It's Midnight ... Is Your Copier On?: ENERGY STAR Copier Performance

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ABSTRACT

In the U.S., copiers use about 7 TWh/year of electricity, and a similar amount of energy is embodied in the estimated 2.2 million tons/year of paper used in copiers. These cost the economy about $500 million/year for the electricity and $2.2 billion/year for paper. The U.S. EPA launched the ENERGY STAR copier program in 1995 to save money and reduce greenhouse gas emissions from copiers. This study evaluated the performance of ENERGY STAR copiers to assess the energy savings they currently achieve and the potential for increasing the savings. We defined methods for auditing and monitoring copiers and carried them out on 228 and 11 machines respectively. About 30% of both ENERGY STAR and conventional copiers were left on at night; while most conventional copiers were in a low-power mode, most compliant machines were fully off. Extrapolating these findings to the entire U.S. copier stock results in higher electricity use than previous estimates, due to the night and weekend status and longer work days. However, this also implies a greater potential for saving energy with power management. We estimate current savings at 570 GWh/year. The main effect of the program is not to change power used in each operating mode, but to change the amount of time spent in each mode. A survey of users found general satisfaction with compliant copiers. Enabling of default duplex on two copiers raised their duplexing rate by 15% and 20% respectively. The full report is available at http://eetd.LBL.gov/EA/Buildings.

Introduction

Background

Office equipment is estimated to have consumed about 7% (Koomey et al. 1995) of the electricity used in commercial buildings in 1990. The ENERGY STAR office equipment program was established in 1992 to reduce this demand to save money and reduce greenhouse gas emissions; copiers were added to the program in 1995. Copiers are estimated to currently use about 10% of office equipment electricity—about 7 TWh/year—and the use is projected to drop to about 5.7 TWh/year by 2000 with the effect of the program (Koomey et al. 1995). The ENERGY STAR program operates by engaging equipment manufacturers in a dialogue to identify energy-saving criteria that are broadly achievable, but represent a significant improvement over existing equipment.

Table 1 shows the requirements for qualification as an ENERGY STAR copier. The criteria specify how the copier is to be configured when shipped to the customer; after installation, it can be changed by the customer or service personnel if desired. Default duplexing[1] was required for high speed machines (>44 copies per minute—cpm) until late 1997; since then it has been optional. The main criteria for the program is the presence of delay timers that cause the machine to enter a low-power state, or turn off. EPA expects no extra manufacturing cost for the ENERGY STAR features, so that the customer saves money from the first day of operation (though manufacturers do report extra design costs). Six months after the program took effect, it was estimated to have captured 33% of the copier market and 7% of the stock (Dataquest 1996). Both percentages have probably risen sharply since then.

This study was initiated to evaluate the current energy savings and overall performance of ENERGY STAR[2] copiers, and to provide recommendations for program improvement. As ENERGY STAR copiers were largely new to the market (some compliant models preceded the program), their

[1]Default duplexing means that the standard operating mode is to make double-sided copies.
[2]We use 'ENERGY STAR' and 'compliant' interchangeably; similarly, we use, 'non-compliant', and 'conventional' for non-ENERGY STAR copiers (which generally do not meet the ENERGY STAR specifications).

performance had not been compared to conventional copiers. Previous evaluations of the ENERGY STAR PC and monitor program had found widespread disabling and other implementation problems that defeated power management (Nordman et al. 1996). Anecdotal evidence of dissatisfaction with and disabling of default duplex indicated that there might be similar problems with the copier program. An evaluation of actual copiers and usage patterns would provide for close scrutiny of ENERGY STAR program savings estimates. The project included: a review of the existing literature on copier operating patterns, energy use, and imaging rates; development of methods for field monitoring of copiers (electricity monitoring, audits of night-time status, and duplexing rates); conducting field monitoring; and an assessment of user satisfaction with copiers.

Table 1. ENERGY STAR Copier Program Requirements

	Date in Force[d]	Speed *(cpm)*	Default Time[e] to Low-power	Off	Maximum Power *(W)* Low-Power[c]	Off
Tier 1	July 1, 1995	1-20	N.A.[b]	30 minutes	N.A.	5
		21-44	N.A.	60 minutes	N.A.	40
		>44	N.A.	90 minutes	N.A.	40
Tier 2[a]	July 1, 1997	1-20	N.A.	30 minutes	N.A.	5
		21-44	15 minutes	60 minutes	3.85·*cpm* + 5	15
		>44	15 minutes	90 minutes	3.85·*cpm* + 5	20

Notes: [a]An additional requirement for Tier 2 mid-range copiers is a maximum recovery time from low-power of 30 seconds. [b]"N.A." means "Not Applicable"—that no requirement exists. [c]3.85·cpm + 5 = 86 W for 21 cpm, 169 W for 44 cpm, and 390 W for 100 cpm. [d]The date in force is the date of the model introduction, not the date of sale. [e]The time to low-power or off can be raised up to a maximum of four hours on user request.

