WAYTRONX™

The coolest path to system performance.™

White Paper

Understanding Microwarming

Introduction to Microwarming

A changing world. Our planet is shifting. The tipping point is visible everywhere as we make the change from depending on earth-depleting "brown" energy sources like fossil fuels to earth-sustaining "green" energy sources like solar and wind. We are transitioning away from systems that waste energy to those that conserve it, and hopefully away from global warming toward climate sustainability.

Similarly, the digital electronics industry faces its own energy sustainability challenges. Think of it as a microcosm – literally and figuratively – of the issues faced at the global level. The digital industry, driven by Moore's Law, has delivered consistent performance gains for three decades – and quite impressive gains at that. A single Apple iPod® today contains more computing and communications power than all of the Apollo spaceflights, combined. Thanks to this computing and communications power, processors, computers and communications equipment and the data centers that house them have all enjoyed relentless cost/performance improvement.

But will this megatrend continue? The biggest threat to Moore's Law is the performance-limiting overheating created by the very transistors that deliver the performance of today's digital electronics. In the beginning of Integrated Circuits (ICs), there were only a few hundred transistors on a chip, so heat loss was barely a consideration. Three decades later, however, we are approaching one billion transistors on every chip! At these transistor densities, heat buildup is limiting chip and system performance and threatening to derail the cost/performance benefits of Moore's Law. Without new strategies to eliminate waste heat and cool key components, digital electronics could stagnate in performance for the first time since their advent. According to an article by Lee Gomes in *The Wall Street Journal*, Intel's Gordon Moore "admits that the limitation of power consumption had caught him, as well as the industry, by surprise." Gomes also wrote that "Big chips like the Pentium produce so much heat that Intel worries more about improving energy efficiency than performance."[1]

What is microwarming? At Waytronx, we refer to this megatrend of performance-limiting dissipated heat as ***microwarming***. Microwarming starts at the tiniest element of digital electronics, the transistor, and extends to the integrated environment within and surrounding advanced devices. In fact, microwarming is pervasive in every level of digital integration. Today's CPUs, memory chips, System on Chips (SOCs), graphics processors, and all

ICs are generating ever larger amounts of performance-limiting heat. Computer and consumer electronics makers constantly search for more power efficient components, and still must address more aggressive cooling of their systems, at ever-increasing cost. Data centers require aggressive cooling strategies as cabinet power consumption can now reach 30 kilowatts or more. In fact, data centers have reached an inflection point wherein the cost of cooling the chip/communications device-laden servers has surpassed the capital expenditures to buy them in the first place.

Microwarming limits system performance. As components in the micro electronics industry run at higher speeds with more computing capacity, thermal management has become the performance limiter. Currently, the costs and complexity of cooling techniques are setting overall system performance limits that negate many of the gains in speed and capability in multiprocessors and high-end gaming chips, impacting the growth opportunities for those markets.

The digital electronics industry is employing multiple strategies to deal with the issues that result from the microwarming megatrend such as:

- The latest chip manufacturing processes employ high-K dielectrics
- Chip design now incorporates multiple cores, multiple voltages for memory and logic, and lower operating frequencies
- System designers create more efficient power supplies and specify lower power components
- Chips are built with limiters to literally shut down when certain temperatures are reached

Despite these and other efforts, more aggressive cooling strategies are still required. Today, **Waytronx™ WayCool™ architecture** is the industry's leading openly licensable, open cooling architecture for digital electronics. Its flexibility and cost effectiveness make it ideal for cooling today's digital electronics.

Looking forward, cooling subsystems will increasingly be designed in, rather than added on to digital systems, to maximize performance and eliminate extra cooling costs. Solutions including **Waytronx™ WayFast™** technology and its ***3C for 3-D*** R&D initiatives will provide the industry a roadmap to move seamlessly from today's add-on cooling solutions to highly integrated 3-D packaging systems that include cooling, communications and current (power) delivery. Getting correctly conditioned electricity to high speed transistors is difficult, and dissipating the heat generated by these transistors is just as challenging. Some transistor structures, such as the gate oxide, are only a few atoms thick, so they leak electricity.

