SITE INFRASTRUCTURE WHITE PAPER

Heat Density Trends in Data Processing, Computer Systems, and Telecommunications Equipment

Over the past thirty years, the Information Technology (IT) industry has seen a geometric decrease in the floor space required to achieve a constant quantity of computing and storage capability. While the floor space required to accomplish such a fixed level of computing work has shrunk (technology compaction), the energy efficiency of equipment has not dropped at the same rate. As a result, the density of power consumed and the heat dissipated within the footprint of communication and computer hardware products has increased significantly.

This white paper provides valuable current data and best available insights regarding historical and projected trends in power consumption and the resulting heat dissipation in computer and data processing systems (servers and workstations), storage systems (DASD and tape), and central office-type telecommunications equipment. The topics presented are intended to address the special needs of Information Technology professionals, technology space and data center owners, facilities planners, architects, and engineers.

An Overview of Heat Density Issues

The current conditions

A common misconception among IT users is that technology compaction is making power consumption and cooling issues almost irrelevant, because new generations of products will continue to require less and less space. This view, however, assumes a constant level of processing activity. On a macro or industry level, that is not what is happening. The total amount of processing and storage capability being sold is rising rapidly, mostly because falling prices make new software applications feasible in situations where previously they were not economically viable.

If this voracious growth in applications were not occurring, computer manufacturers would now be experiencing a decline in product volume and a related decline in sales revenues. And since newer technologies can do more work in fewer units, many manufacturers would probably be forced to either increase their price per "box" to offset the reduced volume or face going out of business. But in fact, the opposite is true. Many industry analysts predict growing volumes of computer equipment. The current marketing plans and annual sales forecasts of hardware manufacturers assume they will be selling at least the same number of boxes while prices per box remain the same or fall, and prices per unit of IT capability continue to fall dramatically.

In addition, IT users have realized that servers can be vertically racked (dense packing) to conserve valuable floor space. The resulting power consumption and heat densities that can be created are almost unimaginable, especially to the layperson. Several manufacturers now have the capability to package sixty-four processors (or more by the time this white paper is distributed) in a single vertical equipment rack. The heat dissipated in a 2-foot by 2½-foot rack can be 10 kW or higher. This is the heat equivalent of one hundred 100-watt light bulbs inside a space the size of a typical home refrigerator. Using existing methods to provide sufficient cooling to one such rack is not particularly difficult, but supplying sufficient cooling to hundreds of these racks in a densely packed area requires a whole different approach.

At an industry-wide level, this translates into a *growing* total power consumption by IT products. There will be some companies who do experience a significant decrease in power consumption based on their own particular IT strategy, but they will certainly be in the minority.

A shared interest and responsibility of manufacturers and users

Both manufacturers and users of communication and computing products have a shared interest in being sure that technology spaces, data centers, and other computing facilities can provide sufficient power and the necessary cooling to utilize future generations of equipment. This increase in power and heat densities continues to be driven by the underlying technology of the semiconductor industry, whose factors include the number of transistors on a chip and the power consumption per transistor. As such, all product manufacturers are going to have roughly the same power consumption per box if they all utilize the same chip technology and have the same operating speeds.

As current technology trends continue, hardware manufacturers are becoming increasingly concerned that their customers are not sufficiently attentive to the long-term impact of *Moore's Law,* which predicts the doubling of semiconductor performance every eighteen months. If *Moore's Law* continues to hold (and it is anticipated it will at least through 2005), there will also be a dramatic and continuing increase in product power densities.

To better understand and address the many issues related to these trends, fifteen concerned companies (Amdahl, Cisco Systems Company, Compaq, Cray Inc., Dell Computer Corporation, EMC, Hewlett-Packard, IBM, Intel, Lucent Technologies, Inc., Motorola, Nokia, Nortel Networks, Sun Microsystems, Inc., and Unisys) have joined in a collaborative effort to project their best estimates of future watts-per-square-foot power densities for the footprints of their own products — including the resulting heat dissipation based on anticipated technology trends. Members of the collaboration have also developed an informative graph that charts past and projected heat density trends.

