions that this machine uses Advanced Power Management (p. 1-2, DEC Celebris 590 Owner's Manual). However, the power options defined further in the manual do not use exactly the same terminology as those listed in the APM specification. So, in describing this machine's power options below, we've also listed its equivalent "official" APM state. Configuring power options is accomplished through the system BIOS, as APM specifies. There are four different power management options available, each of which can be independently programmed:

The *monitor suspend timer* places the monitor in a suspend state of minimum power savings after a set period of keyboard or mouse inactivity. This is the DPMS suspend mode. The timer can be set from 1 to 30 min, causing the monitor screen to blank and the energy consumption to drop substantially. The device is not completely off, although it remains at a reduced performance level, including a blanked screen and a recovery time of about 2 to 3

seconds. According to the definition given in the APM specification, the monitor qualifies as an APM Power Managed Device after expiration of this timer.

The *monitor off timer* places the monitor in an off state after a set period of keyboard or mouse controller inactivity. This is the DPMS off mode. The timer can be set from 1 to 30 min, causing the energy consumption to drop to 0W. The monitor screen is still blank, however, the light of the monitor's on/off switch is still illuminated, indicating that power has not been completely cut off. The recovery time of the monitor in this state is about 10 to 13 seconds. The monitor in this off state qualifies as an APM Device in Low Power mode.

The *hard disk suspend timer* allows the hard disk drive to spin down its motor after approximately 21 minutes of disk drive inactivity. This time period cannot be changed. Notice that this suspend timer does not depend upon keyboard or mouse activity such as the first two timers.

The *system suspend timer* places the computer in a maximum power saving (i.e., suspend) state after a set period of CPU inactivity. The timer can be set from 30 min. to 12 hrs. Notice that the system is placed in a suspend mode after the CPU, not the keyboard or mouse, has been idle for a specified period of time. This type of timer is very convenient for users who run programs not requiring keyboard or mouse activity. In terms of the APM System Control power states, the hard disk suspend timer and the system suspend timer could contribute to either the system "standby" or "suspend" mode. However, since they are controlled by two different timers, the assumption is that the former corresponds to APM standby mode and the latter to suspend mode.

Some of the problems at Sites B and F were a direct result of the energy saving features' reliance on keyboard or mouse activity to determine when the machine is idle. In reality, both the PC and the monitor can be in use while there is no keyboard or mouse activity. The DEC Power Options require the hard disk to be idle before it is allowed to spin down, and requires the CPU core to be idle before the CPU clock slows down. This seems to be a more accurate method of designing an energy saving feature simply because the problems experienced at

Sites B and F are eliminated. Even more important is the fact that if these problems had not been experienced at Site B, all of the machines' energy saving features would still be enabled and conserving energy.

The following two tables summarize the APM and DPMS power states in comparison to the DEC Celebris 590 power states:

Table 4a
Power States for the DEC Celebris 590

Power States for the DEC Celebris 590	Intel/Microsoft APM System Control
switched ON	full on
--	enabled
hard disk suspend	standby
system suspend	suspend
switched OFF	off

Table 4b
Power States for the DEC Color Monitor

DEC 14" Color Monitor	VESA DPMS states
switched ON	on
--	standby
monitor suspend	suspend
monitor off ¹⁶	off
switched OFF	--

For the four machines enabled at the primary site, the power options were configured as follows:

- monitor suspend timer, 5 minutes
- monitor off timer, 10 minutes
- hard disk suspend timer, enabled (21 minutes)

¹⁶ This "off" mode is an actual DPMS power level which consumes 0W, yet it differs from the OFF status which occurs by turning the monitor off at its switch.

- system suspend timer, 30 minutes

Thus, if a compliant, enabled machine is left completely idle¹⁷ for one hour, the timers will cause the following energy changes:

- monitor screen blanks at the fifth minute, consuming less power than in the "on" mode;
- monitor power consumption drops to 0W at the 15th minute;
- hard disk is allowed to spin down at approximately the 21st minute; and
- the CPU clock slows at the 30th minute.

After the thirtieth minute, the machine remains in its lowest power mode until user interaction occurs.

Unfortunately, we were unable to see the system suspend timer operate properly. Over the 8 week period where we metered 4 different machines, we never saw any reduction in power consumption after expiration of this timer. This should have resulted in a power reduction to the 20W recorded in EPA's Energy Star Compliant Database. Of course, it is difficult to determine exactly when the CPU is active or inactive, or when it may have been inactive for more than 30 minutes. However, two other tests were conducted to determine whether this timer activates a CPU low power mode. The first test was through the fifth power management option, called the "Quick Suspend". The second test included "spot" metering, which includes taking instantaneous readings of electric demand for a period of time before and after the expiration of the timer. Spot metering will be discussed further in Section II.D.

Quick Suspend is a power management option included in these machines; like the previous four methods, it can be enabled or disabled in the BIOS. The purpose of this option is that the user can immediately engage the system suspend mode by simply typing `<ctrl><alt><esc>`. Thus, if the user knows he will be leaving his computer for a significant period of time, he can begin to conserve energy immediately instead of waiting 30 minutes for the system suspend timer to expire.

Unfortunately, we were also unable to see Quick Suspend operate properly; there was no

¹⁷ The term "idle" indicates that the keyboard, mouse, CPU core, and hard drive are all idle.

power reduction upon typing `<ctrl><alt><esc>`. When the machine was in Windows, the keyboard functionality over-rode this BIOS power option. Pressing `<ctrl><alt><esc>` in Windows offers a different action as it is a Windows function key. When the machine was not connected to the network and remained idle in DOS, `<ctrl><alt><esc>` still did not cause any power reduction. As a matter of fact, when the machine was in the monitor suspend state, pressing `<ctrl><alt><esc>` woke up the monitor to its full power consumption mode (the DPMS on mode) -- remember that the monitor suspend mode is designed to wake up for any keyboard or mouse activity -- and still there was no power reduction due to the CPU clock.

It is still not known why the machine was unable to engage the CPU suspend mode. Initially, the thought was that the network was preventing the CPU clock from slowing or stopping. However, the Quick Suspend did not cause any power reduction even when the machine was disconnected from the network. Thus, the network may not be the problem. However, even without the additional drop in power consumption that the CPU energy saver might afford, this PC is still Energy Star compliant with consumption less than 30W in its sleep mode.

The focus of this metering project was to determine the amount of energy savings directly related to the Energy Star compliant PCs and monitors. This includes system components which are powered down only during idle times. However, this site is a good example of a case where there is a potential for a great amount of energy savings during the *active* mode. Since the PCs are not fully utilized, even while "active", a specific amount of energy is consumed which could be saved through several available technologies. The potential for active mode savings will continue to increase at this site, because the standard procurement procedure has recently been changed to phase out the remainder of the dumb terminals and to replace them with more DEC machines.

Tables 5a and 5b are an expansion of Table 3. They illustrate the active-power energy-saving potential of the DEC machines according to employee utilization patterns. For each PC, the average time per day and percent of day that each Machine spends at full power or in a low power mode is listed. The behavior of Machines 1, 2, and 3 are similar in that they all spend approximately 35% of the day switched on. Please take note that the amount of time during which the Energy Star Program saves energy for these three PCs is the "Low Power" mode,

ranging from 12 to 15% of the day. In general this would account for energy saved due to the DEC's hard disk suspend timer and system suspend timer, however the latter was non-operational as has been already discussed. For an additional 18 to 24% of the day, these three PCs are either in use or are spending time in the idle mode just before the timer expires. For the primary site, and for similar sites, this 18 to 24% of the day is an additional period of time where energy could be saved in the active mode. Mainly this includes CPU clock slowing during non-critical operations and HDD spin-down. At the primary site, both would apply, especially since the CPU's capability is not fully utilized and the HDD is rarely used.

Table 5a
Average Time Spent at each Power Level

Power Level	Average Time Spent at Each Power Level (hrs/day)			
	PC 1	PC 2	PC 3	PC 4
Switched ON	8.3	7.8	9.0	9.8
Full Power	5.4	4.2	5.8	2.0
Low Power	2.9	3.6	3.2	7.8
Switched OFF	15.7	16.2	15.0	14.2

Table 5b
Percent of Time Spent at each Power Level

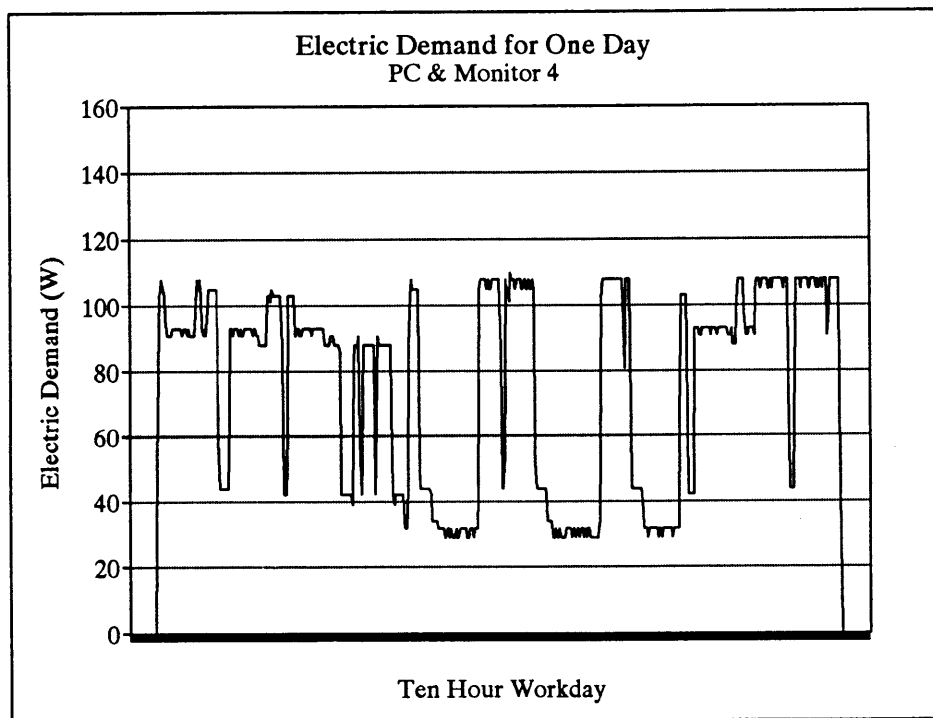
Power Level	Percent of Time at Each Power Level (%)			
	PC 1	PC 2	PC 3	PC 4
Switched ON	35%	33%	37%	41%
Full Power	23%	18%	24%	8%
Low Power	12%	15%	13%	33%
Switched OFF	65%	67%	63%	59%

PC 4 spent more time in the Low Power mode than the other three machines because there were a few nights that it was left on all night; these days were included in the calculation of the "average" time spent at each power level, even though this was not "typical" behavior of the employees. However, it does illustrate that without the Energy Star Program, and without the energy saving features enabled on this particular machine, the energy consumed would have been higher.

D. Data Gathering

An in-line meter manufactured by Synergistics, Inc. was used to gather energy consumption data. Two different techniques were used to gather data: long-term metering and "spot" metering. For the long-term metering, the meter was configured to record over a one minute interval the average potential (volts), current (amps), and electric demand (kW) for each machine¹⁸. Graph 1 shows the type of data retrieved in a plot of electric demand for one DEC machine over a 10-hour workday. The smaller, rapid variations are quite common, and are due to changes in the CPU usage and consumption, the network connection, and standard electrical variations. The larger variations of 5W or more are power levels as a result of the energy saving features. It can be seen that this machine consumes about 103W at its highest power level and various other amounts at several other power levels. The spot-metering determines which hardware changes are occurring within each component.

Graph 1



Spot-metering is a technique where instantaneous readings of electric demand are recorded, rather than the average over a specific time interval. The purpose of spot-metering is to allow

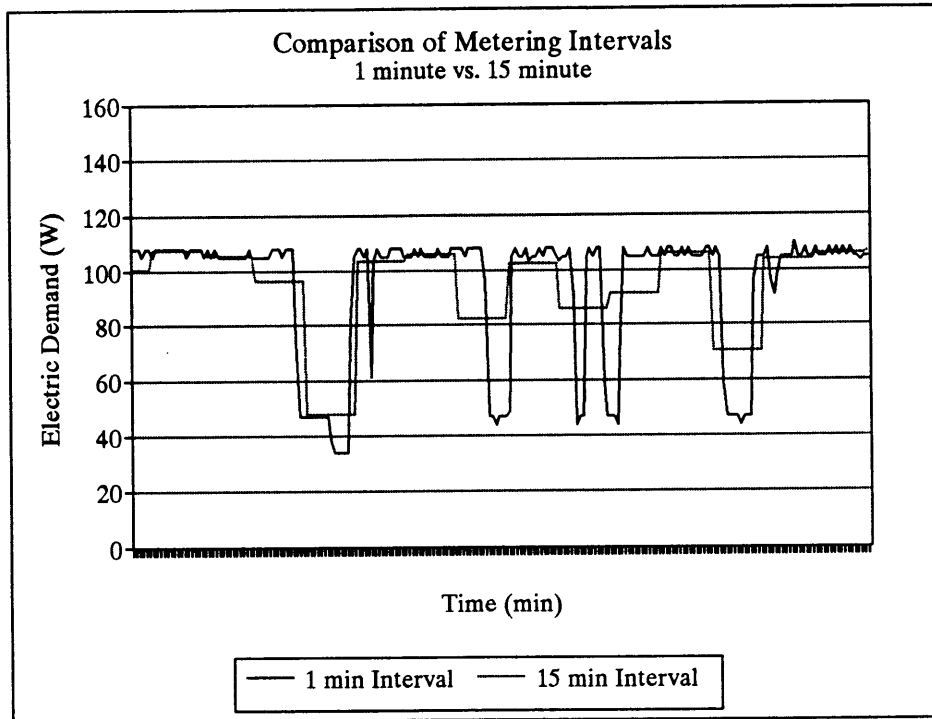
¹⁸ The recorded demand was the total required by PC and monitor.

the total machine data to be easily disseminated into individual PC and monitor energy consumption data. This technique was used as opposed to long-term metering of each component simply to reduce the amount of data collection and analysis required. This technique did not prove to be difficult, since in the data analysis it is very easy to determine whether a power drop is due to a PC or a monitor.

Each PC and each monitor was individually metered in all power modes to determine the typical amount of energy consumed by them. They were all metered on three different weekdays in an attempt to account for possible consumption variations within a particular component; there were no variations worthy of mention. In this case, the energy consumption of the machine is calculated as a simple addition of each of its components. Thus, for example, when the long-term metering effort recorded electric demand of a certain machine at 103W, we were able to determine the DPMS or APM power state and the energy consumption of each component.

In general, a one minute time interval for this type of long-term metering is a fairly high level of data resolution. However, a one minute interval is necessary to understand exactly what is occurring within the computer. As was stated in Section II.C., some energy saving features, including the monitor suspend timer and the monitor off timer, can be set to expire after one minute of idle time. Although in this project they were set for a minimum of five minutes, a resolution over an interval longer than 1 minute is still not clear enough to determine which hardware changes have occurred. For example, there were numerous cases where several power changes occurred within a five or six minute interval. If the resolution of data collection had been over a 15 minute time interval, it would be nearly impossible to determine what power changes had occurred and especially to determine the amount of time spent at each power level. Graph 2 shows the difference between data collected at a one minute interval and the same data averaged over 15 minute time intervals.

