Data Centers and Energy Use: Let's Look at the Data

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ABSTRACT

Data centers are prevalent in a wide range of industries, universities, and government facilities. Energy demand in these facilities is thought to be growing as computing technology changes and IT professionals seek to maximize computing per square foot of data center. In addition, a multitude of methods have been used to estimate and quantify energy intensity. As a result, there is considerable confusion over data centers' electrical use today, and the needs for the future. Research aimed at understanding the present electrical intensity, end use, and key facility systems' operation was undertaken with the ultimate goal of developing energy efficiency improvements in these buildings.

Metrics used in this study allow comparison of the current power density of computing equipment, and provide an indicator of the efficiency of key facility systems. In addition, a metric is included to evaluate how efficiently the Heating, Ventilating and Air Conditioning (HVAC) system operates to maintain satisfactory conditions for computing equipment. A review of the summary benchmark results can identify more efficient systems and practices, and can discover operational problems.

The information presented can be used by data center owners, operators, and designers to understand current performance, to set design and operational criteria for new projects, to identify current best practices in design and operation, and to improve reliability. This study also identifies gaps where additional research is needed to achieve a new level of improved energy efficiency.

Introduction

Data Centers are prevalent and an integral part of today's world. Data centers support the communications industries, and play a major role in the Internet economy. They also support research and learning, and are the "brains" within most corporations and government institutions. The California Energy Commission and the New York State Research and Development Authority realize the importance of these facilities and the opportunity to improve their energy efficiency. Although electrical power demand is high, designers and operators of data centers currently have little information concerning where to place their resources to improve their efficiency. In addition, there is little benchmark data available to highlight what can be achieved in the design of new systems.

The benchmarking reported here involved a strategy that obtained an energy end use breakdown in a number of data centers. A broad definition of a data center was adopted, since similar building issues are present regardless of the computing platform. Two key objectives led to this work: First, utilities, public interest organizations, and those that work with data centers, all have a critical need for more information concerning current data center electric power requirements, as well as future energy demand trends. Energy benchmarking sets the stage for improvements by documenting current energy use and intensity, and over time, can be trended to establish further guidance. The second objective was to identify the energy end-use in data centers. Then, efficiency opportunities could be targeted for each of the intensive areas.

Definitions

Acronym	**Definition**
HVAC	Heating, Ventilation, and Air Conditioning
UPS	Uninterruptible Power Supply
CRAC unit	Computer Room Air Conditioning unit
IT	Information Technology
VAV	Variable Air Volume
PDU	Power Distribution Unit
VFD	Variable Frequency Drive

Background

Energy demand of today's IT equipment and electrical power for systems removing the heat they produce are high compared to ordinary commercial buildings. Although data centers contain various types of computing equipment, building systems in data centers usually have similar characteristics and can account for more than 50% of the total energy. A segment of the data center market even uses excess infrastructure as a selling point, resulting in oversized electrical and HVAC systems. Unfortunately, these oversized systems usually operate inefficiently.

Planning for the future, whether at the utility level, facility level, or computing equipment level has been a challenge. Previously, little publicly available energy benchmark data existed for data centers. Since confidentiality of facility operating information is important to a majority of data center operators, reliable building energy benchmark information was not made available. Data center operators typically track whole building energy use and energy used by the computing equipment. What has been lacking is measured data for comparison of electric power density (Watts/sq ft), energy end use, and efficiency comparisons of key facility systems (HVAC, UPS, lighting, etc.).

HVAC systems typically include computer room air conditioning and ventilation, and may include a large central cooling plant. In addition, lighting and other minor loads are present. Reported here are the energy benchmark results, but since data centers typically are large heat sources and generate the need for high cooling loads with tightly controlled environmental conditions, much of the study focuses on the efficiency of the HVAC systems.

Buildings with data centers have large, constant electrical demand to operate the computing equipment. Current technology has evolved to a practice where computing equipment is typically air cooled through use of energy intensive HVAC systems consisting of large central plant heating and cooling, and use of computer room air-conditioning (CRAC) units or other large air handlers. Data centers often mandate strict environmental design considerations calling for tightly controlled temperature and humidity with the objective of protecting the computing equipment from overheating.

