WHITE PAPER

Profitably Improving Site Infrastructure Energy Efficiency

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Introduction

One measurement of a data center's site infrastructure energy efficiency is the ratio of all power consumed by all electrical and mechanical systems supporting the computer equipment load (total power load) divided by the computer equipment load (critical load). The Uptime Institute, a provider of educational and consulting services for Facilities and IT organizations interested in maximizing data center uptime calls this the data center Coefficient of Efficiency (CoE).

When determining the total power load supporting the data center, it is important to practice diligence in order to obtain the most accurate data. If the facility is a dedicated data center, with few people and little other activity, the utility input to the facility can be used as an estimate of the total power load. If the data center is in a shared facility, special metering instrumentation must be installed to determine the total power load. These measurements are best done at the primary switch gear delivering power to the Uninterruptible Power Supply (UPS) and mechanical systems. The most useful information comes when the UPS and mechanical systems can be monitored separately.

The critical load is best measured as the output of the Power Distribution Units (PDUs) or Remote Power Panels (RPPs) on the computer room floor. Alternately, if the UPS supports nothing but the computer equipment load, it can be used as an alternate measurement of the critical load.

A data center with a CoE of 1.8 to 2.0 averaged over one year would meet the following criteria: utilizes an efficient site infrastructure design, with an efficient UPS system at partial loads, and proactively manages the balance between the actual cooling load and the minimum required amount of operable redundant cooling capacity. This annualized CoE could be further reduced if free-cooling could be employed at appropriate times during the year. Free-cooling occurs by taking advantage of a temperature difference between the computer room and a colder exterior environment or other heat sink.

An important predictor of the CoE is the data center's cooling efficiency and effectiveness. Poor cooling efficiency drives up the CoE. Once a data center is built, measuring and managing cooling efficiency is the most important thing managers can do to directly improve their CoE. This is true because cooling systems operation typically consumes the highest percentage of the total power required to operate the infrastructure.

The Uptime Institute's white paper titled *Reducing Bypass Airflow Is Essential for Eliminating Computer Room Hotspots* indicates that, on average, the 19 data centers it studied had a CoE of 2.4 to 2.6. This means an average data center expended 2.4 to 2.6 times the energy required to power the critical load.

The same Uptime Institute white paper also showed that cooling capacity is often added in an attempt to eliminate hotspots, but usually without the knowledge that there is already excessive cooling capacity installed in the computer room. Even with 2.6 times the cooling capacity operating, 10 percent of the cabinets had input-air temperatures exceeding the 77°F (25°C) maximum temperature recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for reliable computer hardware operation.

It is unfortunate and unnecessary that there are many data centers with a CoE greater than 3.0. These data centers are using over 100 percent more energy than their better managed peers with CoEs of 2.0 or less. Even worse, despite having excessive cooling capacity running, the number of hotspots in the computer room was actually higher than in better managed computer rooms, with up to 25 percent of the cabinets having input-air temperatures greater than the ASHRAE-recommended guidelines.

Problem

Why do so many data centers have excess cooling capacity, but still have server input-air temperatures exceeding the ASHRAE-recommended maximum? There is not one simple answer, however, the root cause is typically a lack of understanding about the science and engineering behind cooling computer rooms. This results in a series of poor decisions about how to best manage cooling, which then results in a poor CoE. Properly managing conditioned airflow is critical, but the secondary issues—cooling unit set points, capacity management, and other factors—also play a significant role.

Here is an example of the steps many Facilities and engineering groups mistakenly take to handle the existence of hotspots, one of the key manifestations of a poor CoE:

- More perforated tiles are added to the area that is hot. The intensity of the immediate hotspot might be minimized, but additional ones are created due to the reduced airflow through all other perforated tiles. This is the result of reduced underfloor static pressure because there is now more open area in the raised floor.
- Set points are lowered on the cooling units, in the hopes of providing more cooling to the room. Either these units are already at 100 percent capacity or they quickly reach the lowered set point and throttle back to their existing cooling level. The hotspots, which might have abated during the transition period of several minutes, quickly reappear. In addition, the lower set point can shift the cooling unit to de-humidify, which actually reduces delivered cooling capacity.

- A cooling unit vendor is summoned and more cooling capacity is ordered and installed.

Regardless of these steps, there are more hotspots in the room than had existed previously and operating costs have increased, much to the surprise of data center operators.

