# Using Simulation to Improve Data Center Efficiency

## Cooling Path Management for maximizing cooling system efficiency without sacrificing equipment resilience

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**04/8/2009**

Modern IT equipment with high power dissipation and powerful internal cooling fans are a primary cause of cooling and efficiency problems in today's mission critical facility. These problems appear when high-velocity, high-temperature exhaust air from IT equipment flows unintentionally into the inlets of surrounding equipment despite measures taken to prevent such occurrences. The conventional approaches to data center cooling design such as the hot aisle/cold aisle layout, kW per cabinet limits and the use of traditional computational fluid dynamics (CFD) software tools are blind to equipment related cooling and efficiency problems.

This paper describes a new CFD-based modeling capability and design methodology that overcomes the limitations of conventional guidelines and traditional CFD-based approaches and is effective at addressing equipment related cooling and efficiency problems in the data center. Depending on circumstances, 30-50% improvement in cooling system efficiency can be achieved by this specialized CFD-based approach.

Executive summary

 

# The Efficiency Challenge of the Modern Data Center

## Make more power available to the IT equipment

Much of the power used for data center cooling is wasted due to suboptimal airflow conditions such as supply air bypassing the IT equipment and flowing directly to the air conditioning unit (ACU) returns. This article will present a step-by-step process to analyze and optimize the paths that air takes from the ACUs to the IT equipment and back. The process can be used to substantially improve cooling system efficiency by configuring any combination of IT and cooling equipment to reduce bypass and recirculation. As a result, more power becomes available for use by the IT equipment or to reduce energy bills. Often efficiency improvements of 30-50% or more can be achieved by this simulation based design and optimization technique.

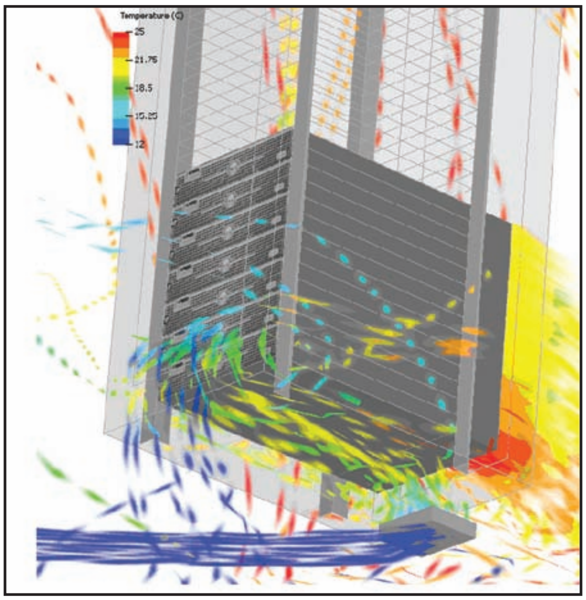

**Figure 1:** Air recirculation within cabinets is a common cause of overheating and efficiency problems

## Energy Efficiency Opportunities

Power utilization in the data center is typically split 50 – 40 between the IT equipment and the cooling system. The remaining10% of total power is used by supporting equipment such as lights and UPSs. [1] The actual percentage breakdown for any specific facility will vary but, in most cases, the cooling system offers a significant opportunity that is under the control of the owner/operator to increase the overall data center efficiency. Power used by the cooling system is typically split evenly between the fans and the chilled water system. Cooling system efficiency, therefore, can be improved specifically by reducing fan and chilled water system power consumption.]

