Title

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ABSTRACT

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. As an important element of the "other" end-use, electronic office equipment merits recognition as a distinct end-use, based on its aggregate energy consumption, contribution to peak demand growth, and potential for improved energy efficiency. Major findings—based on available data on market trends for electronic office equipment, energy intensities, saturation and usage patterns, and efficiency opportunities—include:

- Actual electric loads for the equipment we measured, when in operation, were typically 20-40 % of nameplate ratings. Energy analyses based on nameplate ratings thus overstate actual power requirements.
- Daily load profiles and on-peak diversity factors seem to vary by type of equipment and by office scheduling practices, but more detailed, measured data are needed.
- Both building designers and energy demand forecasters may tend to overestimate office electronics loads, perhaps in reaction to previous underestimates. We estimate typical daytime loads for office electronics (where present) at 10-20 W/m^2, rather than 30-50 W/m^2 as sometimes claimed.
- 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.
- Smaller-scale, dispersed computers and other equipment (small copiers, etc.) have been gaining market share *vs* large, centralized systems. This trend, if it continues, may market penetration among smaller buildings and firms, and management strategies for thermal loads that are dispersed throughout the occupied space.
- 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 improve energy efficiency in both hardware and software, often as a by-product of other objectives such as miniaturization. Several policy options could accelerate these market and technical trends.

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- Future commercial surveys, on-site energy audits, and end-use monitoring projects need to collect better quality, more detailed and more consistent data on office electronics and other miscellaneous end-uses.

THE SUM OF MEGABYTES EQUALS GIGAWATTS: ENERGY CONSUMPTION AND EFFICIENCY OF OFFICE PC's AND RELATED EQUIPMENT*

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INTRODUCTION

Commercial and residential building end-use studies often include an "other" category, which can represent 20-25 % (or more) of total energy use (Piette, 1986 and Meier, 1987). Once an end-use has been relegated to this "other" category, there is often little effort made to examine it further, or to analyze opportunities for improving its energy efficiency. Of special interest within 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 for other than occupant comfort and lighting.[1]

This paper presents initial findings from an ongoing project at LBL and Princeton. One of our ultimate objectives is to establish office electronics as a *distinct, recognized end-use* within the commercial sector. We rely, wherever possible, on *measured* data for both individual equipment and complete buildings. 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.

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 1980's and the 1990's (Roach, 1987 and Squitieri, et al., 1986). This represents a rather dramatic 24 % increase over the estimated 526 TWh of electricity for total commercial electricity use in 1982; 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 in new, New York City commercial buildings (for all plug-in equipment, not just office computers) that range from 55-130 W/m^2 (5-12 W/ft^2) for offices and banks, to 215 W/m^2 (20 W/ft^2) for large computer service centers. These levels substantially exceed lighting power intensities of about 15-20 W/m^2 (1.5-2 W/ft^2) in a well-designed new office building. 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

* This paper presents selected results of an ongoing study; the authors are preparing a more detailed account as a chapter in a a forthcoming book (1989) sponsored by the Swedish State Power Board, on efficient electricity end-use and new generation technology.

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[1] Exceptions are elevators in high-rise offices and mixed-use buildings with restaurants, laundries, food stores, etc. (Nguyen, et al., 1988).

sample of U.S. commercial buildings. However, the fragmentary data we have seen suggest that these 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 both of these issues below.

The EPRI study, already widely quoted in the utility industry, has sparked debate among demand forecasters in utilities and regulatory agencies (CEC, 1987a, p. 3-20). Trends in energy use and peak loads for computers and other office electronics are of concern not only to demand forecasters, but to building designers, mechanical or electrical contractors, code-setting and enforcement organizations, facility managers and "shared-savings" contractors, and energy analysts and policy-makers.

The next section of this paper provides an overview of office electronics as a specific end-use in commercial buildings. The subsections examine available data on: market trends, equipment saturations, rated vs. actual power requirements per unit, and usage patterns. A third section addressed energy efficiency options through changes in hardware, software, and operating strategies. The final section discusses remaining needs for measured data and analysis.

