ESTIMATING TOTAL POWER CONSUMPTION BY SERVERS IN THE U.S. AND THE WORLD

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Final report

February 15, 2007

EXECUTIVE SUMMARY

The amount of electricity used by servers and other Internet infrastructure has become an important issue in recent years as demands for new Internet services (like music downloads, video-on-demand, and Internet telephony) have become more widespread. One of the weaknesses in the literature on data center electricity use has been the lack of credible estimates of the aggregate power used by all servers and associated equipment in the U.S. and the world. The data on the floor area and power densities of data centers are anecdotal and limited by the proprietary nature of such data in most companies. Data on the installed base of servers are also closely held by the companies who track it, and server technology continues to change rapidly, necessitating constant updates to measurements of power used by particular server models.
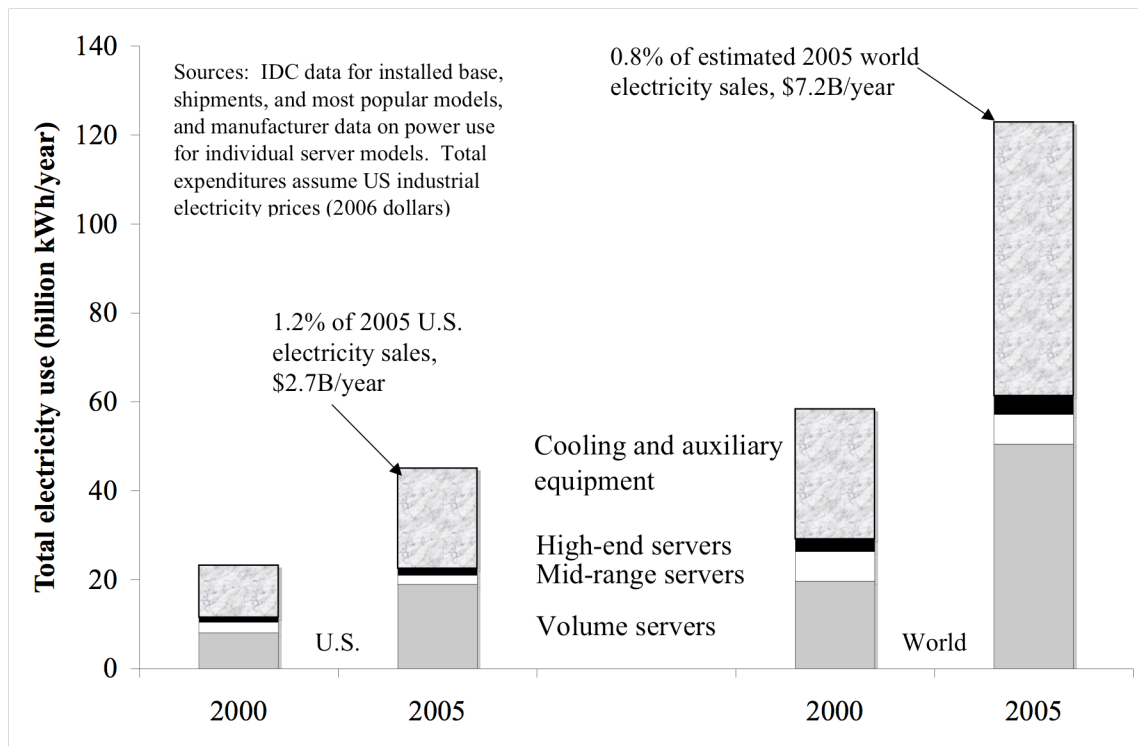
This study estimates total electricity used by servers in the U.S. and the world by combining measured data and estimates of power used by the most popular servers with data on the server installed base. These estimates are based on more detailed data than are previous assessments, and they will be of use to policy makers and businesses attempting to make sense of recent trends in this industry.

Aggregate electricity use for servers doubled over the period 2000 to 2005 both in the U.S. and worldwide (**Figure ES-1**). Almost all of this growth was the result of growth in the number of the least expensive servers, with only a small part of that growth being attributable to growth in the power use per unit.

Total power used by servers represented about 0.6% of total U.S. electricity consumption in 2005. When cooling and auxiliary infrastructure are included, that number grows to 1.2%, an amount comparable to that for color televisions. The total power demand in 2005 (including associated infrastructure) is equivalent (in capacity terms) to about five 1000 MW power plants for the U.S. and 14 such plants for the world. The total electricity bill for operating those servers and associated infrastructure in 2005 was about $2.7 B and $7.2 B for the U.S. and the world, respectively.

This study only assesses the direct electricity used by servers and associated infrastructure equipment. It does not attempt to estimate the effect of structural changes in the economy enabled by increased use of information technology, which in many cases can be substantial.

Figure ES-1: Total electricity use for servers in the U.S. and the world in 2000 and 2005, including the associated cooling and auxiliary equipment

Sources: IDC data for installed base, shipments, and most popular models, and manufacturer data on power use for individual server models. Total expenditures assume US industrial electricity prices (2006 dollars)

0.8% of estimated 2005 world electricity sales, $7.2B/year

1.2% of 2005 U.S. electricity sales, $2.7B/year

Cooling and auxiliary equipment

High-end servers
Mid-range servers

Volume servers

U.S.

World

Total electricity use (billion kWh/year)

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INTRODUCTION

Electricity used by information technology (IT) equipment has been a subject of intense interest since the first ENERGY STAR specification for personal computers was released in the early 1990s (Johnson and Zoi 1992). The first detailed measurements of personal computer electricity use were published in the late 1980s (Harris et al. 1988) followed by estimates of total power used by office equipment (Koomey et al. 1996, Norford et al. 1990, Piette et al. 1991) and assessments of potential efficiency improvements in that equipment (Ledbetter and Smith 1993, Lovins and Heede 1990).

As the 1990s came to a close, it was becoming clear that a new class of IT equipment was increasing in importance.   Computer servers, and the data center facilities in which they were located, were becoming more numerous and more electricity intensive. The first major efforts to understand server electricity use more deeply were spurred by a controversy over the total power used by IT equipment in which dubious claims were made about the contribution of IT equipment to total electricity use in the U.S. (Huber and Mills 1999, Mills 1999). These claims were subsequently refuted (Baer et al. 2002, Kawamoto et al. 2002, Koomey et al. 2002, Koomey et al. 2004, Koomey et al. 1999, Roth et al. 2002) but out of the controversy grew the first peer-reviewed measurements of data center electricity use (Blazek et al. 2004, Mitchell-Jackson et al. 2002, Mitchell-Jackson et al. 2003).   Later studies built upon that earlier work to created detailed measurements of data center power use in multiple facilities (Greenberg et al. 2006, Tschudi et al. 2004, Tschudi et al. 2006, Tschudi et al. 2003).

Recent growth in the Internet industry has led the popular press to report on increasing demands for power from data centers (Delaney and Smith 2006, Markoff and Hansell 2006), but these reports are anecdotal and may not reflect aggregate trends.   Reports of large demand growth have also prompted interest from the policy community in promoting higher efficiency in these facilities (Loper and Parr 2007). The purpose of this study is to accurately characterize electricity used by servers in the U.S. and the world so that public debate can proceed based on accurate data instead of the speculation and hearsay that so often runs rampant in discussions of such topics (Koomey 2003, Koomey et al. 2002).

