Energy Consumption by Commercial Office and Telecommunication Equipment

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ABSTRACT

The dramatic rise of the Internet that began in the mid-1990s fueled a large increase in the stocks of equipment integral to the Internet, including server computers, computer network equipment, and uninterruptable power supplies (UPSs). Concurrently, wireless and fiber-based telephony also experienced strong growth. Arthur D. Little (ADL) recently completed a bottom-up study of about 40 different types of commercial office and telecommunications equipment. The study found that commercial office and telecommunications equipment accounted for about 2.7% of national electricity consumption in 2000, or about 1.1% of national (primary) energy consumption. The "indirect" impacts of office and telecommunications equipment on national energy consumption, such as macroeconomic modifications of the country's energy intensity (energy per unit of Gross Domestic Product) and energy consumed to manufacture office and telecommunications equipment, may exceed the direct energy consumption impact. The literature review did not uncover any prior comprehensive studies of telephone network electricity consumption or UPSs electricity consumption, suggesting that this study developed the first bottom-up estimates of the national energy consumption of both telephone networks and UPSs.

Introduction

The development, acceptance and increasing usage of technology to create, process and exchange information over the past decade has had a dramatic impact upon the consumption of electricity by office equipment in commercial buildings. The rapidly-accelerating use of the Internet impacts electricity use by computers in both homes and offices, as does the infrastructure supporting the Internet (servers, routers, switches, hubs, access devices, etc.). In addition, wireless telephony has also experienced rapid growth, as have local and long-distance telephony to a lesser degree.

In May, 1999, Huber and Mills (1999) brought this point home when they published an estimate that the "Internet"[2] consumed about 8% of U.S. electricity production in 1998, and projected that "half of the electric grid will be powering the digital economy within the next decade"[3]. These dramatic views of current and future Internet consumption have proven most controversial, particularly after a subsequent study (Kawamoto et al. 2001) estimated

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[1] TIAX LLC was formerly the Technology & Innovation business of Arthur D. Little, Inc.

[2] Internet was placed in quotes, as the boundaries of Internet energy consumption remain unclear and difficult to define. Data from Mills (1999) revealed that they include residential PCs in addition to non-residential equipment.

[3] A more complete report by Mills (1999) tempered this forecast a bit, stating "It now seems reasonable to forecast that in the foreseeable future, certainly within two decades, 30 to 50% of the nation's electric supply will be required to meet the direct and indirect needs of the internet".

that *all* office and computer network equipment consumed a much smaller quantity of electricity, about 2% of U.S. electricity in 1999.

To support its strategic planning efforts, the Department of Energy (DOE), Office of Building Technology, State and Community Programs (BTS), contracted Arthur D. Little, Inc. (ADL) to develop an accurate assessment of the energy consumed by office and telecommunications equipment in non-residential buildings. The final report (ADL 2002) critically evaluated and built upon prior work to develop a bottom-up annual electricity consumption (AEC) estimate for about forty (40) different types of office and telecommunications equipment in non-residential[4] buildings. In addition, the study presented scenario-based projections of future office and telecommunications equipment AEC (not presented in this paper), and offered an overview of the indirect impacts of office and telecommunications equipment on U.S. electricity and energy consumption.

This paper summarizes the key findings of ADL (2002) relating to current commercial office and telecommunications equipment, notably an AEC estimate for 2000 and an overview of the indirect impact of the equipment on U.S. energy consumption (e.g., changes in the energy intensity of the economy[5], the energy consumed to manufacture the equipment).

Methodology

Initially, a list was generated of about 40 different equipment types (see Table 1) and preliminary AEC estimates were developed for each to guide the selection of a limited number of key equipment types for more detailed study (see Table 2).

In general, these preliminary estimates were based upon existing literature and studies retrieved at the outset of the project. The raw magnitude of estimated electricity consumption was the primary factor used to decide whether a given equipment type is selected for more refined analysis. In addition, the likelihood of future growth in energy consumption by the equipment type was also considered (e.g., would it consume a significant quantity of energy in 2010?). Lastly, the authors' impressions of the quality of existing data and the degree of benefit gained from further investigation (i.e., how much would additional research improve the estimate's quality) guided the equipment selections.