Dramatic new trends are revealed

Both the historic heat density data presented and the trends revealed are quite dramatic, and include projections and implications for future installations of data processing and telecommunications equipment through the year 2010. In the case of servers, DASD, and workstations, these projections indicate a 15% annual rate of increase with more than a 300% increase in power density over the decade from 1992 to 2002. The data reveals that in 1992, servers and DASD were in the range of 250 watts/ft^2 (2,690 watts/m^2), while projections for the year 2002 show these products increasing to 1,000 watts/ft^2 (10,760 watts/m^2) within the product footprint. Just this increase alone from year 2000 to 2001 is 100 watts/ft^2 (1,100 watts/m^2) within the product footprint, and in each subsequent year the annual change gets larger.

While many existing technology spaces and data centers are likely to be able to provide sufficient electrical power, most will struggle or may not be able to provide sufficient air circulation and air cooling capacity if large numbers of future high-performance IT products are installed. As the projected trends occur over the next three to six years, air from under the floor by itself will not be sufficient to remove the heat being generated. And at some point in the not so distant future, hardware manufacturers are going to have to consider a return to water cooling or other methods of removing heat from their boxes.

Planning a course of action

The ultimate question many customers and users face in building a new facility or doing a major upgrade of an existing space is what gross average power and heat-dissipation density should they plan for in the future? This is an extremely important question and one for which there are no routine answers. If too much site infrastructure capacity is installed, those making the investment recommendations will be criticized for the resulting low site-equipment utilization and poor efficiency. If too little capacity is installed, a company's IT strategy may be constrained, or new services may have to be outsourced because there is no space with sufficient site infrastructure capacity to do the work internally. And once work is outsourced, it may never come back in-house.

Many important variables are identified and discussed in this paper, however, the information presented cannot alone determine what the "right" gross planning average should be for a particular company or site. Hard-ware manufacturers' specifications, user IT strategy, hardware adoption rates, and site-specific space-planning practices must all be considered.

Definitions

Watts is an electrical term for measuring power. The typical way of expressing power density is in watts per square foot (watts/ft^2) or watts per square meter (watts/m^2). For single-phase circuits, watts is the product of multiplying volts $_{\text{line to line}}$ times the current in amperes times the power factor. For three-phase circuits, watts is the product of volts $_{\text{line to line average}}$ times the current $_{\text{line average}}$ in amperes times the power factor times 1.73. Field measurement of watts is difficult without special instrumentation.

Volts times amperes (VA) is the value typically measured in the field because it can easily be obtained using a voltmeter and a clamp-on ammeter. Today, many computer power supplies are power factor corrected to unity (1.0), so watts and volt-amperes are either identical or nearly the same. A kilowatt (kW) is the equivalent of 1,000 watts, and a kilo volt-ampere (kVA) is 1,000 volt-amperes .

Power consumed by computer and communication products is totally converted to heat. Watts per square foot is a way of expressing the amount of power consumed and the resulting heat dissipated within a given amount of floor space. One watt is the equivalent to 3.413 British Thermal Units per hour (BTU/h), and 12,000 BTU/h is the equivalent of one "ton" of cooling. Some engineers may want to convert watts to BTU/h or tons of cooling, because these are more familiar units of measure. For simplicity, this paper uses watts for both power and heat dissipation.

Manufacturer Versus User Methods of Heat Density Measurement

The only density value that can be determined by communication equipment and computer hardware manufacturers is the power consumed by a typical configuration of their product and the space the product occupies called the "footprint." The trend charts presented are calculated in terms of watts/ft^2-footprint (watts/m^2-footprint). Some products can be vertically stacked within equipment racks, and trends have been provided for racks 70 inches to 87 inches (1.8 to 2.2 meters) high full of equipment.

Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers.

The resulting gross watts per square foot (watt/ft^2-gross) or gross watts per square meter (watt/m^2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting. Heat gains or efficiency losses occurring within the space caused by loads other than the computer and communication hardware must be included to develop the overall loads. These additional loads can easily add 5% or more to the total UPS load and 10% to 30% or more to the total computer room cooling load.

The Implications of Increased Heat Density for Technology Spaces and Data Centers

Removing heat from the computer room is not the equipment manufacturer's responsibility

The hardware manufacturer's responsibility is limited to exhausting the heat from their products. Most manufacturers are already using supplemental fans and/or internal refrigeration units to accomplish this, but once the heat is rejected from the product into the surrounding space, it becomes the customer's or user's responsibility to remove this heat from the rack and from the room.

