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Laptop Computers:
How Much Energy Do They Use, and How Much Can We Save?

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Executive Summary

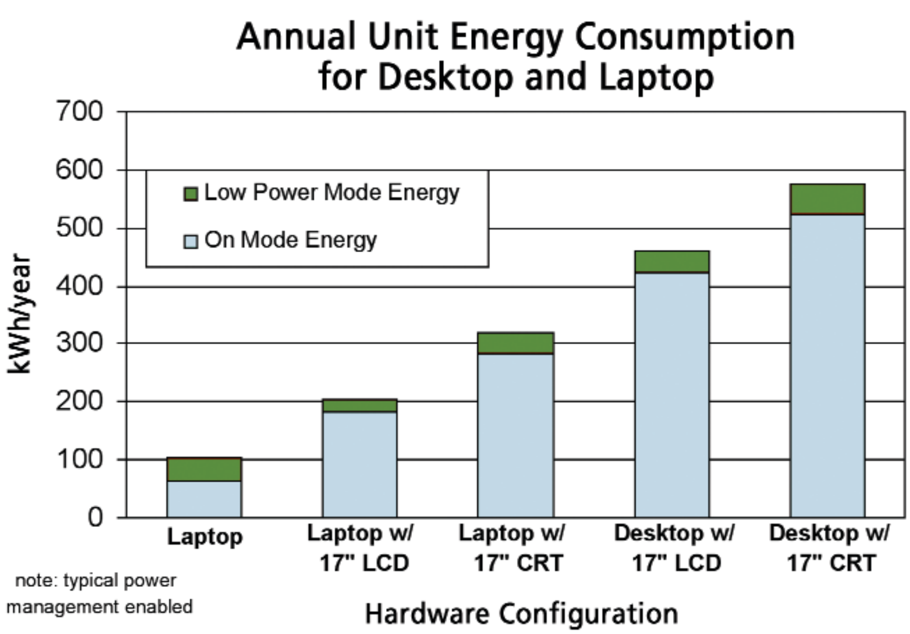
Today in the United States there are over 200 million computers in use in business and residential settings. The annual national energy use of computers and their associated monitors is approximately 85 billion kWh per year, or approximately 2.8% of total US electricity use. Due to their portability, improved performance, and reduced purchase costs, laptop computers are becoming an increasingly popular choice for residential and commercial consumers alike. Laptops employ the latest developments in computer technology due to the need to prevent overheating and to maximize battery life.

To date, there has been little work done to assess and compare the energy efficiency of laptop computers. To this end, NRDC and its consultant, Ecos have prepared this summary and a larger full report. The purpose is to assess the approximate energy efficiency differences between laptops and desktops and among various models of each type in order to determine how much energy the U.S. might save by switching to more efficient designs. In the process, we discuss various ways to characterize computer efficiency on a component basis and system basis, and conclude with recommendations for future policy and research activities in this field.

The Savings Opportunity

While the fastest desktop computers continue to outpace the fastest laptops in absolute speed and processing power, it is now very common to find affordable desktop and laptop computers with roughly comparable performance, especially when running the common software applications found in most offices. As illustrated below, today's average desktop computer with a cathode ray tube (CRT) monitor uses more than five times as much energy as a laptop (570 kWh/yr vs. 100 kWh/yr). Therefore, replacing a desktop system with a laptop system could save about 470 kWh/yr - nearly $40 annually.

Monitor choice greatly impacts the overall system energy usage. For example, simply switching from a CRT to the increasingly common LCD (liquid crystal display), yields the desktop computer user savings of more than 100 kWh/yr. Likewise, much of the energy savings potential from a laptop is negated if it is connected to an external CRT monitor. This figure also shows that even with power management enabled, the majority of the energy consumption happens while the computer is in the *On* mode, not in the various low power modes like *Monitor Sleep, Hardware Sleep,* and *Off*.



Environmental Impacts

The table below puts some of the potential energy and environmental impacts into perspective, demonstrating the significant benefits that can be attained from particular shifts in the current computer marketplace. The section below provides an initial attempt to quantify the potential savings that can be achieved for laptops through further improvements in their design and technology.

Scenario	Energy Saved	Dollars Saved	Tons of CO_2 Saved
25% of US desktops with CRTs are replaced with laptops	20 billion kwh/yr	$1.6 billion/yr	13 million tons/yr
25% of US desktop systems shift from CRTs to LCDs	10 billion kwh/yr	$.8 billion/yr	6 million tons/yr

Key Efficiency Differences

In order to investigate efficiency differences among laptop computers, we used two different approaches:

1) comparing individual components, which included the power supply, battery charging system, display, central processing unit, and power management software.

