Title
Technology Assessment: Electronic Office Equipment

Authors
Harris, J.P.
Roturier, J.
Norford, L.K.
et al.

Publication Date
1988-11-01

LBL-25558 Rev.
UC-405

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

**Technology Assessment:
Electronic Office Equipment**

J. Harris, J. Roturier,
L.K. Norford, and A. Rabl

November 1988

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

LBL-25558
(rev. 11/88)

TECHNOLOGY ASSESSMENT: ELECTRONIC OFFICE EQUIPMENT†

J. Harris and J. Roturier††
Applied Science Division
Lawrence Berkeley Laboratory
One Cyclotron Road
Berkeley, California 94720

L.K. Norford and A. Rabl
Center for Energy and Environmental Studies
Princeton University

November 1988

† This work was supported in part by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, of the U.S. Department of Energy under Contract No. DE-AC0376SF00098. Collaborating researchers at Princeton University's Center for Energy and Environmental Studies were supported by funding from the New Jersey gas and electric utilities through the New Jersey Energy Conservation Laboratory, by the Prudential Insurance Co., and by the New Jersey Department of Commerce and Economic Development. Partial support was also provided by the French Energy Agency (AFME) under contract #6-09-0118.

An earlier version of portions of this paper was presented at the ACEEE Summer Study on Energy Efficiency in Buildings, August 1988, Pacific Grove, California. This material will also appear, in revised form, in the proceedings of the Swedish Power Council conference on future electricity technologies, Lund, Sweden, May 1989.

†† Institute of Technology, U. of Bordeaux; sabbatical visitor at LBL, 1986-87.

ABSTRACT

Electronic office equipment represents a fast-growing but poorly understood component of the "other" end use in commercial buildings. We analyzed technical data and market projections to characterize the electricity usage and efficiency potential for this equipment. There were no published data on actual power consumption of office equipment, so we metered selected pieces of equipment, for comparison with nameplate ratings. Measured power use was typically 20-40% of nameplate ratings. Power use varies for similar equipment; in particular, desktop PCs use about ten times the power of equivalent laptop models. Typical daytime loads for office equipment are about 10-20 W/m^2, roughly equal to lighting loads in a well-designed new office. Future load growth depends on many market and technical factors; U.S. office equipment electricity use in 1995 could range from 130 TWh ("market saturation" of current technology with expanded use of computerized printing), to about 25 TWh if today's most efficient hardware and operating systems became the market norm.

PREFACE

This report, one of a series of end-use energy technology assessment studies by Lawrence Berkeley Laboratory (LBL), examines the available data on energy use and efficiency opportunities for electronic office equipment. The aim of these end-use technology assessment studies is to synthesize current information from both published and unpublished sources so that utilities, state regulatory commissions, energy planners, and others can better identify, evaluate, and select demand-side resources to meet their needs. In addition, we identify important data gaps and, where possible, reconcile differences among data sources. This study was undertaken in cooperation with researchers from Princeton University and the University of Bordeaux. The report is designed to be updated in the future, as the technology continues to develop and better data become available.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the following individuals who provided us with data and other assistance in preparing this report: S. Taylor, Linford Engineering; E. Westman and F. Peterson, Bonneville Power Admin.; R. Alereza, Calif. Energy Commission; P. Black, H. Otten, and S. Greenberg, Univ. of Calif.; N. Mueller, Wisconsin Power and Light; R. Lucas, Battelle Pacific Northwest Labs; and W. Thomas, IBM. Special thanks are due to J. Spadaro and P. Curtiss of the Princeton Center for Energy and Environmental Studies, and to Bruce Nordman and Wilson Lai of LBL, for their help with detailed measurements of equipment power requirements and analysis of data on computer network usage and equipment inventories.

Table of Contents

List of Tables and Figures

1.0 SUMMARY AND KEY FINDINGS

Although it has received little or no attention in most energy studies, the "other" end-use category represents up to 25% of electricity use in new U.S. office buildings. Office electronic equipment, including mainframe and personal computers, peripherals, copy machines, and communications equipment, may account for 5 to 20% of daytime electrical loads in new offices and is one of the fastest-growing components of commercial sector electricity use and peak demand. Electronic office equipment, has become more than just one element of the "other" end use in commercial buildings; it now merits recognition as a distinct end use, based on its aggregate energy consumption, contribution to peak demand growth, and potential for improved energy efficiency.

Some major findings from this study are:

- Actual electric loads for the office equipment we measured were typically 20-40% of nameplate ratings; accordingly, energy analyses based on nameplate ratings greatly overstate actual power use.
- Daily load profiles and on-peak diversity factors seem to vary by type of equipment and by office scheduling practices; more detailed, measured data are needed.
- Smaller-scale, dispersed computers and other equipment (small copiers, etc.) have been gaining market share from large, centralized systems. This trend, if it continues, may affect: (1) market penetration among smaller buildings and firms, and (2) management strategies for thermal loads that are dispersed throughout the occupied space. However, the shift to smaller-scale computers may have little impact on overall energy use for office information services. This is because:
- Input/output devices (terminals, printers, scanners, fax machines and other communications equipment), not computing and data storage equipment itself, are often the major users of power and the largest source of load growth and uncertainty.
- There is significant potential for improving energy efficiency in both hardware and software, often as a consequence of other objectives such as miniaturization. Several policy options could accelerate these market and technical trends.
- Without accurate data, both building designers and energy demand forecasters may now tend to overestimate office electronics loads, perhaps in reaction to previous underestimates. Extrapolating from limited data, we estimate that typical daytime loads for office electronics (where present) in today's newly built U.S. offices are closer to 10-20 W/m^2, rather than the 30-50 W/m^2 sometimes cited.
- Future load growth depends on: (1) increased saturation of equipment and functions (more users of computers and related equipment); (2) changes in usage and "levels of service" (increased computing power and data storage, higher-resolution screens, laser printing, color output, etc.); and (3) improved energy efficiency for a given level of service (more efficient chips and screens, better software control of idling equipment, etc.). Ultimately, office electronics may reduce other energy use for hard-copy production and distribution, business travel, commuting, etc.
- A recent EPRI report estimates 124 TWh of *added* electricity use for electronic office equipment in U.S. buildings, between 1982 and the mid-1990s. We believe that this

estimate is at the high end of a range of possibilities.

- Our alternative order-of-magnitude estimate, at first assuming saturation of the market with office automation equipment based on today's technology and patterns of use, suggests *total* electricity consumption of 115 TWh by 1995. However, technical improvements in hardware and operating systems, based on technology already available but not widely used, could reduce this by a factor of about 5, to 20-25 TWh—roughly the same as today's energy use.
- In the longer term, better integrated inter- and intra-office electronic communications may bring us closer to the long-predicted "paperless office," with major impacts on both energy use and office workforce productivity.

2.0 TECHNOLOGY OVERVIEW

2.1 Background

Since the 1973 energy crisis the efficiency of energy use in buildings, factories, cars, and appliances has continued to improve, as has our ability to quantify the details of energy end use. Yet virtually all energy use studies and energy conservation programs leave an unexamined residual category, called "miscellaneous" or "other." This may include commercial buildings with diverse or mixed occupancy, structures that are unusual or highly specialized, and a large variety of energy-using equipment. Once an end use (or, for that matter, an entire class of buildings) has been relegated to this "other" category, little effort is made to examine it further or to analyze opportunities for improving energy efficiency. This omission is a serious one, since the "other" category can represent 20-25 percent (or more) of total energy use in a commercial building (Piette, 1986). An exploratory study of the "other" end use in the residential sector yielded an estimate of similar magnitude (Meier, 1987).

Of special interest among the "other" energy uses in office buildings is electronic equipment related to the production, use, storage, or transmission of information. These *information functions* represent the principal energy-using "industrial process" in an office building, and the major use of energy other than for occupant comfort and lighting.[1]

One of our objectives is to establish office electronics as a *distinct, recognized end use* in the commercial sector. We have compiled and analyzed information from diverse sources on market trends, equipment characteristics, loads and usage patterns, and options for improved efficiency in both hardware, software, and the operation of electronic equipment. We rely, wherever possible, on *measured* data for both individual equipment and whole buildings. In many cases, the available data are incomplete or seemingly inconsistent. The present paper, limited to the office building subsector, focuses on one of the fastest-growing components of office electronics: personal computers (PCs) and their immediate peripherals such as printers and display terminals. Important issues of energy use and efficiency also apply to other major types of electronic office equipment (copiers, digital scanners, integrated voice/data communications systems, desktop publishing and presentation) and to the growing applications of computers in retail sales, education, etc. These topics must be deferred to future studies.

One recent report, based on a study for the Electric Power Research Institute (EPRI), identified computer loads as a potential source of about 125 TWh (1 TWh = 1 billion kWh) in added electricity consumption between the early 1980s and the 1990s (Roach, 1987 and Squitieri, et al., 1986). This represents a rather dramatic 24% increase over the estimated 526 TWh of electricity

[1] Exceptions to this include office buildings with elevators, and mixed-use buildings that combine offices and non-office uses such as restaurants, laundries, food stores, or light manufacturing. In commercial buildings *other* than offices, computers and electronic equipment may be only a minor part of the total "miscellaneous" load. In most of these cases, the other "process loads" relate to a specific activity or type of occupancy, such as refrigerated storage in restaurants, groceries, and some warehouses; food preparation and sanitation in commercial kitchens; laboratory equipment; and specialized equipment in health care facilities. A recent analysis of several hundred California buildings shows that, with the exception of elevators and specialized process loads, "information equipment" represents the largest single component of "other" commercial energy use (Nguyen, et al., 1988).

for total commercial electricity use in 1982[2]; it is also over half of today's consumption for all commercial lighting (about 200 TWh). The same study cites estimates of wiring requirements for plug circuits that range from 55-130 W/m^2 (5-12 W/ft^2) for new offices and banks in New York City, to 215 W/m^2 (20 W/ft^2) for large computer service centers. (These estimates apply to all plug-in equipment, not just office computers.) These levels substantially *exceed* lighting power intensities of about 15-20 W/m^2 (1.5-2 W/ft^2) in well-designed new office buildings. At present, there are no definitive, measured data on electricity loads and operating profiles for computers and other electronic office equipment, based on a statistically meaningful sample of U.S. commercial buildings. However, the fragmentary data available (see below) suggest that the EPRI load-growth projections may be high, for two main reasons: (1) the calculations rely on nameplate ratings rather than actual power requirements, and (2) the report does not account explicitly for potential efficiency improvements. We discuss future energy use trends in more detail later.

The EPRI study, already widely quoted in the utility industry, has sparked an active debate among energy demand forecasters. This debate is characterized by widely varying opinions and scant data. The California Energy Commission recently compared its own staff's forecasts for "other" commercial sector electricity use with those made by the major California electric utilities. In a recent comparison, the two largest California electric utilities were expecting 1985-1999 growth rates for the commercial "other" end use (not limited to office electronics) that were, respectively, 50% and 200% larger than those predicted by the California Energy Commission staff (CEC, 1987a, p. 3-20). Cumulated over 15 to 20 years, these differences in assumed demand growth rates have a substantial impact on utility resource requirements.

Trends in energy use and load profiles for computers and electronic equipment are of interest not only to utility demand forecasters, but to:

- *building designers and mechanical or electrical contractors,* who need accurate estimates of equipment loads in order to size heating, ventilation, and air conditioning (HVAC) systems and to specify wiring components for plug-in circuits.

- *code-setting and enforcement organizations,* who are concerned with computer loads from the standpoint of HVAC loads and wiring safety, as well as energy efficiency.

- *facility managers and "shared-savings" contractors,* who need to identify load growth due to new computers (and other equipment) in order to have a credible basis for estimating energy savings.

- *energy analysts and policy-makers,* who need reliable data on the major trends in energy use, the main sources of uncertainty in demand, and the most important opportunities for improved end-use efficiency.

[2] This EPRI estimate, extrapolated to 1982 from earlier data, is lower than the U.S. Dept. of Energy data from its 1983 national survey of commercial buildings: total commercial sector electricity use of 656 TWh, of which 153 TWh was in office buildings (EIA, 1986).

The next section of this paper provides an overview of office electronics as a specific end use in commercial buildings. Subsections examine available data on market trends, equipment saturations, rated *vs.* actual power requirements per unit of equipment, and usage patterns. A third section addresses energy efficiency opportunities related to changes in hardware, software, and operating strategies. The final section discusses needs for more measured data and further analysis.

2.2 "Office Electronics" as a Commercial End Use

One difficulty in writing about office electronic equipment is that there is no one widely-accepted definition of what is included in the category. Our definition of office electronics includes all energy-using equipment related to "information processes" associated with business and professional activities, but we recognize that the processes themselves are evolving rapidly, paralleling the rapid changes in office automation technology. New types of electronic equipment are constantly being introduced, as are advanced features, inexpensive smaller models that perform many of the functions of larger models (like desktop copiers and laser printers), and new hybrids that combine microcomputers with familiar devices such as phones, drafting equipment, filing systems, cash registers and point-of-sale inventory systems, and audio-visual presentation systems.[3] In some cases, a familiar piece of equipment may be virtually transformed with new electronic technology. The conventional photocopier, for example, may soon be replaced with "smart copiers" that use scanners to digitize the original page, thus allowing copy-editing or graphics editing, remote transmission, and electronic filing as options in addition to simple copying (Keer, 1986).