Other factors contributing to poor CoE include:

- Lack of site infrastructure capacity
- Lack of a master plan for the computer room layout, leading to improper placement of computer and cooling equipment
- Not measuring, monitoring, and controlling critical environmental factors in the computer room
- Cooling units that are not functioning properly
- Blind trust of computational fluid dynamics (CFD) modeling without field verification to determine the accuracy of the model

As stated earlier, the greatest contributor to inefficiency is bypass airflow, or lost conditioned air. On average, only 40 percent of the cold air coming from the subfloor is going directly into the cold aisle and, in turn, directly supporting IT equipment cooling. The other 60 percent is leaking into areas not directly supporting the cooling of IT equipment through openings under the raised floor, often in perimeter walls, or is being introduced into the computer room through unsealed cable openings, holes in the raised floor, and misplaced perforated tiles.

With only 40 percent of the cold air coming directly into the cold aisle, there is an insufficient amount of cold air to cool the installed servers. The servers mounted in the bottom of the cabinet may get a sufficient amount of cold air, but those at the top of the cabinet get their air from the room, which includes re-circulated hot exhaust air from the IT equipment. Temperatures at the bottom of the cabinet can be 60 to 65°F (16 to 18°C). From the middle of the cabinet up, the input-air temperature can rise to 85°F (29°C), or higher.

Solution

To eliminate bypass airflow and improve site infrastructure energy efficiency, seal all the openings in the computer room that allow cold air to flow any place other than through the raised-floor openings immediately in front of the computer equipment air intakes. There are four steps required. Taken together as an integrated and comprehensive effort, they have the greatest likelihood of reducing bypass airflow, and improving the CoE and overall site energy efficiency.

Step 1: Seal the Computer Room Envelope

Seal all the openings in the perimeter walls. Pay special attention to cable trays and conduits passing through the perimeter walls that might have been properly sealed at one point, but were left open when the next set of cables was installed or removed. It takes regular inspection and proactive action to ensure that these openings remain sealed. Also, inspect the area around columns to make sure conditioned air is not escaping through column facades to adjacent floors.

Look for other openings in the computer room shell envelope, including, for example: air leaks through entrance doors (use people traps that act as both a security device and an air-loss blocker), air leaks through elevators, loading dock doors, windows, overhead wall openings where cables pass through, and holes in the perimeter walls above the dropped ceiling. These openings have to be sealed, isolated, or re-engineered to minimize any air loss from the computer room. Periodic inspection and policing is required.

Any cold air lost from the computer room must be replaced. The energy required for conditioning air for both temperature and moisture content to replace lost air is significant. If it is not done properly, it can not only significantly increase the amount of energy required to operate the mechanical system, but also cause the operating environment to deteriorate. Sealing these openings is not only imperative to eliminate the loss of conditioned air; it is also a fire code requirement.

Step 2: Seal Openings in the Raised Floor

Seal all openings in the raised floor, which include cable openings and other holes. A cable opening is usually an opening no larger than 8 x 8 inches (20 x 20 centimeters). Anything larger than that requires special attention. Clearly, the larger the unsealed hole, the greater the amount of bypass airflow and the more wasted cooling unit capacity.

Cable openings and holes in the raised floor should not be sealed using solutions such as duct tape, bubble wrap, or cardboard, as these are unsightly, temporary, and prone to failure. They may also introduce undesired particulate contamination into the computer room.

Acceptable methods of sealing raised floor openings include pillows, foam, and filament grommets. Pillows and foam have the lowest initial cost, but the greatest life-cycle cost. Both pillows and foam are limited to the opening size that can be sealed and require constant inspection to ensure they are still in place. The pillows have a tendency to get pushed under cabinets or fall to the subfloor, allowing bypass airflow to escape.

To use foam seals, a hole must be cut to allow the cables to pass through. The degree of precision in cutting the opening will determine how good the sealing is. If additional cabling is run through the opening, the hole is typically not enlarged. Instead, the foam is discarded or bent up and out of the way, which exposes the hole, allowing bypass airflow to enter the room.

While the use of pillows or foam as methods of sealing raised floor openings are acceptable, the recommended sealing solution is KoldLok® Grommets, as they do not emit particulate contaminants, are highly effective, and remain in place. These products seal the openings to 100 percent without cable installation and to more than 90 percent with a worst-case array of cables installed. Cables can be repeatedly installed or removed without jeopardizing the sealing capability of the unit. The KoldLok solution stays in place, provides automatic re-sealing capability over years of service, and requires no bypass airflow inspection or policing. This might not be the least expensive initial purchase solution, but it is the least expensive on a life-cycle (total cost of ownership) basis.

