# Energy Savings from Energy Star Personal Computer Systems

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Recent studies have shown that many personal computers (PCs) are left on 24-hours per day even though they may only be used 30–40% of the normal workday (Szydlowski & Chvála 1994; Tiller & Newsham 1993). In an effort to reduce this waste, the U.S. Environmental Protection Agency (EPA) introduced the ENERGY STAR (ES) rating program in June 1993. The ES-compliance requires that the power consumption of the PC system must automatically reduce to 30 W or less during periods of inactivity. Although a number of manufacturers are offering ES-compliant computers, the energy and dollar savings are not well documented.

To quantify the energy savings potential of ES-compliant PCs, a metering study was conducted at a typical single-story commercial office building located in Northern California. The energy consumption of the monitor and the central processing unit (CPU) for the ES-compliant PCs was monitored in 15-minute time-series-records to emulate the utility billing demand interval. The potential energy savings are computed by comparing the 24-hour demand profile of an ES-compliant PC to that of a standard PC.

The analysis presented in this paper shows that the ‘‘as-operated’’ energy savings at the office building are 211 kWh/yr per PC system and the total annual savings from the use of 40 ES-compliant PC systems are 8,400 kWh/yr. This savings represents a 59% reduction in PC systems energy consumption at this building.

## INTRODUCTION

A major California utility company has been conducting a research and development project named Advanced Customer Technology Test for Maximum Energy Efficiency (ACT$^2$) for the past several years (Brohard 1992). It is a project to design, implement and measure integrated packages of technologies which are optimized for maximum energy efficiency at selected customer facilities in the utility's service territory. ACT$^2$ demonstrations are carried out at both commercial and residential sites, including new construction and existing buildings. The ACT$^2$ mission is as follows:

> *To provide scientific field test information, for use by the utility and its customers, on the maximum energy savings possible, at or below projected competitive costs, by using modern high-efficiency end-use technologies in integrated packages acceptable to the customer.*

As part of ACT$^2$, a computer monitoring study was conducted at a typical single-story office building in Northern California to determine the energy savings achievable through the use of ES-compliant PC systems. This new, 15,000 ft$^2$ single-story office building can house up to 75 employees, was officially opened in June of 1994, and is ACT$^2$'s representative new construction, commercial building. Computer monitoring was conducted during normal operations between March and July of 1995.

Although the energy consumption of the heating, ventilating, and air-conditioning equipment (HVAC) is declining due to stringent building codes and increased equipment efficiencies, the energy consumption of office equipment (personal computers, printers, photocopiers, faxes, etc.) is increasing rapidly. With the explosion of information technology and increasing need to use the information highway to perform routine day-to-day activities, a desktop personal computer (PC) has become essential. It is estimated that in office buildings, office equipment accounts for approximately 5% to 20% of the total building electric load (Piette et al. 1991; Lovins & Heede 1990). A significant portion of this load is from the use of PCs.

The main objective of this study was to estimate the potential savings from use of ES-compliant PC systems. In addition to the description of the monitoring and savings analysis, a brief history of the ENERGY STAR Program, the national impact of the program, and previous work in this area are also presented in this paper.

## POLICY EFFORTS TO REDUCE OFFICE EQUIPMENT LOAD GROWTH

Office equipment became an important source of electricity load growth for electric utilities and building owners in the 1980s, as PC systems and associated peripherals became widespread. This growth was associated with the migration of computing power from large centralized mainframe systems to the desktop PC systems (Harris et al. 1988; Nordman et al. 1996). Utilities, governments, and individual building owners are concerned with understanding the changes in energy used by office equipment.

Several programs and policies designed to reduce energy use by office equipment have recently been adopted in the U.S. and Europe. The most significant market-pull activity is the U.S. EPA's ENERGY STAR office equipment program. This program, announced during the summer of 1993, has ushered a new generation of power-managed office technologies into the marketplace. Over 2000 models of computers, monitors, and printers are now listed as ES-compliant products. The EPA recently expanded the program to include copiers and fax machines. To qualify as an ES-compliant PC or monitor, the equipment must be able to reduce power consumption to 30 W or less during idle periods (Johnson & Zoi 1992).