Graph 2



E. Data Analysis

The results of the monitor spot metering are displayed in Table 6. As previously mentioned, there are significant demand variations for both the DPMS "on" and "suspend" modes for supposedly identical equipment. This conclusion was expected and is probably not very important except in the attempt to magnify results from this site to a larger study group for comparison purposes. In addition, note that the DPMS off mode consumes 0W, even though it differs from switching the monitor off¹⁹. The third point to notice is that the suspend mode only consumes 10W, which is one-third of the maximum requirement by the Energy Star Program.

¹⁹ In some cases, equipment that is switched off yet plugged in consumes power, as much as 12W!

Table 6
Monitor Electric Demand in Power Levels

Power Level	Idle Time Until Power Level Engages	Recovery Time	Electric Demand (W)			
			Monitor 1	Monitor 2	Monitor 3	Monitor 4
on	--	--	59	59	54	54
suspend	5 min	2 - 3 sec	10	10	12	10
off	15 min	10 - 13 sec	0	0	0	0

Table 6 suggests that most of the savings should occur due to the initiation of the suspend mode instead of the off mode. This is demonstrated in two ways: by the amount of reduction in electric demand, and by the amount of idle time until the power levels engage. For each of the four monitors, the demand is decreased more due to the suspend mode than due to the off mode. For example, Monitor 1 reduces its demand 49W by enabling the suspend mode, whereas enabling the off mode causes only an additional 10W drop. Of course, another way to configure the power saving timers would be to enable only the monitor off timer, setting it for 5 minutes. Then, in comparison to the method illustrated in Table 6, the savings after 5 minutes would be 59W instead of 49W. Of course, the drawback of this method is that the recovery time for the monitor would be 4 to 5 times higher, and thus this method is not desirable.

Thus in this study the timers were set at 5 minutes for the suspend mode and an additional 10 minutes for the off mode. With these settings, the monitor will engage in the suspend mode at least as often as the off mode and probably even more, simply because the suspend mode is engaged on the way to the off mode. In other words, if there is an occasion when the computer is idle for 10 minutes, the suspend mode will engage but not the off mode. Thus, savings will tend to be higher due to the suspend mode as opposed to the off mode.

Another variable in determining which mode results in the highest savings is the amount of time the monitor spends in each mode. For a 30 minute idle time, for example, the monitor spends the first 5 minutes in the on mode, the next 10 minutes in the suspend mode and the following 15 minutes in the off mode. So, even if the suspend mode is engaged more frequently than the off mode, the monitor may spend more time in the off mode than in the

suspend mode. Table 7a shows that this occurs at the primary site. The monitors spend a significantly longer time in the off mode than in the suspend mode. However, because the amount of energy savings due to the off mode are much less than that of the suspend mode, the relative energy savings of the suspend mode are much higher than that of the off mode, as shown in Table 7b.

Table 7a
Monitor Average Time Spent at each Power Level

Power Level	Average Time Spent at Each Power Level (hrs/day)			
	Monitor 1	Monitor 2	Monitor 3	Monitor 4
Switched ON	8.3	7.8	9.0	9.8
on	4.4	4.7	5.2	2.5
suspend	1.5	1.2	1.1	0.8
off	2.4	1.9	2.7	6.5
Switched OFF	15.7	16.2	15.0	14.2

Table 7b
Monitor Amount of Energy Saved at each Power Level

Power Level	Amount of Energy Saved (Wh/day)			
	Monitor 1	Monitor 2	Monitor 3	Monitor 4
Switched ON	214	169	186	387
on	--	--	--	--
suspend	190	150	155	322
off	24	19	31	65
Switched OFF	--	--	--	--

The spot metering sessions also revealed the amount of energy consumed by the PC in each of its power levels. Remember, though, that at the primary site we were unable to engage the system suspend timer. Thus our results do not include any savings from this mode, and we only have two power modes, full on and standby, corresponding to the APM system states.

One of the most significant conclusions from spot metering the PC alone was the additional energy required for the PC to communicate with the network server. The machine consumes

less energy while disconnected from the network than when connected to the network and communicating with the network server. In fact, the difference was from 12 to 17W! Note, however, that this includes the additional energy required to power the network card, approximately 5W. It is still not clear exactly why the consumption is so much higher, but several computer procurement employees felt that it is due to the additional CPU activity which occurs as it communicates with the network server and "listens" for any possible incoming commands. In fact, one manufacturer said that the power consumption of a CPU differs depending on the type of software running.

Table 8
PC Electric Demand in Power Levels

Power Level ²⁰	Idle Time Until Power Level Engages	Recovery Time	Electric Demand (W)			
			PC 1	PC 2	PC 3	PC 4
full on A	--	--	49	49	51	49
standby A	21 min	3 - 5 sec	44	44	49	44
full on B	--	--	34	34	34	32
standby B	21 min	3 - 5 sec	32	29	32	29

This difference is reflected in Table 8, where each APM state is split into two groups: "full on A" if the PC is full on and communicating with the network and "full on B" if the PC is full on and not communicating with the network. Likewise, "standby A" means that the hard drive has spun down, yet the CPU is communicating with the network; "standby B" means that the hard drive has spun down, and the CPU is not communicating with the network. This is the lowest power state which these DEC machines entered, and it should be below 30W to be compliant with the Energy Star Program. PCs 1 and 3 probably would drop to below 30W if the CPU energy saver were operational.

The machine's connection to the network does not preclude it from dropping into its low power modes. The HDD can still spin down because this action depends on inactivity of the HDD. Although the CPU clock did not slow, as was stated before, this was not due to the network connection since this feature did not engage even when disconnected from the

²⁰ "A" indicates that the PC is connected to the network; "B" indicates that it is not.

network. We also found that the machine was not awakened from periodic polling of the network server.

Table 9a shows that on average PCs 1, 2, and 3 spend most of their time in the full on mode, and PC 4, which was accidentally left on for a few nights, spends a much higher portion of its day in the standby mode. This contributes to the fact that the amount of energy saved due to the hard disk suspend timer is only minimal (see Table 9b). Overall then, we find that for the machine as a whole, most of the savings occur due to the energy saving features of the monitor instead of the PC.

Table 9a
PC Average Time Spent at each Power Level

Power Level	Average Time Spent at Each Power Level (hrs/day)			
	PC 1	PC 2	PC 3	PC 4
full on A	3.8	1.7	4.0	1.5
standby A	0.2	0.7	0.9	0.8
full on B	1.6	2.4	1.8	0.5
standby B	2.7	2.9	2.3	7.0
full on A+B	5.4	4.1	5.8	2.0
standby A+B	2.9	3.6	3.2	7.8

Table 9b
PC Amount of Energy Saved at each Power Level

Power Level	Amount of Energy Saved (Wh/day)			
	PC 1	PC 2	PC 3	PC 4
full on A	--	--	--	--
standby A	1	4	2	4
full on B	--	--	--	--
standby B	5	15	5	21

An important point to clarify is that the amount of time the PC spends in standby mode may not be equal to the amount of time it is idle. Due to the nature of the energy saving features

of the DEC Celebris 590, the standby mode may be engaged (i.e., the hard drive is spun down) while the user is working. Remember that the standby mode is engaged after a period of hard drive inactivity, not after a period of keyboard or mouse inactivity.

The results of the spot metering sessions were then applied to the recorded electric demand of the long-term metering for each machine. Table 10 shows how these two pieces of information were used to determine the power level and hardware action of each component of Machine 4. Each time a demand of 103W was reached by Machine 4, we know that the PC is in its "full on" mode, communicating to the network server, consuming 49W, and the monitor is in its "on" mode, consuming 54W.

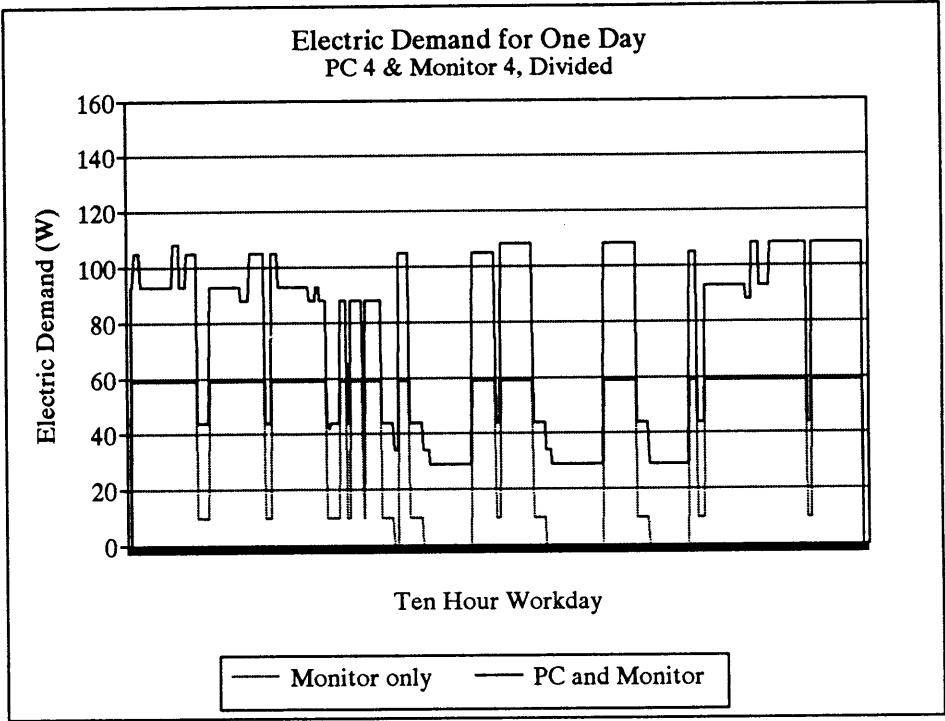
Table 10
Machine 4, Electric Demand in Power Levels

Machine 4	PC 4			Monitor 4	
Demand (W)	Demand (W)	APM State	Net Access	Demand (W)	DPMS State
103	49	full on	yes	54	on
98	44	standby	yes	54	on
86	32	full on	no	54	on
83	29	standby	no	59	on
42	32	full on	no	10	suspend
39	29	standby	no	10	suspend
32	32	full on	no	0	off
29	29	standby	no	0	off

The spot metering results assisted in dissection of long-term metering results as opposed to keystroke monitoring devices, such as that developed by NRC of Canada. One reason is because the NRC software would inform us only of monitor activity, since only the monitor responds to keyboard or mouse activity. It would not be able to tell us whether the hard drive had spun down since its action depends upon hard drive use and not keyboard or mouse activity. The second reason that the NRC software was not used is that it is not compatible in a windows environment, which is used at the primary site.

Graph 3 shows the electric demand of Machine 4 for the same day as in Graph 1, yet divided according to the consumption of each component.

Graph 3



F. Results: Savings from the Monitors

It is obvious from Tables 7b and 9b that most of the energy saved is due to a reduction in power consumed by the monitor. This result was expected as the monitor is the most energy intensive component of the computer. In fact, DEC refers to its "monitor off" timer as a "one-half power saving state". Table 11 compares the amount of energy consumed for each monitor, divided according to power level and whether or not the energy saving features are enabled. Each value listed in the table is the averaged over all days the monitor was in use.

The first column lists the power levels as defined by the DPMS Standard. In the second column, the total consumption of a disabled monitor, 489Wh/day, is divided based on the amount of time it would have spent in each power level, had it been enabled. This format shows the potential to save energy if the monitor is enabled. The value of 205Wh/day identifies the energy consumption of the disabled monitor while it was idle and could have been sleeping. The remaining 15Wh/day is due to the 10W suspend mode power level. Thus the excess energy consumed due to disabling the energy saving features is 190Wh/day. Note that most of the savings result from enabling the suspend mode.

Table 11: Monitor Consumption in Power Levels
Monitor 1:

Power Level	Consumption of Disabled Monitor (Wh/day)	Consumption of Enabled Monitor (Wh/day)	Savings due to Enabling the Monitor (Wh/day)
on	260	260	--
suspend	205	15	190 (1.5¢)
off	24	0	24 (0.2¢)
total	489	275	214 (1.7¢)

Monitor 2:

Power Level	Consumption of Disabled Monitor (Wh)	Consumption of Enabled Monitor (Wh)	Savings due to Enabling the Monitor (Wh)
on	275	275	--
suspend	162	12	150 (1.2¢)
off	19	0	19 (0.2¢)
total	456	287	169 (1.4¢)

Monitor 3:

Power Level	Consumption of Disabled Monitor (Wh)	Consumption of Enabled Monitor (Wh)	Savings due to Enabling the Monitor (Wh)
on	281	281	--
suspend	168	13	155 (1.2¢)
off	31	0	31 (0.3¢)
total	480	294	186 (1.5¢)

Monitor 4:

Power Level	Consumption of Disabled Monitor (Wh)	Consumption of Enabled Monitor (Wh)	Savings due to Enabling the Monitor (Wh)
on	137	137	--
suspend	330	8	322 (2.5¢)
off	65	0	65 (0.5¢)
total	532	145	387 (3.0¢)

Table 12 summarizes the daily values of Table 11 and extends the savings over a one year period for both the four computers metered and for the entire office. Since there are 100 compliant monitors in this office, it is assumed that the four which were metered are typical of the remaining 96. Note that the total yearly savings which would result from enabling the

energy saving features on the monitors is about \$491.

Table 12:
Monitor Yearly Savings

Number of Monitors	Yearly Savings (\$)				
	Monitor 0	Monitor 1	Monitor 2	Monitor 3	TOTAL
One Cluster: One Monitor of each type	\$4.48	\$3.56	\$3.56	\$8.03	\$19.63
Entire Office: 25 Monitors of each type	\$112	\$89	\$89	\$201	\$491

G. Results: Savings from the PCs

The spot metering allowed us to determine that at the expiration of the 30 minute system suspend timer, there was no change in the energy consumed by the PC. Because of this and the fact that the Quick Suspend function did not decrease the energy consumption (see Section II.C.), we concluded that the CPU energy saver was non-operational. The effect that this may have had on the PCs is uncertain. However the reported "Watts in Sleep" of the PC is 20W according to the Compliant Product Database, a difference of 10 to 12 W from the measured results. In general, therefore, the energy savings due to the PC were minimal, especially when compared to the energy saved due to the monitor's energy saving features. The following series of tables lists the energy saved by each PC, when the features are disabled and when they are enabled.