Benchmarking Activity

A measurement methodology and metrics most useful for comparing data centers and their facility systems was developed. The metrics allow comparison of widely varying data centers regardless of the design, and the types of computing equipment. These metrics illustrate measured electric intensity, which is useful to trend overall load growth and to predict future needs. They also provide insight into how efficiently the building systems were designed and are operating. Energy use and systems operational information was obtained primarily on chillers, UPS systems, and CRAC units. This data was obtained by connecting power sensors to the host electrical panels, or by reading from the equipment's digital meters, if in existence. Additional operational data, such as flow, and temperature measurements were obtained from existing facility management systems to the extent they were available and finally were supplemented by direct measurement if not readily available.

Tables 1 and 2 summarize the metrics and other information used in this study. Ten data centers in various industries, housing various types of computing equipment were included in this study.

The case studies and summary benchmarking data are available through the LBNL website: www.datacenters.lbl.gov

During the project, the on-site team noted potential efficiency opportunities through visual observation, analysis of the data, and discussion with facility personnel. These opportunities were described to the participating facility in a final report. The observations were qualitative in nature, and were based upon the site team's prior experience and limited observations. In some cases, recommendations for further investigation were made. These recommendations typically required additional evaluation by the owner but could result in short or long-term efficiency improvement.

Fourteen data centers in eleven facilities, (where three facilities had two data centers each) were included in this study. To develop a more robust data set, many more benchmarks will be needed. Once this information is available however, building operators will be able to gauge the relative performance of their facility systems and intensities of various computing equipment. In the future, a mechanism for self-evaluation is proposed for development that would allow a data center owner/operator to compare his data center's performance to a larger sampling of data centers. This information should improve the ability to predict future power requirements and size systems more efficiently.

Table 1. Data Center Metrics

Whole Building Electrical Power:	**kW**
Load Intensity:	
Data Center floor area	square feet (sq ft)
Total load density	W/ sq ft
Computing load density	W/ sq ft
HVAC load density	W/ sq ft
HVAC:	
Chiller plant	
Chiller Efficiency	kW/Ton
Chilled Water Plant Efficiency	kW/Ton
Chiller load	Tons
Data Center Load	Tons
HVAC air systems	
CRAC unit fan, and humidity control energy	
Central air handling fan power	Cubic Feet per Minute per
Air handler fan efficiency (where possible to obtain)	kW (CFM/kW)
External temperature and humidity	°F, %
Data Center Electrical power demand:	
UPS Loss	kW
Computer load (from UPS Power)	kW
HVAC - chilled water plant (if central plant exists)	kW
HVAC - central air handling, and/ or CRAC Unit energy	kW
Lighting	kW
Design Data:	
Design basis for Computer load	kW/sq ft
Design basis for Chilled Water, air side HVAC, and UPS Systems	Temperature Humidity Flowrate % Efficiency Total load etc.

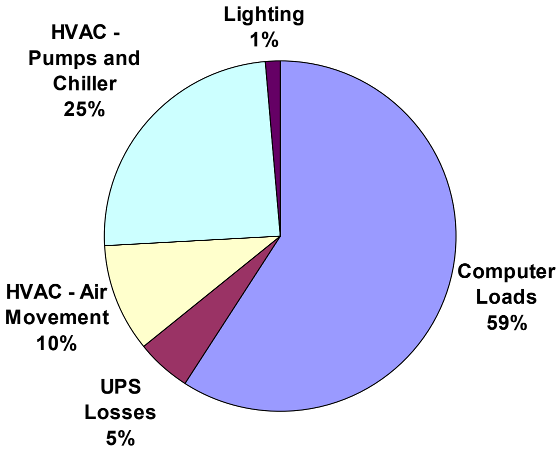
Table 2. Additional Data Center Information