With the information developed in the project we: created standard operating patterns for conventional and ENERGY STAR copiers; made better assessments of conventional copiers and current savings from the ENERGY STAR copier program; identified opportunities to improve the program to increase customer satisfaction and energy savings; and made recommendations on program and copier design.

Overview of Copier Energy Use

While copier electricity use is complex in its details—particularly within individual imaging events—for the purposes of this study, representing that complexity was not required. Power management features include auto-off and low-power ("energy-saver") modes.

To provide a basis for comparing the electricity use of copiers, the American Society for Testing and Materials issued a test procedure in 1987, with a significant revision in 1994 (ASTM 1994). The ASTM test is the only standard test in widespread use in the U.S. or Europe. The test was designed to provide performance data suitable for comparing the electricity use of copier models. This is accomplished by recording average *power levels* for one hour periods as well as calculating a monthly total energy use based on a standard *operating pattern.* Because it was developed for comparison and not prediction of energy use, the test's operating pattern is not derived from typical use patterns and so the monthly (annual) energy use figures derived from it should be interpreted with caution. Copiers are assumed to be left on only two nights a month (never for copiers with an auto-off feature) and never on weekends. The ASTM test provides a basis for standard terminology.

Figure 1 shows a prototypical weekday loadshape for three copiers—a conventional copier always on, a conventional copier with an average use pattern, and an ENERGY STAR copier fully enabled. Active copying energy is not shown—it only adds about 10% to the electricity use and is not currently a target of power management. Any copier can be manually turned off at night and many conventional copiers have auto-off or low-power features. ENERGY STAR copiers are more likely to have and utilize the features.

Several key factors affect copier energy use, and influence the savings from the use of more efficient copiers. For conventional copiers this includes the fraction of copiers that have power management features, how they are configured (e.g. the fraction enabled), and the number of hours each

day during which the copier is used. For ENERGY STAR copiers, we expect to see shorter delay times, higher enabling rates, and lower 'off' power levels. In addition, we expect to see daytime energy savings on some machines.

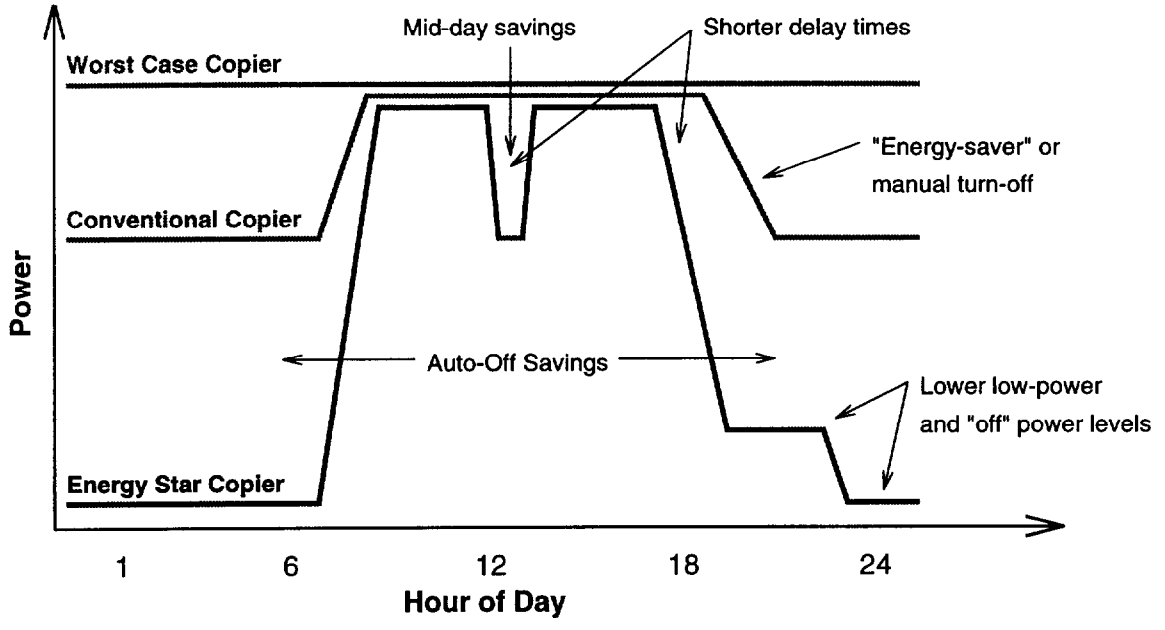

Figure 1. Prototypical Copier Loadshapes

The ASTM test defines five copier modes: "copying", actively making copies; "standby", immediately ready to copy, but not doing so; "energy-saver", using less power than when in standby mode, but not off; "plug-in", plugged-in to an outlet but not turned on; and "warm-up", becoming ready to copy. Many copiers use some energy in plug-in mode, even if they appear to be completely off. Copiers may be switched off manually, or automatically by an auto-off feature. The ASTM definitions do not distinguish between these states, though the copier may draw different levels of power.

