Energy Efficiency of Electronic Office Equipment: Case Study for a Building Retrofit

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In 1990, a major California utility selected a San Francisco-based energy consulting and design firm to develop a design for maximum energy efficiency in an existing office building in San Ramon, California. This was the pilot demonstration of the Advanced Customer Technology Test (ACT^2) for Maximum Energy Efficiency project. One challenge of this pilot project was to prepare the design component for electronic office equipment.

To the author's knowledge, this is the first case study of this kind ever done. Despite the availability of a significant amount of data and detailed documentation on technologies and their energy intensity, as well as some studies on office equipment energy demand, we have been unable to find any previous published applications of energy efficiency measures to a real office space, using monitored data on equipment use. Therefore, we had to develop strategies and methods to evaluate our project's design options, to monitor installed and replacement equipment, and to calculate annual energy savings.

We designed energy conservation measures and calculated the energy savings for the copiers and the laser printers. We also investigated energy efficiency options for the computers. Even though most of the office equipment is turned off at night and when not in use, the amount of achievable energy savings resulting from the design options is surprisingly high. Annual energy savings of 40 to 70 percent for the copiers and 40 to 80 percent for the laser printers can be achieved. Energy-efficient desktop computers or laptops can save 65 to 90 percent of the load of the existing energy-intensive machines. This paper presents an overview of our design process and findings for these three types of equipment.

Introduction

In 1990, a major California utility selected a San Francisco-based energy consulting and design firm to perform a maximum energy efficiency design in an existing office building in San Ramon, California. This was the pilot demonstration of the Advanced Customer Technology Test (ACT^2) for Maximum Energy Efficiency project. One challenge of this pilot demonstration project was the design component for the electronic office equipment.

Plug loads in the office space account for 78,000 kWh of annual electricity consumption according to the base case DOE-2 model simulation that was provided to the designers. It is 15 percent of the total electricity consumption, equal to the ceiling lighting load. Plug loads include personal computers, printers, copy machines, task lighting, video equipment, and other miscellaneous equipment.

Monitoring data show a plug load peak of 20 kW. This is equivalent to 1 W per square foot and represents the low end of a typical range for an office building.[1] Considering the high volume of electronic equipment installed in the area, this might suggest that equipment use is low (more than 110 microcomputers, 39 laser printers and four copiers are installed in the office space, for 90 employees). Higher equipment use would increase the annual energy demand of the plug loads, which already equals the lighting load. This case study demonstrates how significant plug loads add to the energy intensity of an office building and, therefore, how important it is to consider energy efficiency measures for electronic office equipment in any energy efficiency audit or design.

Available office equipment monitoring data aggregate different types of equipment. Because electronic equipment nameplate wattage does not represent mean wattage used, we could not rely on the nameplate readings included in the equipment inventory. Therefore, we had to collect additional monitoring data to calculate the energy savings of our design options.

We measured the load of task lights, computers, copiers, and printers, which we believe should represent most of the plug loads. The design of energy efficiency measures for task lighting is part of the project lighting design and is not presented in this paper.

We developed a set of main design criteria for screening energy efficiency measures. Our criteria were technical specifications/performance of existing equipment, output quality of imaging technologies, reliability of equipment, user acceptance, and cost-effectiveness.

The following sections present our design options, methods, and results for the copiers, laser printers, and computers.

Copiers

Four copiers are located in the office area. Three are desktop machines, rated at 20 copies per minute (cpm), and the fourth is a significantly larger, floor-mounted machine installed in a copy room and rated at 85 cpm.

Product Research and Design Options

To design energy efficiency measures, we first explored other imaging and fusing methods. We looked at potentially energy-efficient methods such as ion deposition, chemical cold fusing, preheat platens, and a cold pressure fusing process. None of these methods has been applied to 20-cpm or 85-cpm copier equipment. In addition, cold pressure fusing copiers, developed in the early 1980s, have been discontinued by the manufacturers because of output quality problems inherent in the process.

Therefore, only two design options were available: (1) replacement of existing copiers with copiers using the same imaging and fusing technologies but less energy intensive, and (2) the use of an energy-saver timer feature. No additional control systems were considered because the machines are already turned off at night and stay off during weekends and holidays.

