Measured Energy Savings of an Energy-Efficient Office Computer System

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Recent surveys have shown that the use of personal computer systems in commercial office buildings is expanding rapidly. In warmer climates, office equipment energy use also has important implications for building cooling loads as well as those directly associated with computing tasks. Recently, the Environmental Protection Agency (EPA) has developed an Energy Star (ES) rating system intended to endorse more efficient machines. To research the comparative performance of conventional and low-energy computer systems, a test was conducted with the substitution of an Energy Star computer system for the main clerical computer used at a research institution. Separate data on power demand (watts), power factor for the computer, monitor and power demand for the dedicated laser printer were recorded every 15 minutes to a multichannel datalogger. The current system, a 486 DX-66 MHz type computer (8 megabytes (MB) of random access memory (RAM), 340 MB hard disk) with a laser printer was monitored for an 86-day period. An ES computer and an ES printer with virtually identical capabilities were then substituted and the changes to power demand and power factor were recorded for an additional 86 days. Computer and printer usage patterns remained essentially constant over the entire monitoring period. The computer user was also interviewed to learn of any perceived shortcomings of the more energy-efficient system. Based on the monitoring, the ES computer system is calculated to produce energy savings of 25.8% (121 kWh) over a year.

Introduction

According to the Environmental Protection Agency (EPA), personal computers (PCs) and related office equipment are the fastest-growing new electrical load in the commercial sector. In 1990, DeLaHunt found that 15 - 17% of the total electricity consumption in commercial buildings in the Pacific Northwest was due to computers and other miscellaneous office equipment. Piette et al. (1991) estimated that the fraction of energy use in commercial buildings from office equipment was growing at an annual rate of 5.8% in 1989 with the contribution of personal computers expected to be the largest source of new growth over the next decade. Currently, computers are believed to account for 5% of all commercial electricity consumption, and could account for 10% by the year 2000 (EPA, 1993). Furthermore, the EPA estimates that 30- 40% of the nation's 30-35 million personal computers are left running at night and on weekends. This estimate is given credence by Pratt et al. (1990) which found that an average utilization factor of personal computers of approximately 19%, suggesting that a significant fraction was left on during nights and weekends. Other evidence comes from the National Resource Council of Canada. The energy use patterns of 94 computer systems were monitored with a predicted reduction in mean computer energy consumption of 58% if computers were switched off after 60 minutes of inactivity.

With these facts in mind, the EPA developed its Energy Star (ES) program to reduce the impact of personal computer systems on commercial building energy use. Systems in compliance with the ES program are defined as computers, monitors, and printers able to enter a low-power state of 30 watts (W) or less when left inactive (as compared with over 100 W needed for these components when active). The various technologies used to reduce computer system energy use to comply with the ES Program are summarized in Table 1 (Ledbetter and Smith, 1993).

Previous Studies

Data collection on measured power consumption of computers, monitors and associated printers is spotty. Harris et al. (1988) measured the short term energy use of a variety of electronic office equipment. The electrical demand of 24 desktop personal computers with monitors ranged from 31 - 209 W; the measured average demand of two laser printers was 140 and 129 W. Researchers

Table 1. Summary of Technologies Used to Reduce Computer System Energy Use

	Conventional	Energy-Saving Technology
Computer	Constant fan speed Constant CPU speed 5 V CPU Standard 3.5" hard drive Constant power for peripherals	Variable fan speed Slow CPU during quiescent periods 3.3 V CPU Smaller 2.5" hard drive Shut down communication ports
Monitor	Constant operation at full power	Power down to a level sufficient to keep the video tube warm
Printer	Fuser is constantly reheated	Fuser quiescent mode; allows the fuser to cool down between print jobs

widely acknowledge that actual electrical use of a personal computer differs widely from the nameplate rating of the unit, often suggesting that average demand is approximately 30% of the nameplate values (Norford et al., 1990; Jacobs et al., 1992). Tiller and Newsham (1992) measured the energy use of several hundred computers and peripherals, finding that measured power demand density was 0.3 W/ft^2—much lower than the 1.3 W/ft^2 calculated from nameplate ratings (W/ft^2 relates to equipment density in buildings). Recently, Patel et al. (1993) found that a 386-based personal computer and a 19" color monitor had a nameplate rating of 252 W while the unit actually used 146 W when in use and 143 W when in standby mode. Similarly, a popular laser printer had a nameplate power rating of 900 W against 575 W used when actively printing and 31 W when in standby mode.