Table 13: PC Consumption in Power Levels

PC 1:

Power Level	Consumption of Disabled PC (Wh)	Consumption of Enabled PC (Wh)	Savings from Enabling the PC (Wh)
full on A	186	186	--
standby A	10	9	1 (~0¢)
full on B	54	54	--
standby B	91	86	5 (~0¢)
Total	341	335	6 (~0¢)

PC 2:

Power Level	Consumption of Disabled PC (Wh)	Consumption of Enabled PC (Wh)	Savings from Enabling the PC (Wh)
full on A	83	83	--
standby A	35	31	4 (~0¢)
full on B	82	82	--
standby B	99	84	15 (~0.2¢)
Total	299	280	19 (0.2¢)

PC 3:

Power Level	Consumption of Disabled PC (Wh)	Consumption of Enabled PC (Wh)	Savings from Enabling the PC (Wh)
full on A	204	204	--
standby A	46	44	2 (~0¢)
full on B	61	61	--
standby B	79	74	5 (~0¢)
Total	390	383	7 (~0¢)

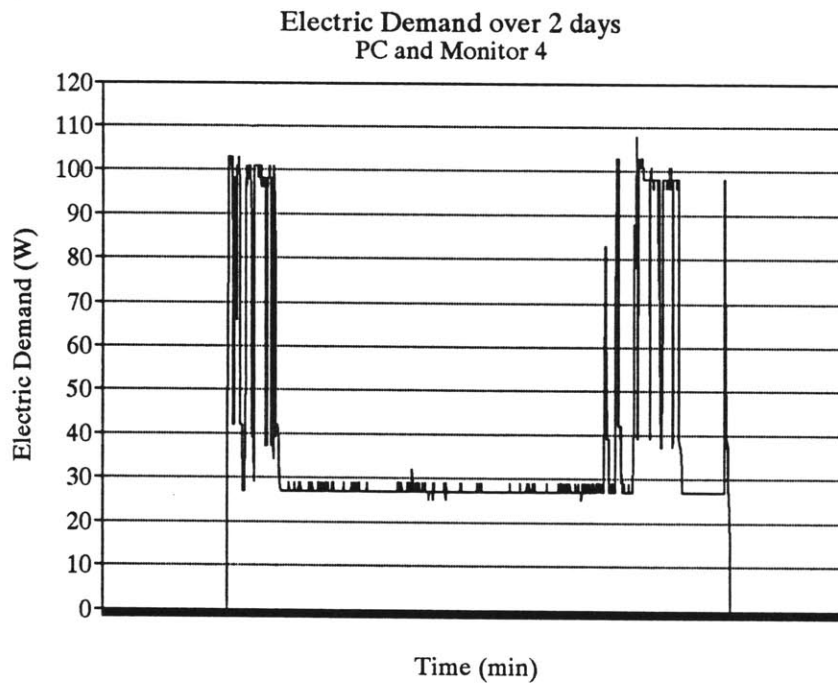
PC 4:

Power Level	Consumption of Disabled PC (Wh)	Consumption of Enabled PC (Wh)	Savings from Enabling the PC (Wh)
full on A	74	74	--
standby A	39	35	4 (~0¢)
full on B	16	16	--
standby B	224	203	21 (~0.2¢)
Total	353	347	25 (0.2¢)

H. Overnight Savings

Machines 1, 2, and 3 were consistently turned on at the beginning of the workday and off at the end of the workday. However, Machine 4 was accidentally left on overnight for 20% of the days it was used²¹. This means that for the average of 14.2 hours during which the machine should have been off (see Table 7a), it was operating at its lowest power mode of 29W (see Table 8), overnight, as shown in Graph 4. This also means that if we had not enabled Machine 4, it would have been operating at 86W for the entire night, the demand for a "full on" machine without network communication. Thus the savings for each day it was left on overnight are 810 Watt-hours (Wh), or about 6.5 cents²². This is in contrast to the average savings over all recorded days of about 3 cents, as displayed in Table 11d above.

Graph 4



²¹ This value agrees with EPA's estimate that 20% of computers are left on overnight.

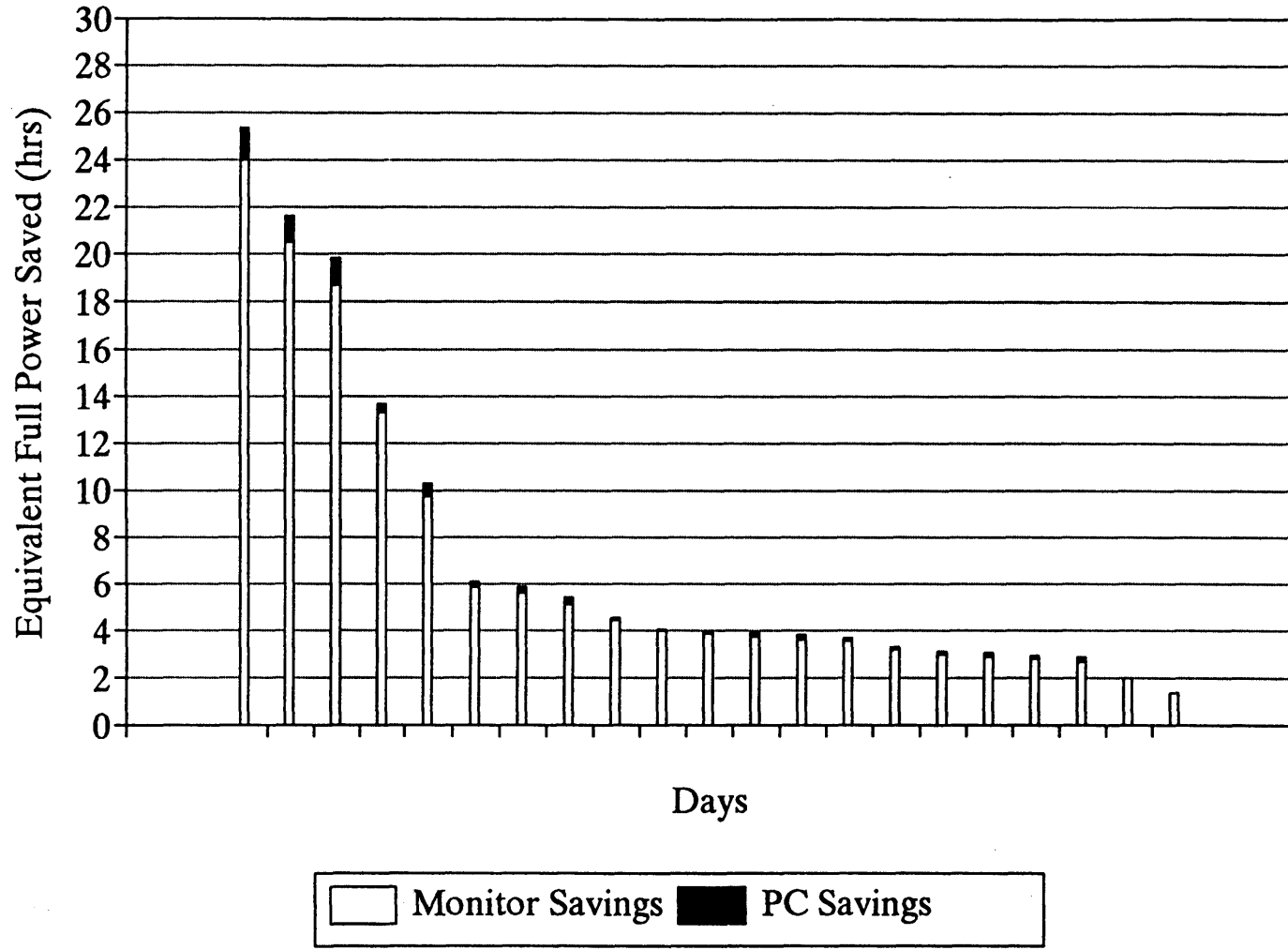
²² assuming \$0.08 per kWh

I. Equivalent Full Power of Savings

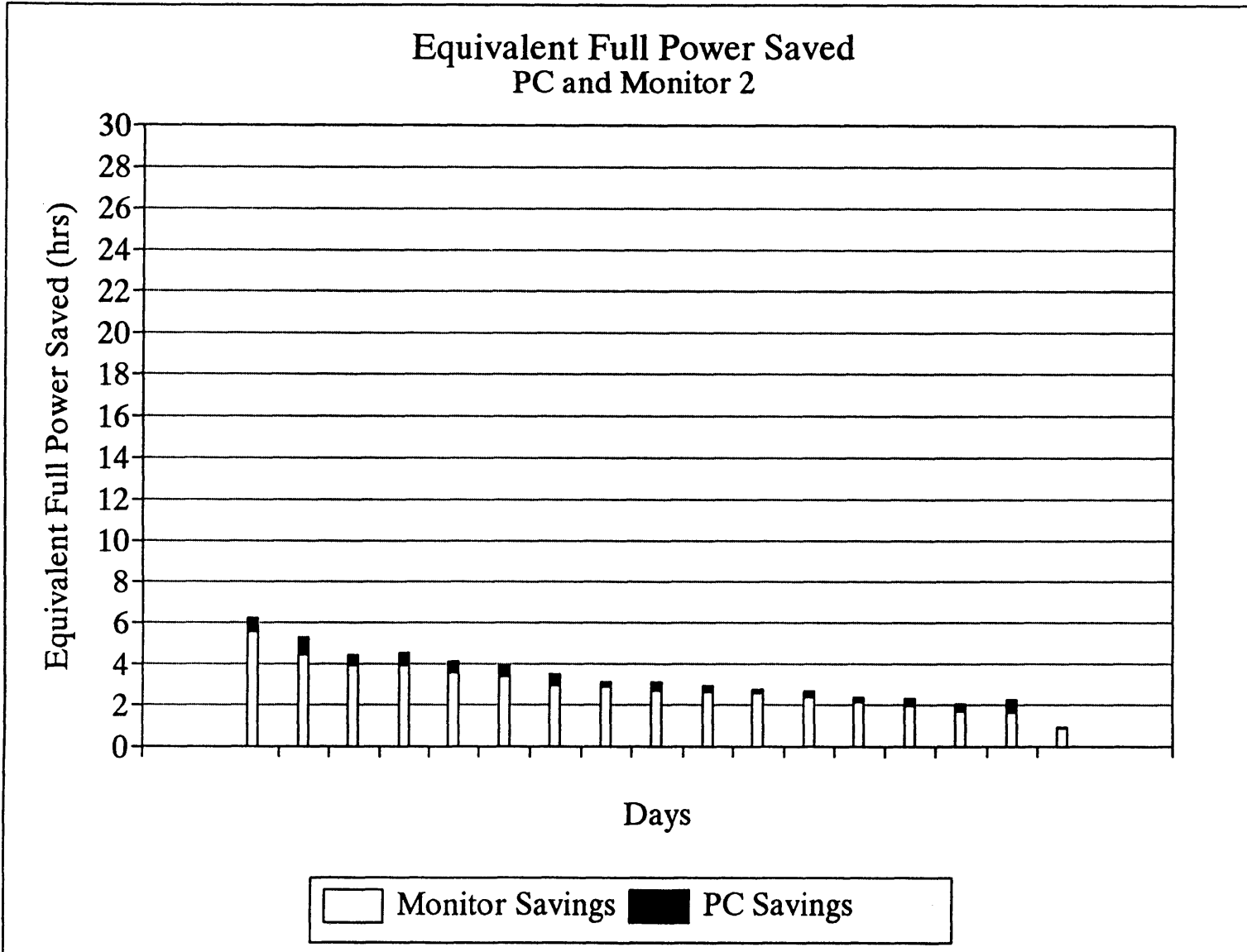
The energy savings have been expressed as the difference between operating the machine with and without the energy saving features enabled. A convenient method of reporting the energy savings is through equivalent full power calculations. The energy saved is then expressed as the amount of energy the machine would consume by running at full power for a certain time period. For example, an equivalent full power value of 2 indicates that the PC in question saved enough energy to operate itself at full power for 2 hours.

The following graphs show the Equivalent Full Power Saved (EFPSaved) for each Machine, divided into its PC and Monitor components. Here, the ratio of Monitor savings to PC savings is readily seen, and the total savings is written as EFPSaved, in hours. The total savings could be greater than 24 hours simply because the PC and Monitor save energy at the same time. By expressing them as additive values, occasionally the value of EFPSaved will be larger than 24 hours.

