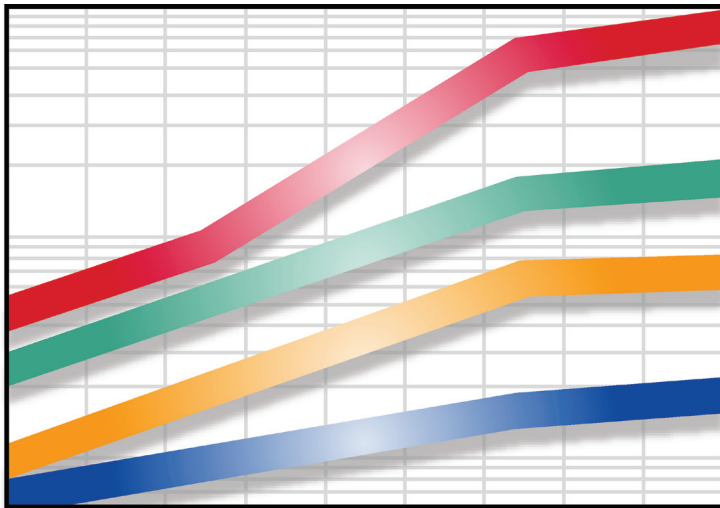


# 2005-2010 Heat Density Trends in Data Processing, Computer Systems, and Telecommunications Equipment



**2005-2010 Heat Density Trends  
in Data Processing,  
Computer Systems, and  
Telecommunications Equipment:  
Perspectives, Implications, and the Current Reality  
in Many Data Centers**

---

**By Kenneth G. Brill, Executive Director,  
The Uptime Institute, Inc. ®**



# **2005-2010 Heat Density Trends in Data Processing, Computer Systems, and Telecommunications Equipment: Perspectives, Implications, and the Current Reality in Many Data Centers**

---

Over the past 40 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 for 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. Also the cost of the computing hardware required to accomplish a task has been dropping over the same 40-year period, while the power consumed by the hardware in the same product footprint has climbed continuously. The result is the watts of embedded power consumption per \$1,000 of IT hardware spending has risen steadily. This means that for a constant level of annual IT spending, power consumption in the same product footprint will go up and density will rise.

## **This white paper:**

- Provides useful history and information on past and future IT product densities.
- Quantifies the actual densities typical of current enterprise data centers.
- Introduces the concept of IT Yield as a simple management tool which cuts through confusion to focus on cost and performance optimization.
- Discusses the dramatic differences between forecasted density and actual density.
- Presents an illustration of how to reconcile forecast and actual densities.
- Defines product footprint, gross computer room, and other terms and metrics.
- Provides several simple and inexpensive solutions to hot-spot problems.

# Introduction and History

This updated white paper, using 2005 predictions for the 2005-2010 Product Heat Density Trends Chart, is the result of many years of collaboration between The Uptime Institute, Inc.<sup>®</sup> (the *Institute*) and the Thermal Management Consortium, which has subsequently reformed as the TC9.9 Technical Committee of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE).

The Thermal Management Consortium for Data Centers and Telecommunications Rooms was originally composed of Amdahl, Cisco Systems, Compaq, Cray, Dell, EMC, Hewlett-Packard, IBM, Intel, Lucent, Motorola, Nokia, Nortel, Sun Microsystems, and Unisys. Started in 1997 with a few manufacturers and subsequently expanded to include the entire industry, the Thermal Management Consortium's purpose was to build a consensus among hardware manufacturers on the environmental requirements for electronic hardware deployed in larger computer rooms. The objective of the Consortium was to provide thermal leadership to the Information Technology (IT) industry so customers could confidently and economically install high heat density computer and communication equipment to achieve high reliability and availability.

In 2001, the original Thermal Management Consortium reformed as the TC-9.9 Technical Committee under the auspices of ASHRAE. The TC 9.9 committee has produced a number of very important documents<sup>1</sup> including:

- *Datacom Equipment Power Trends and Cooling Applications 2005* (124 pages, \$48)
- *Thermal Guidelines for Data Processing Centers* (55 pages, \$43)

Some of the data for Figure 2 of this white paper is taken from *Datacom Equipment Power Trends and Cooling Applications 2005*. The technical staff of the *Institute* wrote the text of this white paper explaining the significance of increasing heat density to consulting engineers, customers and end users, and other interested parties. Some of the information on current computer room conditions comes from the *Institute's Site Uptime Network*<sup>®</sup> that comprises 68 leading users of computer and communication equipment. The findings, conclusions, and recommendations presented herewith are the responsibility of The Uptime Institute, Inc.

