

**Electricity Used by Office Equipment and Network Equipment in the U.S.:
Detailed Report and Appendices**

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ABSTRACT

In spite of the recent explosive growth in the use of office and network equipment, there has been no recent study that estimates in detail how much electricity is consumed by that equipment in the United States.

In this study, we examined energy use by office equipment and network equipment at the end of 1999. We classified office equipment into 11 types; for each type we estimated annual energy consumption for residential, commercial, and industrial use by combining estimates of stock, power requirements, usage, and saturation of power management. We also classified network equipment into six types and estimated the annual energy consumption for each type.

We found that total power use by office and network equipment is about 74 TWh per year, which is about 2% of total electricity use in the U.S. More than 70% of this energy use is dedicated to office equipment for commercial use. We also found that power management currently saves 23 TWh/year, and complete saturation and proper functioning of power management would achieve additional savings of 17 TWh/year. Furthermore, complete saturation of night shutdown for equipment not required to operate at night would reduce power use by an additional 7 TWh/year.

Finally, we compared our current estimate with our 1995 forecast. We found that the total difference between our current estimate and the previous forecast is less than 15%. We also identified the factors that led to inaccuracies in the previous forecast.

Introduction

Use of the Internet has spread rapidly. During the past 10 years, the number of registered domain names¹ has increased from 16,000 to 15 million, and the number of world-wide web sites has increased from zero to 10 million. Meanwhile, annual shipments of computers have increased by a factor of five (Information Technology Industry Council 1998), and network devices like routers and switches have become ubiquitous. In spite of this growth, there has been no recent study that assesses in detail how much electricity is dedicated to computer equipment or network equipment in the United States. The last comprehensive study in this area is Lawrence Berkeley National Laboratory's study in 1995 (Koomey et al. 1995), prior to the Internet's emergence as an important force in the U.S. economy.

In this study, we examine energy use by office equipment and network equipment in the U.S. We classified office equipment into 11 types. For each type, we estimated annual energy consumption (TWh/year) for residential, commercial, and industrial use by combining the stock, power requirement, usage, and saturation of power management. An estimate was made for the case of complete saturation of power management and proper functioning as well as current practice for power management and operation. Further, we estimated energy use in the case of complete shutdown during nights and weekends of all office equipment except servers,

¹A definition of "domain name" can be found at <<http://www.register.com/faq/glossary.cgi>>.

minicomputers, mainframes, and faxes. We also evaluated the uncertainties in our estimate by conducting a sensitivity analysis.

We classified network equipment into six types and estimated annual energy use (TWh/year) for each type based on sales revenue. We also surveyed energy use for the LBNL network and compared the results to our U.S. estimate to assess its reasonableness.

Finally, for energy use by commercial office equipment, we compared our current estimate with our 1995 forecast and identified the factors that led to inaccuracies in the previous forecast.

Methodology

Office Equipment

Classification. We classified office equipment into 11 types as shown in Table 1. Multi-function devices (MFDs) fall into several different categories, and although good energy data on these product categories are not available, all indications are that the energy use of each type behaves similarly to a conventional single-function type (copier, laser printer, or inkjet printer). Therefore, we allocated MFDs into appropriate single-function categories. Further, we classified each equipment type as residential, commercial, or industrial, based on the place where it is used.

Table 1. Classification of Office Equipment

<i>Equipment Type</i>	<i>Definition</i>
Portable Computer	Notebook or sub-notebook computer
Desktop Computer	Desktop or desktide computer that is used as a client computer and has a price lower than \$25,000
Server	Desktop or desktide computer that is used as a server computer and has a price lower than \$25,000
Minicomputer	Computer whose price is between \$25,000 and \$350,000. Peripherals such as tapes and disk storage are considered part of minicomputers
Mainframe	Computer whose price is higher than \$350,000. Peripherals such as tapes and disk storage are considered part of mainframes
Terminal	Non-programmable terminal usually connected to mainframes or minicomputers
Display	Display for desktop computer, including CRT and LCD
Laser Printer	Includes multifunction devices whose major function is laser printing
Inkjet Printer	Includes dot matrix printers and multifunction devices whose major function is inkjet printing
Copier	Includes multifunction devices whose major function is copying
Fax	Fax machines

Definition of Power Management. For computers, displays, and laser printers, we considered only one low-power mode. Although many machines have more than one power management mode, we do not believe that the power level differences and available data on the distribution of modes across the year justify using more than the one mode we chose.

For inkjet printers and faxes, we ignored power management, because their power requirements are usually below the ENERGY STAR® standard low-power level even without power management, and because many of these machines have no low-power mode.

There are many terms for operating modes. To keep the terms consistent among all the equipment types, we used only three terms, “active,” “low-power,” and “off” as shown in Table

2. We defined active mode for copiers, faxes, and printers as the state when devices are ready but not printing or copying. Instead of defining another mode for printing or copying, we estimated the extra energy use for copying or printing separately.

Table 2. Power Management Mode*

Term in This Paper	Active	→ Low-Power	→ Off
Term in Industry	Active → Standby	→ Suspend(Sleep)	→ Off
Desktop/Portable/Server	Active → Sleep	→ Deep Sleep	→ Off
Display/Terminal	Ready	→ Sleep	→ Off
Laser Printer	Ready	→ Sleep	→ Off
Inkjet Printer	Ready(Standby)	→ Sleep(Energy Zero)	→ Manual-Off/Auto-Off
Copier	Ready(Standby)	→ Sleep	→ Off
Fax			

*Modes shown above with strikethrough are ignored in our analysis.

General Methodology. For each type of equipment, we estimated residential, commercial, and industrial energy use as summarized in Figure 1.

First, we estimated total stock using shipment data and device lifetime and then split it into residential, commercial, and industrial stock using the saturation at home and the ratio of commercial stock to industrial stock.

Second, we estimated the average power requirement in each mode (active, low-power, off), average usage (mode distribution over a week), and the power-management-enabled rates for residential and non-residential (i.e. commercial and industrial) use. We did not differentiate these parameters between commercial and industrial equipment. For printers, copiers, and faxes, we also estimated the extra energy use for printing or copying by combining the average imaging rate (number of images printed or copied in a year) with the average energy use for each image. This estimate is necessary because the power used when printing or copying is much higher than the active power.

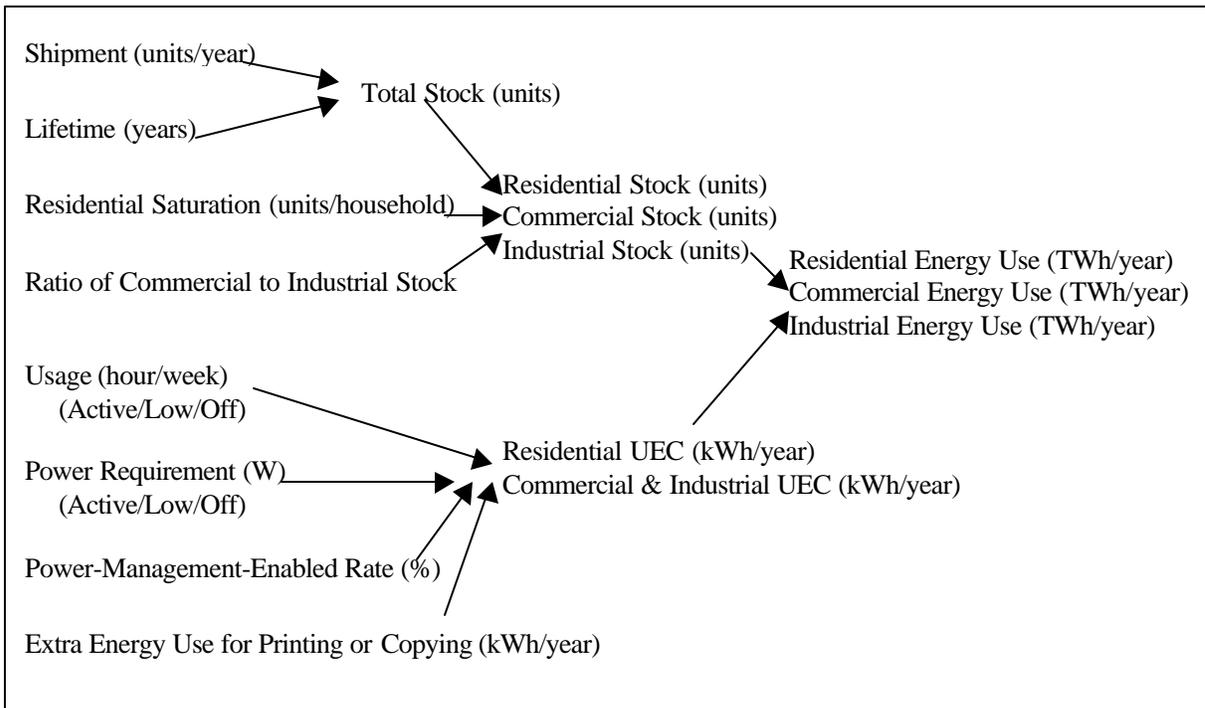


Figure 1. Calculation Flow

Third, we estimated the unit energy consumption (UEC) for residential and non-residential use by combining the power requirement, usage, power management enabled rate, and the extra energy use for printing or copying. The UEC is the average annual energy used by each unit.

Finally, multiplying the UEC by the stock, we estimated residential, commercial, and industrial energy consumption. Figure 1 shows the flow of calculations for each type of equipment.

Stock. First, we estimated the total stock for each type of equipment based on shipment data (Information Technology Industry Council 1998, Appliance Magazine 1999) and lifetimes. The lifetimes are derived from our previous study (Koomey et al. 1995). The use of a single lifetime for each type of equipment is a simplification, but the available data do not justify a more complex formulation.

Second, the residential stock for each type of equipment is derived from published residential equipment saturation rates (DOE 1999, CEMA 1999). For laser printers, survey data results indicate that the residential stock is larger than the commercial stock, but we believe this result to be unrealistic. We concluded that this inaccuracy is caused by tendency of survey respondents to mistake inkjet printers for laser printers, so we corrected by assuming that half of the people responding to these surveys made this mistake.

Finally, we estimated non-residential stock by subtracting residential stock from the total stock and splitting the remainder into commercial and industrial stocks based on the ratio of commercial floor space to industrial conditioned space from Commercial Building Energy Consumption Survey in 1995 (DOE 1998) and Manufacturing Energy Consumption Survey in 1994 (DOE 1997).

Table 3 shows the stock for each type of equipment. The accuracy of commercial and industrial stock estimates depends heavily on the accuracy of the assumed lifetimes. There are some uncertainties in the residential stock of printers because of the inaccuracy of survey data.

Table 3. Stocks of Office Equipment at the End of 1999 (millions)

	<i>Total</i>	<i>Residential</i>	<i>Commercial</i>	<i>Industrial</i>
Portable Computer	22	16	5.3	0.76
Desktop Computer	110	55	48	6.8
Server	3.3	0	2.9	0.42
Minicomputer	2.0	0	1.5	0.50
Mainframe	0.11	0	0.096	0.011
Display	110	55	48	6.8
Terminal	110	0	10	3.3
Laser Printer				
Total	28.0	6.3	19	2.7
<8 ppm	7.8	6.3	1.3	0.18
8-12 ppm	8.7	0	7.6	1.1
>12 ppm	11	0	10	1.4
Inkjet/Dot Printer	74	50	21	2.9
Copier				
Total	11	3.8	6.5	0.93
<21 cpm	6.6	3.8	2.5	0.35
21-44 cpm	2.8	0	2.4	0.35
>44 cpm	1.9	0	1.6	0.24
Fax	28	6.3	19	2.7

Power Requirement. For all equipment except servers, minicomputers, and mainframes, we estimated power requirements mostly based on our own measurements (unpublished) or measurements by others (Nordman et al. 1998, Brown 2000, and EPA 2000). To calculate power levels for copiers and laser printers, we took the weighted average of the power levels across device speeds because power levels vary considerably by the speed (images/minute) of each unit. We assumed that the power requirements for residential use are same as those for commercial and industrial use except for desktop computers, laser printers, and copiers.

For servers, we measured the power requirements for several machines and found it to range from 50 W to 270 W. We estimated average power use as 75 W.

For minicomputers and mainframes, it is difficult to estimate the average power requirement because of the wide range of power requirements for CPUs² (Central Processing Units) and the various kinds of peripherals such as tapes and disk storage.

For minicomputers, we assumed that the IBM AS/400 is the representative machine and estimated the average power requirement for the CPU based on measured data (IBM 1999). By assuming the power requirement for peripherals combined with the power requirement for the CPU, we estimated the average power requirement for minicomputers as 1,000 W.

For mainframes, we had two more difficulties, one of which is the recent significant decrease in power requirements and the other is the lack of measured data. We separated the stock of mainframes into the new stock shipped from 1996 until now and the old stock which were shipped before 1996. We assumed that the IBM S/390 is the representative machine for the new stock and estimated the power requirement for one type of IBM S/390 whose price is close to the average price of mainframes. We also estimated the average power requirement for the old stock based on Koomey et al. (1995). Finally, based on a weighted average of power requirements for the new stock and the old stock, we estimated the average requirement for mainframes at 10 kW.

We also assumed that CPUs of minicomputers and mainframes are always on but their associated peripherals are off at night. We did not consider power management for minicomputers and mainframes.

In sum, there are significant uncertainties in the power requirements for servers, minicomputers, and mainframes.

Usage (Mode Distribution). We estimated the average usage (mode distribution over a week) for each type of office equipment in the case that it has power management capability and that it is enabled. Several factors combine to determine the average mode distribution. The causative factors are the work habits of the machine's users, the configuration of power management features, and the degree to which equipment is turned off manually. We defined the following three parameters that describe those factors.