"OFFICE ELECTRONICS" AS A COMMERCIAL END-USE

One difficulty in writing about office electronic equipment is that there is no single, widely-accepted definition of what is included. Our own definition includes all energy-using equipment related to the "information processes" associated with business and professional activities—but we recognize that these processes themselves are rapidly evolving, paralleling changes in office automation technologies. New types of electronic equipment are constantly being introduced—as are advanced features, inexpensive smaller models (like desktop copiers and laser-printers) that perform many of the functions of larger models), and new hybrids that combine microcomputers with other familiar equipment such as phones, drafting equipment, filing systems, cash registers with point-of-sale inventory systems, and audio-visual presentation systems. In some cases, a familiar piece of equipment may be virtually transformed with new electronic technology. Today's conventional photocopier, for example, may be eventually 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).

Market Status and Trends

Table 1 presents some published market-research estimates for selected office equipment, including the 1986 stock and estimated annual sales. According to Table 1, about 13 million out of the total 32.5 million single-user PCs were in business use in 1986 stock, as well as 375,000 minicomputers and over 2,000 mainframes.[2] Table 1 shows that monochrome monitors still outnumbered color monitors by nearly two to one. Non-impact printers, including both inkjet and laser-printers, were under 10 % of the stock but over 15 % of new sales in 1986.

[2] A different source estimated that there were about 11 million PCs in business use in 1987, representing about half of the 21.6 million "computer screens" used (Stromer, 1986, citing a report by Comtec).

For each type of equipment in Table 1, annual sales are large (25-45 %) in comparison to the 1986 stock. This shows how rapidly the sector is changing, both due to growth and to rapid equipment turnover. One recent market study reported that, of 2.8 million PCs planned as business purchases in 1987-88, about 10 % of these (267,000) were to replace existing PCs (Personal Computing, 1987). A separate study projected business sales of 3.6 million PCs in 1986, with 22 % for replacements and 78 % for new or expanded use (Stromer, 1986). Annual 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—indicating a "maturing" and increasingly saturated market for business PCs.

An important trend, not obvious from Table 1, has been the tendency for PCs and other smaller computers to overtake mainframes in a number of 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, mainframes and single-user PC's had *reversed* their market positions after only four years. 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 B, a fourfold increase over 1982 sales). The number of PCs sold in 1986 was 2.5 times larger than in 1982. Over the same period, the number of mainframe units sold 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.

The overall U.S. market for data processing equipment is about $80 billion per year (Electronics, 1987a).[3] 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 %. U.S. sales of data processing equipment closely mirror the aggregate market patterns for five major industrialized countries: Japan, France, the U.K., W. Germany, and Italy, with data processing equipment sales of about $78 billion and a total electronics equipment market of $149 billion (*Electronics*, 1987b).

A continuing market shift from larger computers to smaller ones (and to laptop portables) is predicted by most analysts, along with other trends that could affect energy intensities. One source that periodically reviews reports by other industry analysts has estimated the following *annual* growth rates in dollar sales, from 1987 to 1990 (Data Analysis Group, 1987, pp. 86-87):

6 %	for large computers (> $1 M)
11 %	for medium computers ($100 K - $1 M, 15-128 users)
27 %	for multi-user micros, workstations ($6 K - $25 K)[5]
17 %	for desktop PCs
28 %	for laptops
31 %	for non-impact (laser) printers

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

- 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.
- *Color printers and plotters* are increasing in popularity; estimated 1987 sales were 650,000 units, projected to increase to 1.1 million by 1990. Color laser-printers may be introduced soon (Nihei, 1987).[6]
- *High-resolution and color monitors* are gaining in popularity; both tend to be more energy-intensive than conventional monochrome units (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.
- *Desktop publishing* systems are relatively new but growing in popularity, with sales jumping from an estimated 84,000 in 1986 to nearly 550,000 by 1990. They typically include a PC workstation or minicomputer, high-resolution display, laser-printer, and other energy-intensive devices such as *optical scanners*.
- In the next few years, laser printers will make high-quality computer output easier and cheaper; this will translate into a potentially large source of electricity demand growth. In the long term, however, improvements in communications links and protocols across different computer systems may ultimately allow the widespread use of electronic media as a substitute for hard-copy, with resultant large savings in energy.