We selected four copiers as possible replacements for the 20-cpm machine. Within the rated speed range of large copiers (85-cpm), the choice of a replacement copier was limited to two machines (one 80-cpm and one 90-cpm copier).

Load Model

Power consumption of copiers is difficult to measure and characterize. Usually four kinds of energy use are distinguished: plug-in energy, warm-up energy, standby energy, and copying energy.[2] If an energy-saver timer was available, we also characterized the energy use when the copier is in energy-saver mode or sleep mode. We call this energy use "energy-saver energy."

In each mode, the power usage shows significant oscillations or transients; therefore, energy demand is sensitive to the length of the measuring period. Energy demands are also sensitive to ambient conditions such as temperature and humidity.

To calculate the annual energy savings of replacing an existing copier and to evaluate the energy savings associated with the use of an energy-saver timer, it was necessary to design a method that reproduces the annual energy consumption of a copier based on the equipment characteristics, parameters of machine use, and the ambient conditions.

The author developed a microcomputer spreadsheet-based method, or model, that simulates 5-minute or 30-minute load profiles for a typical weekday and a typical weekend/holiday day. Five-minute load profiles were used for the 20-cpm copiers, and a 30-minute load profile was used for the 85-cpm copier because 30-minute data were the only monitoring data available. However, 30-minute monitoring data cannot provide sufficient information to evaluate accurately the load impact of using an energy-saver timer set on 30-minute idle time (the setting assumption used in our design).

Data Used and Produced by the Model. The model is designed from the following installed copier data:

- Minimum of nine days (one week plus two weekends) of 5-minute load monitoring data (30-minute data were used for the 85-cpm copier)
- Daily counter readings (number of copies per day) and time of reading
- Measured plug-in energy (plug-in energy can also be read easily from the monitoring data), standby energy, copying energy
- Measured first-page speed and second-and-following pages speed
- Annual average of copies produced.

The model uses the following input data for simulating the load of a replacement machine:

- Plug-in energy, warm-up energy, standby energy, copying energy, and energy-saver energy (when applicable)

- First-page speed and second-and-following pages speed
- Warm-up time.

The model produces the following output data:

- Load profile of a typical weekday and a typical weekend/holiday day without the use of the energy-saver timer and with the use of the energy-saver timer set on 30-minutes idle time (when applicable)
- Resulting annual energy consumption.

Model Description. The model is designed in three steps:

- Development of production profiles (number of copies made) of weekdays and weekend/holiday days from monitoring data
- Development of load profiles for a typical weekday and a typical weekend/holiday day from production profiles and copier load data, and calculation of annual energy consumption
- Analysis of idle times over the monitoring period and calculation of energy-saver timer savings.

Data Collection

The electrical loads of the 20-cpm copiers were monitored for 9 to 12 days. The collected load data were averages of 5-minute intervals. The load of the 85-cpm copier is permanently monitored as part of the building monitoring program. The collected load data were averages of 30-minute intervals. We used two weeks of data in the model.

The existing machines and all prospective replacement machines also were tested independently for power consumption. Power was recorded for the following modes: printing of 50 pages for the 85-cpm copier (20 pages for the 20-cpm copiers), 30 minutes in standby mode, 5 minutes in plug-in mode, and 15 minutes in energy-saver mode (when applicable). The power consumption results are shown in Table 1.

The installed copiers and their prospective replacements also were tested for speed. The time to produce the first page (single-sided copy, original placed in the automatic document feeder) was measured. The speed to produce the second-and-following pages also was calculated. The calculation integrates the time measurement to produce 50 pages from an original document of 50 pages (one copy, single-sided pages, document placed in automatic document feeder) and the first-page speed from the previous measure. The speed results are shown in Table 2.

Energy Savings Results

The annual energy consumption of each replacement copier was calculated using the load model.

Among the four replacement machines for the 20-cpm copiers, one model achieves annual energy savings of 70 percent, and 75 percent when the energy-saver timer is used and set on 30-minute idle time. (Existing equipment annually consumes 750–780 kWh per machine; the replacement model is projected to consume 190 kWh with the energy-saver timer on.)