A copier's operating pattern is the distribution of time spent in each mode plus the imaging rate. We define three primary modes as "On", "Low-Power", and "Off". Our "on" mode combines the copying, standby, and warm-up ASTM modes. Our "low-power" and "off" modes correspond directly to the ASTM "energy-saver" and "plug-in" modes. Our "standard operating pattern" is an estimate of current use patterns from which annual energy use, existing program savings, and potential further savings can be calculated.

The ASTM test assumes that copiers are only rarely left on during nights and weekends, but the ENERGY STAR copier program was developed in part due to the belief that copiers are frequently left on during non-work hours. Thus, a key factor is the level of power use typical during night and weekend hours (which far exceed daytime hours).

Previous Work

To develop our assessment procedure for the performance of ENERGY STAR copiers, we first reviewed the available literature on copier electricity and paper use. There have been no previous efforts to measure ENERGY STAR copier performance. ASTM tests are commonly conducted by manufacturers, but rarely reported. We found only one collection of test results (Dandridge 1997). Various monitoring studies and audits have been conducted, but they provide little more than anecdotal evidence of copier energy use. Policy analyses have assessed the potential for energy savings from power management, but generally pre-date the ENERGY STAR program and incorporate little or no field measurement. User satisfaction is key to power management success but only one study we found addressed the issue (Levinsson & Nicander 1996).

Methodology

We identified three primary methods to evaluate the performance of energy-efficient copiers—model audits, night-time audits, and detailed monitoring. These illuminate the character and use of features that underlie the ENERGY STAR copier program. We also used user satisfaction surveys and measured duplexing rates.

Model Audits are used to identify 'machine characteristics' (e.g. power management and duplexing features), and determine how to inspect and change configurations. *Night Audits* reveal copier status during night and weekend hours, and offer an opportunity to check configurations. *Detailed Monitoring* can be used to evaluate operating patterns, verify operation of controls, and extrapolate to annual use. *Duplexing Measurement* allows calculation of baseline measures of duplexing rates and the effect of enabling default duplex. *User Satisfaction Surveys* aim to reveal the reaction of copier users to the machines ENERGY STAR and other features. *National Estimates* of copier energy use and savings are extrapolations based on the stock of copiers present in the U.S., average power levels, and a standard operating pattern.

We reviewed copier characteristics data collected by Buyer's Laboratory, Inc. (BLI 1997). These provide valuable data on specific models. Previous analysis of these data (Nordman 1996) reviewed several characteristics, including relative speeds of simplex and duplex copying. In the course of monitoring and auditing, we reviewed the product manuals for about 30 individual copier models and assessed their electricity and paper features. During our night audits, we recorded each copier's location, brand, model number, power status (if off, manually, or by auto-off), and other information. We visited 228 copiers at seven sites.

We set the monitoring period for this project at two weeks, recording power use every 30 seconds using a power transducer and a datalogger. We did not change the copier's configuration, even if any ENERGY STAR features were disabled, and monitored eleven copiers at six sites. We derived average weekday and weekend day energy use, then extrapolated to annual energy use.

We surveyed 56 users of eleven ENERGY STAR copiers to determine their awareness of the model's energy saving features, level of satisfaction with them, and suggestions for improvements. Before surveying users, we audited the copier to find out which features were present and enabled. We did not ask about ENERGY STAR features that were disabled.

Our estimates for national copier electricity use and savings from ENERGY STAR copiers are based on several sources. For power levels, we used the ASTM test results collected in 1994 (Dandridge 1997). For the standard operating pattern, we estimated the hours of daytime use from monitored data collected during this project and reported by others. For night status, we used the findings from our night audits. We defined an operating pattern for each of four copier speed categories.

Results

Audits

The primary purpose of our late night audits was to determine the percentage of compliant and non-compliant copiers in each major mode (on, low-power, or off) during night and weekend time. From loadshapes in the literature, we determined copier night-time status for 18 copiers. We found an aggregate status of 31% on and 11% in a low-power mode for a total of 42% at least partially on. The largest collection of night-time copier audit data was from Bayview Technologies, Inc. (Wood 1997). These audits were conducted at about 20 locations in the U.S. from late 1995 through 1997 and were primarily designed to survey the status of personal computers and monitors. Table 2 presents the main Bayview results. The Bayview audits were generally conducted between 6 and 7 p.m. on weeknights, early enough in the evening so that copiers would rarely have had enough time to automatically turn off. These figures may therefore exaggerate the percent of copiers on all night. However, the large fraction of copiers on at night highlights the importance of the auto-off feature of the ENERGY STAR program.

