WHITE PAPER

Cooling Capacity Factor (CCF) Reveals Stranded Capacity and Data Center Cost Savings

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Executive Summary

The average computer room today has cooling capacity that is nearly four times the IT heat load. Using data from 45 sites reviewed by Upsite Technologies, this white paper will show how you can calculate, benchmark, interpret, and benefit from a simple and practical metric called the Cooling Capacity Factor (CCF)[1].

Of the 45 sites that Upsite reviewed, the average running cooling capacity was an astonishing 3.9 times (390%) the IT heat load. In one case, Upsite observed 30 times (3,000%) the load. It is hard to believe that sites are this inefficient.

When running cooling capacity is excessively over-implemented, then potentially large operating cost reductions are possible by turning off cooling units and/or reducing fan speeds for units with directly variable fans or variable frequency drives (VFD).

Though a great deal of focus is placed on improving computer room cooling efficiency, the average data center could reduce their operating expense by $32,000 annually simply by improving airflow management (AFM).[2]

AFM improvements increase cooling efficiency, which could result in immediate operating cost savings and greater IT system reliability. As cooling represents approximately half of infrastructure costs, PUE improves as well. With a reduction in energy usage, everyone benefits, as carbon emissions are also reduced.

The same AFM improvements also release stranded cooling capacity which enables companies to increase server density without the capital cost of additional cooling equipment. Improved cooling utilization may also extend the life of a site, deferring capital expenditure required to build a new data center.

Numerous solutions are designed to improve cooling efficiency, ranging from something as simple and important as blanking panels to complete containment systems. Hype abounds when it comes to the potential benefits of each new “best practice”. How can you truly know what potential there is to make a difference? Will you be able to deploy more IT equipment? Will you eliminate hot-spots and/or reduce the Power Usage Effectiveness (PUE) for your data center? How much of a difference will improved AFM make at your site? To make informed decisions about investing in additional cooling capacity or AFM initiatives, you should first determine how well you are utilizing your current resources.

Calculating the CCF is the quickest and easiest way to determine cooling infrastructure utilization and potential gains to be realized by AFM improvements.

[1] The CCF is the ratio of total running manufacturer’s rated cooling capacity to 110% of the critical load. Ten percent is added to the critical load to estimate the additional heat load of lights, people, etc.

[2] $24,000 from turning off 4 cooling unit fan motors + $8,000 from reduced maintenance costs for the 4 units.

History

1) In the past, computer rooms were laid out in a "legacy" configuration—all the IT equipment facing the same direction. Though aesthetically pleasing, this resulted in very poor AFM and a mixing of supply and exhaust air. Very low cooling unit set-points and extra cooling units were used to combat poor AFM.

2) Typically when a data center is commissioned, all cooling units are turned on and left on, even with a low heat load in the room. And while server densities have dramatically increased, the total room heat load is often much less than the running cooling capacity.

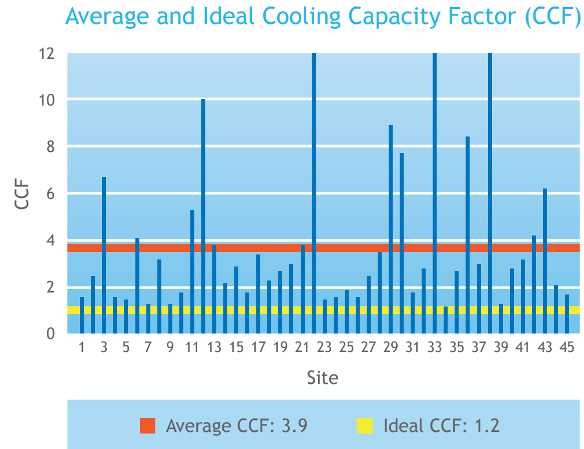
3) When data center managers were having difficulty cooling an area of their room, they often consulted with cooling unit manufacturers. Since no one compared installed cooling capacity to heat load, problems were assumed to be due to a lack of capacity. The real issue of poor AFM remained hidden, and additional cooling units were purchased.

Field Findings—Nearly Every Site Has Opportunity for Improvement

Site data collected from 45 EnergyLok Profile assessments reveal some surprising statistics. **Figure 1** shows that data centers of all shapes and sizes have significant opportunity for improvement.