Replacing the 85-cpm copier with the 80-cpm machine achieves annual energy savings of 60 percent. The use of a 90-cpm copier shows annual energy savings of 45 percent. Because the monitoring load data were 30-minute data for the 85-cpm copier, it was not possible accurately to calculate the additional savings created by the energy-saver timer. (The existing 85-cpm copier annually consumes 3,470 kWh; the 80-cpm replacement is projected to consume 1,420 kWh, and the 90-cpm replacement, 1,900 kWh.)

Laser Printers

Thirty-nine laser printers are installed in the office space. They are typical desktop machines, each equipped with a 4-to-8-page-per-minute engine. Eight serve Macintosh microcomputers and 31 serve IBM-compatible microcomputers (PCs). PCs are connected on a Banyan local area network, but only two of the PC laser printers are shared on the network. Macintoshes are connected on Appletalk.

Product Research and Design Options

We designed two types of energy-efficiency measures: control of the laser printers and replacement of dedicated laser printers with fewer, networked printers. Both types of measures can be combined.

Five laser printers stay on 24 hours per day. One control measure is the use of either a direct digital control (DDC) system or a simple timer to shut down these printers at

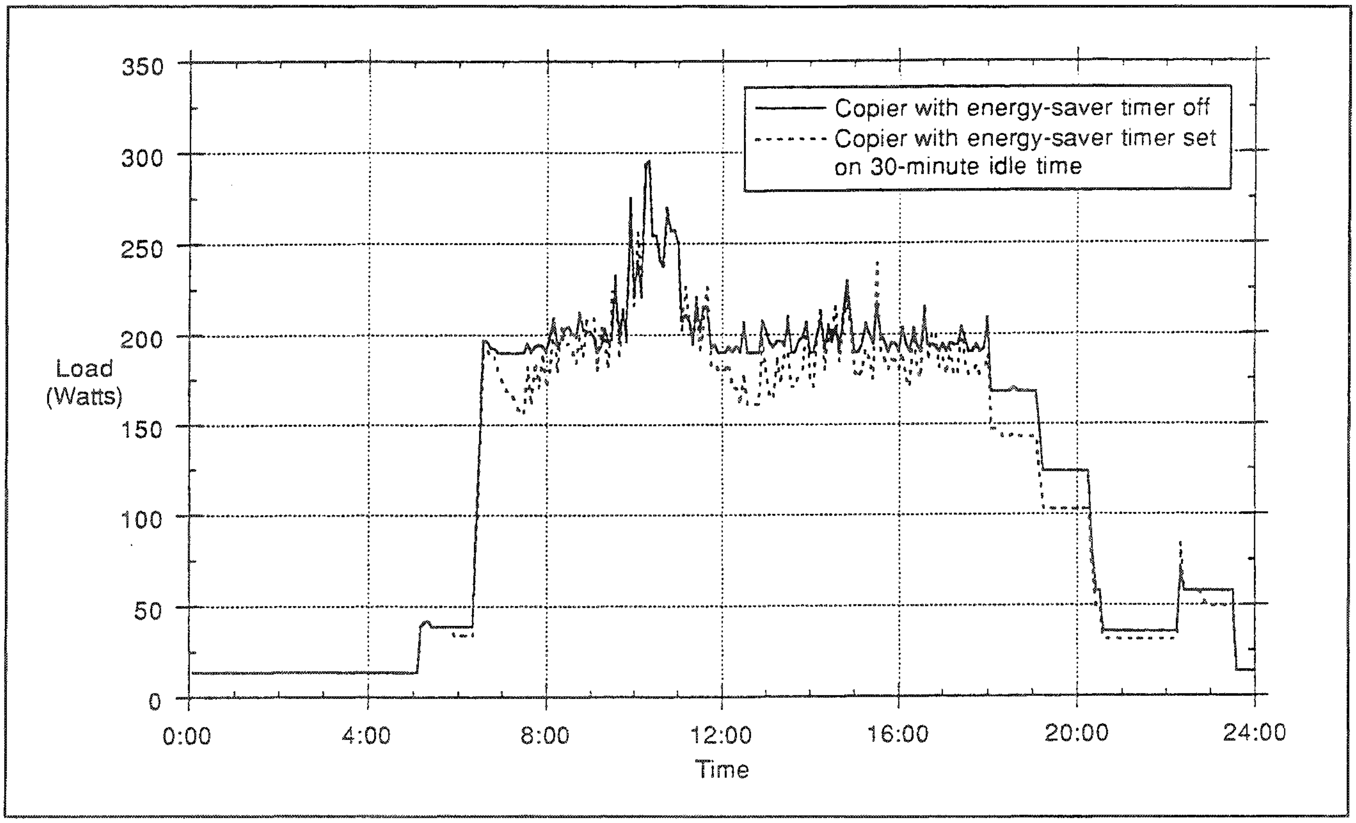

Figure 1. Example of Copier Weekday Load Profiles Generated by the Model (Copier with Energy-Saver Timer On and Off)

night and on weekends/holidays. A DDC system is preferable because it is easier for a user to remotely switch on a printer (using a dial-in system, for example) when needed, than to manually switch it on.

Another control measure is to use a printer with a built-in control system that partially shuts down the machine after a set idle time. Compared to the previous measure, this feature offers the advantages of additional energy savings during working hours when the machine idles. The machine automatically restarts when a print job is sent. Like the copiers, the printer goes through a warm-up mode after each sleep mode and before printing. The warm-up time can slow the printing process if the printer time to process the data is shorter than the warm-up time.