Equivalent Full Power Saved PC and Monitor 1

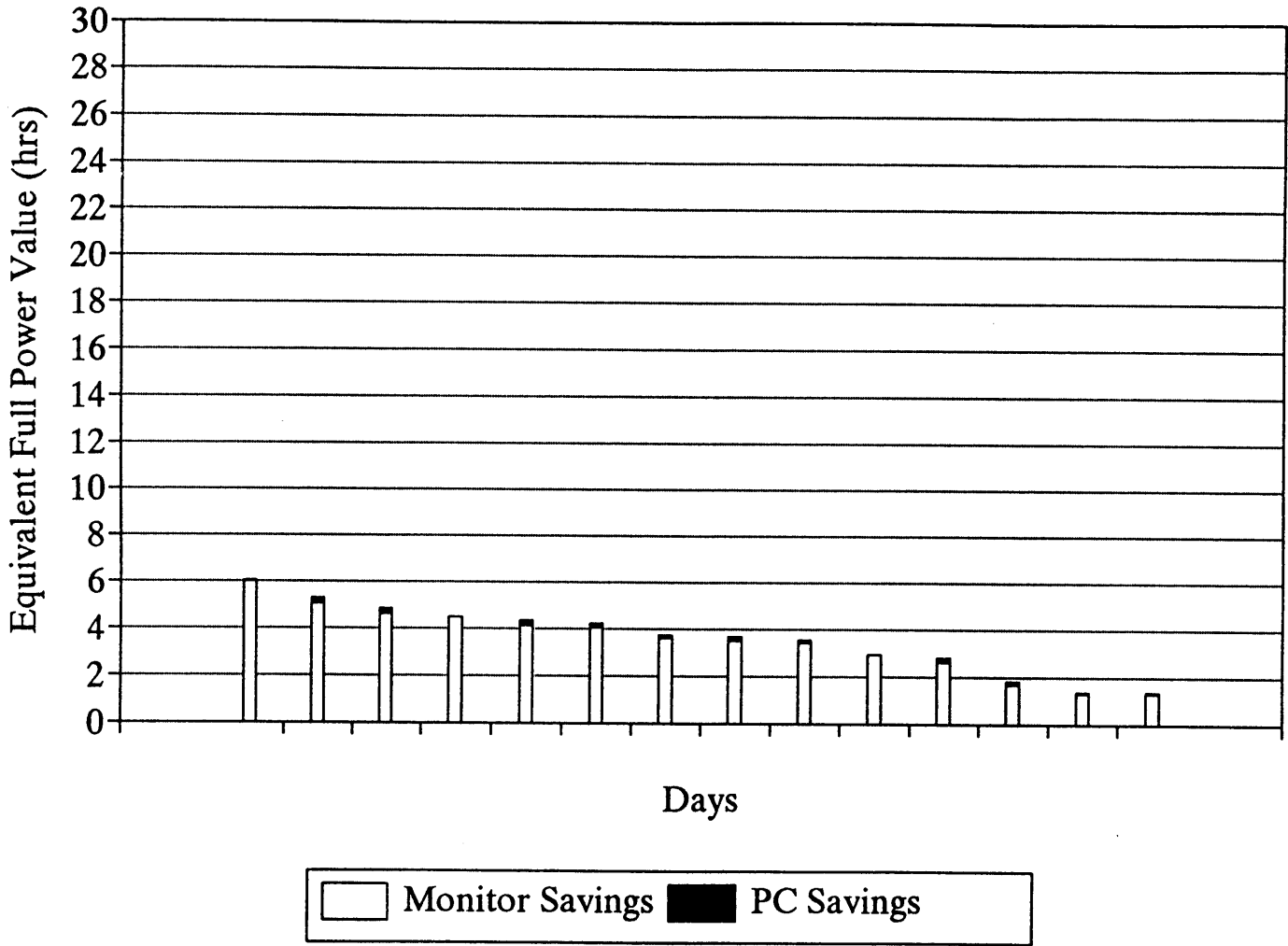


Graph 5



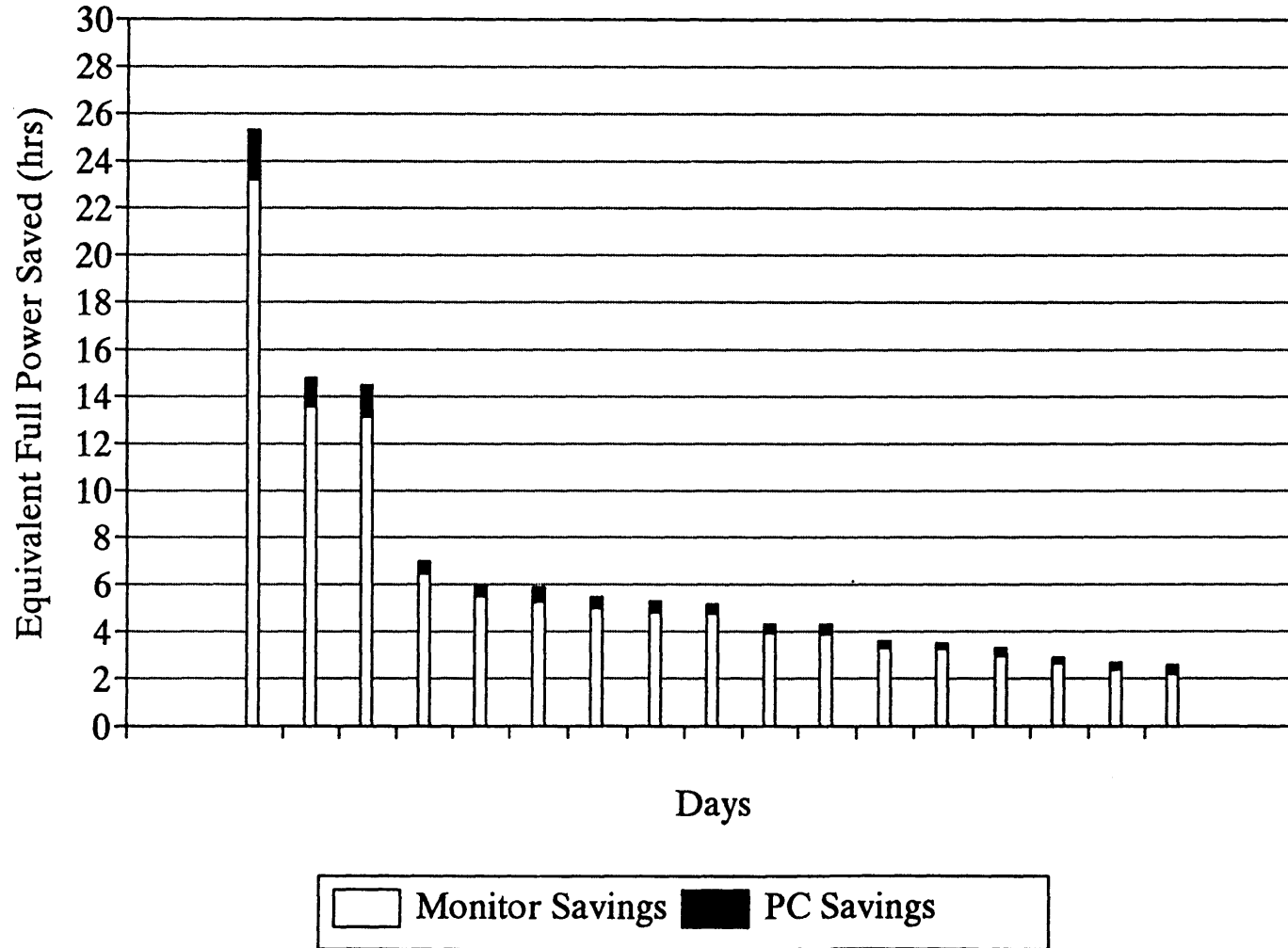
Graph 6

Equivalent Full Power Saved
PC and Monitor 3



Graph 7

Equivalent Full Power Saved PC and Monitor 4



Graph 8

J. Comparison with EPA Estimated Savings

Table 12 shows the potential yearly savings from enabling the four DEC monitors at the primary site: \$4.48/yr, \$3.56/yr, \$3.56/yr, and \$8.03/yr. Estimated yearly savings for all machines are:

$$25 \text{ units} \times \$4.48/\text{unit}/\text{yr} = \$112/\text{yr}$$

$$50 \text{ units} \times \$3.56/\text{unit}/\text{yr} = \$178/\text{yr}$$

$$25 \text{ units} \times \$8.03/\text{unit}/\text{yr} = \$201/\text{yr}$$

$$\text{Net Savings of 100 units} = \$491/\text{yr}$$

Estimated savings reported by EPA are calculated as the difference in operating a conventional computer and an Energy Star compliant computer. Their calculations follow²³:

$$\text{Conventional Computer:} \quad 100 \text{ units} \times \$39.41/\text{unit}/\text{yr} = \$3,941/\text{yr}$$

$$\text{Energy Star Compliant Computer:} \quad 100 \text{ units} \times \$19.55/\text{unit}/\text{yr} = \$1,955/\text{yr}$$

$$\text{Net Savings of 100 units:} \quad \$3,941/\text{yr} - \$1,955/\text{yr} = \$1,986/\text{yr}$$

There are several reasons for the discrepancy between estimated and actual savings. One is that EPA's calculations assume that 20% of the computers are left on overnight. At the primary site, 75% of the computers were turned off at night; of the remaining 25%, they were switched off 80% of the time, leaving only 5% of all computers left on overnight. This accounts for some of the 50% decrease reported by EPA's worktable. Additional differences include the assumed length of work day (9.5 hours) and assumed idle time per day (5.5 hours). The primary site's employees worked about 9 hours per day, and the computers were idle an average of 2.9, 3.6, 3.2, and 7.9 hours per day, including any overnight idle hours.

K. Savings due to Less Aggressive Settings

Potential savings for the primary site were calculated using rather aggressive settings. The first energy management mode is engaged after only 5 minutes of idle time. EPA's Memorandum of Understanding (MOU) version 2.1 requires manufacturers to ship the computers with energy saving features enabled such that they will engage after 15 to 30 minutes idle time. The following calculations compare savings which would result if these

²³ <http://www.epa.gov>

less stringent times were adopted. Incidentally, the computer users were willing and did not mind that the idle times were so strict, so the only drawback may be wear and tear on system components.

Table 14a indicates the amount of time each monitor at the primary site spent in its first power level (monitor suspend mode) which engages after 5 minutes. The first column is the actual metered time; the second column is for a 10 minute idle time before powering down; the third is for 15 minutes idle time. The significance of these numbers is the percent difference as the idle time before powering down is increased. Note that the amount of time spent in the first low power mode significantly drops such that the low power mode is not engaged for Monitors 3 and 4 with a 15 minute idle time; thus there are no savings.

Table 14a
Monitor Time Spent in First Low Power Level

	Time Spent in First Low Power Mode (min.)				
	5 min Idle Time	10 min Idle Time		15 min Idle Time	
		minutes	pct change	minutes	pct change
Monitor 1, 20 days ²⁴	1,590	778	-51%	146	-91%
Monitor 2, 17 days	1,234	542	-56%	73	-94%
Monitor 3, 14 days	922	372	-60%	0	-100%
Monitor 4, 19 days	994	437	-56%	2	-100%

Table 14b
Increased Cost with Less Aggressive Settings

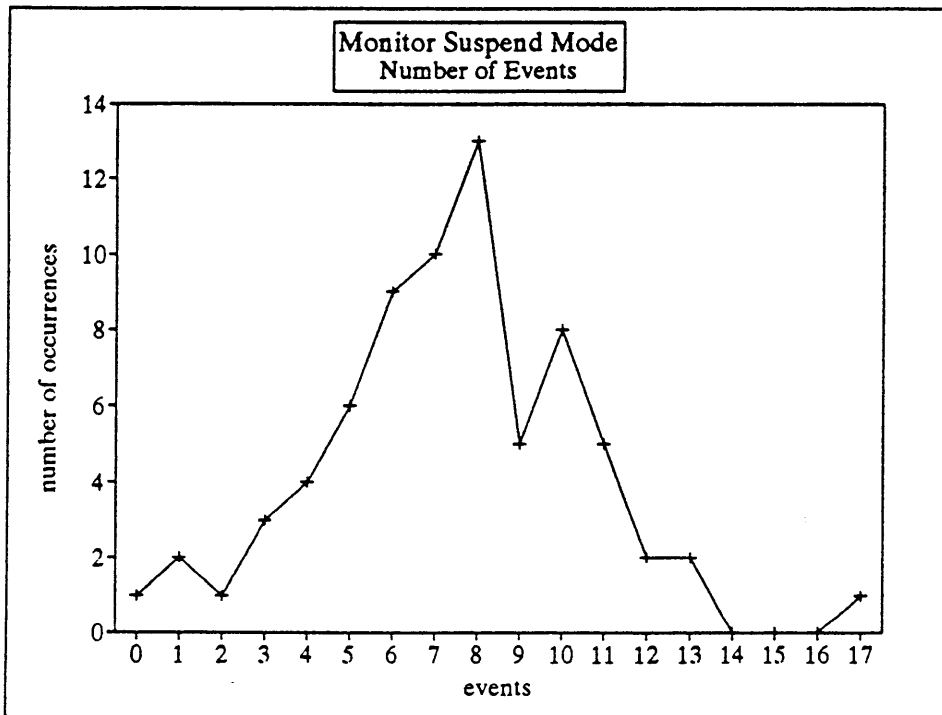
	Increased Cost with Less Aggressive Settings	
	10 min Idle Time	15 min Idle Time
Monitor 1	12.9%	22.8%
Monitor 2	11.6%	19.4%
Monitor 3	9.3%	15.7%
Monitor 4	14.1%	25.0%

²⁴ does not include weekdays and weekends when there was no PC or monitor use.

Table 14b illustrates the cost increase if 10 and 15 minute idle times are used on the monitor suspend timer. Both calculations are based upon the 5 minute idle time for each machine.

The potential of wear and tear on system components by repeated powering up and down is dependent on the number of times a low power mode is engaged. For some users, it is possible that with more aggressive timers, such as those of the primary site, the machine will experience many powering down events each day. Some manufacturers offer software which monitors a CPU's integrity and its potential to experience thermal shock due to repeated power cycles²⁵. The following histogram includes the number of times the machines at the primary site engaged the first low power mode (the monitor suspend mode) each day.

Graph 9

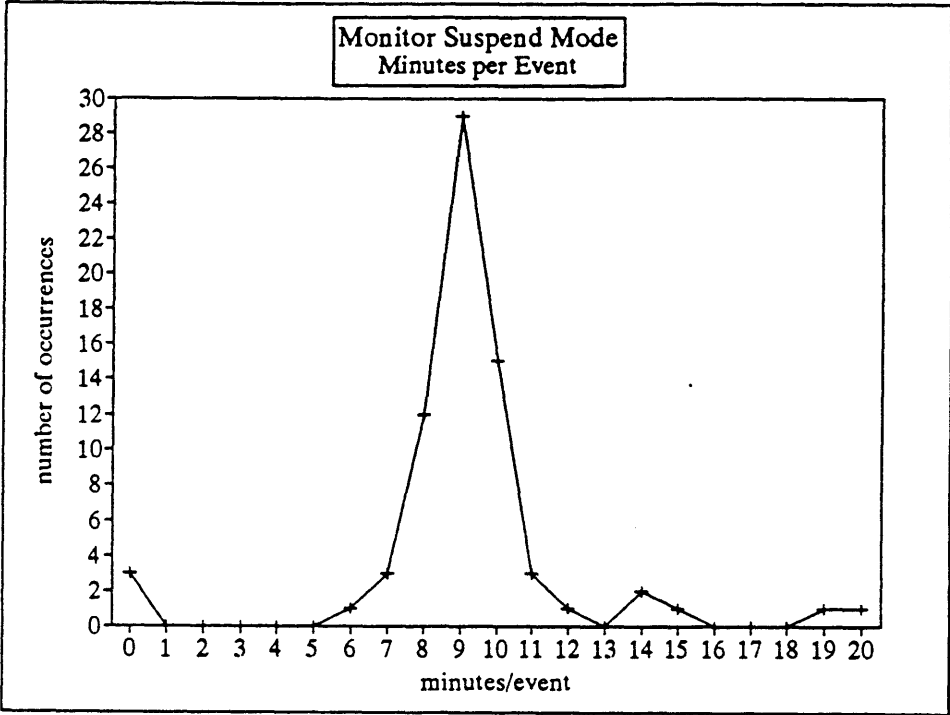


It is also possible that more aggressive settings will cause a machine to power down and be immediately awakened. The next histogram plots the average length of time the monitors spent in the suspend mode for each time this mode was engaged (minutes per event). There are only three occasions when the monitor was in the suspend mode for less than one minute.

²⁵ For example, Sun Microsystems, Inc. offers this capability for its UltraSPARC-I Servers.

Of course, the values used in this histogram are from a 5 minute idle time; the values would change if it were created for the 10 and 15 minute idle times.

Graph 10



SECTION III: POWER MANAGEMENT IMPROVEMENTS

A. Energy Consumption of PC Components

Microprocessors

CPU energy consumption varies widely, depending on numerous factors such as: clock speed, number of transistors, chip size, voltage, amount of on-chip cache. In general, a CPU with higher clock speed, more transistors, larger chip size, higher voltage, and on-chip cache will consume the most power. Power consumption of CPUs varied from 3.5W to 35W in high level PCs and workstations. In one case, the microprocessor chip was found to consume 27% of the computer's total power consumption; in another, it consumed from 23 to 27% of the CPU unit's power, depending on the clock speed.

A CPU may also consume different amounts of energy based on the software it is running. Applications which are more demanding of CPU resources will consume more power. One CPU consumes a maximum of 35W and an average of 26W, depending on what software is running²⁶.

Disk Drives

Metered read/write activities for HDDs were about 3 to 5W, about 4 to 6% of the CPU unit's active power. Power consumption is reduced by allowing the disk to stop spinning. During power management, the drive still consumes a small amount of power, as little as 1% of its active mode demand. Although spin-up power is much higher than that required for read/write activities (up to 5 times as much)²⁷, it is only a momentary spike; the actual demand over a 15 minute time interval is barely affected. FDDs consume about the same as HDDs, but leaning toward less consumption; they require almost no power during idle times. Other reports claim about 0 to 7W²⁸.

²⁶ Consumption depends on voltage fluctuations, the CPU module's bus frequency, and the video bus frequency.

²⁷ Dandridge, C.B., p.48

²⁸ Norford, 1990.

Fax/Modem Cards

Identical computers with and without fax/modem cards were metered; the difference in consumption was about 5W. One significant aspect was discovered concerning power management of fax/modem cards. As long as modem application software is open, the modem consumes power, even if it has not yet dialed the access number or made its connection. For power management reasons, exiting such applications is recommended. On the other hand, a computer in its deepest sleep mode often will cut power to ports; if the application is open, consumption would be reduced in this manner. This is not necessarily a recommended solution since such power management techniques are those which disconnect computers from networks.