Most significant from this data is that the average CCF of the 45 sites reviewed was 3.9, or running cooling capacity was 3.9 times (390%) the heat load in the room. Running means that only the number of active/running cooling units was considered in the calculations. Many sites have already turned off some of the excess cooling units in the room. These inactive standby units were not considered in the calculations. **Figure 2** shows the CCF data for each of the 45 sites reviewed.

Figure 2



The range of room sizes demonstrates that issues of over-implemented cooling are not unique to small, less sophisticated sites. The average CCF of the five largest sites reviewed was 2.4, significantly better than the overall average of 3.9, but still over twice the cooling needed.

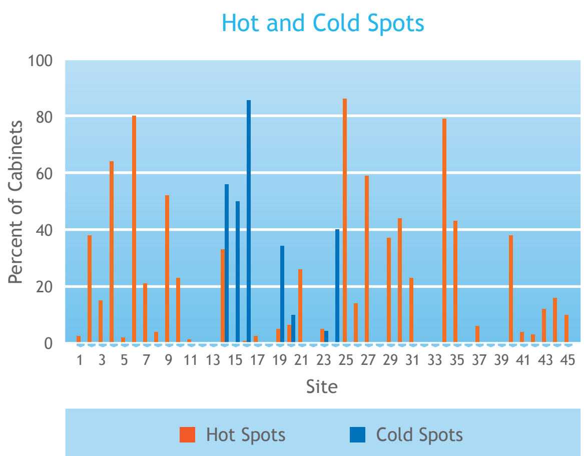
Raised-floor bypass open area is made up of unsealed cable openings and penetrations, and perforated tiles placed in hot aisles or open areas. The percentage of bypass open area is calculated by dividing the bypass open area by the total open area in the raised floor. This percentage should be less than 10%.

Figure 1

	Raised floor area (sq ft)	# of running cooling units	Raised floor bypass open area (%)	Hot spots (%)	Cold spots (%) (Data from 8aa sites)	Proper perforated tile placement (%)	Cooling Capacity Factor (CCF)
Averages	7,527	8	48%	20%	35%	77%	3.9
Minimum	720	2	13%	0%	0%	7%	1.2
Maximum	37,000	40	93%	86%	86%	100%	32.0
Recommended	**NA**	**NA**	**0%**	**0%**	**0%**	**100%**	**1.2**

The most important metric in a computer room is the percentage of hot and cold spots, which should be zero. These figures are determined by counting the number of cabinets containing at least one piece of IT equipment that requires cooling and an intake air temperature above or below the desired range. No hot spots were observed at only nine (20%) of the 45 sites. Cold spot data collected for the last eight sites reviewed showed only one site without cold spots. Data on the percentage of cabinets at each site that contain a hot or cold spot is shown in **Figure 3.**

Figure 3



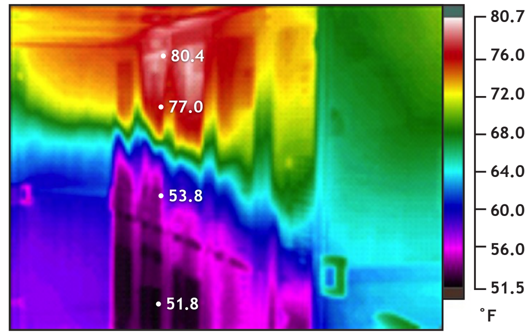


Figure 4

Figure 4 shows a dramatic difference in the intake temperatures of IT equipment located in the bottom of cabinets versus the top in a fully-contained cold aisle. This is the result of an insufficient volume of conditioned air being delivered to the contained space due to unsealed cable openings throughout the raised floor. Compounding this, the contained aisle had open spaces between IT equipment in the cabinets that allowed conditioned air to flow out of the space and exhaust air to flow in. So even though cold-aisle containment had been installed and the site had a CCF of 3.8 (380%), IT equipment intake temperatures were not improved. A more cost-effective solution would have been to address AFM fundamentals throughout the site. After progressing through these fundamentals, full containment may later become necessary.

Cooling infrastructure consumes more electricity in a data center than any other facilities infrastructure component. Yet perforated tiles, the easiest and least expensive way to manage airflow and cooling resources, are properly located only 77% of the time. Only 6 out of the 45 sites reviewed had properly placed all their perforated tiles. Perforated tiles should never be placed in open spaces or hot aisles.