Features and System Descriptions	Example Descriptions
HVAC	Central water-cooled chilled water plant, central air handling system with VAV control
	Distributed air-cooled CRAC units
	Air-cooled chillers with CRAC units supplying air under floor
	Central air handlers use outside air economizers
Variable-speed-drives	Centrifugal chiller with VFD
	Primary/ Secondary with VFD
	Central air handler with VFD
Electrical Distribution	N+1 UPS's
	N+1 at the PDU level
	Backup power generators
Control Strategies	Multiple cooling towers operated in parallel
	Minimum number of chillers operated
	CRAC units in empty areas turned off.
	Humidity control disabled on CRAC units
	VAV system with duct static pressure of 0.75"
	Chilled water setpoint fixed at 50 °F
	Condenser water setpoint fixed at 70 °F
	Chiller kW/Ton monitored continually
	Air side economizers used on
Temperature and Humidity Setpoints	Return air temperature maintained at 70 °F ± 5 °F
	Supply air temperature of central air handlers maintained at 50 °F
	Relative humidity maintained at 50 % ± 10%
Redundancy/Reliability	N+1 at UPS level
	N+1 at PDU level
Estimate of Occupancy	Data center is 40% full - physical capacity
	Operating at 30% of UPS capacity

Benchmark Results

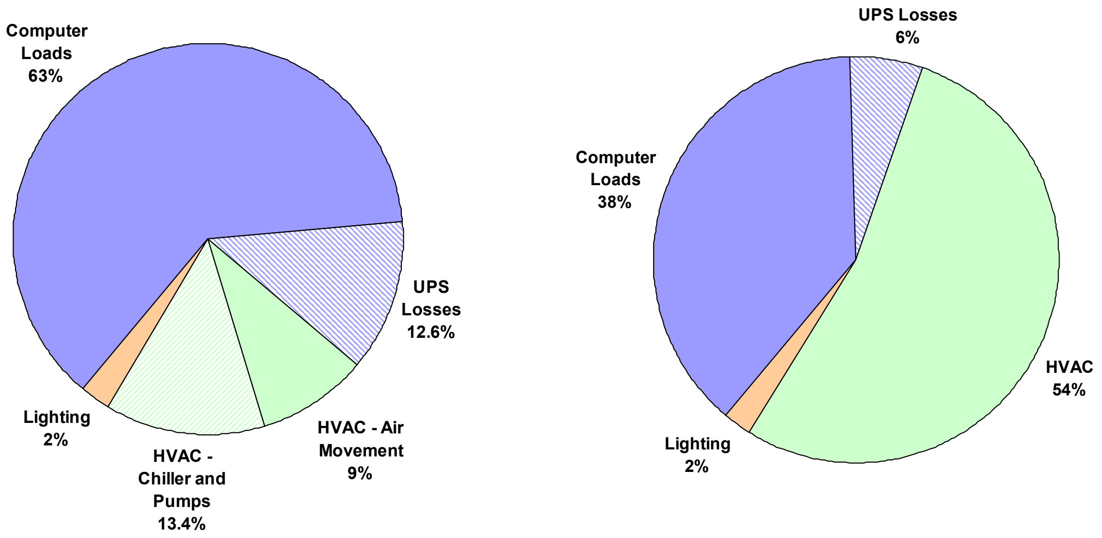
End use energy breakdowns were obtained for the data centers in this study. Figure 1 illustrates the energy end-use information that is provided by the benchmark measurements for a typical data center.

Figure 1. Representative Energy End Use Breakdown



Typically, the end use components consisted of the electrical loads for the computing equipment (fed from UPS systems), UPS system losses, HVAC – chilled water plant, HVAC – computer room air conditioners, and lighting. The relative percentages of each of these components varied according to the computing load intensity and the efficiency of the infrastructure systems necessary to support the computing. For example, the percentage of the total power to the computing equipment varied between 33% and 73 %. Similarly, the other end use components varied considerably as shown below in figure 2.