This paper concentrates on general-purpose office electronics, such as PCs, workstations, and minicomputers,[4] along with the computer peripherals used for data storage, inter- and intra-office communications, and other business functions. Other special-purpose types of computerized equipment (electronic drafting systems or point-of-sale electronic cash registers) are sometimes found in offices, but these are not our primary concern. We discuss briefly some energy characteristics of other office equipment for processing and storing information on paper—mainly copiers and telefax (fax) machines. However, we pay little attention here to large mainframe computers, which once dominated the market but are now losing ground to smaller, dispersed computers and networks. From an energy-use perspective, it may be less significant whether the computing and data storage functions occur in a central computer or at the desktop, given the many factors affecting all computer hardware efficiency, as well as uncertainties about future trends in energy-intensive input/output (I/O) equipment such as terminals, printers, and digital scanners.

---

[3] There are equivalent trends in the industrial sector, with many process controllers and sophisticated machine tools using specialized microprocessors, or in some cases conventional PCs, as integral components (Akbari, *et al.*, 1988).

[4] Definitions of micro-, mini-, and mainframe computers are blurred, and continually evolving as computation power becomes cheaper and more miniaturized. The term "workstation" is commonly applied to the more powerful and/or special-purpose microcomputers, but some large workstations are based on single-user minicomputers. One 1985 reference drew distinctions based only on cost: a microcomputer was a system costing $1,000 to $20,000; minicomputers cost $20,000 to $250,000, and mainframes cost more than $250,000. Continuing declines in cost *vs.* computing power may render such fixed definitions obsolete.

2.2.1 Market Status and Trends

The U.S. market for data processing equipment, in total, is about $80 billion per year (Electronics, 1987a).[5] Peripheral equipment and copiers account for over one-third of total dollar sales, with mainframes, single-user PCs, and multi-user micro's and mini's each representing about 20%. Table 1 presents some published market-research estimates of the 1986 stock and 1986 annual sales (including replacements), for selected office equipment. Such numbers should be read with caution, especially where several private market research firms are cited as sources. Their estimates may be subject to differing methods, judgmental factors, and varying definitions of equipment and market categories. According to Table 1, about 13 million out of the total 32.5 million single-user PCs in the 1986 stock were used for business, as well as 375,000 minicomputers and more than 2,000 mainframes. (A single mini or mainframe may support a few to several dozen users.) Some business and technical users have both a PC and shared access to a mini or mainframe; the PC may be used either for separate applications or as a "dumb terminal," to log-in to a larger machine. A different source estimated that about 11 million PCs were in business use in 1987, representing about half of all 21.6 million "computer screens" used (Stromer, 1986, citing a report by Comtec). Table 1 shows that monochrome monitors still outnumbered color monitors by nearly two to one. Non-impact printers, including both inkjet and laser printers, made up less than 10% of the stock but more than 15% of new sales in 1986.

For each type of equipment in Table 1, annual sales are large (25-45%) compared with the existing stock in 1986. This suggests how quickly the sector is changing, as a result of both increasing demand and rapid turnover of existing equipment. One recent market study reported that, of 2.8 million planned PC purchases by businesses in 1987-88, about 10% (267,000) were to replace existing units (Personal Computing, 1987). A separate study projected business sales of 3.6 million PCs in 1986, with 22% as replacements and 78% for new or expanded use (Stromer, 1986).[6] Annual PC sales were expected to rise to 5.3 million in 1990 and 9.8 million in 1994, but with the fraction of new units dropping to 64% in 1990 and 55% in 1994. These numbers suggest a maturing (and increasingly saturated) market for business PCs.

The stock numbers in Table 1 may be misleading if one is concerned mainly with energy use. For example, in 1986 the estimated number of single-user PCs in business was only three-fourths the number of home PCs, but in aggregate the business PCs may use at least ten times more energy than home PCs—after we account for larger, multi-user PCs and workstations in offices, the greater use of printers and other peripherals, and the longer periods of daily use.

Another important trend, not obvious from Table 1, has been the tendency for PCs and other smaller computers to displace mainframes in many new and established markets. In 1982, mainframes represented about 30% of the dollar value of all computers sold in the U.S. market ($7 billion out of $21 billion; *Statistical Abstract*, 1988, Table #1285). Single-user PCs ($3.9 billion) represented 18% of dollar sales, with mini's and multiuser workstations making up the balance. By 1986, only four years later, mainframes and single-user PCs had *reversed* their

[5] This is more than half of the $150 billion electronics market, which also includes communications equipment, consumer electronics, and industrial test and measurement devices.

[6] For comparison, an estimated 1.2 million office typewriters were sold in 1986 (CBEMA, 1987, p. 157).

Table 1: Estimates of U.S. Stock and Annual Sales for Selected Electronic Office Equipment[a]

(in thousands of units)

Equipment Type	1986 Stock[d]	Annual Sales[e]	
		1986 (est.)	1996 (proj.)[k]
Single-User PCs	32,500	7,800[f]	
Business Use	*(13,000)*	*2,600*[f]	*16,900*
Home Use	*(17,500)*	--	
Schools	*(2,000)*[g]	--	
Text Processors	--[f]	660[f]	2330[f]
Minicomputers[b]	375	90	220
Mainframes	2.4	9.9	13.8
VDT Monitors	23,000	7,600[h]	
Mono	*(15,000)*	--	
Color	*(8,000)*	--	
Printers and Plotters	21,000	6,100	17,500
Impact[c]	*(18,000)*	*(5,000)*[i]	
Non-impact	*(2,000)*	*(900)*[i]	
Plotters	*(1,000)*	--	
Office copiers	--	1,300	3,200
Fax machines	590[j]	130	320
Electronic typewriters		1300	1150

Notes and Data Sources for Table 1:

(a) Sales and stock estimates from different sources (see below) may use inconsistent definitions and assumptions; they should be compared with caution.

(b) Includes minicomputers and super-mini's (costing up to $1.5 million), technical workstations, and multi-user microcomputers (costing less than $25,000).

(c) Including dot-matrix printers.

(d) Except as noted, 1986 stock estimates are from the U.S. Dept. of Commerce, *Statistical Abstract of the United States, 1988*, Table #1286, citing unpublished data from Future Computing, Inc., Dallas, Texas. The stock data for PCs exclude multi-user PCs.

(e) Except as noted, est. 1986 sales and 1996 sales forecasts are from CBEMA (1987).

(f) There are widely conflicting estimates of 1986 PC sales, due in part to differing definitions. Table #1285 in the 1988 *Statistical Abstract* estimates sales of 7,100 K units, citing Dataquest, Inc., San Jose, Calif. A lower figure for 1986 PC sales, 4,800 K units, was reported in "Computer Industry Abstracts," 2nd Quarter 1987, published by Data Analysis Group, Inc., La Mesa, Calif., p 101. Their original source is an article by Hambrecht and Quist in *Infoworld*, 12 Jan. 1987, p 15. Other estimates of 1986 PC sales reported in this same issue of "Computer Industry Abstracts" are even lower: 2,000 K and 2,700 K units (pp 103, 104); these studies focus on market share and thus may not include all sales. These last numbers are closer to the CBEMA estimate of 2,600 K units, which we show on the next line as PC sales for "business use." The CBEMA definition excludes PC's under $1,000; this excludes many units purchased for home or school use. CBEMA also has a separate category for dedicated text processors, (shown separately in the Table) which may be lumped with PCs in other stock and sales estimates.

(g) Another source (CBEMA, 1987, p. 111) estimates only 300 K units "in use" in schools during 1985-86, citing the National Center for Educational Statistics. However, the CBEMA data may exclude many units costing under $1000.

(h) This estimate for monitors is for "PC terminals" (i.e., may exclude terminals used for multi-user mini's and mainframes), as reported in "Computer Industry Abstracts," 2nd Quarter 1987, p. 123. The original source is "The Shifting Images of the Monitor Market," in *Computer Reseller*, Dec. 1986, p. 44. Note that CBEMA (1987) has a much lower estimate for 1986 sales of "general-purpose terminals," 1,890 K units, dropping to 1,480 K by 1996 due to "competition from low-end PCs."

(i) From J.W. Dower, N. Luft, S. Puopolo, *1987 Printout Annual*, p. 4. This source estimates sales by printer type; the total for 1986 was close to the total shown from CBEMA (1987): 5,900 K *vs.* 6,100. Laser printers are the fastest-growing component of non-impact printer sales. Laser printer sales predictions for 1987 range from 80-400 K units, based on different market studies cited in "Computer Industry Abstracts," 2nd Quarter 1987, pp. 119-120. The authors of this compilation, the Data Analysis Group, predicted 1987 laser-printer sales at 160-200 K units, based on their review of other studies. However, this same firm was quoted in a May 1987 issue of *Publish* as predicting 1987 laser-printer sales at only 81 K units.

(j) Fax stock estimates are extrapolated from 1984 estimates in Becker, 1986, citing a survey by Venture Development Corp., Natick, Mass.

market positions. Mainframe sales, while increasing in dollar value, had dropped to 19% of the total U.S. market ($8.8 billion out of $45 billion), while PCs were at 37% (of $16.9 billion, a fourfold increase over 1982 sales). The number of PCs sold in 1986 was 2.5 times larger than in 1982. During the same period, mainframe unit sales grew only slightly, from 2,100 to 2,400. The total stock of single-user PCs in the workplace increased more than tenfold, from 1.2 million to 13 million, between 1981 and 1986 (*Statistical Abstract*, 1988, Table #1286). Stromer (1986) cites a forecast by Comtec that PCs, which in 1986 represented 51% of all computer screens in business use, would have 70% of the (much larger) business market by 1994.

This shift to smaller machines often means that central computer rooms, while still prominent for some industries and firms, are in many cases being replaced by a network of smaller, multi-user computers or individual workstations dispersed throughout the office space. This dispersion, while often increasing flexibility for the user, presents new problems for designers in managing thermal loads, sizing power circuits, and providing wiring for intra-office and external communications. Most analysts predict a continuation of the trend toward smaller computers, along with other trends that would both increase energy use (growth of laser printing) and decrease it (popularity of laptop PCs). One source estimates the following *annual* growth rates in dollar sales, from 1987 to 1990, based on a review and comparison of forecasts by other industry analysts (Data Analysis Group, 1987, pp. 86-87):

6%	for large computers (> $1 million)
11%	for medium computers ($100,000 - $1 million, 15-128 users)
27%	for multi-user micros, workstations ($6,000 - $25,000)[8]
17%	for desktop PCs
28%	for laptops
31%	for non-impact (laser) printers (increasing from one-third to two-thirds of all printer sales)
- 7%	for impact printers

The same report identifies several near-term trends that may affect both computing power and energy intensity:

- A significant shift toward *laser printers*, which require 5-10 times the power of impact printers (see Table 2 and the discussion, below) is perhaps the most dramatic trend. Prices for small laser printers are dropping rapidly; in place of centralized "printer rooms," some computer systems now provide one or more of these high-quality printers in a convenient location near each small group of users. Some single-user PCs and workstations are configured with their own dedicated desktop laser printer.
- *Color printers and plotters* are increasing in popularity; estimated 1987 sales were 650,000 units, projected to increase to 1.1 million by 1990. Most of these are inkjet, dot-matrix, or pen-plotters, with relatively low energy intensities (whether monochrome or color). Industry sources expect color laser printers to be introduced soon, but targeted initially to

[8] No estimates were given for computers in the $25,000 - $100,000 range.

mainframe applications because of the expected $30-40,000 price tags (Nihei, 1987).[9]

- *High-resolution and color monitors* are gaining in popularity; both tend to be more energy-intensive than conventional monochrome units. High-resolution monitors may double their market share, to 4 million out of 14 million units sold in 1990. Color monitors use about 1.5-2 times the power of monochrome displays (see Table 2).
- Conversely, low-energy-use *laptops* are expected to increase their share of new PC sales, from about 30% in 1986 to 40% in 1990, but there is uncertainty over how much their usage (for travel and take-home work) might displace *vs.* add to usage and connect-time by desktop PCs.
- *Desktop publishing* systems are relatively new products that typically combine a powerful PC workstation or minicomputer, a high-resolution display, and a laser printer, as well as other energy-intensive devices such as *optical scanners.* The rapid growth in popularity of desktop publishing systems is expected to continue, with sales jumping from an estimated 84,000 in 1986 to nearly 550,000 by 1990. The market for desktop optical scanners themselves, only 10-15,000 units in 1986, may increase nearly tenfold by 1990.

2.2.2 Equipment Saturations in Commercial Buildings

Utilities around the country have conducted dozens of statistically-based end-use surveys of the commercial building stock. Very few of these, however, provide sufficient detail on electronic office equipment and other components of the "other" end use. One exception is a series of on-site commercial building surveys conducted by California utilities and the California Energy Commission. These studies collected detailed inventory data and nameplate ratings on computers and other miscellaneous equipment (Alereza, 1987 and Nguyen *et al.*, 1988). The initial results for 855 commercial buildings in one utility's service area showed an average electricity connected load[10] for **all** "miscellaneous equipment," in large and small offices of 24 W/m^2 (2.2 W/ft^2). Computers (excluding other office equipment, such as copiers) averaged about half of this, or 11 W/m^2 (1 W/ft^2) (Alereza, 1987). Newer (post-1975) large office buildings tended to have significantly larger computer equipment loads, on average; these loads were typically 16-22 W/m^2 (1.5-2.0 W/ft^2; Nguyen *et al.*, 1988). For other building types, the differences between pre-1975 and post-1975 buildings were mixed, showing no clear pattern.

2.2.3 Design Requirements for New Buildings

The latest update of ASHRAE Standard 90.1P, in discussing HVAC sizing criteria, recommends a value of 8 W/m^2 (0.75 W/ft^2) for receptacle loads in new offices (ASHRAE, 1987).