## Current Industry 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 the case. 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

---

<sup>1</sup> Go to [www.ashrae.com](http://www.ashrae.com).

be forced to either increase their price per “box” to offset the reduced volume or face going out of business. In fact, the opposite is true. Box prices are falling and quantities are rising. 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. The heat dissipated in a 2 ft by 2½ ft rack can currently be 10 kilowatts (kW) or higher, and designs for future equipment assume 30-50 kW in the same space. Ten kW is the heat equivalent of one hundred 100-watt light bulbs packed inside a space the size of a typical home refrigerator (50 kW is the heat equivalent of five hundred 100 watt bulbs). Using existing methods to provide sufficient cooling to supply one such rack is not particularly difficult, but supplying reliable cooling to hundreds of such racks in a densely packed area requires a totally different cooling approach. As density increases, cooling systems which historically have been “loosely coupled” in the sense that malfunctions and failures could occur without affecting IT performance will become “tightly coupled” and require uninterrupted cooling<sup>2</sup>.

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

Based on a 5-year *Institute* study of almost 1,000,000 square feet (ft<sup>2</sup>) or 93,000 square meters (m<sup>2</sup>) of computer rooms, actual power consumption in the electrically active area has risen by 39% from the end of 1999 to the end of 2005. While substantial, this increase is significantly less than what would be predicted by the Product Heat Density Trends Charts in this paper. The gap between density forecasts and current reality illustrates a major industry planning problem that will be discussed later in this paper.

## **A Shared Self-Interest and Mutual Interdependence Between Manufacturers and Users**

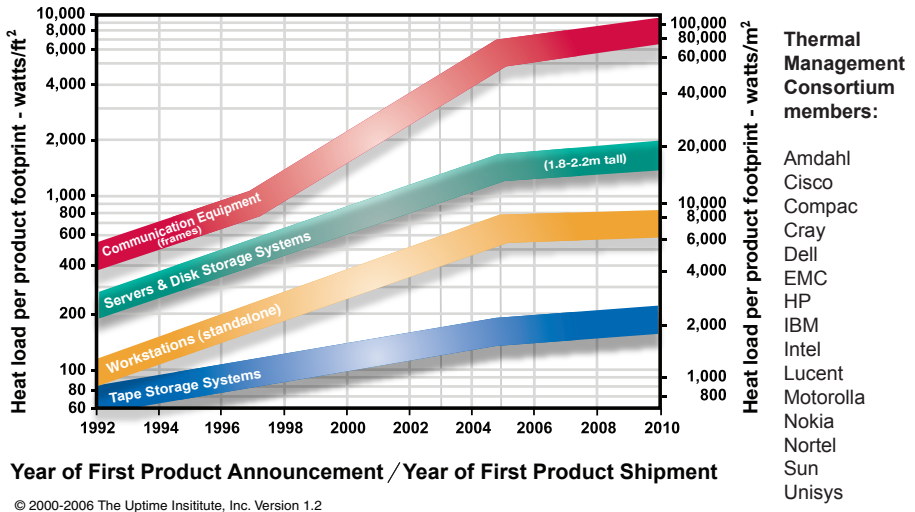
Both manufacturers and users of communication and computing products have a shared interest in being confident that technology spaces, data centers, and other computing facilities can provide sufficient power and the necessary cooling to utilize future generations of equipment. This increase in power 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 will 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 24 months. If Moore’s

---

<sup>2</sup>See the *Institute’s Continuous Availability Requires Continuous Cooling* white paper for a technical discussion of these issues.

**Figure 1: 2000-2010 Product Heat Density Trends Chart**



The trends on this chart show annual rates of increasing product footprint heat density ranging from 7% to 28%. Data center managers should be cautious, since the average density spread across the entire room will be reduced by the space required for aisles and site infrastructure equipment.

Law continues to hold (and it is anticipated it will continue at least through 2010 based on scientific discoveries currently being converted to production technologies), there will also be a dramatic and continuing increase in product power densities.