1. *Nighttime Status* – whether the equipment is active, at low-power, or off during nights and weekends
2. *Daytime Status* – whether the equipment is active, at low-power, or off during daytime
3. *Daytime Length* – the length of the time during which the equipment is regularly used

These parameters for commercial and industrial use are estimated mainly based on the results of power datalogging and audits for night status (Nordman et al. 1998, Nordman et al. 2000, and Brown 2000). However, we were not able to locate any comparable data about servers,

² We use the term “CPU” for central processing units of minicomputers and mainframes. Peripherals are not included in CPUs.

minicomputers, and mainframes, so we made assumptions for those three types of equipment. The parameters for residential use are estimated based on the survey data (DOE 1999 and CEMA 1999), other studies (Meyer and Schaltegger 1999) and some assumptions. Although some businesses are run out of houses and some computers are provided by businesses for use at home, we folded those situations into our residential use estimate.

Based on the estimated parameters, we calculated the average mode distribution of each type of office equipment. There is significant uncertainty in the usage for servers, minicomputers, and mainframes. There are also some uncertainties in residential usage because of the lack of data.

Power Management Enabled Rate. The power-management-enabled rate is the percentage of equipment that has power management capabilities and whose power management is properly operating. Equipment that has power management capability but that has not been correctly enabled is not included in this category.

We estimated the rate for each type of equipment mainly based on the results of audits for nighttime status (Nordman et al. 1998 and Nordman et al. 2000). For portable computers and servers, we made assumptions because of the lack of data, so there are some uncertainties.

Extra Energy Use for Printing or Copying. Extra energy use for printing or copying is the energy required beyond the energy used in active mode. We estimated this extra energy use by combining the average imaging rate³ with the average extra energy use for each image. Making assumptions about paper use rates⁴ and duplexing rates⁵, we estimated the imaging rate for each type of equipment. We also assumed the average extra energy use for each image as 1 Wh for all the types of equipment.

Because most assumptions are based on data cited by other papers or on our own judgments, there are uncertainties. However, this methodology is potentially more accurate, because total paper consumption is well known, which limits the inaccuracies in total energy consumption for printing or copying.

Unit Energy Consumption (UEC). UEC is the average annual energy use by each piece of equipment. The UEC for each type can be described by the following equation. EPC_i is zero for computers, displays, and terminals.

$$UEC_i = (SPM_i \times (PA_i \times HA_i + PL_i \times HL_i + PO_i \times HO_i) / 7) \times 365 / 10^3 \\ + ((1 - SPM_i) \times (PA_i \times (HA_i + HL_i) + PO_i \times HO_i) / 7) \times 365 / 10^3 \\ + EPC_i$$

where

UEC_i = Unit Energy Consumption for equipment type i (kWh/year)

i = index for equipment type

PA_i = Average active mode power for equipment type i (W)

PL_i = Average low-power mode power for equipment type i (W)

³ The imaging rate is the average number of images printed or copied by each unit in a year.

⁴ The paper use rate is the average amount of paper printed or copied by each unit in a year.

⁵ The duplexing rate represents the ratio of images placed onto duplexed sheets to images placed onto singled-sided sheets. A 100% duplexing rate uses half as much paper as a 0% duplexing rate. Duplexing Rate = (Imaging Rate – Paper Use Rate) * 2 / Imaging Rate.

- PO_i = Average off mode power for equipment type i (W)
- HA_i = Hours of operation in active mode for equipment type i (hours/week)
- HL_i = Hours of operation in low-power mode for equipment type i (hours/week)
- HO_i = Hours of operation in off mode for equipment type i (hours/week)
- SPM_i = Power-management-enabled rate for equipment type i (%)
- EPC_i = Extra energy for printing or copying for equipment type i (kWh/year)
- 365 = days per year
- 7 = days per week

The UEC for each type of equipment is shown in Table 4.

Table 4. Best Estimate of Unit Energy Consumption for Office Equipment in 1999

<i>Equipment Type</i>	<i>Residential UEC (kWh/year)</i>	<i>Commercial/Industrial UEC (kWh/year)</i>
Portable Computer	8.6	24.6
Desktop Computer	49	213
Server	*	560
Minicomputer	*	5,840
Mainframe	*	58,400
Terminal	*	183
Display	57	205
Laser Printer	16	283
Inkjet/Dot Printer	22	74
Copier	288	874
Fax	70	119

* We assume that there are no servers, minicomputers, mainframes, and terminals in the residential sector.

Network Equipment

Classification. We classified network equipment into six types as shown in Table 5. We did not include the switching equipment contained in the telephone system.

Table 5. Classification of Network Equipment.

<i>Equipment Type</i>		<i>Definition</i>
WAN ⁶ Equipment	Router	Throughput-capacity is multi-gigabit. Interfaces and controllers are specialized for WAN (e.g. Cisco 12000).
	Switch	
LAN ⁶ Equipment	Router	Routers and switches usually used for LAN (e.g. Cisco 2500, 4500, 7000).
	Switch	
	Access Device	Access concentrators and access servers
	Hub	Passive hubs and switching hubs

General Methodology. We were not able to get any shipment data for network equipment so we had no alternative but to estimate energy use in the U.S. by using worldwide sales revenue for each equipment type. First, we estimated the domestic sales revenue during the past four years by allocating the worldwide revenue based on the ratio of the number of host names or domain

⁶ WAN means Wide Area Network. LAN means Local Area Network.

names in the U.S. to the world. Second, we assumed a representative model for each equipment type and estimated the virtual stock number of the representative model by dividing the domestic revenue by the unit price of the representative model. Finally, assuming all the network equipment operates for 24 hours per day throughout the year, we estimated annual power use for each type of network equipment by the following equation:

$$TEC_i = (REV_i / PRICE_i) \times PA_i \times 8760 / 1000$$

where

TEC_i = Total annual energy consumption of all equipment type i (kWh/year)

i = index for equipment type

REV_i = Domestic sales revenue for equipment type i (\$)

$PRICE_i$ = Price of representative model for equipment type i (\$)

PA_i = Average active-mode power of representative model for equipment type i (W)

8,760 = hours per year

Results and Discussion

Results

Tables 6 and 7 show annual energy use for office equipment and network equipment, which totals 74 TWh/year for both types of equipment.

Figure 2 shows the percentage of annual energy use by residential, commercial, and industrial office equipment and network equipment. Commercial office equipment accounts for more than 70% of energy use, energy use for network equipment is less than 5%, and the remainder is evenly split between residential and industrial.

Figure 3 shows the percentage of annual energy use by active mode, low-power mode, off mode, and printing/copying. We found that 86% of all energy (64 TWh/year) is consumed in active mode, and 4% of all energy (3 TWh/year) is consumed in off mode.

Table 6. Best Estimate of Annual Energy Use for Office Equipment in 1999 (TWh/year)

<i>Equipment Type</i>	<i>Residential</i>	<i>Commercial</i>	<i>Industrial</i>	<i>Total</i>
Portable Computer	0.14	0.13	0.02	0.29
Desktop Computer	2.67	10.21	1.46	14.34
Server	0	1.60	0.23	1.83
Minicomputer	0	8.86	2.95	11.81
Mainframe	0	5.62	0.63	6.25
Terminal	0	1.83	0.61	2.44
Display	3.13	9.82	1.40	14.35
Laser Printer	0.10	5.36	0.77	6.23
Inkjet/Dot Printer	1.10	1.56	0.22	2.88
Copier	1.10	5.71	0.82	7.63
Fax	0.44	2.26	0.32	3.02
Total	8.67	52.95	9.42	71.04

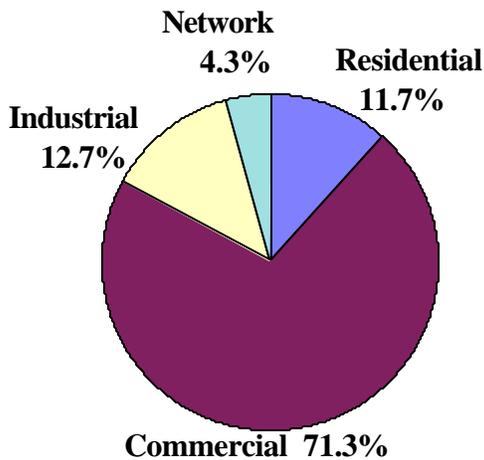


Figure 2. Percentage of Annual Energy Use by Each Sector at the End of 1999

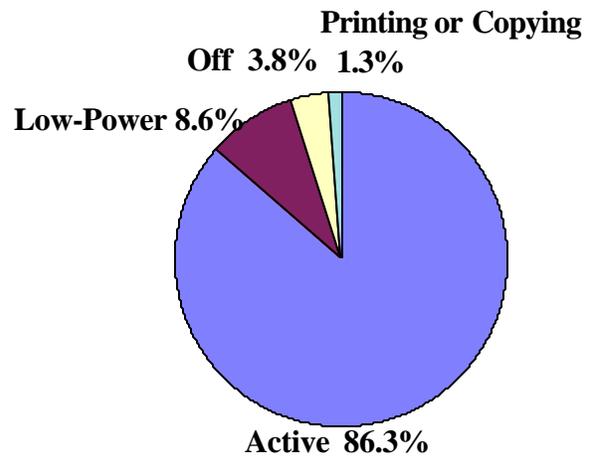


Figure 3. Percentage of Annual Energy Use by Each Mode at the End of 1999

Table 7. Best Estimate of Annual Energy Use for Network Equipment in 1999 (TWh/year)

	<i>Equipment Type</i>	<i>Annual Energy Use</i>
WAN	Router	0.05
	Switch	0.24
LAN	Router	0.68
	Switch	1.31
	Access Device	0.29
	Hub	0.65
Total		3.22

Energy Savings by Power Management and Night Shutdown

Figure 4 shows a breakdown of annual power use by equipment type in the case of: 0% power management present and enabled, current estimates for power management and operation, complete saturation of power management and proper functioning, and complete night shutdown of all office equipment except servers, minicomputers, mainframes and faxes (left on but not used during nights).

Current saturation of power management has achieved energy savings of 23 TWh/year, compared to the hypothetical case with 0% power management present and enabled. Complete saturation of power management (capability and enabling) would save an additional 17 TWh/year. Most of these savings would come from desktop computers, displays and copiers since the power-management-enabled rate for desktop computers is low (= 25%) and the power reductions by power management for displays and copiers are large (for displays, active power = 85 W, low power = 5 W; for copiers, power in auto-off is less than 10 W).

Furthermore, complete saturation of night shutdown for all equipment except servers, minicomputers, mainframes, and faxes would reduce energy use by an extra 7 TWh/year. Most of these savings would be achieved by night shutdown of desktop computers and laser printers since power reductions by night shutdown for desktop computers and laser printers are large (low-power level for desktop computers and laser printers is 25 W) and laser printers are frequently left on at night (according to our survey, 73% of laser printers are on at night).

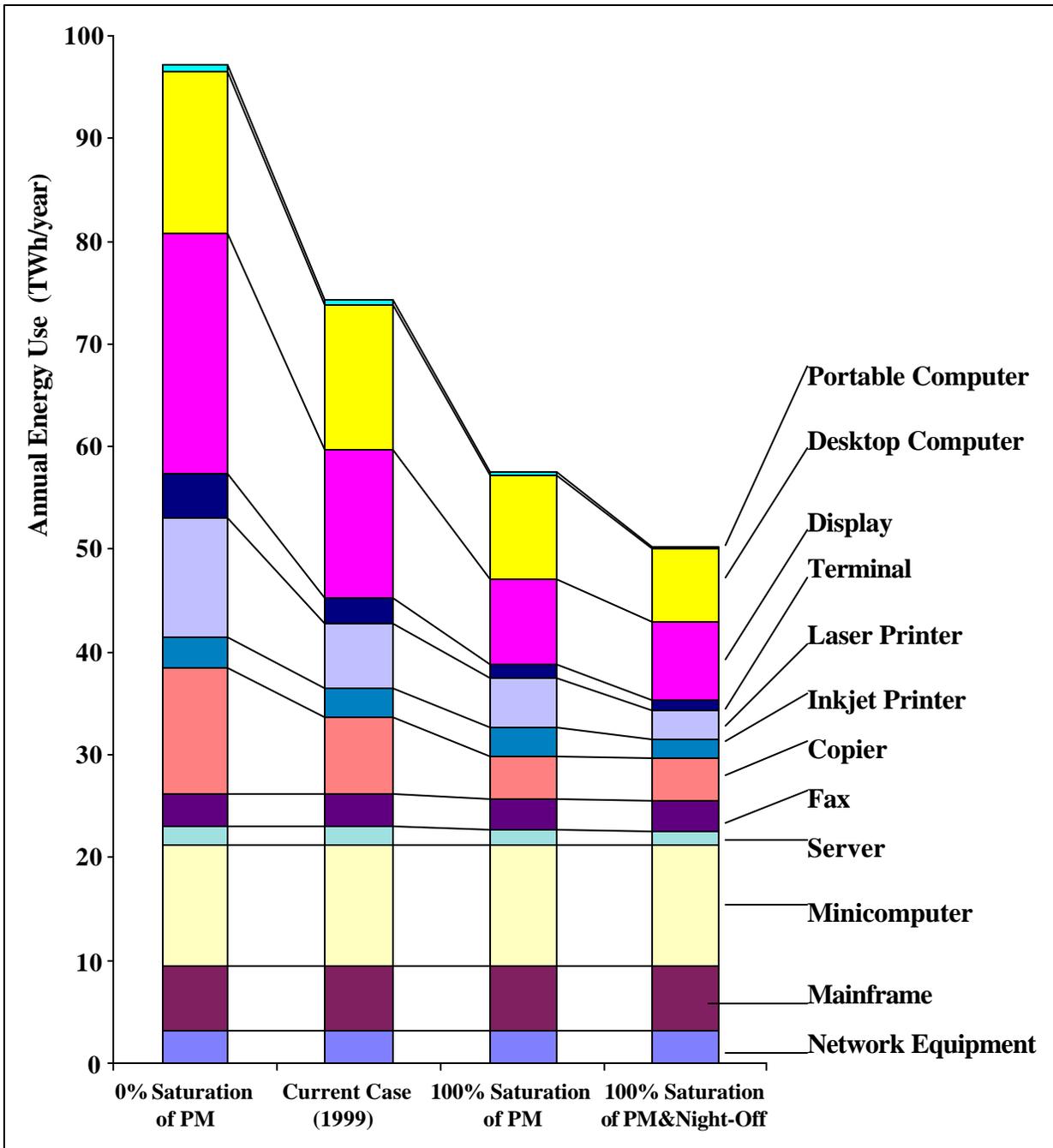


Figure 4. Energy Use by Equipment Type as a Function of Power Management Levels

Uncertainty

For all the input data for office equipment, we conducted sensitivity analyses to evaluate the uncertainty in our estimates of energy use. We estimated the error range for each piece of input data and calculated the resulting error range for annual energy use caused by the error associated with each piece of input data. We found that the uncertainties in the following data might lead to more than 1 TWh/year error in our estimate for energy use:

1. Stock, power requirement, and usage for minicomputers and mainframes
2. Commercial or industrial stock for desktop computers, displays, laser printers, and copiers
3. Usage for residential desktop computers and displays

To check whether our estimate for LAN network equipment is reasonable or not, we estimated the power requirement of the LBNL network equipment, which connects about 5,000 computers, and compared the result with our estimate by scaling the LBNL network to the size of all networks in the U.S. We found that the total difference in LAN network energy per personal computer was less than 20% between LBNL and the U.S. We were not able to check the accuracy of our estimate for WAN equipment though we are confident that the total error in our estimate for network equipment is less than 1.5 TWh/year.

Comparison with Our 1995 Forecast

We compared our current estimate for commercial office equipment with our 1995 forecast for the year 1999 (Koo me y et al. 1995). Results are shown in Figure 5 for the office equipment types that are common to both studies. The total difference is less than 15%. Energy use for desktop computers, printers, and displays is higher than in our 1995 forecast. That is because desktop computers and laser printers are left on at night more frequently than we expected and also because active power for displays is higher than we expected (active power for displays is 85 W; while our previous forecast was 63 W). There is little difference in energy use for minicomputers and mainframes.

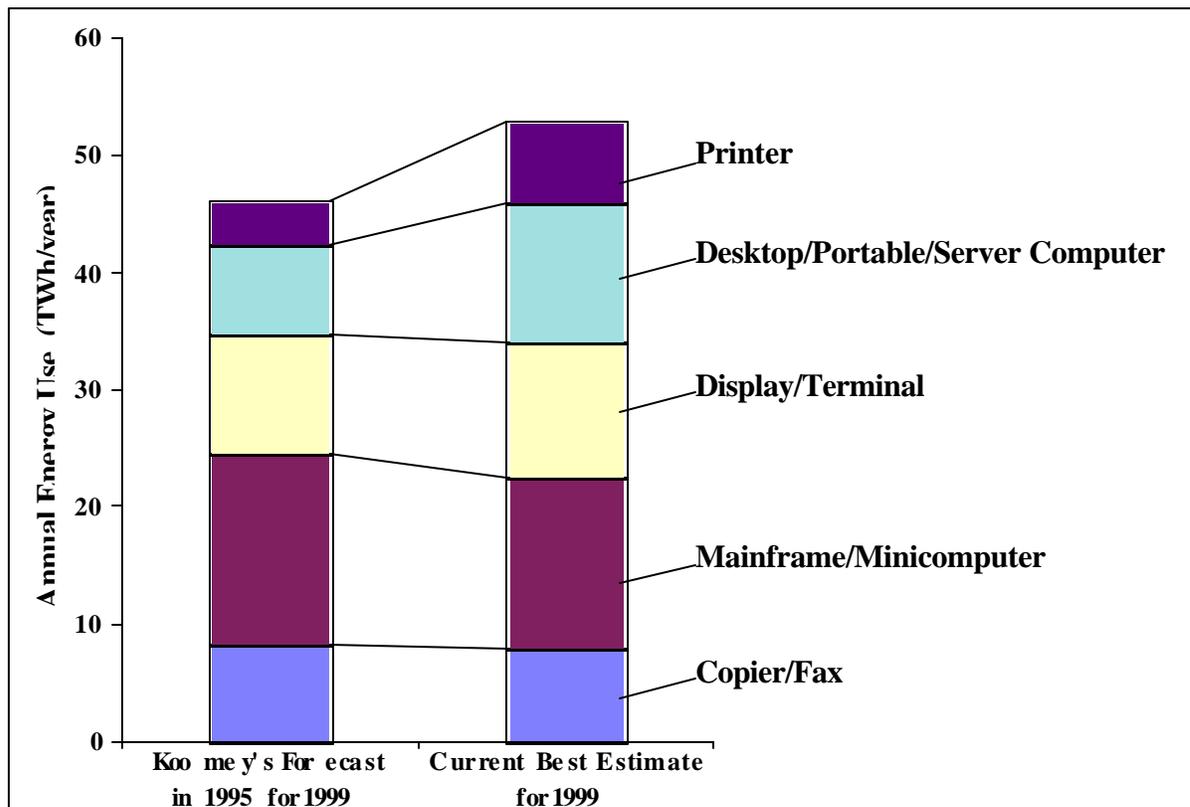


Figure 5. Comparison of Energy Use for Commercial Office Equipment in 1999 Between Current Estimate and 1995 Forecast (Koo me y et al. 1995)

Conclusions and Future Work

Annual energy use by office and network equipment is about 74 TWh/year, which is about 2% of total U.S. electricity consumption today. More than 70% of this energy use is dedicated to office equipment for commercial use, and less than 5% is for network equipment. The rest is split equally between residential and industrial uses. About 3 TWh/year, which is 4% of all the energy use, is consumed in off mode.

Current energy savings achieved by power management are estimated at 23 TWh/year. Complete saturation and proper functioning of power management would achieve additional savings of 17 TWh/year. Furthermore, complete saturation of night shutdown for applicable equipment types would reduce power use by an extra 7 TWh/year.

The difference between current estimate and our previous forecast (Koomey et al. 1995) is less than 15%. The differences are caused mainly by the fact that people leave office equipment on at night more frequently than we expected. Equipment with power management operating may be left on at night more frequently than conventional equipment.

This study estimated the energy use and the energy savings potential for current office equipment. However, office and network equipment are changing rapidly. New equipment such as Web TVs, Web phones, and palm-size computers are already emerging. We need to estimate energy use for such emerging equipment in the near future. We also need to estimate the energy used by the telephone system, which is not included in our current estimates. We also need to consider that the use of office and network equipment may influence energy and resource use in indirect ways that can be important. A complete assessment of these effects is beyond the scope of this paper but is a worthy topic of future research.

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APPENDIX

This appendix presents the detailed assumptions of the calculations presented in the main part of the report. It describes equipment lifetimes, shipments, stocks, power requirements, hourly usage, power-management-enabling rates, and extra energy used for printing and copying. It also describes a detailed uncertainty analysis. There are two major sections, one for office equipment and one for network equipment.

I. OFFICE EQUIPMENT

Lifetimes of Office Equipment

Equipment lifetime is a critical factor in the estimation of stocks. The meaning of “lifetime” in this context is the total amount of time equipment is used, not just by the original owner but by all subsequent owners. Furthermore, “lifetime” measures the total amount of time equipment is actually in use (not just their lifetime until disposal) since some equipment, particularly computers and printers, can linger for several years without being plugged in or turned on before being disposed of.

In Koomey et al. (1995), the calculated stocks were compared with those derived from reported equipment saturations (where data were available) to help validate assumptions about equipment lifetimes. In this study, we assumed the same lifetimes as those used in Koomey et al. (1995). The average lifetime for each type of office equipment are shown in Table A-1.

Table A-1. Average Office Equipment Lifetimes

<i>Equipment Type</i>	<i>Lifetime (years)</i>
Portable Computer	4
Desktop Computer	4
Server Computer	4
Minicomputer	8
Mainframe Computer	9
Terminal	4
Display	4
Laser Printer	6
Inkjet Printer	6
Copier	6
Fax	6

Shipments of Office Equipment

The data include a combination of actual sales data and estimates made by the source. Major data sources are the Information Technology Industry Council (1998) and Appliance Magazine (1999).

Multi-function devices (MFDs) fall into several different categories. While there are no good energy data for these categories, all indications are that the energy use of each type of MFD behaves similarly to a conventional single-function device (e.g., copier, laser printer, or inkjet printer) and so can be aggregated with these types of devices for energy estimates. Sales data generally cite MFDs separately, so we separate the MFDs by type and aggregate them as

appropriate to single-function categories.

We split the sales of laser printers and copiers respectively into three classes based on printing or copying speeds. This is useful for estimating average power requirements, because power requirements depend heavily on printing or copying speed. We could not split the sales of copiers from 1991 to 1993 because of a lack of data. However, we could nonetheless estimate the stock of copiers by assuming that the average lifetime of copiers is 6 years.

We did not need sales data for displays, because we assumed the stock of displays is same as that of desktop computers.

Table A-2 shows shipments of each type of office equipment from 1991 to 1999.

Table A-2. Office Equipment Sales from 1991 to 1999 (thousands)

<i>Equipment Type</i>	<i>1991</i>	<i>1992</i>	<i>1993</i>	<i>1994</i>	<i>1995</i>	<i>1996</i>	<i>1997</i>	<i>1998</i>	<i>1999</i>
Portable Computer	1,711	2,111	2,632	3,533	4,268	5,190	6,025	6,665	7,332
Desktop + Server	7,821	9,763	13,059	14,756	18,109	21,393	25,775	30,035	35,239
Minicomputer	237	242	247	252	256	252	263	255	255
Mainframe	12	12	12	12	11	12	12	12	12
Terminal	3,005	3,130	3,225	3,310	3,350	3,300	3,310	3,340	3,380
Laser Printer									
total	2,900	2,900	3,350	4,213	4,323	4,445	4,672	5,065	5,269
<8ppm	1,000	1,200	1,700	1,747	1,816	1,647	1,259	801	485
8-12ppm	1,900	1,700	1,000	1,130	1,095	1,048	1,640	1,808	2,008
>12ppm	0	0	650	1,336	1,413	1,723	1,773	2,457	2,775
Inkjet Printer	836	1,700	3,500	5,754	9,041	9,244	13,081	16,479	20,475
Copier									
total	1,444	1,466	1,523	1,630	1,701	1,898	1,954	2,011	2,064
<21cpm				1,059	1,052	1,115	1,127	1,133	1,137
21-44cpm				359	390	461	488	519	541
>44cpm				212	258	322	339	359	386
Fax	1,966	2,141	2,386	2,526	2,778	4,345	5,529	6,082	6,690

Residential Stock of Office Equipment

Portable Computers, Desktop Computers, and Displays. According to the Consumer Electronics Manufacturing Association (CEMA) (1999), 42% of U.S. households had one desktop computer, and 5.7% of U.S. households had more than one desktop computer in 1999. CEMA (1999) also says 13% of U.S. households had one portable computer, and 1.3% of U.S. households had more than one portable computer in 1999. According to Morissette (1999), 52 million households had at least one computer (desktop or portable computer) in 1999. According to the U.S. Department of Energy (DOE) (1999), 35.6 million households had at least one computer (desktop or portable computer) in 1997. Since there has been explosive growth in the residential stock of computers over the last five years, the DOE data appear outdated. Although the CEMA numbers appear high, only CEMA explicitly reports the saturation of portable computers, so we use the CEMA data for our best estimate.

Assuming that all households that have more than one desktop or portable computer have two desktop or two portable computers, respectively, we estimated the residential saturation of desktop and portable computers as 0.53 and 0.16 units/household, respectively. The number of U.S. households is estimated to be about 101 million in 1998 (U.S. Census Bureau 1998). Multiplying the residential saturation of computers by the number of U.S. households, we estimated the residential stock of desktop and portable computers as 55 million and 16 million, respectively.

We assumed the residential stock of displays is same as that of desktop computers.

Laser Printers and Inkjet Printers. According to CEMA (1999), 16% or 16.2 million U.S. households have laser printers. According to US DOE (1999), 12.6 million households had laser printers in 1997. Both the CEMA and DOE estimates account for more than half of the total stock of laser printers (even excluding MFDs, in the case of DOE). In other words, both of these survey results indicate that the residential stock of laser printers is larger than the commercial stock. However, we believe this result is unrealistic. We conclude that the inaccuracy is a result of the tendency of survey respondents to mistake inkjet printers for laser printers. We assumed that this error was made in 50% of cases; therefore, we estimated the residential stock of laser printers at 6.3 million, which is half of the DOE estimate. We assumed that all residential laser printers are low-speed models (< 8 pages per minute or ppm).

To estimate the residential stock of all types of printers, we assumed that 80% of residential computers (including both desktop and portable computers) have printers. Our estimate of the total stock of residential printers was thus 56.5 million.

Finally, by subtracting the residential stock of laser printers from the total stock of residential printers, we estimated the residential stock of inkjet printers as 50.2 million.

