WHITE PAPER

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

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Executive Summary

Computer rooms today, on average, have cooling capacity that is nearly four times the IT load. With data from 45 sites reviewed by Upsite, this white paper will show how you can calculate, benchmark, interpret and benefit from a simple, practical metric called the Cooling Capacity Factor (CCF).

This is significant, as there is a great deal of focus placed on improving computer room cooling efficiency as a way to reduce overall data center energy consumption, lower operating expenses, increase computer room density, and reduce carbon emissions.

Power Usage Effectiveness (PUE) has emerged as a popular metric for determining the overall efficiency of data center infrastructure. Study of PUE components reveals that the cooling infrastructure is the single largest consumer of power in data centers. Improvements to cooling infrastructure efficiency will have the largest effect on reducing a site's PUE. However, PUE does little to reveal how well the cooling infrastructure is currently being utilized and how much potential there is in making improvements.

There are numerous solutions that aim to improve cooling efficiency, ranging from something as simple and important as blanking panels to full-aisle containment. There is a lot of hype around the potential benefits of each new best practice. How do you truly know the potential there is to make a difference in your computer room? Will improved airflow management (AFM) make a difference at your site? By how much? What do you implement first?

To make informed decisions about spending money on additional cooling capacity or AFM initiatives, you first have to determine how well your current resources are being utilized.

Of 45 sites that Upsite has reviewed, the average running cooling capacity is an astonishing 390% of the heat load in the computer room. In some cases there is over a 3,000% capacity of the heat load.

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

The quickest and easiest way to determine the utilization of cooling infrastructure and the potential gains to be realized by improvements to AFM is to calculate what Upsite calls the Cooling Capacity Factor (CCF). The CCF is the ratio of total running nameplate cooling capacity to 110% of the critical load. This simple metric reveals the utilization of the most costly facilities infrastructure component in data centers. Calculating the CCF is the first step towards improving energy efficiency, reducing operating expense, improving the room environment, and supporting increasing server density.

History

How is it possible for sites making an effort to improve efficiency to have four times the cooling capacity needed? There are three primary causes.

- In the past, computer rooms were laid out in a "legacy" configuration—all the IT equipment facing the same direction. This was aesthetically pleasing, but resulted in very poor airflow management and mixing of supply air and exhaust air. Very low cooling unit set-points and extra cooling units were used to combat poor AFM.
- When a data center is typically commissioned, all the cooling units are turned on, and left on, even if the heat load in the room is low. And while server densities have dramatically increased, the total room heat load is often much less than the running cooling capacity.
- When data center managers were having difficulty cooling an area of their room, they often consulted cooling unit manufacturers for advice. Since no one compared installed cooling capacity to heat load it was assumed that problems were due to a lack of capacity. The true problem of poor airflow management remained hidden and additional cooling units were purchased.

Benefits of Knowing CCF — "Right-Sizing Cooling"

Often companies 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 aisle containment. Knowing the CCF for a computer room is important at any stage of AFM evolution and can help prioritize AFM improvement initiatives.

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 stranded capacity. In many sites there is excess cooling capacity and cooling problems. These are areas where IT equipment intake temperatures exceed desired maximums. Calculating the CCF reveals whether the cause is primarily a lack of capacity or poor AFM.

The biggest cause of stranded capacity is bypass airflow – supply air from the cooling units that does not pass through IT equipment before returning to the cooling units. Eliminating bypass airflow and improving airflow management are fundamental steps in optimizing cooling infrastructure. These are prerequisites for the efficient operation of any computer room and can even help site managers get the most out of their aisle containment investment.

There are numerous benefits that result from right-sizing cooling capacity:

- The computer room environment improves.
- Hot and cold spots are eliminated.
- The throughput and reliability of IT equipment increases.
- Operating costs are reduced by improved cooling effectiveness and efficiency.
- Released stranded capacity increases room cooling capacity, while deferring capital expenditure for additional cooling infrastructure. This enables business growth through the deployment of additional IT projects or other investments.