The most recent relevant research to the planned study was completed by a national laboratory in which 222 PC workstations were metered over a one-week period (Szydlowski and Chvála, 1994). The study found that the average standard PC used 144 W (central processing unit (CPU) = 85 W, monitor = 60 W) and power demand of other added peripherals (printers, scanners, external modems, etc.) brought the total up to 173 W. The standard PC was estimated to consume 341 kWh annually. A 24-hour workday demand profile found that the average computer has a hat-shaped demand profile with PC electrical demand at 76% of its potential maximum (a diversity of 24%) during the peak hours from 8 - 4 p.m., but with a base load value during the evening and early morning hours of 18%. The power density of the workstation equipment tested in the buildings was 0.62 W/ft^2. Devices that sense keyboard/monitor inactivity and power off the monitor were tested on 11 different workstations with a resulting 21% reduction in daily electrical demand and a 34% reduction in average maximum electricity consumption.

Methodology

To research the comparative performance of conventional and low-energy computer systems, we conducted a test of the substitution of an Energy Star computer system for the main clerical computer used at the Building Design Assistance Center (BDAC). Separate data on power demand (watts), power factor for the computer, monitor and power demand for the dedicated laser printer were recorded every 15 minutes to a multi-channel datalogger. The data allowed realistic analysis of comparative computer system performance. The main clerical computer was chosen since its intensive use patterns would represent a conservative minimum expectation for energy savings of an ES system.

The conventional computer system consisted of a 486 DX-66 MHz type PC with 8 megabytes (MB) of random access memory (RAM) and 340 MB hard disk. A 17" color video display terminal (VDT) was linked to the computer and monitored on the same circuit. A 600 dot-per-inch laser printer with 14 MB of internal RAM was also part of the equipment. The conventional system was monitored for 86 days. An Energy Star computer and an Energy Star printer with virtually identical capabilities were then substituted. Table 2 lists the instantaneous power measurements for the two computer systems in their typical configuration, along with their nameplate ratings. The measurements were made using a digital power analyzer with a 0.5 second integration rate.

According to the manufacturer, power demand for the ES computer is reduced during normal operation through

Table 2. Short-Term Power Demand Measured Watts/(Nameplate Rating)

	Computer	Monitor	Printer
Standard System	46.0 (173)	85.2 (180)	30 - 931 W (770 W)*
Energy Star System	31.0 (230)	85.5 (180)	17 - 634 W (700 W)*
Energy-Save Mode	25.0	3.5	18

* The energy use of both the standard laser printer and the ES model in our study was measured in a recent survey (*PC Magazine*, 1993). The average consumption was reported as 178 W and 71 W when printing and in rest mode, respectively. The same values for the chosen ES printer model was 143 W and 23 W.

increased components integration on the motherboard rather than the use of many insert cards commonly incorporated into most conventional computers. Power demand for the ES computer is further reduced in standby mode by the reduction the CPU clock-speed from 33 MHz to 8 MHz and by also disengaging the hard drive. The ES computer enters the saving mode in two steps: First, the hard drive is shut off after 5 minutes of being idle. Then the CPU and monitor are powered down after an additional 5-minute period of inactivity. The ES printer is set up to enter a low-power mode after a 15-minute period of inactivity.

Measurements

High-accuracy watt transducers were used to measure the electrical demand of both the computer (and monitor) and the printer. Given the commonly expressed concern of utilities that computer systems exhibit very poor power factor, the power factor (ratio of true to apparent power; W/(V x A)) of the computer system was monitored. The readings from the instrumentation were scanned every five seconds with integrated averages output to datalogger storage every 15 minutes. The data were then downloaded to the site mainframe computer for storage and plotting of the daily power use and power factor.