Annual Electricity Consumption (AEC) Calculation Methodology

For almost all equipment types, the AEC calculations followed the methodology outlined in the following section. Figure 1 depicts the basic methodology used to develop the AEC estimates.

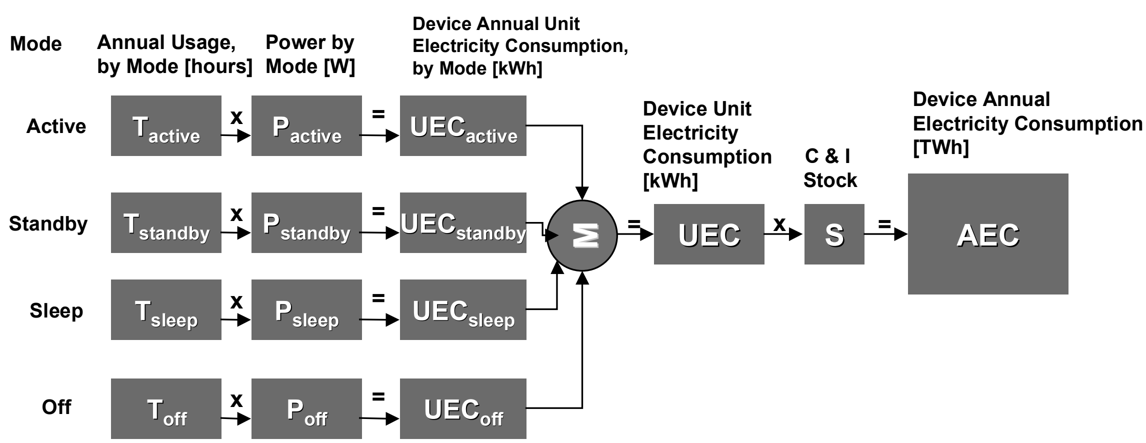
[4] Includes equipment in commercial and industrial buildings, as well as telecommunications equipment not in buildings (e.g., on pedestals, cell towers, etc.).

[5] Energy intensity denotes the amount of energy expended to produce a unit of GDP.

Table 1. Preliminary List of Equipment Types Investigated

Computer Network Equipment	Personal Computers (PCs)	Telephone Network Equipment	Other
❑ Hub ❑ LAN Switch ❑ Router ❑ WAN Switch ❑ RAS (Remote Access Server) ❑ CMTS (Cable Modem Termination System)	❑ Desktop ❑ Laptop ❑ Workstation	❑ Cell Site Equipment ❑ Transmission (Fiber Optic Terminal) ❑ Public (Analog) Phone Network ❑ Private Branch Exchange (PBX) ❑ Wireless Phone	❑ Facsimile Machines ❑ Point-of-Sales (POS) Terminals ❑ Typewriters ❑ ATMs (Automated Teller Machines) ❑ Scanners ❑ VSATs (Very Small Aperture Terminals) ❑ Supercomputers ❑ Smart Handheld Devices ❑ Dictation Equipment ❑ Desktop Calculators ❑ Handheld Calculators ❑ VMS (Voice Mail Systems)
Copiers ❑ 7 Bands (speeds)	**Printers** ❑ Laser (four speeds, color) ❑ Inkjet ❑ Impact ❑ Line ❑ "Other"	**Uninterruptable Power Supplies** ❑ Ten Power Classes ❑ Three Technologies	
Displays ❑ Monitor ❑ General Display	**Server Computers** ❑ High-End (>$1,000k) ❑ Mid-Range ($100k-$1,000k) ❑ Workhorse ($25k-$100k) ❑ Low-End (<$25k) ❑ Data Storage		

Figure 1. Annual Electricity Consumption Methodology



First, the unit energy consumption (UEC, in kWh) of a single device (say, a laptop PC) for an entire year was calculated. The UEC equals the sum of the products of the approximate number of hours that each device operates in a commercial building setting in each power modes, T_m, and the power draw in each mode, P_m[6]. Next, an estimate of the **stock** (i.e., installed base) of the device – in this example laptop computers – in the commercial buildings sector, *S*, were obtained or developed. The product of the stock and the device UEC yielded the total annual electricity consumption, AEC, for that equipment type.