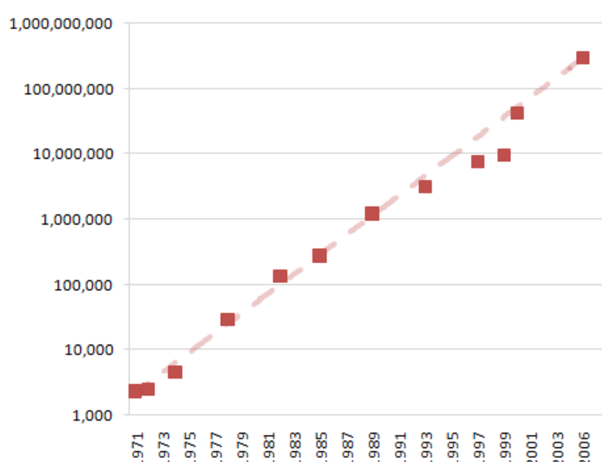
Moore's Law will drive digital electronics for another decade or more thanks, in part, to Waytronx thermal management solutions.

Moore's Law

Moore's Law describes an important megatrend in digital electronics -- that the number of transistors that can economically be placed on a chip doubles approximately every two years. The observation was first made by Intel co-founder Gordon Moore in 1965. The trend has continued for more than half a century and is not expected to stop for a decade or longer.

Figure 1 shows an example of Moore's Law, the increasing number of transistors in Intel microprocessors from 1971 to 2006. Performance capabilities such as processing speed, memory capacity and digital image quality are linked to Moore's Law. All of these are improving at exponential rates as Moore's Law increases the number of transistors on a chip. Today, new chip designs may exceed one billion transistors (see figure 2).

Here's a graph of the transistor count of each major Intel x86 chip family release from 1971 to 2006:



The dotted line is the predicted transistor count if you doubled the 2,300 transistors from the Intel 4004 chip every two years since 1971.

Figure 1: Example of Moore's Law

Processor	Transistor count	Date of introduction	Manufacturer
Intel 4004	2300	1971	Intel
Intel 8008	2500	1972	Intel
Intel 8080	4500	1974	Intel
Intel 8088	29 000	1979	Intel
Intel 80286	134 000	1982	Intel
Intel 80386	275 000	1985	Intel
Intel 80486	1 200 000	1989	Intel
Pentium	3 100 000	1993	Intel
AMD K5	4 300 000	1996	AMD
Pentium II	7 500 000	1997	Intel
AMD K6	8 800 000	1997	AMD
Pentium III	9 500 000	1999	Intel
AMD K6-III	21 300 000	1999	AMD
AMD K7	22 000 000	1999	AMD
Pentium 4	42 000 000	2000	Intel
Barton	54 300 000	2003	AMD
AMD K8	105 900 000	2003	AMD
Itanium 2	220 000 000	2003	Intel
Itanium 2 with 9MB cache	592 000 000	2004	Intel
Cell	241 000 000	2006	Sony/IBM/Toshiba
Core 2 Duo	291 000 000	2006	Intel
Core 2 Quad	582 000 000	2006	Intel
G80	681 000 000	2006	NVIDIA
POWER6	789 000 000	2007	IBM
Dual-Core Itanium 2	1 700 000 000	2006	Intel

Figure 2: Transistor counts of processors exceed one billion today

Microwarming in Transistors

One of the major challenges in ICs that use nanoscale metal oxide semiconductor (MOS) transistors is the increase in leakage currents. These transistors also dissipate considerable power even when not switching due to sub-threshold leakage. In the past, the sub-threshold leakage of transistors has been very small, but as transistors have been scaled down, sub-threshold leakage can compose nearly 50% of total power consumption

The amount of waste heat created at the full chip level depends on the circuit blocks, their state, the application workload, as well as process, voltage and temperature conditions.

Silicon dioxide has been used as the gate insulating material in MOS transistors for decades. As transistors have decreased in size, the thickness of the silicon dioxide gate dielectric has steadily decreased. Replacing the silicon dioxide gate dielectric with a high dielectric constant (high-K) material allows increased gate capacitance without the lower leakage effects. Intel, IBM, NEC, and others have recently announced high-K dielectrics in their advanced chip-making processes.

Transistor switching speeds also affect electricity consumption. As transistors change their states between on and off, active current is needed to switch the tens of millions of ICs. The more transistors a chip contains and the faster they change states, the hotter the chip gets. Modern MOS transistors can switch states at rates of several gigahertz (GHz), driving up active power consumption of individual CPUs, multicore processors and graphics chips to more than 100 Watts in many cases.