Table 2. Bayview Audit Results

	On (or Low-Power)	Off	Copiers (*n=*)
Conventional	82%	18%	57
ENERGY STAR	100%	0%	8
All Copiers	84%	16%	138

Notes: The total set includes many more copiers than the two subsets as the brand and model was not always recorded; the brand and model are necessary to determine a copier's speed and if it is ENERGY STAR compliant.

To further understand the after-hour state of copiers, we conducted a series of night-time audits, assessing a total of 228 copiers. The sites included LBNL, three municipal office buildings, a federal office building, two large corporation's offices, and a hospital. Audits were generally conducted after 9 p.m. so that copiers would have enough time to reach their final state for the evening. Results are presented in Table 3.

Table 3. Night-time Copier Status (LBNL audits)

	On	Low-Power	On *or* Low-power	Off	Copiers (*n=*)
Conventional	30%	53%	83%	17%	142
ENERGY STAR	27%	12%	39%	61%	81
All Copiers	29%	38%	67%	33%	223

Notes: Many of the ENERGY STAR copiers that were found 'on' were verified to have had the auto-off feature disabled. On 13 of the 22 ENERGY STAR copiers that were found on, we verified that auto-off had been disabled. Delay times to auto-off were recorded at one site and eight copiers had 90 minute delays with three having 120 minute delays.

There is striking consistency between the Bayview results and the results of our audits for conventional copiers. The Bayview data suggest that the manual turn-off rate is at least 16%, and the LBNL audits suggest that it is at most 17%. The data show that ENERGY STAR compliance does not seem to lead to a significant reduction in the fraction of copiers fully on at night (approximately 30% for both) is surprising and distressing, but mirrors the problems with disabling previously seen to reduce power management savings in PCs and monitors (Nordman et al. 1996). We expected that power management of copiers would vary significantly with copier speed, so we disaggregated the audits by the ENERGY STAR speed segments. The results followed no clear pattern; with low- and high-speed ENERGY STAR copiers *more likely* to be fully on than their conventional counterparts, but medium-speed machines were the reverse. We added a separate 'very high' speed category (>90 cpm) since such copiers are generally used by a single operator, and thus more likely to be turned off manually.

With small sample sizes for the data disaggregated by speed class (particularly for low-speed copiers), we interpret the quantitative results cautiously. Higher speed machines are likely to be used by more people (except very high speed machines) and have longer warm-up times. This could explain the greater disabling of power management of these ENERGY STAR copiers and the lower percentage of conventional copiers off. User complaints about power management may lead to complete disabling of power management rather than lengthening delay times or using only low-power modes (and not auto-off). Anecdotal evidence indicates that copier service personnel are partially or completely responsible for power management disabling. As copier users learn that ENERGY STAR copiers turn themselves off, they may abandon manual turn-off altogether. The Bayview and LBNL audit results, as well as the ASTM test assumptions, are shown in Figure 2.

Electricity Field Monitoring

We had several reasons to monitor ENERGY STAR copiers: to verify that the power management features were working as expected; to observe the delay times; to measure the distribution of imaging events across the day and week; and to compare the monitored data to estimates based on test results to ensure the validity of the test methods.

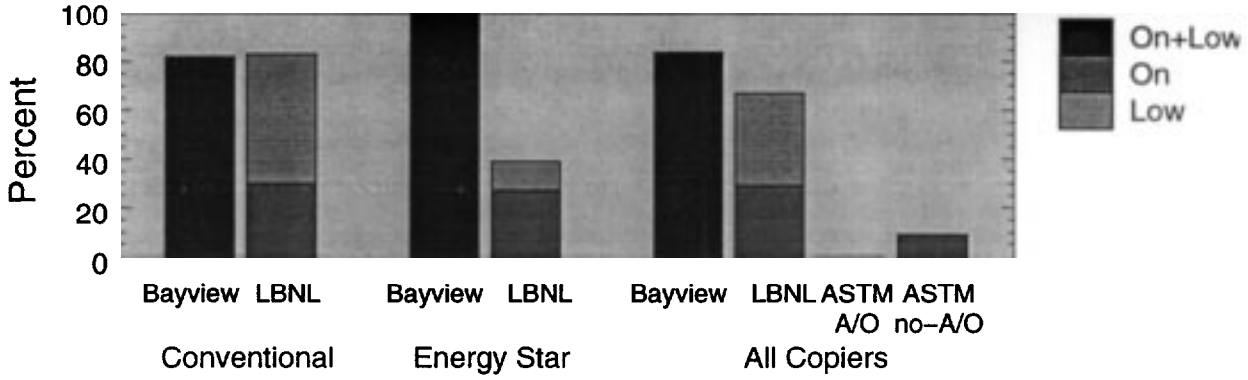

Figure 2. Copier Night-time Status (A/O is Auto-off)

We did not monitor conventional copiers, as we presumed that the power levels and copying energy figures from ASTM tests provide reliable estimates. We monitored eleven copiers, six at LBNL with the rest at a variety of local businesses and public offices. The results are shown in Table 4.