Copiers and Faxes. According to DOE (1999), 3.8 million households had copiers and 6.3 million households had faxes in 1997. Assuming there are no households that have more than one copier or fax, we estimated the residential stock of copiers and faxes as 3.8 million and 6.3 million, respectively. We also assumed that all residential copiers are low-speed models (<21 copies per minute or cpm).

Separating the Stock of Servers from Desktop Computers

Computers can be generally classified into client-use and server-use computers. Most minicomputers and mainframes are server-use computers, but there are both client- and server-use computers among microcomputers (computers whose price are lower than \$25,000). The usage and power requirements are different for client- and server-use computers, so we divided the stock of microcomputers into these two categories.

As defined in Table 1, client-use desktop-deskside microcomputers (desktop-deskside computers whose price is lower than \$25,000) are referred to here as “desktop computers” and server-use desktop-deskside microcomputers are referred to as “servers”.

From Table A-1 and A-2, we calculated the total stock of desktop computers and servers combined (112 million). By subtracting our stock estimate for residential desktop computers (55 million) and assuming that all servers are used in non-residential applications, we arrive at a stock estimate of 58 million for all non-residential computers (desktops, servers, minicomputers, and mainframes). We then used Tables A-1 and A-2 to calculate the stocks of minicomputers and mainframes (2.0 and 0.11 million, respectively). Finally, by assuming the total stock of server-use computers (including servers, minicomputers, and mainframes) is 10% of the stock of non-residential desktop computers, we estimated the stock of server-use computers and non-residential desktop computers at 5.45 million and 54.6 million, respectively. By subtracting the

total stock of minicomputers and mainframes from the stock of server-use computers, we estimated the stock of servers at 3.33 million.

Allocating Non-Residential Stock into Commercial and Industrial Stocks

For all types of equipment except minicomputers, mainframes, and terminals, we assumed that the ratio of commercial stock to industrial stock is equal to the ratio of commercial floor space to industrial conditioned floor space. According to DOE (1998), total commercial floor space in the U.S. is about 60 billion square feet. According DOE (1997), total industrial conditioned floor space is 8.4 billion square feet. Based on these data, we estimated the ratio of commercial stock to industrial stock at 7: 1.

For minicomputers, mainframes, and terminals, we assumed the same ratio as used in Koomey et al. (1995).

Table A-3 shows the commercial and industrial shares of non-residential office equipment stock. We split non-residential stock into commercial and industrial stocks based on these ratios.

Table A-3. Commercial and Industrial Shares of Non-Residential Office Equipment Stock

<i>Equipment Type</i>	<i>Industrial Share</i>	<i>Commercial Share</i>
Portable Computer	12.5%	87.5%
Desktop Computer	12.5%	87.5%
Server	12.5%	87.5%
Minicomputer	25.0%	75.0%
Mainframe	10.0%	90.0%
Terminal	25.0%	75.0%
Display	12.5%	87.5%
Laser Printer	12.5%	87.5%
Inkjet Printer	12.5%	87.5%
Copier	12.5%	87.5%
Fax	12.5%	87.5%

Power Requirements of Office Equipment

General Methodology. For all equipment types except servers, minicomputers, and mainframes, we estimated the power requirements based primarily on our own measurements or measurements made by others. To calculate power levels for copiers and laser printers, we use a weighted average of power levels across device speeds since power levels vary considerably by the speed (images/minute) of each unit.

We assumed that the power requirements for commercial and industrial equipment are the same. We also assumed that the power requirements for residential equipment are the same as those for commercial and industrial use except for desktop computers, laser printers, and copiers.

Results. Table A-4 shows the weighted average power requirement for each type of office equipment.

Table A-4. Power Requirements for Office Equipment

<i>Equipment Type</i>	<i>Active (W)</i>	<i>Low-Power (W)</i>	<i>Off (W)</i>
Portable Computer	15	3	2
Desktop Computer	Residential Use	50	1.5
	Commercial/Industrial Use	55	1.5
Server	75	25	1.5
Minicomputer	1,000	500	0
Mainframe	10,000	5,000	0
Terminal	75	5	0.5
Display	85	5	0.5
Laser Printer	Residential Use	30	1
	Commercial/Industrial Use	77	1
Inkjet Printer	17	*	2
Copier	Residential Use	115	1.5
	Commercial/Industrial Use	185	8.7
Fax	11	*	0

Notes on Portable Computers

Active Mode – According to measurements by Lawrence Berkeley National Laboratory (LBNL), the active-mode power requirements of portable computers range from 12 W to 22 W when the battery is fully charged. We estimated the average active-mode power requirement at 15W. Because of the limited set of measurements, there is uncertainty associated with this estimate.

Low-Power Mode – According to measurements by LBNL, the power requirements of portable computers in low-power modes range from 1.5 W to 6 W when the battery is fully charged. According to Nordman et al. (1997), the average power requirement for low-power mode is 3W. We estimated the average power requirement in low-power mode at 3W. Because of the limited set of measurements, there is uncertainty associated with this estimate.

Off Mode – According to a measurement by LBNL, off-mode power requirements range from 1.5 W to 2 W when the battery is fully charged. We estimated the average off-mode power requirement as 1.5 W. Because of the limited number of measurements, there is uncertainty associated with this estimate.

Notes on Desktop Computers

Active Mode – The average active power requirement of PCs varies considerably, with some machines using less than 30 W and others using more than 55 W. According to the specification tables for IBM PCs, the average active power requirements of new home and business PCs are about 50 W and 65 W, respectively. According to measurements by LBNL, the average active power requirement of Macintoshes, Pentium PCs, and pre-Pentium PCs are 47 W, 54 W, and 50 W, respectively. We estimated the average active power requirements of the residential and non-residential desktop computer stock at 50 W and 55 W, respectively.

Low-Power Mode – According to the U.S. Environmental Protection Agency (EPA) (2000), the average power requirement of new ENERGY STAR compliant PCs in low-power mode is

about 25 W. We estimated the average low-power mode power requirement of desktop computers at 25 W. We assumed that there is no difference in the power requirements of residential and non-residential desktop computers in low-power mode.

Off Mode – According to measurements by LBNL, the off-mode power requirements of Macintosh computers range from 2 W to 3 W, and the off-mode power requirement of PCs is less than 1 W. We estimated the average off-mode power requirement of desktop computers at 1.5 W. Because of the limited number of measurements, there is uncertainty associated with this estimate. We assumed there is no difference in the off-mode power requirements of residential and non-residential desktop computers.

Notes on Server Computers

Active Mode – The average active power requirement for server computers varies considerably, since some servers are simply high-end regular PCs while others are specifically manufactured as servers and have more capabilities and higher power demand. The line between a high-end server and a minicomputer is not clear.

According to measurements by LBNL, the active-mode power requirements of server computers range from 50 W to 270 W. Server computers whose power requirements are higher than 100 W usually have more than one CPU. We estimated the average active-mode power requirement at 75 W. Because of the limited number of measurements, there is uncertainty associated with this estimate.

Low-Power Mode, Off Mode – We assumed the power requirements for server computers in low-power mode and off mode are same as those for desktop computers. Again because of the limited number of measurements, there is uncertainty associated with this estimate.

Notes on Mainframes (with Peripherals)

Active Mode – It is difficult to estimate the average power requirement of mainframe computers because of:

1. The wide range of power requirements for Central Processing Units¹ (CPUs) and the varying the number of CPUs used in mainframe computers.
2. The various kinds of peripherals associated with mainframes such as tapes and disk storage.
3. The recent decreases in power requirements resulting from the emergence of C-MOS technology and internal disc systems.
4. The lack of measured data.

We separated the stock of mainframes into new stock, shipped between 1996 and present, and old stock, shipped before 1996.

We assumed that the IBM S/390 is a representative machine for new stock based on sales data

¹ We use the term “CPU” for the central processing units, motherboards, and power supplies of minicomputers and mainframes. Peripherals such as tape drives and external disks are not included in CPUs.

and its close-to-the-average price for mainframes. We estimated the power requirement of an IBM S/390 at 2.0 kW by assuming that the power requirement is approximately half of the rated power requirement. We also assumed the power requirement for peripherals (tapes, etc.) is 2.0 kW. Thus, the average power requirement of the new stock of mainframes plus peripherals was estimated at 4.0 kW.

Based on Koomey et al. (1995), we estimated the average power requirement of the old stock of mainframes with peripherals at 13.3 kW.

Finally, based on a weighted average of power requirements for the new and old stock, we estimated the average power requirement for mainframes at 10 kW. There is significant uncertainty in this estimate.

Low-Power Mode – Based on Koomey et al. (1995), we define the low-power mode for mainframes as the time when peripherals are off at night. Low-power mode of mainframes does not mean power management; it means that peripherals are off but CPUs are still on.

We estimated that the average power requirement for mainframes in low-power mode is 5.0 kW since the power requirement of CPUs accounts for about half of the active-mode power requirements of mainframes. There is significant uncertainty in this estimate.

Off Mode – Off mode for mainframes describes machines that have useful life but are not plugged in, such as spares. Therefore we assumed the off-mode power requirement of mainframes to be 0 W.

Notes on Minicomputers (with Peripherals)

Active Mode – It is difficult to estimate the average power requirement of minicomputers because of:

1. The wide range of power requirements for CPUs and the varying number of CPUs used in minicomputers.
2. The various kinds of peripherals associated with minicomputers such as tapes and disk storage.

Based on sales data, we assumed that the IBM AS/400 is a representative minicomputer machine. We estimated the average power requirement of the CPU as 500 W based on measured data (IBM 1999). By assuming that the power requirement for peripherals is also 500 W, we estimated the average power requirement of minicomputers as 1.0 kW. There is significant uncertainty in this estimate.

Low-Power Mode – As with mainframes, the low-power mode of minicomputers does not mean power management; it means that peripherals are off but CPUs are still on. We assumed that the power requirement of minicomputers in low-power mode is the power requirement of the CPU only, which is 500 W. Again, there is uncertainty in this estimate.

Off Mode – Off mode for minicomputers describes machines that have useful life but are not plugged in, such as spares. Therefore we assumed the off-mode power requirement of minicomputers to be 0 W.

Notes on Displays

Active Mode – According to LBNL measurements, the power requirement of 17-inch displays is about 85 W. According to Nordman et al. (1997), the power requirements of 15- to 21-inch displays range from 75 W to 120 W. We assumed the average size of displays is 17 inches and thus estimated the average power requirement of displays at 85 W.

The calculations above assume that all displays are cathode-ray tubes (CRTs), but, in actuality, the portion of displays that are flat-panel devices (e.g., liquid crystal displays or LCDs) is becoming significant. Because flat-panel displays use considerably less energy than the same size CRT display (perhaps half as much on average) our estimate could be too high by this amount.

Low-Power Mode – According to EPA (2000), the average power requirement of new ENERGY STAR-compliant displays in low-power mode is 5 W. According to Nordman et al. (1997), the average power requirement of displays in low-power mode is also 5 W. We estimated the average power requirement of displays in low-power mode at 5 W.

Off Mode – According to LBNL measurements, the power requirement of displays in off mode is about 0.3 W. We estimated the average power requirement of displays in off mode at 0.5 W.

Notes on Terminals

Active Mode – Since most terminals are 14- and 15-inch black-and-white terminals, we assumed that the average power requirement of terminals is same as that for 15-inch displays, or 75 W.

Low-Power Mode – Because the standard low-power mode for ENERGY STAR is same for terminals and displays, we assumed that the average low-power mode for terminals is the same as that for displays, or 5 W.

Off Mode – We assumed the average off-mode power requirement of terminals to be the same as that for displays, or 0.5 W.

Notes on Laser Printers

Active Mode – For laser printers, power levels vary considerably by the capacity (images/minute) of the unit. We calculated a stock-weighted average across the power levels listed in Table A-5 to arrive at the levels used in our energy calculations.

Table A-5. Average Power Requirements for Laser Printers in Active-Mode (LBNL)

<i>Equipment Type</i>	<i>Average Power Requirement of Active Mode (W)</i>
Black & White Laser Printer	6-10 ppm 16-18 ppm 24-32 ppm
Color Laser Printer	43W 73W 105W 150W

Low-Power Mode – By calculating the stock-weighted average of the measured data in Table A-6, we estimated the average power requirement for residential and commercial/industrial stock of laser printers.

Table A-6. Average Power Requirements for Laser Printers in Low-Power Mode (EPA 2000)

<i>Equipment Type</i>	<i>Average Power Requirement of Low-Power Mode (W)</i>
Black & White Laser Printer	8ppm <8 ppm
	25W 20W

Off Mode – According to Meyer and Schaltegger (1999), the average power requirement for laser printers in off mode is 0.9 W. We estimated the average power requirement for laser printers in off mode as 1.0 W.

Notes on Inkjet Printers

Active Mode, Low-Power Mode – According to EPA (2000), the average active-mode power requirement of new ENERGY STAR-compliant inkjet printers is 17 W. Because most new inkjet printers are compliant with ENERGY STAR and there has not been significant power reductions during the past several years, we estimated the average active-mode power requirement of inkjet printers at 17 W.

Because most inkjet printers do not have specific low-power operating modes, we did not make a separate estimation of energy use in low-power mode for this device.

Off Mode – According to Meyer and Schaltegger (1999), the average off-mode power requirement for inkjet printers is 2.8 W. We estimated the average power requirement for inkjet printers in off mode at 2 W.

Notes on Copiers

Active Mode, Low-Power Mode – According to Nordman et al. (1998), the average power requirements of active mode and low-power mode for each class of copiers are as shown in Table A-7. The average power requirement of low-power mode for low-speed copiers was estimated at 62 W, assuming that is the same as the low-power standard of 20 cpm ENERGY STAR copiers. By stock-weighting the average power requirement for each class of copiers, we estimated the average power requirements of commercial/industrial copiers in active mode and low-power mode at 183 W and 76 W, respectively. Because all residential copiers

are low-speed copiers, we estimated the average power requirement of residential copiers in active mode and low-power mode at 115 W and 62 W, respectively.