PREVIOUS WORK

Several peer-reviewed estimates of power used by servers and data centers were completed around the year 2000 (Kawamoto et al. 2001, Mitchell-Jackson et al. 2002,

Roth et al. 2002). The most detailed and comprehensive of these was that by Roth et al. (2002), which used aggregate data from IDC (http://www.idc.com) by server class and measured power data on a representative server for each class.   The study also assessed the electricity used by data storage (tape and hard disk drive) systems and network equipment.

Unfortunately, little recent peer-reviewed work has been completed in this area. One exception was an extension of the Roth et al. analysis to 2004 completed by Ton and Fortenbery (2005) as part of their work on server power supplies. This work used the same analytical structure as Roth et al. but updated the installed base and power use per unit estimates to reflect more recent data.

This analysis improves on the Roth et al. analysis for servers by estimating power use for servers in 2000, 2003, 2004, and 2005, and by using the latest IDC estimates of the installed base of servers in each class (which are calculated using IDC's detailed stock accounting model, not available to Roth).   In addition, this analysis relies on power estimates from a much more detailed assessment of server power use for the most popular server models in each size class. IDC supplied to me their detailed data on installed base by server model, which allowed for a more sophisticated attribution of power use to the most common server models in each class.

DATA AND METHODOLOGY

Data center power use consists of information technology (IT) loads (such as servers, disk drives, and network equipment) and infrastructure loads (cooling, fans, pumps, lighting, and uninterruptible power supplies or UPSs).   This study focuses on the server loads (which represent 60-80% of total data center IT loads) and the infrastructure energy use associated with those servers. **Figure 1** shows conceptually the boundaries of the study.

The analysis in this report relies on detailed data from IDC <http://www.idc.com/> on the installed base and shipments of servers, plus measured data and estimates of the power used per unit for the most common server models in each server class in the U.S. and the world (including the U.S.).   The IDC data (Cohen and Josselyn 2007) are widely respected and used in the IT industry, but as with all data, they have strengths and weaknesses, and these must be clearly understood before drawing conclusions from the data.

Data made available by IDC included

1) Total installed base of servers by server class, historical and projected, for the U.S. and the World, 1996 to 2010

2) Total shipments of servers by server class, historical and projected, for the U.S. and the World, 1996 to 2010

3) Installed base of servers by model and manufacturer, for the U.S. and the World, 1998 to 2003

4) Shipments of servers by model and manufacturer, for the U.S. and the World, 1996 to 2005

One important component of this analysis is the size of the installed base of servers. IDC estimates the installed base using data on shipments and equipment lifetimes derived from manufacturer reporting and market surveys. The server lifetime estimates are based on reviews of server service contracts and other survey data.

I relied on IDC's data on aggregate installed base for 2000, 2003, 2004, and 2005, split into three server classes (volume, mid-range, and high-end), and into U.S. and world regions. IDC defines these server classes based on the cost of the system: volume servers cost less than $25,000 per unit, mid-range systems cost between $25,000 and $500,000 per unit, and each high-end system costs more than $500,000 per unit.

These data include servers in both enterprise and scientific ("high performance") computing applications, and exclude upgrades to existing servers. Blade servers, which are an important component of recent growth in the total numbers of servers, are subsumed under the volume server class, with one blade counting as one server. Some servers that are incorporated into other equipment (such as network equipment) are counted, depending on where in the supply chain they are sold. The IDC data also include servers that are not housed in data centers—the number and location of such servers may affect the appropriate value for estimating power used by cooling and associated infrastructure.

Another important category of servers that may be underrepresented in the IDC data is that of custom servers used by some large Internet companies (such as Google) that are ordered directly from the manufacturer as personal computer motherboards but are then used as servers. One estimate reported in the New York Times in June 2006 (Markoff and Hansell 2006) was that Google owns about 450,000 servers worldwide. It is not known whether all of these servers are the custom-designed units described above and how many are standard servers that would have fallen under the IDC "volume server" category. If all of these servers were added to the volume server category for the world in 2005 they would increase the volume server installed base by 1.7%. It is also not known how many other companies have followed Google's lead in purchasing such custom designed "motherboard servers".

Barroso (2005) of Google reported a "typical" power use for low-end servers of 200 Watts, which is close to our estimates for volume server power use per unit in 2004 and 2005 sales in Table 4 (below). Assuming that this power use estimate is correct for Google's servers, the total worldwide electricity use for volume servers would also go up about 1.7% if these servers were added to our totals.

The general approach for calculating total power use was to estimate a power use per server that could be multiplied by IDC's total installed base. I assumed that the weighted average power per unit of the six most popular models in each class in the installed base would be a reasonable proxy for the average power use per unit. This approach assumes that the models chosen accurately characterize the servers in a given class, and that

assumption should be assessed in the future as more accurate data become available. The installed base by model was only available through 2003, so adjustments were required for 2004 and 2005 to estimate power used by servers in 2005.

IDC's total installed base estimates (plus shipments and implied retirements) are shown in **Table 1**. Volume servers dominate the installed base, representing 90-95% of the servers on a unit basis. Mid-range servers comprise most of the rest, with the high-end servers only responsible for a few tenths of one percent of the total on a unit basis. The U.S. houses between 30 and 40% of the servers in the world, depending on server class.

Table 2 shows the six most popular server models in each server class in terms of installed base in 2000, based on IDC data for the U.S. and the world, **Table 3** shows the same results for 2003, and **Table 4** shows the top three most popular server models shipped in 2005. The exact installed base and shipment numbers by model are not shown here because of confidentiality concerns, but the *total* installed base or % of total shipments represented by the servers shown in Tables 2, 3, and 4 are shown in **Table 5**.

The most popular models comprise a larger share in the U.S. than in the world. These results indicate that the U.S. market is more concentrated on a model basis than is the world market. The most popular servers comprise significant percentages of the installed base (between 16% and 38%) and an even larger share of the 2005 shipments.

I use the market share for each of the most popular servers to calculate a weighted average power use per unit for each server class. For example, if each of the three most popular US volume servers in Table 4 have 10% of the market, the "weight" for each server's power use will be 10% divided by 30%, or 33.33%.

Estimating power use for each server is not easy. The power use of electronic equipment varies with hardware configuration, usage, and environmental conditions. The power supplies for these devices are sized for the maximum loads expected when the server is fully configured, so the actual measured loads observed in typical installations are much lower than the rated power of the power supply.

Unfortunately, measured data on energy use are not commonly made available for most servers, especially older ones (that is changing for more recent models—see ASHRAE (2004) and the discussion of "Typical power use per unit" in the future work section). In addition, estimating power use is complicated because each server can have multiple disk drives, vary significantly in installed memory, and commonly have multiple processors and redundant power supplies.

I assign a power use per unit for each server based on measured data, on-line server configuration calculators, or estimates from manufacturer specification sheets. When "typical" measured power was not available, I multiplied the maximum measured electricity use or the maximum rated input power of the power supply by factors taken from industry experience to estimate typical power use.

Maximum measured electricity use is widely reported by some manufacturers (e.g. IBM) and for others (e.g., HP, Dell) it is possible to calculate it using on-line configuration

tools. When I used such tools to estimate maximum measured power, I included the maximum amount of RAM, the largest size and number of hard drives, n+1 redundant power supplies, processor-intensive workloads, and two processors at the fastest clock speeds. To convert such power estimates for high end servers to typical power use I multiplied maximum measured power by 66%, which is the rule of thumb accepted by IBM. For volume and mid-range machines, I used a factor of 40%, after discussions with power experts at Dell, which reflects the lower utilization and less dense configurations common with the smaller machines.