CD-ROM drives

Two different types of external CD-ROM drives were metered. One was manufactured by SGI and the other by MicroSolutions. Both consume energy even when there is no CD in the drive. In fact, in both cases, there was negligible additional energy consumed when the drive spins the CD; most of the energy consumed was due to powering the drive itself. The external SGI drive consumed 4W and the external MicroSolutions drive consumed 4.3W. As an aside, the consumption of the MicroSolutions drive was 3W due to the inefficiency of the AC-DC converter and 1.3W to power the drive itself.

Both drives must be turned off manually for energy conservation since there is no other opportunity to power them down. CD-ROM drives are typically used less than a hard disk drive since they are read-only devices. They cannot be used for typical hard drive functions such as virtual memory and storing user files. They tend to have high idle times unless the machine is running software from the drive, or if they are being used to play a music CD; some CD-ROM drives are in use for hours by people who listen to music through speakers or headphones as they work.

Data Buffers

Data buffers act as interfaces for buses and I/O devices. Thus each device has a buffer, including printers and monitors, but also CPUs. CPU data buffers consume about 2W, while I/O data buffers, which are smaller, consume only about 1W. Due to the Energy Star

program, even data buffers can be powered down, by an external power down pin. Data buffers are simply small amounts of physical memory between the bus and device or device controller. This power management technique is similar to that of memory.

Speakers

Stereo speakers may be included in the monitor case or external to the computer. These are not the small speakers found in the CPU chassis, but larger speakers used for the more complex audio of music CDs or video games. If they are included in the case of the monitor, they will cause increased power consumption of the monitor, from 3 to 10W. During power down, the monitor must also reduce power to the speakers such that the total power for the display and speaker is less than 30W. If they are external to the computer, they still increase overall power consumption, but as an external I/O Device, they do not contribute power consumption which is regulated by the Energy Star program.

Graphics Accelerators

Graphics boards cause an increased consumption of 3 to 4W for the CPU chassis. Although they do not directly increase the consumption of monitors, computers with graphics boards are used with high performance monitors of high resolution. These monitors generally consume more energy than their counterparts which have lower resolution and refresh rates.

Network Cards

As described at the primary site, network cards cause an energy consumption increase in two ways: by powering the card itself plus increased CPU activity to communicate with the server. The increased CPU activity varies depending on whether the client is in direct communication with the server, e.g. by downloading files, or merely maintaining the connection. The increase in demand at the primary site was from 12 to 17W for both functions.

Memory Management Unit

Sometimes, the power consumption of MMU and level-1 cache is included in the consumption of the processor, as a processor subsystem. For example, the one manufacturer lists only the consumption of the entire subsystem which includes the Floating-point Unit (FPU), Memory

Management Unit (MMU), Level-1 Data cache, Level-1 Instruction cache, and bus interface. Together, they consume 12W.

B. Potential for More Energy Conservation

More energy conservation can come either from turning off components which have not yet been considered, such as sound cards and CD-ROM drives, or by further reductions by those which have already been considered. For example, the Energy Star program requires a demand in idle times of 30W or less. It is possible, however, to reduce demand even further. Swedish TCO standards require a maximum demand of 3W in sleep -- and several manufacturers have met this requirement, including ViewSonic's PT810 monitor²⁹.

There is also a great potential to reduce energy consumption during the active mode. The reason is that it is very common for computers to be under-utilized; the individual components are more powerful or faster than necessary to complete certain tasks. An example is a high speed CPU which completes tasks fairly rapidly and then remains idle most of the time. This is the case at several sites, including the primary site where simple word processing software is run with a Pentium processor. Many laptop manufacturers take advantage of such strategies to save energy and prolong battery life. For example, the CPU clock can be slowed down during non-critical tasks and immediately returned to full speed when necessary. This is termed "performance on demand". Other components may also be involved, including hard drives that spin down to save 5 to 7W.

Clearly, one method to conserve additional energy is to solve the problems encountered in the field; this includes the summary of problems from Sites A through F, listed in Section II.A. Areas where no additional energy can be conserved include the volatile main memory and cache, I/O Controllers, and CPU internal memory which retains configuration information.

²⁹ *Windows Magazine*, March 1996, p.132

C. Future Trends and Energy Consumption

Lower operating voltage will continue to reduce power dissipation of CPUs. However, additional devices and higher clock frequencies paired with the desire for additional capabilities will continue to increase overall power consumption. However, several relatively new technologies may contribute to future reductions in computer power consumption:

1) Flat-panel monitor technologies have already begun to appear on desktop PCs. They replace the energy intensive CRT monitors which are standard. Unfortunately, the cost of flat panel displays is currently too high for the general market. As this new application ages, however, prices are expected to drop dramatically, leading the way to much lower monitor power consumption³⁰. One example is the NEC MultiSync LCD200, is 50% cheaper in 1996 than in 1995, however it is still priced at about \$3000.³⁰

2) Recently one manufacturer made available a virtual CD-ROM which is available to all users with LAN access.³¹ This would reduce energy consumption from physical CD-ROMs at every computer, and would increase the efficiency of workers who would otherwise have to change to a different computer to use a common CD-ROM.

3) Network PCs are manufactured by several companies including Oracle, IBM, Toshiba, and Wyse. They are an inexpensive solution to desktop PCs which are primarily used to access Web sites and email accounts. They consist of a CPU, memory, modem, and input device, and cost as little as \$500. They are diskless, with software and files residing on remote servers. They reduce the number of devices, speed access times by loading only sections instead of entire applications, and may prevent computers from becoming under-utilized. This technology, paired with virtual components accessible on networks, could set a new trend in the desktop computer industry.

4) Another technology which may change in the near future are insulators with lower dielectric constants. This would simultaneously allow signals to propagate faster on a chip and reduce power dissipation.³²

5) Digital Versatile Discs (DVDs) or Enhanced CDs are similar to regular audio CDs except that they store video, sound, and data all on one disk. Thus, they can be played on a

³⁰ *Windows Magazine*, Mar. 1996, p.115

³¹ *BYTE*, Dec. 1995, p.153

³² *IEEE Spectrum*, Jan. 1996, p.51

CD audio player or on a CD-ROM drive of a computer. They are enhanced such that if played on a computer, they include video clips as well. They are expected to be on the market within about one year. The potential to reduce energy consumption by not requiring separate storage devices for each media. In addition, they will not render current CDs inactive since DVD players can also read music CDs and CD-ROM disks.³³

6) High performance Direct Memory Access (DMA) may speed up processing, allowing for increased CPU utilization. With DMA, information is passed from virtual memory directly to other devices without involving the CPU. The CPU is thus freed up to perform other tasks, is not necessary for certain tasks, and may spend more time in low power modes.

³³ *PC World*, Mar. 1996, p.41

PART II: WORKSTATIONS

SECTION IV: PC AND WORKSTATION DIFFERENTIATION

Workstations are not as common as PCs today; one estimate suggests that there were 16 million PCs sold in 1995, but only 1 million workstations.³⁴ However, the potential for energy conservation in workstations begins to approach that of PCs due to the way they are used and how much energy they consume. Workstations usually consume more energy than the typical desktop PC due to their powerful capabilities. In addition, they tend to be left on for 24 hours each day, whereas most PCs are switched off at night. This adds tremendously to the potential energy which could be saved through utilizing energy conservation techniques in workstations.

Some manufacturers, like Sun Microsystems, Inc. and Silicon Graphics, Inc. have already begun to install energy saving hardware in their workstations. A similar problem arises in workstations as in PCs: how to ensure they are enabled and are compatible with the operating environment or network. This section details discoveries in the area of workstation power reduction strategies, focussing on how they differ from those of PCs. In addition, presented below are the results of a university case study on potential energy savings due to workstation power management.

A workstation is in essence a larger and more powerful desktop PC in terms of specifications and abilities. This means that a typical workstation has a larger HDD, more memory, faster CPU, and more capabilities than a typical desktop. Thus in this sense they are quite similar. However, the organization and architecture of a workstation can be very different than that of a PC, as well as the method the workstation uses to complete tasks.

³⁴ *IEEE Spectrum*, Jan. 1996, p.61

A. Architecture

Initially, workstations were easily recognizable by their style of architecture, known as RISC, Reduced Instruction Set Computing. The intent behind RISC architecture is to simplify processor operation and to enhance performance. It is generally characterized by:

- fewer memory references and more register³⁵ references,
- instruction pipelines, and
- reduced instruction sets.

Registers are storage devices which are usually located on the main processor chip. They are organized as a type of small, fast buffer and contain the most frequently accessed operands. Registers operate in a similar manner as cache except that they are faster than both main memory and cache, increasing CPU speed. Instruction pipelines enhance performance by allowing the processor to execute independent operations simultaneously, thus speeding throughput. Reduced instruction sets mean that the compiler programs are smaller; thus less memory is occupied, speed is increased, and faults are reduced.

Another technique to increase CPU speed is to implement an entire CPU on a single chip, including main processor, floating-point processor, and cache. A single chip is needed to eliminate the delays that result from passing signals between chips. This style of CPU organization is generally possible only through the use of RISC architectures due to lack of physical space when a non-RISC CPU is placed on a single chip. Thus, many of the fastest CPUs employ RISC architecture.

Recently, several manufacturers began to produce workstations which can compete with the RISC-based machines; they employ the style of architecture which is found in IBM-compatible PCs to produce a "PC-based workstation". These workstations implement one or more of Intel's Pentium processors. Thus, these workstations and Pentium PCs differ only by the number of CPUs (uni- vs. multi-processor), CPU speed, HDD size, amount and type of memory, video graphics capabilities, various multimedia components, and monitor size and resolution. Incidentally, Intel also manufactures a Pentium-based CPU for servers, again with desktop architecture. There is not necessarily a difference between Pentium- and RISC-based

³⁵ High-speed memory internal to the CPU.

workstation specifications. What differs is the instruction-level programming techniques, as described above. In a similar manner, RISC-based CPUs have begun to appear in desktop PCs and laptops, although they are not as common as Pentium-based machines.

B. Reliance on the Server

Some workstations are part of a network system in which they are more reliant on the server than a typical PC would be. In these systems, the workstation provides the user with local processing, multimedia devices, and supreme color graphics and video capabilities; the server controls the flow of data to and from multiple workstations, stores program and user files, assists the workstation in certain processing tasks, and works to preserve the integrity of the system. In a sense, workstations are reminiscent of dumb terminals which run from a large remote computer. However, there are vast differences between workstations and dumb terminals, as dumb terminals don't have the local "intelligence" of their own CPU, storage devices, or memory as do the workstations. The benefits of workstations over dumb terminals include: higher speed for all functions with less server/client communication, local processing, advanced multimedia applications, and the ability to save files to a local HDD.

Typically workstations are not turned "off" at the end of the day and "on" at the beginning of the day as in desktop PCs; one network expert described this difference by commenting that workstations "... are pretty much meant to be on all the time." There are two reasons for such a statement. The first is due to the unique network relationship between the server and each workstation. Typically, a server receives user-altered files from dozens of workstations, contacts other servers, downloads software and configurations to the workstations, and coordinates communication between itself and each workstation. These server functions may occur while the workstation is in use or idle; thus, the workstation may not truly be "idle" when a human is not using it. This would not be the case for a stand-alone workstation, however there is another reason that users may leave workstations "on".

The second reason involves users who may remotely access a workstation. Frequently, there may be several users on a workstation, one who is using the entire workstation (CPU, memory, monitor, and keyboard or mouse), plus one who logs onto a particular workstation

via laptop computer, desktop PC, or another workstation. These "hidden" users are only accessing the workstation's CPU and memory. It is also possible that the "hidden" user is the only user, opening up many opportunities for energy conservation as well as potential conflicts.

Implementation of various energy conservation strategies must take the server/client relationship into account. For example, if a workstation is off, it can't communicate with its server. Also, the machine should not be shut off if a remote user is logged on. Of course, it is very possible that on a given evening, a specific workstation may not be used at all by remote users or the server. And by looking solely at this fact, it may seem that the workstation could be very easily turned completely off to conserve energy. However, this is not always beneficial to the server/client relationship.

The method of communication between the many workstations and servers involves a complex method of polling, waiting, and data transfer, entirely coordinated by the server. CPU speed reduction may not be recognized by certain networks. And typically, any strange behavior by the workstation requires the server to disconnect it from the network to protect itself and the other clients. One example where turning the workstation completely off would not be beneficial would be the following: the user may log off of the workstation, leaving altered files in memory. If the server is currently too busy to receive these files, the workstation normally will wait until there is less traffic, and then transfer the files. However, if during that time the workstation is turned off, these files may be lost. Although most workstations have a method of recovering these files once the machine is re-booted, they are usually in the form of file fragments which may be incomplete or damaged.

The method a network uses to transfer and save files is called a File System. In a typical server/client relationship, the workstation HDD stores the operating system files and receives program and user files from the server. This is called a Network File System (NFS). In addition, sometimes workstations use a portion of the computer's memory as a temporary storage device; this is called a RAM disk. Using a RAM disk is faster and conserves energy

since the computer uses less energy and time to access RAM than to access the HDD³⁶ or the server. The stored information in the RAM disk is volatile and is thus lost when the power supply is cut.

The Andrew File System (AFS) encourages this additional type of behavior in workstations to improve efficiency and speed. The workstation stores certain program files in the RAM disk instead of copying them from the remote server each time the program is engaged by the user. To determine which program files it downloads from the server and which files it saves in the RAM disk, the workstation monitors the frequency of usage of particular program files. Those retained in the RAM disk are those which are accessed most frequently. For example, if the World Wide Web (WWW) is accessed frequently on a particular workstation, then a copy of the WWW browser files will be stored in memory. Thus even if the user logs out, the programs remain intact for the next user. However, if power is cut to the workstation, these program files must be reloaded from the server, thus defeating the time saving and speed increasing benefits of the AFS. Incidentally, this is the type of system which was found at the workstations case study site.

Because the workstation and server work together to create a powerful and efficient system, many benefits of this environment will not be seen if the workstation is operated as a "stand-alone" system. Although it is possible to configure a workstation to operate without the network, in general this circumvents the purpose of utilizing the powerful resources provided by the server. Because of this relationship, workstations are not meant to be completely shut off or disconnected from the network. One disconnection has occurred, a lengthy boot up process must occur.

C. Capabilities

Workstations are typically used in applications where PCs are inadequate. They are designed to handle high level graphics, computer-aided drafting and design (CADD), videoconferencing, and other demanding applications. The speed of the CPU plays an important role in the ability

³⁶ This is the opposite of virtual memory, where HDD space simulates extra memory which does not physically exist. Virtual memory is discussed in Section I.F.

of the workstation to handle high-level graphics applications. Thus, workstations typically have faster CPUs to accommodate this capability. They are also convenient to run software faster than a desktop PC which has less memory and/or a slower CPU. Since workstations have higher frequencies & more memory, and perhaps even multiple microprocessors (particularly in the Pentium-based workstations), valuable time can be saved. A third application is in multimedia where components such as cameras, speakers, voice recognition equipment, and CD-ROM changers (similar to those on stereo systems) are used. A fourth and increasingly prevalent application is for high speed internet connections to servers across the world. This can be either to send and receive email, to access the WWW, or to post to a Bulletin Board System (BBS). They are more convenient than a desktop PC because of their higher speed; they can connect to a server more quickly and can communicate with the server at a more rapid pace.