Equipment Saturations in Commercial Buildings

California utilities recently conducted an extensive series of on-site commercial building surveys, which included detailed inventory data and nameplate ratings on computers and other miscellaneous equipment. The initial results, for 855 commercial buildings in one California utility's service area, showed an average electricity connected load of 11 W/m^2 (1 W/ft^2) for computers in large and small offices (Alereza, 1987). This was based on nameplate ratings, not actual power requirements (which are generally lower; see Table 2). Newer (post-1975) large office buildings tended to have significantly larger computer equipment loads, typically 16-22 W/m^2 (1.5-2.0 W/ft^2; Nguyen *et al.*, 1988).[7]

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[5] No estimates were given for computers in the $25 K - $100 K range.

[6] Color copiers, priced at around $4 K, 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 monochrome equipment, with energy requirements per page increased by nearly this same factor.

[7] A more detailed analysis by Nguyen, *et al.* (1988) was based on a set of "usage factors" (defined as the ratio of power consumption "under normal operating conditions" to nameplate ratings). These usage factors were based in part on an earlier ASHRAE study (Alereza and Breen, 1984); 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, compared with the measured data presented in Table 2, below.

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). 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. Past ASHRAE guidelines for estimating miscellaneous equipment loads were slightly 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. 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).

The limited amount of available data—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, and many existing or renovated buildings, as well. 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).[8] 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 2**. For these buildings, miscellaneous electric equipment loads were higher than the nominal values assumed in California's statewide building standard. 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 new office buildings range from 11 to 22 W/m^2 (1 to 2 W/ft^2).

Typical Equipment - Actual vs. Rated Loads

We used a portable power meter to make short-term measurements of the actual power requirements for selected PCs, components, and peripheral equipment. We measured power in "active" operation and standby mode, and compared both measurements with nameplate ratings. Measured data are presented in **Table 2** and **Figure 2.**[9] Our principal findings include:

- Significant variations in power requirements for equipment in the same general category (laptop vs. desktop PCs, impact vs. laser-printers).
- Nameplate ratings which overstate actual measured power by factors of 2-4 for PCs and 4-5 for printers. This is especially significant, since many demand projections and building design decisions are based on rated rather than measured demand.

[8] Maximum loads, including an assumed diversity factor.

- Once turned on, PCs are essentially a constant load; power requirements for printers vary by a factor of about 2 between standby and printing modes.

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

(a) *Desktop and laptop PCs.*

Nameplate power ratings typically overestimate actual power consumption by a factor of 2-4. 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). Macs use less power than IBM PCs, for roughly equivalent computing and storage. Newer models with equivalent performance are often more energy-efficient. 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 the IBM PC using only about *one-tenth* the power. The large range in power requirements prompted us to measure power requirements for individual components of a few machines. The results discussed below are shown in the last two columns of Table 2, for monitors, and in Figure 2 for other components of the IBM models.

(b) *Monitors*. Monochrome monitors for IBMs and the Atari required 26-32 W. Color displays for the AT, PS-2, and Mac-2 are much more energy intensive, requiring 48-66 W.[10] 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 typical 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.

(c) *Other PC components*. Figure 2 shows separate measurements on our IBM models for disk drives, power supplies, and logic boards. Floppy disk drives power increases by 2-7 W.[11] This are the only noticeable source of power variation once the computer is turned on; it is so small that computers can be considered constant power devices. Electrical power for hard disks does not appear to scale with storage capability, at least in typical PC sizes (see Figure 2). 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 a variety of 10-30 MB, full-height drives. Power supplies for the five desktop units we measured required 11-25

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[9] Note that "Average" measured power refers to an average of several short-term readings of a few minutes each; little fluctuation was noted. "Peak" readings occur when all disk drive motors are in use.

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

[11] 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.

W. Power use for logic in the IBM PC series ranges from 11 to 13 W for "motherboards"; extra boards on the models we measured consumed 12 to 35 W per machine. Including power for the disk controller cards, integrated circuit chips accounted for 32-71 W, or 28-42 % of the total PC power requirements for our IBM models. Thanks to low-power transistors, our laptop Toshiba 1100-Plus required only 11 W when operating. The power supply, rated at 15 W in and 10 W out, uses about one-third of the total power. Disk access increased the measured power by about 2 W per drive; we could not detect a change in power when disconnecting the LCD screen or the disk drives. Trickle-charging the battery pack required 8 W.