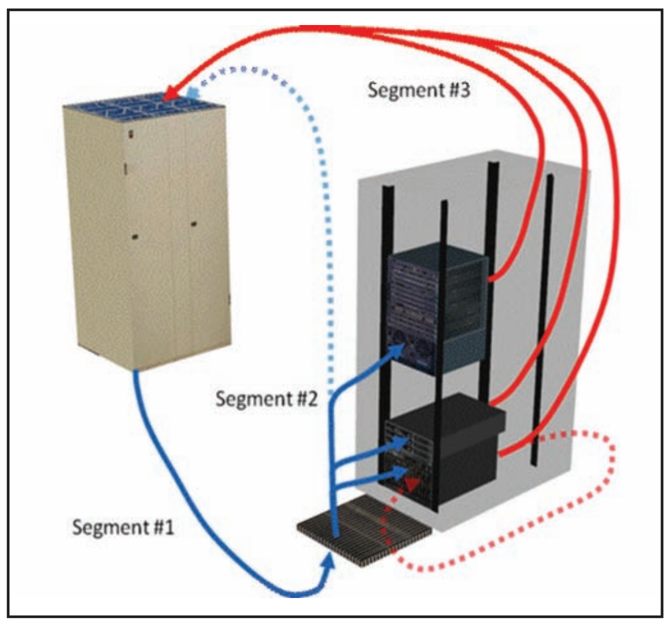


**Figure 2:** The Cooling Path is the route taken by the cooling air from the air handler supply to the equipment inlets and from the equipment exhausts to the air handler returns

For historical reasons, cooling systems are often designed under sweeping assumptions that grossly oversimplify the physics of airflow. For example, it is common to use a maximum kW per cabinet assumption to approximate the worst case IT loading condition. There are three major problems with this type of sweeping assumption.

Firstly, it is completely blind to the most common cooling problems that occur in the data center which are thermal interactions between the IT equipment and the surrounding environment. An example is shown in Figure 1 where exhaust air cannot escape the cabinet and is forced back into the intake

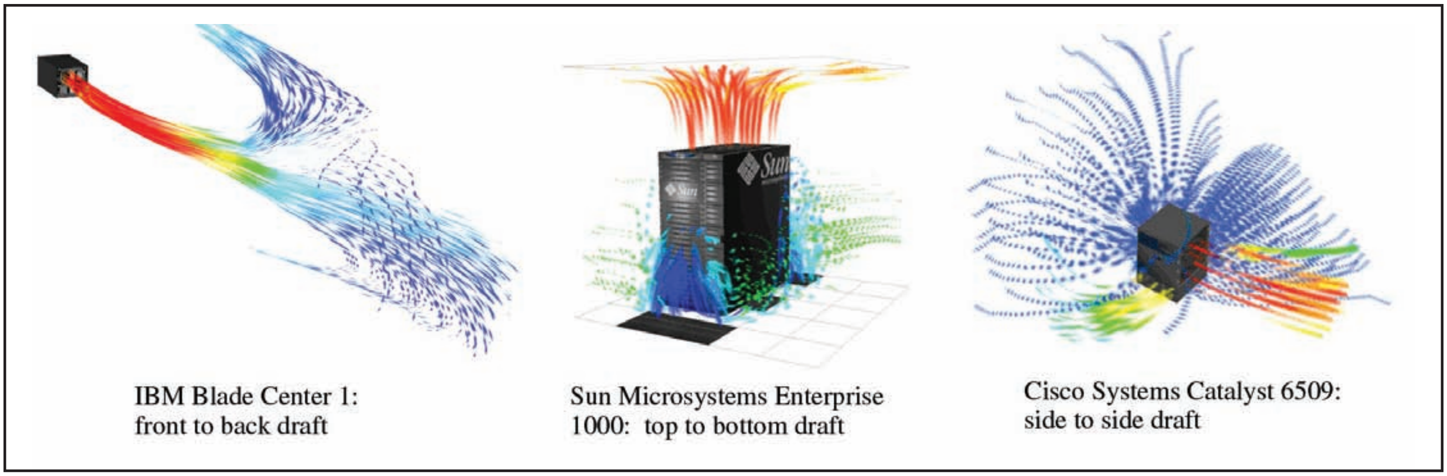


**Figure 3:** Thermal footprints are unique to model of IT equipment

through a gap between the bottom of the unit and the cabinet.

Secondly, equipment related thermal problems cannot be solved for all-time with a single, blanket design solution because the IT equipment is under constant change due to refresh or changing business requirements. Over time, data centers experience dozens of different worst case conditions. Each condition must be addressed individually at the time of occurrence to maintain acceptable levels of resilience and operating efficiency.