Site Examples Highlight the Commonality of Overlooked AFM Improvements

As the industry evolves, data center managers are challenged by ever-increasing IT equipment densities, and pressured to reduce operating expenses. Often managers turn to advanced AFM solutions such as full containment. However, in many circumstances the expectations of these efforts are unmet because AFM fundamentals have been overlooked. Even if expectations are met, the full benefits of these solutions will not be realized unless AFM fundamentals are addressed as well.

Another solution that is often inappropriately incorporated into computer rooms is fan-assisted perforated tiles, which are meant to address an insufficient volume of conditioned air to cool adjacent IT equipment. While fan-assisted tiles do deliver more conditioned air, they do so at the cost of reducing conditioned air volume coming out of perforated tiles in the surrounding area and increasing electrical load in the room. In most cases, simply sealing unmanaged openings in the raised floor will enable existing perforated tiles to produce sufficient volumes of conditioned air. This solution has other benefits such as increasing conditioned air volumes through all perforated tiles in the room, reducing or eliminating hot spots, and enabling the raising of cooling unit set-points. Calculating a room's CCF quickly identifies the potential for solving cooling problems. Obviously, there are appropriate applications and benefits of fan-assisted tiles. When raised floor heights and/or obstructions limit conditioned air volume in an area of a room, or high-density cabinets require more cooling than standard perforated tiles or grates can deliver.

The profound benefits that can result from calculating a site's CCF and making fundamental AFM improvements is shown in the following example of a 9,000-sq. ft. computer room.

This room had 170 cabinets drawing a total load of 240 kW and cooled by seven cooling units rated at 70 kW each and one unit rated at 85 kW. Electricity cost was $0.10/kWh. The site manager was struggling to maintain appropriate IT equipment intake air temperatures with a site CCF of 2.2. In other words, the running cooling capacity was 220% of the room's heat load, indicating that the site's cooling challenges were due to poor AFM and not insufficient cooling capacity.

To "right-size" the cooling infrastructure, simple improvements were made to the room including:

- Sealing cable openings
- Installing blanking panels
- Adjusting both the number and location of perforated tiles
- Adjusting the position of a few cabinets
- Sealing spaces where cabinets were missing in a row

Doing this eliminated all IT equipment hot spots and allowed two cooling units to be turned off, which resulted in a savings of $21,900 per year and a payback period of less than eight months!

Benefits of Knowing CCF — "Right-Sizing" Cooling to the IT Load

Companies often skip or fail to complete the application of AFM fundamentals (sealing raised-floor holes and openings in cabinets, managing perforated tiles, etc.) before moving to advanced forms of AFM such as containment. Knowing the CCF for a computer room is important at all stages of AFM evolution and can help prioritize AFM improvement initiatives. Tracking CCF as improvements are made to the room demonstrates the value of investments in efficiency and correlates to improvements in PUE.

If little or no AFM improvements have been made, then calculating your CCF and determining what you need to do to improve utilization will reveal your potential ROI and payback period. If extensive AFM improvements have already been made, then the CCF will reveal the effectiveness of AFM improvements and the potential benefits for further improvements.

The CCF is a direct indicator of the stranded cooling capacity in the data center. In most sites, there is excess cooling running in the space while there is inadequate cooling of the IT hardware. Inadequate cooling is when the IT equipment intake temperatures are above or below the standards established by ASHRAE for mission-critical facilities. The recommended and allowable IT equipment intake air temperature ranges established by ASHRAE are shown in **Figure 5.** ASHRAE explicitly states that the recommended range is appropriate for legacy equipment. Determining your CCF reveals whether the root cause of poor intake air temperature is due to a lack of capacity or poor AFM.