[9] Color copiers, priced at around $40,000, will be a necessary complement to most applications of color computer print-out. Both color laser printers and color copiers are three or four times slower than equivalent monochrome equipment (depending on whether they use a three- or four-color process). Energy requirements per page would increase by nearly this same factor, but the increase in overall energy use for color printing may be less, since many printers already have significant standby time (for laser printers, power requirements drop by about 50% in standby mode; see Table 2).

[10] These results are based on nameplate ratings, not actual power requirements, which are generally lower (see Table 2).

The ASHRAE recommended range for other building types is from 1 W/m^2 (0.1 W/ft^2) for warehouses and restaurants to 11 W/m^2 (1.0 W/ft^2) for hospitals. The latest California energy codes for commercial buildings allow 11 W/m^2 (1.0 W/ft^2) for miscellaneous plug loads, or more if special occupancy requirements are documented (CEC, 1987b). In the past, ASHRAE guidelines for estimating miscellaneous equipment loads were somewhat higher; the 1980 ASHRAE standard for new buildings recommended 10-13 W/m^2 (0.9 to 1.2 W/ft^2) for general offices, 19-23 W/m^2 (1.8-2.1 W/ft^2) for purchasing and accounting departments, and 47 W/m^2 (4.4 W/ft^2) for "offices with computer display units" (ASHRAE 1977). The ASHRAE 90-1975 standard used 11 W/m^2 for miscellaneous loads, in a sample calculation of cooling loads. Of course, these guidelines dated from a time when (mainframe) computers and video terminals were less common but far more energy-intensive per unit of computing power than is the case today. "General office space" was assumed **not** to have widely distributed PCs and workstations, but to include only loads from typewriters, calculators, postage machines, etc.

The limited data available on new offices (and numerous anecdotes) suggest that current guidelines of roughly ten watts per square meter for miscellaneous loads may understate actual daytime loads for at least some new office buildings, as well as for many existing, older buildings. For example, in nine new office/mixed-use buildings in Northern California ranging from 1,300 to 32,500 m^2, the (weighted) average load for miscellaneous plug-in equipment (not just electronic equipment) was 17 W/m^2 (1.6 W/ft^2), with a range of 9 to 24 W (Taylor, 1987).[11] This was 85% of the (weighted) average lighting load of 19 W/m^2 (1.8 W/ft^2); equipment loads actually *exceeded* lighting loads in two of the buildings. For three of these buildings, totaling nearly 46,000 m^2, equipment load data were available for each individual tenant's space, as shown in **Figure 1**. For these buildings, miscellaneous electric equipment loads were higher than the values assumed in California's statewide building standard. On the other hand, we have found few examples of office buildings that require 55+ W/m^2 for computers only, as cited in the EPRI article for computer loads in new, large New York office buildings (Squitieri, et al., 1986).

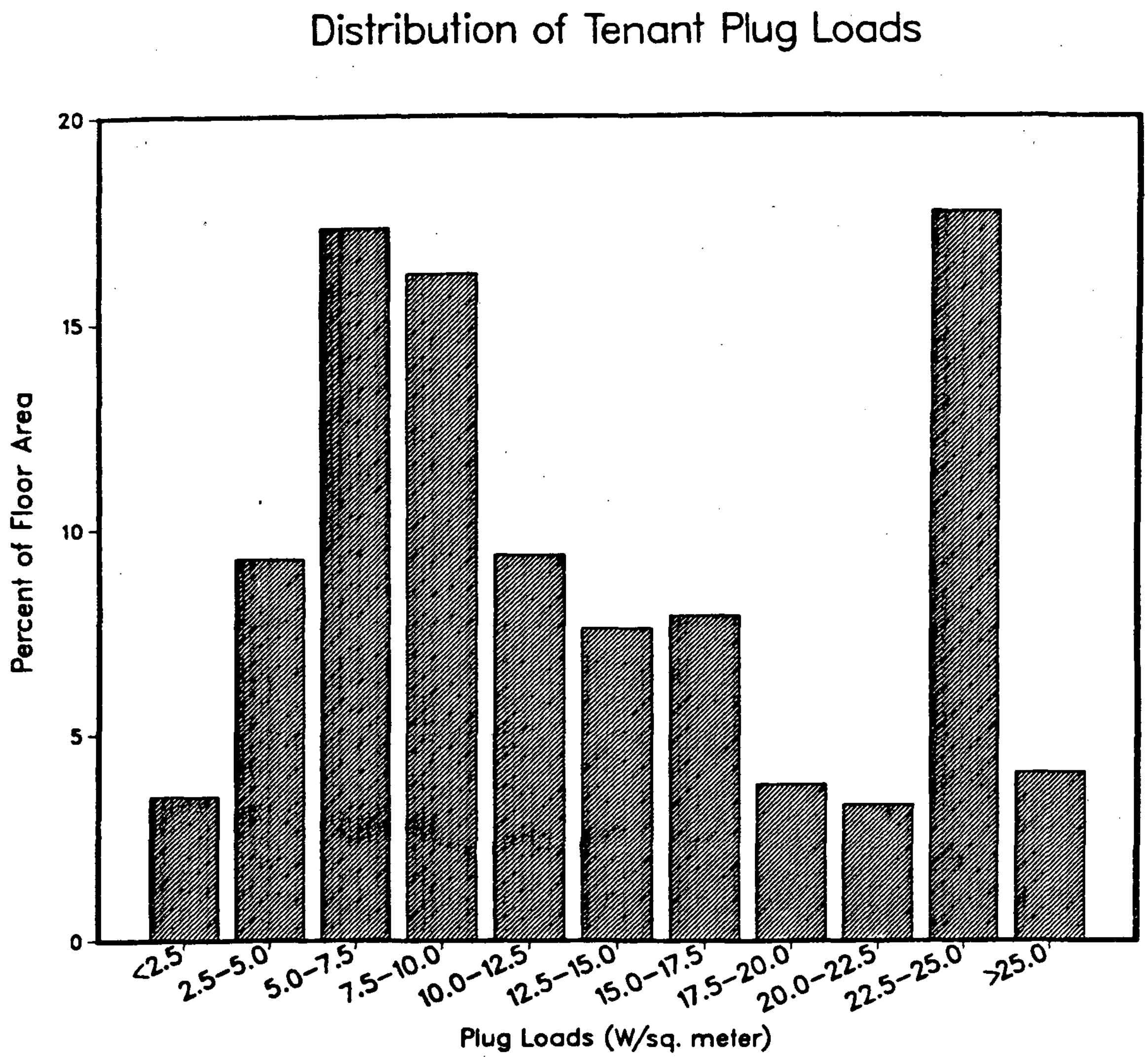
Leaving aside special cases (e.g., banks, engineering firms with computerized drafting systems, computer service bureaus, etc.), where computers are the equivalent of a "process" load, we would estimate that typical values for miscellaneous plug-in loads (not just electronic equipment) in today's typical new office buildings range from 11 to 22 W/m^2 (1 to 2 W/ft^2). Even this lower value represents over half of the lighting load in a well-designed new office building.

It is important to keep in mind that the highly automated "office of the future" represents a design challenge not only for new buildings but for continued use of older buildings. For many years to come, *existing* buildings, rather than new construction, will absorb most of the load growth from office electronics (Clevinger, 1987). However, there are two important mitigating factors: (1) Much of the commercial stock is thoroughly renovated every few years, often when there is a change of tenants. Replacement of the lighting system is often part of a renovation; use of more efficient lamps, ballasts, and fixtures can maintain or improve lighting quality while reducing existing lighting power densities of 45-75 W/m^2 by roughly a factor of two. This

[11] Maximum daytime loads, including an assumed diversity factor.

lighting load reduction makes it possible to increase office electronics loads without adding HVAC capacity. (2) There will be increasing options for workers in the "electronic office" to move their workplace, at least part of the time, to their homes or other remote locations.[12] Of course, this dispersion does not eliminate either the electrical or thermal loads associated with office electronics, but it may mitigate the impacts of computer loads on the existing office building stock. A third factor is the potential for improved energy efficiency in office electronics, which we address below.

[12] Clevinger (1987) refers to recent studies that predict up to 25% of the office workforce working in "remote locations" by 1990. This sounds high to us, unless it includes suburban offices linked electronically to a corporate central office.



XBL 8811-3833

Figure 1. Distribution of tenant equipment load intensities in three new mixed-use commercial buildings in Northern California. The mean value is 14.1 W/m^2 (1.31 W/ft^2); the median, by floor area is 1.4 W/m^2 (1.04 W/ft^2). These maximum daily equipment loads, for all plug-in equipment (not just office electronics) include an assumed diversity factor. Source: S. Taylor, 1987.

3.0 PERFORMANCE AND COST CHARACTERISTICS

To characterize energy use by electronic office equipment, one must look beyond typical equipment intensities and overall connected loads, to also consider the variations in power use per unit, the power required by each major component (PC screens, memory, disk drives, etc.), and typical daily profiles of equipment usage and electricity demand. Our preliminary investigation of manufacturers' published specifications for electronic office equipment showed little consistency in reporting either power requirements or heat output. We decided to conduct short-term metering tests for a number of common office PCs and peripherals, and at the same time to measure changes in power requirements for start-up and standby mode, and to isolate the power requirements of individual PC components by disconnecting and reconnecting them. This section reports the results of these one-time measurements, discusses the limited data available on office equipment load profiles, and then reviews several important technical options for improving energy efficiency.

3.1 Typical Equipment—Actual *vs.* Rated Loads

The recent study of miscellaneous equipment in California commercial buildings (Alereza, 1987 and Nguyen *et al.*, 1988) relied on a set of "usage factors" based in part on an earlier ASHRAE study (Alereza and Breen, 1984). The usage factor was defined as the ratio of power consumption under "normal operating conditions" to nameplate rating; estimated values were 0.85 for computers and related equipment, and 0.8 to 1.0 for most other office equipment (except copiers, at 0.5). For computer equipment, these estimates appear high by at least a factor of two, since the measured data presented in **Table 2** shows lower ratios of actual to rated load, without even accounting for intermittent daytime use of some equipment. Estimates of load diversity for electronic office equipment, based on typical operating patterns, are also subject to great uncertainty. Improving these estimates will require more detailed (and costly) end-use monitoring.

We used a portable power meter to make short-term measurements of the actual power requirements for selected PCs, components, and peripheral equipment.[1] We measured power in "active" operation and standby mode, and compared both measurements with nameplate ratings. Measured data are presented in Table 2 and **Figures 2 and 3**. Our principal findings are:

- Nameplate ratings typically overstate actual measured power by factors of two to four for PCs and by factors of four to five for printers (see Figure 2). This is significant because most electricity demand forecasts and building design (HVAC sizing) decisions are based on rated rather than measured equipment loads.

---

[1] While our choice of equipment to meter was based in part on convenience, we suspect that the results would be similar if we measured other models or types of electronic office equipment.

Table 2: Rated vs. Measured Loads for Selected Equipment

Equip. Type and Model	Features[a)]	Rated[b)] Power	Measured Power[c)] Average	Peak	Avg. as % of Rated	Peak	Screen Only Rated	Meas'd
Desktop PC's								
IBM PC #1	2 FD	240	94.5	99.5	39	95	40	28.5
IBM PC #2	2 FD, 3 SB	240	91.2	97.8	38	93	40	26.0
IBM PC #3	2 FD, 2 SB	240	93.9	98.1	39	96	40	26.0
IBM XT #1	FD, 20Mb HD	440	111.0	114.5	25	97	40	30.0
IBM XT #2	FD, 10Mb HD	440	117.0	123.0	27	95	40	27.0
IBM XT #3	FD, 30Mb HD, 3 SB	440	115.0	120.0		26	96	40
IBM XT #4	FD, 10Mb HD, 2 SB	440	117.0	121.5	27	96	40	27.0
IBM AT #1	2 FD, 30Mb HD	500	166.0	169.5	33	98	40	30.5
IBM AT #2	2 FD, 30Mb HD, 3 SB	500	165.0	167.0	33	99	40	30.0
IBM PS-2/30	FD, 20Mb HD	212	76.0	78.0	36	97	74	32.0
IBM PS-2/50	FD, 20Mb HD, SB, Color	322	109.0	109.0	34	100	74	43.0
IBM PS-2/60	FD, 70Mb HD, SB, Color	580	172.0	172.0	30	100	92	48.0
IBM PS-2/80	FD, 70Mb HD, SB, Color	672	209.0	209.0	31	100	184	61.0
Mac-512	FD		39.5	43.0	-	92		
Mac-Plus	FD	60	31.4	34.3	-	92		
Mac-SE #1	FD, 20Mb HD	100	40.0	44.5	40	90		
Mac-SE #2	FD, 20Mb HD	100	45.0[d)]	45	-			
Mac-2	FD, 40Mb HD, Color	358	130.0	133.0	36	98	128	66.0
Compaq Port.I #1	2 FD, 3 SB	192	97.0	100.5	51	97		
Compaq Port.I #2	2 FD, 2 SB	192	117.0	122.0	61	96		
Compaq Port.I #3	2 FD, 2 SB	288	80.3	82.5	28	97		
Compaq Port.III	2 FD, 20Mb HD, 2 SB	288	85.3	89.5	30	95		
Atari 1040ST	FD	118	46.2	48.6	39	95	43	31.7
Unix PC	FD, 20Mb HD	240	94.0	95.2	39	99		
Laptop PC's								
Zenith 181	2 FD	21	11.6	16.1	55	72		
Data General 1	2 FD	-	6.2	9.5	-	65		
Sharp 7000		-	29.4	30.5	-	96		
Toshiba 1100-Plus		-	10.8	12.1	-	89		
Impact and Inkjet Printers[e)]								
HP Thinkjet		17	3.1	9.8	18	32		
Epson RX-80		50	9.7	24	19	40		
Epson MX-100		100	19.1	31	19	62		
Imagewriter II #1		20-180	13.0	23.0	-	57		
Imagewriter II #2		20-180	11.2	41.0	-	27		
Okidata 83A		76	19.7	44.3	26	44		
Okidata 92		76	18.3	46.0	24	40		
IBM Proprinter		84	26.3	46.0	31	57		
Diablo 630		336	46.0	94.0	14	49		
Laser Printers								
HP 2686A		850	140.0	315.0	16	44		
Laserwriter Plus		531	129.0	233.0	24	55		