Microwarming in Modern Integrated Circuits

Microwarming, in the form of waste heat generated by today's ICs (including advanced CPUs, GPUs, memory chips, chipsets, SOCs, etc.), is a function of elements including: the efficiency of ICs, their total transistor count, the design approach for their circuit blocks, the technology used in their construction, and the frequency and voltage at which they operate. If a chip gets too hot, it will fail. Waste heat buildup from ICs is the prime cause of microwarming in modern computers.

Many CPUs and GPUs include thermal sensors that shut down the computer if reasonable temperature bounds are exceeded. It is unwise to rely on such sensors as they are not universally implemented, and may not prevent repeated incidents from permanently damaging the integrated circuit. To reduce both power use and heat generation, ICs often shut down or idle circuit blocks with low workload, or scale back the operating clock speed under high temperatures.

Despite all of the chip processing and design improvement techniques for ICs, processor power consumption has been on the increase. And, because transistor densities have increased, power densities have increased as well. The end result of the combination of increasing power densities and increasing die sizes means that CPUs are fast hitting a "power wall."

The Power Wall. First, this power wall is starting to limit processor performance. The processor performance is less than predicted by the Moore's Law transistor count. Figure 3 shows the recent slowing of operating clock speed increases of Intel 32 bit processors.

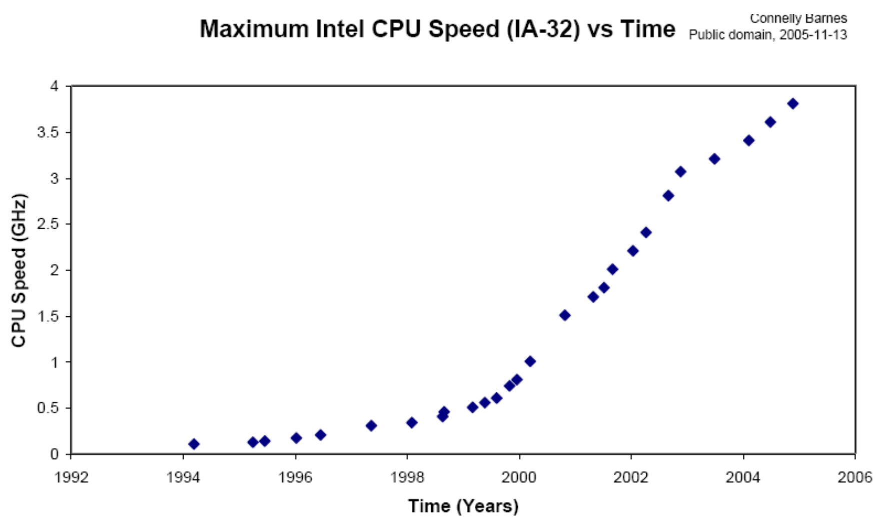


Figure 3: The recent slowing of operating clock speed increases of Intel 32 bit processors.

Second, the power density of processors causes an extreme localized heat problem that is increasingly difficult and costly to address. Power densities cannot keep increasing indefinitely. If architects continue on their present course of adding more and more functionality to a single die, active cooling will be required for all new CPU designs at some point.

Historically, Intel's first Pentium CPUs were already producing a considerable amount of heat, but specifications allowed operation without any special heat removal. Later processors required at least a passive heat sink for trouble free operation. Today, most all CPUs require an active cooling system -- at a minimum a heat sink plus fan -- to ensure cooling to allowable operating temperatures.

To remove this huge amount of thermal energy from a CPU requires highly sophisticated solutions. Those heat removal solutions need to be attached very closely to the microprocessor because once the heat conducting connection to the CPU is lost, the processor overheats, leading to shutdown or failure. The large amounts of heat must then be moved to the ambient environment, not simply passed to the rest of the system.

Waytronx™ WayCool™ architecture has been designed specifically to address the extreme power density and cooling requirements of advanced CPUs, multicore processors and high performance graphics chips. WayCool Carbon technology conductively removes heat at rates up to four times that of typical copper plate heat conductors. **WayCool™ Mesh, WayCoolant™ liquid coolant and WayCool™ hermetically sealed pumps** combine with traditional fan cooling to provide a hybrid liquid + air cooling architecture of unprecedented convenience and cooling capability. Future CPU and graphics processor designs are now incorporating "MIPs per WATT" design goals in addition to traditional performance attributes. This shows the increasing attention to power consumption and power dissipation in the designing of modern processors. **WayCool™ Mesh** offers a roadmap incorporating **WayFast™ I/O** capabilities as well as a power delivery fabric that will enable future **3D packaging** at even higher power densities. For more information, see www.waytronx.com

Microwarming in Computers, Servers and Communications systems

"…in its long-running race to boost performance, the computer industry has hit a major hurdle: The newest hardware -- particularly the servers that run most business programs and Web sites -- draws too much electricity and generates too much heat." – article in The Wall Street Journal, November 14, 2005[2]

A result of Moore's Law and advanced packaging techniques is an ever increasing heat density of equipment. According to the Uptime Institute (www.uptimeinstitute.org), system heat density for a variety of systems is increasing at a rate of 7 to 28% per year.[3] Note that the vertical scale in Figure 4 is logarithmic, indicating an exponential growth rate.