Table A-7. Average Power Requirements for Copiers in Active and Low-Power Mode (Nordman et al. 1998)

<i>Copier Type</i>	<i>Active (W)</i>	<i>Low-Power (W)</i>
Low Speed <21 cpm	115	N.A.
Mid Speed 21-44 cpm	180	75
High Speed >44 cpm	290	97

Off Mode – According to EPA (2000), the average off-mode power requirements of new ENERGY STAR-compliant copiers were estimated as shown in Table A-8. Since most new copiers are compliant with ENERGY STAR, we assumed the average power requirement of copiers in off mode is same as that for ENERGY STAR copiers. By stock-weighting the average power requirement of each class of copiers, we estimated the average power requirement of commercial/industrial copiers in off mode at 8.5 W. Because all residential copiers are low-speed copiers, we estimated the average power requirement of residential copiers off mode at 1.4 W.

Table A-8. Average Power Requirements of Copiers in Off Mode (EPA 2000)

<i>Copier Type</i>	<i>Off (W)</i>
Low Speed <21 cpm	1.4
Mid Speed 21-44 cpm	14.1
High Speed >44 cpm	11.4

Notes on Faxes

Active Mode – Because most faxes do not have a specific low-power operating mode, we did not estimate power requirements for faxes in low-power mode separately. As shown in Table 2, we consider “ready/standby” mode as the active mode for faxes. “Send/receive” modes are ignored here because of the very small amount of time spent in those modes. According to EPA (2000), the average power requirement of new ENERGY STAR-compliant faxes in active mode is 11.2 W. Because most new faxes are compliant with ENERGY STAR, we estimated the average power requirement of residential faxes in active mode at 10 W and that of commercial/industrial faxes at 15 W.

Usage of Office Equipment

General Methodology. We estimated the average usage (mode distribution over a week) for each type of office equipment. Low-power mode describes the case that equipment has power management (PM) capability and that PM is enabled. Several factors combine to determine the average mode distribution. Causative factors are the work habits of the machine’s users, the configuration of power management features, and the extent to which equipment is turned off manually. We defined the following parameters that describe those factors:²

² For commercial and industrial use, these parameters were estimated mainly based on the results of power data logging and night audits.

1. Nighttime Status – whether the equipment is on (active or low-power) or off during the night.
 $Night_{On} = \text{Average rate of "on" during nighttime (\%)}$
 $Night_{Off} = \text{Average rate of "manually off" during nighttime (\%)}$
2. Daytime status for PM-enabled machines
 $Day_{Active} = \text{Average rate of "active" during daytime (\%)}$
 $Day_{Low} = \text{Average rate of "low-power" during daytime (\%)}$
 $Day_{Off} = \text{Average rate of "off" during daytime (\%)}$
3. Daytime Length
 $Daytime = \text{Average time during which equipment is used in a week (hours/week)}$
 $Nighttime = \text{Average time during which equipment is not used in a week (hours/week)}$

“Daytime” originally meant regular working hours for office workers. We expanded the meaning of “daytime” from the office work hours to the average time during which each type of office equipment is used. For example, we estimated “daytime” for commercial laser printers at 56 hours per week, which means about 11 hours per work day, because this equipment is usually shared and therefore used for longer than an individual’s work day.

We also used “daytime” for residential equipment. We estimated “daytime” for residential laser printers at 3.5 hours/week, for example, which means people at home use their laser printers for an average of 3.5 hours per week. “Daytime” is different from the time during which machines are active. “Daytime” does not account for power-management status or machines that are turned off. “Nighttime” is defined as the time not accounted for by “daytime”.

Usage is estimated in the following way:

$$HA_i = Daytime_i \times Day_{Active,i}$$

$$HL_i = Daytime_i \times Day_{Low,i} + Nighttime \times Night_{On,i}$$

$$HO_i = Daytime_i \times Day_{Off,i} + Nighttime \times Night_{Off,i}$$

where

$$HA_i = \text{Hours of operation in active mode for equipment type } i \text{ (hours/week)}$$

$$HL_i = \text{Hours of operation in low-power mode for equipment type } i \text{ (hours/week)}$$

$$HO_i = \text{Hours of operation in off mode for equipment type } i \text{ (hours/week)}$$

We assumed there is no difference in usage between commercial and industrial equipment.

Results. Tables A-9 and A-10 show the best-guess estimates of average office equipment usage (hours/week) for each equipment type and power mode.

Table A-9. Residential Usage

<i>Equipment Type</i>	<i>Active (hr/week)</i>	<i>Low-Power (hr/week)</i>	<i>Off (hr/week)</i>	<i>Disconnected (hr/week)</i>
Portable Computer	10	5	0	153
Desktop Computer	10	5	153	0
Display	10	5	153	0
Laser Printer	0.7	4.3	163	0
Inkjet Printer	5	(*)	163	0
Copier Low-Power Enabled	7	69	92	0
Low-Power & Auto-Off Enabled	7	20	141	0
Fax	134	(*)	34	0

* We did not estimate use of low-power modes for inkjet printers and faxes.

Table A-10. Commercial and Industrial Usage

<i>Equipment Type</i>	<i>Active (hr/week)</i>	<i>Low-Power (hr/week)</i>	<i>Off (hr/week)</i>	<i>Disconnected (hr/week)</i>
Portable Computer	19	61	0	88
Desktop Computer	19	61	88	0
Server	101	50	17	0
Minicomputer	74	76	18	0
Mainframe	74	76	18	0
Display	19	61	88	0
Terminal	19	61	88	0
Laser Printer	11	118	39	0
Inkjet Printer	71	(*)	97	0
Copier Low-Power Enabled	27	113	28	0
Low-Power & Auto-Off Enabled	27	27	114	0
Fax	150	(*)	18	0

* We did not estimate use of low-power modes for inkjet printers and faxes

Notes on Commercial and Industrial Desktop Computers

We estimated usage of commercial/industrial desktop computers based on the parameters in Table A-11.

Table A-11. Parameters for Commercial and Industrial Usage of Desktop Computers

Nighttime Status	On	35%
	Off	65%
Daytime Status of PM-enabled Machines	Active	40%
	Low-Power	40%
	Off	20%
Daytime Length	48 hours/week	

Nighttime Status – According to Nordman et al. (2000), 65% of desktop computers are off during night.

Daytime Status of PM-enabled Machines – According to Newsham et al. (1994), about 20% of desktop computers are off during the daytime. According to Szydlowski et al. (1994), desktop computers are active for 38% of the daytime and at low power for 62% of the daytime when the PM timer is set to 15 minutes. We believe that the rate of active-mode use

has increased since 1994 because of the frequent access to the Internet, so we assumed that desktop computers are active for 40% of the daytime, at low power for 40%, and off for 20%.

Daytime Length – We used the same daytime lengths as used in Koomey et al. (1995).

Notes on Residential Desktop Computers

We estimated usage of residential desktop computers based on the parameters in Table A-12. Because these estimates are heavily dependent on assumptions, there are significant uncertainties.

Table A-12. Parameters for Residential Usage of Desktop Computers

Nighttime Status	On	3%
	Off	97%
Daytime Status of PM-enabled Machines	Active	100%
	Low-Power	0%
	Off	0%
Daytime Length		10 hours/week

Nighttime Status – We assumed 3% of all residential desktop computers are left “on” during the night.

Daytime Status of PM-enabled Machines – We assumed that residential desktop computers are always active during the daytime.

Daytime Length – According to CEMA (1999), residential desktop computers are used for an average of 10 hours per week.

Notes on Portable Computers

We assumed that the use of portable computers is same as the use of desktop computers except that portables are disconnected when off. Because our estimates are heavily dependent on assumptions, there are significant uncertainties.

Notes on Servers

We estimated server usage based on the parameters in Table A-13.

Table A-13. Parameters for Usage of Servers

Nighttime Status of PM-enabled Machines	Active	45%
	Low-Power	45%
	Off	10%
Daytime Status of PM-enabled Machines	Active	90%
	Low-Power	0%
	Off	10%
Daytime Length		56 hours/week

We assumed that 10% of all servers are off, accounting for machines that are either not plugged in (spares) or not turned on. For servers without power management, we assumed the remaining

90% are always in active mode. For servers with power management, we were forced to consider nighttime active and low-power modes separately, since servers are used in network environments that sometimes provide nighttime services like monitoring and backups. We assumed that half of operating servers with power management are in low-power mode during nighttime and the other half are in active mode. Finally, we assumed the daytime length as 56 hours/week, which is longer than that for desktop computers because servers are generally shared. There are significant uncertainties in our estimates because of the heavy dependence on assumptions.

Notes on Minicomputers and Mainframes

We assumed the same mode distributions for minicomputers and mainframes as Koomey et al. (1995). Because the estimates are heavily dependent on assumptions, there are significant uncertainties.

Notes on Displays and Terminals

We assumed that the usage for displays and terminals is same as that for desktop computers.

Notes on Commercial and Industrial Laser Printers

We estimated the usage of commercial/industrial laser printers based on the parameters in Table 14.

Table A-14. Parameters for Commercial and Industrial Usage of Laser Printers

Nighttime Status	On	70%
	Off	30%
Daytime Status of PM-enabled Machines	Active	20%
	Low-Power	70%
	Off	10%
Daytime Length	56 hours/week	

Nighttime Status. – According to Nordman’s unpublished 199 survey, 27% of laser printers are off during the night.

Daytime Status of PM-enabled Machines – According to Brown (2000), PM-enabled laser printers are ready 21% of the daytime and at low power for 79% of the daytime. We assumed that 10% of laser printers are off during the daytime to account for machines that are turned off.

Daytime Length – We assumed laser printers are used for 56 hours per week, a longer period than that for desktop computers because laser printers are usually shared.

Notes on Residential Laser Printers

We estimated the usage of residential laser printers based on the parameters in Table 15. Because the estimates are heavily dependent on assumptions, there are significant uncertainties.

Table A-15. Parameters for Residential Usage of Laser Printers

Nighttime Status	On	1%
	Off	99%
Daytime Status of PM-enabled Machines	Active	20%
	Low-Power	80%
	Off	0%
Daytime Length		3.5 hours/week

Nighttime Status – We assumed that 1% of all laser printers are left “on” during the night.

Daytime Status of PM-Enabled Machines – We assumed that laser printers are active for 20% of the daytime and at low power for 80% of daytime.

Daytime Length – According to Meyer and Schaltegger (1999), residential laser printers are used 3.5 hours per week.

Notes on Commercial and Industrial Inkjet Printers

We estimated the usage of commercial/industrial inkjet printers based on the parameters in Table A-16. Because the estimates are heavily dependent on assumptions, there are significant uncertainties.

Table A-16. Parameters for Commercial and Industrial Usage of Inkjet Printers

Nighttime Status	On	35%
	Off	65%
Daytime Status	Active	80%
	Off	20%
Daytime Length		28 hours/week

Nighttime Status – We assumed the same usage of commercial/industrial inkjet printers as that for desktop computers, since both are usually used individually.

Daytime Status – We assumed that commercial/industrial inkjet printers are off during the daytime at the same rate as desktop computers, since both are usually used individually.

Daytime Length – We assumed that inkjet printers are used 28 hours per week, which is half the amount of time that we assumed for laser printers because inkjet printers are generally not shared like laser printers.

Notes on Residential Inkjet Printers

We estimated the usage of residential inkjet printers based on the parameters in Table A-17. Because the estimates are heavily dependent on assumptions, there are significant uncertainties.

Table A-17. Parameters for Residential Usage of Inkjet Printers

Nighttime Status	On	1%
	Off	99%
Daytime Status	Active	100%
	Off	0%
Daytime Length		3.5 hours/week

Nighttime Status – We assumed that 1% of all inkjet printers are left “on” during the night.

Daytime Status – We assumed that inkjet printers are always “on” during the daytime.

Daytime Length – According to Meyer and Schaltegger (1999), inkjet printers are used 3.5 hours per week.

Notes on Commercial and Industrial Copiers

We estimated the usage of commercial/industrial copiers based on the parameters in Table A-18.

Table A-18. Parameters for Commercial and Industrial Usage of Copiers

Nighttime Status	On or Auto-Off	80%
	Manual Off	20%
Daytime Status of Low-Power-Enabled Machines	Active	45%
	Low-Power	45%
	Off	10%
Daytime		61 hours/week

Nighttime Status – According to Nordman et al. (1998), 16% of copiers are off between 6 and 7 p.m. We believe that a few of those copiers were auto-off because 6-7 p.m seems early as an average end of the business day. We therefore assumed that 10% of copiers are turned off manually during the nighttime. Assuming that an additional 10% of copiers are off, to account for machines not in use, we then assumed that 20% of copiers are turned off manually during the night.

Daytime Status of Low-Power-Enabled Machines – We assumed slow-speed copiers (20cpm) are in low-power mode for 75% of the daytime and active mode for 25% of the daytime. We assumed that mid-speed copiers (21-44 cpm) are in low-power mode for 50% of the daytime and in active mode for 50% of the daytime. We assumed that high-speed copiers (45cpm) are in low-power mode for 25% of the daytime and in active mode for 75% of the daytime. By taking a stock-weighted average, we estimated that copiers are in low-power mode for 50% of the daytime and in active mode for 50% of the daytime. We also assumed that no copiers are auto-off during the daytime and that 10% of all copiers are turned off manually during the daytime.