2) comparing overall product speed and performance per unit of energy consumed while utilizing system performance benchmarking software.

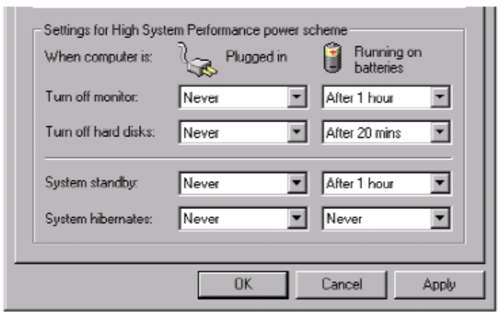
Power Supplies - Our measurements showed that laptop power supplies are remarkably efficient, typically achieving nearly 90% efficiency at peak load. This is far higher than the efficiencies typically found in power supplies used in desktop computers and other consumer electronics products. The best designs could maintain efficiencies nearly that high over most of their operating range, while others declined in efficiency fairly dramatically at partial load, where the system operates a substantial portion of the time.

Battery Charging Systems - Our measurements did not reveal any major efficiency differences in battery charging systems across the various laptop models tested, though differences in battery *capacity* and run-time were significant. The need for portability appears to keep most such battery components fairly similar. S*mart charging* technology allows batteries to automatically inform the charger regarding their temperature and state of charge. On average, about 20% more AC energy is required to operate a computer in battery mode and then recharge it, compared to simply leaving it plugged in. By contrast, we have found the battery charging systems used in other consumer products to be much less efficient.

Displays - Laptops' LCD displays vary widely in the amount of information (pixels) they can display per watt of power consumed. Some of this is attributable to differences in screen brightness, size, and performance, while the rest is likely due to differences in the technologies employed. Some displays, for example, provide better off-angle viewing or more accurate rendering of colors and moving images than others, but may consume more power to do so.

CPUs - The three largest central processing unit (CPU) manufacturers for laptop computers — Intel, AMD, and Transmeta — all have recently released chips that improve computer energy efficiency significantly. Most of these designs are "mobile" processors only, meaning their efficiency features (the ability to run at lower clock frequencies and voltages during periods of inactivity) are specifically intended for laptop computers. This includes Intel's Pentium M (Centrino system) chips and AMD's "PowerNow!"-equipped Athlon processors. Transmeta's Crusoe is predominantly a laptop processor, but has also been utilized in NEC's new PowerMate Eco desktop system. In most cases, the manufacturer's motivation for selecting the more efficient chip is to maximize the amount of time a user can use the laptop between battery charges.

Power Management - Power management software allows a computer to reduce power to various components after periods of inactivity. The largest savings typically result from dimming or switching off the screen, reducing processor speed, shutting down the hard drive, or putting the entire computer into "sleep" mode after longer periods of time. This sleep capability varies widely across various operating systems, computer manufacturers, and component types, and is frequently not fully enabled by the user. In most operating systems, maximum performance is synonymous with AC state and slower performance is synonymous with battery state, meaning that large savings opportunities can go untapped when computers are plugged into AC power.



This power management window, available to the user through Windows 2000 software, allows the user to set different power management functions based on whether the computer is plugged in (AC state) or running on batteries (Battery state).

What Is the Impact of More Efficient Laptop Components?

In the table below, the efficiency differences of various components are summarized. Also given are the estimates of how much energy would be saved if the most efficient components were adopted. The savings are quantified in two different duty cycle scenarios: the Road Warrior scenario, which refers to a laptop as it is used by a business traveler, and the Desktop Replacement scenario, which refers to a laptop that remains plugged in most of the time. The potential savings for each component overlap somewhat so cannot be simply added together, but they do approximate the energy benefits that are associated with improving the efficiency of each component individually.

Applying Benchmarking Software to Assess System Performance

Looking at the individual components can make comparisons unnecessarily complicated and not entirely accurate, since the laptop components operate together as a system. Also, the simple measures of battery life frequently published in computer magazines are not meaningful comparisons of the relative efficiencies of two laptops. One laptop can achieve a longer battery life than the other by simply running slower or having a larger battery. Using benchmarking software tools to compare functional performance per unit of AC energy consumed can help to improve the fairness and relevance of efficiency comparisons across a range of laptop and desktop computers. This type of system metric measures the efficiency of the interaction of all the components.