[6] The AEC model assumes that the different modes are distinct but, in reality, many devices do not have clear-cut power draw levels for each mode. For instance, the power draw of an "active" desktop PC can vary significantly depending on how it is used.

Table 2 displays the stock and UEC estimates for the different key equipment types; ADL (2002) provides details about the stock and UEC calculations, as well as the sources used to develop each estimate.

Table 2. Commercial Stock and UEC Estimates

Device Type	Stock (thousands)	UEC (kWh/year)	Comments
Computer Network Equipment			
Hubs	94,000	11	Ports; 1.25W / port
LAN Switches	95,000	35	Ports; 4W / port
Routers	3,300	350	40W / router
WAN Switches	50	3,100	Shelves; 350W / shelf
Copiers	8,900	1,080	7 different bands (speeds)
Displays			
Monitors	63,000	330	CRT and LCD, by screen size
General Displays	13,000	260	
Personal Computers (PCs)			
Desktop PCs	59,000	300	
Laptop PCs	12,200	32	
Workstations	2,600	720	
Printers			
Laser	6,800	690	4 speed classes; color
Inkjet	6,000	92	
Server Computers			
High-End	16,500	22,000	Supercomputers not included
Mid-Range	185	10,700	
Workhorse	580	5,700	
Low-End	4,100	1,100	
Data Storage			
Optical/Tape Drive	12,500	71	4 classes of equipment
Magnetic Disk Storage	160	4,000	Terabytes
Telecom Networks			
Cell Site Equipment	100	23,000	Equipment sets; 4 cell sizes
Transmission (Fiber Optic Terminals)	1,000	1,800	Terminals; 200W / terminal
Public Network (Analog)	170,000	6.0	Analog public phone lines; 0.68W / line
Private Branch Exchange	56,000	17	Subscribers ; 1.96W / subscriber
UPSs (Uninterruptable Power Supplies	13,500	430	Three types, 10 power classes

Source: ADL, 2002

The following sub-sections elucidate the derivation of the estimated the values of the device commercial stocks, usage patterns, and power draws (by usage mode).

Commercial building equipment stock. Commercial building equipment stock simply means the number of devices deployed and in use in commercial buildings[7]. When available, published equipment stocks from other studies (e.g., industry market reports) were used.

[7] The stock estimates assumed that all equipment deployed was in use; however, in reality, some portion of the devices deployed was not in use. The unused portion of the stock was assumed to be small.

However, many commercial stock estimates came from sales data and equipment lifetimes (e.g., IDC reports, ITIC 2001) and taking the sum of the sales data over the past *y* years (where *y* represents the equipment lifetime) to develop a stock estimate. This approach has its flaws, in that relatively large (percentage-wise) errors can occur for equipment with short lifetimes, and that it does not incorporate a retirement model to effectively take into account different vintages of equipment (in contrast to ADL, 1993). To develop a feel for the potential error magnitude of the summing approach, ADL (2002) compared an industry estimate of laser printer stock to a sum of shipment data and projections over the four-year product lifetime and found a difference of only about 3% between the two, an error that likely is less than the error of either stock estimate.