D. Components

Workstations generally have more powerful components including larger memory, higher CPU speeds, larger monitors with higher resolution, and larger storage capacity. They also have additional components which allow them to perform the functions required of the powerful application programs. This includes more powerful graphics accelerators, double buffering, external cache with cache controllers, 3D-RAM, stereo speakers, video cameras, cooling towers, and additional fans.

Cache

Workstations usually have a larger cache, allowing them to transfer more data faster, but also making them more energy intensive. In addition to primary cache, many workstations and high-end desktop and laptop computers support secondary cache, also known as external cache (external to the chip). External cache (ecache) adds functionality and speed, but unfortunately it also increases energy consumption. Thus, a workstation with more ecache will consume more power than a PC without it or a workstation with less of it. For workstations that have ecache, there must also be a separate bus and interface between itself and the CPU. The interface is a data buffer, which consumes additional energy.

Main Memory

Most workstations use a combination of both static RAM (SRAM) and dynamic RAM (DRAM) to take advantage of the benefits of both types, including the higher speed of SRAM and the lower cost of DRAM. It is not uncommon to find main memory in the form of DRAM and cache and ecache in the form of SRAM. One drawback of using DRAM for main memory is that it requires periodic refreshing to retain its data -- periodic meaning in the range of milliseconds. If power is cut to the memory cards, the memory contents are lost. The use of the higher cost SRAM seems to be more beneficial for energy conservation simply because SRAM only requires power to the memory card itself, without the need for additional refresh circuitry power. However the DRAM technology has changed somewhat such that new DRAM chips require only minuscule current for refresh during standby. For example, the 16Mbyte DRAM cards manufactured by Matsushita uses only 0.9 μ A refresh current in comparison to about 0.5 mA in earlier devices³⁷. Thus DRAM cards become more competitive with their lower first cost plus an allowance for power saving techniques.

Frame Buffer

A Frame Buffer is essentially memory for the display device; it temporarily stores a full frame of picture data at once. Frame Buffers are composed of bit arrays which correspond to pixels (picture elements) of the monitor. The resolution of a monitor (measured in horizontal and vertical pixels) in part determines the size requirement of the frame buffer. The number of bits per pixel in the frame buffer determines the complexity of images that can be displayed³⁸. Color graphics require several bits per pixel, hence a larger frame buffer. A technique known as double buffering is sometimes seen in workstations to further enhance graphics. Two frame buffers are used together to produce what seems to be smooth animation. The graphical contents of one frame buffer are displayed while the other buffer is being updated; when the update is complete, the buffers are switched.

DRAM and Video RAM (VRAM) are the most commonly implemented frame buffer memories. In general, DRAM provides the best density and has the best understood

³⁷ *IEEE Spectrum*, Jan. 1995, p.35-39

³⁸ <http://www.sun.com>

technology curve, but is generally too slow⁴. DRAM interleaving and VRAM offer only minimal improvements over DRAM. And SRAM, which is quite fast, is generally too expensive to implement. Sun Microsystems and Mitsubishi Electronics developed a new frame buffer design which they call 3D-RAM. It is a special type of DRAM which integrates the high performance of SRAM technology with the lower cost of DRAM. Their literature claims that it "...handles 3-D graphics ten times faster than conventional VRAM, at lower system cost"⁴.

Graphics Accelerator

High-level graphics software requires memory- and CPU-intensive operations. Graphics accelerators (or graphics "cards") assist the main processor by calculating pixel values and writing them into the frame buffer; the main processor is thus freed up to perform other tasks. Macintosh manufactures 3-D graphics accelerators with 128k of SRAM cache, 512k of secondary SRAM cache, and two custom ASICs³⁹. Graphics Accelerators are manufactured using different types of ASICs (essentially chips) consisting of a graphics processor and a frame buffer controller. Some desktop PCs are able to perform certain high-level graphics applications using graphics accelerators; in general, however, the most powerful accelerators are those found in workstations which have higher speed CPUs, larger frame buffer memories, and several bits per pixel. Workstations generally are equipped with high resolution monitors, an indication that it also contains a powerful graphics accelerator containing a fast CPU and large frame buffer. The energy consumption of each component scales with its ability.

Monitors without the need for graphics accelerators utilize the standard video card. These chips allow input of graphics and video signals and output of images to the monitor as they convert information from an analog to a digital format. The SGI Indy is equipped with an XL video board as a standard component. The XZ graphics board is an option; upgrading to this capability involves removing the XL board and replacing it with two boards which make up the XZ capability. The first XZ board plugs into the slot left empty by the XL board; there is also a second slot to fit the second XZ board. Power consumption of the SGI Indy is increased due to the power requirements of the additional board.

³⁹ Application-Specific Integrated Circuit: a non-standard gate array designed for proprietary use.

There is some variation in energy consumption among different accelerators. For example, Sun manufactures graphics accelerators with different capabilities, including the TurboGX and the TurboGXplus. The TurboGX graphics accelerator card features support for 1024 x 768 and 1152 x 900 monitor resolutions, a small form factor, and an 8-bit color frame buffer. The TurboGXplus graphics accelerator card features an 8-bit color frame buffer, hardware double buffering, support for a wide range of monitor resolutions, from 1024 x 768 to 1600 x 1280, and a small form factor. The increased energy consumption of a workstation with a TurboGXplus accelerator is due to additional components on the card itself, a higher resolution monitor, and two frame buffers.

Cooling Towers

Very powerful workstations use what manufacturers call "cooling towers" in addition to fans to cool processor chips. They are actually metal fins attached to the surface of the chip to transfer the dissipated heat over a larger surface area and enhance heat transfer rates to the air. Many of the more powerful workstations require cooling towers for their processors. Many workstations have multiple processors, including main CPUs and additional ASICs. For example, the SGI Indy XZ workstation has two cooling towers: one on the main processor and one on the graphics board's processor.

E. General Trends

Workstations will most likely be found in a university setting or in an office where high-level graphics capabilities are required, such as the office of an architect or of a computer graphics company. In a university setting, students use workstations to run CPU- and memory-intensive software, and for fast access to the internet (email, WWW, BBS, etc.). In general, there is a trend toward a larger number of workstations, however this does not mean that there will be a corresponding decrease in the number of desktop PCs. It seems that workstations and PCs *in general* are used for different purposes and the appearance one should not promote the decline of the other. Of course there are many tasks which both a PC and workstation can perform equally well, such as simple spreadsheet and word processing tasks, certain types of graphics applications and even software requiring complex mathematical computations. But

the price of a high-end desktop PC is a few thousand dollars; the price of a high-end workstation is easily 5 to 10 thousand dollars, plus a 2 to 5 thousand dollar monitor⁴⁰.

If desktop PCs become less common in the future, two likely reasons would be continuous laptop computer improvements and the advent of network PCs. Laptop computers are not only lightweight and portable, but they offer the same technologies as in the desktop PC at a relatively reasonable price. Network PCs have been recently introduced by Oracle, IBM, Toshiba, and Wyse Technology and could be available as soon as 1997. They are small portable terminals with keyboard/mouse, display unit, and communication links to networks of more powerful computers. Although they may operate slower than a desktop PC, they only cost around \$500.

F. Usage

Usage patterns of workstations are in some ways very similar to those of PCs. Although you don't find workstations very often in office buildings or private residences, you definitely find both PCs and workstations in a university setting. Both PCs and workstations are used in clusters, laboratories, and private offices, and by students, professors, and staff alike. Thus, they both have an equal potential for energy conservation, except that PCs are much more prevalent than workstations, and that workstations consume more energy than PCs. One area where the usage patterns of w's differ from pc's is that they are generally left on overnight in laboratories and private offices, where PCs are turned off.

In universities, workstations are located in clusters, which are open to the entire university community; in offices, which are open to only one or a few individuals; in labs, where they can be used by only the occupants of that lab; and in sporadically located individual classrooms. In the clusters, workstations are used during the whole day, as there are usually many less workstations than students. For example, at MIT there are about 350 cluster workstations available for around 10,000 students. However, at night, most workstations are not used -- in one cluster, 98% were left on and idle from midnight until about 6am. In

⁴⁰ <http://www.sun.com>

offices, the workstation stays on all day and all night, no matter how often it is used. They may be used for one hour per day or 1 hour per week, but they are still on with no opportunity for power management. In labs, workstations are used in conjunction with lab equipment to analyze specific data gathered in the lab. Thus, most are in use throughout the day, but are left idle at night when researchers have left for the day. There are however specific cases where simulations or compilations are run late into the night, or even all night, but they are still completely powered when only the CPU, HDD, and memory are being used. In other words, at a minimum the monitor could power down to save energy on those machines running simulations, with monitor, CPU, HDD, and CD-ROM power management for all others.

Another use of workstations is to have the ability to access them remotely if needed. Those people who were asked about leaving their workstation on at night commented that they might need to access it from home in the evening. However, it is possible to put the CPU asleep before leaving for the day, allowing it to awaken automatically when it's contacted by modem. And it is certainly possible to save energy by turning the monitor off, since it is only needed when the user is in the same room with the workstation.

Students using workstation clusters are not constrained to a typical 40 or 50 hour work week as users in most non-university office buildings. On average, cluster workstations were shown to be used from about 7am through midnight, although not continuously, for Monday through Friday. Weekend usage dropped only slightly from weekday usage, with the lowest usage on Sundays.

Another usage pattern in universities is that workstation cluster usage follows the term. Thus, during mid-term breaks and during the summer, workstation usage drops dramatically. There is a great potential for energy conservation during these low usage times. Usage in labs and private offices usually remains the same because they are mainly populated by graduate students, faculty members, and staff who do not keep the same schedule as the general student population. The usage of workstations in labs and offices generally remains the same during these times, with the greatest potential for energy conservation on weekends and in the evenings.

G. Energy Conservation Techniques

Monitors

Only a few workstation monitors have a power saving capability, including the SGI RGB Multiscan, the Sony GDM-17E10, and the Sony GDM-17E11. They each have power saving indicators which illuminate when the monitor enters the power saving state. They do not follow the DPMS standard as many desktop monitors, but the technology is similar. They power down to "suspend" mode when the horizontal or vertical signal is not present; this corresponds to the suspend and standby modes of the DPMS standard. They enter "active-off" mode when both the horizontal and vertical signals are not present; this corresponds to the off mode of the DPMS standard. They are not included in EPA's list of compliant monitors, although they would be compliant since they consume less than 30W in the lowest sleep mode (active-off).

Microprocessors

Workstation microprocessors have similar power management capabilities as those of desktop PCs. They suspend operations and enter a reduced-power state without losing memory contents. The user is able to return to the initial state of operation quickly and without the need to re-boot the system. They have a CPU standby mode which allows the CPU clock to shut down after a period of idle time.⁴¹ In addition, their other processors, such as ASICs offer power management. The CPU also maintains a control register which allows fan, disk, and monitor power down.

Sun Microsystems, Inc. and Silicon Graphics, Inc. offer power management capabilities with some of their workstations. These capabilities are by no means the "standard" in workstation production. In fact, there are only a few workstations which appear on the Energy Star compliant product database⁴², including the Sun SPARCclassic, SPARCstation4, SPARCstation5, and SPARCstation Voyager, plus TriGem TGstation SDI-500 and SDI-700. The SGI Indy offers CPU power management but is not listed in EPA's database. In addition,

⁴¹ Internal clocks shut down if there is no bus activity after a WAIT instruction has been sent.

⁴² This is only a partial listing of those in the database; it is periodically updated.

Sun manufactures servers with the same CPU power management capabilities as in its workstations.

There is no indication in the literature whether this capability can be accessed by the user, either to enable and disable it or to change the idle time until power save engages.

Fans

One manufacturer provides a variable speed drive fan to cool the drives of an external storage device. It is called a "multi-disk pack", providing 4.2 or 8.4 GBytes of storage. The cooling fan is able to vary the amount of airflow by changing the fan rotation speed. Thus only the amount of air required for cooling is provided, and the components are not over-cooled. The intent of the variable speed drive fan is to reduce noise output, but there are still some energy saving benefits, albeit very small. However, the capability for manufacturers to save energy in this manner is noted.

HDDs

Computers using virtual memory will tend toward less energy savings, but probably not by very much. Virtual memory is not memory at all; rather, it is hard disk space that is used as memory when more memory is needed than is available. It can slow the computer's performance since it takes longer to communicate with the HDD than RAM, but is sometimes necessary, especially if several programs are running simultaneously. Virtual memory increases energy consumption of the computer in three ways:

- 1) the CPU access time to the HDD is longer than to RAM
- 2) it takes more energy to access the HDD than to access RAM
- 3) the HDD is constantly needed by the CPU since it simulates memory; there will be less idle time while the workstation is in use

Another drawback of virtual memory is that if the HDD does spin down during active times, it may be constantly spinning down and re-awakening in response to power management signals and CPU-to-virtual memory signals. Another similar situation could occur during inactive times. Workstations sometimes store user files on the HDD and copy them to the server when there is less "traffic". With the typical technique of spinning-down the HDD during idle times,

it is possible that the HDD will be sleeping by the time the server is ready to accept files. The workstation CPU will wake up the HDD to perform this function and then allow it to go to sleep again. In both of these cases, the energy saving capability is over-ridden by workstation functionality. Of course, this is only a drawback if wear and tear on the HDD affects its lifespan or integrity. One manufacturer provides power management software to monitor the frequency of shutdown requests⁴³. If it determines that the thermal shock of repeated power cycles could contribute to decreasing hardware reliability, the shutdown request is deferred.

CD-ROM drives

There is no known method to reduce power in CD-ROM drives. CD-ROM drives can be either internal or external to the workstation casing. If they are internal, most of the energy is consumed when the CPU accesses the CD. If they are external, they may receive their power from the computer or from their own receptacle. Those which receive their power independently of the CPU have their own on/off switch. They are connected to the CPU solely through a data and instruction bus.

In this case, it may be possible for the drive to receive a signal from the CPU to shut down its power supply, although this has not been yet seen. The other opportunity is for the user turn them off manually until they are needed, and then to turn them off again after use. CD-ROM drives on MIT's campus are external drives, each with its own power supply, AC/DC converter, and on/off switch; they are on all the time. There is a great potential for energy savings because they are consuming electricity whether or not they contain a CD, and whether or not they are spinning or transferring data. Also, their usage times are very infrequent because they are used only for a small fraction of the time that the workstation itself is in use.

H. Power Consumption

The above discussion indicates that workstations tend to consume more energy than desktop PCs because they have additional components, faster speeds, higher resolution monitors, better multimedia capabilities, and larger components (storage size, memory type and size, etc.).

⁴³ The software is not exclusive to HDDs.

However, the division between desktop PC and workstation is not extremely strict since many desktop machines have equivalent capabilities. The distinction is even less definite since the comparisons must be made across several types of architecture, including IBM-compatible machines, Macintosh, and RISC-based machines. The following table compares the energy consumption of several workstations and desktop PCs found in each of the sites in this report.

Table 15
Comparison of Workstation and PC Consumption

Macintosh 6100 (14" color monitor)	78 W
Macintosh 7100 (17" color monitor)	150 W
Macintosh Quadra 840av (17" color monitor)	142 W
Macintosh Quadra 950 (17" color monitor)	200 W
Gateway 2000 (14" color monitor)	159 W
Acer Power (17" color monitor)	120 W
NEC Image 466es (17" color monitor)	135 W
Sun SPARCclassic (17" color monitor)	103 W
Sun SPARCstation5 (17" color monitor)	131 W
IBM POWERstation320H (19" b/w monitor)	267 W
DECstation 5000/25 (16" color monitor)	157 W
SGI Indy (17" color monitor)	172 W

Notice that the Macintosh Quadra 950, consumes more than even the RISC-based SGI Indy workstation. Both have relatively high graphics capabilities in comparison to other machines in their class. On the other hand, the SPARCclassic workstation is a very low energy consumer, even when compared to desktop PCs.