When neither typical nor measured maximum power was available, the last resort was to use the maximum rated input power of the power supply taken from the specification sheet for the server. Sometimes these sheets only report the *output* power of the power supply, and in that case I divided the output power by 70% efficiency (which is typical for server power supply efficiency) to estimate the maximum rated input power. To estimate typical power, I multiplied rated input power by 25%, 30%, or 40% for volume, mid-range, and high-end servers, respectively. This range of factors reflects recent research (Ton and Fortenbery 2005) and industry experience (based on my conversations with Intel, IBM, Dell, and other manufacturers). Use of these factors yields results comparable to that for servers for which I do have measured data.[1]

Table 6 summarizes the calculation of total power use. The installed base estimates are taken from Table 1, and average power use per unit data for 2000 and 2003 are the weighted averages from Table 2 and 3, respectively. The average power use per unit in 2004 is calculated assuming that the retirements in 2004 (from Table 1) have the same power use per unit as the average for the year 2000 installed base, and that the shipments in 2004 have the same power use per unit as the weighted average power of new equipment from Table 4. The procedure is repeated in 2005, assuming that the retirements in that year also use the same amount of power per unit as the average for the year 2000 installed base.

Direct power consumption (million kW) is the product of installed base and average power use per unit, while the direct electricity consumption (billion kWh) is calculated from the direct power consumption assuming that servers operate 100% of the year (i.e. with a load factor of 100%).

The total power consumption associated with servers in data centers also includes the electricity use of cooling and auxiliary equipment. The Uptime Institute characterizes such infrastructure loads using the Site Infrastructure Energy Efficiency Ratio or SI-EER (Brill 2007a), which is the ratio of total data center electricity load to IT electricity load. Malone and Belady (2006) call that same ratio "Power Usage Effectiveness", and it's typically about 2, based on the detailed results extracted from recent benchmarking measurements for data centers (Greenberg et al. 2006).   An SI-EER of 2 means that total

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[1] For details on the power calculations on a server-by-server basis, email Jonathan Koomey at JGKoomey@stanford.edu.

loads are double the IT load—said a different way, every kWh of electricity use for IT loads means another kWh of electricity use for infrastructure. I apply an SI-EER of 2 to direct server loads in Table 6 to get total loads associated with servers (this approach assumes that all servers in IDC's installed base are located in data centers, an assumption that should be tested as more detailed data become available).

The total electricity bill is calculated assuming U.S. industrial electricity prices for 2000, 2003, 2004, and 2005, taken from the Energy Information Administration's *Electric Power Annual* (http://www.eia.doe.gov/cneaf/electricity/epa/epat7p4.html) and adjusted to 2006 dollars using the implicit GDP deflator. Most data centers are large enough to qualify for industrial rates in the U.S. Because no comparable price data exist for the world, I also apply the U.S. industrial prices to world consumption.

RESULTS

We explore different dimensions of the results below, beginning by summarizing total electricity use for servers in the U.S. and the world, comparing year 2000 to previous results, and then analyzing the changes in key drivers of the results from 2000 to 2005.

Total electricity use and expenditures

Electricity use associated with servers doubled from 2000 to 2005, representing an aggregate annual growth rate of 14% per year for the U.S. and 16% per year for the world. Almost all of this growth is attributable to growth in the numbers of servers (particularly volume servers), with only a small percentage associated with increases in the power use per unit.

Total direct power consumption for all servers in the U.S. in 2005 is about 2.6 million kW. Including cooling and auxiliary equipment increases that total to about five million kW, which is equivalent (in capacity terms) to five 1000 MW power plants. Total server electricity consumption in the U.S. is 23 billion kWh in 2005. When electricity use for cooling and auxiliary equipment is included, that total rises to 45 billion kWh, or about 1.2% of retail electricity sales in that year[2], resulting in a total utility bill of $2.7 billion (2006 dollars) when valued at U.S. industrial electricity prices (see **Figure 2**). Total server power and electricity consumption for the world as a whole is about two and a half times bigger than for the U.S.

Comparisons to previous analysis

Figure 3 shows ratios of results from this study to those from Roth et al. (2002) for the U.S. in the year 2000 (Roth found total electricity used by servers in the U.S. in 2000 to

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[2] U.S. retail electricity sales in 2005 were 3661 billion kWh <http://www.eia.doe.gov/cneaf/electricity/epa/epat7p2.html >. World electricity sales in 2005 are estimated to be about 14,700 billion kWh, derived from US DOE. 2006. *International Energy Outlook 2006*. Washington, DC: Energy Information Administration, U.S. Department of Energy. DOE/EIA-0484(2006). June. (http://eia.doe.gov/oiaf/ieo/).

be 10.1 billion kWh). The split between mid-range and high-end servers was different in Roth et al. and so I lump those two classes together to create a consistent comparison (Koomey 2001).

The estimates of installed base in 2000 in this study are about 20% greater for volume servers and about 10% less for the larger servers. The bigger differences are in the power use per unit, where this study's estimate for volume server power use per unit is about 50% greater than that for Roth, while the estimated power use for the larger servers is about 30% less.   Coincidentally, the weighted average power use per unit across all servers is about the same, so the larger number of units is what drives this study's results to be about 16% higher than the total electricity use estimates in Roth et al.

Changes from 2000 to 2005

Figure 4 shows ratios of 2005 to 2000 results for the U.S. The power use per unit for all product types is higher in 2005 than in 2000, but the shifts in installed base (with the number of units of volume servers doubling and the number of mid-range servers declining about 40%) mitigate the effects of higher per unit power levels. The overall increase in total electricity use is driven almost entirely by the increase in the number of volume servers. **Figure 5** shows the same results for the world. The story is strikingly similar, with the additional result that the total installed base is growing more quickly in the world than in the U.S. over this period.

FUTURE WORK

Distribution of power use over models

The most popular models represent a significant portion of each server class, but it is important to investigate the implications of this approach for the accuracy of the estimated power use per unit. The gold standard of accuracy in this regard would be to estimate power use for each and every model in the installed base and weight-average that power use per unit across the entire installed base. Time and resource constraints prevent such a comprehensive approach, so a reduced sample was needed, but choosing that sample can be difficult.   The accuracy of the choices depends in part on the shape of the distribution and where the most popular models fall in that distribution. The popular models may be the less costly and complex ones, but the relationship between cost of information technology (IT) equipment and energy use is tenuous at best.

The most popular volume servers only cover 16% of the installed base in 2003, but fortunately that class of servers tends to be more homogeneous than the larger systems. The high-end systems are the most heterogeneous, but the most popular models for this class of server cover a much larger portion of the installed base (29% to 36%), which mitigates to some extent the effect on accuracy the shape of the distribution might introduce in that instance. Further work is clearly needed on this issue as more accurate data become available.

Estimating typical power use per unit

Further analysis is needed on the relationship among typical power, rated input power, and maximum measured power. The factors used in this analysis are based on recommendations from technical representatives of the major manufacturers, but measured data using a standardized protocol is the most accurate way to arrive at typical power use for servers in the field (ASHRAE 2004). Computational workloads also have an important effect on power use per unit (particularly as new power-saving technologies are incorporated into the equipment) but data on this effect are sparse. That situation should improve as new protocols for energy measurements for servers come into effect in coming months (for example, see <http://www.energystar.gov/datacenters> and <http://www.spec.org/specpower/pressrelease.html>).