Not all ES-compliant units are equal in their energy efficiency. Efforts to assess, specify, and procure more efficient equipment are hampered by the lack of standard methods for measuring and reporting the energy use of each device. Currently, the EPA allows manufacturers to conduct their own measurements, so the data in the EPA ES product list has not been verified by independent tests. To address this void, the Energy Policy Act of 1992 calls for a voluntary national testing and information program for office equipment. The Department of Energy (DOE) has worked with representatives from the Council on Office Product Energy Efficiency (COPEE) to develop such standards. However, industry commitment to this process has been limited.

A major reason for the rapid adoption of ES equipment in the marketplace was the signing of executive order (E.O. 12845) by President Clinton. Under this order, the world's largest purchaser of office equipment, the U.S. government, is required to purchase ES-compliant PCs, monitors, and printers. This market-pull strategy has had a significant effect on the market penetration of ES-compliant equipment. Similar activities to promote energy-efficient office technologies are underway in several European countries and Japan (Dandridge 1994; Smith et al. 1994). These standards are much more stringent than the EPA's ES Program.

## NATIONAL IMPACT OF SAVINGS FROM THE ENERGY STAR PROGRAM

A recent study (reported in another paper within this panel), based on an end-use forecast of office equipment energy use for the U.S. commercial sector, found that the information equipment currently uses about 7% of all commercial sector electricity (Koomey et al. 1995). Without the advent of power-management technologies such as those fostered by the ES Program, today's office equipment energy use would grow to 7.6% of commercial sector electricity use by the year 2010. Office equipment here is defined as PCs, monitors, printers, copy machines, fax machines, plus mainframe and mini-computers. Total electricity use for office equipment is currently 63.5 TWh (1 TWh $= 10^{12}$ Wh). Electricity use by monitors is the largest of the desktop devices, accounting for 9.3 TWh in 1995. PC CPUs account for 8.9 TWh.

The likely energy and dollar savings in the commercial sector from the ES Program for all five product categories are significant on a national scale. Total electricity savings will range from 10 to 23 TWh/yr in 2010, and will most likely be about 17 TWh/yr by 2010. The most likely level of savings represents the annual output of three 1,000-MW power plants, and results in net benefits to society exceeding $1 billion per year after the year 2000. Again, power-management of monitors is the most significant product category, accounting for 80–100% of the savings. The cost of achieving ES efficiency levels is estimated by the PC and monitor manufacturers to be negligible. This policy therefore should save society large amounts of money with minimal expenditure of public funds or private capital.

There are several important uncertainties associated with these estimates of savings from ES PCs and monitors. These include the penetration of power-managed equipment, power-consumption trends, and usage patterns with power-management features. Research efforts to better understand the usage patterns of power-management features are discussed in the next section.

## FIELD PERFORMANCE OF POWER-MANAGEMENT IN PCs AND MONITORS

Several recent case studies have been conducted to better understand the field performance of power-management features. Results from case studies of eleven power-managed PCs and monitors have been compiled by Lawrence Berkeley National Laboratory (LBNL) (Nordman et al. 1996). In addition to conducting measurements at its own site, LBNL compiled the primary measurements from PCs and monitors measured by Massachusetts Institute of Technology (MIT) and the Florida Solar Energy Center (FSEC). The PCs and monitors were metered for three to twelve weeks, with annual operating profiles extrapolated from the short-term measurements.

Of the three ES-complaint PCs and three monitors metered at LBNL, only two were enabled, and one of these not optimally. The LBNL on-site effort also consisted of auditing 70 PCs and 70 monitors for their power-management features. About half of the PCs and monitors had power-management features, but less than half of those were enabled, as reported in Nordman et al. (1996). Even when enabled, several of the power-management features were not saving energy because of problems with the network.

FSEC reported on the energy savings from one user's switch from a standard computer system and printer to a properly enabled ES-compliant model of each (Lapujade & Parker 1994). They found 50 kWh/yr savings for CPUs and 75 kWh/yr savings for monitors under actual operating conditions (FSEC 1995).

Researchers at MIT measured PC system energy use at one site and surveyed the power-management features at six others (Norford & Bosko 1995; Norford et al. 1990). Power management was enabled on four systems (it had been disabled previously) and monitored data collected for each system. Unique amongst these projects is the use of 1-minute data, which was used in the LBNL report to validate the estimates from the 15-minute data provided by the other sources.