**The 2000-2010 Density Predictions (Made in 2000) Were Dramatically Higher Than Industry Expectations**

To better understand and address the many issues related to density, 15 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) joined in a collaborative effort to project their best estimates of their own products’ future densities based on anticipated technology trends. Members of the collaboration developed the *2000-2010 Product Heat Density Trends Chart* of past actual and projected future heat-density trends. This chart is shown in Figure 1. A definition of terms is provided in a later section in this paper on page 14.

The data shown on the *2000-2010 Product Heat Density Trends Chart* (and the subsequent 2005 update for 2005-2010 which is Figure 2) are meant to provide a general overview of the actual power consumed and the actual heat dissipated by data processing and telecommunications equipment. It is important to note the Y-axis (vertical) is on a logarithmic scale which visually understates the absolute annual increase in density. 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 announced or shipped. If users deploy less than a full configuration, they will need to downwardly adjust the data from the chart.

Product nameplate values will imply higher levels of power consumption and heat dissipation than will actually occur. 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. Actual power consumption will be significantly less than the nameplate. Manufacturers are beginning to offer more realistic power consumption figures in the site preparation guides. If this information is not there, users should demand it.

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 2000-2010 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. This is projected to continue through 2005 when all product families drop to 5% annually. This drop is also contained in the 2005 projections. The increase in heat dissipation from 2000 to 2001 alone is 500 watts/ft<sup>2</sup>-product (5,500 watts/m<sup>2</sup>-product).

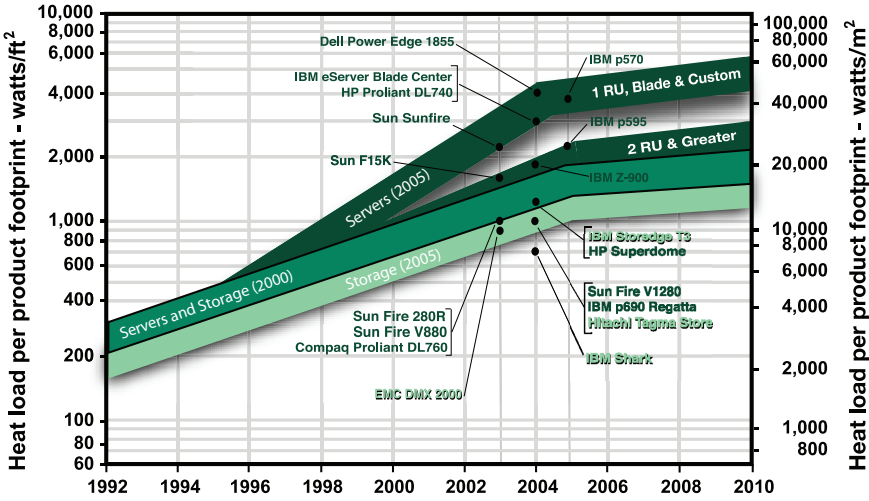
The trend shown for servers and DASD storage is for densely packed equipment in vertical "tall racks" with a height between 70 inches and 87 inches (1.8 to 2.2 m). The rate of increase is 15% annually through 2005, and the increase from 2000 to 2001 is 100 watts/ft<sup>2</sup>-product (1,100 watts/m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

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<sup>2</sup>-product (800 watts/m<sup>2</sup>-product).

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<sup>2</sup>-product (160 watts/m<sup>2</sup>-product).

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

**Figure 2: 2005-2010 Product Heat Density Trends Chart**



**Year of First Product Announcement / Year of First Product Shipment**

- 2000 Projection for Servers and Storage
- 2005 Projection for Storage
- 2005 Projections for Servers - 2 RU & Greater
- 2005 Projections for Servers - 1 RU, Blade & Custom

2006 The Uptime Institute, Inc. Version 2.0 2005-2010 trend prediction data source: ASHRAE, Datacom Equipment Power Trends and Cooling Applications, 2005. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org.

All of the earlier information and qualifications about Figure 1 are also applicable to Figure 2.

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/ft² (2,690 watts/m²), while projections for the year 2002 show these products increasing to 1,000 watts/ft² (10,760 watts/m²) within the product footprint. Just this increase alone from year 2000 to 2001 is 100 watts/ft² (1,100 watts/m²) within the product footprint, and in each subsequent year the annual change grows.