The power demand and power factor were recorded for 86 days with the original configuration before changing to the ES system. A similar monitoring period was then carried out with the new system. Each morning, recorded data from the monitoring were reviewed by the project engineer. An example of the daily plots of system performance (computer, monitor and printer power use and power factor), both for the conventional computer system and the ES system are shown in Figures 1 and 2, respectively. Note that the computer and monitor make up about two-thirds of the energy use of the complete computer system. As much as possible with a functioning system, usage patterns were held constant during the monitoring. The same user was maintained and daily start-up times were similar throughout the monitoring period. Also, the data acquisition system recorded the running total "on time" on each day so that the final data could be normalized to adjust for remaining differences in operating hours in the pre- and post-retrofit periods.

The daily plots for the standard system show that its power demand is very uniform after start up. The average demand of the computer and monitor was approximately 122 W; the printer power demand averages 69 W when powered. The similar comparison plot for the ES system shows a less predictable power demand for the computer system, particularly for the printer. The function of the energy-saving mode on the ES computer system over the lunch-time hour is very noticeable on the computer and monitor. The more efficient ES computer system used 16% less energy on the two comparative days (two days are comparative when the systems are powered "on" for the same amount of time).

As utilities have claimed, power factors associated with both computer systems were very low, averaging approximately 0.65 when they were on. Of particular interest was the fact that computer power factor was further degraded when the energy saving mode is in operation (during the noon hour). During a 24-hour monitoring period with the ES system, the power factor dropped from 0.68 during active use to 0.60 when in the energy-saving mode.

Monitoring Results

Table 3 lists the relevant performance data on the conventional computer system as measured over an 86-day period. In our analysis "working days" mean any day in which the computer system was used. It is worth noting that the studied computer system is generally turned off during night and weekend hours.