It is typically far easier to supply power to a high-density load than it is to remove the heat dissipated by it. A pair of 208-volt, 60-ampere, single-phase conductors in a one-inch conduit can supply up to 10,000 watts of power (derating to 80% per National Electric Code). The equivalent air flow required to remove this heat is 2,100 cubic feet per minute (59 m^3/min) assuming an underfloor air temperature of 60°F (15°C) and a 15°F (8°C) temperature rise in the return air. Many sites with poor static pressure will require as many as eleven perforated floor tiles to allow this much air to come up from under the raised floor.

The installation planning guides of several computer manufacturers optimistically assume 700 cubic feet per minute (20 m^3/min) from each perforated floor tile. However, field measurements in many sites indicate the actual air flow to be 200 cubic feet per minute (6 m^3/min) or less from commonly used 25% opening perforated floor tiles. Under typical computer room conditions, each 200 cubic feet per minute (6m^3/min) of cold circulated air will dissipate about 1,000 watts. In some locations within a computer room, air is actually being sucked down into the plenum rather than being pushed up for proper cooling. The actual field conditions should be verified before assumptions are made about a particular site.

Several hardware manufacturers currently have new products on their drawing boards for release in the not too distant future that will consume at least 16 kilowatts of power. Assuming the width of these new products is four feet (two floor tiles), and assuming two facing rows of equipment are to be installed, and further assuming the perforated tile air flow is 200 cubic feet per minute, which is typical of most data centers, the resulting aisle required between rows would be sixteen perforated floor tiles or a width of thirty-two feet just to allow sufficient cooling. Many IT managers are going to be very distressed with this substantial loss of floor space.

Short-term solutions to anticipated problems

Most sites have not yet experienced heat dissipation problems because their gross power density has either been low or their equipment layouts have been sufficiently spread out to reduce the gross averages to a capacity that can be handled by the installed cooling systems. Unless users have concentrated quantities of equipment in large areas, any wide disparity in heat dissipation between footprint and gross values may be masking existing cooling technology issues.

Existing raised-floor air-cooling methods work well up to about 40 watts/ft^2-gross (430 watts/m^2-gross). Above that point, careful attention must be paid to subtle yet very significant mechanical engineering issues. These include under-floor static pressure, cable dams and other air-flow restrictions, unnecessary openings, the quantity, placement, and percentage opening of perforated floor tiles, equipment rack selection, and other factors.

Unfortunately very few computer rooms or technology spaces have sufficient useable cooling and/or airflow capacity to handle the projected heat loads and heat density. Those with shallow raised floors will struggle to deliver sufficient air volume. Many will have to spread out equipment creating unusable "white space" on their floors to reduce the gross heat density to the capacity their cooling systems can handle.

In the short term, increasing under-floor static pressure by permanently blocking all unnecessary air escape routes is essential. This includes sealing cable cutouts behind and underneath products or racks as well as penetrations in the subfloor or walls or ceiling and any other openings in the raised floor. Perforated floor tiles with 25% openings could be replaced with 40% and 60% grates to permit a much higher air flow. For sites with unused raised floor space, deliberately spreading equipment out to create white space and reduce the average gross watts per square foot power consumption will be a viable option.

In the longer term, more carefully engineered solutions will have to be found. Another issue that must be addressed is matching the thermal ridethrough capability of the air-cooling system with the battery discharge time of the UPS. Room temperatures in high density areas will rise rapidly if cooling is interrupted for any reason.

The Functional Allocation of Gross Space within a Typical Data Center

There are four categories of gross space within a technology space or data center that require specific use planning relative to heat density. For purposes of planning calculations, any white space currently reserved for future equipment expansion should be allocated to the appropriate categories in anticipation of the ultimate intended use of the space.

1. <u>Electrically active IT hardware product footprints.</u>
   These consist of computers and telecommunica tions equipment including communication frames, servers, rack-mounted equipment, DASD, and tapes.