The estimates of the portion of the total stock that resides in commercial (versus residential) buildings reflected a combination of household device penetration data and judgement by the authors; ADL (2002) provides details of the stock calculations for different devices. Ideally, the study would have differentiated between office and telecommunications equipment located in commercial[8] and industrial buildings and segregate the energy consumption as such. Three reasons led to the decision to not differentiate between the energy consumed in commercial and industrial buildings. First, building equipment surveys that delineate the relative density of office equipment in commercial and industrial buildings were not found. Second, it proved difficult to differentiate between the usage and power draw characteristics in commercial and industrial buildings, further complicating any attempt to segregate energy consumption between commercial and industrial use. Third, the proper allocation of telecommunications equipment between commercial and industrial buildings was not clear, and some equipment did not truly fall into either category (e.g., cell site equipment). Thus, with the blessing of the project sponsor, it was decided to use the generic *commercial building* appellation to refers to *non-residential buildings*, because commercial buildings do appear to contain the vast bulk of office equipment stock[9].

The number of stock segments chosen for each equipment type depended primarily upon the energy consumption estimate accuracy gains from adding additional segments, as well as the availability of information for each segment. For example, establishing separate stock segments for laptop PCs, desktop PCs, and workstations was justified by the distinctly different operating patterns and energy consumption levels of these segments. Furthermore, each segment consumed an appreciable amount of energy and effective data was available for each segment. In contrast, laptop computers were not disaggregated by model and vintage, as further refinement would not have had a large impact upon the total energy consumption by office and telecommunications equipment in commercial buildings.

Usage patterns. A device's usage pattern refers to the number of hours per week that, on average, a device operates in a given mode. Most equipment types have three modes (see Table 3). In many cases, power management (PM) strategies (such as maximum times to enter "sleep" mode and maximum "sleep" mode power draw levels specified by the voluntary ENERGY STAR® program) and their degree of implementation have a major impact on the amount of time spent in each operating mode.

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[8] The EIA considers data centers to be commercial buildings (Boedecker 2001).

[9] Kawamoto et al. (2001) estimate that commercial buildings account for ~85% of all electricity consumed by non-residential office equipment.

Table 3. Office Equipment Usage Modes

Mode Type	Description	Example
Active	Device carrying out intended operation	• Monitor displays image • Copier printing
Stand-By	Device ready to, but not, carrying out intended operation	• Monitor displays screen saver • Copier ready to print
Sleep	Device not ready to carry out intended operation, but on	• Monitor powered down but on • Copier powered down but on
Off	Device not turned on but plugged in	• Monitor off, plugged in • Copier off, plugged in

In many cases, usage pattern data came from surveys (e.g., Nordman et al. 2000, Webber et al. 2001), where researchers actively monitored the usage pattern in a building for a period of time, ranging from days to several weeks, or sampled and recorded the night status of equipment. Usage patterns tended to have a bias towards office buildings, as most usage surveys were carried out in these building types. The Energy Information Administration (EIA 1998) estimated that just under half of all personal computers (PCs) found in commercial buildings in 1995 reside in offices. ADL (2002) provides the details of the usage patterns (by mode) used for all device UEC calculations.

Power draw by mode. The UEC estimates incorporated power draw data for different equipment types and segments for each mode of operation. Implicit in the power draw by mode valued used was the assumption that all of the different devices folded into a single equipment type or segment drew, *on average*, the power level in a given mode, and that no appreciable correlation between power draw level and usage existed[10]. In reality, those simplifications are not completely true; however, in general, the error introduced by this assumption was likely on the order of or less than errors in the usage patterns and commercial stock estimates. ADL (2002) contains all of the power draw values used in the UEC calculations.

Whenever possible, the UEC calculations incorporated actual power draw measurements for the "active" power draw (e.g., Kawamoto et al. 2001; Meyer and Schaltegger AG 1999), as opposed to the device rated power draw. Rated power draws represent the maximum power that the device's power supply can handle and do not equal the actual power draw. Consequently, using rated power draws to estimate energy consumption would have lead to dramatic over-estimation of energy consumption; data from ADL (2002) revealed that, on average, the actual "active" mode power draw of most office and telecommunications equipment ranged from 5 to 50% of the rated power draw, with an average value of about 33%.

