# What an Energy-Efficient Computer Can Do


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When you buy an energy-efficient desktop computer, you're getting more benefits than just a lower electric bill -- - and some of those benefits may be even more important to your business.

Consider, for example, a powerful new machine, say a 33- or 50-MHz 486 running Windows or OS/2 on a sharp color screen, with a hard drive, floppy drive, and expansion options. An undiscriminating buyer who didn't ask about energy use might, in the summer of 1993, end up with a commodity-like CPU box that uses 60-80 watts (without major expansion cards), plus a 14" color monitor using an additional 60-80 watts. Total: around 150 watts for a typical installation whenever it's turned on, whether you're actually using it or not. Models a year or two older can easily use 200-250 watts, but to be conservative, let's compare like with like -- a new computer against a better new computer, not the new one against the old one it replaces.

In contrast, a discriminating buyer might end up with a machine of equal power and better ergonomics, yet using a third as much power when it's actually being used and a fifth as much when it's left alone a few minutes and "hibernates" into a standby mode. For example, *PC World*, in its August 1993 issue, p. 62, reports that IBM's PS/2 E computer, fully loaded with 16 MB of RAM, uses around 45-47 watts running (around 10 for the CPU and 37 for the active-matrix LCD monitor) and only 29 watts when asleep (8 CPU, 21 monitor). Let's use this 50-MHz 486 computer as an example, since it nicely combines the best features found scattered among diverse offerings by a wide range of manufacturers.

## *Energy savings: direct use*

Around 30-40% of North American office computers are normally left on 24 hours a day, 7 days a week, even though they're used only during workdays. Moreover, computers are typically used -- as measured by keystroke activity -- only a tenth as much of the time as they're turned on. Thus around 90% of the energy used by all desktop computers could be saved if disused equipment could be automatically turned off until it were needed again.

A power-managed computer like the PS/2 E doesn't actually turn *off* when it's in standby mode during working hours; rather, it greatly reduces its power consumption so that it's instantly ready when needed again. (That's important because if you have to wait more than a few seconds, the company loses more money on your salary than the saved electricity is worth.) However, the PS/2 E can go into standby mode more of the time, because that's done automatically, not by waiting for the user to remember to turn it off during prolonged periods of disuse. The arithmetic could therefore look something like this for a user trained to turn the machine off at the end of the workday, and knowing that it'll temporarily "wake up" again if needed during the night to receive a fax or other message:

- for 30-40% (say 35%) of the computer population, save all 150 watts by turning the computer completely off on nights and weekends, i.e., save 460 kWh/y

- during the 2,000-hour-a-year nominal working period, when a 150-watt computer would use 300 kWh/y, save 104 watts (150 - 46) during the ~200 hours of actual intensive usage, plus 121 watts (150 - 29) during the ~1,800 hours of standby, for a total of 239 kWh, or an 80% saving; note that because 104 and 121 watts are not very different, it's not important whether we got the 200:1,800 split exactly right

- thus save a total of about 699 (say 700) kWh/y -- roughly one-third of it through the better computer's efficiency and power management features, and two-thirds by turning off the computer after hours if it would otherwise have been left on.

However, if the user can't be counted on to turn off the computer after hours and would normally have left it on continuously, then the power-managed efficient computer saves even more electricity:

- as above, during the 2,000-hour-a-year nominal working period, when a 150-watt computer would use 300 kWh/y, save 104 watts (150 - 46) during the ~200 hours of actual intensive usage, plus 121 watts (150 – 29) during the ~1,800 hours of standby, for a total of 239 kWh, or 80%

- during the other 6,766 hours of the average year, save 150 - 29 = 121 watts, or 819 kWh/y, through the computer's automatic standby mode

- thus save a total of 1,057 kWh/y -- half again as much as if the operator learned to flip the switch! (That's because 65% of operators already did so. The best of both worlds is to turn off your computer at night *and* let it power-manage itself during working hours.)

Let's conservatively adopt the former, lower savings. (They'd be only slightly different with the CRT monitor option for the PS/2 E, which uses more power than the LCD monitor when operating but less, as little as 8 watts, when in standby; future LCD models will probably reverse this advantage.) Now, besides the roughly 700 kWh/y of electricity that the efficient computer saves directly, what else does it do for you?