Notes to Table 2

a) Nameplate ratings are sometimes given in voltage and amperes; we assumed a power factor (PF) of 0.8 for computers and screens, and 0.7 for printers, plotters, and copiers (rated watts = volts x amperes x PF).

b) Abbreviations used to describe equipment features: FD = floppy disk drive (5-15 W for a 360-kilobyte (Kb) drive and controller card); HD = hard disk drive (25-55 W for a 10-30-Mb hard drive and controller card); SB = special boards for expanded memory, graphics, expanded calculation, printer port, or modem (5-10 W for most boards); Color = color monitor (monochrome is standard except as noted).

c) Includes computer and monitor screen. Except as noted, measured power is an average for several short-term measurements using a Dranetz Model 808 Electric Power/Demand Analyzer. There was little variation among the short-term readings; accuracy of the averages reported in the Table is about 2 W.

d) Measured with a conventional watt-hour meter, by clocking 1 revolution (1.8 Wh).

e) For printers, the "average" column refers to the power draw when in **standby** mode (not printing); "peak" refers to typical usage when printing, typically 2-3 times the standby power. In addition printers in use have pronounced (up to 80-700 W) short-term power oscillations, on the order of seconds, probably caused by drum heaters and paper feeds. These are not included in our "peak" values.

The overall average power required while the equipment is turned on will thus be between these "average" and "peak" numbers, but is difficult to estimate since it depends on the printing demand. This last number, if available, would be more directly comparable to the "average" shown in this table for other equipment.

The Thinkjet is an inkjet printer, with notably low power requirements. The Diablo is a daisy-wheel impact printer; daisy-wheels are fast being replaced by laser printers. The rest are dot-matrix impact printers.

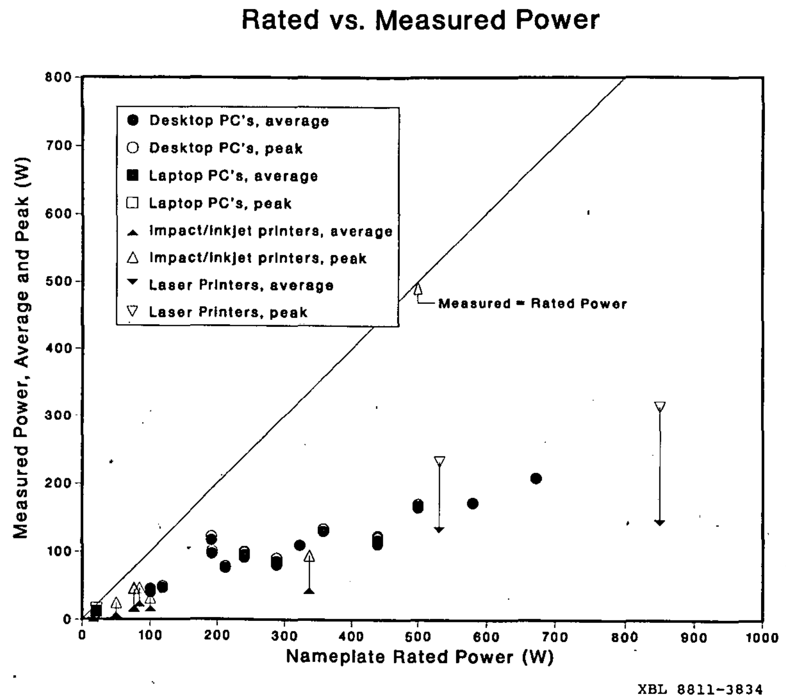


Figure 2. Measured *vs*. Rated power for PCs and printers. Data plotted from Table 2 show the range in power requirements for similar types of equipment and the large discrepancy between nameplate ratings and actual measured power (average while in use).

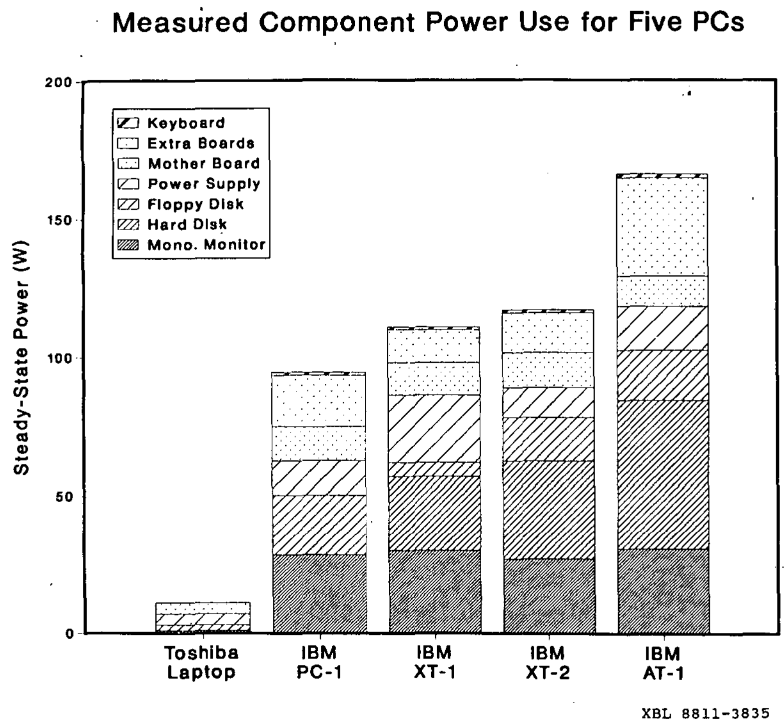


Figure 3. Measured component power requirements for five PCs. Measurements were made using a Dranetz Model 808 Electric Power/Demand Analyzer. Component power was determined by disconnecting each component and noting the power drop. These averages of several short-term measurements are accurate to about 2 W. Comparisons with other PCs are shown in Table 2. Source: Field measurements by Princeton Univ. CEES

- There are significant variations in power requirements for equipment in the same general category: laptop *vs.* desktop PCs (Figures 2 and 3) or impact *vs.* laser printers (Figure 2).

- For PCs in particular the most recent models tend to provide more computing and storage per watt of power.

- Once turned on, PCs are essentially a constant load; power requirements for printers vary by a factor of about two between standby and printing modes.

Here are further observations for each type of equipment reported in Table 2:

(a) Desktop and laptop PCs. As noted, nameplate power ratings typically overestimate actual power consumption by a factor of two to four. There is also a large range in measured power use: over 20:1 between the lowest-power laptop models and the most powerful desktop workstations (IBM PS-2/80 and Apple Macintosh-2, both with color monitors). Macintosh models use less power than IBM PCs, for roughly equivalent computing and storage. For most model lines, newer models (with equivalent or better performance) tend to be more energy-efficient. For example, the current generation IBM PS-2 Model 30 requires about one-third less power than the older XT. Similarly, the Model 50 uses about one-third less than an equivalent AT. The Mac SE with a 20-MB hard disk uses no more power than an earlier Mac 512 with no hard disk. The recently released Compaq III, with a 20-MB hard disk, provides increased capabilities but uses less power than two out of three of the first-generation Compaq I models tested.

Laptop models, to conserve battery operating time and weight, are forced to use very low-power components, such as liquid-crystal (LCD) displays and CMOS-type logic boards (see below). They provide computing functions equivalent to an IBM PC using only about *one-tenth* the power. Our laptop Toshiba 1100-Plus required only 11 W when operating. This large range in PC power requirements prompted us to measure power requirements for individual components of a few machines.

(b) *PC components.* Figure 3 shows measured power for major components of four IBM desktop PCs and one laptop. Use of floppy disk drives increases power by 2-7 W.[2] This is the only noticeable source of power variation once the computer is turned on; it is so small that office computers can be considered constant power devices. Hard disks are spinning (drawing constant power) whenever the machine is on. Measured power for hard disks on our IBM models ranged from 27-54 W, including the disk controller card. Power for hard disks does not appear to scale with storage capability, at least in typical PC sizes (see Figure 3). Manufacturer's specifications for a current-generation hard disk drive (*BYTE*, 1988) rate a 65-MB half-height drive at only 11 W, less than the 15-54 W we measured for several older 10-MB to 30-MB, full-height drives. Power supplies for the five desktop units we measured required 11-25 W. Power supply for the Toshiba laptop used about 4 W (one-third of the total), although it was rated at 15 W input, 10 W output. Trickle-charging the battery pack required 8 W. Power

[2] However, this increase did not show up in our measurements of peak *vs.* average power for the IBM Model PS-2 series; see Table 2.

use for logic boards in the IBM PC series ranges from 11 to 13 W for "motherboards"; extra boards consumed 12 to 35 W per machine, for the models we measured. In all, integrated circuit boards (including the disk controller cards) accounted for 28-42% (32-71 W) of the total PC power requirements for our IBM models. In a later section, we discuss two major technological trends affecting energy efficiency of computer logic boards: continued miniaturization and the shift to low-power transistors.

(c) *Monitors.* Monochrome monitors required 26-32 W for the IBMs and the Atari we metered. Color displays for the AT, PS-2, and Mac-2 are much more energy intensive, requiring 48-66 W.[3] Both monochrome and color screens show essentially no power reduction when the screen intensity is turned down, or when a "screen-saver" feature is enabled. The average monochrome monitor using video-type (CRT) technology requires two to three times the power of a complete laptop computer (which relies on LCD or other low-power displays). The typical monitor used with an IBM desktop PC consumes as much power as an entire Mac-Plus, which also has a CRT display. On the other hand, the LCD screen for our Toshiba laptop used a negligible amount of power; we could not detect a change when disconnecting the screen.

(d) *Printers and plotters.* Table 2 shows a variation of about 2:1 between average and peak power for printers—much larger than for computers.[4] As with computers, the nameplate power ratings for printers are very conservative (by a factor of 4:1 or 5:1), and there is a wide range of measured power levels: a 10:1 ratio for inkjet *vs.* dot-matrix printers, a further doubling for a daisy-wheel impact printer (Diablo 630), and another increase by two to three times for small laser printers like our HP and Laserwriter-Plus models. Laser printers are becoming very popular because of their high print quality, flexibility, and steadily declining prices (now well below $2000). Although laser printers are much more energy intensive than impact printers, their actual power use is only about one-third of the nameplate-rated power.

3.2 Usage Profiles and Energy Consumption

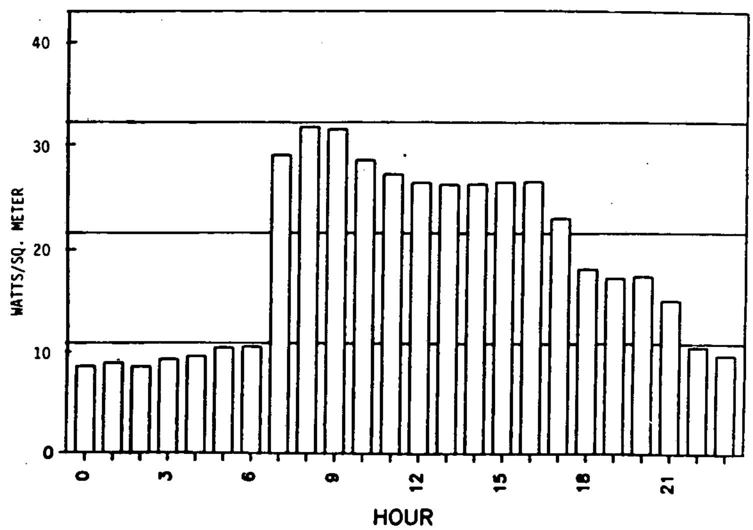
Electric utilities are primarily concerned with the growth of *on-peak* loads resulting from electronic office equipment. This makes it important to understand the actual usage patterns that determine daily load profiles, as well as annual energy consumption. There is much speculation about daily profiles for electronic equipment usage, but few measured data. Most mainframe and many minicomputer systems operate continuously; some may be shut down on weekends. Anecdotally, PC usage patterns vary widely; some may be consistently shut off when not in use, others left on virtually all the time. Control of shared peripherals, such as laser printers, is probably even more lax than that of PCs or other individual equipment.

---

[3] The latest model VGA color screen (used with the PS-2 Model 50) required 43 W when operated in monochrome mode.

[4] For printers, "average" power is defined as standby (non-printing) mode; "peak" power is measured during a print cycle. Many printers experience brief (10 second) power peaks during warm-up: according to our measurements this is about 80 W for inkjet and dot-matrix printers, and 500-700 W for desktop laser printers.