Nordman et. al. (1996) derived the energy savings from power-management using three methods. The first method is based on the ''as-operated'' conditions. In this case, the energy savings are the difference between the actual measured consumption using power management, and a baseline condition assuming the power-management is not enabled. If the power management is not enabled, the PC and monitor power is constant. The second method to derive energy savings uses a ''standardized'' operating pattern based on previous studies of PC and monitor usage patterns at Pacific Northwest National Laboratory (PNNL) (Szydlowski & Chvála 1994), and at National Research Council of Canada (Tiller & Newsham 1993). The third method to derive energy savings is a ''maximum savings'' scenario assuming that the PCs and monitors would be left on 24-hours per day.

As-operated energy savings for the eleven PCs, monitors, and PC-monitor systems are about 40 kWh/yr per PC system. Under the standard operating schedule (on 20% of nights and weekends), the savings are about 200 kWh/year. The majority of the savings are from monitor power management.

One important conclusion of the LBNL study is that the power-management configuration can have a large impact on the energy savings. The power-management systems vary in complexity. Early ES-compliant PCs have minimal options for power-management, while today's new machines with Advanced Power Management have up to 29 options (Intel/Microsoft 1992 and Intel/Microsoft 1993). A critical outstanding research issue is to evaluate the percentage of complaint machines that are enabled and successfully saving energy. As of October 1995, ES-complaint PCs and monitors were required to be shipped enabled, which should increase the percentage of PCs and monitors using power-management. Ensuring that these devices routinely enter low-power modes is also important. The highest priority for increasing energy savings from power-management is to enable the power-management option for the monitors, since they are generally easier to configure than are PCs, less likely to interfere with system operation, and have greater savings for each device.

The difficulty of knowing how to properly configure most PC systems is the largest current barrier to achieving the savings potential from power-management. Better software controls could greatly alleviate this problem.

## PC CONFIGURATION AT THE ACT$^2$ OFFICE BUILDING

There are approximately 40 identical ES-compliant PCs (AT&T/NCR System 3227) in the ACT$^2$ office building. A typical PC configuration includes: (1) AT&T/NCR System 3227 with an IntelDX-486 CPU, (2) AT&T/NCR 3298-0280 17'' enhanced super video graphics array (SVGA) low power monitors, and (3) all PCs are connected to a local area network. Although there are several power-management mechanisms, the PCs in the office building use the power-management software to enable/disable power-management features.

In general, most computers are delivered with power-management features disabled. This is because it is important that the monitor is compatible with the CPU power-management features. If not, the monitor could be damaged beyond repair. Since it is very common to purchase the CPU and the monitor from different manufacturers, the ''disabled'' power-management setting upon delivery is normal for safety reasons. At the office building, the power-management on all PCs was enabled prior to delivery by the manufacturer, because both CPUs and monitors were purchased from the same manufacturer.

ES-compliant PCs are equipped with either software controlled or some combination of software/hardware controlled power-management capability to power-down the hard drive, the monitor, and the CPU after a fixed or user defined period of time. The system will return to normal operation when either the mouse is moved, or a key is pressed. The hard drive will return to normal operation after an operation is performed that accesses the hard drive. Depending on the system configuration, the system could take several seconds to return to normal operation. A power-management program, called up and executed once during system setup, controls the degree of power management available with the system according to the available software and display capabilities. Table 1 shows the three levels of power management for the AT&T/NCR PC systems at the office building.

***Table 1.*** *Levels of Power Management for the AT&T/NCR PC Systems at the Office Building*

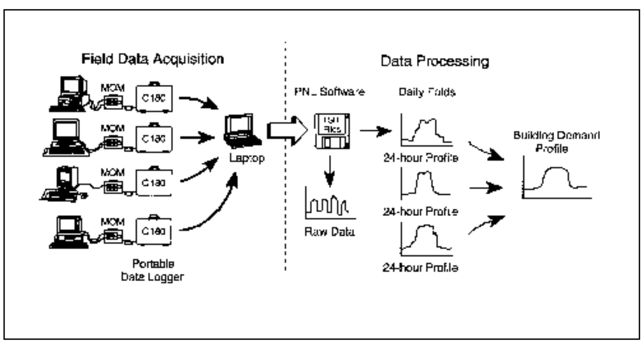
| Power Management Modes | Power Level[a] (W) | Percent of Full-ON Power |
|---|---|---|
| ON | 105–125 | 100 |
| SUSPENDED | 22 | 20 |
| OFF | 5[b] | 5 |

[a]Total PC system power, i.e., CPU (30W) and Monitor (75W-95W).
[b]Residual power consumption of the power supply, etc.