More detailed segmentation of the server markets

The aggregate segmentation of the server market used in this analysis masks some important variations in that market. The high performance computing (HPC) market, for example, has different usage patterns than do business servers, but even within the business category there are large variations. For example, Internet search is much different than web hosting, which is much different from application hosting. In addition, variations in the physical characteristics of mid-range and high-end servers may interact in complex ways with different usage patterns and have a substantial impact on power use per unit. More detailed market segmentation may be helpful in disentangling some of these effects.

Forecasts of future electricity use

It is particularly difficult to forecast trends in the IT industry. If the current IDC worldwide forecast holds true, installed base for volume servers will grow by more than 50% from 2005 levels by 2010, while mid-range and high-end installed base will decline 20-30%. If power per server remains constant, those trends would imply an increase in electricity used by servers worldwide of about 40% by 2010. If in addition the average power use per unit goes up at the same rate for each class as our analysis indicates that it did from 2000 to 2005, total electricity used by servers by 2010 would be 76% higher than it was in 2005.

The IDC forecast incorporates several trends that will affect power used by servers, including the move to more use of blade servers (which will tend to increase power use), and the shift to consolidation and virtualization (which will tend to decrease power use by reducing the number of physical servers that are needed). The industry has recently become more sensitive to total cost of ownership for these facilities, driven by the increasing importance of infrastructure and utility costs relative to IT costs (Brill 2007a). The total cost of building a large data center is now on the order of $100 to $200M, which is sufficient to get the attention of the CEO of most large organizations. That visibility to corporate management is likely to drive operational and design improvements that should over time improve the Site Infrastructure Energy Efficiency

Ratio and spur the adoption of energy metrics and purchasing standards for efficiency of IT equipment within these companies (Brill 2007a, Brill 2007b).

Total power used by data centers

This analysis focused on the most important component of electricity used in data centers (servers). Similar analyses are needed for data storage and network equipment, so that the total power use of all data centers can be estimated. Roth et al. (2002) found that electricity use for separate data storage devices in 2000 was 1.6 billion kWh or about 16% compared to the 10.1 billion kWh for U.S. servers alone. That study was not able to separate network equipment energy into the component found in data centers and that found in other facilities, and that is a key area where more data and analysis will be needed. It will also be necessary to separate the installed base of servers into those housed in data centers and those that are not, to more accurately estimate the SI-EER.

Opportunities for efficiency improvements

Previous work indicates substantial potential for improving the design and operation of IT equipment and data center infrastructure (Brill 2007a, Eubank et al. 2004, Greenberg et al. 2006, Tschudi et al. 2004, Tschudi et al. 2006), but additional data collection, analysis, and policy changes are needed to realize those improvements in the real world. Many of the changes required to capture those potential savings are institutional in nature, and involve addressing the misplaced incentives that pervade the industry. Current market structures and practices are aligned with minimization of first cost instead of reduction of total cost of ownership, but that will change as new metrics are adopted and companies change design and purchasing practices to reflect the new emphasis on minimizing total costs.

CONCLUSIONS

The amount of electricity used by servers and other Internet infrastructure has become an important issue in recent years. This study estimates total electricity used by servers in the U.S. and the world by combining IDC data on the installed base with measured data and estimates of power used by the most popular servers. These estimates are based on more detailed data than previous assessments, and they will help policy makers and businesses attempting to make sense of recent trends in this industry.

Aggregate electricity use for servers doubled over the period 2000 to 2005 both in the U.S. and worldwide. Almost all of this growth was the result of growth in the number of volume servers, with only a small part of that growth being attributable to growth in the power use per unit. Total power used by servers represented about 0.6% of total U.S. electricity consumption in 2005. When cooling and auxiliary infrastructure are included, that number grows to 1.2%, an amount comparable to that for color televisions. The total power demand in 2005 (including associated infrastructure) is equivalent (in capacity terms) to about five 1000 MW power plants for the U.S. and 14 such plants for the world. The total electricity bill for operating those servers and associated infrastructure in 2005 was about $2.7 B and $7.2 B for the U.S. and the world, respectively.

ACKNOWLEDGMENTS

ABOUT THE AUTHOR

Jonathan Koomey is a Staff Scientist at Lawrence Berkeley National Laboratory and a Consulting Professor at Stanford University. Dr. Koomey is one of the foremost international experts on electricity used by computers, office equipment, and data centers, and is the author or co-author of eight books and more than one hundred and fifty articles and reports on energy and environmental economics, technology, forecasting, and policy. He has also published extensively on critical thinking skills. He holds M.S. and Ph.D. degrees from the Energy and Resources Group at the University of California at Berkeley, and an A.B. in History of Science from Harvard University. In 1993 he won the Fred Burgraff Award for Excellence in Transportation Research from the National Research Council's Transportation Research Board.   He was named an Aldo Leopold Leadership Fellow in 2004 and an AT&T Industrial Ecology Fellow in January 2005. He has been quoted in the New York Times, the Wall Street Journal, Barron's, The Washington Post, Science, Science News, American Scientist, Dow Jones News Wires, and the Christian Science Monitor, and has appeared on Nova/Frontline, BBC radio, CNBC, All Things Considered, Marketplace, On the Media, Tech Nation, and the California Report, among others. His latest solo book is *Turning Numbers into Knowledge: Mastering the Art of Problem Solving* <http://www.analyticspress.com>, now in its third printing (and recently translated into Chinese). For more biographical details and a complete publications list, go to <http://www.koomey.com>.