## *Energy savings: air conditioning*

The energy used by a computer ends up as heat in the room and normally must be removed by air conditioning. Typical office air conditioning systems use about 0.5 unit of energy to provide each unit of cooling and air-handling. Thus saving 700 kWh directly saves an additional 350 kWh or so in cooling energy. One might expect a somewhat larger saving in practice because the mechanical system's fans and pumps are "cube-law" machines whose energy use varies as roughly the cube of their flow, so even a modest flow reduction offers the potential to save a lot of energy. However, the actual saving is often less because few fans and pumps are equipped with adjustable-speed electronic drives; most chillers incur performance penalties at part-load; and almost one fourth of offices are electrically heated, so they would need extra electricity to make up for the useful heat that inefficient office equipment had provided in the winter. The net "energy bonus" in the average office building therefore falls from about 50% to roughly 35% or 245 kWh. The actual figure will depend on the building and climate. It would be bigger, for example, in big buildings, hot climates, and gas-heated areas, but smaller in small buildings, cold climates, and electrically-heated areas.

## *Energy savings: uninterruptible power supply and distribution*

Many offices use an uninterruptible power supply (UPS) to protect costly and critical computers from power surges, brownouts, blackouts, lightning, etc. This prudent practice is increasingly the norm where data-processing needs are at all mission-critical, and that definition fits a rapidly expanding range of businesses. But the UPS circuitry loses some fraction of the electricity that flows through it -- typically from 10-15% at optimal loads to 30% under many circumstances. (One of the most robust and efficient 1.5-kVA models, for example, loses about 15% of its typical throughput plus a further 10% all the time just for standby power.)

A conservative 20% typical loss means that the efficient computer's direct energy savings of about 700 kWh/y increase to 840, plus the air conditioning savings of 245, for a total of 1,085. And since about 4-8% of the electricity used in a big office, 3-4% in a small office, is typically lost in the distribution wiring inside the building -- losses which heat the wires and further boost air conditioning requirements -- it is probably conservative to suppose that about 1,130 kWh/y is required at the meter to run the inefficient instead of the efficient computer.

## *Economics: utility bills*

In 1992, the average commercial customer of U.S. electric utilities paid 7.6¢/kWh. The 1,130 kWh/y saving from an efficient computer like the PS/2 E is thus worth $86 a year to the business's bottom line. Present-valued over six years at a typical utility discount rate (5%/y in real terms), that's about $440. For a business with a 10% gross margin and a typical marginal tax bracket, nearly $6,000 in additional sales would be needed to increase profits by the same amount.

Actual electric-bill savings, however, are likely to be higher, because most commercial customers pay both an energy charge and a capacity charge. Saving computer energy typically saves more than the average amount of capacity (the peak rate of power usage), for two reasons. First, equipment heat accumulates in the building during the day, contributing somewhat cumulatively to the afternoon air conditioning load. Second, the capacity bonus for air conditioning savings averages not 35% but around 50% because there is no offsetting electric heating in the summer, when most utilities experience their annual peak load and hence are more concerned about capacity. It might therefore be reasonable to estimate electric-bill reductions nearer $100 a year or $510 present-valued, but the exact value depends on many details including your utility's rate structure.

## *Economics: air-conditioning capacity*

Assuming that the exact times of day when people are actually using their computers vary fairly randomly around the office, both the inherent efficiency and the even more frugal standby mode of the energy-saving computer will reduce its average contribution to the peak need for air conditioning on hot afternoons. The average reduction in heat generation implied by the figures above is about 119 watts per computer, or about 150 watts counting the avoided UPS and wiring losses. That 150 watts reduces by 0.042 “tons” the amount of air conditioning capacity required to maintain summer comfort. Since that equipment will itself release some unwanted heat into the space to be removed all over again (so-called “compounding of self-induced loads”), the total saving in capacity is probably at least 0.046 tons.

The complete cost of an air conditioning system (equipment, ducts, pipes, etc.) in a typical new U.S. office building averages around $2,800/ton (1992 $). The capacity avoided by using one efficient computer thus cuts about $130 off the capital cost of the building. If the building has a fairly dense gross-floorspace allowance of 130 sq ft/person (the national average of about 280 is larger than is truly representative of general practice in a well-occupied office building), that’s about $1 saved per square foot of floorspace. That’s more than 1% of total construction cost, and could reduce rents by more than typical competitive margins of 5-10¢/sq ft-y. (Indeed, Rocky Mountain Institute’s detailed research on all kinds of efficient office equipment showed in 1990 that a completely systematic approach to modern office equipment -- not just the computer and monitor but also photocopiers, fax machines, etc. -- can cut as much as 6-8% of construction cost off the capital budget, often enough to make an otherwise uneconomic development succeed.)