Monitors

Each of the power saving monitors in this study have a "suspend" mode and an "active-off" mode. According to the monitor literature, suspend mode is activated when either of the two video signals is missing. All of the power saving monitors entered the active-off state immediately without engaging the suspend mode first. The active-off mode initiates when both horizontal and vertical signals are not present. Power consumption in the active-off mode

was 12W, with a 3 second delay to return to the ready mode. The active-off mode is similar to a type of "quick-start" functionality found in some monitors. Each of these monitors consumed 12W in "active-off" mode and 12W when plugged in and turned off by the switch. The "quick-start" technique is favorable from the productivity viewpoint, but not from the energy conservation viewpoint.

The power consumption of workstation monitors varies greatly, and is not necessarily proportional to the size of the screen. The following table lists the workstation monitors which were metered:

Table 16
Comparison of Workstation Monitors

Monitor	Watts per square inch	Watts in Ready mode	Watts in Low Power	Energy Star Compliant?
DEC VRC-16 (16" color) (for DECstation 5000/25)	0.84	103 W	N/A	no
IBM 6091 (19" b/w) (for IBM POWERstation320H)	0.86	134 W	N/A	no
Sony GDM-17E10 (17" color) (for Sun SPARCstation5)	0.76	105 W	12 W	not on list ⁴⁴
Sony CPD-1790 (17" color) (for Sun SPARCclassic)	0.53	74 W	N/A	no
Sony GDM-17E11 (17" color) (SGI RGB Multiscan)	0.79	110 W	12 W	not on list

The power consumption per unit area of the above workstation monitors is higher than that of the PCs in the previous section, at around 0.64 W/sq.in., except for the Sun SPARCclassic monitor. This monitor has a lower resolution than the other Sony monitors and is not capable of supporting the higher-level graphics applications.

⁴⁴ Although power consumption in sleep mode is less than 30W, it is not on the EPA list and does not have an Energy Star logo.

MBus Module

The processor is part of a CPU subsystem or module which also includes external cache, an external cache controller, and a voltage regulator. One specific module, the Sun STP5011 module consumes about 35W. This includes the STP1021 SuperSPARC-II microprocessor, the STP1090A Module XBus Cache Controller (MXCC), external SRAM cache, and a voltage regulator to maintain CPU and external cache supply voltage to within the tolerance range. In particular, voltage regulators are required whenever the CPU core is operated at a lower voltage than the I/O devices. This is becoming more common since higher operating voltages increase heat generation within the chip. Unfortunately, the inefficiency of the regulators themselves cause additional energy consumption, on the order of 6W.

The 35W consumed by the processor subsystem depends upon the type of processor (speed, amount of instruction and data cache, size, supply voltage, etc.), the type and amount of external cache (SRAM, DRAM, etc.), and the efficiency of the voltage regulator. The breakdown of power in the module is shown in the following table.

Table 17
Microprocessor Module

CPU Sub-system	Sun STP5011	about 35 W
microprocessor	Sun SuperSPARC-II	17 W ⁴⁵
external cache controller	Sun STP1090A	6 W
external cache	1Mbyte SRAM	6.4 W
voltage regulator inefficiency		5.75 W

Microprocessors

- more consumption with more powerful processors

Power consumption generally increases with more powerful processors due to many different aspects of the processor architecture, such as technology (e.g., CMOS), geometry (e.g., 0.5 micron), process (e.g., drawn 3-layer Si), data bus width (bits), CPU speed, CPU core voltage, and amount of on-chip cache. Other factors which affect consumption includes how the processor is defined. For example, the superSPARC-I and II are called processor subsystems

⁴⁵ This assumes the worst case power consumption with 5.25V. Average consumption is about 14W.

because they include the Memory Management Unit (MMU), data and instruction cache, and a bus interface unit on the processor chip itself. The following chart is intended to give an example of typical power consumption values of various microprocessors; it is not necessarily meant to be a comparison tool since there are multiple factors which differ among the different chips.

Table 18
Comparison of Several Sun Microprocessors

	micro SPARC-I	micro SPARC-II	super SPARC-I	super SPARC-II	ultra SPARC-I	ultra SPARC-II ⁴⁶
Bus width	32-bit	32-bit	32-bit	32-bit	64-bit	64-bit
Technology		0.5 μ m 3-layer CMOS	BiCMOS	BiCMOS	0.5 μ m 4-layer CMOS	0.35 μ m 5-layer CMOS
On-chip cache	none	none	36 kBytes	36 kBytes	32 kBytes	2 MBytes
CPU speed	50 MHz	70 MHz	50 MHz	75 MHz	143 MHz	300 MHz
CPU voltage	5 V	3.3 V	5 V	5 V	3.3 V	2.5 V
Power Management	no	yes	no	no	yes	
Power, W	6 W	6 W	12 W	14 W	30 W	

Comparing the microSPARC-I and -II shows that a 40% increase in CPU speed with a corresponding 66% decrease in voltage results in equal power consumption. Similarly, the SuperSPARC-I and -II shows that a 50% increase in CPU speed results in a 17% increase in power consumption.

- lower and variable voltages

In a similar manner as PC and laptop computers, workstations take advantage of the benefits of lower operating voltages. They also vary the voltage among various components and interfaces. One example is the Sun microSPARC-II. Sun claims that this chip "optimizes" its

⁴⁶ Not all information is available for this processor.

power consumption with a 3.3V core, 5.0V for peripherals, and either 3.3V or 5.0V for memory cards.

- more consumption due to higher CPU speed

CPUs which operate at higher clock speeds consume more energy. Two Sun microprocessors are available at different processor speeds. The values for processor consumption are given with the understanding that the processor is identical except for processor speed. The microSPARC-II is available operating at 70 MHz consumes 6 W, while operating at 85 MHz it consumes 7 W. The superSPARC-II consumes 12.1 W at 50 MHz and 13.6W at 60 MHz. Thus in one case a 20% increase in clock frequency caused a 17% increase in power consumption, while in the second case the 20% increase in speed caused a 12% increase in consumption.

Within the PowerPC⁴⁷ processor line are two examples of power conservation with increased CPU speed. This is possible only with the simultaneous application of energy reduction strategies. The 603e and 604 processors were upgraded by increasing the CPU speed and the number of transistors while decreasing the voltage and die size. The result is faster processors which consume the same or less power as their predecessors.

Table 19¹⁵
Upgrading PowerPC Processors

	old 603e	new 603e	old 604	new 604
die size, mm ²	98	81	196	148
no. of transistors	2.6 million	2.6 million	3.6 million	5.6 million
on chip cache size, kByte	32	32	32	64
max clock speed, MHz	120	166	133	166
voltage of processor core, V	3.3	2.5	3.3	2.5
voltage of bus and I/O interface, V	3.3	3.3	3.3	3.3
power dissipation at max speed	3	3	14	10

⁴⁷ Manufactured jointly by IBM, Motorola, and Apple.

From this chart, two mathematical comparisons were made to give a general idea of the changes in energy consumption occurring:

- with an 11% increase in clock frequency, doubled bus width, and a 40% increase in number of transistors comes a 467% increase in power consumption
- with a 40% increase in clock frequency and a corresponding 25% decrease in operating voltage and 17% decrease in chip size, there is no change in power consumption by the CPU.

In general, it is still true that the reduction of CPU clock speed is one strategy to reduce consumption. This can occur during "true" idle times, when the CPU is not being used by the server, a user, or a hidden user, or during active times when the CPU is under-utilized.

However, the availability of microprocessors at different CPU speeds opens up a related strategy, which is to only purchase a workstation which meets immediate and near future needs. Much energy can be wasted by using a high-powered workstation for tasks which a less powerful workstation or a desktop PC can easily perform. If it is perceived that a very powerful workstation may be needed much further into the future, it is possible to upgrade the workstation with a more powerful processor. Most workstations offer several options to upgrade.

- power down CPU

CPUs are powered down by slowing the CPU clock or stopping it completely. This occurs as the external power down pin initiates an internal reset which stops the CPU clock and PLL⁴⁸.

One processor, the microSPARC-II, has the ability to reduce its power consumption by about two-thirds. It consumes 6 W while operating at 70 MHz, 7 W at 85 MHz, and conserves 4 W with power management.

Data Buffer:

Data buffers are quite frequent as they are used to temporarily store data which will be transmitted to another device. Two examples include printer buffers and frame buffers (for displays). Workstations which have external cache must also use a data buffer to move data between the external cache and the data bus. An example appears in the UltraSPARC Data

⁴⁸ PLL stands for Phase Lock Loop. Since proper clocking is essential at higher frequencies, an on-chip electronic device is used to reduce system clock skew which could cause instability.

Buffer which is essentially two chips connecting the UltraSPARC-I processor and its cache to a 144-bit data bus. The data buffer is a 0.5 micron 4-layer CMOS ASIC which operates at 3.3V and consumes a maximum of 2W. There is also a data buffer for I/O devices, such as a printer, which consumes 1W. They have power management capabilities which are initiated when the CPU clock is stopped. During these times it consumes essentially 0W. From the above example of the Mbus Module power consumption, an additional 3W can be added for a similar data buffer for a total of about 38W.

Speakers

Nearly all workstations have small internal speakers which consume negligible energy. These are the speakers which are used to alert the user of incoming email, a non-fatal error, or during the boot-up process. In addition, external stereo speakers are becoming more popular for use with various other multi-media applications such as teleconferencing and computer games, or for playing sound clips. External speakers are not included in the calculation of workstation energy consumption, and therefore will not affect Energy Star compliance. However, they still consume energy and thus increase overall energy consumption. Some monitors allow the user the option to upgrade by adding stereo speakers in the monitor casing itself. If this is done, the speakers must be magnetically shielded from the HDD.

Manufacturers offer variations of stereo speakers, consuming from 3 to 35W. One manufacturer offers speakers which require a 35W amplifier. Another imbeds two 2W speakers into the keyboard. Still another offers wireless 20W external speakers or 10W internal speakers, both requiring radio transmitters.⁴⁹

- video cameras consume approximately 0 to 10W depending on the size and type of camera.

⁴⁹ *PC World*, Mar. 1996, p. 216.

SECTION V. DETAILED DISCUSSION OF PRIMARY SITE

Case Study of the Massachusetts Institute of Technology (MIT)

The Massachusetts Institute of Technology has a server/client network including 1200 workstations and 50 servers. Every four or five years the oldest workstations are retired and newer workstations become the norm. Thus, the typical workstation purchased for the MIT community five years ago is very different from those purchased today. Five years ago there were 1000 workstations on campus, including the DECstation 5000/25 and the IBM POWERstation 320H. The DEC5000 workstation is quite slow by today's standards, with a CPU speed of only 25MHz. It does, however, have a 16" color monitor, unlike the IBM320H which has only a black and white monitor. The IBM is quite bulky, employs a 19" b/w monitor, and provides the benefit of a 3D color⁵⁰ graphics processor; needless to say, it is the highest energy consumer among all other workstations at MIT. The following table compares energy consumption of the 5 types of workstations currently in use on MIT campus.

Table 20
Energy Consumption⁵¹ of Workstations at MIT

	Monitor	CPU	Total
DECstation 5000/25	103 W	54 W	157 W
IBM POWERstation 320H	134 W	133 W	267 W
Sun SPARCclassic	74 W	29 W	103 W
Sun SPARCstation5	105 W	26 W	131 W
SGI Indy	86 W	82 W	172 W ⁵²

The newer workstations at MIT are the Sun SPARCclassic, the Sun SPARCstation5, and the Silicon Graphics, Inc. Indy workstation. The workstations which are currently in use include each of the 5 types in the above table. By the end of 1996, there will only be Sun SPARCstation5 and SGI Indy machines on campus, thus completing retirement of the DEC

⁵⁰ capable of supporting a color monitor even though a b/w monitor is utilized

⁵¹ Reported values are for energy consumption in the ready mode.

⁵² including external CD-ROM drive which consumes 4W

and IBM workstations. There are no plans to further increase the number of workstations beyond 1200, but only to continuously upgrade the type of workstation. Even though the newer workstations are more powerful than the older ones, they are not necessarily a higher energy consumer. The energy intensive IBM workstation is a good example of this, as is the energy conserving Sun SPARCclassic.

The newer workstations, manufactured by Sun and SGI have power saving capabilities. The SPARCclassic and SPARCstation5 machines appear on EPA's database of Energy Star compliant products. Both are capable of powering down their monitor, HDD, CPU, and fan. The SGI, although it does not appear on EPA's list, includes power saving hardware for the monitor and CPU. The monitors of all three workstations have the ability to power down when they no longer receive a video signal from the CPU. This means that if the CPU is switched off or if the communication link between the CPU and monitor is broken, the monitor will drop into its low power mode.

Currently on MIT's campus all of the 1200 workstations are left on 24 hrs/day. They are only turned off for a few hours each year for maintenance purposes, so it can be assumed that they are on for 24 hrs/day, 365 days/year. The usage of workstations varies according to many factors, some of which have already been described above. One cluster at MIT which was chosen as a case study is accessible to the entire MIT community, has new and very powerful workstations, and is located in a very convenient location on campus. Due to all of these factors, it is one of the busiest clusters on the entire campus. Yet, the workstations are not fully utilized. There is a strong demand for workstations, however only between the hours of 8am until about 11pm. The average idle time of workstations in this cluster was 61% of the day, with a minimum usage of 40% and a maximum usage of 88% of the day. The 39% idle time is mostly accounted for between the hours of 11pm and 8 am when most clusters are virtually empty. The following calculations show how much energy is consumed by the workstations on a daily and yearly basis, and how much of that energy could be saved if some form of energy saving techniques were employed.

There are 20 Silicon Graphics, Inc. (SGI) Indy workstations in the case study cluster. These machines have a R4600PC CPU module which operates at 133 MHz and 5 V; it has 64 M

RAM (main memory) with a maximum of 256 M, 32 M of on-chip cache, 512 k secondary cache, a 540 M HDD (with a max of 1.05 G), one 3½ inch FDD, an external CD-ROM drive, a 17" color monitor (Sony GDM-17E11, 1280 x 1024 pixels, 8-bit), internal stereo speakers, external camera, and external microphone. They are considered to be a high-end workstation due to their many components and capabilities. As reported above, the results of electrical metering were as follows:

- demand of SGI machine, including CPU, monitor, and external CD-ROM drive was 172 W
- demand of CPU only was 82 W
- demand of monitor only was 86 W
- demand of external CD-ROM only was 4 W

The values reported above were taken while the workstation was in ready, but not active mode. The demand of the PC increases slightly during active times, specifically when the workstation is communicating with the server.

There are only a few SGI machines which are able to sleep during idle times. They are those which use the default login screen and screensaver. The SGI machine is capable of powering down its monitor and CPU in response to software signals from the default screensaver.