(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.[12] 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, due to high print quality, flexibility, and declining prices (now well below $2000). While laser-printers are much more energy-intensive, they use only about one-third of the nameplate rated power.

Usage Profiles and Energy Consumption

Electric utilities are primarily concerned with the growth of *on-peak* loads due to 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 little measured data. Most mainframe and many minicomputer systems operate continuously; some may be shut down on weekends. Anecdotally, PC usage patterns ranges from those consistently shut off when not in use to those left on virtually all the time. Control of peripherals, such as a laser-printer shared by several workstations, is probably much more lax.

At present, we have only limited data on measured load profiles **Figures 3a and 3b** are examples of daily load profiles for miscellaneous office "plug" loads, but neither one contains electronic office equipment exclusively. Figure 3a shows a typical weekday load profile for all "tenant loads" (including both plug loads and lighting), for a medium-size leased office building in New Jersey. 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 late afternoon and evening. Lights were not metered separately, but an inventory and on-site visits provide an estimate of 16 W/m^2 (1.5 W/ft^2) for general purpose and task lighting during the day, and 1-2 W/m^2 at night. Thus, the daytime tenant load due to office equipment is about 15 W/m^2 (1.4 W/ft^2).[13] At night, office equipment power drops to about 5-6 W/m^2; approximately 40% of the office equipment is left running. Some of this equipment is needed for remote communications, but the

[12] 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: about 80 W for the inkjet and dot-matrix printers, and 500-700 W for the laser-printers.

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

majority, including word processors and copying machines, appear to be powered up unnecessarily.

The second data source (Figure 3b) comes from end-use monitoring of a small office building (about 850 m^2) in the Pacific Northwest. Most of the "plug" loads shown, based on an inventory, are due to office electronics.[14] 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 this.

ENERGY EFFICIENCY OPPORTUNITIES

Potentially offsetting expected load growth for office electronics are 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.

Potential Hardware Improvements

Laptop computers, 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) chips 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). Use of CMOS chips could eliminate a large fraction 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 thus become today's dominant technology for more 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 would account for nearly half the integrated circuit market by 1990 (Davies, 1983 and Meindl and Sturm, 1988). While CMOS is slightly slower than NMOS, cost has been the main factor limiting its usage. There is a premium of about 50-100 % for CMOS chips, at present. Outside the laptop PC market, a market 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). A second 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. Some chip developers are already using 3.3 V in new four- or sixteen-MByte memory chips, in lieu of the current industry standard of 5 V (Chou and Simonsen, 1987). The number of devices per chip has been quadrupling every three years a trend that should persist until the early 1990's (Meindl, 1987). 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

[14] Not included in Figure 3b is power for a separately metered minicomputer, which shows a similar daily load profile and would add about 10 % to the plug loads.

gain in data storage should come at no increase in electrical power.

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 has been applied to smaller models, due to limitations on the output rate.[15] Copy quality is a concern to some users we talked to, since the surface of the copies is glossier than with a plain-paper copier using conventional heat-and-pressure fusing. With much lower standby power requirements (12 W, according to Lovins), there is no warmup time as with conventional copiers, and quieter operation since no fan is needed to cool off the paper. Also, cold-fusion copiers may be reduce cooling loads and improve comfort where occupants share a small office with a desktop copier. A new series of high-end computer printers (i.e., 1-2 million sheets/month) uses 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). The manufacturer claims that this new process is more reliable (with 100 moving parts rather than 4000) and lower in first-cost than an equivalent conventional machine. C. Itoh Electronics has also recently developed an alternative to the laser printer, with their machines based on ion-deposition technology (Cook, 1987 and Le, 1988). The printer drum is much harder than the light-sensitive drums used in laser printers, making it possible to fuse the toner to the paper by means of pressure rather than heat-and-pressure, which is now standard. The available models have output rates of 30 and 45 pages per minute (ppm). C. Itoh is considering the application of the same technology to mid-range, 15-20 ppm printers. The ion-deposition printers are claimed to have lower first-cost and enhanced drum durability as well as reduced electricity consumption, contributing to lower per page costs than for laser printers of comparable size.