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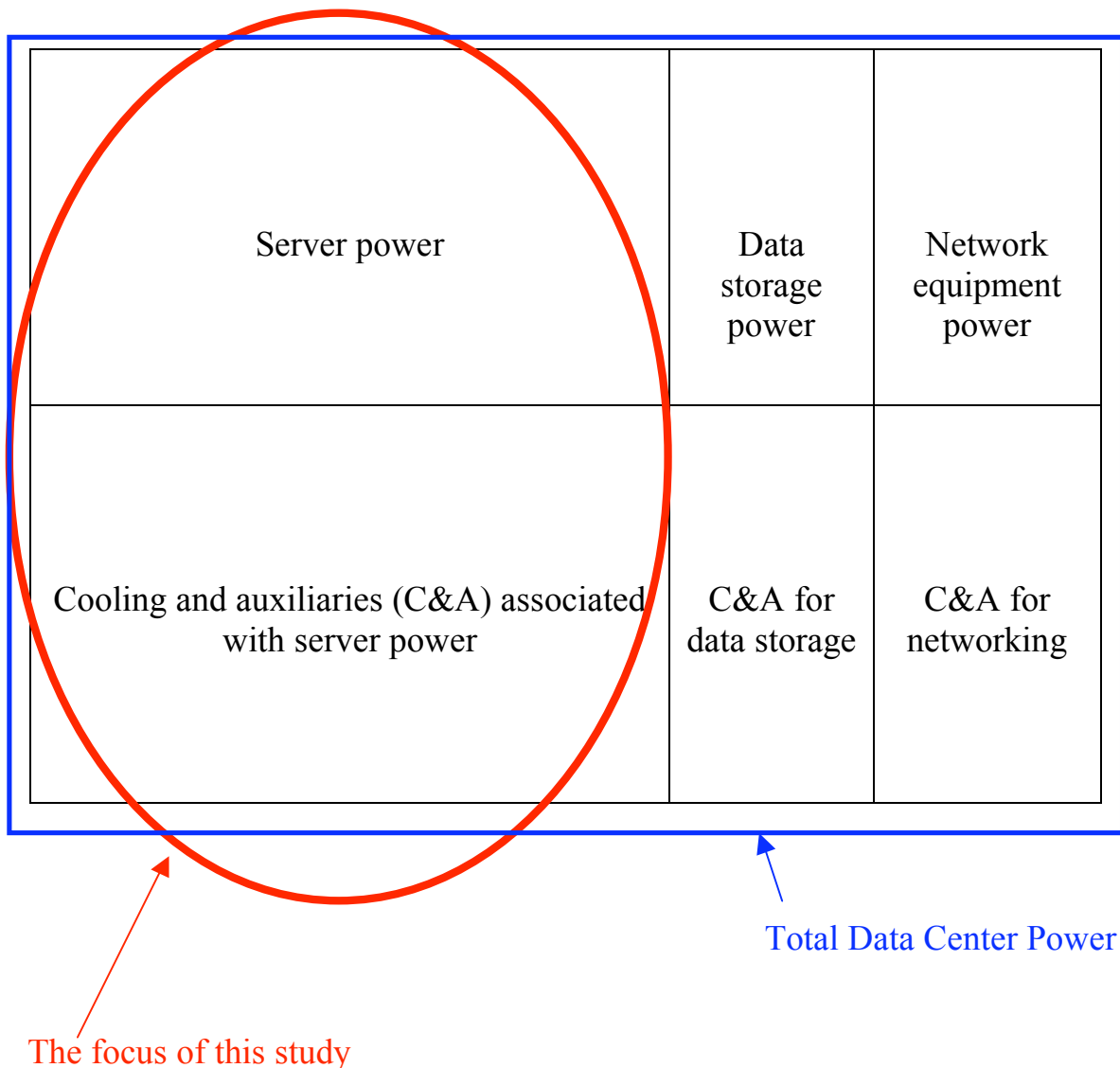
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Figure 1: Boundaries of this study

This study focuses on the largest single component of data center power use: servers and the associated cooling and auxiliary equipment (C&A) needed to support them. Other important components of data center electricity use include data storage and network equipment, which together represent 20 to 40% of total data center load, but accurate recent data on power use has not yet been developed for this equipment. C&A power includes losses associated with the backup power systems, power conditioning, power distribution, air handling, lighting, and chillers.

Server power	Data storage power	Network equipment power
Cooling and auxiliaries (C&A) associated with server power	C&A for data storage	C&A for networking

Total Data Center Power

The focus of this study

Figure 2: Total electricity use for servers in the U.S. and the world in 2000 and 2005, including cooling and auxiliary equipment

Total electricity use (billion kWh/year)

Sources: IDC data for installed base, shipments, and most popular models, and manufacturer data on power use for individual server models. Total expenditures assume US industrial electricity prices (2006 dollars)

0.8% of estimated 2005 world electricity sales, $7.2B/year

1.2% of 2005 U.S. electricity sales, $2.7B/year

Cooling and auxiliary equipment

High-end servers
Mid-range servers

Volume servers

U.S.

World

Figure 3: Comparison of year 2000 estimates in this study and those of Roth et al., including U.S. installed base, power use per unit, and total server electricity use.
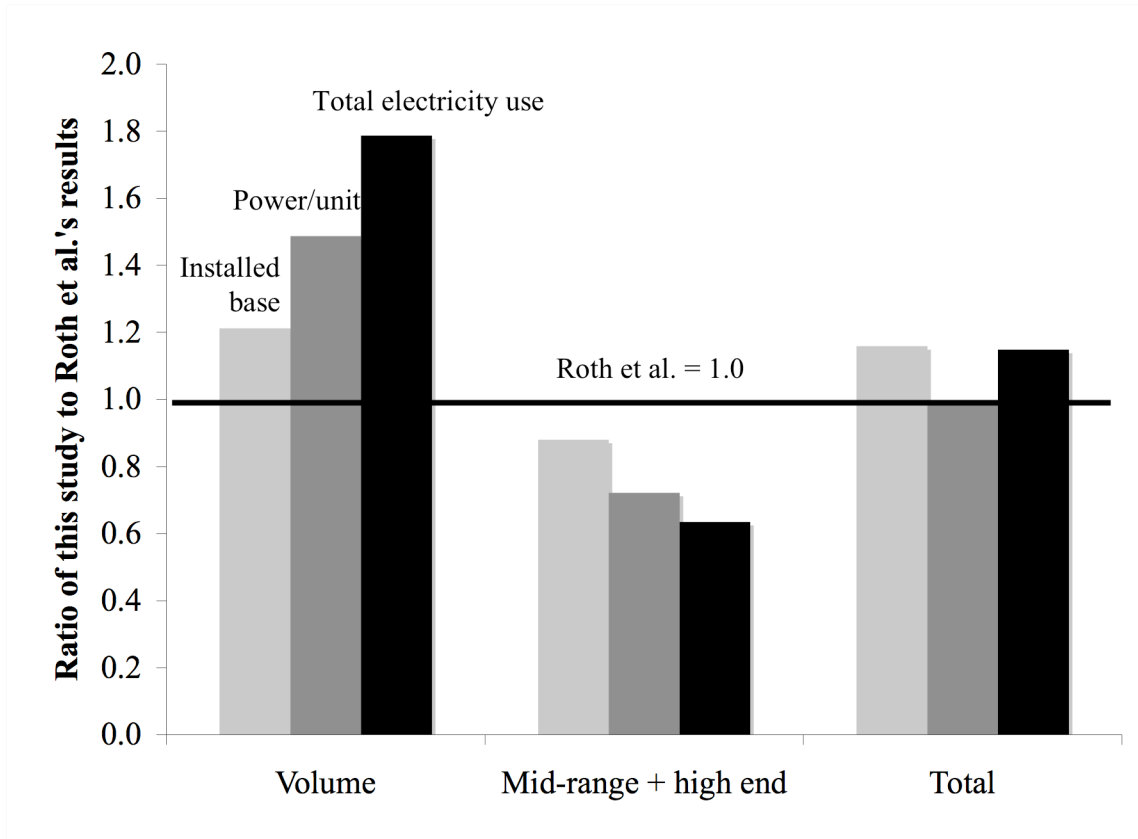
Figure 4: Comparison of 2005 to 2000 installed base, power per unit, and total electricity use for the U.S.
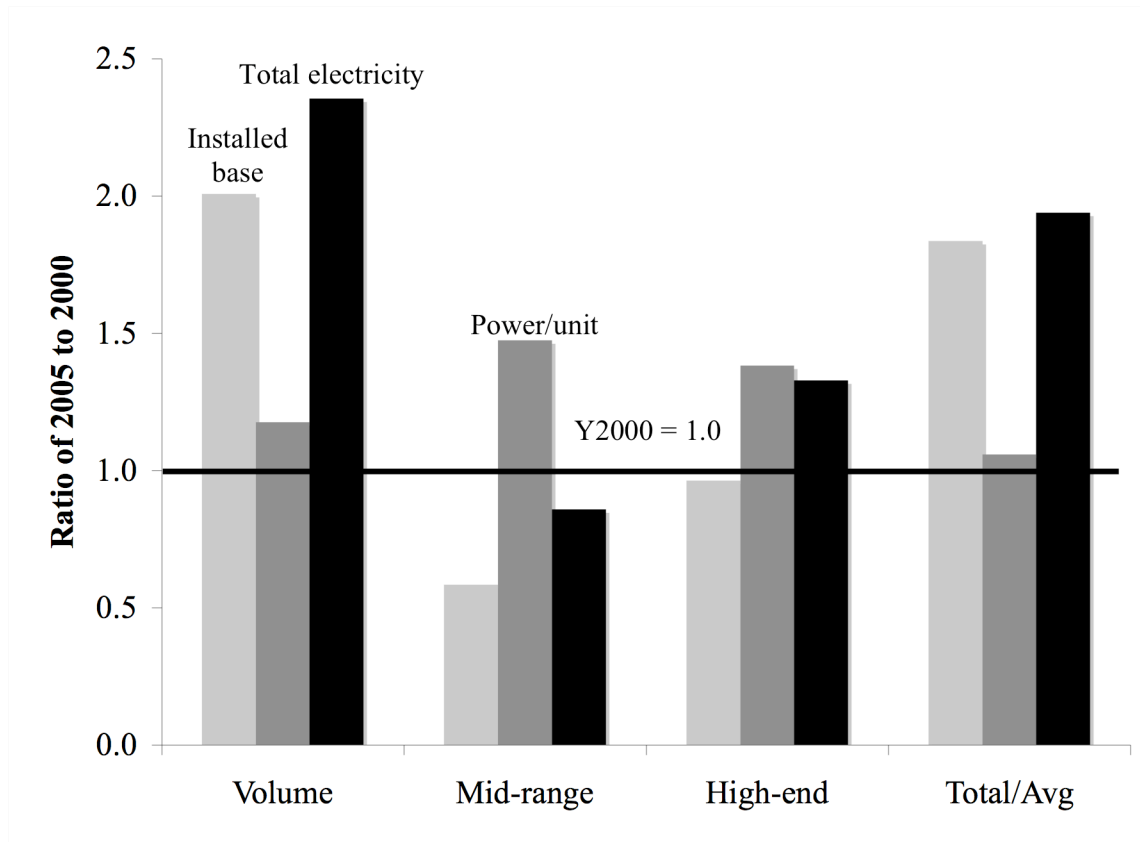
Figure 5: Comparison of 2005 to 2000 installed base, power per unit, and total electricity use for the World