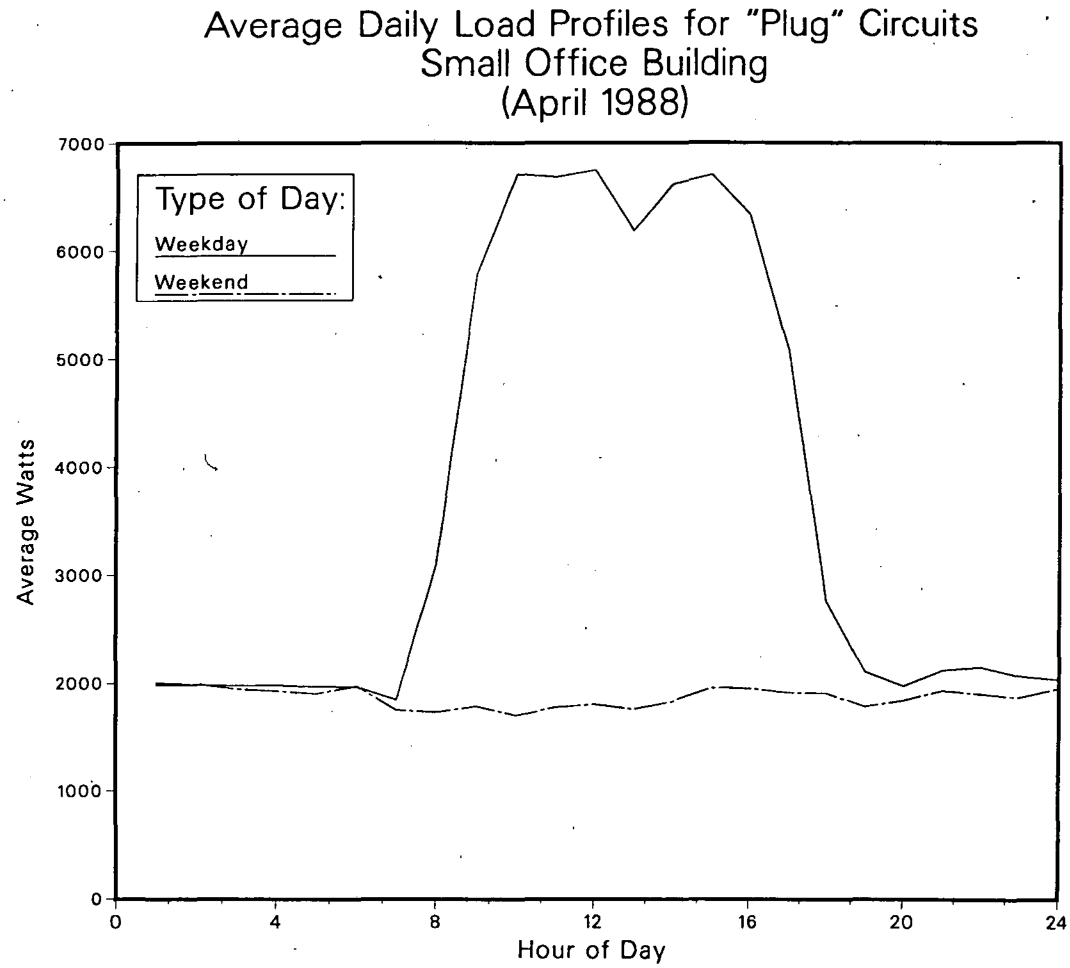
At present, we have measured load profile data from only a few sources (**Figures 4a**, **4b**, and **4c**), none of which provides direct evidence on load profiles for electronic office equipment only. Figure 4a shows a typical weekday load profile for all "tenant loads" (including plug loads and lighting), for a medium-size, leased office building in New Jersey. Tenant electricity consumption was measured by metering the electrical risers serving tenant spaces. These risers provide power for lights, plug loads, ventilation system fans, and terminal reheat coils. Measurements were taken in the spring, after the heating coils were turned off; one-time measurements of fan loads were subtracted from the total, to yield the power attributed to tenant lights and plug loads. Lights were not metered separately, but power levels for individual fixtures, combined with a count of the fixtures, gave a power level of 15 W/m^2 (1.4 W/ft^2) for general purpose lighting and 1 W/m^2 (0.1 W/ft^2) for task lighting. The total, 16 W/m^2, represents an upper bound for lighting power, which might be lower if some lights were manually turned off at times during the day. According to on-site visits, the lighting levels at night are estimated to be 1-2 W/m^2. The remaining tenant load for office equipment peaks at about 15 W/m^2 around 8 to 9 a.m.[5] The decrease later in the day (about 5 W) could be the result of less use of lights or office equipment. Tenants leave the building at 5:30 p.m. and the cleaning crew is at work until 10 p.m., which accounts for the gradual decrease in measured power in the evening. At night, office equipment power drops to about 5-6 W/m^2. We conclude that approximately 40% of the office equipment is left running at night. Some of this equipment is needed for remote communications, but the majority, including word processors and copying machines, appeared to be powered up unnecessarily.



XBL 8811-3836

Figure 4a. Typical daily load profile—miscellaneous plug loads in a New Jersey leased office building (12,100 m^2). Hourly submetered tenant lighting and general-purpose office equipment loads for a typical spring weekday, 1986. Lights account for about 16 W/m^2 (1.5 W/ft^2), and are almost all turned off when the cleaning crew leaves at 10 p.m. Miscellaneous office equipment appears to be a nearly constant load, at 9-11 W/m^2 (0.8-1.0 W/ft^2). Metered data exclude the central computer facility (40 kW, or about 3.3 W/m^2) and kitchen equipment. Source: Field measurements by Princeton Univ. CEES

[5] A central computer facility, with a total load of about 40 kW, would be equivalent to about 3.3 W/m^2 if it were allocated to the total floor area.



XBL 8811-3838

Figure 4b. Average weekday "plugs" load profile, small office building. These data show weekday average hourly loads for April 1988 for a recently-constructed, two-story building of about 850 m^2. Computers and other office electronic equipment represent most of this load; not included is a separately metered minicomputer, which would add about 10% to the loads shown. Data come from monitoring equipment installed by Battelle Pacific Northwest Labs.

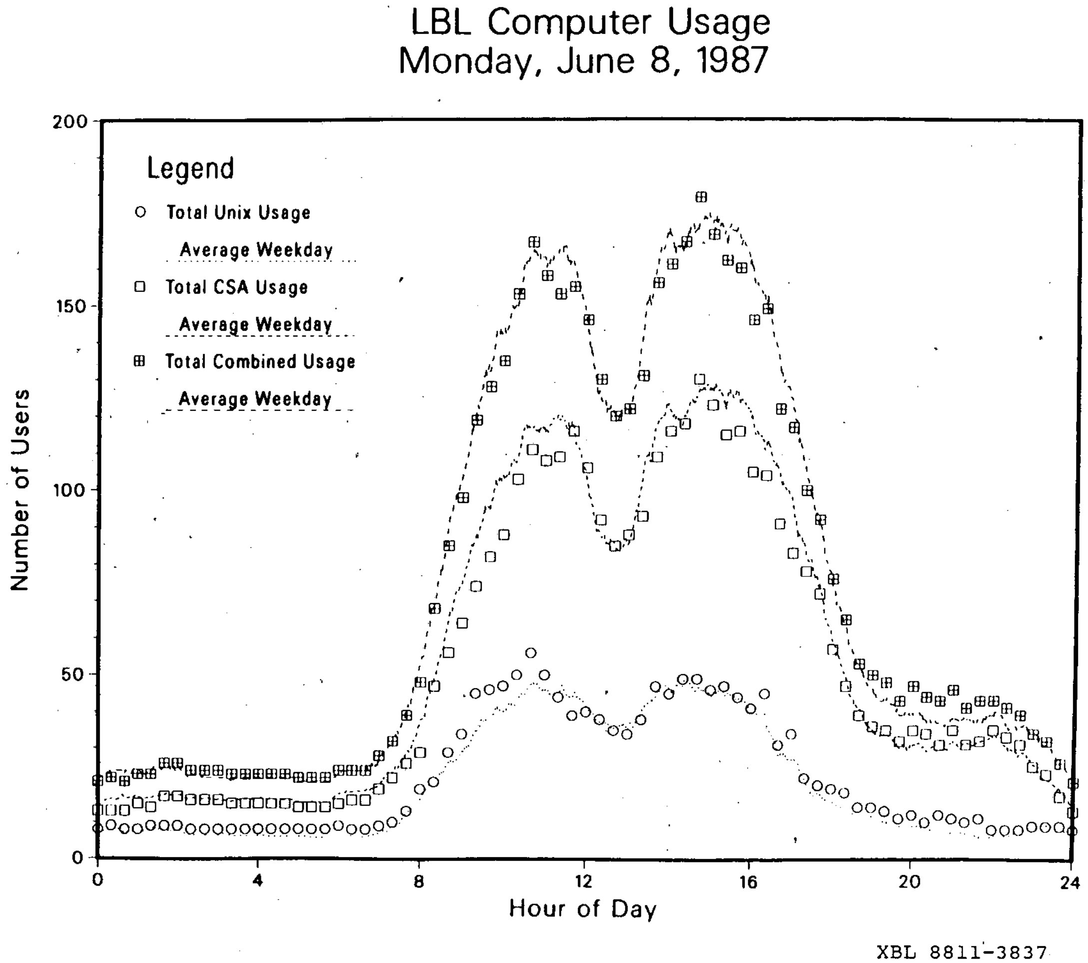


Figure 4c. Typical weekday profile of logged-in users at Lawrence Berkeley Laboratory, for networked Unix and VMS computers. Note the lunchtime drop in usage. (Some terminals may be left on even when the user is not logged in.) Usage patterns vary little over the five weekdays; weekend use on the two machines is typically 40% of the weekday usage on Saturdays, and 20% on Sundays. Source: System accounting data from LBL.

The second data source (Figure 4b) comes from end-use monitoring in a small office building (about 850 m^2) in the Pacific Northwest. Based on a detailed equipment inventory, about 90% of the plug loads shown are due to electronic office equipment.[6] Maximum load, about 7.9 W/m^2 (0.7 W/ft^2), occurs from 9:00 a.m. to 4:30 on weekdays; night and weekend power is fairly constant at about 30% of the daily peak.

A third set of usage profile data come from log-in records for a bank of eight minicomputers at a DOE National Laboratory (LBL), connected through a local network to users with "dumb" terminals. Once again, the data provide only an indirect indicator, because they show the number of logged-in users rather than electricity load. However, in Figure 4c (unlike Figures 4a and 4b) non-computer office loads are excluded. Figure 4c shows a typical weekday profile of logged-in users. The drop at lunchtime and the well-defined morning and afternoon peaks—in contrast to the "block" profile of total tenant loads in Figures 4a and 4b—are characteristic of other occupancy-driven (scheduled) office loads, such as lighting. Computer usage patterns are quite stable for the five weekdays; Saturday usage is typically 40% of the weekday average and Sunday usage about 20%. This usage profile measures *computer* use more directly than Figures 4a and 4b, but does not include peripherals such as printers and disk drives, which (along with the central minicomputers) are constantly on. Log-in patterns for network users may not be typical of usage or load profiles for individual or networked PCs. At LBL, user charges for connect-time provide some incentive to log off the central computers, but some terminals may be left on even when the user is not logged in.

In the future, improved data will come from continuous, on-site monitoring of commercial buildings, such as the forthcoming data from the Electric Loads and Conservation Assessment Project (ELCAP) sponsored by Bonneville Power Administration. Even with careful submetering, however, it will be difficult to keep track of rapid turnover in office equipment stock, and to isolate electronic equipment from other office plug loads such as task lighting, portable electric heaters, chilled- and hot-water drinking fountains, office coffeepots, refrigerators and other lunchroom appliances, etc.

3.3 Energy Efficiency Opportunities

Potentially offsetting expected load growth for office electronic equipment are some major opportunities for improved energy efficiency in both hardware and system operations. Some of these changes may occur naturally, in response to technology advances or market pressures (e.g., user demands for increased PC power without use of a fan, reduced desktop "footprints," and improved portability). Others may need encouragement.

[6] Not included in Figure 4b is power for a separately metered minicomputer, with a daily load profile similar to the plug loads. If included, it would add about 10% to the plug loads shown.

3.3.1 Potential Hardware Improvements

Advances in microelectronics will continue to reduce electrical power requirements for a given level of computing or storage capacity. The potential reductions in power are so great that forecasts of increased computing power should, arguably, be decoupled from electrical load growth.

The power consumed by an electronic chip depends mainly on the type of transistors used. Laptop computers (and pocket calculators), which must be capable of extended battery operation, rely on "complementary metal-oxide semiconductor" (CMOS) technology, rather than the "n-channel metal-oxide semiconductors" (NMOS) used in desktop PCs. Both types draw similar amounts of power when a transistor is switched, but CMOS requires almost no power when inactive (Horowitz and Hill, 1980, p. 328). Memory chips, in particular, are inactive most of the time. Widespread use of CMOS chips in desktop systems could eliminate much of the power now consumed by chips—about 30-40% of the total for the IBM PCs we measured.

Reduced electrical power means less thermal energy to remove from a chip; the thermal benefits of CMOS become more important to chip designers as more transistors are packed on a chip. CMOS has become today's dominant technology for powerful integrated circuits (Meindl, 1987 and Chen, 1986). One chip designer (Chen) predicted in 1986 that within a decade most digital circuit designs, including microprocessors and memory, would shift from NMOS to CMOS. Other analysts have predicted that CMOS will account for nearly half the integrated circuit market by 1990 (Davies, 1983 and Meindl and Sturm, 1988).