## AUTOMATIC DATA ACQUISITION SYSTEM

The methods and procedures used to collect the field data and process it into a useful form are described in this section. Figure 1 illustrates the field data acquisition and the data processing flow schematically.

***Figure 1.*** *Field Data Acquisition and Data Processing Flow Schematic*



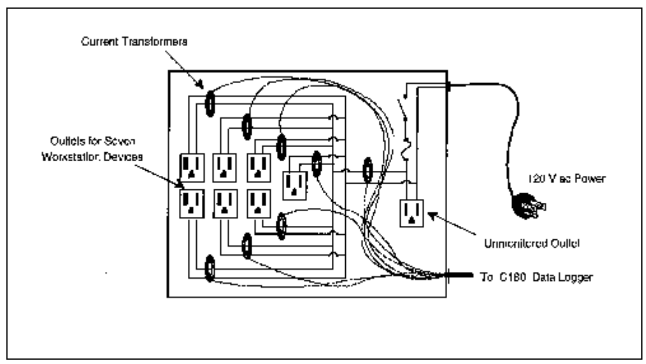

Data acquisition systems, composed of a PNNL-developed multiple-outlet monitor (MOM) and a Synergistic Control Systems C180™ data logger, were used to conduct all the field measurements (Szydlowski & Chvála 1994). The MOM, shown in Figure 2, was developed as a substitute multiple-outlet electric power strip that can separately monitor up to seven workstation devices. The C180 data loggers used electric current transformers (CTs) and potential transformers (PTs) built into the MOM to sample the amperage and voltage and to conduct real-time calculation of true electric power and apparent power for each of the seven outlets and the total workstation.

The monitor and the CPU are generally connected to the first two outlets of the MOM. The C180 data loggers are capable of recording more than one week of 15-minute interval data in internal battery-backed random access memory (RAM), so the data acquisition equipment did not need attention during the monitoring period. IBM-compatible portable computers were used to communicate with the data loggers via the SYNERNET® software program (Synergistic Control Systems, Inc.). SYNERNET was used to control both the configuration of the C180s and automatic data transfer to the portable computer.

All electric power measurements recorded using the C180 data logger are true power for both sinusoidal and nonsinusoidal voltage and current wave forms. The accuracy of the monitoring equipment was verified by PNNL by comparing the waveform profile obtained from a C180 data logger and from BMI 3030A PowerProfiler (Szydlowski & Chvála 1994).

The power consumption of the monitor, the CPU and the total power consumption were recorded at 15-minute intervals for a two-week period for ten ES-compliant PC systems at the office building. Installation and removal of the monitoring equipment required a short shutdown of the workstation equipment. The monitoring equipment was typically installed during work-hours in less than 5 minutes. During the monitoring period, the equipment was typically located

***Figure 2.*** *Multiple-Outlet Monitor (MOM)*



under the computer desk or table and was transparent to the user's operation of the workstation. The data logger monitored the PC systems for at least two-weeks to capture the occupied and unoccupied profiles. At the end of the monitoring period, data were downloaded to a portable computer in the field, and the loggers were moved to the next workstations.

# ANALYSIS OF MEASURED DATA

Of the 40 ES-compliant PC systems, ten were monitored for a period between 14 to 20 days. In addition to the 15-minute measured data, one time measurement of the maximum power consumption of a CPU (30 W) and a monitor (95 W) were also taken. The power-management feature was enabled on all PCs that were monitored. During the suspended mode of operation the power supply to the monitor is totally shut-off, but the CPU is still powered and consumes around 25 W. When the monitoring was initiated all PCs remained ON even during the unoccupied hours (7 p.m. to 8 a.m. on weekdays and all day on weekends). After the first two PC systems were monitored, the employees were told by management to turn OFF the computers during unoccupied hours. Therefore, two of the ten PC systems monitored remained in the suspended mode during the unoccupied hours on weekdays and all hours on weekends. Although none of the last eight PCs monitored remained on during the unoccupied hours or during weekends, management reports that occasionally a few PC systems were being left on at night.