There are additional benefits beyond just turning off computer room air conditioning (CRAC) units that, while more difficult to quantify, are real improvements to the data center environment and produce significant cost savings. They include:

- Improved cooling unit efficiency through increased return air temperatures.
- Improvements to IT equipment reliability by elimination of hot spots and cold spots.
- Increase in supported IT load through improved utilization of airflow.
- Reduced carbon footprint via reduction in utility usage.
- Deferred capital expenditure by increasing the utilization of existing infrastructure.

Site Examples

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

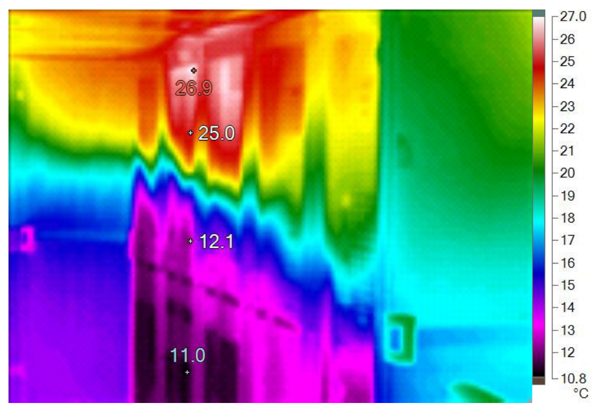


Figure 1

This image (figure 1) of a fully contained cold aisle shows a dramatic difference in the intake temperatures of IT equipment in the bottom of the cabinets versus the tops of cabinets (the doors had been closed just prior to taking this image). This is the result of an insufficient volume of conditioned air being delivered to the contained space and unsealed open spaces in the cabinets that allow conditioned air to flow out of the space and exhaust air to flow in. So even though cold-aisle containment has been installed, and the site has a CCF of 3.8 (cooling capacity of 380% of room load) the IT equipment intake temperatures were not improved. A more cost-effective solution would have been to seal cable openings and install blanking panels throughout the site. As densities increase at this site, full containment may later become necessary.

Another advanced solution that is often inappropriately incorporated into computer rooms is fan assisted perforated tiles. The problem they address is an insufficient volume of conditioned air to cool the adjacent IT equipment. While fan assisted tiles do deliver more conditioned air, they do so at the cost of reducing the volumes of conditioned air coming out of perforated tiles in the surrounding area, and by adding heat load. In most cases, sufficient volumes of conditioned air can be produced from the existing perforated tiles simply by sealing unmanaged openings in the raised floor. This solution has many other benefits such as increasing the volumes of conditioned air through all perforated tiles in the room, reducing or eliminating hot spots, and supporting the ability to raise cooling unit set points. Calculating a room's CCF quickly identifies the potential for solving cooling problems with inexpensive solutions. There are, of course, appropriate applications for fan assisted tiles. When raised floor heights and/or obstructions limit the volume of conditioned air in an area of a room, or when very high density cabinets require more cooling than can be delivered by standard perforated tiles or grates. In these cases, fan assisted tiles are necessary.

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

This room had 170 cabinets drawing a total load of 300 kW. The load was being cooled by eight cooling units rated at 70 kW each and one unit rated at 85 kW. The cost for electricity was $0.10/kWhr. The site manager was struggling to maintain appropriate IT equipment intake air temperatures. The site's CCF was calculated to be 2.2. In other words, the running cooling capacity was 220% of the room's heat load. A CCF of 2.2 indicates that the site's cooling challenges were due to poor AFM not insufficient cooling capacity.

To right-size the cooling infrastructure, a number of simple improvements were made to the room including sealing cable openings, installing blanking panels, and making adjustments to both the number and location of perforated tiles. By doing this all IT equipment hot spots were eliminated and two cooling units could be turned off. This resulted in saving of $21,900 per year and a payback period of less than eight months!

