Measuring and Managing Data-Center Energy Use

Findings—and resulting best practices—from a study of energy use in 22 data centers

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With annual energy costs per square foot that are 10 to 30 times those of typical office buildings, data centers are an important target in energy-saving efforts. They operate continuously, which means their electricity demand always is contributing to peak utility-system demand, an important fact given that utility pricing increasingly reflects time-dependent tariffs. Energy-efficiency best practices can hold the key to significant savings, while improving reliability and yielding other non-energy benefits.

This article will summarize best practices developed from an extensive study of energy use in 22 data centers.

SPECIFY EFFICIENT UPS SYSTEMS AND IT-EQUIPMENT POWER SUPPLIES

One of the best ways to improve data-center energy efficiency is to reduce heat loads attributed to power conversion within both information-technology (IT) equipment and the data-center infrastructure. With conventional battery-based double-conversion uninterruptible-power-supply (UPS) systems, power is converted from alternating current to direct current back to alternating current, resulting in large energy losses, which are compounded by the cooling energy needed to remove the resulting heat. Making matters worse, the efficiency of the power conversion drops dramatically when UPS systems are lightly loaded, which almost always is the case because of desires to maintain redundancy and keep loads around 40 percent. Figure 1 shows wide variations in UPS efficiency.

With a more-efficient UPS system, an immediate reduction in overall electrical-power demand

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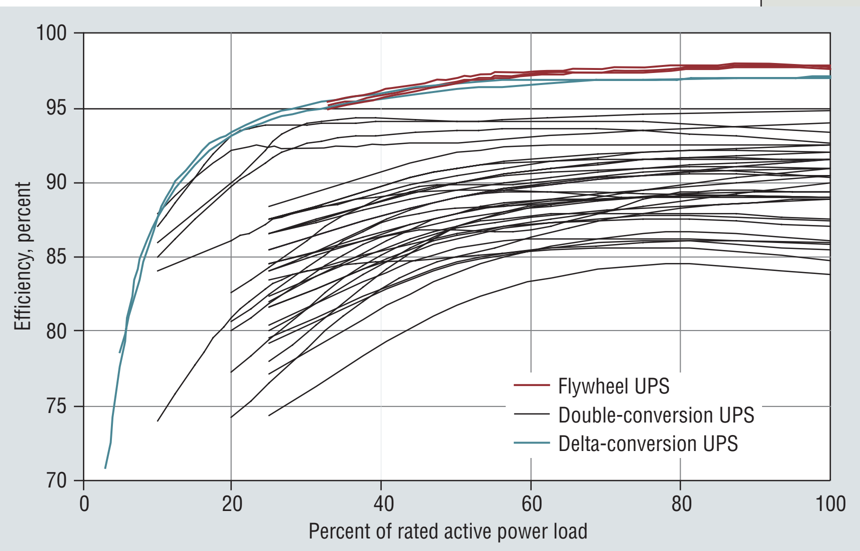

FIGURE 1. Factory measurements of UPS efficiency using linear loads.

of 20 to 30 percent can be achieved. Additionally, downsizing HVAC and upstream electrical systems (in new construction) can result in capital-cost savings and excess capacity.

A similar phenomenon occurs *within* IT equipment, such as servers, where multiple power conversions typically occur. Conversion from alternating current to direct current and then multiple direct-current conversions contributes to IT-equipment energy loss. Lawrence Berkeley National Laboratory (LBNL) found a wide range of efficiencies in power supplies used in servers. With more-efficient power supplies, additional energy- and capital-cost savings can be obtained.

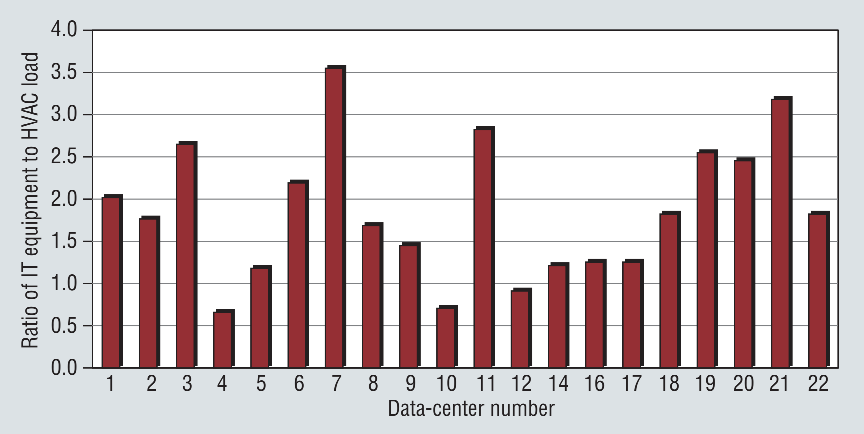

FIGURE 2. Data-center HVAC effectiveness.