2. <u>Service clearances for the above equipment.</u>

3. <u>Site infrastructure support equipment.</u>
   This includes facility equipment installed on the raised floor or within the technology space supplying cooling or power to the IT equipment. Cooling systems include chilled-water air handlers or computer room air-conditioning units, and criti cal power equipment covers, in-room UPS systems and batteries, PDU's, static transfer switches, trans formers, and load distribution panels. (Sites with a low gross watts per square foot of power and cooling capability will devote significantly less space to site support equipment than sites with higher capacity).

4. <u>Electrically inactive areas.</u>
   These include main aisles, the portion of cross aisles not used for product service clearance,incidental storage, and building structural components.

The amount of space consumed by each of these four categories determines the physical personality of a data-processing or telecom environment. An examination of many data-processing centers provides the following typical allocation of gross computer room space within the four categories described above. Individual sites may vary widely from these values, which are regarded as broadly representative of current industry practice.

If minimum manufacturer-recommended service clearances are strictly used in the front and back cross aisles (which results in equipment being on top of partial floor tiles with no access to the underfloor), the best case space available for product footprints is 30%. If whole-floortile increments product footprint space drops to 25%, and service clearances would increase to 35%. These figures assume an average overall heat density of 100 watts/ft²-gross or less. Sites designed for a higher heat density will require more space for site infrastructure support equipment which will reduce the space available for product footprints.

Electrically-active IT hardware product footprints	30%*
Service clearances around products	30%
Site infrastructure support equipment on raised floor	20%
Aisles, columns, and other electrically inactive areas	20%
Total gross space	100%

*Best case

Adapting Product Footprint Density Trends to the Total-Space Average

The product averages given on the Product Heat Density Trends chart are for the actual heat dissipated by the type of equipment divided by the footprint of the equipment (not including service clearance). Modifications are required to adapt product density trends from the equipment footprint to the average for the total space. The following example shows one approach for doing this.

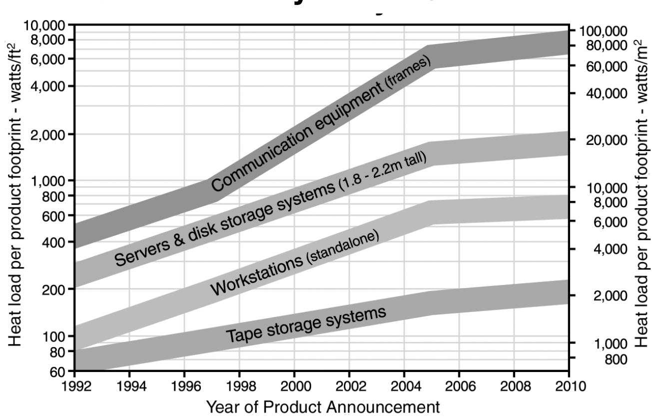
A. According to the heat density chart, DASD in 1999 was 600 watts/ft²-foot print (6,460 watts/m²-footprint).
B. Utilization of the electrically active hardware over the equipment or product footprint is 30% of the gross space.
C. For estimating purposes, the average gross watt density in the space for fully configured DASD-type products including service clearances, aisles, and other electrically inactive space is the product of A X B or 180 watts/ft²-gross (1,940 watts/m²-gross). This average will be increased if the products areutilized with less than the recommended service clearance and decreased if aisles or service clearances are greater than recommended.
D. This average (C) will require further downward modification if less than the full product configuration is utilized in an equipment frame. If not all processors available are installed, or if only a portion of the hard drives available are installed, the heat load is decreased accordingly.

Communications Frame

A communications frame, as listed on the chart, is a physical structure used by the communication industry to house electronic equipment modules and provide mechanical, structural, and shipping support. Traditionally, this equipment has been located in telco central offices. With the Internet buildout, some of this central office equipment is beginning to appear in data centers. Typical product footprints in the communications industry are 1 foot x 2 feet (.3 m x .6 m) or 2 feet x 2 feet (.6 m x .6 m). Height may vary between 63 inches to 88 inches (1.6 to 2.25 m).

Heat Density Trends and Projections for IT Products

Product Heat Density Trends Chart



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The trends on this chart show annual rates of increasing product footprint heat density ranging from 7% to 28%. Caution! The overall computer room's heat density will be reduced by the white space for aisles and site infrastructure equipment. See White Paper section on "Adapting Product Footprint Density Trends to the Total-Space Average."