Figure 2. Benchmarking Examples



The data center shown to the left utilized a highly efficient system that was thoughtfully designed using best practices with better than standard HVAC components and controls. The center represented by the chart on the right utilized traditional distributed air-cooled computer room air conditioners.

In similar fashion, issues with UPS systems, lighting, and other systems are highlighted. In one facility, benchmarking discovered that the entire cooling for the computing equipment was being handled through the make up air (house) system, yet all of the computer room air conditioners were operating utilizing unnecessary fan energy and adding to the cooling load.

HVAC Systems

By focusing on the various HVAC systems and their components, the benchmark data reveals that energy use can vary by factors of 3 or more for systems that serve essentially the same purpose. The study utilizes an interesting metric to compare the relative efficiency of the overall HVAC system. By comparing the energy used for cooling the data center (i.e., the HVAC power in kW) to the UPS output, which should closely resemble the computer loads (in kW), an indicator of HVAC system performance is obtained. A lower value indicates that the system is likely to be more energy efficient. This metric is defined as follows:

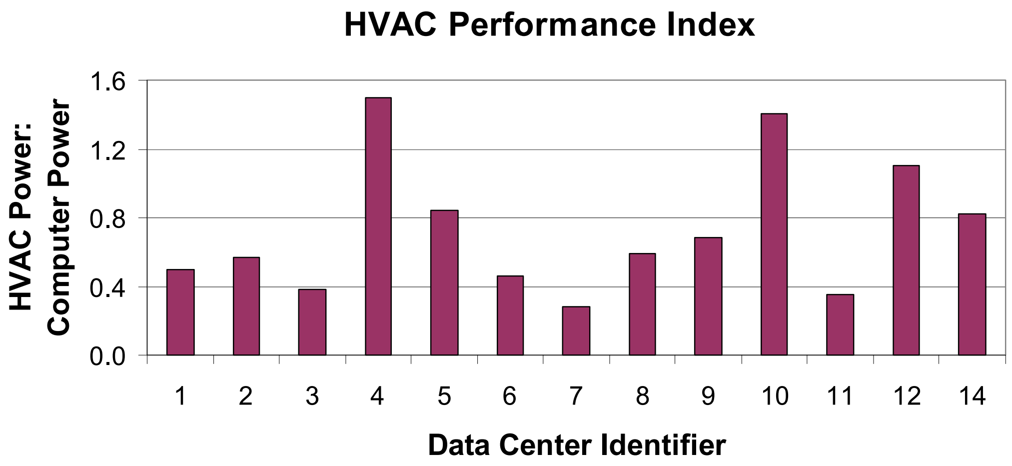
$$HVACperformanceindex(\%) = \frac{kW_{HVAC}}{kW_{UPSOutput}}$$

For this study, many different HVAC system designs were observed and measured. Figure 3 shows a comparison of data for 13 system configurations in the data centers measured in this study.[1] This information highlights that there is wide variation in system design and energy efficiency. This wide variation underscores the need to understand the

[1] Due to measurement complications, comparable data was not available for Facility 13.

features and principles of the more efficient systems. This will lead to best practices in design and construction of these systems.