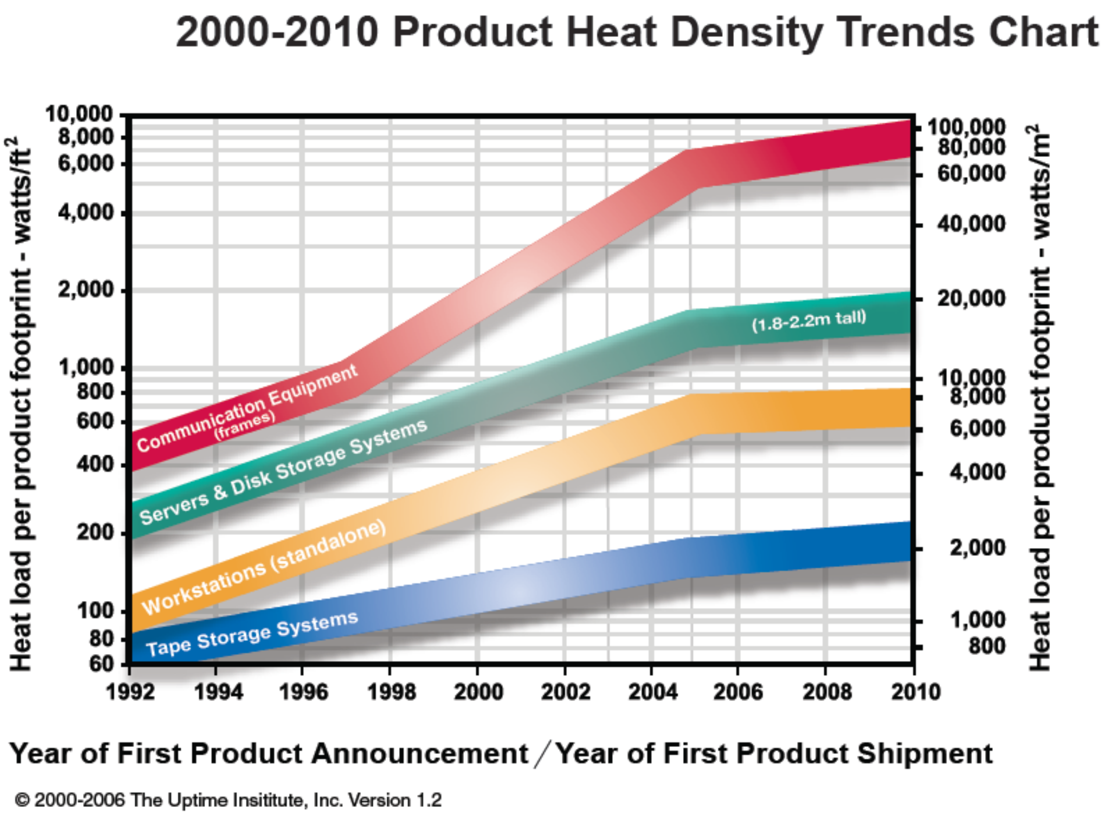


Figure 4: Copyright The Uptime Institute www.uptimeinstitute.com

New server trends, such as 1U form factor and blade servers are increasing the density trend in servers, according to The Uptime Institute, Inc. as seen in Figure 5.[4]