Two 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 can be categorized in two types, those without intake air temperature problems and those with 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 existing capacity for business growth.

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

Calculating Cooling Capacity Factor

The CCF is calculated by dividing the total running, nameplate 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 cooling capacity. For example, if there are 10 cooling units installed each with a rated capacity of 30 tons, 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. It is important to make sure that the UPS output used is only for the room being calculated. If the UPS feeds other rooms, then those loads need to 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

If the nameplate rated cooling capacity is not known, then the model number can be found on the cooling unit nameplate (figure 2) and used to determine the capacity by looking the unit up online or by calling the manufacturer.

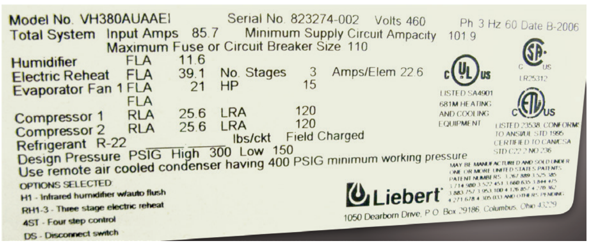


Figure 2

How to Interpret Your CCF

If the CCF for a room is between 1.0 and 1.1, then there is little to no redundant cooling capacity. It is critical that the fundamentals of AFM be thoroughly implemented in these rooms so that as much redundant capacity as possible is made available. It may even be necessary to install an additional cooling unit 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. But there is no opportunity to turn off cooling units.

If a CCF is 1.1 to 1.2 then the number of running cooling units is likely being managed well. There are approximately one to two redundant cooling units for each 10 units running. In most cases, this is sufficient to maintain the room temperatures when/if a cooling unit fails. It is not recommended that any cooling units 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. A CCF of 3.0 means that the total rated cooling capacity of running units three times 110% of the IT load.

Field Findings

Site data collected from 45 EnergyLok Profile assessments reveal some surprising statistics (figure 3).

Most significant from this data is that the average cooling capacity factor of the sites reviewed was 3.9 (running cooling capacity was 390% of the heat load in the room). Running means that only the number of active / running cooling units were considered in the calculations. Many sites have already turned off some of the excess cooling units in the room.

The range of room sizes demonstrates that issues of over implemented cooling are not unique to small, less sophisticated sites. The average CCF of

Figure 3

	Raised floor area (sq ft)	# of running cooling units	Raised floor bypass open area (%)	Hot spots (%)	Cold spots (%) (Data from 6 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

the five largest sites reviewed was 2.4, significantly better than the overall average of 3.9, but still approximately twice as much cooling as 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. The percentage of bypass open area should be less than 10%.

The most important metric in a computer room is the percentage of hot and cold spots. These figures are determined counting the number of cabinets that contain at least one piece of IT equipment that requires cooling with an intake air temperature above or below the desired range. The percentage of hot and cold spots should be zero. No hot spots were observed at only nine (20%) of the 45 sites. Data on cold spots was collected for eight sites. Of those eight sites only one had no cold spots.

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 only 77% of the time properly located. Only six (13%) of sites had properly placed 100% of their perforated tiles. Thought should be given to the placement of every perforated tile. There should never be perforated tiles in open spaces or hot aisles.

Optimal Ranges for CCF

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

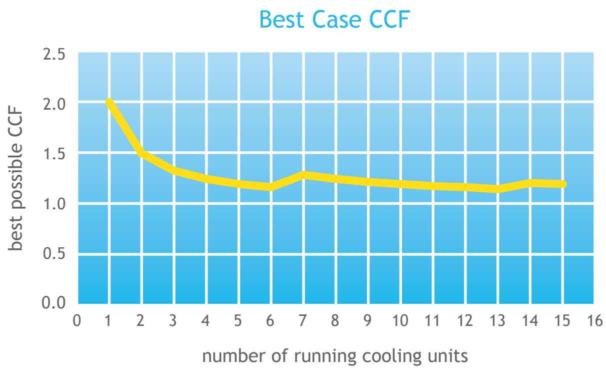
Room configuration has a large effect on the potential CCF that can be achieved. If there are significant areas of cabinets facing in the same direction (legacy layout) and significant amounts of standalone equipment, then AFM is inherently inefficient and limits how closely coupled cooling capacity can be to the IT load. The best achievable CCF will be around 1.75 to 2.0. Open-air rooms and rooms without containment will have a best possible CCF, which would be higher than they would 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 1.1.