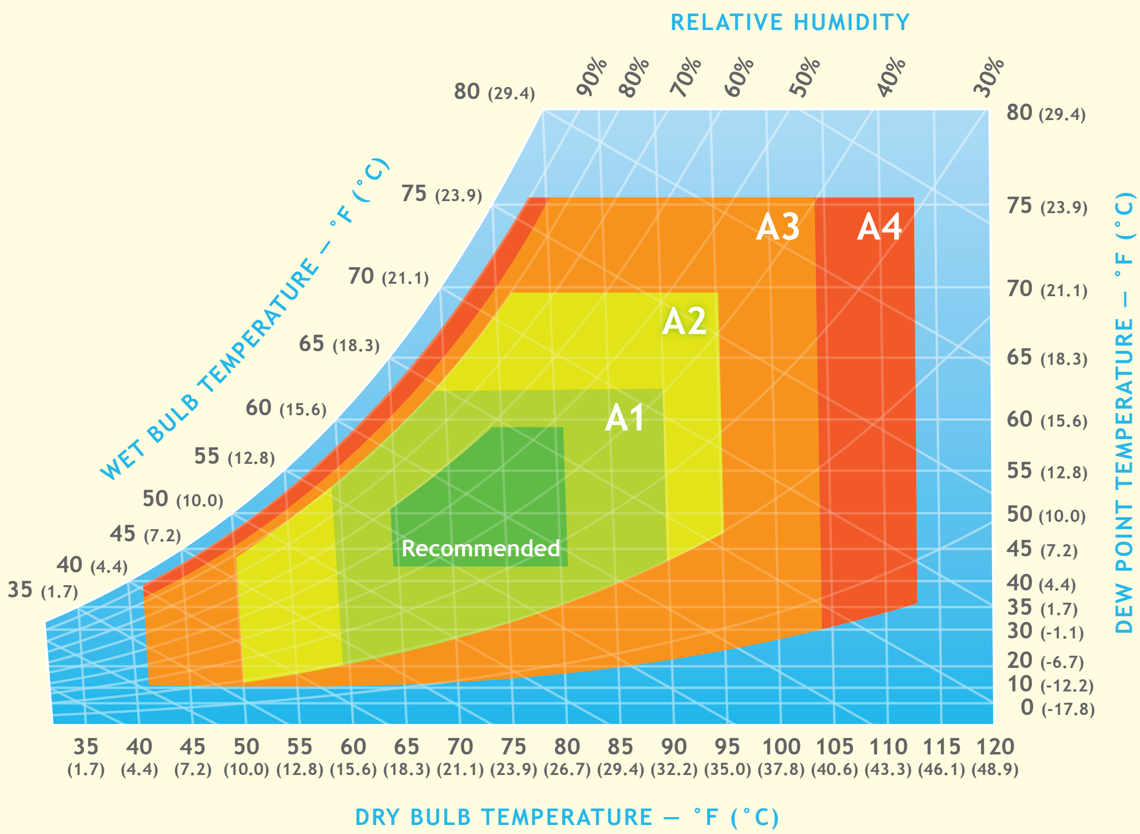
The biggest cause of stranded capacity is bypass airflow — supply air from the cooling units not passing through IT equipment before returning to the cooling units. Minimizing bypass airflow is fundamental to optimizing cooling infrastructure. Another way to estimate bypass airflow is to multiply the UPS load by 120, the industry average for CFM/kW of IT load. This is the required airflow in CFM for the IT load. Compare this to the airflow delivered by the running cooling units and you will likely find that the room is dramatically oversupplied with conditioned air. The manufacturer's specifications provides cooling unit airflow volume data. Another inefficiency indicator is to compare the supply air temperature from the cooling units to some of the highest rack intake air temperatures. The temperature increase is the result of hot exhaust air from the IT load contaminating cooling supply air.

Right-sizing cooling capacity provides numerous benefits:

- Improved cooling unit efficiency through increased return-air temperatures
- Improved IT equipment reliability by eliminating hot and cold spots
- Reduced operating costs by improved cooling effectiveness and efficiency
- Increased room cooling capacity from released stranded capacity
- Enabled business growth by increasing capacity to cool additional IT equipment
- Deferred capital expenditure for additional cooling infrastructure, or construction of a new data center
- Improved PUE from reduction of cooling load
- Reduced carbon footprint by reducing utility usage

Figure 5

Temperature and Humidity: 2011 Allowable Environmental Envelopes



RECOMMENDED	
Class	Dry Bulb, °F(°C)
A1 to A4	64.4 to 80.6 (18 to 27)

Most data centers follow the recommended guidelines

ALLOWABLE	
Class	Dry Bulb, °F(°C)
A1	59.9 to 89.6 (15 to 32)
A2	50 to 95 (10 to 35)
A3	41 to 104 (5 to 40)
A4	41 to 113 (5 to 45)

CCF for Both Types of Rooms

The primary purpose of a computer room is to provide stable and appropriate intake air temperature for IT equipment. As such, computer rooms are in either of two categories, those with and those without intake air temperature problems.