**High End Products Announced 2000-2005 Significantly Exceeded Predictions**

The 2000-2010 predictions were met with widespread industry disbelief. However, by 2002, it had become clear that the densities of new server products were running well above the predicted trend band while DASD storage products were running slightly below predictions. It became clear that original single band for servers and storage was really two different product bands. It further became clear about 2003 that servers had diverged into two different server product families. Figure 2 shows only the updated predictions for just servers and DASD because they constitute the largest majority of load in most enterprise data centers<sup>3</sup>. Actual density of representative products announced in 2003, 2004, and 2005 are plotted and the datapoints confirm the validity of the density bands shown.

<sup>3</sup> For 2005-2010 density predictions of communications equipment, workstations, and tape, refer to ASHRAE's *Datacom Equipment Power Trends and Cooling Applications 2005*.

# Relating Product Footprint to Gross Computer Room or Technology Space

The bands for expected product density shown in Figures 1 and 2 are for the actual load by the type of equipment divided by the actual product footprint of the equipment (not including service clearance). Racks and cabinets are assumed to be fully populated with equipment.

Within a computer room or technology space are four different functions that require specific planning relative to density. For the purpose of planning calculations, any white space currently reserved for future equipment should be allocated to one of the categories based on the intended use of the space. The categories, which together comprise the space, are:

- 1. Electrically active IT hardware product footprints.** These consist of computers and telecommunications equipment including communication frames, servers, rack-mounted equipment, DASD, and tapes. This area is what Figures 1 and 2 call the product footprint.
- 2. Service clearances for access to IT hardware.**
- 3. Site infrastructure support equipment.** 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 cooling units (chilled-water air handlers or computer room air-conditioning units) and critical power equipment which includes in-room UPS systems and batteries, power distribution units (PDU), static transfer switches, transformers, and load distribution panels. (Sites with a lower power and cooling design density will devote significantly less space to site support equipment than sites with higher capacity).
- 4. Electrically inactive areas.** These include the main computer room aisles, the portion of cross aisles not used for product service clearance, safety egress aisles, and building structural components within the computer room.
- 5. Gross computer room area is the sum of 1 through 4.**

The amount of space consumed by each of these four categories determines the physical personality of a data-processing or telecom environment. Individual sites may vary from the following values (an average heat density of 100 W/ft<sup>2</sup>-gross (1,075 W/m<sup>2</sup>) or less is assumed) which are representative of average industry practice and could benefit from significant optimization improvement to increase the percentage of product footprint achieved. 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.

1. Electrically active IT hardware product footprints best case (worst case is 15% or even lower reflecting a failure of critical layer management to measure and focus on IT Yield)	18%
2. Service clearances around products	30%
3. Site infrastructure support equipment located on raised floor	17%
4. Aisles, columns, and other electrically inactive areas	35%
<hr/>	
5. Total gross computer room space	100%

## IT Yield Can Be Used to Convert Product Footprint to Gross Computer Room and Vice Versa

The ratio of electrically active footprints (1) to the gross computer room (5) is the gross computer room IT Yield. IT Yield is an objective measure of how well the computer room is laid-out and managed. Using the definitions above, the best-case yield is 20% and most computer rooms run 15% or lower. Sites which claim an IT Yield above 20% are not utilizing manufacturer recommend service clearances or code-required aisles and egress spacing or have an ultra-low density.

Converting product density to gross computer room density simply requires multiplying the appropriate product footprint density times the gross computer room IT Yield. For example, a product density of 1,500 W/ft<sup>2</sup> (1,600 W/m<sup>2</sup>) times an IT Yield of 0.18 results in a gross computer room density of 270W/ft<sup>2</sup> (2,900 W/m<sup>2</sup>).