The lower the number of cooling units the higher the best possible CCF will be. If there are only two cooling units in a room, then the best possible CCF will be approximately 2.0. One unit will be required to support the load and one unit for redundancy. So there will be 2.0 times or 200% more cooling capacity than IT load. This is necessary so that if one unit fails the other can carry the load. The following table (figure 4) and graph (figure 5) and show the relationship between cooling unit number and potential CCF.

Figure 4

# of units required to support total load (IT x 1.1)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
# redundant	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3
# of units running	2	3	4	5	6	7	9	10	11	12	13	14	15	17	18
Best case CCF	2.00	1.50	1.33	1.25	1.20	1.17	1.29	1.25	1.22	1.20	1.18	1.17	1.15	1.21	1.20
1 redundant unit per # of required units	1.0	2.0	3.0	4.0	5.0	6.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	4.7	5.0
Average load on each cooling unit under normal conditions	50%	67%	75%	80%	83%	86%	78%	80%	82%	83%	85%	86%	87%	82%	83%
Average load on each cooling unit when 1 fails	100%	100%	100%	100%	100%	100%	88%	89%	90%	91%	92%	92%	93%	88%	88%

Figure 5



Remediation

First step
Calculating the CCF will likely reveal excess running cooling capacity. If so, realizing the most improvement requires following a proven process.

Second step
The second 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. Often electrical equipment such as power distribution units (PDU) 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. Grommets that seal effectively are required.

Third step
The third 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 the sides of the cabinets need to be sealed if not sealed by design. Spaces between cabinets and under cabinets need to be sealed to retain conditioned air at the IT equipment face and to prevent hot exhaust air from flowing into the cold aisle.

Fourth step
The fourth step is to manage perforated tile and grate placement 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.

In most cases, even with high percentages of excess cooling capacity running, these fundamental airflow management steps must be implemented before changes can be made that will reduce operating expenses. It is a common misconception that airflow management (AFM) initiatives reduce operating expenses. Improving AFM will improve IT equipment reliability and throughput, and free stranded capacity. But 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 variable frequency drives.

Additional Important Metrics

While not required for calculating a room's CCF, a few other 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 on the supply side. In other words, how much exhaust air is mixing with supply air. The change in temperature from IT equipment exhausts to cooling unit returns, clearly reveals the amount of mixing that occurs in the room on the exhaust side. Put another way, how much cold supply air is mixing in with exhaust air.

Supporting Tool: 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 cooling capacity factor 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. A summary of data and calculations is also emailed to users.

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 then use the maximum recommended temperature defined by ASHRAE, 80˚F (27˚C).

Minimum 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 then use the minimum recommended temperature defined by ASHRAE, 64˚F (18˚C).

The total critical power dissipation in the room

The total critical power dissipation in the room is 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.

Room load

The room load is the critical load, or UPS load in the room plus an additional 10%. Room load = UPS load x 1.1. This simplistic method is used to estimate the heat load for the room. For various reasons the actual heat load could be higher or lower.

Total Running Cooling Capacity

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 cooling capacity. If there are 10 cooling units installed each with a rated capacity of 30 tons, 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.

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, sheaves are out of adjustment. It is a best practice to at least annually check 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.
- Assumes 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.

Please Note:

To ensure that IT equipment is not damaged by excessive temperatures and that downtime does not result, it is extremely important that any changes to AFM only be made while carefully monitoring the IT equipment, and as part of a comprehensive cooling optimization plan. 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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