Software and Operations

The most effective way of reducing a computer's energy use is to turn it off when not in use. Many desktop computers are left running throughout the day, and sometimes even at night and on weekends. Even a computer with low-power CMOS chips needs power for hard-disk drives, the monitor, and the power supply, which together 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 turn off the power. Booting times vary 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 K this takes about 45 seconds. Since memory failures are rare, the operating system could be modified to make this diagnostic optional, as is done with the Digital Rainbow PC. Future machines may contain their operating system in nonvolatile memory, to avoid the slow 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, while many have no switch at all.[16] An automatic switch for screens (and other components) could use the same sensor

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

[16] 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 the visual reminder of a lighted screen.

currently installed for the "screen-saver" feature—which saves virtually no energy. The necessary switching technology has already been developed for laptops, in order to stretch battery operating times (Hogan, 1988); it could now be readily applied to desktop machines.

Energy Labeling and Other "Market-Enhancement"

Some opportunities for more energy-efficient hardware and software will occur through technology evolution and market pressures, often as side-effects of non-energy objectives. Others may require special efforts to accelerate their introduction. One way to draw more attention to energy issues and opportunities, from hardware manufacturers, software developers, and purchasers, is to introduce a state or federal energy performance label for small computers, similar to the labels on other appliances.

Today, one can buy the equivalent of an IBM PC for about $600; at this point, annual energy costs of $50-100 become significant (both purchase price and annual energy costs for a PC are comparable to a large refrigerator). To make a labeling program easy to implement, the manufacturer might provide information only on the steady-state power. The label might show annual energy costs for continuous operation, perhaps noting that this would be cut by a factor of four if the computer were turned on only 40 hours per week. A special symbol could be used for models with special features, such as automated power-down built-in to the hardware or operating system software.

Another policy option involves use of the public sector's purchasing power to create a stronger "market-pull" for more energy-efficient PC hardware and software. For example, major government, institutional, or corporate purchasers could adopt more stringent purchasing criteria, which emphasize the *lowest* energy and peak power use that is cost-effective on a life-cycle basis.[17] Similarly, utility energy audit and conservation incentive programs for commercial customers could add a special emphasis on electronic equipment, including brand- and model-specific information that make it easier to compare energy-efficient features, along with other performance attributes. Finally, government agencies or utilities could sponsor the development and wide dissemination of public domain software that assists with energy-saving operation of PCs and networks.

CONCLUSION: DATA NEEDS AND FUTURE WORK

There are a number of steps needed to develop better information on trends in energy use and opportunities for efficiency for electronic office equipment. As part of ongoing research at LBL and Princeton, we hope to collaborate with other organizations on:

- development and dissemination of standard definitions for miscellaneous end-use loads, equipment types, etc., to improve comparability of results.

[17] It will take time, however, for the market to respond to this "demand-pull." At present—in part because of the lack of awareness of computers and other electronic office equipment as energy users—there are few practical choices for even an informed and motivated buyer.

- analysis of data from on-site commercial surveys and end-use metering.
- examination of energy use and technology trends for other types of electronic equipment (telefax machines, copiers, scanners) and other non-residential building types.
- a more extensive, independent assessment of available market-research studies on market trends, and the longer-term energy implications of a "paperless office."

Basically, the issues of improved energy efficiency in electronic office equipment parallel those for now 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.

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Table 1: Estimates of U.S. Stock and Annual Sales for Selected Electronic Equipment[a]
(in thousands of units)

Equipment Type	1986 Stock[d]	Annual Sales, 1986
Single-User PC's	32,500	7,800[e]
Business Use	*(13,000)*	--
Home Use	*(17,500)*	--
Schools	*(2,000)*	--
Minicomputers[b]	375	--
Mainframes	2.4	--
VDT Monitors	23,000	7,600[f]
Mono	*(15,000)*	--
Color	*(8,000)*	--
Printers and Plotters	21,000	5,900[g]
Impact[c]	*(18,000)*	*(5,000)*[g]
Non-impact	*(2,000)*	*(900)*[g,h]
Plotters	*(1,000)*	--

Notes and Data Sources for Table 1:

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

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

(c) Including dot-matrix printers.