Finally, a single, blanket cooling solution by definition leads to over cooling, excessive power consumption and reduced efficiency in order to cover all possible worst case conditions. Often 30-50% of the power used to operate the chiller and the air handler fans can be recovered by a cooling design that fits the current IT configuration. [2] Fan power consumption is proportional to the cubic root of fan speed so reducing airflow by a factor of two reduces fan power consumption by a factor of eight. Similarly, a 9 °F increase in chilled water temperature set point decreases chiller power consumption by about 25%.

Given these challenges, a design methodology is needed that overcomes the limitations of the conventional design guidelines (hot aisle/cold aisle, blanking) and the traditional CFD-tools by properly accounting for the cooling and efficiency problems caused by IT equipment and the time varying nature of IT deployments.

## Addressing the Energy Efficiency Challenge

### Cooling Path Management

Cooling Path Management (CPM) is a CFD-based methodology for data center cooling design and optimization. CPM can address all possible airflow-related cooling breakdowns and sources of inefficiency for any configuration of room, cooling system and IT equipment. CPM can be used for initial cooling system design and for ongoing management of cooling system performance that is a challenge due to IT equipment related cooling problems and the time-varying nature of IT deployments. CPM is based on a specialized implementation of CFD analysis that solves the governing equations for fluid motion and heat transfer over the full range of physical scale that occurs in the data center

 