For rooms without intake air temperature problems, calculating the CCF provides valuable insight into the potential to run the room more efficiently. This reduces operating costs and frees up existing capacity for business growth.

For computer rooms with intake air temperature problems or challenges maintaining proper intake air temperatures, the first question to be answered is: Are the issues due to a lack of cooling capacity or poor AFM? The CCF will clearly answer this question.

Calculating Cooling Capacity Factor

The CCF is calculated by dividing the total running manufacturer's stated cooling capacity (kW) by 110% of the IT critical load (kW).

The total running cooling capacity is the sum of the running cooling units' rated capacities. If all cooling units are running, then this will be the same value as the total installed rated cooling capacity. For example, if there are 10 cooling units installed with a rated capacity of 30 tons each and seven are running, then the total running cooling capacity is 739 kW (7 x 30 tons = 210 tons, 210 tons x 3.52 = 739 kW). To convert tons to kW, multiply tons by the constant 3.52.

The IT critical load in the room is equal to the UPS output(s) for the room. Ensure that the UPS output used is only for the room being calculated. If the UPS feeds other rooms, then those loads must be subtracted from the total UPS output. To account for typical room load not reflected in the UPS output, add 10% for lights, people, and building envelope.

Cooling Capacity Factor (CCF) =
Total Running Cooling Capacity / UPS Output x 1.1

Cooling units are typically referred to by the manufacturer's stated capacity, such as a 30-ton or 20-ton cooling unit. If the manufacturer's stated cooling capacity is unknown, record the model number on the cooling unit nameplate **(Figure 6)** and search online or call the manufacturer.

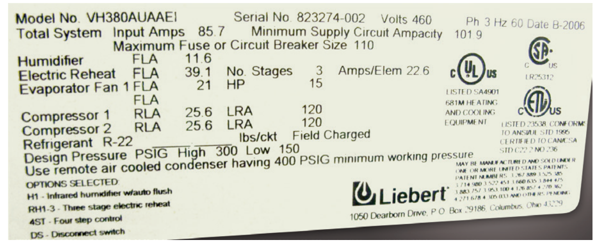


Figure 6

It is important to know that the manufacturer's stated capacity refers to the unit's total capacity at standard conditions, which refer to the temperature and relative humidity of the air returning to the cooling unit. Typically the standard conditions are 75˚F (24˚C) and 45% relative humidity (RH). If the return air conditions differ, the unit will have a different cooling capacity. If the return air is cooler than the standard condition, the unit will deliver less than the stated capacity. If the return air is warmer than the standard condition, the unit will be capable of more than the stated capacity.

Calculation of CCF uses the manufacturer's stated cooling capacity because if the room is configured reasonably well, then it will be possible for the unit to deliver at least the rated capacity. However, in their current state, many cooling units have a lower return air temperature set-point than the standard condition. The difference between the delivered capacity at current conditions and the potential capacity at the standard condition, or higher return temperature, is a form of stranded capacity.

How to Interpret Your CCF and Determine the Amount of Opportunity at Your Site

For rooms with a CCF of 1.0 to 1.1, there is little to no redundant cooling capacity. It is critical that AFM fundamentals be thoroughly implemented in these rooms to make available the maximum redundant capacity possible. It will then be necessary to install an additional cooling unit(s) to have redundant capacity. AFM improvements will likely improve IT equipment intake temperatures and create an environment where cooling unit set-points can be raised, which increases cooling unit efficiency and capacity. However, there is no opportunity to turn off cooling units or reduce fan speeds.

For rooms with a CCF of 1.1 to 1.2, the number of running cooling units is very closely coupled to the heat load in the room. IT intake temperatures are not outside of the ASHRAE recommended range and AFM fundamentals have been thoroughly implemented.

There is approximately one redundant cooling unit for every 10 units running. In most cases, this is sufficient to maintain the room temperatures if a cooling unit fails. Cooling units should not be turned off unless the room has 24-hour-by-forever monitoring and staffing.