Step 3: Install Internal Blanking Panels, End Row Panels, and Over the Top Blockage

Another contributor to cooling inefficiency is bypass airflow within IT cabinets. The way to prevent this is to install blanking panels in unused rack unit openings to prevent rear-to-front circulation of hot exhaust air from the servers. This action helps to ensure that the computer equipment air-intake temperature, especially at the top of racks, is within the recommended range for maximum reliability. When evaluating blanking panels, it is critical to select a product that produces the best possible seal of the opening, preferably 100 percent. A recently completed two-dimensional (2D) CFD modeling study of blanking panel effectiveness showed that as much as 20 percent of air volume at server intakes can be recirculated hot exhaust air even when there are small openings between blanking panels and between blanking panels and equipment. The use of HotLok® Blanking Panels which seal 99.96 percent of a 1U open area were found to be very effective in the 2D CFD analysis.

As IT equipment load densities continue to increase, hot air re-circulation due to inadequate airflow around the ends of rack rows and across the top of racks into the cold aisle becomes more significant. Blocking or inhibiting hot air re-circulation will address this problem, but the most important step is getting sufficient airflow into the cold aisle through a comprehensive computer room cooling tune-up.

Step 4: Tune Computer Room Cooling

Now that all the undesired openings are sealed, the next step is to tune the computer room. This is done with a detailed study of the heat-load, cooling capacity, and airflow, which takes into account how many cooling units need to be operating, how many perforated tiles need to be installed, and where they should be placed.

Tuning the room is a complex process that requires following the proper sequence of actions described below, however, the process needs to be adjusted to accommodate the conditions of each environment. Sealing the bypass openings and tuning the room must occur in tandem, or increased equipment air-intake temperatures and equipment damage may result. Throughout all aspects of the computer room tuning, IT equipment air-intake temperatures must be monitored to avoid excessively high temperatures.

The first action as part of Step 4 is to determine the heat-load. This can be done by adding together all of the PDU or RPP outputs. It can also be accomplished by monitoring the UPS system(s) outputs. If the former is possible, it can be the better method, but it depends on metering that is often inaccurate. The results will provide a good understanding of how the power load is distributed within the computer room, i.e., which area of the room is heavily loaded and which is lightly loaded. If the UPS output(s) are used, the distribution of this power must be understood, especially if output power goes to multiple computer rooms. Often, there is equipment outside the computer room that is powered from the UPS system. This non-IT load must be subtracted when calculating the IT load on the computer room raised floor.

The second action is to evaluate the performance of the cooling units on the raised floor. This cooling unit evaluation includes checking temperature and humidity set points and sensitivities. Are they at the correct setting and are they consistent throughout the room?

The third action is to check the calibration of the return-air sensors. A key factor is to ensure that the instrument being used to monitor the calibration is itself properly calibrated. A piece of test equipment that is out of calibration can produce erroneous results that will contaminate the entire tuning process. Also, the readings must be taken at the same location as the cooling unit's sensor.

The fourth action is to check each cooling unit for proper functioning and to verify each cooling unit's actual delivered cooling capacity. First, compare the temperature difference (delta T) across the cooling coil with the indicated performance of the unit. If the stated cooling capacity is 50 percent, the delta T should be a minimum of 8˚F (4˚C), with 9 to 10˚F (5 to 6˚C) being the better delta T range. Second, force the unit into 100 percent cooling, if it is not already cooling at that level. This is done by lowering the temperature set point for a brief time (less than 5 minutes). Measure the supply air temperature at the 100 percent cooling condition. Once the supply air temperature has stabilized, return the set point to the original setting. The 100 percent capacity delta T is calculated using the 100 percent function-supply temperature and the original return-air temperature. That delta T should be a minimum of 17˚F (9˚C), with a delta T of 18 to 19˚F (10 to 11˚C) being even better.

The airflow volume from each cooling unit should be measured annually and also whenever maintenance is done on the blowers or motors, or when the belt is adjusted or replaced. The airflow volume should at least match, if not exceed, the volume specified by the manufacturer. Failing to confirm actual cooling unit airflow is one of several significant sources of error in CFD modeling. Low airflow volumes often occur when the heating, ventilation, and air-conditioning (HVAC) maintenance vendor has put two sets of pleated filters on the return of the cooling units. One set of pleated filters is sufficient (two are not better than one). Other factors affecting airflow volumes include dirty filters and misadjusted or slipping belts. Often this measurement process will reveal significant performance deficiencies that will need to be corrected before proceeding.