## Energy Savings

A typical daily operating pattern of an ES-compliant PC at the office building is shown in Figure 3. The maximum total power consumption during normal operation is between 120 W to 130 W, with the CPU consuming between 25 W and 35 W and the monitor between 85 W and 95 W. To estimate the ''as-operated'' savings (described later in this section) from the ES-compliant PC systems, typical weekday profiles for the ten PC systems were developed from the monitored 15-minute interval data:

$$\text{profile}_i = \frac{\sum_{j=1}^{n} \text{load}_i(j)}{n}$$

where:

i = time of day
j = day number during monitoring period (separated by weekday and weekend)
n = total number of days monitored
Load = load of monitor, CPU, or total that is recorded by logger

Average hourly profiles for each of the ten ES-compliant PC systems are developed from the monitored 15-minute interval data and are shown in Figure 4. Note that the computers are usually turned on between 8 a.m. and 9 a.m. and turned off between 5 p.m. and 6 p.m., with exception of

***Figure 3.*** *Typical Profile of an ES-Compliant PC System at the Office Building*

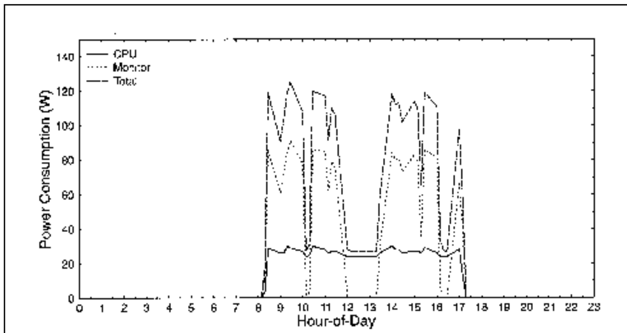
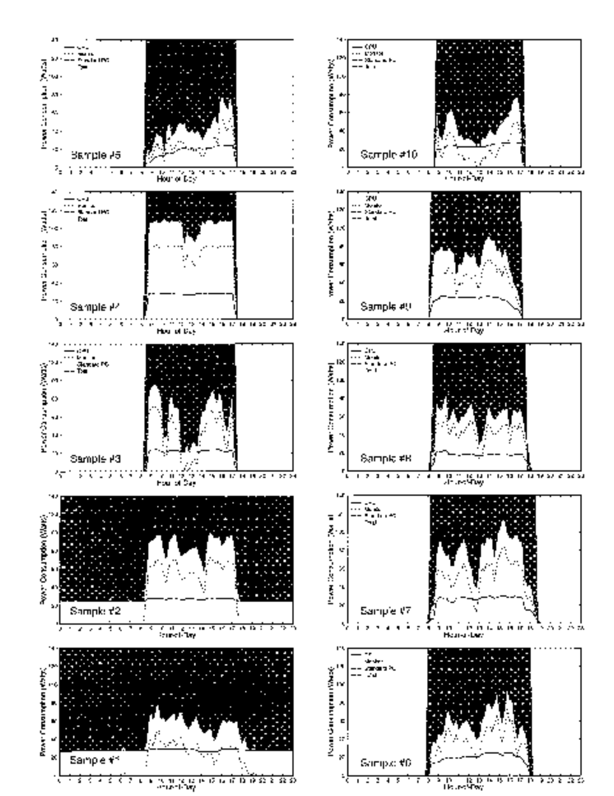



***Figure 4.*** *Average Hourly Profiles for the Ten ES-Compliant PC Systems Based on At Least Two Weeks of Monitored Data*



sample numbers 1 and 2. Also, most PC systems show reduced consumption during the lunch hour, between 12 p.m. and 1 p.m., and a maximum consumption between 3 p.m. and 4 p.m. (3:45 p.m.). Note that the power consumption of the CPU remains flat all day, except at startup or shut-down, because the difference between the Full-On (30 W) and suspended mode (25 W) operation is small. The tails at start-up and shut-down were caused because the PC systems are not turned ON/OFF at the same time every day during the monitoring period.