### Actual Gross Computer Room Density

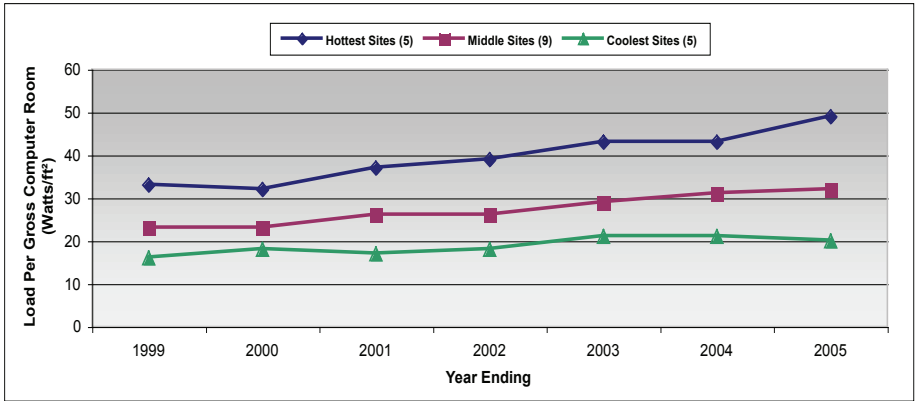
Based on a 6-year *Institute* longitudinal study (starting at the end of 1999) of 19 computer rooms totaling 960,000 ft<sup>2</sup> (89,000 m<sup>2</sup>) and 31,000 kW of UPS power consumption, the average gross computer room density in these enterprise data centers at the end of 2005 was 32 W/ft<sup>2</sup> (344 W/m<sup>2</sup>). Over the six years, density increased 39% or an average of 6.5% per year.

The five sites with the highest density in 1999 also tended to have the highest density in 2005. Generally, these were major financial institutions. Their 48% density increase was accomplished by an 86% increase in UPS power consumption and a 26% increase in active floor space. The five sites with the lowest density remained the lowest and their increase in density was below the average. The middle nine sites increased UPS consumption by 44% with a slight increase in floor space which resulted in density increase of 39%. Table 1 and Figure 3 present the summary data from this study. The *Institute* regards the number of computer rooms included and their 50,000 ft<sup>2</sup> (4,700 m<sup>2</sup>) average size to be broadly representative of the enterprise data centers of major institutions. The data is the most accurate and reliable available because the companies participating in the study share common definitions and consistent benchmarking practices.

**Table 1: Changes in UPS Power, Gross Space, and Density Over a Period of 6 Years (1999-2005)**

	UPS Power Consumed	Gross Space	Density
Hottest Sites (5)	+86%	+26%	+48%
Middle Sites (9)	+43%	+2%	+39%
Cooler Sites (5)	+24%	-	+23%
Study Average (19)	+44%	+4%	+39%

**Figure 3: Actual Computer Room Density for 19 Computer Rooms Totaling 1,000,000 Ft<sup>2</sup> (93,000 M<sup>2</sup>)**



The changes reported in this study began after the completion of Y2K upgrades in 1999. The following several years were marked by a slow rate of hardware turnover because much IT equipment had just been replaced. This slow rate of change was further impacted by the economic slowdown that occurred starting in late 2001. The hottest sites included major financials which saw a major business upturn starting in 2003.

### Why Are Predicted and Actual Densities Different By More Than an Order of Magnitude?

Using an IT Yield of 15% (for worst case) and 20% (for best case) to convert the 32 W/ft<sup>2</sup> (344 W/m<sup>2</sup>) average actual 2005 gross computer room density in enterprise data centers into the equivalent product density results in a range of product densities from 160 W/ft<sup>2</sup> to 213 W/ft<sup>2</sup> (1,725 W/m<sup>2</sup> to 2,300 W/m<sup>2</sup>). For comparison, the predicted 2005 product density from Figure 2 is 3,500 W/ft<sup>2</sup> (37,700 W/m<sup>2</sup>) for 1 RU and custom servers, 1,800 W/ft<sup>2</sup> (19,400 W/m<sup>2</sup>) for 2 RU and greater servers, and 1,000 W/ft<sup>2</sup> (10,800 W/m<sup>2</sup>) for DASD storage. These differences are profound!

Possible explanations for the major divergence between density actuals and density predictions (servers are more than an order of magnitude and 525% for DASD storage) include:

- IT performance requirements vary by industry. Some industries, like financials, require more capability than others. A one-size-fits-all IT assumption may lead to wrong results.
- Computer rooms are a stew of technologies. Some employ the very latest, some employ antiquated hardware. Not all IT applications require the performance features of the high-end equipment shown in Figure 2.
- Figure 2 assumes customer implementation of all features and options. Depending upon hardware type, this may not happen in the first year of deployment.
- “Turf” issues prevent full utilization of available IT space. Individual application groups often control specific floors space within the computer room and guard and prevent others from using this space. Based on personal, but unscientific observation, this factor reduces IT Yield by a factor of 20 in many computer rooms.