These saved capital costs in construction are very important. For example, in a business that normally replaces its office equipment every 4-5 years, it’s often worth replacing *all* of it before moving into a new building -- hence buying some of it prematurely -- in order to get the most efficient models. That premature purchase often more than pays up front for its extra carrying cost, by making the new building's mechanical systems far smaller, simpler, and cheaper.

Most offices aren’t new, but their cooling equipment -- chillers, pumps, fans, cooling towers, etc. -- has to be replaced about every twenty years because it wears out. In fact, most existing cooling equipment will have to be replaced even earlier -- usually *during* the 1990s -- as its CFC refrigerants are phased out. Efficient office equipment is a key element of a strategy that saves most of that roughly $800-1,000/ton renovation cost, by first reducing the cooling loads so that the replacement equipment can be several fold smaller than the original version. In many cases, a comprehensive strategy, depending critically on efficient office equipment, can even expand the role of alternative (nonrefrigerative) cooling techniques so far that the vapor-compression chiller is completely eliminated. (See E SOURCE’S *1992 The State of the Art: Space Cooling and Air Handling*, and supplements, for details.)

## *Economics: UPS and wiring savings*

It’s hard to estimate how much more construction cost could be saved if a developer knew in advance that the computers would be efficient, but the illustrative numbers above suggest about a one-fifth reduction just in the *wiring* capacity typically specified for plug-in equipment. That’s well worth pursuing: it might be worth very roughly $200 per workstation.

Even more valuable is the option of using a local or in-computer substitute for a central UPS. The UPS itself bears a significant capital cost, nearly $2 a watt, and it becomes only about half as big, saving roughly $200 per computer, when the computers become twice as efficient. In addition, dedicated wiring needed from the UPS to a special power socket at each desk often costs $200 per workstation.

Now that the new computer draws so little power, and may well (like the PS/2 E) use low-voltage chips, it may be more conveniently backed up by even something as simple as a small battery. Some aftermarket vendors already sell a micro-UPS on a card to go into AT-style expansion slots, and it would be easy to fit a simple backup battery into 3.3-volt computers even if they lack such slots. Alternatively, a very small UPS can be sized just to the computer and perhaps to its own peripheral equipment. That local UPS can then be switched off with the computer, avoiding the roughly 10% standby losses from having a large UPS on all the time in case any machine on the floor or in the building might be turned on. This approach also eliminates the roughly $200-per-workstation cost of dedicated UPS wiring.

## *Economics: avoided renovations*

The biggest economic gains are in offices whose wiring and cooling capacity isn't adequate for equipment for which they were never designed. (The microcomputer itself is hardly more than a decade old, but many buildings date back decades.) To cure tenant complaints, owners of older buildings often have to spend anywhere from a few dollars to tens of dollars per square foot upgrading wiring capacity, and as much or more to add cooling and air-handling capacity where duct sizes permit. Efficient office equipment can answer such an owner's prayer: by drawing less power and releasing less heat, it can often stretch existing capabilities (especially when combined with modern lighting retrofits) and thus avoid the costly upgrade altogether.

A special case, found ever more commonly, is where wiring is inadequate not because it can't carry enough current to power the equipment, but because its neutral wires are overloaded by harmonics from computers' switching power supplies. (A Canadian utility found on a typical floor of its own headquarters, for example, that the office equipment was drawing 65 amperes of fundamental phase current, but that the neutrals carried 96 amperes of third-harmonic current -- about enough to cause a fire.)

Here too, costly wiring upgrades can often be avoided by taking advantage of a hidden feature of the new generation of efficient computers. Their power supplies are much smaller (24 watts in the case of the PS/2 E, rather than the common 200 watts in older models), but have both higher efficiency and much better power quality. The greatly reduced harmonic output helps to avoid or cure common power-quality problems such as overloaded neutrals. Significant additional savings can often come from avoiding power-quality problems that interfere with other equipment, and from reducing the size of transformers needed to carry the harmonics.