Table 1: Installed base, shipments, and retirements of servers for the U.S. and the World

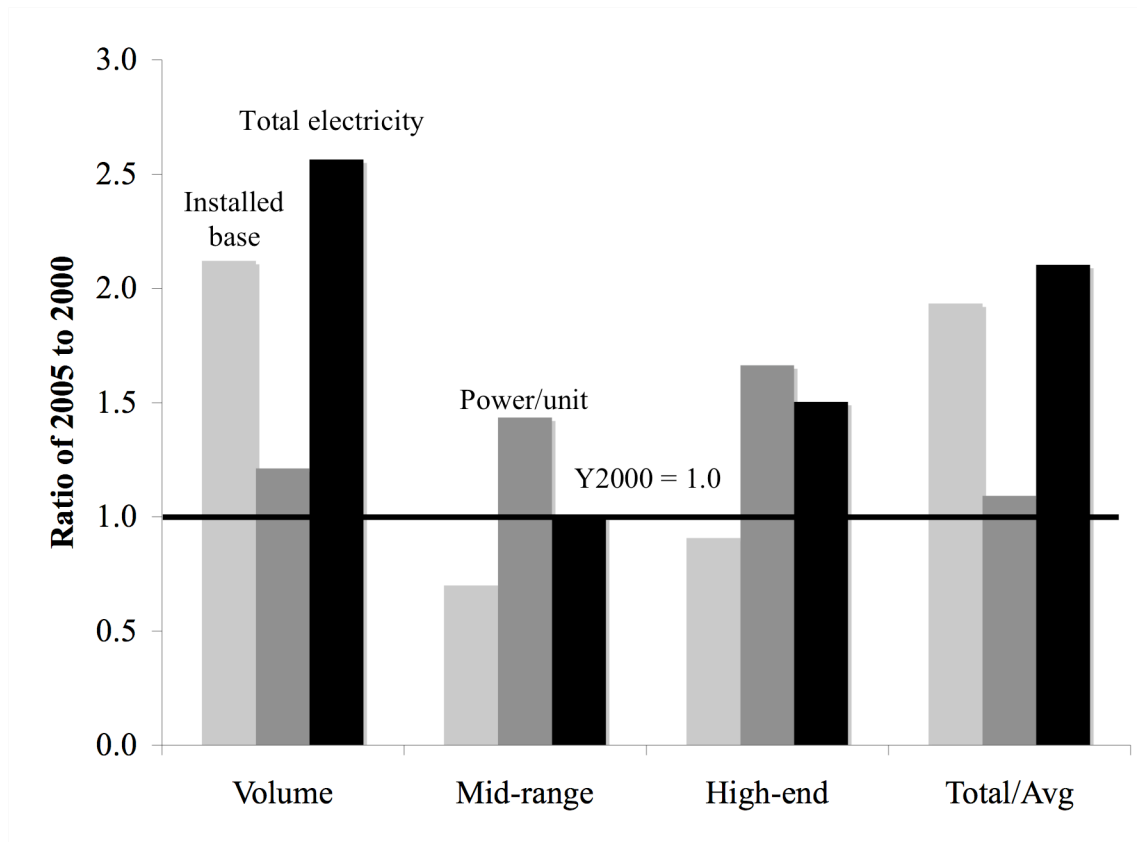|		Units	All servers: U.S.				All servers: World (5)			
			Volume	Mid-range	High-end	Total	Volume	Mid-range	High-end	Total
Total Installed Base (1, 2, 3)	2000	Thousands	4,927	663	23.0	5,613	12,240	1,808	65.6	14,114
	2001	Thousands	5,907	701	22.5	6,630	15,596	1,890	69.1	17,555
	2002	Thousands	6,768	574	23.1	7,365	16,750	1,683	59.0	18,492
	2003	Thousands	7,578	530	21.4	8,130	18,523	1,540	62.3	20,125
	2004	Thousands	8,658	432	23.3	9,113	23,441	1,238	66.0	24,746
	2005	Thousands	9,897	387	22.2	10,306	25,959	1,264	59.4	27,282
Total Shipments (2, 3)	2000	Thousands	1,659	111	4.8	1,774	3,926	283	13.0	4,223
	2001	Thousands	1,492	66	3.6	1,562	3,981	206	10.4	4,198
	2002	Thousands	1,714	67	3.1	1,784	4,184	204	9.4	4,397
	2003	Thousands	2,069	76	2.9	2,148	5,017	211	8.8	5,237
	2004	Thousands	2,517	53	2.8	2,572	6,083	184	8.6	6,275
	2005	Thousands	2,721	62	2.6	2,786	6,822	187	8.5	7,017
Total Retirements (4)	2000	Thousands	300	116	5	420	1,631	264	10	1,905
	2001	Thousands	513	28	4.1	545	626	125	6.9	757
	2002	Thousands	853	194	2.5	1,049	3,030	411	19.6	3,461
	2003	Thousands	1,259	120	4.6	1,383	3,243	355	5.5	3,603
	2004	Thousands	1,437	151	0.9	1,589	1,165	485	4.9	1,655
	2005	Thousands	1,482	106	3.7	1,592	4,304	161	15.1	4,481

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(1) Installed base is measured at the end of any given year (December 31st).
(2) Installed base and shipments for all years from IDC data, filename IDC_QShare_InstalledBaseForecast2006.xls, release date February 3, 2006.
(3) Installed base and shipments include both enterprise and scientific servers. They do not include server upgrades.
(4) Retirements are derived from the installed base and shipments numbers. Retirements in 2000 derived using 1999 installed base (not shown) and year 2000 shipments.
(5) World includes the U.S.