OPTIMIZE AIR MANAGEMENT

As computing power skyrockets, data centers are beginning to experience higher concentrated heat loads. In facilities of all sizes—from small data centers housed in office buildings to large data centers essentially dedicated to IT equipment—effective air distribution has a significant impact on energy efficiency and equipment reliability. Energy benchmarking using a metric that compares energy used for IT equipment to energy used for HVAC systems (Figure 2) reveals that some data centers perform better than others. For this metric, a higher number indicates that proportionately more electrical power is being provided for computational equipment than for cooling. In other words, the HVAC system is more effective at removing heat from IT equipment. The variation from worst to best is *fivefold.* This can be attributed to a number of factors, including how cooling is generated and distributed; however, air management is a key part of effective and efficient cooling.

Improving "air management," or optimizing the delivery of cool air and the collection of waste heat, can involve many design and operational practices. Air-cooling improvements often can be made by addressing:

- The short-circuiting of heated air over the top of or around server racks.
- The short-circuiting of cooled air back to air-conditioning units through openings in raised floors, such as cable openings and misplaced floor tiles with openings.
- Misplaced raised-floor air-discharge tiles.
- Poorly located computer-room air-conditioning (CRAC) units.
- Inadequate ceiling height or an undersized hot-air-return plenum.
- Air blockages, which are common with piping and large amounts of cabling under raised floors.
- Openings in racks that allow air bypass ("short-circuiting") from hot areas to cold areas or vice versa.
- Poor airflow through IT-equipment racks caused by restrictions in rack structure.
- IT equipment with side or top air discharge adjacent to front-to-rear-discharge configurations.
- Inappropriate—either too high or too low—underfloor pressurization.

One's general goal should be to minimize or eliminate inadvertent mixing between cooling air supplied to IT equipment and hot air rejected from the equipment. Air distribution in a well-designed system can reduce operating costs, reduce investment in HVAC equipment, allow increased utilization, and improve reliability by reducing processing interruptions and equipment degradation attributed to overheating.

Solutions to common air-distribution problems include:

- The use of "hot-aisle/cold-aisle" arrangements, by which racks of computers are stacked with the hot discharge sides facing each other and the cold inlet sides facing each other (Figure 3).

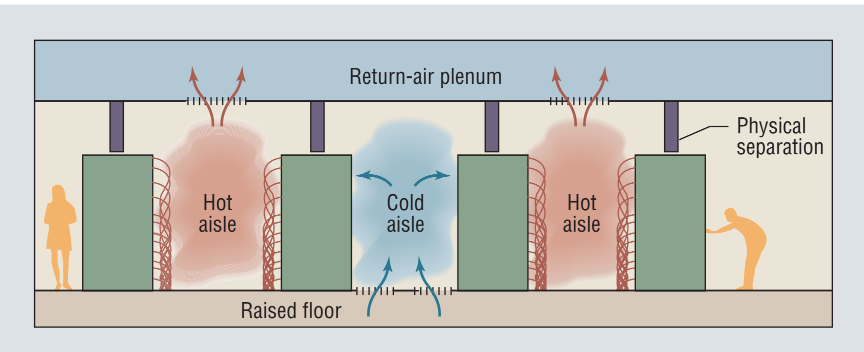

FIGURE 3. Typical hot-aisle/cold-aisle arrangement. Cold air can be distributed from above or below.

• Sealing openings in underfloor systems.

• Blanking unused spaces in equipment racks.

• The careful placement of CRAC units and floor-tile openings, often through the use of computational-fluid-dynamics modeling.

• Collecting heated air through high overhead plenums or ductwork and efficiently returning it to the air handler(s).

• Minimizing obstructions to proper airflow.

CAPITALIZE ON FREE COOLING

Data-center IT-equipment cooling loads are nearly constant throughout the year. Water-side economizers utilizing evaporative cooling (usually provided by cooling towers) can be used to indirectly produce chilled water to cool a data center when outdoor conditions are mild or at night. This "free cooling" is best suited to climates with wet-bulb temperatures lower than 55 F for 3,000 or more hours a year. Free cooling can improve the efficiency of a chilled-water plant by lowering chilled-water approach temperatures (i.e., precooling chilled water before it enters a chiller) or eliminate the need for compressor cooling, depending on the outdoor conditions and overall system design. With free cooling, chilled-water-plant energy consumption can be reduced by up to 75 percent, with related improvements in reliability and maintenance through reductions in chiller operation. Because this solution does not affect the quality of air entering IT equipment, it can be an economical alternative to air-side economizers in the retrofit of a chilled-water-cooled data center.

Air-side economizers also can provide free cooling; however, their use is somewhat controversial. While some IT-based data centers routinely use outside air without apparent complications, others are concerned about contamination and thermal control in their equipment rooms. Having seen the use of outside air result in energy-efficient operation in several data centers, LBNL is planning to examine the validity of contamination concerns. The American Society of Heating, Refrigerating and Air-Conditioning Engineers' data-center technical committee, TC 9.9, is expected to develop guidance. For now, simply using a standard commercial-building economizer is not recommended—not without an engineering evaluation of the local climate and contamination conditions.