## *Economics: utility investment*

Office equipment has been the fastest-growing load in the fastest-growing sector (commercial). It keeps at least a dozen giant (thousand-megawatt) power plants fully occupied, tying up utility investments worth at least $30 billion. Not adopting efficient office equipment could cost utilities tens of billions of additional dollars in the 1990s and more later.

In our example, one energy-efficient desktop computer that saves a peak load of about 150 watts saves the utility from having to install about 174 watts of generating, transmission, and distribution capacity. (The difference arises because on the hottest summer day, grid losses double to a national average of 14%.) That saved 174 watts represents approximately $370 worth of utility investment avoided -- more if we fully count certain extra costs for reserve margin and spinning reserve.

Actually, it's much better than that, because microcomputers traditionally have a very inefficient power supply with a very poor "power factor" -- the fraction of delivered energy that actually makes the machine run. Low power factor makes the utility install capacity to make and deliver much more power than it can actually bill you for. Poor power factor can easily double the utility's investment. However, the most efficient computers like the PS/2 E also happen to have much better-designed power supplies with a far higher power factor. The power supply's efficiency and power factor are also flatter across its full operating range, whereas they fall off dramatically when an ordinary 200-watt computer power supply is running at low load, which occurs most of the time. Depending on assumptions, the actual investment avoided by the utility could thus be on the order of $500-800. No wonder many utilities encourage their customers to buy only the most energy-efficient computers -- and even offer their customers cash rebates for doing so!

## *Environment*

Not having to deliver about 1,130 kWh/y to the more efficient computer means not having to generate about 1,213 net kWh (since 7.3% of all U.S. power generated gets lost in the grid). (This conservatively assumes that computers have no worse power factor than the average load. In fact, they do, and the actual avoided generation is probably considerably larger.) Each kWh not generated, if made from coal, avoids turning a pound of coal into air pollution.

More precisely, if an efficient computer displaces coal-fired electricity, which is about 55% of the U.S. total, and if we properly count the "upstream" emissions from mining, transportation, plant-building, etc. as well as the direct emissions from burning the coal, then the computer's annual saving of 1,213 net generated kWh will avoid producing about

- 3,250 pounds or 1.63 [short] *tons* of carbon dioxide (which causes global warming) (or about 15-30% less burning an average mixture of fossil fuels),

- 30 pounds of sulfur dioxide (which causes acid rain), and

- 12 pounds of nitrogen oxides (which contribute to acid rain, smog, and global warming),

plus assorted particulates and heavy metals. An emerging system of "emissions trading" may eventually permit the makers or users of such efficient office equipment to capture the financial benefits of the reduced powerplant pollution. The C02 saving alone, not counting the other pollutants, would often be considered to have a societal value around $85+. But even without monetization and trading, with efficient computers we'll all breathe easier and have less reason to worry about climatic change and harm to forests and lakes.

If the saved electricity came instead from a nuclear power plant, it would avoid making each year about three quarters of a curie (which is a lot) of the dominant long-lived radioactive wastes -- strontium-90 and cesium-137 -- plus plutonium equivalent in explosive power to more than a half-ton of TNT. Or if the saved electricity came from an oil-fired power plant, as it might in (say) Hawaii or many developing countries, it would save 1.8 barrels of oil -- enough to drive a family car over 1,500 miles or to drive a superefficient car at least halfway around the world. And one efficient computer does all that *every year*.

These approximate figures apply on average to the United States. But in developing or formerly socialist countries, where the power system tends to be much less efficient, the environmental and economic benefits would be even larger.

Some of the latest "green" computers, including the PS/2 E, also use recycled or recyclable materials and are designed for easy disassembly and recovery of materials. This, plus their longer operating life, should reduce the need for mining, transporting, processing, and disposing of diverse metals, plastics, and other materials, bringing many cumulatively important indirect environmental benefits.

### *Perhaps the biggest benefit: Productivity*

Per square foot of floorspace, officeworkers' salaries, employer taxes, and benefits are typically about one hundred times the building's total electric bills. Thus a one percent gain in labor productivity is worth about the same to a business's bottom line as *eliminating* its electric bills.

Increasingly detailed and persuasive evidence compiled by a Rocky Mountain Institute study now in preparation suggests that modern energy-efficiency techniques, ranging from improved thermal comfort to daylighting and better artificial lighting, can probably improve office productivity by at least 5%, and in some cases by 15% or more. Productivity is notoriously hard to measure, but some industries, like insurance, travel bookings, and mail sorting, routinely and rigorously measure both throughput and quality, and their findings support this conclusion.