Although CMOS is slightly slower than NMOS, cost is the primary reason for its limited use up to now. There is at present a premium of about 50-100% for CMOS, at the retail level, as shown in **Table 3**. Because of the added cost, there has been little incentive for computer manufacturers, on their own, to switch to CMOS. The exceptions include laptops, a few special-purpose chips associated with batteries in desktop machines, and cases where there are heat-dissipation problems for the computer as a whole.[7] Outside the laptop PC market, a shift to CMOS will probably be driven by the trend toward increased chip density, and the corresponding need to reduce the amount of heat dissipated, at both the chip level and the machine level. Increased density will also reduce the energy required per transistor switching operation, a benefit which will accompany faster chips (Meindl, 1987).

[7] Computer-level heat dissipation can also be handled with a fan, as in the Macintosh SE and Mac II. However, we have talked with some users who find the noise objectionable.

Table 3: Retail Prices of Equivalent NMOS and CMOS Chips

NMOS Chip	Unit Price	CMOS Chip	Unit Price
8085	$ 2.49	80C85	$ 4.49
8155	2.49	81C55	3.99
8243	1.75	82C43	3.49
8250A	6.49	82C50A	9.95
27512-25*	11.95	27C512-25	12.95**

* An EPROM (erasable, programmable, read-only memory chip).
** On sale (reg. 14.95)

A second important factor affecting energy efficiency is the move toward lower chip voltages, dictated by larger-scale integrated circuits that fit more transistors in a given area of silicon. As the physical size of a circuit decreases, voltages need to decrease to prevent excessive electrical gradients, which can damage chips. Some developers of new four- or sixteen-MByte memory chips are already using 3.3 V, instead of the current industry standard of 5 V (Chou and Simonsen, 1987). The shift from NMOS to CMOS will be encouraged by the need to reduce heat generation as chip densities increase (assuming voltages remain at 5 V). Beyond some point, however, further density increases will require lower voltages.[8] The number of devices per chip has been quadrupling every three years, a trend that should persist until the early 1990s (Meindl, 1987). The speed of personal computers, measured in millions of instructions per second (MIPS), is projected to increase by a factor of ten between 1985 and 1995 (Peled, 1987), a rate slower than the increase in chip density. If these projections hold true, by 1995 the typical business computer will perform many more calculations in the same period of time, but consume less energy than today's machines.

For many applications, conventional video-type screens (CRTs) can be replaced by "flat screen" (liquid-crystal) displays; this is already the norm for laptop computers. The newer laptop screens use backlighting for improved visibility, but even with this added requirement, power for a flat LCD screen will drop to a few watts, from 30-50 W for a CRT. Color LCD screens of acceptable quality appear to be technically feasible (and slightly more power-intensive) but will be more expensive. Technical advances in materials and recording heads for disk storage are expected to increase storage density by a factor of five within five years (Kryder, 1987). Since the drive motors do not have to work any harder, the gain in data storage should require no increase in electrical power. Data storage on optical disks, initially used in larger systems, offers even greater gains in the ratio of power use per megabyte of data storage.

[8] We can assess this using a linear measure of transistor size: the scale factor, S (Meindl, 1987). As the scale factor is reduced, transistor area decreases as S^2. Because the supply voltage is also reduced by S, in order to maintain constant electrical gradients the power per chip area remains constant. Switching time drops with S, and therefore the energy per switching operation (power X time) decreases as S^3.

Finally, recent innovations in laser printing and photocopying could significantly reduce power requirements. Lovins (1987) reports that some Canon and Siemens photocopiers use a cold-compression roller rather than a heated drum to fuse toner onto the paper, with a tenfold savings for this component of the copier. Cold-fusing technology, because it limits the printer output rate, has been applied to smaller (slower) models.[9] Copy quality is also a concern to some users, since the surface of the copies is glossier than with a plain-paper copier using conventional heat-and-pressure fusing. Cold-fusion copiers have much lower standby power requirements than conventional copiers (only 12 W, according to Lovins), no warmup time, and quieter operation (since no fan is needed to cool off the paper). Cold-fusion copiers may reduce cooling loads, and improve comfort where occupants share a small office with a desktop copier.

Another innovation has been introduced in a new series of high-end computer printers (6000 lines/minute, or about 1-2 million pages/month) which use a magnetic rather than electrostatic method to attract the toner to the rotating print drum, saving an estimated two-thirds of the energy required by an equivalent laser printer (Bull, 1988). Pressure, rather than a static charge, transfers the toner to the paper (Eltgen and Magnenet, 1980). The manufacturer claims that this new process is more reliable (with 100 moving parts rather than 4000) and has lower first-costs than an equivalent conventional machine.

Two companies have recently introduced an alternative to the laser printer, based on ion-deposition technology (Cook, 1987, C. Itoh, 1988, and Le, 1988). Both the Miltope Series 75 (rated at 75 pages/minute) and the C. Itoh Megaline (30 pages/minute) use a Delphax printer engine. The printer drum is much harder than the light-sensitive drums used in laser printers; this makes it possible to fuse the toner to the paper by means of pressure rather than heat-and-pressure, which is standard for most laser printers (and plain-paper copiers). C. Itoh Electronics is considering application of the same technology to mid-range, 15-20 ppm printers. In a cost comparison prepared for C. Itoh, the ion-deposition printers had total per-page costs at the low end of the range for comparable laser printers. However, this range is quite large (between about 1.5 ¢ and 3.8 ¢/page) and electricity costs represent less than 5% of the total.

Recently introduced "laser copiers" combine a digital scanner with a laser printer. The digitizing of images allows some copy editing to be done at the machine, but as yet such copiers are not standardized to accept input from other computer files, remote copiers, or other electronic sources (Keer, 1986). Once this has been done, we may see systems that combine scanners, printers, and copiers taking over a large share of the market for separate devices. Fax machines, now enjoying rapid growth in popularity, already combine a scanner and printer. Some fax models now on the market can be used as digital copiers although with reduced quality and output speed compared with standard copiers (Blankenhorn, 1988). The initial effect of such "combination office appliances" may be an increase in equipment saturations and energy use, along with improved quality, convenience, and flexibility for hard-copy output. Eventually, however, new devices may lead to a *decrease* in total energy use for printing, as better-integrated systems, both inter- and intra-office, reduce the need for printing drafts and extra copies, while also making more efficient use of hard-copy input and output devices (i.e., less time spent idling at full power).

[9] For example, Canon's PC-30 personal copier prints at a relatively slow 8 pages per minute (ppm).

3.3.2 Software and Operations

The most effective way of reducing an office machine's energy use is to turn it off (or to a reduced-power "standby" setting) when not in use. Many desktop computers are left running throughout the day, and in some cases even at night and on weekends. Even a computer with low-power CMOS chips uses energy for hard-disk drives, the monitor, and the power supply; together these represent at least two-thirds of the total (see Figure 2). The time (and extra steps) required to "boot up" a computer when it is first turned on will influence user decisions to manually turn off the power for periods of expected idle time. Booting times varied from 32 to 55 seconds, for several PCs we measured. Part of the problem lies in the memory check performed at the beginning of each startup; for an older IBM PC with 640 kilobytes (640 K) of memory, this takes about 45 seconds. Since memory failures are rare, it would make sense to modify the operating system to make this diagnostic optional, as with the Digital Rainbow PC. Future machines may contain their operating system in nonvolatile memory, to avoid the slow startup step of reading a disk.

Most video monitors require only about ten seconds to show a picture once the power is switched on. Thus, a separate, automatic power switch for monitors would be a logical step. At present, some video monitors have manual power switches only, and some have no switch at all.[10] An automatic switch for screens (and other components) could use the same sensor currently installed for the "screen-saver" feature, which prolongs screen life but saves no energy, according to our measurements. Ideally, screens and other components would automatically switch to a dormant, low-power mode when not used for a (user-specified) time interval. They would then be reactivated at the touch of any key (or, for equipment tied to a communications network, by receipt of an incoming message). The necessary switching technology is already used in some laptop PCs, in order to stretch battery operating times (Hogan, 1988); it could be readily applied to desktop machines.

Relatively little is known about the percentage of time that major energy-using components of a computer or system are actually required *vs.* idle, during normal periods of use. However, some suggestive data on "idle times" for terminals were obtained from system accounting files on the LBL minicomputer network (**Table 4**). These data show that, at any given moment, about half of the logged-in users had been "idle" for at least ten minutes during on-peak hours, and more than 60% of users had been idle longer than ten minutes during evening and weekend off-peak hours.[11] In many cases where idle times are less than 10 minutes, the user may still be at work on a closely related task. Longer times suggest that the terminal may have been left logged in unnecessarily, while the user works on something unrelated. On the other hand, even after logging off the LBL network, the power to an individual terminal may be left on.

---

[10] Note that there is also some risk of increased power usage with a manually-switched screen; computers might be left on for even longer periods of inactivity, without a lighted screen to remind the user that the computer is on.

[11] "Idle time" is defined as a period with no keystroke; this may include times when the user is waiting for a batch command to be executed. "On-peak" periods were 9 a.m. to 7 p.m., weekdays. Although the off-peak period represented the most hours (about 6150 hours/year) it had a much smaller user base, averaging 2.8 users compared with 11.7 average users during the on-peak period. Thus, nearly two-thirds of the usage (user-hours) was on-peak.

Table 4: Idle Time for LBL Computer Users

Range of Idle Time*	Percent of Users Idle			
	On-peak**		Off-Peak	
	Bin %	Cum. %	Bin %	Cum. %
0 minutes	29.3	29.3	25.3	25.3
>0 and ≤4	11.2	40.5	9.1	34.4
>4 and ≤10	10.0	50.5	4.0	38.4
>10 and ≤30	15.1	65.6	7.4	45.8
>30 and ≤60	11.6	77.2	5.7	51.5
>60 and ≤120	10.6	87.8	6.7	58.2
>120 minutes	12.2	100.0	41.8	100.0

Notes for Table 4:

Observations were made for one week in June, 1987, for networked users of the LBL Unix 8 minicomputer. The data exclude idle time for the microcomputer used to display the queue for a networked (multi-user) laser printer.

* Idle time is defined as a period with no keystroke; this may include periods when the user is waiting for a batch command to be executed. In many cases, idle times of less than 10 minutes do **not** indicate that the user has "wastefully" left the terminal logged in, while engaged in unrelated activities. Conversely, power to individual terminals may be left on, even after they are logged off the LBL network.

** On-peak is defined as 9 a.m. to 7 p.m., weekdays only.

Manually turning equipment on and off is an inconvenience, but encouraging office workers to switch off unused PCs (like lights) may be a reasonable option for the near term, until hardware and software vendors introduce automated power switching as a standard feature. For a PC, screen, and small printer that use 150 W and are left on continuously, the annual energy charge will be about $92, and the demand charge $15, for a total of $107.[12] In addition, the heat generated by PCs and related equipment adds to the cooling load in most office buildings, but can reduce winter heating energy requirements in buildings and zones which require supplemental heat. Cooling season energy costs for electronic equipment are increased by about 1/COP (where a typical system coefficient of performance, COP, may be 2.0-3.0). These indirect effects on space conditioning loads are quite site-specific; some of the cooling load may be met with "free cooling," using an outside-air economizer that requires fan energy only. Turning off the PC for nights and weekends would cut the energy charge by nearly a factor of four, leaving the demand charge unchanged. Total costs (excluding effects on space conditioning energy) would decrease from $107 to about $40 per year.

Since it is unlikely that all the PCs in a given office (i.e., on the same utility meter) would be in use at the same time, automated standby switching could realize additional savings of perhaps 30% in *diversified* on-peak usage, thus reducing demand charges. With effective automatic switching, typical electricity operating costs would be reduced to about $25-30 per year. (Of course, both the baseline numbers and potential savings would be reduced by future technological improvements, just as they would be increased by the trend to larger PCs and more energy-intensive screens and printers). Other significant savings may be possible through automated switching of energy-intensive equipment such as laser printers and copy machines.[13]

3.3.3 Energy Labeling and Other "Market-Enhancement"

Some opportunities for more energy-efficient hardware and software will come from technology evolution and market pressures, often as side effects of non-energy objectives. Others may require special efforts. An energy performance label, similar to the labels on other appliances, would be one way to draw the attention of hardware manufacturers, software developers, and purchasers to energy-saving opportunities. Labeling could be done either through a voluntary industry testing and rating program, or through an extension of existing Federal or state appliance energy labeling programs. To reflect hardware efficiency, an energy label would only need to include information on steady-state power. However, by including energy use over a "typical operating cycle," the energy label could also give credit to efficient operating systems (as in laptops) that automatically shut down components until they are needed.

How much impact could energy labels have? As with many new technologies, buyers of the first few generations of PCs and other equipment are mainly concerned with cost,

---

[12] We assume typical commercial building electricity costs include an energy charge, typically 7 cents/kWh, and an on-peak demand charge, roughly $8/kW per monthly billing period, or $100/kW for the year.

[13] For example, a laser printer typically requires at least 30 seconds for the compiler to compose and format a page; this allows enough time for the toner-fusing drum to reheat, if if it were normally left in a cool(er) standby mode.

performance, compatibility, and reliability—but not power requirements. In the past, most PCs were so expensive that their energy cost seemed irrelevant. But when one can buy the equivalent of a basic IBM PC for about $600, annual energy costs of $50-100 may begin to be noticeable. Both the purchase price and annual energy costs of a basic PC are now roughly comparable to those of a large refrigerator. Of course, most business PCs are more powerful and more expensive, and total usage costs are still dominated by the user's own salary and benefits. Added to this, the person who decides which computer equipment to purchase is often not the one who pays the utility bills (a problem not unique to computers). Still, one might expect some market segments, such as larger corporate and governmental purchasers, to respond if better information were available on relative energy efficiency, especially for the tenfold differences in energy costs such as those for laptop *vs.* desktop PCs. Despite their limitations, we tend to favor labeling strategies over mandatory energy efficiency requirements for computers and electronic equipment. Mandating efficiency standards for office equipment seems too risky at present, given the rapid rate of change in electronics technology and applications.