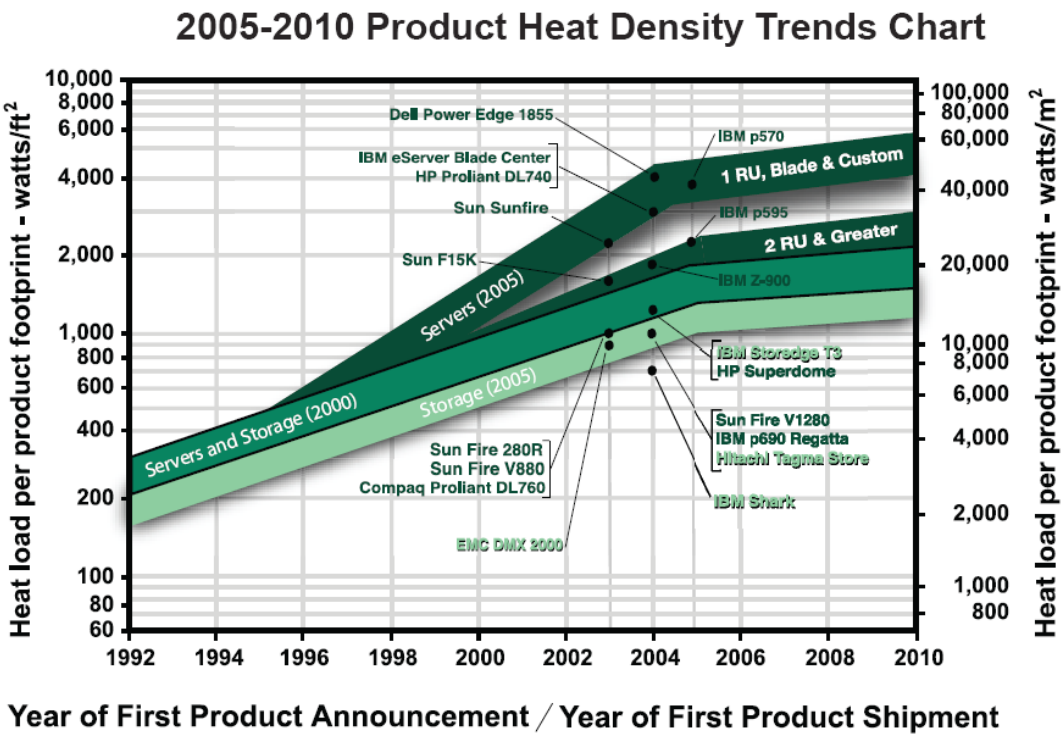


Figure 5: Copyright The Uptime Institute, Inc. www.uptimeinstitute.com

Energy saving techniques and recommendations for computers are provided by groups such as Climate Savers Computing Initiative and the federal government Energy Star 4.0 Computer specification. For example, Tier 1 Energy Efficiency Requirements are listed in Table 1 for different types of computers.

Tier 1 Energy Efficiency Requirements: *Effective July 20, 2007*	
Product Type	**Tier 1 Requirements**
Desktops, Integrated Computers, Desktop-Derived Servers and Gaming Consoles	**Standby (Off Mode):** <= 2.0 W **Sleep Mode:** <= 4.0 W **Idle State*:** • **Category A:** <= 50.0 W • **Category B:** <= 65.0 W • **Category C:** <= 95.0 W *Note: Desktop-derived servers (as defined in section 1. F) are exempt from the Sleep level above.*
Notebooks and Tablets	**Standby (Off Mode):** <= 1.0 W **Sleep Mode:** <= 1.7 W **Idle State*:** • **Category A:** <= 14.0 W • **Category B:** <= 22.0 W
Workstations	**TEC Power (P_{TEC}):** <= 0.35 * [P_{Max} + (# HDDs * 5)] W *Note: Where Pmax is the maximum power drawn by the system as tested per the test procedure in Section 4 of Appendix A, and #HDD is the number of installed hard drives in the system.*

Table 1: Copyright Energy Star and Climate Savers Computing Initiative

Desktop computers: Today's desktop computers use multiple fans for heat management. A power supply fan often plays a double role, not only keeping the power supply from overheating, but also removing warm air from inside the case. Additional fans and active cooling systems are needed for the CPU, for advanced graphics cards, for chipsets, memory and hard disk drives. Most manufacturers recommend bringing cool, fresh air in at the bottom front of the case, and exhausting warm air from the top rear. A slightly positive airflow results in less dust build up if dust filters are used. The normal operation of cooling methods can be hindered by other causes, such as dust, poor airflow, or poor conductive heat transfer from ICs. A new key performance metric is the *performance per watt ratio* on computers. **WayCool™ Reference Designs** provide licensable turnkey solutions to the highest performance cooling requirements of computers. **WayCool hybrid liquid + air cooling** can integrate multiple cooling solutions into one, combining CPU and chipset, or graphics and memory cooling, for example.