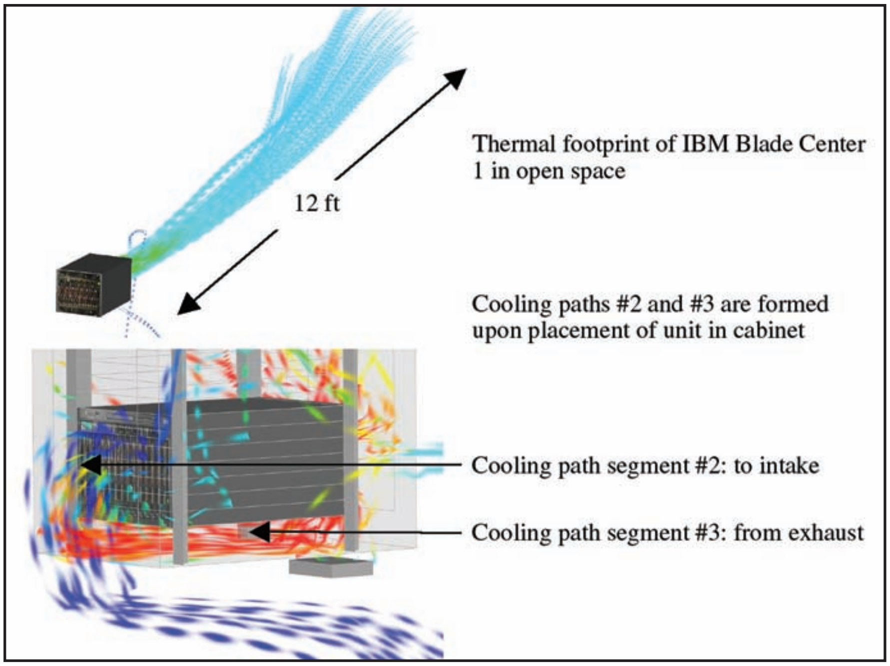


**Figure 4:** Thermal footprints interact with the surrounding environment to form segments #2 and #3 of cooling path

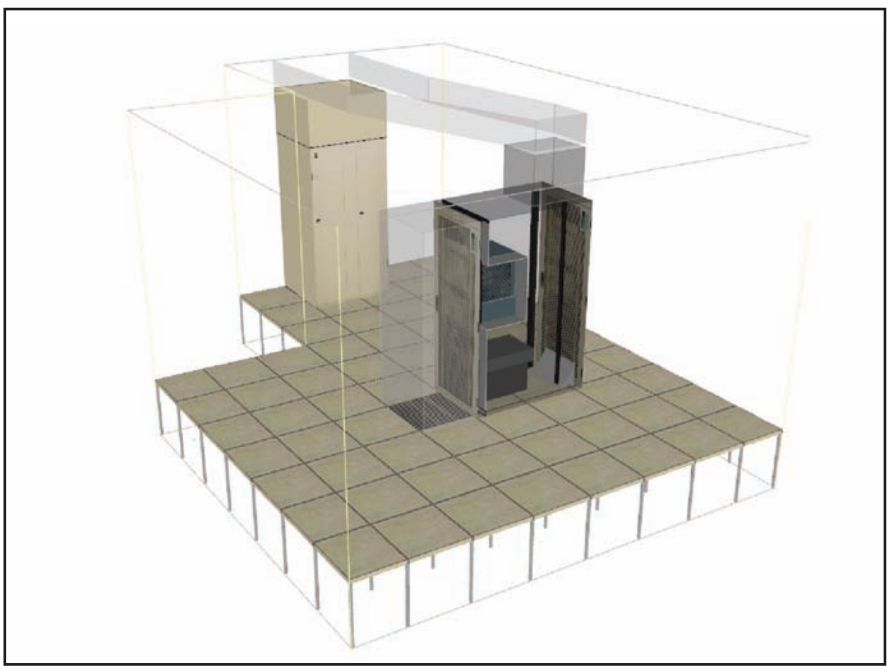

**Figure 5:** A simple data center system with one air handler and three different models of IT equipment

(from small gaps within cabinets to the open room). This implementation of CFD provides a 3D graphical view of the entire "cooling path" over which the breakdowns occur.

The cooling path is the route taken by the cooling air from the air handlers to the intakes of each unit of IT equipment and from each exhaust vent back to the air handlers. Cooling paths are formed by the thermal and physical characteristics of the IT equipment, cabinets and room and the way they are configured within the data center. The cooling path can be split into three primary segments to simplify the CPM design process as shown in Figure 2.

Each segment of the cooling path has a specific design goal and associated set of design options. This makes CPM intuitive, easy to use and applicable to all possible combinations of IT equipment, cabinets and rooms.

***Key concept: A cooling path is 100% efficient when it is completely free of vortices, bypass and recirculation***

The design objective for Segment #1 is to meet the temperature and airflow requirement for each floor grille by finding the right combination of floor height, air handler selection and placement of air handlers, floor grilles and under floor objects. The design process is often streamlined by pre-setting some of the variables and then sequentially setting the remaining variables to meet the requirements. A common practice starts with a hot aisle/cold aisle floor tile arrangement followed by air handler selection and placement. Fine tuning can be performed by adjusting the locations of the air handlers, under floor objects (pipes and cable trays) and floor grilles. CPM is an effective technique for under floor and airflow return design and is universally applicable to any configuration of room and floor grille arrangement. The design objectives for Segments #2 and #3 are to meet the intake temperature and airflow requirements for each unit of IT equipment. Additional requirements to minimize bypass and recirculating airflow can be imposed to fine tune to increase cooling system efficiency.