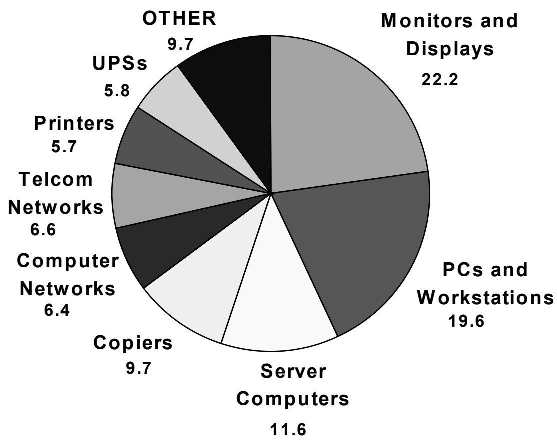
Key Equipment Types—Year 2000 Annual Electricity Consumption

The preliminary AEC estimates identified eight key equipment categories that received significantly more detailed studied (see Table 2) and accounted for almost 90% of the total preliminary AEC. In sum, the AEC analyses revealed that commercial office and

[10] That is, machines that have higher "active" power draw do not operate for longer periods than those that draw less power.

telecommunications equipment consumed 97 TWh of electricity in 2000, and that the key equipment categories accounted for almost 90% of the total (see Figure 2).

Figure 2. Year 2000 Non-Residential Office and Telecommunications Equipment Annual Electricity Consumption, in TWh



Total AEC = 97 TWh (*site*) or ~1.1 quads (*primary*)

Personal computers and monitors represented just over 40% of the total AEC (42 TWh site, or 0.46 quads of primary energy). The equipment forming the backbone of the Internet (server computers, computer networks, telephone networks, and UPSs) consumed about 30% of all non-residential office and telecommunications equipment electricity (30 TWh site, or 0.33 quads primary). Imaging devices (copiers and printers) accounted for more than 15% of electricity consumed (15 TWh site, or 0.17 quads), while computer and telecommunications network equipment consumed about 13% of electricity (13 TWh site).

Placed in a national context, commercial office and telecommunications equipment accounted for 2.7% of national electricity consumption in 2000, or ~1.1% of the 97.7 quads of primary energy consumed in the U.S. in 2000 (see Table 5). Put in another context, this is equivalent to 9% of electricity consumed nationwide in commercial buildings.

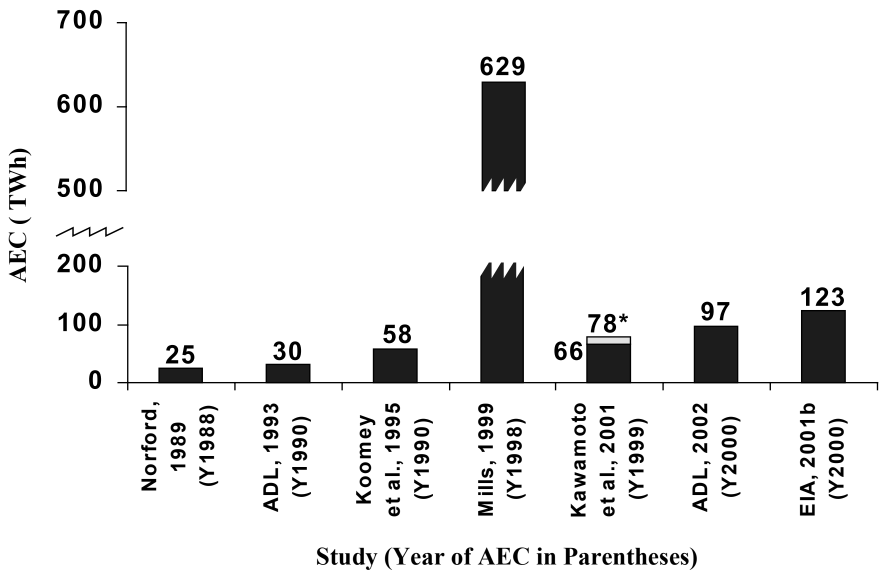
Table 5. Commercial Office and Telecommunications Equipment Electricity and Energy Consumption in a National Context, for Year 2000

Sector	Electricity Consumed (TWh)	Primary Energy Consumed (Quads)	Source
Non-Residential office and telecommunications equipment	97	1.07*	ADL (2002)
Commercial Sector	1,100	16.0	BTS (2001)
National Total	3,610	97.7	EIA (2001c)
*Based upon a primary-to-electricity conversion ratio of 10,958 Btu per kW-h (BTS, 2001).			