- IT Yield is further reduced by a common practice of partially filling racks to reserve space for future equipment. Again, based on unscientific personal observation of many computer rooms, racks typically appear to be less than 50% full. (Beginning in 2006, the *Institute* is modifying its 19-site study to capture more scientific measurements of rack fill.)

It is possible to close the gap between predictions and reality by using a number of unscientific, but realistic assumptions in the following illustrative example. We can assume:

- The technology stew in a data center lags the predictions in Figure 2 by 2 years.
- That the hardware features and functions actually implemented are 75% of what is possible.
- Turf issues cut best case IT Yield by 20%.
- The rack fill in server area is 50%.
- Forty percent of the computer room is filled with high-density hardware and the balance of room is filled with equipment at a density of  $\frac{1}{4}$  of the high density area.

The calculation for modifying predicted density would be:

- Assume a 2003 predicted density of 1,500 W/ft<sup>2</sup> product footprint (16,100 W/m<sup>2</sup> product footprint).
- Reduce this by a factor of 25% to reflect options not implemented.
- The resulting predicted product footprint density would be 1,125 W/ft<sup>2</sup> product footprint (12,100 W/m<sup>2</sup> product footprint).

The calculation for modifying actual gross computer room density would be:

- Start with the 49 W/ft<sup>2</sup> (527 W/m<sup>2</sup>) of the five hottest sites.
- Assume 40% of the computer room is at high density, 60% of the computer room is at low density.
- Further assume the density of low-density portion of the room is  $\frac{1}{4}$  that of the high-density area.
- The resulting modified actual density in the high performance area is 75 W/ft<sup>2</sup> (807 W/m<sup>2</sup>).

The calculation for modifying the IT Yield would be:

- Assume a best case IT Yield of 20%.
- Reduce this by 15% for the poor layout found in most computer rooms.
- Reduce this again by a factor of 25% for Turf inefficiencies.
- Reduce this again by a rack fill factor of 50% in 85% of the high performance area only.
- The resulting modified IT Yield is 7.3%.

Converting the modified actual computer room gross density of 75 W/ft<sup>2</sup> (807 W/m<sup>2</sup>) by the modified IT Yield of 7.3% results in a modified actual product footprint density of 1,030 W/ft<sup>2</sup> (11,100 W/m<sup>2</sup>) which compares favorably with the modified predicted product footprint density of 1,125 w/ft<sup>2</sup> (12,100 W/m<sup>2</sup>).

What these very unscientific calculations show is that there is still a lot of art to predicting or reconciling density.

For senior executives, these calculations should be a wake-up call to focus on improving IT Yield. All too often, computer rooms are arbitrarily laid out with little consideration for long-term cost and performance consequences. Computer room layout is now a scientific engineering discipline. Failure to address this issue is likely to have profound consequences as densities rise.

## Converting to KW Per Rack or Cabinet Less Error Potential Than Current Density Metrics

Clarity is essential to successful communication within data center teams and especially with senior management. One area that traditionally causes intense confusion is density. Consider this question:

What do the following densities have in common?

- 400 W/ft<sup>2</sup> (4,300 W/m<sup>2</sup>)
- 142 W/ft<sup>2</sup> (1,500 W/m<sup>2</sup>)
- 105 W/ft<sup>2</sup> (1,130 W/m<sup>2</sup>)
- 67 W/ft<sup>2</sup> (720 W/m<sup>2</sup>)

This can be a tricky question as each number represents the exact same 2kW rack or cabinet load, but the resulting density is calculated by using different definitions of space.

In sequence:

- 400 W/ft<sup>2</sup> (4,300 W/m<sup>2</sup>) is the 2 kW load divided by the footprint of the rack or cabinet of 5 ft<sup>2</sup> (0.46 m<sup>2</sup>).
- 142 W/ft<sup>2</sup> (1,500 W/m<sup>2</sup>) is the 2 kW load divided by the footprint of the rack or cabinet plus its shared front and back service clearance, resulting in 14 ft<sup>2</sup> (1.3m<sup>2</sup>) per rack or cabinet.
- 105 W/ft<sup>2</sup>(1,130 W/m<sup>2</sup>) is the 2 kW load divided by the footprint of the rack or cabinet plus its shared front and back service clearance, plus additional shared aisles at the end of the row resulting in 19 ft<sup>2</sup> (1.8m<sup>2</sup>) per rack or cabinet.
- 67 W/ft<sup>2</sup> (720 W/m<sup>2</sup>) is the 2 kW load divided by the footprint of the rack or cabinet plus its shared front and back service clearance, plus additional shared aisles at the end of the row, plus space for main aisles, columns, PDUs, and cooling units resulting in gross space of 30 ft<sup>2</sup> (2.8m<sup>2</sup>) per rack or cabinet.