Energy-efficient computers, too, can contribute significantly to more pleasant and productive working conditions in ways that are somewhat more subtle but still potentially important. For example:

- Computers as energy-efficient as the PS/2 E (and all battery portables) dissipate so little heat that they need no fan -- *and hence run silently*. Eliminating the subliminal tension and distraction of the fan noise must help productivity, although we don't yet know by how much.

- Eliminating the fan's air- and dust-path through the machine, eliminating the potential failure of the fan itself, and running the chips cooler, will all make the computer more reliable. The miniature drives (like those in notebook computers), PCMCIA cards, and other features used for energy efficiency also greatly increase ruggedness and often improve shielding against electromagnetic interference. Reduced breakdowns will in turn reduce lost time from unavailable equipment and corrupted data -- potentially a very costly hazard to any business.

- The risk of theft can also be reduced, since such energy-efficient computers are so small that they can easily be locked in a desk drawer.

- Efficient computers release not only less total heat but, in particular, less *radiant* heat. Having infrared radiation shine at you from an inefficient computer or monitor -- the modern version of “slaving over a hot stove” -- contributes significantly to feeling too hot. If you feel too hot, you’re likely either to suffer and become less productive or to reset the thermostat to lower, more energy-costly levels. Either way, your business gets hurt.

- Energy-saving flat LCD screens like the PS/2 E's offer a far wider range of adjustment in angle and position than normal cathode-ray-tube monitors. This geometric flexibility (and their very small footprint, which leaves more space for other work on the desk) lets them better adapt to changing work conditions, furniture layouts, and lighting, thus reducing glare and making them much easier to read. This can be very important to office productivity, since most offices are so poorly lit that people have trouble reading conventional computer screens.

- The LCD screen also essentially eliminates flicker, further boosting productivity and reducing fatigue.

- The very low electromagnetic fields emitted by energy-efficient monitors (virtually zero emissions in the case of the superefficient LCD screen) should reduce any subliminal anxiety felt by those, such as pregnant women, who may be concerned about such emissions.

- The most efficient computers also tend to use expansion options such as PCMCIA cards that are as efficient in ergonomics as in energy. Any time and effort they save, both directly and by how easily they interchange with the battery portable computers that millions of workers use on the road, will contribute directly to productivity. It's not unusual for frequent travelers to find that a modern notebook or subnotebook computer doubles or triples their productivity. Now that gain need not be lost again by the hassle of awkward cable hookups to the desktop computer: a credit-card-sized solid-state “hard disk” can simply pop out of one machine and into the other, taking tens of megabytes of files with it in a uniquely rugged and quickly accessed form.

## *CONCLUSIONS*

An energy-efficient computer brings many important benefits to its owners and users, and to the developers and owners of the building where it is installed. These benefits include in our example:

- direct electrical savings around 80% during office hours

- additional savings, typically about 35% as big, in air-conditioning energy

- further savings in uninterruptible-power-supply losses and wiring losses, raising the total electricity savings to the neighborhood of $100 a year (or about $500 present-valued) at average U.S. commercial rates where a UPS is used (but reliability will be much lower if it isn't)

- avoided capital costs for air conditioning equipment, ranging from about $130 for a new building to about $40 for a routine cooling-system renovation likely to occur in the ‘90s

- halved uninterruptible-power-supply capacity, cutting its capital cost by about $200 where it’s used

- typically about one-fifth smaller plug-load wiring capacity, potentially saving another $200 or so (if the electrical engineer pays attention to the reduced load!)

- possibly lower transformer costs because of reduced computer-power-supply harmonics

- much larger avoided costs (up to thousands of dollars per workstation in difficult cases) for upgrading old offices’ wiring and cooling capacity to accommodate inefficient office equipment and its harmonic generation

- avoided utility investments typically around $370 -- more like $500-800 if we count old, inefficient computer power supplies' far lower power factor

- reduced pollution amounting *each year* (with typical coal-fired generation) to about 1.6 tons of C02, 30 pounds of SOx, and 12 pounds of NOx

- potential productivity gains that may be worth more than all the other economic gains put together

In very round numbers, therefore, a typical installation in an existing office building, with adequate cooling and wiring capacity and no power-quality problems, could save the owner and operator on the order of $500-600, the utility about that much or more, society a lot of pollution, and the business a potentially substantial amount of lost productivity. In new buildings, the capital-cost savings to the building owner can easily double, and in old buildings with inadequate cooling or wiring, those savings can increase manyfold. The societal benefit of each such efficient computer, therefore, is probably on the order of one thousand to several thousand dollars, depending on the circumstances.