Notebook computers: Notebook computers are typically made to rest on a solid surface. Unfortunately a flat surface is the least desirable angle to dissipate heat; lower temperatures are achieved by a chimney effect when a laptop is set at an angle from horizontal. It is important to note that notebooks should not be used on surfaces which impede the free flow of air or shutdown, or heat damage may occur. Laptop stands are accessories which, besides raising the laptop's screen to another height, are also meant to reduce airflow restrictions.

Servers and workstations: 1U or blade servers represent a megatrend in servers for more distributed computing environments for corporate networks, intranets and data centers. Installing a rack of clustered "blade" servers in place of one monolithic piece of server hardware is by no means "opting out of Moore's Law." They are simply choosing to take advantage of it in a different way. Higher quantities of simpler but denser blade servers simply distribute the computing power of the data center in an equally power-dense, but more flexible configuration.

1U and blade servers require advanced cooling solutions that are thin, powerful heat transfer systems that can integrate CPU, chipset and memory cooling in one system. **WayCool technology's hybrid liquid + air cooling architecture** is uniquely suited to the severe form factor and heat removal needs of highly dense server environments. **WayCool Mesh** enables unique form factors, including very thin, single slot cooling with hundreds of watts of capacity. **WayCool hermetically sealed pumps** require no maintenance.

It is also worth considering how rapidly a cooling solution can draw heat way from the source. The lower the temperature inside the server, the more efficiently the microprocessors can operate. This in turn, leads to less energy consumption, while maintaining maximum performance.

Microwarming in Data Centers

Data centers typically contain many racks of flat 1U or blade servers. Air is drawn in at the front of the rack and exhausted at the rear. Because data centers typically contain such large numbers of computers and other power-consuming devices, they risk overheating of the various components if no additional measures are taken. Extensive air conditioning systems are used. As a result, the ongoing energy costs for operating the servers and for air conditioning can outstrip the initial capital cost of the center by several times over its useful life. The average data center today is designed for 1.5 kilowatts per rack, but racks based on blade servers are now reaching 20 kilowatts, according to American Power Conversion, a data center solutions provider based in W. Kingston, Rhode Island.

Waytronx provides advanced cooling solutions for electronics and microprocessors, and reminds data center designers to strategically integrate the cooling elements that accompany high-performance servers and systems. High performance systems, like blade servers, generate large amounts of heat. An effective cooling solution can boost performance while keeping energy consumption in check, dramatically reducing operating costs.

It can be self-defeating to adopt a cooling system that consumes additional energy like high-speed, power-hungry fans, for instance. Such options only compound the power consumption problem. Energy efficient cooling systems employ a hybrid – air + liquid approach and leverage the properties of materials like carbon, liquid, as well as air, to perform cooling functions while minimizing power to operate. **WayCool architecture** employs such a hybrid approach to its system cooling designs.

Another consideration is reliability of the cooling system. Liquid cooling systems often contain toxic materials that can leak and damage sensitive circuit boards. Advanced cooling systems with hermetically-sealed chambers of environmentally "friendly" liquid will ensure the fluid is contained. **WayCool architecture** with **WayCoolant liquids** and hermetically sealed **WayCool pumps** ensure safe, reliable, trouble-free operation.

Additional Microwarming Resources

For more information on microwarming, effective device thermal management and related topics, consult these sources:

www.waytronx.com
www.microwarming.org
http://www.lostcircuits.com/
http://www.lesswatts.org
http://www.energystar.gov/index.cfm?c=computers.pr_crit_computers
http://www.energystar.gov/ia/partners/product_specs/program_reqs/Computer_Spec_Final.pdf
http://www.tomshardware.com/2001/09/17/hot_spot/index.html
http://www.anandtech.com/printarticle.aspx?i=2855
http://www.princeton.edu/~mrm/tutorial/Sigmetrics2001_tutorial.pdf
http://www.climatesaverscomputing.org/program/faq.html
www.uptimeinstitute.org
http://en.wikipedia.org/wiki/Moore_Law

---

[1] Lee Gomes, "Even an Intel Founder Can Still Be Impressed By Technology's Pace," *The Wall Street Journal*, October 10, 2007

[2] Don Clark, "Power-Hungry Computers Put Data Center in Bind," *The Wall Street Journal*, November 14, 2005

[3] Kenneth G. Brill, *2005-2010 Heat Density Trends in Data Processing, Computer Systems, and Telecommunications Equipment*, The Uptime Institute, Inc., 2006

[3] ibid.