To estimate the savings from power-management feature of the ES-compliant computers at the office building, the consumption of the ES-compliant PC system is compared to that of a standard PC system. The maximum power consumption of the ES-compliant PC system at the office building is 125 W with the low-powered CPU consuming 30 W and the monitor consuming 95 W. In a standard PC system the CPU consumes about 45 W of power, while the monitor (17'') consumes 95 W. The power consumption of the standard PC system was estimated by monitoring one standard PC system at this office building and also based on previous field monitoring studies (Szydlowski & Chvála 1994; Tiller & Newsham 1993).

The energy savings from the power-management are calculated two different ways: (1) as-operated and (2) assuming that the PC systems are not turned off during the unoccupied hours (maximum-savings). While estimating the maximum savings, the daily profile for the ES-compliant PC system during the occupied hours is assumed to be similar to the as-operated case, but during the unoccupied hours it is assumed that the ES-compliant PC system is in a suspended mode and consumes about 25 W of power. Once the standard PC system is turned ON, it is assumed that it draws on average 140 W of power.

Table 2 shows both as-operated and maximum-savings (Wh/day) for each of the ten PC systems monitored. As noted in the previous section, the savings are estimated under the assumption that a standard PC system consumes 140 W. Also it is assumed that the standard PC system is turned ON/OFF at the same time the ES-compliant PC system is turned ON/OFF. The as-operated savings are also shown in Figure 4 (shaded portion). The average daily savings per PC system are 1007 Wh/day and 2,373 Wh/day, respectively, for as-operated and maximum-savings cases. The savings on a weekend for the ''maximum-savings'' case are 2,760 Wh/day ([140-25]*24). Note that the average daily consumption for the sampled PCs is 710 Wh/day.

Assuming that there are 210 working days in a year, the annual savings per PC in the ''as-operated'' mode are 211 kWh/yr and in the ''maximum-savings'' mode the annual savings per PC are 926 kWh/yr. The total annual energy savings at the office building from the 40 ES-compliant PCs in ''as-operated'' mode are 8,400 kWh/yr. The use of 210 days is based on the assumption that there are 261 weekdays in a year and of the 261 days approximately 20% of the days are assumed to be either holidays or absence days. The use of 20% is based on the previous work by (Szydolwski & Chvála 1994; Tiller & Newsham 1993; Piette et al. 1995).

***Table 2.*** *Average Daily Energy Consumption and Daily Savings for the ten ES-Compliant PC Systems (17'' Monitors) at the Office Building*

| Sample # | Actual Daily Energy Consumption (Wh) | As-Operated Daily Energy Savings (Wh) | Maximum Daily Energy Savings (Wh) |
|---|---|---|---|
| 1 | 960 | 2,399 | 2,399 |
| 2 | 1,150 | 2,209 | 2,209 |
| 3 | 557 | 702 | 2,421 |
| 4 | 980 | 279 | 2,080 |
| 5 | 393 | 866 | 2,584 |
| 6 | 671 | 763 | 2,423 |
| 7 | 786 | 683 | 2,231 |
| 8 | 577 | 717 | 2,425 |
| 9 | 638 | 621 | 2,372 |
| 10 | 388 | 836 | 2,585 |
| average | 710 | 1,007 | 2,373 |

The 211 kWh/yr energy-savings estimate per ES-complaint PC system at the ACT$^2$ office building compares well with the 200 kWh/yr energy-savings under standard operating schedule reported by the Nordman et al. (1996). EPA estimates that the annual cost for operating a standard PC system 24 hours per day and 365 days a year is about $105 (http://www.epa.gov/docs/GCDOAR/esc-home.html#how). This estimate is based on the assumption that a typical PC system (CPU and monitor) consumes 150 W of power at an energy cost of $0.08/kWh. With the same energy cost it estimates that the ES-compliant PC system costs about $47 to operate year round. Therefore, the maximum-savings are about $58 or 725 kWh/yr. This is slightly lower than the estimate from the ACT$^2$ office building (926 kWh/yr).