However at MIT, this screensaver has been replaced with a standard MIT screensaver. The use of the MIT screensaver directly prevents the SGI monitors from powering down during idle times since its power management software is not in use. Thus, they operate at full power 24 hrs/day, even if they are idle for several hours or overnight. It is understandable why this error occurred. The same MIT screensaver has been used with all workstations for years. It was only recently that workstations with specific screensaver needs have been purchased. In fact, this same problem was also seen with the Sun SPARCclassic and SPARCstation5 machines, plus with the PCs at Site C. The computer installation employees just do not know that the screensaver software is also the method of power management.

The following calculations were made to determine the potential energy savings of the SGI machine if the monitor was able to power down during idle times. The consumption of the monitor in sleep mode was measured on three different SGI machines which are able to power down during idle times. The total consumption of 98W includes:

- 12W for the monitor in sleep,
- 4W for the CD-ROM drive, and
- 82W for the CPU, which did not sleep.

The total 98W is recorded in line 6 of the following chart.

Table 21
SGI Potential Energy Savings

		average daily value	approximate yearly value
1)	average idle time	9.3 hrs	3,395 hrs
2)	average active time	14.7 hrs	5,366 hrs
3)	demand of one workstation	172 W	
4)	consumption of one workstation	4.1 kWh	1,507 kWh
5)	cost ⁵³ to operate one workstation	\$0.33	~\$121
6)	demand of one workstation with power saving monitor ⁵⁴	98 W	
7)	consumption of one workstation with power saving monitor	3.4 kWh	1,256 kWh
8)	cost to operate one workstation with power saving monitor	\$0.28	\$100
9)	savings from one workstation		~\$20
10)	savings from entire cluster (x20)		\$402

The amount of idle time was taken from the workstation's record of login times. It is possible to save energy while a user is logged in, however, and these savings are not included in the calculations above. There can be substantial savings while a user is logged in, since the machine is not always in continuous use. This could come from monitor power down, CPU clock slowing, HDD spinning down, or fan speed slowing. Some research in this area has been done by LBNL.

⁵³ assuming \$0.08/kWh including demand charge

⁵⁴ assuming that the monitor will power down to 12W during idle times

From row 10, operating the cluster with power saving monitors would save \$420 (about 251 kWh) per year. If the amount of energy saved were expanded over the entire MIT campus, the savings increases to \$1,728 per year, since MIT has 86 SGI Indy workstations. However, it is probable that the savings of SGI workstations on the remainder of MIT campus would be larger since the SGI cluster used in these calculations is one of the busiest, with average active time of 61%. In comparison, some of the other clusters have usage times as low as 10%, as is detailed in the next analysis.

The type of calculation completed above can be applied to the many Sun workstations on MIT's campus. There are 277 SPARCstation5 plus 369 SPARCclassic workstations. In contrast to the SGI workstations, both of these Sun workstations are Energy Star compliant. The SPARCstation5 CPU is reported to consume 3 W in sleep, with 24 W in sleep for the SPARCclassic CPU.

The specifications for the SPARCstation5 are as follows: 32-bit RISC architecture, 110MHz, 4M VRAM (frame buffer), 32M DRAM (main memory), 32M SRAM (cache), 1000M HDD, one 3½" FDD, graphics accelerator, 17" color monitor (1280 x 1024 pixels, 67-Hz refresh rate). The CPU consumes 26W⁵⁵ in ready mode, and the monitor consumes 105W. Potential savings would result from 3W in sleep for the CPU which is reported in the compliant product database plus the measured value of 12W in sleep for the monitor (Sony GDM-17E10). Thus, total consumption in ready and sleep modes is 131W and 15W, respectively.

Metering several SPARCstation5 machines produced the results of the following table comparing reported consumption in sleep mode with actual consumption in sleep mode. Neither the CPU nor the monitor of the SPARCstation5 machines dropped into low power modes. The monitor specification available from the manufacturer states that the monitor will go into sleep mode when the video signal from the CPU is not present. The monitor's demand in sleep mode was measured by cutting the video signal from the CPU to the monitor in two different ways: by turning off the CPU, and by unplugging the cord which connects the CPU to the monitor. The result was the same: 12W in sleep mode.

⁵⁵ The SPARCstation5 is already Energy Star compliant in active mode.

A value of 3W was measured for the CPU when it was powered off at the switch. In other words, a SPARCstation5 which is only plugged in will consume 3W. It is possible that "plugged in" consumption is the same value reported in the Energy Star compliant product database as "3 Watts in Sleep", especially Sun refers to its on-off switch as a "Standby" power switch. Note that the consumption of the CPU is less than 30W in active mode. To be compliant with the Energy Star program, a workstation of this type needs only to reduce the power of the monitor to less than 30W in sleep mode. Thus, even if savings of 3W in Sleep are not realized, the SPARCstation5 is still compliant.

Table 22
SPARCstation5, Demand in Ready and Sleep Modes

	Demand in Ready Mode (W)	Reported Demand in Sleep Mode (W)	Measured Demand in Sleep Mode (W)
Monitor (GDM-17E10)	105	--	12
CPU	26	3	--
Monitor + CPU	131		

The SPARCstation5 machines, even though they are Energy Star compliant, save no energy due to the same screensaver problem described above in the discussion of the SGI workstations: the power management software is incorporated into the screensaver software, which has been replaced. Since the monitor already incorporates the hardware to reduce power, it would not be difficult for these workstations to reduce power below 60W. In fact, by restoring the original screensaver, the power consumption during idle times would be $26W + 12W = 38W$.

The following table presents usage values for a typical week to show the variation of consumption each day. This particular SPARCstation5 was in found in a private office where, as described above, there is a very low usage rate, from 1 to 18%. The next table compares actual usage times and corresponding cost of operation with potential savings which would result from enabling the energy saving capabilities. The listed savings are specific *only* to this workstation and others like it which have particularly low usage times.

Table 23
SPARCstation5, Private Office, Usage and Idle Time for a Typical Week

	Usage, hrs	Usage percent	Idle Time, hrs	Idle percent
Monday	2.8	12%	21.2	88%
Tuesday	4.2	18%	19.8	83%
Wednesday	3.8	16%	20.2	84%
Thursday	2.1	9%	21.9	91%
Friday	3.7	15%	20.3	85%
Saturday	0.1	<1%	23.9	~100%
Sunday	0.7	3%	23.3	97%

Table 24
SPARCstation5, Private Office, Potential Savings with low usage

		Average Daily Value	Approximate Yearly Value
1)	average idle time	21.5 hrs	7,848 hrs
2)	average active time	2.5 hrs	913 hrs
3)	demand of one workstation	131 W	
4)	consumption of one workstation	3.1 kWh	1148 kWh
5)	cost to operate one workstation	\$0.25	\$92
6)	demand of one workstation with sleep during idle times	38 W	
7)	consumption of one workstation with sleep during idle times	1.1 kWh	418 kWh
8)	cost to operate one workstation with sleep during idle times	\$0.09	\$33
9)	savings from one workstation		\$59

The third table of this investigation examines the energy saving potential of SPARCstation5 machines under more "typical" usage and idle times. This analysis mirrors the analysis of SGI workstation usage. Notice that due to their higher usage they save less than half of the machine located in the private office.

The SPARCstation5 is capable of reducing energy consumption in sleep mode from 131W to 38W. The SGI workstation consumes much more in sleep mode, from 172W to 98W⁶, since only the monitor is capable of powering down. According to the EPA Energy Star compliant product database, the SPARCstation5 CPU is able to power down to 3W; the total consumption in sleep mode would then be only 15W instead of 38W.

Table 25
SPARCstation5, Cluster, Potential Savings with Typical Usage

		Average Daily Value	Approximate Yearly Value
1)	average idle time	9.3 hrs	3,395 hrs
2)	average active time	14.7 hrs	5,366 hrs
3)	demand of one workstation	131 W	
4)	consumption of one workstation	3.1 kWh	1148 kWh
5)	cost to operate one workstation	\$0.25	\$92
6)	demand of one workstation with sleep during idle times	38 W	
7)	consumption of one workstation with sleep during idle times	2.3 kWh	832 kWh
8)	cost to operate one workstation with sleep during idle times	\$0.18	\$67
9)	savings from one workstation		\$25
10)	savings from all SPARCstation5's on campus (x277)		\$6,996

As was previously stated, there are currently 369 Sun SPARCclassic machines on MIT's campus. The following table analyzes the potential savings. Although SPARCclassic machines are usually equipped with a power saving monitor, only a few on MIT's campus actually have them. Instead, they use older monitors (Sony CPD-1790) which are not Energy Star compliant. Thus, savings for these machines only occur due to CPU clock slowing, HDD spinning down, and fan speed slowing. The following table lists the energy consumption in ready mode and sleep mode plus energy in sleep mode for the few which have power saving

⁶ PC in ready mode, 82W + CD-ROM drive, 4W + monitor in sleep mode, 12W = 98W

monitors. These machines consume only 36W in the ready mode, less than many desktop PCs.

Table 26
SPARCclassic, Demand in Ready and Sleep Modes

	Demand in Ready Mode (W)	Reported Demand in Sleep Mode (W)	Potential Demand in Sleep Mode (W)	
			without power saving monitor	with power saving monitor
Monitor (CPD-1790)	74	--	74	12
CPU	29	24	24	24
Monitor + CPU	103		98	36

The SPARCclassic machines are a more simple type of workstation than the SPARCstation5. They do not have as many capabilities and consume less power in the ready mode. A brief list of their components and corresponding energy consumption follows:

Table 27
Components of Two Sun Workstations

	SPARCclassic	SPARCstation5
CPU speed	50 MHz	110 MHz
Hard Drive	207 M	1000 M
Main Memory (DRAM)	16 M	32 M
Cache (SRAM)	36 M	32 M
Graphics Accelerator	N/A	3D-RAM frame buffer
Video Board (VRAM)	8 M	4 M
Bus	32-bit data bus	32-bit data bus
Monitor ⁵⁷	17" color display	17" color graphic display
External Storage	CD-ROM	CD-ROM
Speakers	internal	internal
Microphone	external	external

⁵⁷ Various monitors are available with each workstation; those listed are the monitors found in the field.

Table 28
Energy Consumption of Two Sun Workstations

	SPARCclassic	SPARCstation5
Monitor Consumption, Ready	74 W	105 W
CPU Consumption, Ready	29 W	26 W
Total Consumption, Ready	103 W	131 W
Total Consumption, Sleep (potential)	98 W	15 W

Three cases are compared in the following chart: actual consumption (lines 1 through 5), potential consumption with no power saving monitors (column 2, line 6 through 10), and potential consumption with power saving monitors (column 3, lines 6 through 10).

Table 29
SPARCclassic, Cluster, Potential Savings with Typical Usage

		Average Daily Value		Approximate Yearly Value	
		No Power Saving Monitor	Power Saving Monitor	No Power Saving Monitor	Power Saving Monitor
1)	average idle time	9.3 hrs		3,395 hrs	
2)	average active time	14.7 hrs		5,366 hrs	
3)	demand of one workstation	103 W			
4)	cons. of one workstation	2.5 kWh		902 kWh	
5)	cost of one workstation	\$0.20		\$72	
6)	demand of one workstation with sleep during idle times	98 W	36 W		
7)	cons. of one workstation with sleep during idle times	2.4 kWh	1.9 kWh	885 kWh	675 kWh
8)	cost of one workstation with sleep during idle times	\$0.19	\$0.15	\$71	\$54
9)	savings from one workstation			~\$1	\$18
10)	savings from SPARCclassics on campus (x369)			\$501	\$6,714

The following is a summary of the potential energy which could be saved through implementation of energy saving features on all workstations with power manageable hardware. This includes the Sun SPARCstation5, SPARCclassic, and SGI Indy. In addition, estimates of past, current, and future energy consumption costs are compared. Table 30 displays the results of cost in dollars for enabled (ES) and disabled energy saving features. "Past" indicates five years ago, while "Future" five years ahead.

Table 30
Cost of Workstations: Past, Present, Future

	SGI Indy	SPARC 5	Classic	DEC5000	IBM320H	Total
Demand, W	172	131	103	157	267	--
Demand, ES, W	98	38	98	N/A	N/A	--
Past Cost	0	0	0	84,610	43,223	127,833
Current Cost	10,366	25,430	26,635	39,609	20,208	122,249
Future Cost	34,233	84,093	0	0	0	118,326
Past Cost, ES	0	0	0	84,610	43,223	127,833
Current Cost, ES	8,638	18,434	26,134	39,609	20,208	113,024
Future Cost, ES	28,526	60,960	0	0	0	89,485
Past Savings	0	0	0	0	0	0
Current Savings	1,728	6,996	501	0	0	9,225
Future Savings	5,707	12,134	0	0	0	28,841

Several main points developed out of this investigation. The first is that the current yearly cost to operate 1200 workstations is less than 5 years ago when there were only 1000 workstations on campus. The reason is that most of the energy intensive 19" monitors of the IBM POWERstation 320H have been removed and replaced by the 17" color monitors of the SGI and two Sun workstations. This results in a demand reduction from 134W to 103W, 133W, and 172W, respectively (see Table 20). In the same way, the IBM POWERstation 320H CPUs, which consume 133W, have been mostly retired and replaced by extremely low energy consuming Sun workstations with 22W and 26W demand.

The values calculated for "future" consumption are the projected cost in five years if the energy saving features are enabled on the SGI and both Sun machines. In the same way, and

for the same reason, the projected cost to operate the 1200 workstations in the future is less than the operation of 1200 workstations in the present and less than 1000 workstations in the past.

The number of workstations assumed in the past, present, and future are summarized in the table below:

Table 31
Number of Workstations, Past, Present, Future

	Past	Present ⁵⁸	Future
DECstation 5000	769	360	0
IBM POWERstation 320H	231	108	0
SPARCclassic	0	369	0
SPARCstation5	0	277	916
SGI Indy	0	86	284

⁵⁸ Actual value as of April 1996.

Conclusion

Several conclusions can be drawn from this thesis, concerning the effectiveness of computer power management techniques, the potential to conserve energy in PCs, monitors, and workstations, and the education of computer users and purchasers. Monitors were shown to offer the most power savings for personal computers. In addition, they offer the most safe power management technique for computers attached to networks. CPU power consumption is possible but must be done carefully, with no reduction in performance or loss of network connection. Several sites were located that had problems with CPU power management techniques.

There are no standard power management techniques which protect the computer user's productivity. The main concern is from components that do not power down according to their own inactivity. Many manufacturers offer CPU and HDD features causing power management according to keyboard and mouse inactivity. In some cases, these features are in direct conflict with usage patterns or software applications and must be disabled. CPUs should power down with CPU and bus inactivity; HDDs should power down due to HDD inactivity; and monitors should power down due to keyboard and mouse inactivity.

Workstation power conservation features are quite similar to those of personal computers, but particular care must be taken with CPU power management techniques if the workstation is dependent on a server. In addition, workstations are more likely to be left on at night, leaving room for high levels of energy conservation. Unfortunately, only a few manufacturers have implemented power management features in workstations.

Power conservation techniques for multimedia peripherals are greatly needed. Large stereo speakers, cameras, graphics accelerators, and high density backup or storage devices such as CD-ROM drives all contribute to increased power consumption in active and idle modes. Specifically, many external components have separate on/off switches; they do not receive power from the CPU and may require special energy management techniques. The need will continue to increase since consumption of PCs, workstations, and monitors is not expected to drop; energy reduction is balanced with higher power consumption of additional components, larger memories, and faster CPUs.

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