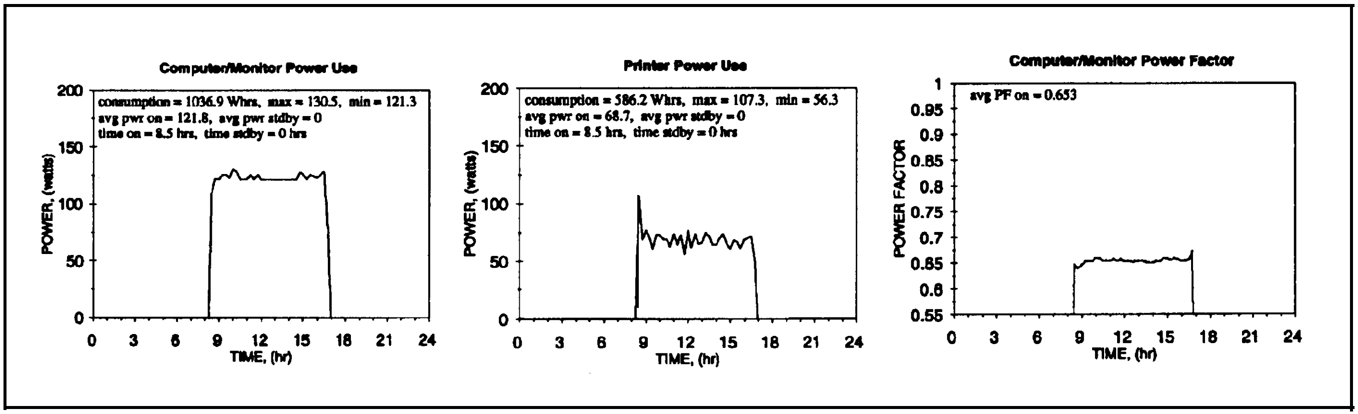

Figure 1. Performance Plot for Standard Computer System

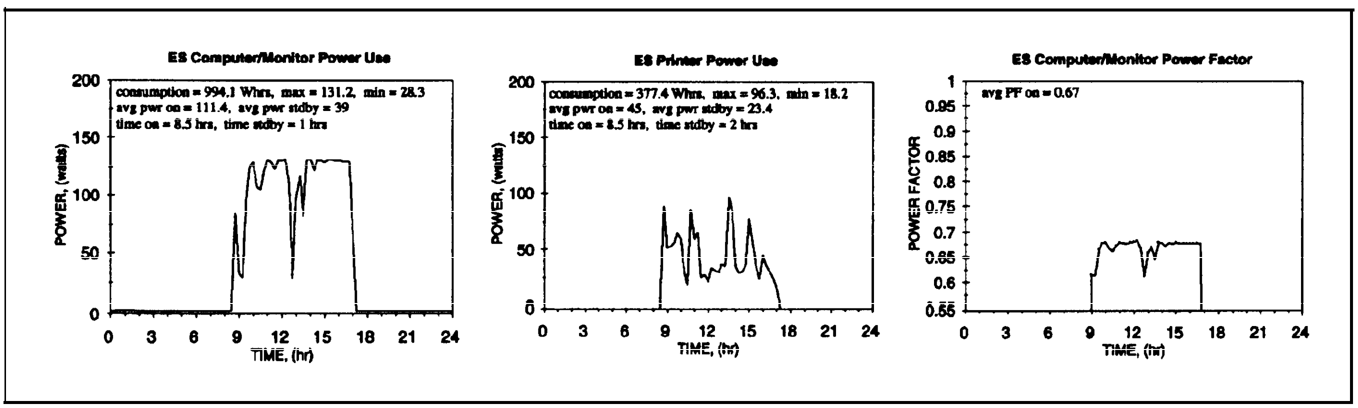

Figure 2. Performance Plot for Energy Star Computer System

Table 4 provides the comparative data for the Energy Star system from the 86 days of measured data. The average number of hours in the standby mode was calculated based on the 15-minute periods in which the electrical demand was less than 50 W for the computer-monitor set and less than 35 W for the printer.

The tabulated average number of hours in which the computer was "on" is based on all 86 days of data. The annual energy use and energy cost in Table 3 is based on the assumption of 2,285 and 2,823 hours of use for the computer and printer, respectively, and an electricity cost of $0.10/kWh (the annual use was calculated using the two 86-day monitoring periods to determine the average number of hours "on" per day for the computer and the printer separately, and then by multiplying these averages by 365 days - these data account for holidays, weekends, and vacation). Although the electrical cost is somewhat greater than typical commercial energy prices, it reflects the fact that energy use from computers and printers add to monthly commercial demand charges.

Figures 3 and 4 show the daily energy use and hours of operation of the standard computer and printer, respectively, over the 86-day monitoring period. There is obviously a strong association between hours of use and daily energy consumption.

Figures 5 and 6 show similar plots for the ES computer and printer, respectively.

Figures 7 and 8 show the average daily computer and monitor electrical demand profile on working days for the standard and ES systems. The profile for the standard computer shows an average machine start up at 8 a.m. with nearly constant electrical demand at approximately 115 W until 5 p.m. with a long tail of steadily diminishing energy consumption during the evening hours (this indicates that the system was occasionally used after 5 p.m.). The profile for the ES computer differs from the standard computer principally during the morning and the lunch-time hour. Interestingly, the ES computer (without monitor) was found to draw 3 W even when the system was off as opposed to negligible consumption for the standard computer. Reasons for this difference are yet unknown. The printers' profiles indicate a quasi-steady state difference of 20 W in power demand when they are powered.

Table 3. Measured Performance of the Standard Computer System
December 2, 1993 - February 18, 1994

Data	Computer	Printer	Both
Total Consumption for the 86-day Period	57.8 kWh	42.6 kWh	100.5 kWh
Total Hours of Operation for the 86-day Period	505.0 hrs	583.8 hrs	NA
Average Working Day Consumption *	1.03 kWh	0.70 kWh	1.73 kWh
Average Hours of Operation per Working Day	9.0 hrs	9.6 hrs	NA
Energy Consumption per Hour of Operation	114 Wh/hr	73 Wh/hr	187 Wh/hr
Estimated Annual Hours of Operation	2285 hrs	2823 hrs	NA
Estimated Annual Energy Consumption	262 kWh	206 kWh	468 kWh
Estimated Annual Energy Cost ($0.10/kWh)	$26.17	$20.62	$46.79

* Working day refers to those days where the instrument has been used, even for only 15 minutes. It can include some weekends and holidays. During the 86-day monitoring period, there were 56 working days for the computer and 61 for the printer. The printer was used more than the computer because it was shared by several persons.