Unfortunately, there are many additional space definitions that can add further confusion, which sometimes produces tragic results. A further problem with defining density as watts per square foot or square meter is that it is too abstract. How does a non-technical manager “see” it or measure it?

The *Institute’s* recommended solution to this dilemma is to use a “kW/cabinet” metric. With this approach, the power consumed within the rack or cabinet is directly determined. This analytical method can provide an easily understood approach to convey trends and potential increases in the site’s power demand. It also increases the clarity and intuitive nature of managing densities in computer room environments.

## Removing Heat From the Computer Room Is Not the Hardware Manufacturer’s Responsibility

The hardware manufacturer’s responsibility is limited to exhausting the heat from within 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 airflow required to remove this heat is 2,100 cubic feet per minute (59 m<sup>3</sup>/min) assuming an under-floor air temperature of 60°F (15°C) and a 15°F (8°C) temperature rise in the return air.

The installation planning guides of several computer manufacturers optimistically assume 700 cubic feet per minute (20 m<sup>3</sup>/min) from each perforated floor tile on a raised floor. However, field measurements in many sites indicate the actual air flow to be 200 cubic feet per minute (6 m<sup>3</sup>/min) or less from commonly used 25% opening perforated floor tiles. Under typical computer room conditions, each 200 cubic feet per minute (6m<sup>3</sup>/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 next-generation products on their drawing boards for release in the not-too-distant future that will consume 30 to 50 kilowatts of power. Assuming the width of these new products is 4 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 (6m<sup>3</sup>/min), which is typical of most data centers, the resulting aisle required between rows would be 16 perforated floor tiles or a width of 32 feet just to allow sufficient cooling. This is an unsatisfactory solution and drives the need for senior executives to pay increasing attention to critical physical layer issues. Failure to address these issues will have tremendous cost and availability consequences.

## Hot Spots Are a Growing Problem

Ten percent of all racks are already too hot and fail to meet industry standards for maximum IT reliability and performance. This percentage is likely to grow as many sites are just beginning to experience heat dissipation problems because previously 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, a 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<sup>2</sup>-gross (430 watts/m<sup>2</sup>-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 airflow restrictions, unnecessary openings, the quantity, placement, and percentage opening of perforated floor tiles, equipment rack selection, and other factors. Computer room layout and management is now a professional discipline with a considerable amount of engineering required.

Unfortunately, very few computer rooms or technology spaces currently have sufficient useable cooling and/or delivered airflow capacity to handle projected future loads and heat density. Sites 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 that their cooling systems can handle.

*Institute* research into computer room cooling indicates 1/3 all perforated tiles are incorrectly located and 60% of all available cooling capacity is being wasted by bypass airflow. Increasing under-floor static pressure to get air where it needs to go requires permanently blocking all unnecessary air escape routes. This includes sealing cable cutouts behind and underneath products or racks (this unmanaged airflow is what is really cooling most computer rooms) as well as the penetrations in the floor or walls or ceiling and any other openings in the raised floor. Perforated floor tiles with 25% openings can be replaced with 40% and 60% grates to permit a much higher airflow. 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. Research and emerging information on cooling problems and solutions are referenced on the *Institute's* website<sup>4</sup>.

In the longer term, more carefully engineered solutions will have to be found. Another issue that must be addressed is matching the thermal ride-through 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.

## Conclusion

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 high-performance IT products are installed. As the projected trends occur over the next 3 to 6 years, air from under the floor by itself will not be sufficient to remove the heat being generated. Additionally, 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.

The ultimate question many customers and users face in building a new facility or performing 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. This illustrative example for closing the gap between predicted future and current actuals may be very useful in solving this dilemma. The results from ongoing *Institute* research may help to answer these questions in the future.