Temperature and humidity fluctuations, as well as particulate and gaseous pollutants, must be considered. Mitigation may involve filtration or other measures.

If outside air is to be used for cooling, adequate access to the outside must be provided. Central air-handling units with roof intakes or sidewall louvers are used most often, although some internally located CRAC units offer economizer capabilities when provided with appropriate intake ducting.

REPLACE OUTDATED RULES OF THUMB: THE EXAMPLE OF HUMIDIFICATION

A remnant of the days of mainframe computers and tape storage, the need for tight humidity control generally can be relaxed or eliminated, as there is very little humidity load from within data centers. In the study undertaken by LBNL, many of the data centers attempting tight humidity control were found to be humidifying and dehumidifying simultaneously. TC 9.9 addressed that issue by developing guidance concerning temperatures and humidity supplied to the inlet of IT equipment.[1] That document allows a much wider range than previously required.

Some data centers perform humidity control on makeup-air units only. Humidifiers employing evaporative cooling (reducing the temperature of recirculated air while adding moisture) also can be effective. An important consideration in reducing unnecessary humidification is operating the cooling coils of air-handling equipment above the dew point (usually by running chilled water above 50 F), eliminating unnecessary dehumidification.

DESIGN FOR EFFICIENT AIR HANDLING

Better performance was observed in data centers utilizing a custom centralized air-handling system. A centralized air-handling system offers several advantages over a traditional multiple-distributed-unit system:

- A centralized air-handling system uses larger motors and fans, which generally are more efficient.
- A centralized air-handling system is well-suited to variable-volume operation through the use of variable-frequency drives, taking advantage of the fact that server racks rarely are fully loaded.
- A centralized air-handling system can take advantage of surplus and redundant capacity, improving efficiency.
- Centralized air-handling units are less likely to fight one another than are distributed units with independent and uncoordinated controls.
- The cooling source for centralized air-handling units often is a water-cooled chiller plant, which typically is significantly more efficient than the cooling source for water- and air-cooled computer-room units.
- A centralized system requires less maintenance.

ALWAYS RIGHT-SIZE

Most data centers are designed based on vague projections of power needs. As a result, they usually are lightly loaded (compared with their design basis) throughout much, if not all, of their lives. Although projecting IT-equipment electrical-power requirements will forever be an inexact science, it is nonetheless important to size electrical and mechanical systems so that they will operate efficiently when overall loading is well below design and yet be scalable to accommodate larger loads.

Providing redundant capacity and sizing for true peak loads can be done in a manner that improves overall system efficiency, but only if a system design approach that considers efficiency is taken. Upsizing duct/plenum and piping infrastructure offers significant benefits in terms of operating costs and future flexibility. The use of variable-speed motor drives on chillers, chilled- and condenser-water pumps, and cooling-tower fans can improve part-load performance significantly, especially when controlled in a coordinated way to minimize overall chiller-plant energy use. Pursuing efficient design techniques, such as medium-temperature cooling loops and water-side free cooling, also can mitigate the impact of oversizing.

Cooling-tower energy use represents a small portion of plant energy consumption. Upsizing cooling towers can improve chiller performance and water-side-free-cooling-system operation significantly. There is little downside to upsizing cooling towers—a slight increase in cost and footprint is all that is required.

PULLING IT ALL TOGETHER

Following best practices is not just a matter of substituting better technologies and operational procedures. Design and decision-making also must be addressed. This entails:

- Integrating energy management with functions such as risk management, cost control, quality assurance, employee recognition, and training and using life-cycle-cost analysis as a decision-making tool.
- Creating design-intent documents to involve all key stakeholders, keeping the team "on the same page" and clarifying and preserving the rationale for key design decisions.
- Adopting quantifiable goals based on best practices.
- Introducing energy optimization at the earliest phase of design to minimize construction and operating costs, avoiding excessive/redundant "safety margins," and right-sizing to trim first costs.
- Including integrated monitoring, measuring, and controls in facility design.
- Benchmarking existing facilities, tracking performance, and assessing opportunities.
- Incorporating a comprehensive commissioning (quality-assurance) process into new-construction and retrofit projects.
- Including periodic "recommissioning" in overall facility-maintenance programs.
- Evaluating the potential for on-site power generation, including combined-heat-and-power technologies.
- Ensuring that all members of the facility-operations staff receive site-specific training that includes identification and proper operation of energy-efficiency features.

REFERENCE

1) TC 9.9 Mission Critical Facilities. (2004). *Thermal guidelines for data processing environments*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

*To learn more about cost-saving opportunities associated with new and existing data centers, visit "Data Center Energy Management: A Self-Paced Training Web Site" (*http://hightech.lbl.gov/DCTraining/top.html*), which the authors are helping to develop.*