Table 4. Monitored Copier Electricity Summary

Speed Range	ID	Tier	Speed *cpm*	Annual *kWh*	Copying *kWh*	Comments (PM="Power Management")
Low	A*	2	16	358	52	Auto-off disabled; low standby
	B	?	20	388	26	PM disabled; manual power-off
	Average			373		
Medium	C*	1	21	128	15	PM working; instant-on
	D*	1	25	1,429	479	Auto-off disabled
	E	1	25	1,629	88	PM disabled; always on
	F	2	30	911	68	Low-power working; auto-off not
	G*	1	40	709	61	PM working
	Average			961		
High	H	1	45	531	68	PM working
	I	?	45	910	369	PM working
	J*	1	50	1,261	274	PM working
	K*	1	50	1,151	294	PM working
	Average			963		

Notes: *Marked copiers were monitored at LBNL. Copier B and copier I are labeled ENERGY STAR and have ENERGY STAR features but do not appear on the EPA list of compliant copiers; they are most likely Tier I.

In general, the ENERGY STAR features performed well. All ENERGY STAR copiers that were confirmed to have auto-off enabled had powered off as expected. Only two of the copiers powered off for a significant period during the day (copiers C and H). The rest had only minimal daytime off-times or none at all. Copier C (21 cpm) utilizes 'instant-on'("rapid fusing") technologies, and powers off completely after each copying job. The annual energy use is estimated to be only 128 kWh. This compares to our estimates for average segment 1 copiers of 790 kWh for a conventional copier, 540 for an average compliant copier of that segment, and 260 kWh with maximum savings[3]. An effort is underway to create a new market (demand and supply) for a higher speed machine with the same characteristics of 'instant on' and low overall energy use (Fanara 1998). Power management on copier E (25 cpm) was completely disabled so it was on 24 hours per day, 7 days per week. Copier B (20 cpm) was also disabled, but was manually powered off at the end of each work day.

[3]'Average' refers to a machine configured and used as typically found in our audits. 'Maximum' is the energy use from a machine configured for the most energy savings from auto-off.

The average active day length varied considerably by copier speed: 6.9 hours for low speed machines, 10.7 hours for medium-speed machines, and 13.1 hours for high speed. The average weekend on-time (for the entire weekend) was zero for low-speed, 1.3 hours for medium, and 3.8 hours for high-speed machines. On every copier with a clear auto-off delay time from the monitored data, the delay time was two hours (changed from the defaults shown in Table 1), as was the delay time till low-power on the single digital copier monitored.

Annual Energy Use Approach. We developed estimates of typical copier energy use based on the data we collected and identified. As with previous studies, we made a separate assessment for each of the six copier speed segments for which stock data are available. We estimated the energy used by conventional copiers, that used by ENERGY STAR copiers in *current* use patterns, and that attainable by *maximum* use of energy-saving features. The monitored data were used to develop operating patterns. The ASTM test results are reliable data on power levels, though the calculation embodies an unrealistic operating pattern and no guidance on imaging rates. We combined these two sources to estimate average energy use by copiers.

Operating Patterns. An operating pattern embodies the number of hours in each mode (on, low-power, off) during each workday as well as the night status (on, low, or off). We derived both types of data from our monitored and audit data and from the literature. From the literature, we found weekday on-times of about 12 hours per day, with machine speeds typically not specified. From our monitored data, we found on-times from 4 to over 14 hours per weekday. With the diversity of office worker schedules and the time necessary for an auto-off mode to engage, long on-times are not surprising.

Studies in the literature include graphs of loadshapes, from which we extracted average on and off times, the night-time mode distribution, and typical weekend status. We found weekday on-times of about 12 hours, with 31% of copiers 'fully on' on weeknights, 11% in a low-power mode, and 58% off; weekend results were similar. Only one of the 18 copiers was identifiable as ENERGY STAR compliant, though many were not identified at all.

The operating pattern for a copier can be summarized as the distribution of time across the three primary modes—on, off, and low-power—plus the imaging rate[4]. Table 5 shows the average time distribution over a year. There is a great disparity between the pattern embodied in the ASTM test and that found by observation of actual copiers. The delay time is amount of time from the end of the work day until the copier powers off. The standard operating pattern includes no weekend on-time.

Table 5. Copier Time Distribution by Speed *(%)* and Day Length and Delay Time *(hours)*

	On	Low-power	On *or* Low-power	Off	Day Length	Delay Time
ASTM Test Assumptions						
Without Auto-Off	27%	5%	32%	68%	9	0
With Auto-off	28%	—	28%	72%	9	0
Standard Operating Pattern						
ENERGY STAR						
Low	40%	5%	45%	55%	6	1
Medium	43%	6%	49%	51%	10	2
High	59%	9%	68%	32%	13	2
Very High	50%	16%	66%	34%	12	2
Conventional						
Low	37%	37%	74%	26%	6	1
Medium	53%	34%	87%	13%	10	2
High	56%	35%	91%	9%	13	2
Very High	53%	27%	80%	20%	12	2

[4]The imaging rate affects total on-time as well as increasing copying energy.