(d) 1986 stock estimates and 1986 PC sales 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 PC's *exclude* multi-user PC's.

(e) A higher estimate of 1986 PC sales, 7,100 K units, is shown in Table #1285 in the 1988 *Statistical Abstract*, citing data from Dataquest, Inc., San Jose, Calif. A significantly 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. The 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), but these studies focus on market-share and thus may not include all sales.

(f) This estimate for monitors is for "PC terminals," as reported in "Computer Industry Abstracts," 2nd Quarter 1987, p. 123 (i.e., may not include terminals used for multi-user mini's and mainframes). Original citation is "The Shifting Images of the Monitor Market," in *Computer Reseller*, Dec. 1986, p. 44.

(g) J.W. Dower, N. Luft, S. Puopolo, *1987 Printout Annual*, p. 4.

(h) 1987 sales predictions for laser printers alone (a rapidly growing subset of non-impact printers) ranges 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 160-200,000 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 81,000 units.

Table 2: Rated vs. Measured Loads for Selected Equipment

Equip. Type and Model	Features[a)]	Rated[b)] Power	Measured Power[c)] Average	Measured Power[c)] Peak	Avg. as % of Rated	Avg. as % of Peak	Screen Only Rated	Screen Only 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		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 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 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 across 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 due to 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.

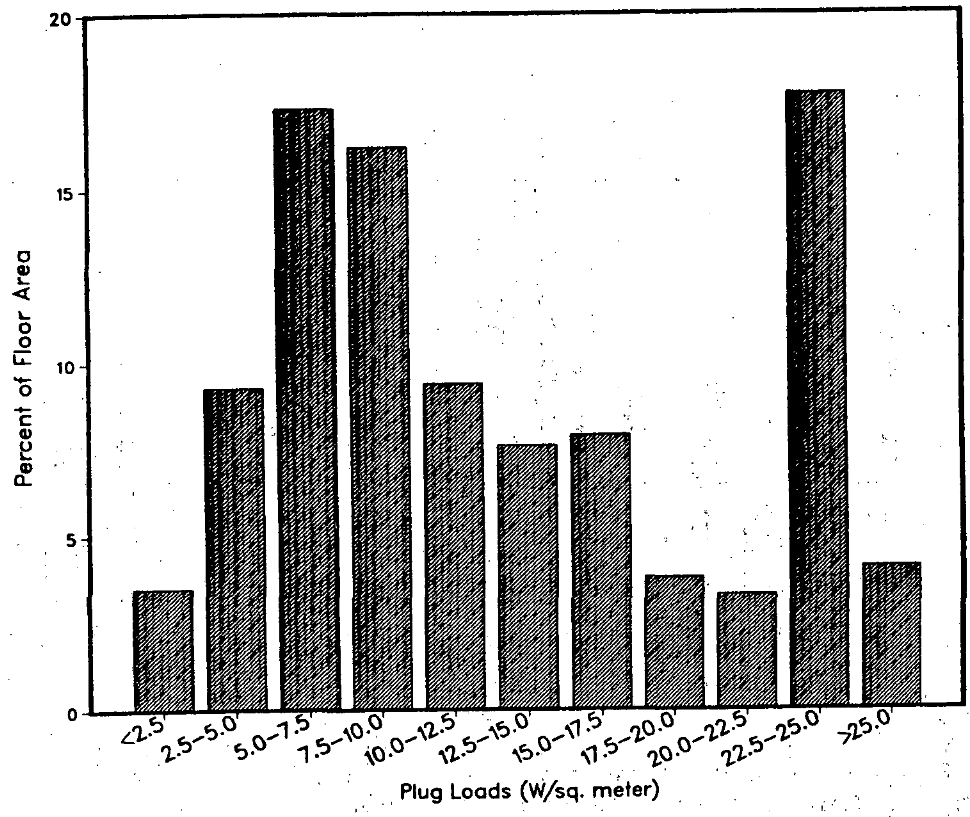

Figure 1. Distribution of Tenant Equipment Load Intensities in 3 New Mixed-Use Commercial Buildings in Northern California. The mean value is 14.1 W/m^2 (1.31 W/ft^2), the median, by floor area is 1.4 W/m^2 (1.04 W/ft^2). These maximum daily equipment loads, for all plug-in equipment (not just office electronics) include an assumed diversity factor. Source: S. Taylor, 1987.