Another policy option involves use of the public sector's purchasing power to create a stronger "market pull" for energy-efficient hardware and software. For example, major government purchasers of PCs and other office equipment (as well as institutions and corporations) could adopt more stringent purchasing criteria that go *beyond* minimizing life-cycle cost to select the system with the *lowest* energy and peak power use that is within, say, 10% of the estimated life-cycle minimum.[14] Similarly, utilities could add an emphasis on electronic office equipment to the energy audit and conservation incentive programs for their commercial customers. Utilities could also distribute to their customers information on energy performance (by brand and model) that would make it easier to weigh energy efficiency along with other features. Finally, government agencies or utilities could help develop and disseminate public domain operating software with control features that provide for the energy-efficient operation of individual PCs and networks.

3.4 Future Trends in Office Equipment Electricity Demand

This section draws on the preceding discussions of current energy use patterns, market trends, and potential efficiency improvements to outline, in broad terms, some alternative scenarios of possible future energy use by electronic office equipment in the U.S. The purpose of this exercise is *not* to construct and defend a single estimate of future demand, but rather to use order-of-magnitude numbers to illustrate the range of possibilities as well as some of the major factors at work. Such estimates are, by necessity, highly judgmental, given the rapid rates of technological change and the large number of unknowns, even for today's stock and energy usage of office electronics. The reader should mentally round off the following estimates to (at most) two significant digits.

Our starting-point is a review of some key assumptions in the EPRI report referred to earlier (Roach, 1987 and Squitieri, et al., 1986). That report presented, with appropriate

[14] In many cases, the minimum life-cycle cost is difficult to estimate precisely, and very different combinations of first-cost and operating cost may produce similar life-cycle cost estimates.

disclaimers, a possible scenario for U.S. electricity load growth in computers and related equipment, from 1982 to the early 1990s. EPRI projected electricity consumption growth of 124 TWh (31 GW increase in connected load) for selected sectors involved in "information activities": manufacturing (headquarters and office functions only), education, retail trade, finance, health care, office services (other than major manufacturing firms), and telecommunications "infrastructure" serving both homes and businesses.[15]

The EPRI estimate appears to us to be at the high end of a range of possibilities, especially if demand-side policies are adopted, to accelerate market trends toward more energy-efficient electronic office equipment. The EPRI study refers to new buildings with computer loads of 55 W/m^2 (or more). There are undoubtedly office-type facilities (financial and data processing service centers, for example) where computers and other equipment are this highly concentrated. However, we would estimate (based on the very limited data discussed above) that typical office equipment loads in new buildings are closer to 10-20 W/m^2. Equipment loads tend to be lower in existing older offices, but over time may approach those in new buildings. As discussed below, our estimates differ from those in the EPRI report on two main issues: actual *vs.* nameplate-rated power, and the relative impacts of efficient technology *vs.* expanded levels of service.

The EPRI estimates of average power per unit of equipment appear high, compared with the measured data we presented earlier. For example, added electricity use by PCs (representing about 17% of the EPRI total) are calculated at 340 W/unit, which seems high by at least a factor of two.[16] Similarly, energy use for terminals (about 5% of the EPRI total) is based on an average rating of 300 W, or more than five times the actual power consumption we measured (i.e., 40-50 W for a terminal plus 10 W for a modem or other networking electronics). These differences in power per unit make EPRI's final numbers much larger than ours, even if we accept the EPRI estimates of added equipment stocks, typical operating hours, and diversity factors.

The EPRI study assumed that minicomputers, which contribute 27% of the total growth in electricity use, required an average of 8500 W. This may be slightly high for future technology, but is close to the 6500 W we measured for a VAX 8700 (with hard disks and tape drive). That machine, in principle, can support 100 users, but typically averages only ten. In this case, the difference between maximum and average capacity translates into a range of power per user from 65 to 650 W—very significant even when we add 40-50 W/user for a dumb terminal and modem.[17] These numbers suggest that it may be inherently more difficult for mini's and mainframes to achieve energy-efficient (full) utilization, compared with the potential for "on-demand

[15] The office electronics we consider in the present report are concentrated in only three of the sectors addressed by EPRI: manufacturing, finance, and office services, which represent slightly over half the total estimated load growth (or 66 TWh). The remainder of EPRI's load forecast involves mainly non-office computer services in health care, retail sales (point-of-sale terminals), and extensive use of home videotex. This makes it difficult to directly compare our numbers and EPRI's.

[16] The EPRI report cites a range from 60 W for a Macintosh, to 614 W for an IBM PC/XT with color screen and dot-matrix printer. Our corresponding estimates, from Table 2, would be 40 W to 175 W.

[17] Or, in some cases, an added 100-150 W for a PC that functions as a terminal while linked to the central computer.

operation" of individual PCs and some other office equipment.

In addition to overestimating unit power requirements, the EPRI report does not explicitly account for future efficiency improvements. Instead, these are "... assumed to be offset by the increased power needs resulting from increased requirements for computer processing capacity and peripherals" (Roach, 1987, p. 7). In contrast, we believe that the potential gains in both hardware and operating efficiency are important enough to be analyzed separately from trends toward increased equipment saturation, usage intensities, and changes in the "levels of service" for electronic equipment.

It is hard to find definitive, published data showing how close we are to market saturation, but anecdotes can be suggestive. One analyst reports that at the Xerox Corporation in 1983, there was roughly one VDT monitor for every ten employees; by 1986 this ratio was one in four and by 1988 it was expected to be one to one (Clevinger, 1987). Saturation of terminals may be one of the simplest cases to estimate; few office workers, managers, or professionals really want to use two or more display screens at the same time.[18] Saturation of other office equipment, especially new hybrid systems for desktop publishing and multimedia presentations, is far more difficult to forecast.

However, a number of published market surveys cite trends toward a maturing market for business PCs, as well as for larger computers. Increasing fractions of new sales are devoted to replacements, upgrades, and a transfer of market share from larger central computers to smaller, networked ones. The market study by Stromer (1988), cited earlier, forecasts a continued growth in PC sales, but a decline in the annual sales growth *rate*, from 33% in 1987 to 12% in 1994. Another annual survey of 7,000 business users found a steady decline in respondents' "expected growth in hardware budgets over the next 3-5 years," from a high of 11.8%/year growth in the 1982 survey, to 7.8%/year in 1987 (Carlyle, 1987).

For purposes of broad estimates, it is convenient to think of computing power in units roughly equivalent to a PC workstation (or the corresponding share of a larger machine). The EPRI report cautions against a narrow perspective of "one PC per person," since "the ultimate goal of office automation is the integration of information work" (Roach, 1987, p. 3-1). Still, the use of a workstation-equivalent to account for general office computing needs may be reasonable, since most of this use involves similar functions: word-processing, spreadsheets, records management, and common access to corporate data bases. From an energy perspective, we have noted that the choice of a mainframe or mini *vs.* a PC may affect energy requirements, but the trend seems to be from larger machines to smaller ones, which seem to have more potential to operate with high utilization factors.

[18] One exception appears to be securities traders and international banking institutions, where some personnel reportedly have six or more screens, each linked to a different computer system. We view this as a temporary anomaly, a symptom of poorly integrated systems that should eventually disappear.

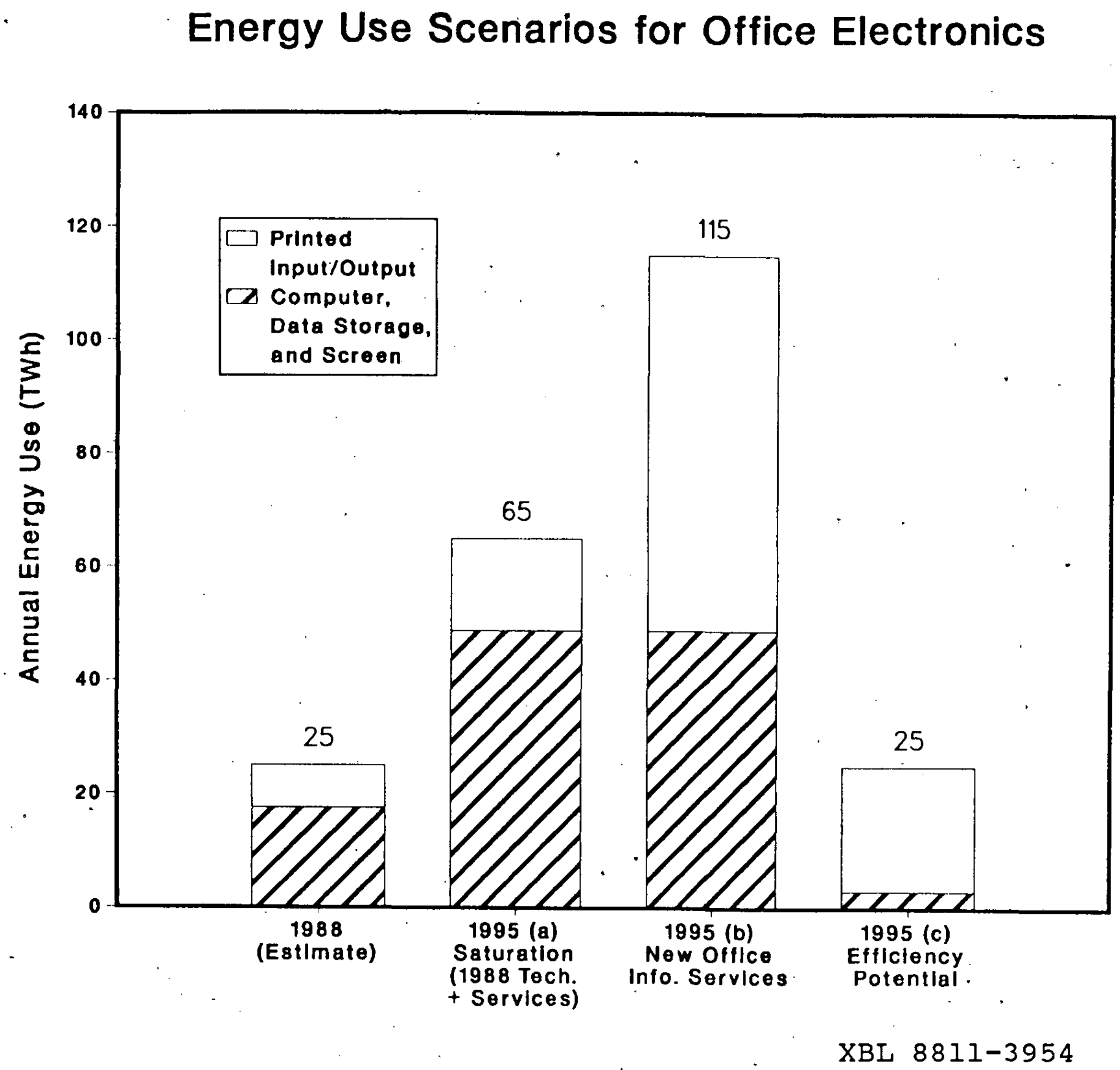


Figure 5. Alternative load growth scenarios for office electronic equipment in U.S. buildings. The current (1988) estimate is based on 25 million "screens" serving 60 million white-collar workers, at an average of 200 W/user (equivalent to a PC workstation or shared mini- or mainframe, plus screen and peripherals) and 5000 hours of operation per year. The 1995(a) scenario assumes today's hardware efficiencies and levels of usage, but shows full "market saturation" at 65 million screens. The 1995(b) scenario shows the impact of new office information services, mainly for increased input/output (I/O) using computer-generated or -scanned print media. Increased power requirements for I/O, from 50 W/user to 200 W/user nearly doubles total energy use, assuming the same technical efficiency and operating hours. The 1995(c) scenario ("technology potential") shows the impact of applying today's most efficient hardware and operating systems universally, reducing the per-user power from 150 W to 15 W for computers, and from 200 W to 100 W for I/O. Better control of idle time would reduce average annual operating hours to 3000, bringing total U.S. electricity use for office electronics back to the range of today's 25 TWh.

Our base-case scenario for 1988 (see **Figure 5**) begins with an estimate of 25 million "computer screens" (workstation-equivalents) in business use, up from 21.6 million in 1986 (Stromer, 1988). Of these, business PCs represented 60% of the total, or 15 million, up from an estimated 11-13 million in 1986 (see Table 1 and Stromer, 1988). Corresponding to these 25 million computer screens there were more than 60 million white-collar workers (not all of whom are potential computer users).[19] We then assume average power requirements of 200 W per "screen." Of this, 150 W is for computing and data storage (either a PC workstation or a shared central computer); the remaining 50 W represents printers and other peripherals (either individual impact printers or shared laser printers). Assuming an average of 5000 annual hours of operation (probably high for workstations but low for central computers/peripherals) annual energy use is about 25 TWh for today's 25 million users. The corresponding daytime peak power is about 5 GW (assuming little load diversity for office equipment at the peak daytime hour).[20]

To translate today's use into the "saturation" case for 1995, we begin with an estimate that the white-collar workforce is expected to grow by at least 30%, adding about 15 million potential users.[21] We will assume that "saturation" of computer usage would correspond to 65 million, for an expected white collar workforce of at least 75 million in 1990. Thus, today's stock of electronic equipment would grow by about 40 million screens (2.6 times) to saturate the mid-1990s market—without allowing for any significant changes in office automation technology.[22] The "market saturation" scenario (1995 (a) in Figure 5, would thus increase office equipment energy use to about 65 TWh. This number at first appears to coincide closely with the 66 TWh estimated by EPRI for three office-related sectors. However, the EPRI number represented energy demand *growth* since 1982, not total energy use. Moreover, there is some office equipment use in the other sectors analyzed by EPRI.