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

---

<sup>4</sup> See the *Institute's Reducing Bypass Airflow Is Essential to Eliminating Computer Room Hot Spots, Alternating Cold and Hot Aisles Provides More Reliable Cooling for Server Farms*, and *Continuous Availability Requires Continuous Cooling* for additional information on current computer room cooling performance in many data centers and the things managers can do inexpensively to make dramatic improvements.

## Definitions

**Gross Computer Room:** Users look at watts per square foot or square meter in a variety of different ways. With an entire room full of communication and computer equipment, users 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 Uninterruptible Power System (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.

**Gross Computer Room Density:** Using the gross computer room as a divisor, the resulting gross watts per square foot (watts/ft<sup>2</sup>-gross) or gross watts per square meter (watts/m<sup>2</sup>-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting. As a rough measure, product density can be converted to gross density by using a best case IT Yield conversion multiplier of 0.2 for English units and 0.018 for metric (for precise conversions, determine the footprint per rack or cabinet and divide it by the number of racks or cabinets in the fully configured gross computer room by that space). Heat gains through walls or ceiling or efficiency losses occurring within the space caused by loads other than the computer and communication hardware must be included to develop the total load within the computer room. These losses or additional loads can easily add 5% or more to the total UPS requirements and 10% to 30% to the total computer room cooling load.

**Heat:** IT equipment consumes electrical energy (power) and converts it to heat. The relationship is exact. One kilowatt per hour equals 3,412 British Thermal Units (BTU) per hour of heat.

**IT Yield:** IT Yield is the ratio of the computer room which can be used for computing divided by the total size of the computer room. It is an extremely useful management tool for objectively measuring the effectiveness of computer room layout. If unmanaged, this ratio will be as low as 15%. The best case is 20% if code required egress, and clearances, and manufacturer service clearances are maintained. Cases higher than 20% indicate code violation or use of different calculation definitions.

**Kilowatts:** 1,000 watts.

**Power:** 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 kilowatt is the equivalent to 3,412 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.

**Product Footprint Density:** 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 “product footprint.” The trend charts presented are calculated in terms of watts/ft<sup>2</sup>-product (watts/m<sup>2</sup>-product). Some products can be vertically stacked within equipment racks, and trends have been provided for racks 70 inches to 87 inches high (1.8 to 2.2 meters) full of equipment.

**Volt-Amperes:** 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. With power factor corrected power supplies common in most computer rooms, kVA and kW are today virtually identical.

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

## About the Author

Mr. Brill is the Founder and Executive Director of The Uptime Institute, Inc.

## About The Uptime Institute

Since 1993, The Uptime Institute, Inc. (the *Institute*) has been a respected provider of educational and consulting services for Facilities and Information Technology organizations interested in maximizing data center uptime. The *Institute* has pioneered numerous industry innovations, such as the Tier Classifications for data center availability, which serve as industry standards today. At the center of the *Institute*'s offering, the 68 members of the Site Uptime<sup>®</sup> Network represent mostly Fortune 100 companies for whom infrastructure availability is a serious concern. They collectively and interactively learn from one another as well as from *Institute*-facilitated conferences, site tours, benchmarking, best practices, and abnormal incident collection and analysis. For the industry as a whole, the *Institute* publishes white papers, offers a Site Uptime Seminar Series and a Site Uptime Symposium & Exhibition Series on critical uptime-related topics. The *Institute* also conducts sponsored research and product certifications for the industry's manufacturers.

## **Disclaimer**

The actual product density trends discussed in this white paper and the pace of advancements for the underlying technology are unforeseeable. Therefore, the information presented in the product density trend charts contained herein should be construed only as a reasonable estimate of the conditions and consequences anticipated at the time of prediction (2000 and 2005). 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 Inc. (the *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 Inc. 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.

## **Reproduction**

Permission is hereby granted to reproduce the product heat density charts (2000-2010 and/or 2005-2010) contained herein, and to quote short passages from the white paper text content, provided the source of the Chart or quotation used is clearly identified as follows: Reprinted with permission of The Uptime Institute Inc. from a white paper titled *2005-2010 Heat Density Trends in Data Processing, Computer Systems, and Telecommunications Equipment*. For customized printed booklet ordering information, please contact the *Institute* at (505) 986-3900 or by email at [tui@uptimeinstitute.org](mailto:tui@uptimeinstitute.org).



**Notes:** \_\_\_\_\_