The fifth action is to determine the required number of operational cooling units from the heat-load data and the cooling capacity information. There should be redundant cooling capacity operating in every area of the room. This brings the load on any one unit below the 100 percent capacity requirement and provides backup capacity if one of the units in a zone should fail. One important note is that if a cooling unit is not cooling properly, the blower must be shut off to allow the redundant cooling capacity of the adjacent unit(s) to provide cooling to the zone normally covered by the failed cooling unit.

The final action is to determine the proper number and placement of perforated tiles that should be installed in the room[1]. The average computer room evaluated in the white paper (*Reducing Bypass Airflow Is Essential for Eliminating Computer Room Hotspots*) had twice as many perforated tiles installed in the room than is required. Once the room is properly sealed, blanking panels are installed, cooling units are delivering rated capacity, the proper number of cooling units are operating, and the underfloor static pressure is brought up to the prescribed level of at least 0.05 inch (1.3 millimeter) of water column, the number and location of perforated tiles can be adjusted[2].

To estimate the required number of perforated tiles, take the total airflow in cubic feet per minute (CFM) or cubic meters per hour (CMH) from the operating cooling units and divide it by 750 CFM/tile (1,274 CMH/tile). This calculation will identify the minimum total number of perforated tiles that should be installed in the room. If grates are installed in any part of the room, each 40-percent grate counts for two perforated tiles, and each 60-percent grate counts as three perforated tiles. None of the perforated tiles or grates should have flow-control dampers attached to their bottom surfaces. (If there is too much airflow in an area, it is better to insert a solid tile than to close a damper. Dampers dramatically reduce airflow even when fully open and must be regularly policed.) The actual number required should be determined by measuring the intake air temperature of all IT equipment and adjusting the number, type, and placement of tiles and grates to create the smallest range between the minimum and maximum intake-air temperature within the ASHRAE guidelines (68–77°F or 20–25°C).

Once the approximate total number of perforated tiles is determined, their arrangement must be adjusted within the cold aisle. The following guidelines have proven to be an effective starting point. For cabinet loads of less than 1.5 kW, the perforated tiles can be checker-boarded down the cold aisle. For cabinet loads of 1.5 to 4 kW per cabinet, a perforated tile needs to be dedicated to each cabinet. For cabinet loads of 4 kW to 9 kW, grates of increasing flow capacity need to be installed at each cabinet.

Use care when employing grates. Depending on static pressure, a 40-percent open grate can release 1,200 CFM/tile (2,040 CMH/tile) and a 60-percent open grate can release up to 1,600 CFM (2,720 CMH). With a cooling unit generating 12,000 to 15,000 CFM (20,040 to 25,500 CMH), one cooling unit will be required for every 10 grates installed in the raised floor.

With a cabinet load above 9 kW, (a) either load tuning must be employed, where other cabinets in the same area carry reduced loads, or (b) the hot exhaust air must be isolated from the cold air through a ducted return or another method.

In summary, this is a complex process. The optimization solution for each unique environment requires a sound understanding of the science and engineering, and following deliberate, well thought out, and often iterative steps. Upsite Technologies engineers can assist you through its suite of KoldWorks^{SM} services.

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[1] For computer rooms in which cooling is currently being supplied through unsealed cable openings under the cabinets, changing the number of perforated tiles or grates or their location must be done very carefully and methodically. Air turnover in a computer room typically occurs once a minute. This means that equipment air-intake temperatures can change very quickly when adjustments are made to the cooling system. Untrained people can get themselves in very serious trouble and cause IT equipment to turn "thermally off" within minutes.

[2] For more information, please see the Uptime Institute's white paper titled *Alternating Cold and Hot Aisles Provides More Reliable Cooling for Server Farms*, found at uptimeinstitute.org.

CoE Improvement Analysis

Implementing the steps and actions described above is the most effective approach toward improving CoE. The following examples of improved CoEs demonstrate energy efficiency improvements and potential cost savings.