The data shown on the Product Heat Density Trends chart is meant to provide a general overview of the actual power consumed and the actual heat dissipated by data processing and telecommunications equipment. These trends reflect data collected from hardware manufacturers for many products. The data emulates the most probable level of power consumption (as if the user took clamp-on power measurements of the installed product) assuming a full product configuration in the year the product was first shipped. If users purchase less than a full configuration, they will need to downward adjust the data from the chart.

Product nameplate values will imply higher levels of power consumption and heat dissipation than will actually occur in the first year of product shipment. This is because many manufacturers install larger power supplies in their equipment than are initially required to achieve power-supply standardization across multiple product lines, or to anticipate future product enhancements or feature upgrades.

Not all products will fall within the trend bands on the chart at every point in time. However, it is the opinion of the contributors to this paper that most equipment will fall within the parameters given and therefore this document provides valuable planning guidance for the design and operation of future data processing and telecommunications spaces.

The rate of increase for heat density ranges from a low of 7% annually for tape storage to a high of 28% annually for communications equipment. All product family trends show an abrupt downward shift to 5% in the annual rate of rise starting in 2006 and continuing through 2010. This is when the Semiconductor Industry Association's *Roadmap for Semiconductors* is predicting a leveling off in semiconductor power consumption. Note that the logarithmic vertical scale used on the chart tends to blur the absolute magnitude of these annual increases.

The rate of increase for communications equipment was 13% annually from 1992 through 1998, at which time it increased to 28% annually, which is projected to continue through 2005 when all product families drop to 5% annually. The increase in heat dissipation from 2000 to 2001 alone is 500 watts/ft^2-footprint (5,500 watts/m^2-footprint).

The trend shown for servers and DASD is for densely packed equipment in vertical "tall racks" with a height between 70 inches and 87 inches (1.8 to 2.2 m). The rate of increase is 15% annually through 2005, and the increase from 2000 to 2001 is 100 watts/ft^2-footprint (1,100 watts/m^2-footprint).

The trend shown for workstations is for standalone versions that would be under desktops in an office environment. The rate of annual increase is 17% through 2005 and the increase from 2000 to 2001 is 75 watts/ft^2-footprint (800 watts/m^2-footprint).

The trend shown for tape storage has a rate of annual increase of 7% through 2005, and the increase going from 2000 to 2001 is 15 watts/ft^2-footprint (160 watts/m^2-footprint).

Authorship and Disclaimer

The text of this white paper was prepared by the technical staff of The Uptime Institute using the best available assumptions and technology projections from information and data provided by a collaborative effort of Amdahl, Cisco Systems Company, Compaq, Cray Inc., Dell Computer Corporation, EMC, Hewlett-Packard, IBM, Intel, Lucent Technologies, Inc., Motorola, Nokia, Nortel Networks, Sun Microsystems, Inc., and Unisys. This resulting white paper has been peer reviewed by knowledgeable members of the Institute's Site Uptime Network® which comprises forty-eight leading users of computer and communication equipment. The findings, conclusions, and recommendations are presented herewith, published under the auspices of The Uptime Institute.

The actual trends and pace of advancements for the underlying technology examined are unforeseeable, therefore, the information presented should be construed only as a reasonable estimate of the conditions and consequences anticipated at this time. Some or all assumptions may later prove to be inaccurate. Accordingly, this publication is distributed and is accepted with the condition that neither The Uptime Institute nor the contributors will accept any liability for any damages or for other consequences resulting from the use of the information contained in or implied by this publication. In addition, The Uptime Institute and each of the contributors disclaim any warranties, expressed or implied by the information contained herein, including without limitation any warranties of merchantability and fitness for a particular purpose.

This white paper is posted and maintained on The Uptime Institute's Website at www.uptimeinstitute.org/heatdensity.html. Concerned readers can also reference two related articles published by ComputerSite Engineering and titled: *Changing Cooling Requirements Leave Many Data Centers at Risk* and *Uptime Best Practice: Alternating Cold and Hot Aisles Provides More Reliable Cooling for Server Farms.* Both of these papers can be found at www.upsite.com/whitepapers.html. Future articles, technical papers, and information on heat density issues will be either posted or referenced on the Institute's Website.

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