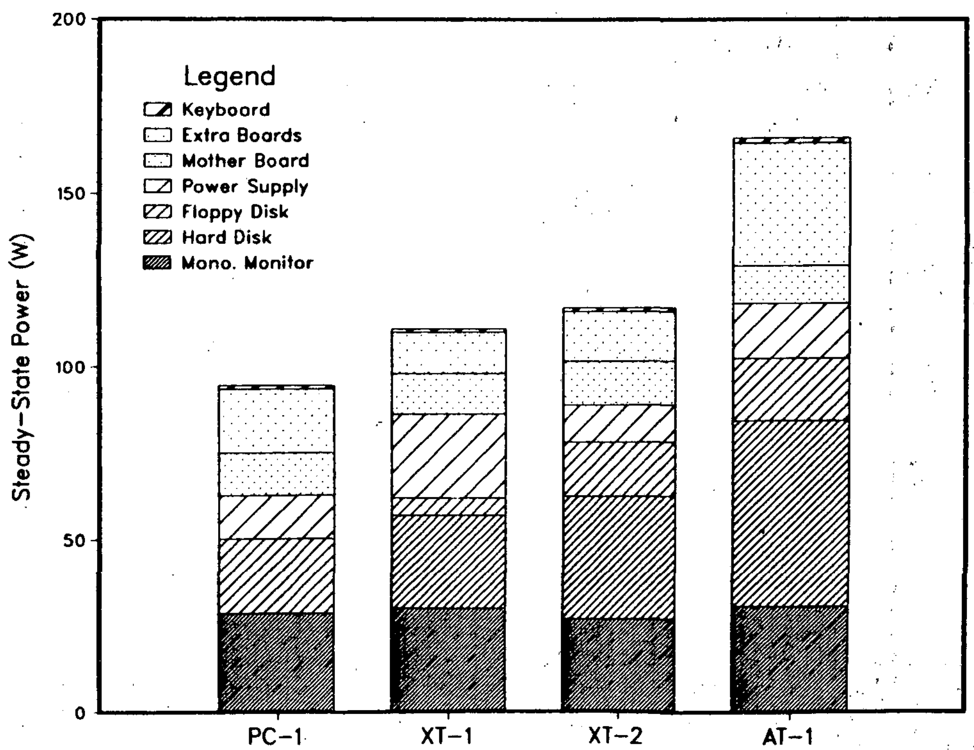

Figure 2. Measured Component Power Requirements for Four PCs. Measurements were made using a Dranetz Model 808 Electric Power/Demand Analyzer. Component power was determined by disconnecting each component and noting the power drop. These averages of several short-term measurements are accurate to about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