## Demand Reduction

To estimate the demand reduction from the use of ES-compliant PC systems, an average demand profile is estimated for the ten PC systems:

$$\text{average profile}_i = \frac{\sum_{k=1}^{m} \text{profile}_i(k)}{n}$$

where:

k = computer number
n = total number of computers monitored
$\text{profile}_i$ = typical weekday profile

The mean and the standard deviation at each 15-minute interval during the occupied hour are shown in Figure 5. Figure 6 shows the normalized power consumption profile. The normalized power is defined as the ratio of the average demand profile to demand profile of a standard PC (140 W). Note the drop in demand during the lunch period (between 12:30 p.m. and 1 p.m.) and increase in demand at 3:45 p.m. The total demand reduction at this site from the ES-compliant PC systems is estimated by multiplying normalized power by the total number of ES-compliant PC systems. The total estimated demand reduction at various times-of-day from the 40 ES-compliant PC systems is shown in Table 3. Although the demand reduction from the ES-compliant PC systems is presented here, it should be noted that the standard deviation is high (30 W).

*Figure 5. Mean and Standard Deviation at Each 15-Minute Interval During the Occupied Hours for the Ten ES-Compliant PC Systems*

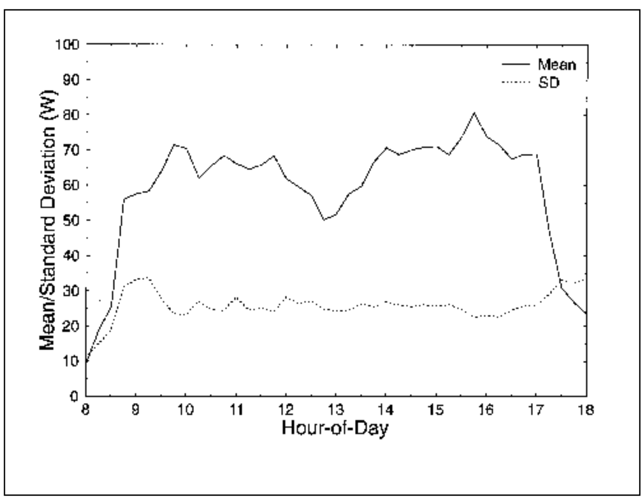



*Figure 6. Normalized Power Consumption Profile for the ES-Compliant PC Systems at the Office Building*

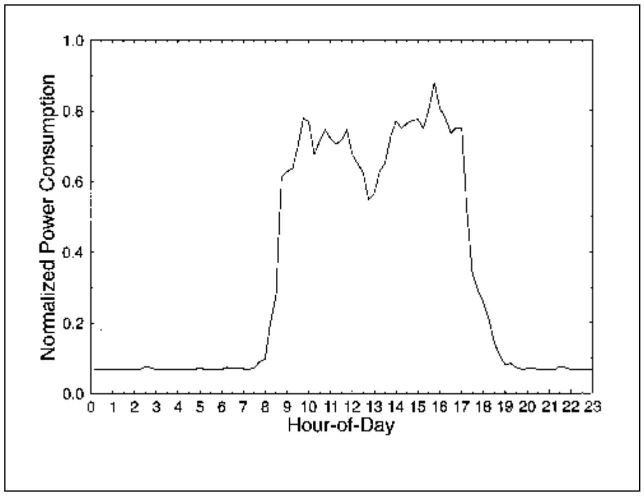



*Table 3. Estimated Demand Reduction from 40 ES-Compliant PC Systems at the Office Building*

| Demand Reduction (kW) | | | |
|---|---|---|---|
| 8–9 a.m. | 3–4 p.m. | 5–6 p.m. | 7–8 p.m. |
| 3.34 | 2.28 | 2.80 | 5.28 |

# CONCLUSIONS

The main objective of the $ACT^2$ project of achieving maximum energy savings possible, at or below projected competitive costs, by using modern high-efficiency end-use technologies in integrated packages has been achieved at this office building. The ES-compliant computers at the office building have been in use for over two years (since June 1994) and there have been no user complaints. The office building, by using the ES-compliant PC systems, is saving about 211 kWh/yr per PC systems which amounts to a total of 8,440 kWh/yr (40 PC systems). Almost all the savings in energy and demand reduction are due to the monitors. This savings represents a 59% reduction in PC systems energy consumption at this building. The maximum savings per PC system at this building are 926 kWh/yr compared to a EPA's estimate of 725 kWh/yr per PC system.

One question that is still unanswered, and which requires further research, is what fraction of the ES-compliant PC systems, in the total populations, is the power-management feature turned ON to successfully save energy and dollars ?

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