Daytime Length – We assumed that commercial and industrial copiers are used for 61 hours per week on average. The daytime length assumed for copiers is higher than that for laser printers based on the assumption that the delay times associated with copiers are longer than those associated with laser printers.

Notes on Residential Usage of Copiers

We estimated the usage of residential copiers based on the parameters in Table A-19. Because the estimates are heavily dependent on assumptions, there are significant uncertainties.

Table A-19. Parameters for Residential Usage of Copiers

Nighttime Status	On or Auto-Off	35%
	Manual-Off	65%
Daytime Status for Low-Power-Enabled Machines	Active	23%
	Low-Power	68%
	Off	10%
Daytime Length		30 hours/week

Nighttime Status – We assumed the same nighttime status for residential copiers as for commercial desktop computers because residential copiers are generally used for business purposes and are not shared.

Daytime Status of Low-Power-Enabled Machines – We assumed that slow-speed copiers (20 cpm) are in low-power mode for 75% of the daytime and in active mode for 25% of the daytime. We also assumed that no copiers are auto-off during the daytime but that 10% of residential copiers are turned off manually during the daytime.

Daytime Length – We assumed that residential copiers are used 30 hours per week, which is half of the daytime length for commercial copiers, because residential copiers are generally not shared like commercial copiers.

Notes on Commercial and Industrial Usage of Faxes

We assumed that 10% of commercial/industrial faxes are off. We also assumed that all faxes are always “on” when in use.

Notes on Residential Usage of Faxes

We assumed that 20% of residential faxes are off. We also assumed that all faxes are always “on” when in use.

Power-Management-Enabled Rates of Office Equipment

The power-management-enabled rate is the percentage of equipment that has power management capabilities and whose power management is properly operating. Equipment that has power management capability but that has not been correctly enabled is not included in this category.

We estimated the rate for each type of equipment mainly based on the results of audits for nighttime status. We assumed that the power-management-enabled rate is same for residential, commercial and industrial use.

The power-management-enabled rate for each type of office equipment is shown in Table A-20.

Table A-20. Power-Management-Enabled Rates of Office Equipment

<i>Equipment Type</i>	<i>Power-Management-Enabled Rate</i>
Desktop Computer	25%
Portable Computer	100%
Server Computer	25%
Display/Terminal	60%
Laser Printer	80%
Copier only “low-power” is enabled	34%
“low-power” and “auto-off” are enabled	34%

Notes on Desktop Computers

According to Nordman et al. (2000), 25% of desktop computers in offices have power management enabled.

Notes on Portable Computers

Because almost all portable computers have power management and have this feature enabled, we assumed that 100% of portable computers have power management enabled. Because this estimate is heavily dependent on assumptions, there is significant uncertainty.

Notes on Server Computers

We assumed same power-management-enabled rate for server computers as for desktop computers. Because this estimate is heavily dependent on assumptions, there are significant uncertainties.

Notes on Displays and Terminals

According to Nordman et al. (2000), 60% of displays in office have power management and have this feature enabled. We assumed that the power-management-enabled rate for terminals is same as for displays.

Notes on Laser Printers

According to Nordman’s unpublished 1999 survey, 83% of ENERGY STAR-compliant laser printers in offices have power management enabled. Considering that most laser printers are ENERGY STAR-compliant, we estimated the power-management-enabled rate at 80%.

Notes on Copiers

According to Nordman et al. (1998), nighttime status for copiers in offices is as shown in Table A-21. According to Webber et al. (2000), 55% of copiers are compliant with ENERGY STAR. Considering that 10% of copiers are turned off manually, we estimated that two thirds of the stock have low-power enabled and one third of the stock have auto-off enabled. We also assumed that all copiers that have auto-off enabled also have low-power enabled.

Table A-21. Nighttime Status of Copiers (Nordman et al. 1998)

<i>Copier Type</i>	<i>Active</i>	<i>Low-Power</i>	<i>Manually Off or Auto-Off</i>
Conventional Copier	30%	53%	17%
ENERGY STAR Copier	27%	12%	61%

Extra Energy Use for Printing or Copying

General Methodology. Extra energy use for printing or copying is the energy required for these tasks beyond the energy used in active mode. We estimated extra energy use by combining the average unit paper consumption, the rate of two-sided printing or copying (duplexing rate), and the extra energy use for each image using the following equation:

$$EPC_i = (UPC_i / (1 - DUP_i \times 0.5)) \times EI_i / 1000$$

where

EPC_i = Extra energy for printing or copying for equipment type i (kWh/year)

UPC_i = Unit paper consumption for equipment type i (sheets/year)

DUP_i = Duplexing rate, fraction of images placed onto duplexed sheets, for equipment type i (%)

EI_i = Extra energy for each image for equipment type i (W/image)

Because most assumptions are based on data cited from other papers or on our own judgments, there are uncertainties in these estimates. However, total paper consumption is well known and as such limits the inaccuracies in our conclusions about total energy consumption for printing or copying.

Typical imaging and paper use rates are not well-documented. Printers and copiers are rated for their maximum monthly imaging rates, and actual use is typically much less than this (e.g., one source estimates that copiers are typically used at about 15% of their rated capacity). Most analyses of imaging energy and paper use begin with the total amount of paper used and then allocate this total based on professional judgment and anecdotal data on typical imaging and paper use rates. We use this approach, relying on a mixture of data cited from others and our own judgment. We estimate the amount of paper likely to be used in homes and subtract this from the total to get commercial and industrial use. We assumed that commercial and industrial UPC are same.

Duplexing Rate. The duplexing rate represents the fraction of all images placed onto two-sided, or “duplexed”, sheets. A 100% duplexing rate requires half as much paper as a 0% duplexing rate.

According to Graff and Fishbein (1995), duplexing rates for copiers are estimated as shown in Table A-22. We estimated the duplexing rate for residential and commercial/industrial copiers by calculating a stock-weighted average duplexing rate for each class of copiers. We assumed that the duplexing rate for laser printers is same as that for copiers. We ignored duplexing for faxes and inkjet printers, because their duplexing rates appear to be much smaller than the rates for copiers. Table A-23 shows the duplexing rates for each type of office equipment.

Table A-22. Duplexing Rate of Copiers (Graff and Fishbein 1995)

<i>Copier Speed (cpm)</i>	<i>1998 Stock (thousands)</i>	<i>Annual Copied Sheets/Unit (thousands)</i>	<i>Duplexing Rate (%)</i>
<10	2,893	1	0%
10-19	1,875	25	2%
20-30	1,128	66	8%
31-45	694	111	14%
46-69	850	141	22%
70-90	215	465	40%
91-	86	1,620	60%

Table A-23. Duplexing Rate of Each Type of Office Equipment

<i>Equipment Type</i>	<i>Residential</i>	<i>Commercial/Industrial</i>
Copier	2%	30%
Laser Printer	2%	30%
Inkjet Printer	0%	0%
Fax	0%	0%

Unit Paper Consumption (UPC) for Residential Office Equipment. We assumed that the amount of copier paper consumed by a residential copier is the same as that consumed by an average low-speed copier, which is about 10,000 sheets/year. We assumed that the annual paper consumption of an inkjet printer or fax is 300 sheets/year, since most of these machines are for home use.

According to DOE (1999), about 15% of all households with PCs used these machines for business as well as private purposes. Drawing from this fact, it is natural to assume that more than 15% of residential laser printers are used for business as well as private purposes. We assumed that 25% of residential laser printers are for business as well as private use and that they consume 5,000 sheets/year. We also assumed that 75% of residential laser printers are only for private use and consume 300 sheets/year. Finally, by calculating stock-weighted averages, we estimated the UPC for residential laser printers at 1,475 sheets/year.

Table A-24 shows the UPC for each type of office equipment.

Table A-24. Unit Paper Consumption of Residential Office Equipment

<i>Equipment Type</i>	<i>UPC (sheets/year)</i>
Copier	10,000
Laser Printer	1,475
Inkjet Printer	300
Fax	300

Unit Paper Consumption (UPC) for Commercial and Industrial Office Equipment. To estimate UPC for commercial/industrial equipment, we first estimated the total weight of paper consumed by all office equipment based on data from Pulp & Paper (1995). Second, by assuming the weight of paper is 5 grams/sheet, we estimated the total number of sheets consumed by office equipment at 840 billion sheets/year. Third, we allocated 45% of total paper consumed to copiers, another 45% to laser printers, 5% to inkjet printers, and another 5% to faxes. Fourth, by subtracting our estimate of residential paper consumption, we estimated commercial and industrial paper consumption for each type of office equipment. Finally, by dividing total paper

consumption by the stock, we estimated the UPC for each type of office equipment.

Table A-25 shows the UPC for each type of equipment.

Table A-25. Unit Paper Consumption of Commercial and Industrial Office Equipment

<i>Equipment Type</i>	<i>UPC (sheets/year)</i>
Copier	45,590
Laser Printer	17,000
Inkjet Printer	1,130
Fax	1,853

Extra Energy for Each Image. According to Nordman et al. (1998), the extra energy used for each image made by copiers is about 1 Wh. According to Brown et al. (2000), the extra energy used for each image produced by laser printers is also about 1 Wh. Since most images are produced by copiers or laser printers, we assumed that the extra energy for each image is 1 Wh for all types of equipment.

Results. Table A-26 shows the extra energy used for printing or copying by each type of equipment.

Table A-26. Extra Energy for Printing or Copying (kWh/year)

<i>Equipment Type</i>	<i>Residential</i>	<i>Commercial and Industrial</i>
Copier	10.1	53.6
Laser Printer	1.5	20.0
Inkjet Printer	0.3	1.1
Fax	0.3	1.9

Uncertainty Analysis

Uncertainty in the Input Data. We estimated the uncertainty in each type of input data based on the quality or origin of the data. We did not separately estimate uncertainty in commercial input data and industrial input data.

Tables A-27 and A-28 show the uncertainty in commercial/industrial and residential input data, respectively.

Table A-27. Uncertainty in Commercial and Industrial Office Equipment Input Data

Equipment Type		Stock (thousand)	Power Requirement (W)			Usage (hour/week) Active / Low / Off	SPM* (%)	EPC** (kWh/yr)
			Active	Low	Off			
Portable Computer	Best Estimate	6,060	15	3	2	19 / 61 / 0	100	0
	Highest Estimate	8,190	18	4	2.5	21 / 67 / 40	100	0
	Lowest Estimate	3,460	13.5	2.5	1.5	17 / 55 / 0	80	0
Desktop Computer	Best Estimate	54,580	55	25	1.5	19 / 61 / 88	25	0
	Highest Estimate	63,630	57.5	27.5	2	21 / 63 / 80	30	0
	Lowest Estimate	43,880	50	22.5	1	17 / 59 / 96	20	0
Server	Best Estimate	3,330	75	25	1.5	101 / 50 / 17	25	0
	Highest Estimate	4,300	90	30	2	119 / 32 / 17	30	0
	Lowest Estimate	2,320	60	22.5	1	81 / 70 / 17	15	0
Mini Computer	Best Estimate	2,020	1,000	500	0	74 / 76 / 18	(B)	0
	Highest Estimate	2,260	1,100	550	0	94 / 65 / 9		0
	Lowest Estimate	1,780	700	350	0	64 / 77 / 27		0
Mainframe	Best Estimate	107	10,000	5,000	0	74 / 76 / 18	(B)	0
	Highest Estimate	119	11,000	5,500	0	94 / 65 / 9		0
	Lowest Estimate	95	7,000	3,500	0	64 / 77 / 27		0
Display	Best Estimate	54,580	85	5	0.5	19 / 61 / 88	60	0
	Highest Estimate	63,630	90	5.5	0.75	21 / 63 / 80	65	0
	Lowest Estimate	43,880	80	4.5	0.25	17 / 59 / 96	55	0
Terminal	Best Estimate	13,330	75	5	0.5	19 / 61 / 88	60	0
	Highest Estimate	16,680	80	5.5	0.75	21 / 79 / 68	70	0
	Lowest Estimate	10,030	70	4.5	0.25	17 / 42 / 109	50	0
Laser Printer	Best Estimate	21,690	77	25	1	11 / 118 / 39	80	20
	Highest Estimate	25,040	82	27.5	1.5	12 / 121 / 35	85	24
	Lowest Estimate	17,480	72	22.5	0.5	10 / 114 / 44	75	16
Inkjet Printer	Best Estimate	23,870	17	(A)	2	71 / (A) / 97	(A)	1.1
	Highest Estimate	27,370	20		2.5	82 / (A) / 86		1.3
	Lowest Estimate	18,120	15		1.5	37 / (A) / 131		0.9
Copier	Best Estimate	7,460	183	76	8.5	27 / 27 / 114	34 (C)	53.6
	Highest Estimate	8,980	193	80	9.0	30 / 30 / 108	39 (C)	63.6
	Lowest Estimate	5,830	173	72	8.0	25 / 25 / 118	29 (C)	43.6
Fax	Best Estimate	21,650	15	(A)	0	150 / (A) / 18	(A)	1.9
	Highest Estimate	24,040	18		0	159 / (A) / 9		2.3
	Lowest Estimate	19,120	13.5		0	141 / (A) / 27		1.5

*SPM = Power management enabled rate (%)

**EPC = Extra energy used for printing or copying (kWh/year)

(A) We did not estimate low-power mode for inkjet printers and faxes.

(B) We did not estimate power management modes for minicomputers and mainframes. Low-power modes of minicomputers and mainframes do not mean power management but rather that peripherals are off while CPUs are on.

(C) We only considered the rate of auto-off enabling for copiers because the uncertainty in the rate of auto-off enabled causes more inaccuracies in the result than does the uncertainty in the rate of low-power enabling.