Comparison of Current Office and Telecommunication Equipment Electricity Consumption Study to Other Recent Studies

Compared to recent studies of office and telecommunications equipment electricity consumption, the ADL study AEC exceeded that of Kawamoto et al. (2001) by about 20%, but is less than 20% of that found by Mills (1999) (percentages are for similar equipment types[11]; raw values[12] shown in Figure 3).

Figure 3. Comparison of Office and Telecommunications Equipment Annual Energy Consumption by Various Studies[13]



* The 78 TWh value shown for Kawamoto et al. (2001) equals the sum of the Kawamoto et al. (2001) value and the telephone central office (CO) AEC estimate of 12 TWh from Koomey et al. (1999).

Two factors were responsible for most of the differences between the ADL and Kawamoto et al. (2001) studies. First, the ADL study incorporated more recent device night status data that showed higher "on" rates and lower power management-enabled rates than Kawamoto et al. (2001). This resulted in much higher unit energy consumption values for monitors, PCs, printers, and copiers. Second, ADL (2002) accessed additional industry data sources that provided a more refined breakdown (segmentation) for most equipment types.

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[11] Similar equipment with Kawamoto et al. (2001): PCs (desktop and laptop), monitors, general displays, laser printers, inkjet/dot matrix printers, copy machines, server/mainframe/mini computers, data storage, facsimile machines, computer network equipment. Similar equipment with Mills (1999): PCs, workstations, server computers, telephone networks, routers; possibly monitors and printers (unclear if included in Mills).

[12] The Mills (1999) value came from a linear extrapolation of his values for internet-related equipment to his entire installed base of equipment; see Section 6.3 of ADL (2002) for a more complete explanation and calculations.

[13] The 66 TWh value reflects that shown in Kawamoto et al. (2001) for commercial office equipment and computer network equipment.

Mills (1999) exceeded the ADL (and all other researchers') AEC values for all equipment types considered by consistently applying extremely high power draw devices to the entire class of equipment. For example, Mills (1999) assumed that Internet backbone routers drawing ~1,000W are representative of the entire U.S. router stock. In reality, most routers are edge routers that draw less than 40W. Unfortunately, the repeated application of very high equipment power draw levels by Mills (1999) made meaningful comparisons with the current study difficult.

It was not readily apparent why the EIA (2001) AEC estimate, which does not include telecom and computer network equipment, exceeds that of the current study.

Indirect Impacts of Office and Telecommunication Equipment Energy Consumption

In addition to its direct impact upon electricity consumption, office and telecommunications equipment indirectly impact national energy consumption and the environment in several ways (discussed in the following paragraphs). All of these issues embody significant complexity and uncertainty, A very preliminary consideration of the indirect impact of office and telecommunications equipment upon national energy consumption indicated that the sum of the impacts is at least of the same order of magnitude as the direct energy consumption of the equipment. The direction of the net impact (i.e., an increase or decrease) remains unclear and requires further, more thorough analysis. ADL (2002) discussed all of the indirect impact in more depth, providing data and sources for the conclusions drawn in the following paragraphs.

The heat dissipated by office and telecommunications equipment affects building cooling, heating, and ventilation loads and its magnitude depends upon the building type and geographical location. During the cooling season, the heat dissipated by office and telecommunications equipment increased air conditioning loads by 0.2kW to 0.5kW per kW of office and telecommunications equipment power draw. In contrast, during the heating season it effectively displaced a portion of the heating load, i.e., each Btu of heat dissipation eliminated about one Btu of heating demand. On the balance, the equipment most likely leads to a net increase in HVAC energy consumption, due to the concentration of office equipment in office buildings[14].