Only two manufacturers, which both use the same printer engine, have equipped their models with such a built-in control system. The idle time can be set at 1 or 8 minutes for one brand and at 2, 4, 6, or 8 minutes for the other. The control system also can be turned off for all machines. We measured the warm-up time for one model. After 30 minutes of sleep mode, the warm-up time was 32 seconds.

We asked the two major manufacturers of laser printers, whose equipment currently comprises 87 percent of the printers in the office space, if they could retrofit existing printers with a similar control system or if they were thinking of introducing such a feature in their future products. Their responses were either negative or inconclusive enough to be considered negative. The author believes it would be comparatively easy for at least one manufacturer to introduce a control system in its laser printers because this system already exists in one of its laser facsimile machines that uses the same engine.

Another energy-efficiency measure is to reduce the total number of printers (31 dedicated for PCs, two networked for PCs, and 8 for Macintoshes) by replacing the current machines with fewer, networked printers. Our analysis of the current printing production shows that three networked printers in the office space are enough to handle the daily volume. The prints from the PCs and the Macintoshes have been aggregated in this calculation. Because only three printers in 20,000 square feet of office space would

Table 1. Copier Power Consumption Test (Watts)

20 cpm Copiers		
Copier Mode	Installed Copiers	Replacement Copiers
Printing	712-910	354-674
Standby	160-179	65-119
Warming up	720-789	229-720
Plug-in	0-30	0-3
Energy-saver	135-172	26-49
80-90 cpm Copiers		
Copier Mode	Installed Copier	Replacement Copiers
Printing	4183	1341-2425
Standby	468	203-349
Warming up	2009	1005-1451
Plug-in	0	0-48
Energy-saver	n/a	146-192

be too far from many users, we calculated the savings associated with the replacement of the current 39 machines with 6, 8, or 10 networked printers.

The final number of networked printers will be dependent upon the office manager's decision (based on acceptability to users) and the capability of the printers to share input from the two computer operating systems (through the printers themselves or through the network interfaces). Existing dedicated printers can be used as networked printers (and upgraded if additional capabilities or features are needed), or new printers with built-in control systems can be purchased.