Table 2: Top six models by server class for the U.S. and the World based on IDC 2000 installed base data

Volume servers: US				Volume servers: World			
Brand	Model	Typical Power (W)	Notes	Brand	Model	Typical Power (W)	Notes
Compaq	ML530	273	3, 6	Compaq	ML370	268	3, 6
Compaq	ML370	268	3, 6	Compaq	ML530	273	3, 6
Dell	2300	107	2, 7	Compaq	200 Total	114	3, 6
Compaq	DL380	131	3, 6	IBM	3000 Total	100	4, 6
Compaq	ML350	139	3, 6	HP	E Series	114	3, 6
Dell	1300	118	2, 7	Compaq	ML350	139	3, 6
Weighted average		186		Weighted average		183	

Mid-Range servers: US				Mid-Range servers: World			
Brand	Model	Typical Power (W)	Notes	Brand	Model	Typical Power (W)	Notes
Sun	450	499	5, 7	Sun	450 Total	499	5, 7
Sun	3000/3500	263	5, 7	Sun	3000/3500	263	5, 7
Sun	4000/4500	432	5, 7	IBM	POWERSERVER C10/C20/E20/E30	106	4, 6
IBM	POWERSERVER C10/C20/E20/E30	106	4, 6	HP	rp 5400 Series / D CLASS 200/U	847	3, 6
IBM	9406 300	327	4, 6	Sun	4000/4500	432	5, 7
HP	K CLASS 100	872	3, 6	IBM	9406 300	327	4, 6
Weighted average		424		Weighted average		423	

High-end servers: US				High-end servers: World			
Brand	Model	Typical Power (W)	Notes	Brand	Model	Typical Power (W)	Notes
Sun	10000 HE	13,456	5	IBM	POWERSERVER S80	1,335	4, 6
IBM	POWERSERVER S80	1,335	4, 6	Sun	10000 HE	13,456	5
IBM	SP Mid B9	2,640	4, 6	IBM	SP Mid B9	2,640	4, 6
IBM	4381	4,813	4, 6	IBM	4381	4,813	4, 6
HP	rp 8400 Series / V CLASS 2200/2250	2,920	3	HP	rp 8400 Series / V CLASS 2500 MR	2,920	3
HP	991 995 996	1,724	3	IBM	9406 640	1,327	4, 6
Weighted average		5,534		Weighted average		4,874	

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(1) For each server class, models shown are ranked in order of their share of installed base in 2003. Shares not shown because of confidentiality concerns.

(2) Dell 1300 and 2300 typical power based on maximum rated input power from Dell spec sheets.

(3) Compaq ML 370, ML350, ML530, and DL380 all assume G1 versions. Typical power based on max. measured power from HP online configurator <http://h30099.www3.hp.com/configurator/calc/Power Calculator Catalog.xls> (N.B., HP and Compaq merged after 2000). HP rp8400 V class and 991/995/996 typical power given in spec sheets.

(4) IBM models' typical power based on max. measured power from IBM estimates (for SP mid B9) or from spec sheets (all others).

(5) Sun models' typical power based on maximum rated input power from spec sheets, except for the 10000 HE for which typical power was given.

(6) Max. measured power multiplied by 40% and 66% to get typical power use for volume and mid-range/high end servers respectively.

(7) Max. rated input power multiplied by 25%, 30%, and 40% to get typical power for volume, mid-range, and high end servers, respectively.

Table 3: Top six models by server class for the U.S. and the world based on IDC 2003 installed base data

Volume servers: US		Typical Power (W)	Notes	Volume servers: World		Typical Power (W)	Notes
Brand	*Model*			*Brand*	*Model*		
HP/Compaq	1600/ML 370	293	3, 6	HP/Compaq	1600/ML 370	293	3, 6
Dell	2650	178	2, 6	HP/Compaq	DL380 G2	150	3, 6
HP/Compaq	DL360	107	3, 6	HP/Compaq	DL360	107	3, 6
HP/Compaq	800/ ML350	165	3, 6	HP/Compaq	DL380 G3	212	3, 6
HP/Compaq	DL 380 G1 DL 380	131	3, 6	Dell	2650	178	2, 6
HP/Compaq	3000/ML 530	345	3, 6	HP/Compaq	3000/ML 530	345	3, 6
Weighted average		207		Weighted average		214	

Mid-Range servers: US		Typical Power (W)	Notes	Mid-Range servers: World		Typical Power (W)	Notes
Brand	*Model*			*Brand*	*Model*		
Sun	450	499	5, 7	Sun	450	499	5, 7
Sun	420R	183	5, 7	Sun	420R	183	5, 7
Sun	V480	432	5, 7	Sun	V880	450	5, 7
Sun	V880	450	5, 7	Sun	V480	432	5, 7
Sun	4000/4500	432	5, 7	HP	rp 7400 Series / N CLASS (rp7410)	1700	3
HP	rp 7400 Series/N CLASS (rp7410)	1700	3	IBM	9406-270	287	4, 6
Weighted average		524		Weighted average		522	

High-end servers: US		Typical Power (W)	Notes	High-end servers: World		Typical Power (W)	Notes
Brand	*Model*			*Brand*	*Model*		
Sun	10000 HE	13,456	5	IBM	p680-S85	1,335	4, 6
IBM	p690-681	11,286	4, 6	IBM	p690-681	11,286	4, 6
IBM	POWERSERVER S80	1,335	4, 6	IBM	POWERSERVER S80	1,335	4, 6
IBM	p680-S85	1,335	4, 6	Sun	10000 HE	13,456	5
HP	rp 8400 Series/V CLASS 2200/2250	2,920	3	HP	rp 8400 Series / V CLASS 2200/2250	2,920	3
IBM	SP Mid B9	2,640	4, 6	IBM	SP Mid B9	2,640	4, 6
Weighted average		6,428		Weighted average		5,815	

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(1) For each server class, models shown are ranked in order of their share of installed base in 2003. Shares not shown because of confidentiality concerns

(2) Dell 2650 typical power based on maximum measured power from Dell online configurator <http://www.dell.com/calc>

(3) HP 1600/ML 370, 800/ML350, 3000/ML530, and DL360 all assume G2 versions. Typical power based on max. measured power from HP online configurator <http://h30099.www3.hp.com/configurator/calc/Power Calculator Catalog.xls>. HP rp8400 V class and rp7400 N class typical power given in spec sheets.

(4) IBM models' typical power based on max. measured power from IBM estimates (for SP mid B9) or from spec sheets (all others).

(5) Sun models' typical power based on maximum rated input power from spec sheets, except for the 10000 HE for which typical power was given.

(6) Max. measured power multiplied by 40% and 66% to get typical power use for volume and mid-range/high end servers respectively.

(7) Max. rated input power multiplied by 25%, 30%, and 40% to get typical power for volume, mid-range, and high end servers, respectively.