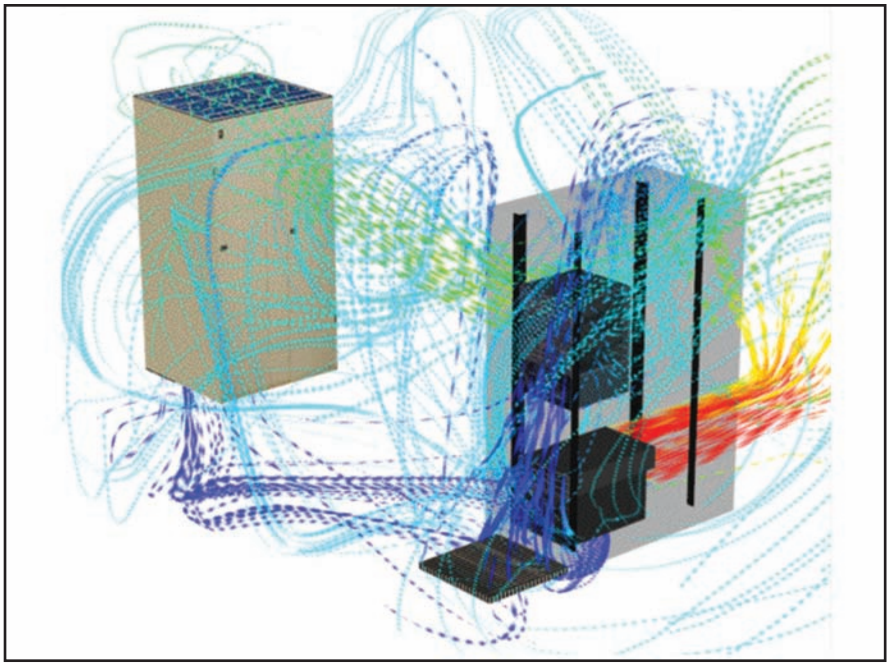

**Figure 6:** Cooling path segments #2 and #3 are completely unconstrained

These requirements are met by finding the combination of cabinet design, cabinet placement, cable routing and u-slot location that are compatible with the thermal characteristics of the IT equipment to be installed.  CPM greatly streamlines design and optimization of Segments #2 and #3 when large numbers of cabinets and IT equipment are involved.

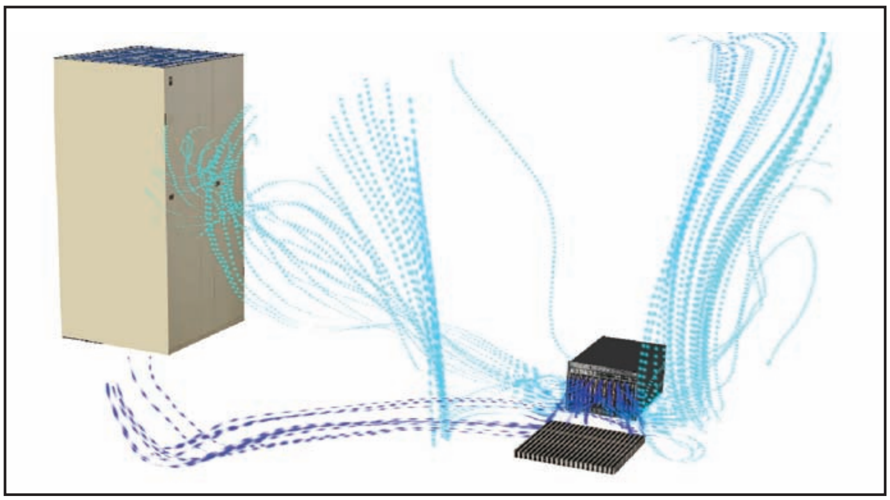

**Figure 7:** Isolated view of cooling path segment #2 for the Blade Chassis which shows significant mixing of supply and return air

Three properties of IT equipment - power dissipation, CFM requirement and ventilation configuration combine to form a unique “thermal footprint” and become the source of cooling path formation for Segments #2 and #3.  Figure 3 illustrates how thermal footprints are unique to IT equipment model type.

Thermal footprints interact with the surrounding environment to define cooling path segments #2 and #3 that lead to and away from the equipment inlets and exhausts as illustrated in Figure 4.

***Key Concept:  Understanding the interactions between thermal footprint and the environment is the basis for addressing the most common data center cooling and efficiency problems***

Given the impact of thermal footprints on the data center environment, it is no surprise that cooling path segments #2 and #3 can change dramatically with each configuration of IT equipment, cabinets