Table 4. Measured Performance of the Energy Star Computer System
February 19 - May 15, 1994

Data	Computer	Printer	Both
Total Consumption for the 86-day Period	54.6 kWh	34.1 kWh	88.7 kWh
Total Hours of Operation (Including Standby)	571.8 hrs	746.8 hrs	NA
Total Hours Standby	177.2 hrs	291.0 hrs	NA
Average Working Day Consumption *	0.88 kWh	0.51 kWh	1.39 kWh
Average Hours of Operation per Working Day **	9.2 hrs	11.1 hrs	NA
Average Hours Standby per Working Day	2.9 hrs	4.3 hrs	NA
Energy Consumption per Hour of Operation **	95 Wh/hr	46 Wh/hr	141 Wh/hr
Estimated Annual Hours of Operation **	2285 hrs	2823 hrs	NA
Estimated Annual Energy Consumption	218 kWh	129 kWh	347 kWh
Estimated Annual Energy Cost ($0.10/kWh)	$21.82	$12.89	$34.71
ES Savings			
kWh	44 kWh	77 kWh	121 kWh
$ Dollars	$4.35	$7.73	$12.08
Percentage Reduction	16.6%	37.5%	25.8%

* During the 86-day monitoring period, there were 62 working days for the computer and 67 for the printer.