Because of our concern about user acceptance, even if 6 to 10 networked printers exceed the system production needs, we proposed offering bubble-jet dedicated printers to the users. Bubble-jet printers are very energy-efficient (a common machine was tested at 3 W average standby load and 10 W average printing load); however, they are

Table 2. Copier Speed Test (seconds per page)

20 cpm Copiers		
	Installed Copiers	Replacement Copiers
First page	712-910	354-674
Following pages	160-179	65-119
80-90 cpm Copiers		
	Installed Copiers	Replacement Copiers
First page	4183	1341-2425
Following pages	468	203-349

slower than laser printers and their output quality is not quite as good.[3] Users of dedicated printers may sacrifice speed and a slight level of quality for the ease of getting prints at their desks. Also, using dedicated bubble-jet printers reduces the load on the network, improving its performance. A drawback of the bubble-jet printers, however, is the high cost of their ink cartridges, compared to the toner cartridges used in the laser printers.

Data Collection

We collected 15 days of load data for six laser printers and the number of pages printed during one week for each of 28 laser printers. We also conducted a weekend survey to evaluate office equipment that stays on. The monitoring data were consistent with the survey.

We also tested laser printers for power consumption using the same equipment that was used for testing the copiers. We measured each machine's standby power for 30 to 45 minutes and printing power for 3 to 6 minutes. For one replacement model equipped with an energy-saver timer, we also measured sleep mode power for 30 minutes and warm-up power.

Significant differences were found between models: measurements show a printing load range of 113–241 W, a standby load range of 36–119 W, and a sleep mode load range of 7–18 W.

Additionally, we surveyed the use of dot matrix printers, which are located in some offices of the building. The power demand of a dot matrix printer is low enough to be disregarded. The survey was conducted to help identify issues that could affect personnel acceptance of the laser printer's energy efficiency options. The results of the survey show that a low volume of prints is produced by the dot matrix machines. The main reasons to use the dot matrix printers are the proximity of the printer (especially for easier manual feeding), the load of the current network (considered too busy), and the ability of the dot matrix printers to handle large paper. One conclusion of this survey is that staff would appreciate networked printers equipped with multiple trays handling different paper types.

Energy Savings Results

Because only a sample of laser printers was monitored, the development of an accurate load model to simulate the load of monitored printers (similar to the copier model) would not have been useful for calculating the energy impact of our design options. We used available data and made additional reasonable assumptions to calculate energy savings. The savings are presented in Table 3.

In summary, control of the laser printers reduces the total laser printer energy consumption by 40 to 65 percent. Forty percent of the energy consumed by the 39 printers can be saved simply by using a DDC system or a simple timer to control the five printers that stay on 24 hours per day. Energy savings of 65 percent can be achieved by replacing the 39 machines with printers that have built-in control systems and setting the systems to a 1-minute idle time.

Replacing the current laser printers with 6 to 10 networked machines provides energy savings of 55 to 80 percent. Energy savings of 55 to 75 percent can be achieved if the existing printers are used as networked printers and if they are controlled at night and on weekends/holidays. Energy savings of 60 to 70 percent can be achieved if printers with built-in control systems are used as networked printers with the control systems set on 1-minute idle time and if no additional external control systems are used. With the addition of an external control system to shut down the printers at night and on weekends/holidays, 80 percent savings can be achieved.

If, in addition to the previous measure, users select the option of having dedicated bubble-jet printers, the previous energy savings will decrease. The additional load of using bubble-jet printers has been calculated as 3 to 7 percent of the existing laser printers' energy consumption.

Computers

Currently, there are more than 110 desktop microcomputers in the office space. Some employees have two computers on their desks, usually one Macintosh and one IBM-compatible. In November 1990, one quarter of the machines were Macintoshes and three quarters were IBM-compatible, in a broad range of brands and models. Since we started our design work, we have observed that computer equipment frequently is replaced. In particular, black and white monitors are quickly replaced with color monitors.

Data Collection

Because the power consumption of desktop computers is relatively steady, energy savings are easier to calculate than for imaging technologies (copiers and printers).[4] We monitored 15 days of load for nine computers. We also conducted a three-day walk-through survey to monitor equipment on-time. From these data we established an hourly load factor profile and a profile of machines on during a weekday.

We tested the power consumption of more than 30 models of desktop computers and their monitors. In our office, we also tested a notebook computer.

Design Options and Results

We investigated several ways to reduce computer energy consumption in the office space. Each is discussed below. Power savings are presented for each options. Because of the relatively steady power consumption of computers, energy and power savings are comparable in percentage (except for laptop or notebook computers that have a sleep mode feature).