Office and telecommunications equipment also increases peak power demand in at least three ways. First, equipment power draw during peak periods increases peak power demand. Second, the heat dissipated by office and telecommunications equipment during periods of peak demand increases peak air-conditioning loads generated by the office and telecommunications equipment. Third, the low power factors of much office and telecommunications equipment increase power demand as well as transmission and distribution losses, increasing the amount of power generation required at the plant. Overall, office and telecommunications equipment likely increases the peak power demand in a given region of the country by 3 to 4%.

An input-output economic-environmental model developed at Carnegie Mellon University (CMU, 2001) estimated the total energy consumed to manufacture different

[14] Office buildings consume significantly more cooling energy than heating energy (ADL 2001).

categories of equipment, including the energy consumed throughout the supply chain to produce the equipment. This approach revealed that the energy consumed to produce office and telecommunications equipment in one year was of the same magnitude as the energy directly consumed during operation of the devices each year.

Office and telecommunications equipment could have a measurable impact upon national energy consumption by enhancing economy-wide productivity to improve the economy's sustainable growth rate and improving the efficiency of energy utilization. As a result, it could accelerate the decrease of the ratio of energy consumption per $ of GDP (i.e., energy intensity). For example, e-commerce between businesses and between businesses and consumers can dramatically improve back-office efficiency (at least in an economic sense) and improve the utilization of existing resources. In addition, office and telecommunications equipment enables telecommuting and remote information exchange, both of which may reduce national energy consumption. However, it is premature to conclude that the acceleration in the rate of energy intensity decrease that occurred in the late 1990s is permanent. Practices such as e-commerce still have minimal exploitation on the scale of the entire economy and that the eventual effect of office and telecommunications equipment upon national energy consumption remains unclear. This also suggests that it will take some time before e-commerce could have a major impact on national energy consumption. Ultimately, over a period of many years, the Internet and e-commerce will likely have the most dramatic impact upon national energy consumption of any indirect impacts of office and telecommunications equipment. Similarly, structural changes in the economy from the growing importance of the less-energy intensive[15] information technology (IT) sector during the 1990s could play a future role in abating national energy intensity in the future. The dramatic downturn in 2001 suffered by IT brings into question the strength and duration of this trend.

The manufacture of a sheet of office paper consumes more than an order of magnitude more energy than is used to electrostatically copy or print an image on the sheet (Nordman et al. 1998). Consequently, the energy consumed to manufacture the paper consumed by office equipment requires more energy (~20 TWh) than is consumed by operation of all copiers and printers.

Conclusions

A bottom-up analysis found that commercial office and telecommunications equipment consumed about 97 TWh of electricity (or 1.1 quads of primary energy) in 2000, an amount equal to 2.7% of national electricity consumption and 1.1% of national energy consumption. Preliminary examination of the indirect impacts of commercial office and telecommunications equipment on energy consumption suggests that they almost certainly are of the same order as – and quite possibly exceed – the energy directly consumed by the equipment.

The study also identified several areas for further study. Based solely on its sheer potential magnitude, the impact of office and telecommunications equipment on the economy's energy intensity warrant continued study, as does the energy consumed throughout the supply chain to produce the equipment. In addition, an investigation of

[15] I.e., a lower ratio of energy consumption per dollar of GDP.

energy-savings opportunities would help to inform DOE as to how office and telecommunications equipment may consume energy in the future, and how it might invest and influence that future. In the context of building energy consumption, a more detailed examination of the peak load and HVAC energy consumption impact of office and telecommunications equipment would provide the basis for improved estimates of building loads and strategies for reducing peak electricity demand. The authors also advocate performing larger-scale equipment usage surveys to reduce uncertainties in usage data, and carrying out surveys over a broader geographic range to reduce possible geographic biases in the data sets.

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