Power Levels. To estimate copier power levels, we used the ASTM test results for 130 copiers of varying speeds collected in 1994 (Dandridge 1997). We calculated the average power levels by six copier segments (see Table 6). Copying energy ranges from 18% to 68% above the standby level; low-power from 27% to 62% of standby (four segments under 40%), and the off power under 10% of standby for all but one of the segments.

Table 6. ASTM Test Results: Speed and Average Power

Speed	Segment	Speed *cpm*	*n=*	Plug *Wh/h*	Warm-up *Wh/h*	Standby *Wh/h*	Low-power[a] *Wh/h*	*n=*	Copying *Wh/h*
Low	1	<=20	37	8	138	115	—	—	136
Medium	2	21-30	31	13	205	172	106	1	208
Medium	3	31-44	22	16	224	183	70	6	241
High	4	45-69	28	39	399	266	97	9	358
High	5	70-90	9	20	507	358	98	1	583
High	6	>90	3	21	826	622	221	1	1,044

Notes: The units are reported as Wh/h rather than W as they are all the average power used over one hour. [a]The low-power column averages *only* those copiers that have a low-power mode reported; the small number of these copiers is notable.

Annual Energy Use. To assess the energy use of typical individual copiers and to extrapolate to national estimates, we estimated annual energy use per machine. We combined the operating patterns and power levels above to estimate annual energy use per copier for several scenarios as follows. The results shown in Table 7 include:

- The basic ASTM operating patterns (consistent manual turn-off) (ASTM Op. Pattern; No Auto-off).
- The auto-off ASTM operating pattern (ASTM Operating Pattern; Auto-off).
- Our standard operating pattern for conventional (non-ENERGY STAR) copiers (Conventional).
- Our standard operating pattern for ENERGY STAR copiers as currently used (ENERGY STAR).
- Operation (configuration) of ENERGY STAR copiers for 'maximum' savings (Maximum).

The energy used for active copying does not vary across these estimates and is included in the totals.

Table 7. Annual Energy Use per Copier *(kWh/year)*

Segment	ASTM Operating Pattern		LBNL Standard Operating Pattern			*Copying*
	No Auto-off	Auto-off	Conventional	ENERGY STAR	Maximum	
1	400	360	790	540	260	*40*
2	590	560	1,200	830	530	*80*
3	660	640	1,190	920	620	*130*
4	1,090	1,070	1,820	1,760	1,210	*190*
5	1,450	1,430	2,520	2,460	1,630	*480*
6	2,500	2,440	4,300	3,960	2,660	*900*

Notes: All scenarios use the ASTM test power levels, differing only in the operating pattern used. "Maximum" assumes that all the copiers have auto-off enabled and low delay times. The percentage savings (by segment operating patterns) are 32, 30, 23, 3, 2, and 8% for current ENERGY STAR use patterns, and 67, 56, 48, 33, 35, and 38% for the maximum savings scenarios.

The reduction that the auto-off accomplishes with the ASTM calculation is at or below 10% for all speeds. Thus, reliance on this method would greatly underestimate the actual impact of the program. By contrast, the LBNL operating pattern indicates a 2% to 32% savings over current use and 33% to 67% reductions with the maximum savings scenario. The annual reduced electricity cost from current ENERGY STAR practice ranges from $5 to $27 (at 8 cents/kWh)—however, this rises to $42 and $131 for the maximum savings scenario. Thus, the program delivers significant savings to the copier user.

Paper Use

The ENERGY STAR program initially included paper efficiency strategies with requirements for duplex capability and default duplexing, as well as the capability to use recycled-content paper. Default duplexing was dropped from the copier program in 1997. Reducing paper demand and using recycled fibers saves production energy and reduces greenhouse gas emissions.

The literature on paper use is limited. For example, we found no previous estimates of paper savings from enabling default duplex. We measured the effect of default duplex enabling on two copiers. We recorded duplexing counters at one week intervals, for at least one month with the machine in default simplex, to establish the baseline rate. We recorded the duplexing rate for several months after enabling default duplex and observed a sustained increase of 15% and 20%. This is particularly impressive in light of quite high duplexing rates on these machines with default simplex. Past efforts have identified the lower speed of duplexing on copiers as a significant barrier to increasing duplexing rates. A review of copiers speeds of conventional copiers (Nordman 1996) and ENERGY STAR copiers found that the compliant machines were not any better in duplexing speed.