Energy-Efficient Power Supplies. One option we explored is replacement of the approximately 60-percent efficient power supplies with power supplies that are 85–90 percent efficient (a reduction of approximately 30 percent in power demand). Such energy-efficient power supplies were not commercially available at the time of this study but can be produced, according one designer.[5] Although producing new power supplies to retrofit the building's existing computers is not cost-effective, this option is viable when producing new computers on a larger scale.

Table 3. Energy Savings for the Laser Printers

Energy Conservation Measures	Annual Energy Savings[a] (kWh)
• Control of the five printers that are on 24 hrs/day	2,451 (40%)
• Replacement of the existing laser printers with printers equipped with built-in control systems[b]	4,035 (66%)
• Replacement of existing laser printers with:	
- 6 networked printers that are on a DDC system	4,473 (73%)
- 8 networked printers that are on a DDC system	3,973 (65%)
- 10 networked printers that are on a DDC system	3,473 (57%)
• Replacement of existing laser printers with:	
- 6 networked built-in controlled printers[b]	4,411 (72%)
- 8 networked built-in controlled printers[b]	4,096 (67%)
- 10 networked built-in controlled printers[b]	3,781 (62%)
• Replacement of existing laser printers with:	
- 6 networked built-in controlled printers that are on a DDC system[b]	5,020 (82%)
- 8 networked built-in controlled printers that are on a DDC system[b]	4,907 (81%)
- 10 networked built-in controlled printers that are on a DDC system[b]	4,795 (79%)
• Additional dedicated bubble-jet printers for:	
- 37 users	-168 (-3%)
- 45 users	-212 (-3%)
- 90 users (whole staff)	-401 (-7%)

(a) Currently, the 39 laser printers in the office space annually consume 6,094 kWh. The annual energy savings shown in the table do not include any incremental HVAC savings.
(b) Built-in control systems set at 1-minute idle time.

Energy-Efficient Desktop Computers. A second option is to replace existing computers with less energy-intensive models. We have measured a new 386SXcomputer with a VGA color monitor at 79 W versus 255 W for the most energy-intensive comparable model in the office.

Another promising way to reduce the energy consumption of desktop computers is to use a software/hardware control system that partially shuts down the computer during machine idling time. A single keystroke revives the machine without any other interventions of the user. Such control systems already exist for battery operable portable computers and we understand that some research institutions are developing and testing a prototype designed for a desktop computer.

Another option we investigated is replacement of the monitor only. Among the CRT monitors we tested, the least energy-intensive was measured at 37 W and the most energy intensive was 133 W. Also, energy-efficient flat-screen LCD monitors increasingly are available as a stand-alone units and, according to many experts, may be available in color in the near future. If concerns increase about the health risks of emissions from standard CRT monitors, there may be an additional incentive to use the LCD screens.

Laptop/Notebook Computers. Another option is to replace desktop computers with laptop/notebook computers while providing at least the same computing power and performance. Laptops (we use the word as a generic term for both laptop and notebook types of computers) are the most energy-efficient computers available today, using one to one-and-one-half orders of magnitude less energy than desktop computers of comparable performance. They are distinguished from other types of portable computers by their ability to operate on battery power. To achieve the longest possible battery life, considerable research has gone into the development of extremely efficient computer hardware and software.

The laptop computer we tested uses less than 10 W of power while active and about 1 W in suspend mode. If it replaces an entire desktop computer (CPU + monitor), such a machine will save an average of about 100 W.

Laptops can be used as replacements for entire existing desktop computers or as replacements for the CPU alone. The maximum amount of energy is saved by replacing the entire desktop computer, but laptop monitors may be unsatisfactory to many users. The monitors currently available on laptop computers are not acceptable to many people because of their small size, the available refresh rate, and the high cost and limited choice of color screens. Similarly, keyboards on laptops are small and often cramped, with numeric keypads either embedded in the alpha keyboard or plugged into one of the computer's ports as a separate option. The components of a laptop cannot be separated, except in a few cases where the keyboard can be detached from the main unit. For users who prefer to place their monitors at eye level or in a specific location, this arrangement may be unacceptable. An option is to use laptops in place of existing desktop CPUs while retaining the existing monitors and keyboards.