For rooms with a CCF of 1.2 to 1.5, there is moderate opportunity to realize savings from turning off cooling units. This can often only be done once AFM improvements have been effectively implemented. This does not require full containment strategies, but does require thorough sealing of raised floor penetrations and open spaces in racks, and best practice placement of perforated tiles and grills.

A CCF of 1.5 to 3.0 is most common. These rooms have substantial opportunity to reduce operating cost, improve the IT environment, and increase the IT load that can be effectively cooled. Rooms in this range often have significant stranded cooling capacity that can be freed up by improving AFM.

Rooms with a CCF greater than 3.0 have great potential for improvement since the total rated cooling capacity of running units is at least three times 110% of the IT load.

Optimal Ranges for CCF

There are several factors that affect the potential best-case CCF for a site.

Room configuration has a large effect on the potential CCF that can be achieved. If there are significant areas of cabinets facing in the same direction (legacy layout) and significant amounts of standalone equipment, then AFM is inherently inefficient and limits how closely coupled cooling capacity can be to the IT load. The best achievable CCF will be around 1.8. Rooms without containment will have a higher possible CCF than if containment strategies were implemented. Rooms in which containment has been predominantly implemented will be able to achieve the lowest CCFs. Depending on the size and number of cooling units, rooms with containment may be able to achieve a CCF as low as 1.2.

With two or three cooling units running, it is difficult to get a low CCF because the redundant units may be required to be operating, adding to overcooling in the space. This does not hold true if the redundant units are in standby or if the units can be run at lower capacity. If there are only two cooling units in a room, then the best possible CCF will be approximately 2.5. One unit will be required to support the load and one unit will be required for redundancy, so there will be 2.0 times or 200% more cooling capacity than IT load. The larger the number of cooling units in a computer room, the lower the potential CCF value.

Remediation—Improving CCF

Calculating the CCF for a computer room reveals excess cooling capacity and opportunity for improvement. Upsite recommends following a practical, impactful, and cost-effective sequence of AFM initiatives that starts with the raised floor then moves to the rack then row. After implementing AFM improvements, changes at the room level need to be made. The CCF should then be recalculated to check progress towards the desired CCF. As more improvements are required this cycle needs to be repeated. The important point here is to utilize what Upsite calls the “4Rs” in their proper sequence.

1: Raised Floor

The first step is to seal all unmanaged openings in the horizontal plane of the raised floor. A thorough effort is required to identify and seal all raised-floor penetrations. Electrical equipment such as power distribution units (PDU) often have large openings that need to be sealed. This effort must be seen to completion because as each hole is sealed, the remaining holes release increasing volumes of valuable conditioned air.

2: Rack

The second step is to seal the vertical plane along the face of IT equipment intakes. Blanking panels that seal effectively (no gaps between panels) need to be installed in all open spaces within cabinets. The space between cabinet rails and cabinet sides need to be sealed if not sealed by design.

3: Row

The third step is to manage airflow at the row level. Spaces between and under cabinets need to be sealed to retain conditioned air at the IT equipment face and prevent hot exhaust air from flowing into the cold aisle. Adjust perforated tile and grate placements to make all IT equipment intake air temperatures as low and even as possible. This will include replacing perforated tiles or grates with solid tiles in areas where excess conditioned air is being provided, and adding perforated tiles to areas where intake temperatures are the highest. All perforated tiles and grates located in dedicated hot aisles and open spaces should be replaced with solid tiles. For high-density rooms and rooms with layout challenges (e.g. low ceilings, cabinet and/or cooling unit placement), partial or full containment strategies may be warranted.

4: Room

In most cases, even with high percentages of excess cooling capacity running, the first three fundamental steps of AFM must be implemented before changes can be made at the room level to reduce operating expenses. A common misconception is that AFM initiatives reduce operating expenses. Improving AFM will improve IT equipment reliability and throughput and free stranded capacity. However, to realize operational cost savings and defer capital expenditure of additional cooling capacity, changes must be made to the cooling infrastructure, such as raising cooling unit set-points, raising chilled water temperatures, turning off unnecessary cooling units, or reducing fan speeds for units with VFD.