Table A-28. Uncertainty in Residential Office Equipment Input Data

Equipment Type		Stock (thousand)	Power Requirement (W)			Usage (hour/week)	SPM* (%)	EPC** (kWh/yr)
			Active	Low	Off	Active / Low / Off		
Portable Computer	Best Estimate	16,090	15	3	2	10 / 5 / 0	100	0
	Highest Estimate	16,890	18	4	2.5	11 / 8 / 75	100	0
	Lowest Estimate	14,490	13.5	2.5	1.5	9 / 3 / 0	80	0
Desktop Computer	Best Estimate	54,530	50	25	1.5	10 / 5 / 153	25	0
	Highest Estimate	57,260	52.5	27.5	2	11 / 8 / 149	30	0
	Lowest Estimate	49,080	47.5	22.5	1	9 / 3 / 156	20	0
Display	Best Estimate	54,530	85	5	0.5	10 / 5 / 153	60	0
	Highest Estimate	57,260	90	5.5	0.75	11 / 8 / 149	65	0
	Lowest Estimate	49,080	80	4.5	0.25	9 / 3 / 156	55	0
Laser Printer	Best Estimate	6,300	30	20	1	0.7 / 4.3 / 163	80	1.5
	Highest Estimate	7,560	33	22	1.5	1 / 8 / 159	85	1.8
	Lowest Estimate	5,040	27	18	0.5	0.5 / 4 / 163.5	75	1.2
Inkjet Printer	Best Estimate	50,200	17	(A)	2	5 / (A) / 163	(A)	0.3
	Highest Estimate	60,240	20		2.5	9 / (A) / 159		0.4
	Lowest Estimate	40,160	15		1.5	4.5 / (A) / 163.5		0.2
Copier	Best Estimate	3,800	115	62	1.5	7 / 20 / 141	34 (B)	10
	Highest Estimate	4,180	120	65	2	9 / 27 / 132	39 (B)	12
	Lowest Estimate	3,420	110	59	1	5 / 14 / 149	29 (B)	8
Fax	Best Estimate	6,300	10	(A)	0	134 / (A) / 34	(A)	0.3
	Highest Estimate	6,930	12		0	150 / (A) / 18		0.4
	Lowest Estimate	5,670	9		0	127 / (A) / 41		0.2

*SPM = Power-management-enabled rate (%)

**EPC = Extra energy used for printing or copying (kWh/year)

(A) We did not estimate low-power modes for inkjet printers and faxes.

(B) We only considered the rate of auto-off mode for copiers because the uncertainty in auto-off enabling rates causes more inaccuracy in the result than is caused by the uncertainty in low-power enabling rates.

Notes on Uncertainty in Commercial and Industrial Stocks

The accuracy of commercial and industrial stock estimates depends on the accuracy of assumptions about equipment lifetimes. We assumed that the uncertainty in the estimates of lifetime for each equipment type as follows:

Equipment Type	Uncertainty
Portable Computer, Desktop Computer, Server Display, Terminal	0.50 year
Laser Printer, Inkjet Printer, Copier, Fax	0.75 year
Minicomputer, Mainframe	1.0 year

Notes on Uncertainty in Commercial and Industrial Power Requirements

When our power-requirement estimates are based mainly on measured data, we assumed that the uncertainty rate in those estimates range from 5 to 10%. When our estimates are based mainly on assumptions, we assumed that the uncertainty rate is 20 to 30%.

Notes on Uncertainty in Commercial and Industrial Usage (Mode Distributions)

Equipment usage is calculated by combining the nighttime status, daytime status, and daytime length. Uncertainty in the daytime status estimates is much lower than the uncertainty associated with the other usage factors, so we did not include daytime status in our total uncertainty estimate. We calculated the uncertainty in usage by combining the uncertainty of the nighttime off-mode rate and daytime length.

We assumed that the uncertainty in daytime length is 5 hours/week for all types of equipment except minicomputers, mainframes, and inkjet printers. We assumed that the uncertainty in daytime length is between 10 and 20 hours/week for minicomputers, mainframes, and inkjet printers.

We assumed that the uncertainty in nighttime off-mode rate is 5% or less for all types of equipment except portable computers, terminals, and inkjet printers. For portable computers, terminals, and inkjet printers, we assumed that the uncertainty in the nighttime off-mode rate is between 10 and 30%.

Notes on Uncertainty in Commercial and Industrial Power-Management-Enabled Rates

We assumed that the uncertainty in the power-management-enabled rate is 5% for all types of equipment except portable computers and terminals. For portable computers and terminals, we assumed that the uncertainty is between 10 and 20%.

Notes on Uncertainty in Commercial and Industrial Energy Use for Printing or Copying

We assumed that the uncertainty in extra energy used for printing or copying is 20%.

Notes on Uncertainty in Residential Stocks

We assumed that the uncertainty rate of the residential stock estimates is 10% for all type of equipment except laser printers and inkjet printers. We assumed the uncertainty rate for laser printers and inkjet printers to be 20%.

Notes on Uncertainty in Residential Power Requirements

When our estimates are based mainly on measured data, we assumed that the uncertainty rate in power requirements is between 5 and 10%. When our estimates are based mainly on assumptions, we assumed that the uncertainty rate is between 20 and 30%.

Notes on Uncertainty in Residential Usage (Mode Distributions)

Equipment usage is calculated by combining the nighttime status, daytime status, and daytime length. Uncertainty in the daytime status estimates is much lower than the uncertainty associated with the other usage factors, so we did not include daytime status in our total uncertainty estimate. We calculated the uncertainty in usage by combining the uncertainty of the nighttime off-mode rate and daytime length.

We assumed that the uncertainty in daytime length is between 0.5 and 1.0 hours/week for all types of equipment.

We assumed that the uncertainty in nighttime off-mode rates is between 1 and 3% for all types of equipment.

Sensitivity Analysis. We conducted sensitivity analysis for the uncertainty associated with each

input data category in order to evaluate the potential error in energy use calculations caused by each uncertainty. Tables A-29 and A-30 show the results of sensitivity analysis for uncertainty in commercial/industrial and residential input data, respectively.

Table A-29. Sensitivity Analysis of Uncertainty in Commercial/Industrial Office Equipment Input Data (GWh/year)

Equipment Type	Stock	Power Requirement			Usage	SPM	EPC
		Active	Low	Off			
Portable Computer	-64/+52	-9/+18	-10/+19	0	-15/+40	+46	0
Desktop Computer	-2285/+1931	-927/+463	-109/+109	-125/+125	-566/+566	-262/+262	0
Server	-565/+543	-361/+361	-5/+11	-1/+1	-45/+37	-22/43	0
Mini Computer	-1414/+1390	-2341/+780	-1200/+400	0	-1001/+1528	(B)	0
Mainframe	-701/+700	-1239/+413	-636/+212	0	-530/+809	(B)	0
Display	-2199/+1859	-621/+621	-52/+52	-62/+62	-837/+837	-697/+697	0
Terminal	-603/+612	-151/+151	-12/+12	-15/+15	-505/+505	-298/+298	0
Laser Printer	-1189/+947	-195/+195	-302/+302	-22/+22	-241/+241	-348/+348	-87/+87
Inkjet Printer	-429/+260	-178/+266	(A)	-60/+60	-634/+198	(A)	-4/+4
Copier	-1424/+1330	-246/+246	-81/+81	-10/+10	-263/+273	-112/+112	-74/+74
Fax	-302/+285	-254/+508	(A)	0	-152/+152	(A)	-10/+10

(A) We did not estimate low-power modes for inkjet printers and faxes.

(B) We did not estimate power management mode for minicomputers and mainframes. Low-power modes of minicomputers and mainframes do not imply power management but rather that peripherals are turned off while CPUs are on.

Table A-30. Sensitivity Analysis of Uncertainty in Residential Office Equipment Input Data (GWh/year)

Equipment Type	Stock	Power Requirement			Usage	SPM	EPC
		Active	Low	Off			
Portable Computer	-14/+7	-12.5/+25	-2/+4	0	-17/+146	+9	0
Desktop Computer	-267/+133	-96/+96	-8/+8	-217/+217	-347/+529	-17/+17	0
Display	-313/+157	-169/+169	-4/+4	-109/+109	-421/+578	-54/+54	0
Laser Printer	-20/+20	-1/+1	-2/+2	-27/+27	-5/+28	-1/+2	-2/+2
Inkjet Printer	-219/+219	-27/+40	(A)	-213/+213	-150/+150	(A)	-5/+5
Copier	-109/+109	-28/+28	-18/+18	-11/+11	-154/+154	-29/+29	-7/+7
Fax	-44/+44	-44/+88	(A)	0	-52/+52	(A)	-1/+1

(A) We did not estimate low-power modes for inkjet printers and faxes.

Findings. Generally, the uncertainty in commercial/industrial input data causes much larger errors in energy use calculations (in absolute terms) than the uncertainty in residential input data. Table A-31 shows the classification of commercial/industrial input data according to the level of error in energy use caused by the respective uncertainty.

Table A-31. Classification of Commercial/Industrial Input Data According to the Level of Error in Energy Use Calculations Caused by Uncertainty in Input Data

<i>Total Error in Energy Use Calculations</i>	<i>Input Data</i>
Over 2,000 GWh/year	<ul style="list-style-type: none"> • Stock of desktop computers and displays • Active power of minicomputers
From 1,000 to 2,000 GWh/year	<ul style="list-style-type: none"> • Stock of minicomputers, laser printers, and copiers • Active power of mainframes • Low power of minicomputers • Usage of minicomputers
From 500 to 1,000 GWh/year	<ul style="list-style-type: none"> • Stock of servers, mainframes, and terminals • Active power of desktop computers, displays, and faxes • Low power of mainframes • Usage of desktop computers, mainframes, displays, terminals, and inkjet printers • Power management enabled rate of displays
Less than 500 GWh/year	<ul style="list-style-type: none"> • All the other input data

For residential input data, uncertainty in the usage estimates for desktop computers and displays causes more than 500 GWh/year error in the energy use calculations.

The results of the sensitivity analysis show that more accurate data are needed for commercial/industrial stocks, active power, and usage. For the other factors, however, the sensitivity results validate the estimates used in our energy calculations.

Comparison with Our 1995 Forecast

Difference between Current Best Estimate and Our 1995 Forecast. We compared our current estimate for commercial office equipment with our 1995 forecast (Kooimey et al. 1995) of 1999 electricity consumption by office equipment. Because we did not separate “micro computers”³ into desktop, portable, or server computers in our 1995 forecast, we cannot separately compare our current estimates for those categories with our 1995 forecast. Instead, we combined our current estimate for desktop computers, portable computers, and servers into one category and compared the combined result to the “micro computers” category from the 1995 forecast.

Tables A-32, A-33, and A-34 show our current estimate, our 1995 forecast, and the difference between our current estimate and the 1995 forecast, respectively.

Table A-32. Current Best Estimate of 1999 Energy Use

Equipment type	Stock (thousands)	PA* (W)	PL* (W)	PO* (W)	HA** (hr/week)	HL** (hr/week)	HO** (hr/week)	SPM (%)	EPC (kWh/yr)	E (TWh/yr)
Desktop Computer	55,970	56	18	1.5	24	61	76	32%	0	11.9
Mini Computer	1,520	1,000	500	0	74	76	18	(B)	0	8.9
Mainframe	96	10,000	5,000	0	74	76	18	(B)	0	5.6
Display	47,760	85	5	0.5	19	61	88	60%	0	9.8
Terminal	10,000	75	5	0.5	19	61	88	60%	0	1.8
Laser Printer	18,980	77	25	1	11	118	39	80%	20.0	5.4
Inkjet Printer	20,890	17	(A)	2	71	(A)	97	(A)	1.1	1.6
Copier	6,530	185	76	8.7	28	71	69	68%	53.6	5.7
Fax	18,940	15	(A)	0	150	(A)	18	(A)	1.9	2.3

*PA, PL, PO = Power requirement in active mode, low-power mode, and off mode, respectively

³ Micro computers are all computers whose price is less than \$25,000. Desktop computers, portable computers, and servers are micro computers.

**HA, HL, HO = Hours in active mode, low-power mode, and off mode, respectively

Table A-33. 1995 Forecast for 1999 Energy Use

Equipment type	Stock (thousands)	PA (W)	PL (W)	PO (W)	HA (hr/week)	HL (hr/week)	HO (hr/week)	SPM (%)	EPC (kWh/yr)	E (TWh/yr)
Desktop Computer	52,790	50	25	0	15	44	109	33%	0	7.5
Mini Computer	1,514	1,250	625	0	74	76	18	(B)	0	11.1
Mainframe	90	10,000	5,000	0	74	76	18	(B)	0	5.3
Display	52,790	63	14.3	0	30	29	109	47%	0	8.4
Terminal	10,000	63	14.3	0	30	29	109	47%	0	1.6
Laser Printer	27,850	80	25	0	8.5	50.5	109	91%	14.9	3.6
Inkjet Printer	24,060	9	(A)	0	52	(A)	116	(A)	1.2	0.6
Copier	7,820	190	150	10	30	27	111	38%	10.5	5.8
Fax	13,120	22.5	(A)	0	168	(A)	0	(A)	50.8	3.2

Table A-34. Difference between Current Estimate and 1995 Forecast of 1999 Energy Use (D = Current Estimate – 1995 Forecast)

Equipment type	DStock (thousands)	DPA (W)	DPL (W)	DPO (W)	DHA (hr/week)	DHL (hr/week)	DHO (hr/week)	DSPM (%)	DEPC (kWh/yr)	DE (TWh/yr)
Desktop Computer	3,170	6	-7	1.5	9	17	-33	-1%	0	4.4
Mini Computer	6	-250	-125	0	0	0	0	(B)	0	-2.2
Mainframe	6	0	0	0	0	0	0	(B)	0	0.3
Display	-5,030	22	-9.3	0.5	-11	32	-21	13%	0	1.4
Terminal	0	12	-9.3	0.5	-11	32	-21	13%	0	0.2
Laser Printer	-8,870	-3	0	1	2.5	67.5	-70	11%	5.1	1.8
Inkjet Printer	-3,170	8	(A)	2	19	(A)	-19	(A)	-0.1	1
Copier	-1,290	-5	-74	-1.3	-2	44	-42	30%	43.1	-0.1
Fax	5,820	-7.5	(A)	0	-34	(A)	34	(A)	-48.9	-0.9

(A) We did not estimate low-power modes for inkjet printers and faxes.