Assumptions:

Computer room area: 20,000 ft^2 (1,858 m^2)
Critical power load: 2,000 kW
Overall density: 100 W/ft^2 (1,076 W/m^2)
Utility rate: (USD) $0.10/kWhr

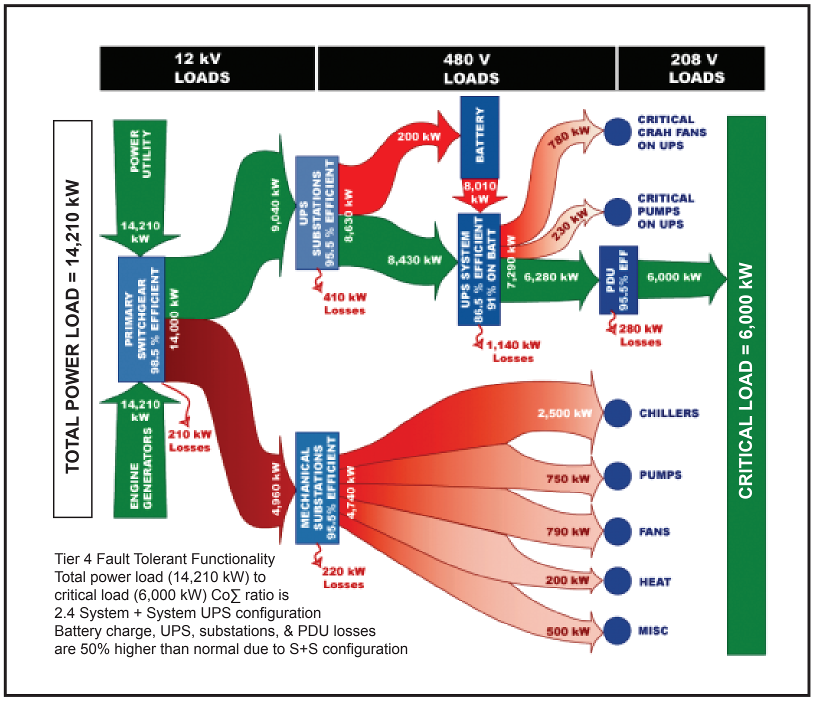
Example 1:

Initial total power load: 6,400 kW
Initial CoE: 3.2 (3.2 = 6,400 kW/2,000 kW)
Improved total power load after remediation: 4,000 kW
Reduction in total power load: 2,400 kW (38 percent)
Improved CoE: 2.0 (2.0 = 4,000 kW/2,000 kW)
Annual savings at $0.10 / kWhr: $2.1 million (USD)

Example 2:

Initial total power load: 5,200 kW
Initial CoE: 2.6 (2.6 = 5,200 kW/2,000 kW)
Improved total power load after remediation: 4,000 kW
Reduction in total power load: 1,200 kW (23 percent)
Improved CoE: 2.0 (2.0 = 4,000 kW/2,000 kW)
Annual savings at $0.10 / kWhr: $1.05 million (USD)

In both cases, the cost of implementing the changes necessary to reduce the CoE would be a fraction of the first-year cost savings. In many cases, the recovered cooling capacity will more than pay for the computer room tune-up by eliminating or deferring the need to install additional cooling capacity. Even as a stand-alone investment, the return on investment is usually less than one year and the quality and stability of cooling within the computer room increases dramatically.



Tier 4 Fault Tolerant Functionality
Total power load (14,210 kW) to critical load (6,000 kW) CoΣ ratio is 2.4 System + System UPS configuration
Battery charge, UPS, substations, & PDU losses are 50% higher than normal due to S+S configuration

$$\text{Co}\Sigma = \frac{\text{total power load}}{\text{critical load}}$$

CoΣ = Coefficient of Efficiency

total power load = all power conserved by all electrical and mechanical systems directly supporting the computer equipment load

critical load = all power conserved by computer equipment

About Upsite

Upsite Technologies, Inc. develops energy-efficient, high-availability solutions specifically designed to optimize your data center's critical physical infrastructure and ensure site uptime, reliability, and flexibility.

As the innovator of engineered sealing solutions, Upsite continues to research and develop products and services to complement and enhance the already extensive lines of patented KoldLok® and HotLok® products and KoldWorksSM services. Our inventions optimize thermal load capacity, target hotspot remediation, reduce intermittent equipment failures, improve equipment reliability, minimize bypass airflow, and diminish capital costs associated with installing additional cooling equipment.

Upsite's well-engineered solutions are employed by data centers worldwide to help reduce their carbon footprint and minimize energy and operating costs. Upsite's products and services currently optimize more than 6 million ft^2 (550,000 m^2) of data center space.