We found no copiers in our night audits that had the default duplex feature operating, so we do not estimate any savings at present. However, if it were operating, then we estimate that paper use by copiers in segments 4 and 5 would drop by approximately 10%. Assuming 1 million tons of paper per year are used in copiers these segments, a 10% reduction would avoid 100,000 tons of paper production, with a retail value of $100 million, an energy content equivalent to 320 GWh and a carbon benefit (EPA 1997a) of 1.62 MMTCE.

User Satisfaction

We conducted a total of 56 surveys at four different sites for 11 copiers. The subjects were selected randomly from among the copier users found near the machines in question. We asked about the power management features, the duplexing performance (including default duplex), and overall satisfaction with the machine.

Regarding power management, of the 65% that knew that the copier powered itself off after a time of non-use, the median delay time for auto-off was thought to be about 30 minutes. However, for most of these machines the *actual* delay time was 2 hours. About 40% thought that the warm-up time was too long.

The users were quite satisfied with the copiers overall and over 80% would recommend the copier to others. One quarter of the respondents made comments about duplexing, half favorable and half unfavorable. The unfavorable comments focused on the particular implementation of duplexing, such as controls, relative speed, or jamming problems. We found high levels of satisfaction with the ENERGY STAR copiers, though the fact that many of these copiers were relatively new may have contributed to their improved reliability.

National Estimates

We estimated the national energy use of copiers along with the existing and potential savings of the ENERGY STAR program. We combined the estimates of energy per copier in Table 7 with the number of copiers in the stock in 1995 (Dataquest 1994). The results are shown in Table 8. For comparison, the total electricity use that results from the ASTM operating pattern is 4,400 GWh/year for the regular operating pattern and 4,190 GWh/year for the auto-off operating pattern. These scenarios apply each operating pattern to the entire stock of U.S. copiers and so do not reflect the turnover of stock. With approximately one third of the stock of copiers now compliant, the current savings from the ENERGY STAR program is 570 GWh/year. This is a 7% savings, and one third of the difference between the conventional and ENERGY STAR totals for the entire stock—1,700 GWh/year, a 21% savings. The potential savings—all copiers compliant and configured for maximum savings—are 4,240 GWh/year, a 52% savings from conventional copiers.

We estimated the energy, carbon, and dollar savings the current and maximum scenarios. We take the embodied carbon in electricity as 0.25 million metric tons of carbon equivalent (MMTCE) per

TWh. Our electricity savings are calculated at 8 cents/kWh, though actual savings are higher due to reduced cooling requirements with less heat output from copiers (Cramer 1995). Each TWh of energy savings embodies approximately $80 million. Current savings are 570 GWh/year of electricity, 0.14 MTCE/year of carbon, and $46 million/year. The potential savings are 4,240 GWh/year of electricity, 1.06 MTCE/year of carbon, and $339 million/year.

Table 8. Scenarios of Annual Energy Use, all U.S. Copiers *(GWh/year)* and Copier Stock (000)

Seg.	Speed *(cpm)*	Conventional	ENERGY STAR	Maximum	*Copying*	Stock (000)
1	<=20	3,130	2,130	1,020	*170*	3,950
2	21-30	1,280	890	570	*90*	1,070
3	31-44	860	660	450	*80*	720
4	45-69	1,730	1,680	1,150	*140*	950
5	70-90	540	530	350	*80*	210
6	>90	660	610	410	*70*	150
Total		8,190	6,490	3,950	*625*	7,060

We compared our estimates to others we found in the literature for all copier energy and present the results in Table 9. The Dandridge and Harris estimates pre-date the ENERGY STAR program launch. The CCAP estimate is made to track the effectiveness of the EPA's Climate Change Action Plan.

Table 9. Comparisons of National Estimates; Energy Use and Savings *(TWh/year)*

Scenario (year estimated for)	Conven-tional	ENERGY STAR As-is	ENERGY STAR Max.	Savings As-is	Savings Max.	Comments
Dandridge					2.2	
Harris et al. (1994)	3.7				0.2	
Koomey et al. (2000)	7.0		5.5	2.3		
EPA CCAP (1995)	5.0	2.8	2.5	2.2	2.5	CCAP power levels
ASTM Op. Pattern	4.2				0.2	This study
Standard Op. Pattern	8.2	6.5	3.9	1.7	4.3	This study
Paper Use	7.0	7.0	6.7	0.0	0.3	This study

Notes: "Conventional" represents a copier stock with no ENERGY STAR copiers. "As-is" is the current operating pattern, with "Max." the pattern reflecting maximum savings. All estimates except Koomey use stock levels from Dataquest. The CCAP figures shown here are *not* those estimated by the CCAP spreadsheet, but rather use the CCAP annual energy use figures and the total stock. The Standard Operating Pattern is presented in Table 5. The paper savings are hypothetical, reflecting a 10% reduction in paper use in segment 4 and 5 copiers due to default duplexing. The "years" above are those that the scenarios are estimated for, not necessarily the year in which the estimate was made. The energy savings listed for paper use are the electricity equivalent of the embodied savings in avoided paper production; "Max" in this case is for the default duplex only, and does not address the potentials of other paper efficiency measures. The 6.5 TWh/year figure for our standard operating pattern for ENERGY STAR copiers "as-is" reflects the entire stock being compliant. With only about a third of the stock compliant, the as-is estimate is 7.6 TWh/year.