Other Important Metrics

While not required for calculating a room's CCF, additional metrics are also useful in determining the effectiveness and efficiency of the AFM in a computer room:

- The number of hot and cold spots is the fundamental measurement of cooling effectiveness.
- The change in temperature from cooling unit supply to IT equipment intakes reveals how much mixing occurs in the room on the supply side, or how much exhaust air is mixing with supply air.
- The change in temperature from IT equipment exhausts to cooling unit returns reveals how much mixing occurs in the room on the exhaust side, or how much cold supply air is mixing with exhaust air.

In addition, PUE has become the most popular metric for determining the overall efficiency of data center infrastructure. In fact, PUE data reveals that the cooling infrastructure is the single largest consumer of data center power. Therefore, improving cooling infrastructure efficiency will have the largest effect on reducing a site's PUE. However, while PUE is a good overall metric, it does not identify the root problem and opportunities for improvement. This requires further analysis, and demonstrates why the CCF metric is so valuable. This quick and simple calculation reveals the utilization of your computer room cooling infrastructure. Improvements in a site's CCF will also improve its PUE.

Supporting Tools

Upsite's Online CCF Calculator

To help users get started, Upsite has created an online CCF Calculator (http://www.upsite.com/cooling-capacity-factor-calculator). By entering some simple site data, data center managers can estimate the CCF for their site. While this is not intended to replace an onsite assessment, determining the CCF is the first step in understanding the utilization of existing cooling capacity and opportunities to improve the environment, reduce operating costs, and increase server density. CCF and potential cost savings are calculated and a summary of data and calculations is also emailed to users.

Upsite's Bypass Airflow Clarified White Paper

This paper clarifies the common misconception of bypass airflow. (http://www.upsite.com/bypass-airflow-white-paper).

Glossary of Terms

Maximum Air Intake Temperature, "Hot spot"

The maximum allowable IT equipment intake air temperature that has been established for the site. If a maximum has not been established, use the maximum recommended temperature defined by ASHRAE, 80.6°F (27°C).

Minimum Air Intake Temperature, "Cold spot"

The minimum allowable IT equipment intake air temperature that has been established for the site. If a minimum has not been established, use the minimum recommended temperature defined by ASHRAE, 64°F (18°C).

Total critical power dissipation in the room

The total load of IT equipment. This value is best summed from the power distribution units in the room being reviewed. The UPS load for the reviewed room is acceptable if adjustments are made (subtractions) for any equipment supported by the UPS that is outside of the room being reviewed.

Total Running Cooling Capacity

The sum of the running cooling units rated capacities. If all cooling units are running, this will be the same value as the total installed rated cooling capacity. If there are 10 cooling units installed with a rated capacity of 30 tons each and 7 are running, then the total running cooling capacity is 739 kW (7 x 30 tons = 210 tons, 210 tons x 3.52 = 739 kW). To convert tons to kW, multiply tons by the constant 3.52.

For many reasons, cooling units do not (or cannot) deliver their rated capacity. Calculating the CCF is not intended to be a precise evaluation; it provides a very valuable indicator of utilization.

Stranded Capacity

The portion of the mechanical system that is running, but not contributing to, a dry-bulb temperature change because of return air temperatures, system configuration problems, poor AFM, or equipment layout.

Most stranded capacity can be inexpensively recovered by a mechanical system "tune-up", which includes improving AFM and adjusting cooling unit set-points.

Assumptions

- Cooling unit fan motors are running at full speed, no variable frequency drives (VFD).
- Cooling units are capable of delivering their full rated capacity. For multiple reasons, cooling units may not be delivering their full rated capacity: Chilled water valve is stuck, filters are dirty or have greater resistance than OEM filters, extra filters have been added, refrigerant is not fully charged, or sheaves are out of adjustment. It is a "best practice" to check at least annually the delivered capacity of all cooling units at full capacity.
- Heat load other than IT load (building envelope, lights, people, etc.) is 10% or less of IT load.
- UPS and other medium and high-voltage electrical components are outside the computer room.
- Raised-floor unmanaged open area is improved to less than 10% of total raised-floor open area.
- Cooling unit fan motor load is cooled by redundant capacity.

CAUTION:

To prevent IT equipment damage due to excessive temperatures and any subsequent downtime, it is extremely important, as part of a comprehensive cooling optimization plan, to carefully monitor IT equipment during any AFM changes. The appropriate CCF for each room is dependent on many factors, such as, but not limited to: cooling unit size, cooling unit number and placement, room configuration, heat load distribution, raised-floor height, and ceiling height.

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