Table 4: Top three models by server class for the U.S. and the world based on IDC 2005 shipments data

Volume servers: US		Typical Power (W)	Notes	Volume servers: World		Typical Power (W)	Notes
Brand	*Model*	*Power (W)*	*Notes*	*Brand*	*Model*	*Power (W)*	*Notes*
Dell	2850	231	2, 6	HP	DL380	222	3, 6
HP	DL380	222	3, 6	Dell	2850	231	2, 6
HP	DL360	187	3, 6	HP	DL360	187	3, 6
Weighted average		217		Weighted average		218	

Mid-Range servers: US		Typical Power (W)	Notes	Mid-Range servers: World		Typical Power (W)	Notes
Brand	*Model*	*Power (W)*	*Notes*	*Brand*	*Model*	*Power (W)*	*Notes*
IBM	i5-520	495	4, 6	IBM	i5-520	495	4, 6
IBM	p5 570	858	4, 6	IBM	p5 570	858	4, 6
Sun	V490	554	5, 7	Sun	V490	554	5, 7
Weighted average		641		Weighted average		638	

High-end servers: US		Typical Power (W)	Notes	High-end servers: World		Typical Power (W)	Notes
Brand	*Model*	*Power (W)*	*Notes*	*Brand*	*Model*	*Power (W)*	*Notes*
IBM	p5 595	14,190	4, 6	IBM	p5 595	14,190	4, 6
HP	rp 8420	2,303	3, 6	HP	SUPERDOME	6,968	3
Sun	E25K	15,840	5, 7	Sun	E25K	15,840	5, 7
Weighted average		10,673		Weighted average		12,682	

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(1) For each server class, models shown are ranked in order of their market share in 2005.

Market shares are not shown because of confidentiality concerns.

(2) Dell 2850 typical power based on maximum measured power from Dell online configurator <http://www.dell.com/calc>

(3) HP volume servers assume G4 versions. Typical power based on max. measured power from HP online configurator <http://h30099.www3.hp.com/configurator/calc/Power Calculator Catalog.xls>

HP rp8420 based on maximum measured power from spec sheets. Superdome typical power taken from spec sheets.

(4) IBM models' typical power based on max. measured power from spec sheets.

(5) Sun models' typical power based on maximum rated input power from spec sheets.

(6) Max. measured power multiplied by 40% and 66% to get typical power use for volume and mid-range/high end servers respectively.

(7) Max. rated input power multiplied by 25%, 30%, and 40% to get typical power for volume, mid-range, and high end servers, respectively.

Table 5: Percentage of shipments and installed base represented by the models used to estimate power levels

	2000 installed base	2003 installed base	2005 shipments
US			
Volume servers	20%	16%	23%
Mid-range servers	23%	26%	38%
High-end servers	28%	38%	39%
World			
Volume servers	18%	16%	19%
Mid-range servers	20%	23%	28%
High-end servers	21%	31%	24%

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(1) Table shows the percentage of total 2000/2003 installed base or 2005 shipments represented by the most common models shown in Tables 2, 3, and 4, based on IDC data.

Table 6: Electricity used by servers for the U.S. and the World

		Units	All servers: U.S.				All servers: World			
			Volume	Mid-range	High-end	Total/Avg	Volume	Mid-range	High-end	Total/Avg
Total Installed Base (1)	2000	Thousands	4,927	663	23.0	5,613	12,240	1,808	66	14,114
	2003	Thousands	7,578	530	21.4	8,130	18,523	1,540	62	20,125
	2004	Thousands	8,658	432	23.3	9,113	23,441	1,238	66	24,746
	2005	Thousands	9,897	387	22.2	10,306	25,959	1,264	59	27,282
Average power use per unit (2, 3)	2000	W/unit	186	424	5,534	236	183	423	4,874	236
	2003	W/unit	207	524	6,428	244	214	522	5,815	255
	2004	W/unit	213	574	6,973	248	216	578	6,783	252
	2005	W/unit	219	625	7,651	250	222	607	8,106	257
Direct power consumption (4)	2000	Million kW	0.9	0.3	0.1	1.3	2.2	0.8	0.3	3.3
	2003	Million kW	1.6	0.3	0.1	2.0	4.0	0.8	0.4	5.1
	2004	Million kW	1.8	0.2	0.2	2.3	5.1	0.7	0.4	6.2
	2005	Million kW	2.2	0.2	0.2	2.6	5.8	0.8	0.5	7.0
Total power consumption (7) (including cooling and aux equipment)	2000	Million kW	1.8	0.6	0.3	2.6	4.5	1.5	0.6	6.7
	2003	Million kW	3.1	0.6	0.3	4.0	7.9	1.6	0.7	10.2
	2004	Million kW	3.7	0.5	0.3	4.5	10.1	1.4	0.9	12.5
	2005	Million kW	4.3	0.5	0.3	5.2	11.5	1.5	1.0	14.0
Direct electricity consumption (5, 6)	2000	Billion kWh	8	2.5	1.1	12	20	7	3	29
	2003	Billion kWh	14	2.4	1.2	17	35	7	3	45
	2004	Billion kWh	16	2.2	1.4	20	45	6	4	55
	2005	Billion kWh	19	2.1	1.5	23	50	7	4	61
Total electricity consumption (7) (including cooling and aux equipment)	2000	Billion kWh	16	4.9	2.2	23	39	13	6	58
	2003	Billion kWh	27	4.9	2.4	35	69	14	6	90
	2004	Billion kWh	32	4.4	2.9	40	89	13	8	109
	2005	Billion kWh	38	4.2	3.0	45	101	13	8	123
Total electricity bill (8) (including cooling and aux equipment)	2000	Billion 2006 $	0.9	0.3	0.1	1.3	2.1	0.7	0.3	3.1
	2003	Billion 2006 $	1.5	0.3	0.1	1.9	3.9	0.8	0.4	5.0
	2004	Billion 2006 $	1.8	0.2	0.2	2.2	5.0	0.7	0.4	6.1
	2005	Billion 2006 $	2.2	0.3	0.2	2.7	6.0	0.8	0.5	7.2

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Notes to Table 6

(1) Installed base is measured at the end of any given year, taken from Table 1, based on IDC data.

(2) Average power use in 2000 & 2003 for each server class taken from Tables 2 & 3, based on an installed base weighted average of power use for the top 6 servers in each class

(3) Average power use in 2004 calculated assuming that retirements in 2004 (from Table 1) use the same amount of power per unit as does the year 2000 installed base,
and that new units in 2004 use the same amount of power per unit as the sales-weighted average of shipments in 2005 of the top three units for each server class (Table 4).
The procedure is repeated for 2005, assuming that retirements in that year also use the same amount of power as the 2000 installed base.

(4) Direct power use is the product of the total installed base and the average power per unit. It does not include utility transmission and distribution losses.

(5) Total electricity use converts total power in million kW to billion kWh assuming 8760 hours per year for 2003/2005 and 8784 kWh/year for 2000/2004 (leap years).

(6) Servers are assumed to operate 100% of the year

(7) Total electricity consumption (including cooling and auxiliary equipment) is twice that of the direct server power consumption, based on typical industry practice.

(8) Electricity bills for U.S. and World servers calculated assuming average U.S. industrial electricity prices from the Energy Information Administration,
adjusted to 2006 dollars using the GDP deflator http://www.eia.doe.gov/cneaf/electricity/epa/epat7p4.html