(B) We did not estimate power management modes for minicomputers and mainframes. Low-power modes of minicomputers and mainframe do not mean power management but rather that peripherals are off while CPUs are on.

Decomposition of Differences. We analyzed the difference between our current estimate and previous forecast to determine the causes of the major differences.

The differences can be decomposed into the following equation by using a Taylor expansion:

$$\begin{aligned}
 E_i^{1999} - E_i^{FC} = & \left(\frac{\mathcal{E}}{\mathcal{S}t o c k}_i \right)^{FC} \times \Delta S t o c k_i + \left(\frac{\mathcal{E}}{\mathcal{S}P M}_i \right)^{FC} \times \Delta S P M_i + \left(\frac{\mathcal{E}}{\mathcal{E}P C}_i \right)^{FC} \times \Delta E P C_i \\
 & + \left(\frac{\mathcal{E}}{\mathcal{P}A}_i \right)^{FC} \times \Delta P A_i + \left(\frac{\mathcal{E}}{\mathcal{P}L}_i \right)^{FC} \times \Delta P L_i + \left(\frac{\mathcal{E}}{\mathcal{P}O}_i \right)^{FC} \times \Delta P O_i \\
 & + \left(\frac{\mathcal{E}}{\mathcal{P}A \cdot \mathcal{S}t o c k}_i \right)^{FC} \times \Delta P A_i \times \Delta S t o c k_i + \left(\frac{\mathcal{E}}{\mathcal{P}L \cdot \mathcal{S}t o c k}_i \right)^{FC} \times \Delta P L_i \times \Delta S t o c k_i + \left(\frac{\mathcal{E}}{\mathcal{P}O \cdot \mathcal{S}t o c k}_i \right)^{FC} \times \Delta P O_i \times \Delta S t o c k_i \\
 & + \left(\frac{\mathcal{E}}{\mathcal{P}A \cdot \mathcal{S}P M}_i \right)^{FC} \times \Delta P A_i \times \Delta S P M_i + \left(\frac{\mathcal{E}}{\mathcal{P}L \cdot \mathcal{S}P M}_i \right)^{FC} \times \Delta P L_i \times \Delta S P M_i + \left(\frac{\mathcal{E}}{\mathcal{P}O \cdot \mathcal{S}P M}_i \right)^{FC} \times \Delta P O_i \times \Delta S P M_i \\
 & + \left(\frac{\mathcal{E}}{\mathcal{P}A \cdot \mathcal{H}A}_i \right)^{FC} \times \Delta P A_i \times \Delta H A_i + \left(\frac{\mathcal{E}}{\mathcal{P}L \cdot \mathcal{H}L}_i \right)^{FC} \times \Delta P L_i \times \Delta H L_i + \left(\frac{\mathcal{E}}{\mathcal{P}O \cdot \mathcal{H}O}_i \right)^{FC} \times \Delta P O_i \times \Delta H O_i \\
 & + \left(\frac{\mathcal{E}}{\mathcal{U}S a g e}_i \right)^{FC} \times \Delta U S a g e_i + \left(\frac{\mathcal{E}}{\mathcal{U}S a g e \cdot \mathcal{S}t o c k}_i \right)^{FC} \times \Delta U S a g e_i \times \Delta S t o c k_i + \left(\frac{\mathcal{E}}{\mathcal{U}S a g e \cdot \mathcal{S}P M}_i \right)^{FC} \times \Delta U S a g e_i \times \Delta S P M_i \\
 & + \left(\frac{\mathcal{E}}{\mathcal{S}t o c k \cdot \mathcal{S}P M}_i \right)^{FC} \times \Delta S t o c k_i \times \Delta S P M_i + \left(\frac{\mathcal{E}}{\mathcal{S}t o c k \cdot \mathcal{E}P C}_i \right)^{FC} \times \Delta S t o c k_i \times \Delta E P C_i \\
 & + Residual(\Delta^3)
 \end{aligned}$$

where

$E1999$ = Current estimate for energy use in 1999

EFC = Forecast in 1995 for energy use in 1999

and

$$\left(\frac{\mathcal{E}}{\mathcal{Usage}} \right) \times \Delta Usage = \left(\frac{\mathcal{E}}{\mathcal{HA}} \right) \times \Delta HA + \left(\frac{\mathcal{E}}{\mathcal{HL}} \right) \times \Delta HL + \left(\frac{\mathcal{E}}{\mathcal{HO}} \right) \times \Delta HO$$

We decomposed the difference between current estimate and forecast of energy use by micro computers, displays, laser printers, inkjet printers, copiers, and faxes in 1999. The results are shown in Table A-35.

Table A-35. Decomposition of Differences between Current Estimate and 1995 Forecast of 1999 Energy Use (GWh/year)

<i>Decomposition Term</i>	<i>Desktop Computer</i>	<i>Display</i>	<i>Laser Printer</i>	<i>Inkjet Printer</i>	<i>Copier</i>	<i>Fax</i>
$\left(\frac{\mathcal{E}}{\mathcal{S}tock}\right)^{FC} \times \Delta Stock$	452	-804	-1,142	-80	-957	1,439
$\left(\frac{\mathcal{E}}{\mathcal{S}PM}\right)^{FC} \times \Delta SPM$	35	-489	443	0	-612	0
$\left(\frac{\mathcal{E}}{\mathcal{E}PC}\right)^{FC} \times \Delta EPC$	0	0	142	-2	337	-642
$\left(\frac{\mathcal{E}}{\mathcal{P}A}\right)^{FC} \times \Delta PA$	341	2,762	-54	533	-171	-850
$\left(\frac{\mathcal{E}}{\mathcal{P}L}\right)^{FC} \times \Delta PL$	-259	-338	-23	0	-310	0
$\left(\frac{\mathcal{E}}{\mathcal{P}O}\right)^{FC} \times \Delta PO$	451	150	159	291	-59	0
$\left(\frac{\mathcal{E}}{\mathcal{U}sage}\right)^{FC} \times \Delta Usage$	3,253	1,658	3,248	215	3,663	-276
$\left(\frac{\mathcal{E}}{\mathcal{P}A \cdot \mathcal{S}tock}\right)^{FC} \times \Delta PA \times \Delta Stock$	21	-263	17	-70	28	-378
$\left(\frac{\mathcal{E}}{\mathcal{P}L \cdot \mathcal{S}tock}\right)^{FC} \times \Delta PL \times \Delta Stock$	-16	32	7	0	51	0
$\left(\frac{\mathcal{E}}{\mathcal{P}O \cdot \mathcal{S}tock}\right)^{FC} \times \Delta PO \times \Delta Stock$	27	-14	-51	-38	10	0
$\left(\frac{\mathcal{E}}{\mathcal{P}A \cdot \mathcal{S}PM}\right)^{FC} \times \Delta PA \times \Delta SPM$	-4	-221	-23	0	41	0
$\left(\frac{\mathcal{E}}{\mathcal{P}L \cdot \mathcal{S}PM}\right)^{FC} \times \Delta PL \times \Delta SPM$	7	-93	3	0	-245	0
$\left(\frac{\mathcal{E}}{\mathcal{P}O \cdot \mathcal{S}PM}\right)^{FC} \times \Delta PO \times \Delta SPM$	0	0	0	0	-4	0
$\left(\frac{\mathcal{E}}{\mathcal{U}sage \cdot \mathcal{S}tock}\right)^{FC} \times \Delta Usage \times \Delta Stock$	196	-158	-1,035	-28	-606	-123
$\left(\frac{\mathcal{E}}{\mathcal{U}sage \cdot \mathcal{S}PM}\right)^{FC} \times \Delta Usage \times \Delta SPM$	15	-578	590	0	-674	0
$\left(\frac{\mathcal{E}}{\mathcal{P}A \cdot \mathcal{H}A}\right)^{FC} \times \Delta PA \times \Delta HA$	174	365	-37	198	-105	91
$\left(\frac{\mathcal{E}}{\mathcal{P}L \cdot \mathcal{H}L}\right)^{FC} \times \Delta PL \times \Delta HL$	-101	-399	-30	0	-500	0
$\left(\frac{\mathcal{E}}{\mathcal{P}O \cdot \mathcal{H}O}\right)^{FC} \times \Delta PO \times \Delta HO$	-139	-30	-102	-48	32	0
$\left(\frac{\mathcal{E}}{\mathcal{S}tock \cdot \mathcal{S}PM}\right)^{FC} \times \Delta Stock \times \Delta SPM$	2	47	-141	0	101	0
$\left(\frac{\mathcal{E}}{\mathcal{S}tock \cdot \mathcal{E}PC}\right)^{FC} \times \Delta Stock \times \Delta EPC$	0	0	-45	0	-56	-285
<i>Residual (Δ^3)</i>	-3	-244	-146	-20	-47	40
ΔE	4,451	1,383	1,780	949	-81	-983

Findings. The total difference between the previous forecast and our current estimate is less than 15%. Our current estimate of energy use by microcomputers, displays, laser printers, and inkjet printers is higher than our 1995 forecast. Current estimate of energy use for minicomputers and faxes is lower than our forecast in 1995.

For microcomputers and laser printers, the differences in estimates of usage are the most crucial factor describing the difference in the total results. The difference in usage estimates arose because the rate that equipment is left on during nights and weekends is higher than we expected previously.

For displays, inkjet printers, and minicomputers, the difference in estimates of active-mode power requirements are the most crucial factor describing the difference in the total results. Previously, we predicted that the average power requirement of displays would be 63 W; our current estimate is 85 W. This difference arose mainly because large screen displays (17-inch or larger) have become more popular than previously expected. For inkjet printers, we previously predicted that the average power requirement would be 9 W; our current estimate is 17 W. For minicomputers, we predicted that the average power requirement would be 1,250 W; our current estimate is 1,000 W.

For faxes, differences in stock estimates are the most crucial factor describing the difference in the total results.

II. NETWORK EQUIPMENT

Lifetimes of Network Equipment

Network equipment is very new, and equipment lifetimes are unknown, although they are expected to be short since network equipment evolving rapidly. We assumed that the lifetime for all types of network equipment is four years.

Domestic Sales Revenue from Network Equipment

First, we estimated worldwide sales revenue from network equipment during the past four years for each type based on Oro' dero's quarterly reports (Oro' dero 1996, 1997, 1998, 1999). Second, we allocated worldwide sales revenue to the U.S. and other countries based on the ratio of the number of host names in the U.S. to those in other countries. Table A-36 shows the domestic sales revenue for network equipment from 1996 to 1999.

Table A-36. Domestic Sales Revenue from Network Equipment, 1996-1999 (million US\$)

<i>Equipment Type</i>	<i>Domestic Sales Revenue (million US\$)</i>
WAN Router	1,130
Switch	5,458
LAN Router	13,210
Switch	19,932
Access Device	6,662
Hub	4,228

Ratio of Power Requirement to Price for Network Equipment

We first chose a representative model for each type of network equipment. We selected CISCO products as the representative model of all types of network equipment except hubs because the prices and power requirements of CISCO products are readily available. We selected a 3COM product as the representative model for hubs because of its popularity. Next, we estimated the power requirement for each representative model by assuming that the real power requirement is half of the rated power requirement. Then, we estimated the price for each representative model based on prices quoted from several online shopping sites. Finally, we calculated the ratio of power requirement to price.

Table A-37 shows the representative model and its ratio of power requirement to price for each type of network equipment.

Table A-37. Ratio of Power Requirement to Price for Selected Network Equipment

<i>Equipment Type</i>	<i>Representative Model</i>	<i>Ratio of Power Requirement to Price (W/\$1000)</i>
WAN Router	CISCO 7500	5.0
	CISCO BPX 8620	5.0
LAN Router	CISCO 2500	6.0
	CISCO 2900	7.5
	CISCO AS5300	5.0
	3COM SuperStack 2	17.5

Reasonableness of Estimates of Energy Use by LAN Routers and Switches

Network equipment is dedicated to computers on the network, so there must be a correlation between the total power requirement of network equipment and the number of computers on the network. We surveyed LBNL's network and estimated what portion of the power requirement of LAN routers and switches is dedicated to each computer at LBNL by dividing the total power requirement of all LAN routers and switches by the total number of computers (including desktop, portable, and server computers). Similarly, we estimated what portion of the power requirement of LAN routers and switches is dedicated to each computer in the U.S. by dividing the total power requirement of all LAN routers and switches by the total number of commercial and industrial computers in the U.S. (including desktop, portable, and server computers). Finally, we compared these two values and evaluated the reasonableness of our estimate. Table A-38 shows the results of this comparison.

Table A-38. Comparison of the Power Requirement of LAN Routers and Switches Per Computer in the U.S. and LBNL

<i>Estimate</i>	<i>U.S.</i>	<i>LBNL</i>
Total Power Requirement of LAN Routers and Switches	228.7 MW	16,360 W
Number of Computers	60.7 million	5,000
Power Requirement of LAN Routers and Switches per Computer	3.77 W/unit	3.27 W/unit

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