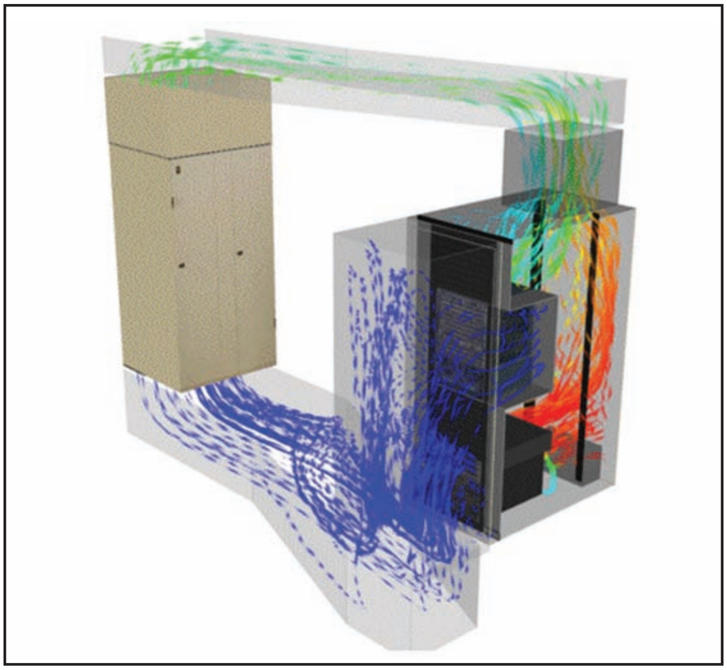

**Figure 8:** Cooling path segments #2 and #3 are completely constrained

and room. As a result, resilience and efficiency are dramatically impacted by IT equipment refresh and locations changes.

***Key concept: CPM is effective for maintaining resilience and energy efficiency as IT configurations change over time***

The simple system shown in Figure 5 will be used to show how cooling paths #2 and #3 are defined by the interactions between thermal footprint and the environment and how CPM is used to improve cooling system efficiency. Two versions of this system will be examined.

The first has a typical raised floor configuration that supplies air to a floor tile in front of the cabinet within which sit the IT equipment. This design does not constraint cooling path segments #2 and #3 as shown in Figure 6.

Further, air volume is oversupplied by 50%. Oversupply of air and unconstrained cooling paths create significant amounts of bypass and air recirculation which significantly reduces cooling system efficiency.

| Version | Description | % bypass | % recirculation | Average inlet temperature | Cooling system power requirement |
|---|---|---|---|---|---|
| **1** | Unconstrained cooling paths | 45% | 39% | 75.6 °C | — |
| **2** | Fully constrained cooling paths | 0% | 0% | 62.1 °C | **Reduced by 46%** |

**Table 1:** The effect of Cooling Path Management on cooling system efficiency

Figure 7 is an isolated view of the Blade chassis server at the bottom of the cabinet to show cooling path segment #2 in detail for this unit.

Here, 44% of the supply air comes from the air handler (dark blue) and 56% comes from the room (light blue). This drives up the intake temperature to 73 °F which is 10 °F higher than the air being supplied by the air handler – a highly inefficient condition.

The second design option for this facility has air ducts that completely constrain cooling paths #2 and #3 as shown in Figure 8.

Further, the air handler is supplying the exact amount of air in CFM that is required by the IT equipment. As a result, bypass and recirculation are completely eliminated and the cooling paths are100% efficient. Perfect constraint of these segments maximizes the cooling effect of the air handler, drops the average inlet air temperature by about 13 ºF and reduces the CFM requirement by 50%. With the extra margin on inlet temperature, the chilled water set point can be increased by 13 ºF. By matching the supply to the demand, fan speed can be reduced by 30%. This results in a 20% and a 50% reduction in power consumed by the chiller and fans respectively. Table 1 summarizes the results of CPM on the efficiency of this simple data center system.

## Summary

In real-world data centers, complete cooling path constraint is not practical as IT configuration flexibility is often needed to meet business requirements. This makes CPM for real-world data centers an ongoing effort to minimize the negative impact of partially unconstrained cooling paths on resilience and efficiency. This is a difficult to impossible task without the benefit of a simulation-based methodology like CPM and a CFD tool that can reveal the full details of cooling path segments #2 and #3. Finally, visibility of the entire cooling path makes CPM a useful and cost effective approach initial cooling system design and for ongoing change management of the facility to maintain acceptable levels of IT equipment resilience and energy efficient operation over its lifespan.

## References


1. For more information see, Tschudi, Greenburg, Mills, et. al. (2006) Best Practices for Data Centers: Lessons Learned from Benchmarking 22 Data Centers, ACEEE Summer Study on Energy Efficiency in Buildings, Berkeley, CA
2. For more information see, Malone, C. and Belady, C. (2006) Metrics to Characterize Data Center IT Equipment Energy Use. Proceedings of 2006 Digital Power Forum, Richardson, TX


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## About Future Facilities

Future Facilities (http://www.futurefacilities.com) is dedicated to providing simulation-based design and operational management solutions to address the thermal and efficiency problems facing the modern mission critical facility. The company's main product is 6SigmaDC, a suite of integrated software products that is the backbone of the cooling path management approach to design and operational management of the data center.