Major findings of our study are that copiers use more electricity than has been estimated in the past due to more copiers actually on nights and weekends, and that ENERGY STAR features are disabled more often than previously thought. This makes the potential energy savings from power management larger than had been anticipated but the portion of this that is currently being attained is smaller. Reducing energy use embodied in paper remains an untapped resource.

Discussion and Conclusions

Outstanding Issues and Future Directions

The greatest opportunity to improve on the current savings from ENERGY STAR copiers is to increase power management enabling rates. The rate at which ENERGY STAR copiers have power

management features disabled (at least 27%) seems excessive. Evidence suggests that sales and service personnel are responsible for most disabling, which informed previous efforts to increase enabling (EPA 1997b). Further work is needed to understand why disabling occurs and what measures are successful at preventing or reversing it. Manufacturers could improve manuals by including specific sections on the benefits of power management, how to check the configuration, how to enable power management features, and suggested signage and labeling.

Reducing paper use remains a significant untapped opportunity for energy and cost savings and reducing greenhouse gas emissions, with default duplex a notable example. More research is necessary to better understand how to raise duplexing rates and to document the savings from doing so. Manufacturers could be of great assistance in this effort.

For future copier models, standardization of terms, symbols, and controls could reduce confusion among users and make power management and duplexing more acceptable. In our auditing of copier models, we found much diversity and contradiction in use of terms. Controls should be more transparent and consistent across models, and frequent tasks (e.g. to switch between 1:1 and 1:2) should take just one button push or touch screen touch. A standard 'eject' feature to empty the duplex unit should be defined (e.g. 2 'reset's in a row), and power switches should be placed near the front top of the copier for easy access.

The advent of digital copier and multi-function devices suggests convergence among these and computer printers and possibly fax machines. Test procedures need to be created to properly assess the electricity and paper use of these devices. We can expect new devices to be considerably more configurable than current ones, both in hardware options and in the interface and other software.

Conclusions

With approximately a third of the copier stock now compliant, we estimate the current savings of the ENERGY STAR program to be 570 GWh/year (equivalent to $55 million/year, including cooling savings). With the entire stock made up of compliant copiers, the savings would be 1,700 GWh/year. The potential program savings—all copiers compliant and configured for 'Maximum' savings—are 4,240 GWh/year.

Our estimates of national copier energy use are considerably higher than previous estimates. Our potential savings estimate is also higher, so while the program is currently garnering only a portion of this, the absolute savings are still compelling. Maximally implemented power management would raise annual savings from $45 million (current stock and use), to $240 million/year (all stock).

The savings achieved are primarily from the auto-off feature. Low power savings were envisioned as accomplishing daytime savings, but instead may have their primary effect as saving night and weekend energy on copiers for which a low-power mode is acceptable but for which auto-off is not. As average copier use patterns differ across countries, energy use and savings per copier can be expected to vary as well.

We estimate that only 15% of *conventional* copiers are manually turned off. Our audits indicate that power management on conventional copiers puts most of them into a low-power mode at night, but few accomplish auto-off. We found 61% of ENERGY STAR copiers off at night, so the program has had considerable success in reducing night and weekend copier energy use. However, compliant copiers are just as likely as non-compliant machines to remain fully on (not in low-power or off). Thus, the program has *not* diminished the common practice of disabling power management—about as many ENERGY STAR copiers are fully on at night as conventional ones. However, it has shifted many copiers from low-power to off mode at night, and this provides most of the program's energy savings.

Our detailed monitoring found little operation of auto-off during weekday daytime hours. Only low-speed copiers entered a low-power mode during the day, though most medium and large copiers were Tier I and so were not required to have a low-power mode. Auto-off appeared to operate reliably, with two hour delay times dominant, on those copiers with the feature enabled. One 'instant-on' copier we monitored had particularly low energy use. Not surprisingly, larger copiers were used for more hours per day than were smaller copiers. We found one week of detailed monitoring at 15-minute intervals sufficient for assessing copier performance of most copiers. However, for copiers that power down frequently during the day, finer measurements are needed.

Our survey found most people are satisfied with the performance of their ENERGY STAR copiers. The major complaints cited were about paper jams and duplexing speed. The machines were perceived as more reliable than others. Unfortunately, ENERGY STAR copiers are not faster at duplexing than conventional machines; the difference remains a significant barrier to higher duplexing rates.

Default duplexing was found disabled on every copier we saw. However, when we enabled it on two machines, the duplexing rate rose 15% and 20%. Thus, while the initial barrier to default duplexing is considerable, the benefits are significant.

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