Figure 3. Relative Data Center HVAC System Performance



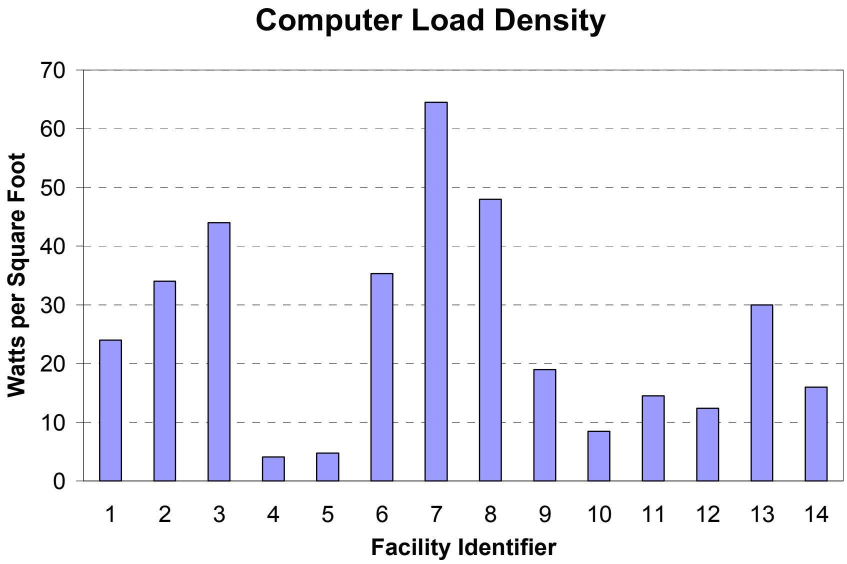
The HVAC system was further benchmarked by examining chilled water and computer room air conditioning systems. For the chilled water plant, the traditional efficiency metric, kW/Ton, was used. Chiller, pumping, and fan energy (for cooling towers) and the corresponding tons of chilled water produced were obtained. Wide variations in efficiency (dominated by the chiller efficiency) were observed.

Computer room air conditioning energy was similarly determined. Here, it is more difficult to obtain accurate airflow measurements – typically delivered by many air handlers into common underfloor areas or a network of ducting. As a result, an efficiency metric such as cfm/kW was not generally determined. We instead rely on the comparison of overall HVAC performance. This is an area where further research could pinpoint additional efficiency issues.

Computing Loads

The electrical load that the computing equipment requires must all be removed as heat by the HVAC system. The electric power density can vary significantly from data center to data center. Figure 4 shows the measured electric power density due to the computing equipment alone. In the calculation to determine this metric, the Uptime Institute's definition of "electrically active" floor area is used in the denominator. This effectively excludes areas such as walkways or storage spaces, which are more likely to have electric power density similar to commercial office buildings.

Figure 4. Benchmarked Computer Load Densities



Uncertainties in predicting the computing equipment loads make HVAC system sizing a challenge. Measured electric power density is typically quite less than what is specified during design. This occurs for several reasons: facility designers using name plate data (which typically leads to loads that are several times greater than actual), uncertainty for future equipment power density, unnecessary or compounding conservatisms, computing equipment (and load) is added gradually over time as business needs dictate. In addition, reliability strategies require that multiple, redundant equipment be available. This introduces significant inefficiency for standby or part load operation. While the computing load varies for each application, measured data from facilities with similar computing missions will help "right-size" the cooling equipment. Cooling systems are often more efficient when operated near their full design load. This study found computing loads at all facilities below 65 W/sq ft. Use of benchmark data can lead to better prediction of design loads and better build-out strategies. Designing systems and components in closer alignment with actual operating loads will also lead to more efficient operation.

Observed Efficiency Improvement Opportunities

Based upon the limited data collected and site observations, a number of efficiency recommendations are emerging as better practices for the facilities monitored. These are categorized in broad categories, and include design and control issues:

Table 3. Observed Energy Efficiency Opportunities

Chilled Water Plant Design Issues	• Chiller efficiency dominates the efficiency of the chilled water plant but this includes use of variable speed drives, raising chilled water temperature, and lowering condenser water temperature • Water cooled chillers are more efficient • Use of free cooling using cooling tower water when conditions permit. • Improve cooling tower efficiency by operating all cooling towers at reduced fan speed (variable) rather than operating fewer towers at full speed. • Reduce pumping energy through use of variable speed drives.
Air System Design Issues	• Improve airflow management utilizing hot and cold aisles, closing unnecessary openings in raised floors, partitioning to direct hot and cold air, and utilizing modeling programs to optimize airflow. • Use of variable speed drives on fans • Establish broader ranges of temperature and humidity control. • Use of large air handlers with ability for air-side economizing in lieu of traditional computer room air conditioners. Include high efficiency fans, motors. • Underfloor air distribution may not be necessary. Large ducted overhead systems with directed air into hot aisles can be more efficient. Consideration of thermal stratification for supply and return is essential. • All computer room air conditioners may not need to operate to maintain conditions. Turning off some units may be possible.
Electrical System Design Issues	• Uninterruptible power supply efficiency should be considered. Efficiencies decrease at part load conditions. Redundancy strategies and part load operation should be considered when sizing, selecting, and operating UPS systems. • Use of conventional lighting controls such as occupancy sensors, reduced lighting levels, and/or lights-out operation should be pursued.
HVAC control strategies	• Chilled Water supply, condenser reset strategies. CHWS can be 50 °F. Condenser water can be based off of wet bulb temperature, or if gateways exist, differential refrigerant pressure. • In overhead systems duct static pressure can be lower than 1.5 " w.g. One facility used 0.75" w.g. resulting in efficient fan operation. • Monitoring kW/ton of chiller and chilled water plant to see if strategies result in savings. • Staging of chillers: VFD centrifugals should be run in parallel, constant speed chillers should be loaded as fully as possible. • Some facilities didn't have properly working economizers. Hasn't been able to get controls vendor to fix it for years. • Use of conventional lighting controls such as occupancy sensors, reduced lighting levels, and/or lights-out operation should be pursued. • Turning off humidity control in CRAC units in many climates may be possible. Units tend to fight each other with one in humidification and one in dehumidification. Steam humidification is better, not the electric humidification in CRAC units.
Rack Configuration Issues	• Hot and cold aisles need to be maintained. Many facilities did not follow this protocol. Better coordination between IT and facility managers is necessary. • Rack loading is often inconsistent with some racks partially loaded, some fully loaded, and others empty. Even distribution would aid thermal performance.

Conclusion and Recommendations

Energy benchmarking results can help to visualize energy end uses in complex data center facilities. For a data center owner/operator there are a number of high value benefits. Measured energy use determined by a benchmarking program can provide a baseline for tracking energy performance over time. It can be used to better predict future needs leading to more efficient sizing of supporting facility systems. Benchmarking can also be used to prioritize where resources need to be applied to achieve improvements in energy efficiency.

Use of the metrics developed for this project provides a mechanism for comparison of facility systems and components to other data centers. This is possible even though the system design and configuration may be completely different. By analyzing the variations in the data, current better practices can be identified. The strategies and configurations resulting in the most efficient operation can then be applied to new designs or retrofit into existing facilities. Large apparent variations in the energy use of systems or components may signify design, installation, operational, or maintenance problems. Finding the reason for the discrepancy could solve on going operational or maintenance problems or correct inefficiencies originally built into the facility. For data center designers, access to actual comparison data will highlight better practices and lead to new creative energy efficient designs, and operating strategies. Future activity should be directed at developing such a database, which should ideally include both measured data, and design data. In addition, a benchmarking tool is needed such that building operators can perform their own evaluations.

This benchmarking activity illustrated that certain HVAC design strategies can be far more efficient than conventional data center cooling strategies. Designs using central air handling, free cooling, water-cooled chillers, and variable speed driven mechanical equipment were found to be more energy efficient in this study. The benchmarking also identified opportunities for optimizing existing mechanical and electrical equipment through improved control strategies, such as staging of UPSs, increasing chilled water temperatures, and better air distribution through rearrangement of racks into hot and cold aisle configurations.

Public interest funding should be provided to assist data centers in this benchmarking process, and to provide assistance in implementing solutions that will improve energy efficiency and/or reduce peak load. Furthermore, public interest funding should be directed at developing new technologies (e.g., power supplies that are energy efficient at partial loads) or innovative strategies (e.g. quantitatively compare the energy usage associated with various strategies for managing cold air inflow and hot air discharge) that would not otherwise be developed by industry. Additional insight on important R&D topics may be found in LBNL's research roadmap for High Performance Data Centers.

References

LBNL websites: http://datacenters.lbl.gov; http://enduse.lbl.gov/Projects/InfoTech.html

NYSERDA website: www.nyserda.org

California Energy Commission: http://www.energy.ca.gov/process/industry/industry_index.html