This first scenario does not yet account for potential increases in other types of electronic office equipment, mostly related to high-quality printed output and to electronic scanning, digitizing, and transmission of hard copy. Advances in laser printing are making it easier and cheaper to produce high-quality computer output; this has the potential to translate into a large growth in electricity demand. Other recent product innovations with large market potential include scanners, optical character recognition, and presentation graphics systems. For these devices, we envision continued technical advances, sales growth, and powerful new applications,

[19] The Bureau of Labor Statistics (BLS) estimated 1986 white-collar employment, including management, professionals, technicians, sales and administrative personnel, at 61 million (Statistical Abstract, 1988, pp. 376-7). The EPRI report cited a 1983 BLS estimate of 55 million.

[20] Both these numbers, and the EPRI estimates, exclude the impact of office equipment loads on heating and cooling energy. Added cooling and fan energy could represent another 20-40% of indirect energy use, depending on HVAC system efficiencies, for those buildings (and hours of the year) that require cooling; similarly, heating energy would be reduced in some cases.

[21] The Bureau of Labor Statistics predicted a 30% workforce growth for several sectors where white-collar employment is concentrated (retail trade, finance and insurance, business services, education, and legal services); together, these sectors account for about half of all white collar workers (Statistical Abstract, 1988, p. 380). CBEMA (1985) projected the number of "office workers" increasing from 58 million in 1984 to 81 million by 1995, a growth of 40%.

[22] This is reasonably consistent with the market forecast cited by Stromer (1988) which envisions roughly a tripling of PCs in use between now and the mid-1990s, some of which would replace larger machines.

most likely as components of integrated office automation systems. For example, scanners, laser printers, and copiers may soon be integrated as components of a single desktop machine, perhaps shared by several users (Blankenhorn, 1988).

We think that such changes in office automation technology will affect energy use for hard-copy input/output devices more than energy needs for computing and data storage. Thus, the second scenario (1995 (b) in Figure 5) includes an added 150 W/user, beyond the 200 W already estimated for computers, screens, and printers. In this scenario, increased energy use by advanced copiers, scanners, fax machines, telecommunications, and other electronic office equipment would nearly double our annual energy estimate, from 65 TWh to about 115 TWh. This is, again, a market saturation scenario for 1995, which allows for a significant change in office automation services but still does not reflect any improvements in hardware or operating system efficiency.

The last scenario (1995(c) in Figure 5) attempts to account for the hardware and operating system efficiency opportunities discussed above, most of which are already on the market. It illustrates the technical potential for reducing projected electricity demand by a factor of about five, to about 25 TWh, or the same level as today, but with virtually full saturation of the office sector, and major changes in the level of office automation. This scenario assumes that market trends, reinforced by aggressive demand-side policies and programs, would allow today's "best" (most energy-efficient) technology to become the market average by the mid-1990s.

For example, the 150 W/user represented by the computer, data storage, and screen, could be reduced to 15 W without sacrificing computing power or capabilities, by using today's best laptop technology. The 200 W/user that we projected for input/output devices could probably be cut in half through the use of more efficient printing and scanning technology. Thus, the scenario assumes a reduction from 350 W to 115 W/user, on average. Better automated control of equipment usage and idling time could reduce average annual usage from 5,000 to 3,000 hours. This is still more time than the average user would require for computing or information management, thus allowing some off-peak usage hours for non-interactive computing, printing, or data transfer jobs. These alternative assumptions, for 60 million users, give us a final order-of-magnitude estimate of roughly 20-25 TWh/year as the "technical efficiency potential" for energy use by office electronics by the mid-1990s.

In the longer term, there are other powerful forces that may slow energy demand growth for office electronics. Continuation of today's trends toward increased system integration and inter-system compatibility could eventually allow electronic media to replace much of the paper now being generated. This is in contrast to our present, hybrid approach, which in many cases uses office electronics to produce more (and better) paper output, encode and transmit the visual image with a fax, print it again, and then convert it back to electronic storage using a scanner. Prospects for a "paperless office" have been discussed (on paper, of course!) for several years, but the time may finally be approaching when major vendors introduce practical hardware and software products aimed at this goal.[23] In addition to gains in office worker productivity and

[23] For example, IBM has just announced a major new office automation system called "Image Plus," which includes image-processing as well as conventional functions such as text-processing and electronic communications.

office support costs, the aggregate energy and cost savings for paper manufacturing, printing, distribution, file storage, and waste disposal (or recycling) could be substantial.

During the past few months, the authors of this paper have developed their own first-hand experience with electronic communication. During most of the period when the actual writing was done, the four of us were located in Princeton, New Jersey; Berkeley, California; Paris, France; and Bordeaux, France. We established an electronic link via Bitnet to exchange drafts and comments, and submitted electronic as well as hard-copy drafts for review and editing in this volume. Although the electronic mail was often fast and convenient, it somehow did not replace the need for printing and copying repeated drafts on paper, amounting to many hundreds of pages by the time the article went to press. Clearly, the Age of Electrons has not yet fully replaced the Age of Wood Fibers.

The objective of this system is "to move from a paper-based to a computer-based system for information storage and retrieval." The system is targeted initially to medium- or large-scale firms or government agencies, especially those involved in "case-work" activities which produce a high volume of non-coded document information in diverse formats, such as insurance, banking, real estate, health care, social services, and criminal justice (IBM, 1988).

4.0 RECOMMENDATIONS FOR FUTURE WORK

Much work is needed to develop better information on energy use trends for electronic office equipment and on energy efficiency opportunities. Ongoing research at LBL and Princeton, in cooperation with other organizations, will focus on:

- development and dissemination of standard definitions for miscellaneous end-use loads, equipment types, etc., to allow better comparability of results from on-site surveys and end-use load metering projects.

- analysis of data from several completed or planned commercial on-site surveys, as well as from end-use metering of plug loads from the ELCAP project and other sources.

- examination of energy use (rated *vs.* measured) and the underlying technology trends for other types of electronic equipment (telefax machines, copiers, scanners) and for other non-residential building types (schools, retail, etc.).

- an extensive assessment of available studies on market trends, including important but seldom-examined issues such as retirement and replacement rates, and the long-term energy implications of a "paperless" office.

In many ways, the issues of improved energy efficiency in electronic office equipment parallel those for more familiar topics such as commercial lighting and space conditioning. Opportunities range from simple operational and housekeeping measures to subtle—or sometimes dramatic—advances through new technology. Some of these will occur through the natural evolution of technology and market forces, but to speed this process we can provide better information to all the actors on both supply and demand sides of the marketplace. This process can only begin once we recognize and quantify the importance of electronic equipment as a distinct, growing, and potentially costly electrical load, not just part of the "other" uses in the commercial sector.

5.0 REFERENCES

H. Akbari, M. Warren, A. de Almeida, D. Connell, J. Harris, "Use of Energy Management Systems for Performance Monitoring of Industrial Load-Shaping Measures," forthcoming in *Energy*, 1988.

R. Alereza, California Energy Commission staff, personal communication, October 1987.

T. Alereza and J.P. Breen, "Estimates of Recommended Heat Gains Due to Commercial Appliances and Equipment," *ASHRAE Transactions*, 90:2A, 1984, pp. 25-58.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), "Proposed Standard for the Energy Efficiency Design of New Buildings," Third Public Review Draft, Sept. 29, 1987, pp. 8-21 and 9-2,-3, Atlanta, Georgia.

[ASHRAE], *Handbook of Fundamentals*, 1977, page 25.20.

S. Becker, "Fax Meets High-Tech Objective of Speed and Cost-Effectiveness," *Office Systems, 1986*, pp. 60-68.

D. Blankenhorn, "Pursuing One Peripheral," *Datamation*, October 15, 1988, pp. 71-76.

[Bull, 1988]. Product literature, Bull MP 6090, and personal communication from Bull sales representative, April 1988.

[*BYTE*] Manufacturers' advertisement for a hard-disk drive, *Byte* magazine, April 1988.

C. Itoh Electronics, Inc., Personal communication, C. Itoh regional sales manager, July 1988.

California Energy Commission (CEC, 1987a), "Demand Forecasting Issues: CFM 7," Sacramento, Calif., Report P300-87-015, August 1987, pp. 3-18 to -23.

California Energy Commission (CEC, 1987b), "Notice to Building Officials" on alternative compliance methods for Title 24 code requirements, mimeo, Sacramento, Calif., November 23, 1987.

R.E. Carlyle, "Midrange Shootout: Mini/Micro Survey," *Datamation*, Nov. 15, 1987, vol. 33, no. 22, pp. 60-76. (Citing a 1987 market survey by Datamation/Cowen & Cowen.)

J.Y. Chen, "CMOS—The Emerging VLSI Technology," *IEEE Circuits and Devices Magazine*, March, 1986, pp. 16-31.

S. Chou and C. Simonsen, "Chip Voltage: Why Less is Better," *IEEE Spectrum*, April, 1987.

M. Clevinger, comments on "Smart Office Buildings," in *Technology and the Future of the U.S. Construction Industry*, U.S. Congress, Office of Technology Assessment, 1987, pp. 34-38.

[Data Analysis Group], "Computer Industry Abstracts," published by the Data Analysis Group, Inc., La Mesa, Calif., Second Quarter 1987.

Computer and Business Equipment Manufacturers Association (CBEMA), "Computer and Business Equipment Marketing and Forecast Data Book," CBEMA, Washington, DC, 1985.

Computer and Business Equipment Manufacturers Association (CBEMA), "The Computer, Business Equipment, Software & Services, and Telecommunications Industry, 1960-1996," CBEMA, Washington, DC, 1987.

R. Cook, "Page Printers," *Byte*, September, 1987, pp. 187-197.

R. D. Davies, "The Case for CMOS," *IEEE Spectrum*, October, 1983, pp. 26-31.

[Electronics, 1987a]. "1987 U.S. Market Report," *Electronics*, January 8, 1987, pp. 51-74.

[Electronics, 1987b]. "1987 Overseas Market Report," *Electronics*, January 22, 1987, pp. 65-88.

Energy Information Administration (EIA), U.S. Dept. of Energy, "Commercial Buildings Consumption and Expenditures, 1983," Report DOE/EIA-0318 (83), September 30, 1986.

J-J. P. Eltgen and J. G. Magnenet, "Magnetic Printer Using Perpendicular Recording," *IEEE Transactions on Magnetics*, Vol. Mag-16, No. 5, September 1980.

M. Hogan, "Industry Outlook," *PC World*, May, 1988.

P. Horowitz and W. Hill, *The Art of Electronics*, Cambridge University Press, Cambridge, 1980.

IBM (International Business Machines), Internal product information and personal communications from W. Thomas, IBM Southwest Marketing Division, Oakland, California, 1988.

K. Keer, "Technology is Redefining Copying-Machine Functions," *Office Systems*, March 1986, pp. 34-44.

M.H. Kryder, "Data Storage Technologies for Advanced Computing," *Scientific American*, 257:4, October 1987, pp. 117-125.

M. Le, C. Itoh Electronics Corp., personal communication, July 1988.

A. Lovins, "Advanced Electricity-Saving Technologies and the South Texas Project," Report to the Electric Utility Department, Austin, Texas, Rocky Mountain Institute, May 1987, p. 19.

A. Meier, "Saving the 'Other' Energy in Homes," *Energy Auditor and Retrofitter,* Nov.-Dec., 1987.

J.D. Meindl, "Chips for Advanced Computing," *Scientific American*, 257:4, October 1987, pp. 78-88.

J.D. Meindl and J. Sturm, personal communication, 1988.

D. Nguyen, R. Alereza, E. Hamzawi, "Energy Consumption by Computers and Miscellaneous Equipment in Commercial Buildings," forthcoming in *Proceedings* of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, Calif., August 1988.

W. Nihei, "The Color of the Future," *PC World*, February 1987, pp. 278-83.

A. Peled, "The Next Computer Revolution," *Scientific American*, 257:4, October 1987, pp. 57-64.

[Personal Computing], "Business Computing in a Flux," *Personal Computing*, December 1987, p. 369, citing as a source Comtec Market Services.

M.A. Piette, "A Comparison of Measured End-Use Consumption for 12 Energy-Efficient, New Commercial Buildings," *Proceedings* of the 1986 ACEEE Summer Study, Santa Cruz, California, August 1986.

C. Roach, "Productivity Tools for the Information Economy: Possible Effects on Electricity Consumption," final prepublication draft report to the Electric Power Research Institute, Palo Alto, Ca., mimeo, June 1987.

R. Squitieri, O. Yu, and C. Roach, "The Coming Boom in Computer Loads," *Public Utilities Fortnightly,* Dec. 25, 1986, pp. 30-34.

Statistical Abstract of the United States, 1988, 108th Edition, U. S. Dept. of Commerce, Bureau of the Census.

R. Stromer, "New Service Forecasts Future of Microcomputer Market through 1994," *PC Week*, vol. 5, p. 130, March 1, 1988.

S. Taylor, Linford Engineering, Oakland, Calif., personal communication, 9/87 and 11/87.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720