** Includes Standby.

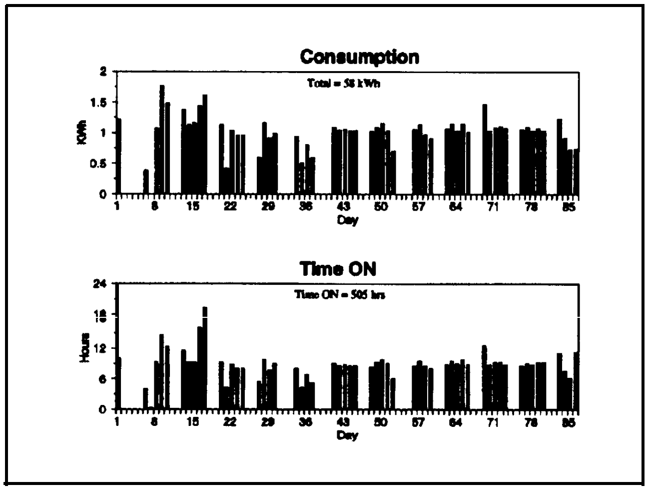

Figure 3. Energy Use and Hours of Operation of the Standare Computer

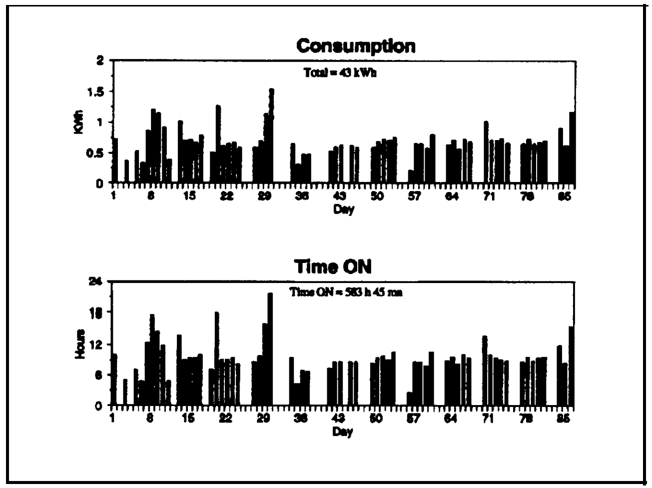

Figure 4. Energy Use and Hours of Operation of the Standard Printer

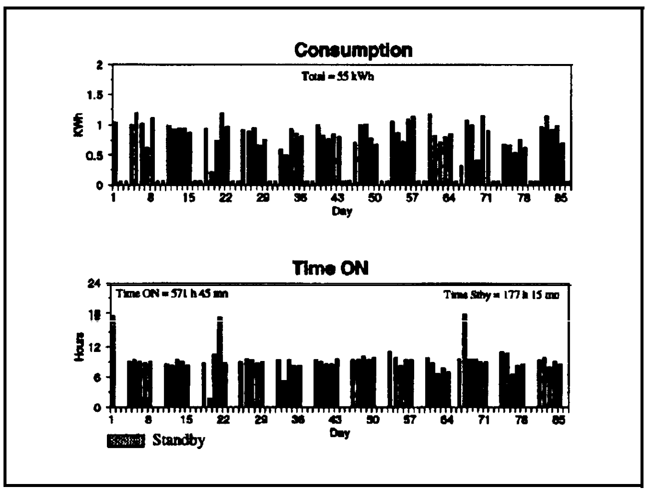

Figure 5. Energy Use and Hours of Operation of the ES Computer

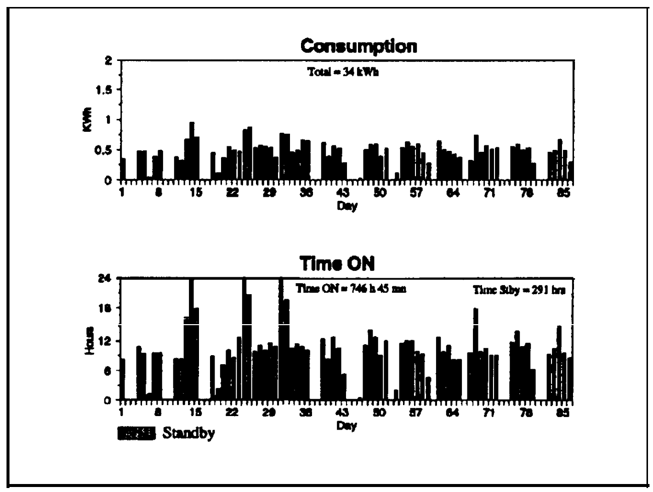

Figure 6. Energy Use and Hours of Operation of the ES Printer

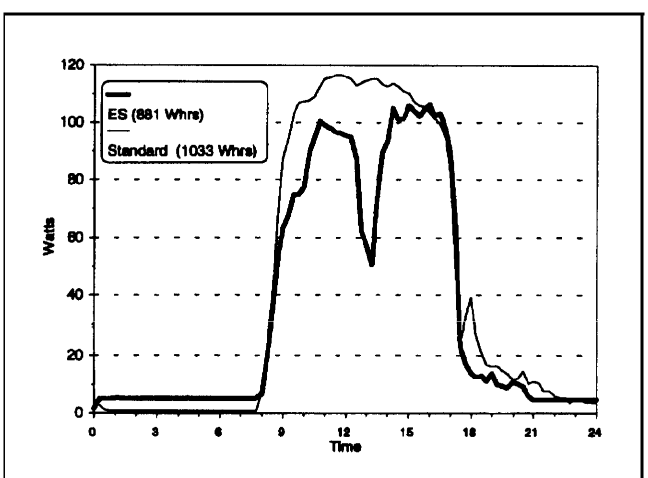

Figure 7. Average Power Demand of the Computers

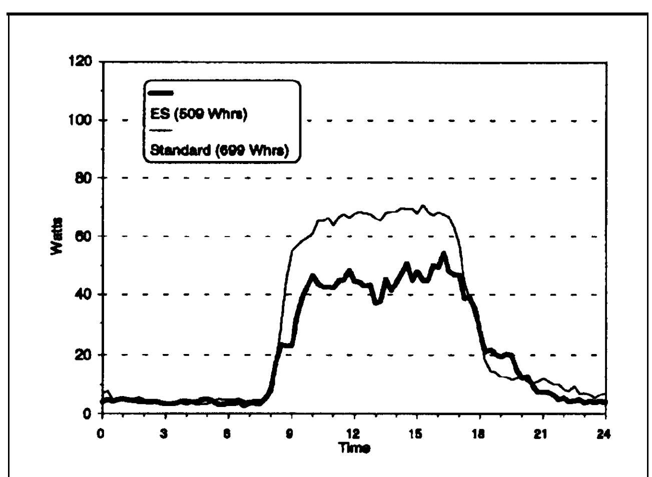

Figure 8. Average Power Demand of the Printers

Savings

Based on our monitoring, we estimate that our standard computer/printer configuration used approximately 468 kWh per year. Of this total approximately 56% of the load comes from the computer/monitor with the balance from the dedicated printer. We estimate that the ES computer system will use 347 kWh per year under similar use conditions. Of the 25.8% overall energy savings (121 kWh/yr), analysis of the metered data shows that most of the potential savings in our case comes from a 37.5% reduction in printer energy use.