It is thus hard to avoid the conclusion that the indirect economic benefits of an energy-efficient desktop computer can be comparable to or larger than any perceived capital-cost premium. That is, even if efficient computers look costlier, they may actually be cheaper when all their economic benefits are properly counted.

## About the author and organization

*Amory B. Lovins, 45, cofounded and directs research at Rocky Mountain Institute in Old Snowmass, Colorado. Originally a consultant experimental physicist educated at Harvard and Oxford, he has received an Oxford MA (by virtue of being a don), six honorary doctorates, a MacArthur Fellowship, and the Mitchell "Alternative Nobel," and Onassis Prizes; held a variety of visiting academic chairs, briefed eight heads of state; published twenty books and several hundred technical and popular papers; lectured and broadcast extensively, served on the Department of Energy's senior advisory board; and consulted for scores of utilities, industries, and governments worldwide. He is founder of and Principal Technical Consultant to E SOURCE (Boulder, Colorado) -- the premier information source on advanced techniques for electric end-use efficiency, serving several hundred utilities, industries, governments, and other organizations worldwide.* THE WALL STREET JOURNAL'S *Centennial Issue named him among 28 people in the world most likely to change the course of business in the '90s.*

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*Review by RMI's Energy Program Director, H. Richard Heede, is gratefully acknowledged. Any remaining errors are the author's.*

## For further reading:

"Efficient Use of Electricity," RMI/EPRI joint article, pp. 65-74, *Scientific American,* September 1990, RMI Publication #90-19, 8 pp., $4 postpaid

"Energy-Efficient Office Equipment," 12-page set of overhead slides used to keynote the Electric Power Research Institute's first industry conference on this subject, June 1992, $5 postpaid from RMI's Sharon Troyer

"Negawatts for Buildings," *Urban Land*, pp. 4 + 26-29, July 1992; RMI Publication #D92-22, 5 pp., $3 postpaid

"The 'Negawatt' Revolution: New Techniques for Electric Efficiency," *Site Selection*, pp. 5-11, November 1990, RMI Publication #E91-2,8 pp., $4 postpaid

*Energy-Efficient Office Equipment,* detailed technical report, RMI Publication #E91-6, 184 pp., $950 postpaid

The American Council for an Energy-Efficient Economy (Washington DC) is publishing a brief Buyers' Guide to office equipment; excellent promotional literature is available from Pacific Gas & Electric Co. (San Francisco), Ontario Hydro (Toronto), and Consolidated Edison Company (New York City); and a collaborative industry/public-interest/academic research group is drawing up new standards and recommendations to complement USEPA's "Energy Star" voluntary standards.

## For further information on resource efficiency generally:

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RMI is an 11-year-old, independent, nonprofit resource policy center that fosters the efficient and sustainable use of resources as a path to global security. Its ~40 staff explore the links between energy, water, agriculture, transportation, "green" real-estate development, local economic development, and security. A free publications list (both popular and technical) is available on request, as is a *Newsletter* published three times each year. RMI provides consultancy and other support and collaboration with corporate, governmental, and other entities and with individuals and communities. Your suggestions and tax-deductible donations are welcome.

## For advice and referrals on green real-estate projects:

Rocky Mountain Institute's Green Development Services program provides counsel and referrals for the highly integrative design of environmentally responsive and unusually rewarding real-estate projects:

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## For detailed technical information on electric efficiency:

The most detailed and current information available comes in a technical subscription service (which can include phone, fax, and onsite support for particular projects) founded in 1992 by Rocky Mountain Institute, and incorporating its previous in-house COMPETITEK service:

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E SOURCE serves hundreds of utilities, industries, governments, research groups, and other organizations worldwide. Its core technical library, updated bimonthly, includes a half-dozen encyclopedic *State of the Art* "Technology Atlases" on advanced techniques for profitably saving electricity in all sectors and nearly all applications, including office equipment. Those volumes document the calculations summarized here.