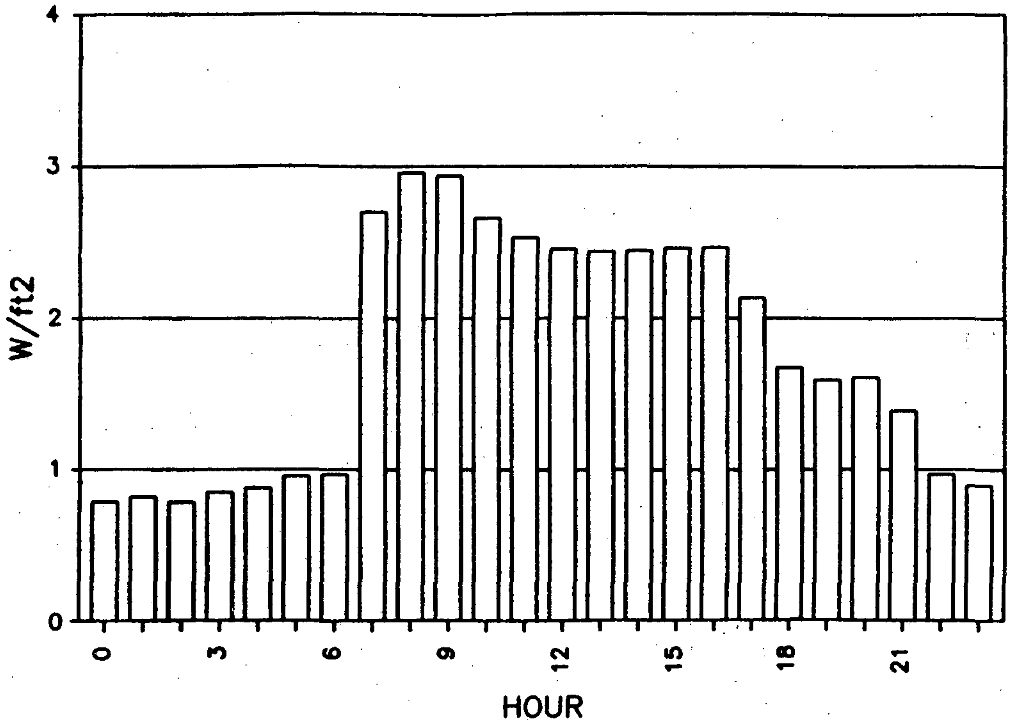

Figure 3a. Typical Daily Load Profile - Miscellaneous Plug Loads in a New Jersey Leased Office Building (12,100 m^2). Hourly submetered tenant lighting and general-purpose office equipment loads for a typical spring weekday, 1986. Lights account for about 16 W/m^2 (1.5 W/ft^2), and are almost all turned 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

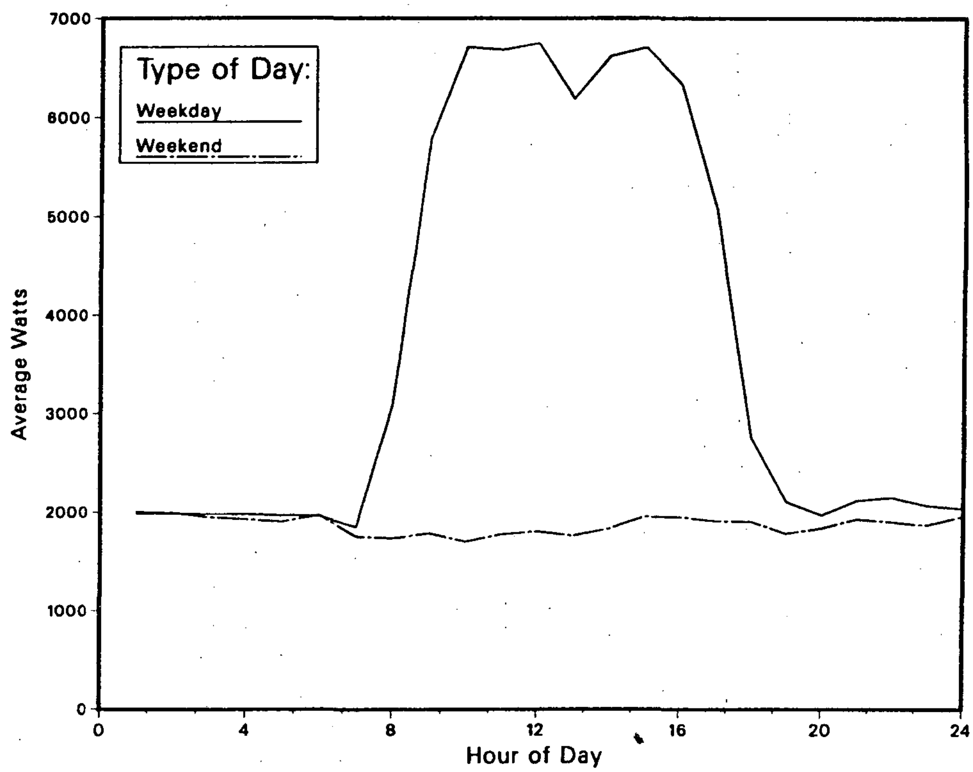

Figure 3b. Average weekday "plugs" load profile, small office building. These data show weekday average hourly loads for April 1988 for a recently-constructed, two-story building of about 850 m^2. Computers and other office electronic equipment represent most of this load; not included is a separately metered minicomputer, which would add about 10 % to the loads shown. Data come from monitoring equipment installed by Battelle Pacific Northwest Labs.