Because there is currently no benchmarking software that is ideal for an energy efficiency metric, Ecos evaluated three different benchmarking tools: BAPCO's MobileMark 2002, Futuremark's PCMark 2002, and PC World's PC WorldBench4. MobileMark and PC WorldBench4 were chosen because of their claims to represent "normal" office user performance, while PC Mark was chosen because it is easy to use. Unfortunately, we were unable to gather meaningful energy consumption values that related to the performance score for PC Worldbench4, and as a result, only MobileMark and PCMark were used to generate system efficiency metrics.

The resulting laptop system efficiencies, as defined using MobileMark software, are listed in the table on the following page. These data represent initial efforts by Ecos to assess the validity of this type of system level approach and other benchmarks could change the relative performance ranking of the laptops tested. Nevertheless, these data indicate that large system efficiency differences exist among laptop computers with different configurations (larger scores indicate greater efficiencies). Even within one form factor (thin and light) we see that the highest score (6.3) is more than three times the lowest score (1.9).

We also employed PCMark to compare desktops to laptops. Efficiency was calculated in a similar way as the MobileMark benchmark: total performance score (CPU+memory+hard drive) divided by the AC watt-hours consumed during the test.

Component	Possible Efficiency Improvement	National Annual Energy Savings: Road Warrior (GWh)	National Annual Energy Savings: Desktop Replacement (GWh)
Display	From 64,000 pixels/watt to 128,000 pixels/watt	260	550
Power Supplies	From partial load efficiency of 56% to 85% From full load efficiency of 80% to 90%	210	520
CPU	From Intel P3 Max Performance to P3 Battery Optimized	180	520
Power Management	From 50% of laptops PM enabled to 70% laptops PM enabled	20	220
Battery System	From 80% to 85% efficiency	30	9

The range of scores for the laptops was 532 to 3696 and for desktops was 295 to 519, where a higher score indicates higher efficiency. Note that the most efficient desktop we measured, the NEC Powermate Eco PC, achieved a score comparable to that of the least efficient laptop we measured.

Laptop Tested by Ecos Consulting	CPU Power Management Enabled?	MobileMark Performance Score	MobileMark Battery Life (hours)	Measured Energy to Charge Battery (AC Watt-hours)	System Efficiency[2] (Performance/ Watt)
IBM T23 (Intel P3 Mobile) Thin and Light	No	111	3.3	58.8	6.3
IBM T40 (Intel Centrino) Thin and Light	Yes	95	4.2	66.1	6.0
Sharp MM-10 (Transmeta Crusoe) Ultra Portable	Yes	60	2.5	35.2	4.3
Fujitsu S-Series Lifebook (AMD Athlon 4) Thin and Light	Yes	94	2.4	58.6	3.9
MiTAC (AMD Athlon 4) Thin and Light	No	66	2.2	77.1	1.9
Toshiba Tecra 8100 (Intel P3) Desktop Replacement	NA[1]	50	2.4	67.0	1.8

Using this type of efficiency metric, a laptop like the IBM T40 can achieve a high efficiency score by attaining a relatively good performance score while using an average amount of AC energy. Alternatively, the Sharp laptop achieved a better than average efficiency score with a relatively low performance score because it consumed a comparatively small amount of AC energy.

[1] There is only one power mode for this CPU.
[2] System Efficiency = (MobileMark Performance Score) * (MobileMark Battery Life) / (Measured Energy to Charge Battery)

CONCLUSIONS

Our preliminary research suggests three important conclusions:

- Laptops offer the potential for major energy savings relative to desktops. **The best laptops are at least 5 times more energy efficient than the worst desktop systems (computer and CRT monitor).** However, highly efficient laptop components could be readily incorporated into desktop designs, preserving the basic form factor and functionality of a desktop while saving energy and space and reducing noise from cooling fans. However, the present trend is the reverse, with each new desktop computer model incorporating faster, higher power CPUs and video cards.

- While there are clearly significant energy efficiency differences in the components of computers, those technologies change rapidly and interact closely, making it difficult to drive overall improvements in system efficiency with component-based specifications. Employing instead benchmarking software and an AC watt-hour meter to capture overall product efficiency in *On* mode offers key advantages. It allows manufacturers to choose combinations of individual components and software to achieve the greatest energy savings at the lowest cost, and reduces the need for frequent updates to the technical details of an efficiency specification. The next step to further understand and quantify these system level differences is to create, with input from stakeholders in the computer industry, a benchmark specifically for energy efficiency.

- Specifications such as ENERGY STAR® that currently recognize efficient computers in the marketplace should be revised to include consideration of *on* mode energy use – the most important single fraction of overall energy use. Based on our preliminary measurements, separate specifications for laptops and desktops are warranted. A similar methodology should be employed in each, however, so buyers understand the savings they could achieve by purchasing not just a more efficient desktop and screen, but a highly efficient laptop instead.

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