High-quality color LCD monitors are available in two brands of laptops. For users who accept the LCD monitor, the laptop can be mounted on a swing-arm device with a separate full-sized keyboard for use at desk level. Separate LCD monitors are available (monochrome only at the time of this project) but their quality is not superior to that available in laptops.

In addition to the reduction in energy consumption, laptops have the advantage of portability. Staff personnel who travel or who occasionally work at home, will appreciate the convenience of a laptop. Additionally, files will not need to be transferred to diskettes for transportation to a separate home computer.

Because of the need to meet or exceed the performance of the existing computers, we have developed the following list of criteria, in addition to specific user needs, which we feel must be met by the replacement laptop computers:

- 386SX minimum, unless the 286 is acceptable to user
- External keyboard port
- External monitor port (VGA)
- Expansion chassis or station
- Serial port
- Parallel port
- Networkable
- Battery operable.

Each user may have specific needs that will influence his/her choice of a laptop. Typically, only three expansion slots are available in a laptop expansion chassis or station. Machines whose users require more than three expansion cards will not be good candidates for replacement (unless some of the features that now require cards come as standard features on laptops).

Conclusion

For this case study, considering that most office equipment is turned off at night and when not in use, the amount of achievable energy savings resulting from our design options is surprising. Using commercially available copiers and printers to replace existing equipment, energy savings of 40 to 80 percent can be achieved. Our measurements also show that some desktop computers are one third as energy intensive as others in their performance range.

The energy-efficient electronic office equipment that we reviewed is not designed and marketed for its energy efficiency, mainly because there is no driving force to do. Energy-efficient equipment also is no more expensive than energy-intensive equipment (with the exception of a laptop computer when compared to a desktop model).

Because electronic office equipment is generally expensive and does not last very long, even large energy savings cannot economically justify the replacement of a machine that is not obsolete. However, there is no additional cost of choosing energy-efficient equipment when it is time to purchase a new machine or to replace an obsolete one.

We believe that the results provided in this study can motivate corporations to equip their offices with available energy-efficient office equipment, thereby contributing to the creation of the necessary driving forces for further development of such products. Additionally, the information generated in this study exemplifies the need for:

- Information about energy use of office equipment (instead of misleading nameplate power ratings)
- Energy policy measures directed towards the energy efficiency of office equipment.

Acknowledgments

The study described in this paper was funded by Pacific Gas and Electric Company (PG&E), Research and Development, under contract No. Z-19-2-045-91. The opinions, findings, conclusions, and recommendations expressed herein are solely those of the author and do not necessarily reflect the view of PG&E.

We would like to thank Jeff Harris at the U.S. Department of Energy/Lawrence Berkeley Laboratory; Mary Ann Piette and Steve Greenberg at Lawrence Berkeley Laboratory; Les Norford at Massachusetts Institute of Technology; Steve Blanc, Grant Brohard, and Lance Elberling at PG&E Research and Development; Amory Lovins at the Rocky Mountain Institute; and Jacques Roturier at the University of Bordeaux (France) for providing technical information, data collection, and equipment.

Endnotes

1. Harris et al. estimate that typical daytime load for electronics in typical new office buildings, averaging highly computer-intensive occupancies with more normal ones, are closer to 10–20 W/m^2 than the 30–50 W/m^2 often cited.
2. The American Society for Testing and Materials adds a fifth kind of energy use--machine energy--that is the energy used when the copier is plugged in 24 hours per day and turned on 9 hours per day but not making copies. Therefore, machine energy is a combination of the plug-in energy and standby energy.
3. Inkjet printers were tested by Harris for power consumption. 1990. Competitek.
4. Our measurements show a slight increase of the power consumption when a floppy drive is operating (i.e., a floppy disk is spinning). Otherwise the load is relatively constant, whether or not data are being processed.
5. Steve Stevens, SLP/Calmont Power Supplies. These power supplies also are designed to increase the power factor, thereby saving additional energy at the power plant.

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