The produced savings, particularly for the computer and video monitor, depends on usage pattern. In our case, the computer and printer are heavily used during the day, and usually turned off during the night, which limits the savings potential. We believe this to be desirable since it would lead to conservative estimates of potential energy savings. Higher reductions would be observed for a computer used occasionally, or often accidently left on at the end of the day. Savings in less intensively used systems could easily be double the 25.8% observed in our conservative case study. In any case, we find it logical to choose Energy Star equipment since there is usually no cost premium associated with ES computers and printers over machines without the energy saving features of similar performance (PC Computing, 1993; Nadel, 1994).

If the intensively used computer system monitored in this study was operated for an entire year, we would estimate its annual operating "on" hours at 2,285 for the PC, or 26% of the time, and 2,823 for the printer, or 32% of the time. This corresponds to typical annual operating hours of 1,450 - 2,876 in larger scale studies (Piette et al., 1991). Even with similar usage patterns, we found that the ES computer system was used more extensively in its 86-day monitoring period than was the standard system. Thus, we normalized the energy use data for each period by the total number of operating hours before calculating the savings to eliminate bias potentially introduced by differences in use.

Qualitative Results

Our study's computer system user was displeased with the slowness of the ES printer start-up cycle. A major reason is that the printer reduces power use by turning off the fuser in sleep mode. However, waiting for it to warm up again can be bothersome. This is particularly noticeable since the printer in question receives heavy use. Typically it takes approximately 20 seconds for the fuser to heat up before a document can be printed. Measurements showed the time from print request to begin printing a single page was 27 seconds for the ES printer against 12 seconds for the standard laser printer. Once started, the print speeds, in terms of pages per minute, were virtually identical for both the ES and standard printer at approximately 8.4 seconds per page.

Recently, ES printers have become available that have an "instant on" fuser that should eliminate the wait for printer start up (PC Computing, 1993). Our user found no difficulty or limitation with the ES system's computer and monitor, which were entirely satisfactory.

Conclusions

A monitoring study was conducted to allow estimation of the energy savings of the substitution of an Energy Star (ES) computer system. The original computer system was conventional: a 486 DX-66 MHz personal computer with a 17" color monitor and a laser printer. The replacement computer and printer had identical performance characteristics with the exception that the new system qualified for the ES program. The chosen computer system is extensively used as a main clerical computer at a research institution and was believed to be a good candidate system to demonstrate the most conservative savings level that might be experienced.

High accuracy power transducers were used to measure the computer and monitor wattage and power factor and the wattage of the laser printer. Data was output to a multichannel datalogger scanned every five seconds with integrated averages output every 15 minutes to storage. Data was taken on each of the two systems for a period of 86 days.

Based on our monitoring, an annual saving of 25.8% in energy use (121 kWh/yr) was estimated for the ES system over the conventional one. By design, this case study probably represents a minimum expected savings level since the computer system is intensively used. Although the laser printer accounted for only about 42% of the measured energy use of the original system, it represented 64% of the achieved savings from its substitution in the ES system. The typical daily electrical load profiles for the conventional computer had the typical "hat" shape seen in commercial buildings where equipment is turned on and off during operating hours (Taylor and Pratt, 1990). The load shape of the ES computer system was less predictable, although clearly showing the effect of the energy-saver mode for the computer and monitor during the lunch hour. The measured average power factor for the standard and ES systems was low at 0.66 for both systems. It is noteworthy, however, that the power factor of the ES computer dropped from 0.68 during normal operation to 0.60 during periods when the energy-saving mode was activated.

Our data show that the energy savings of the ES system is strongly influenced by its degree of use and whether the components are left on during evening hours. The authors emphasize that the energy savings of the ES system in this case study likely represents a minimum expectation for most systems. The computer and printer tested are extensively used and usually turned off during evening hours. Other computer systems with nonintensive use patterns and less vigilant operation could easily see savings from Energy Star systems double those estimated in our study. Average savings of ES systems in large-scale installations must await more extensive metering projects with large, statistically representative samples.

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