Data Center Airflow Management Basics: Key Steps for Optimizing Cooling Performance

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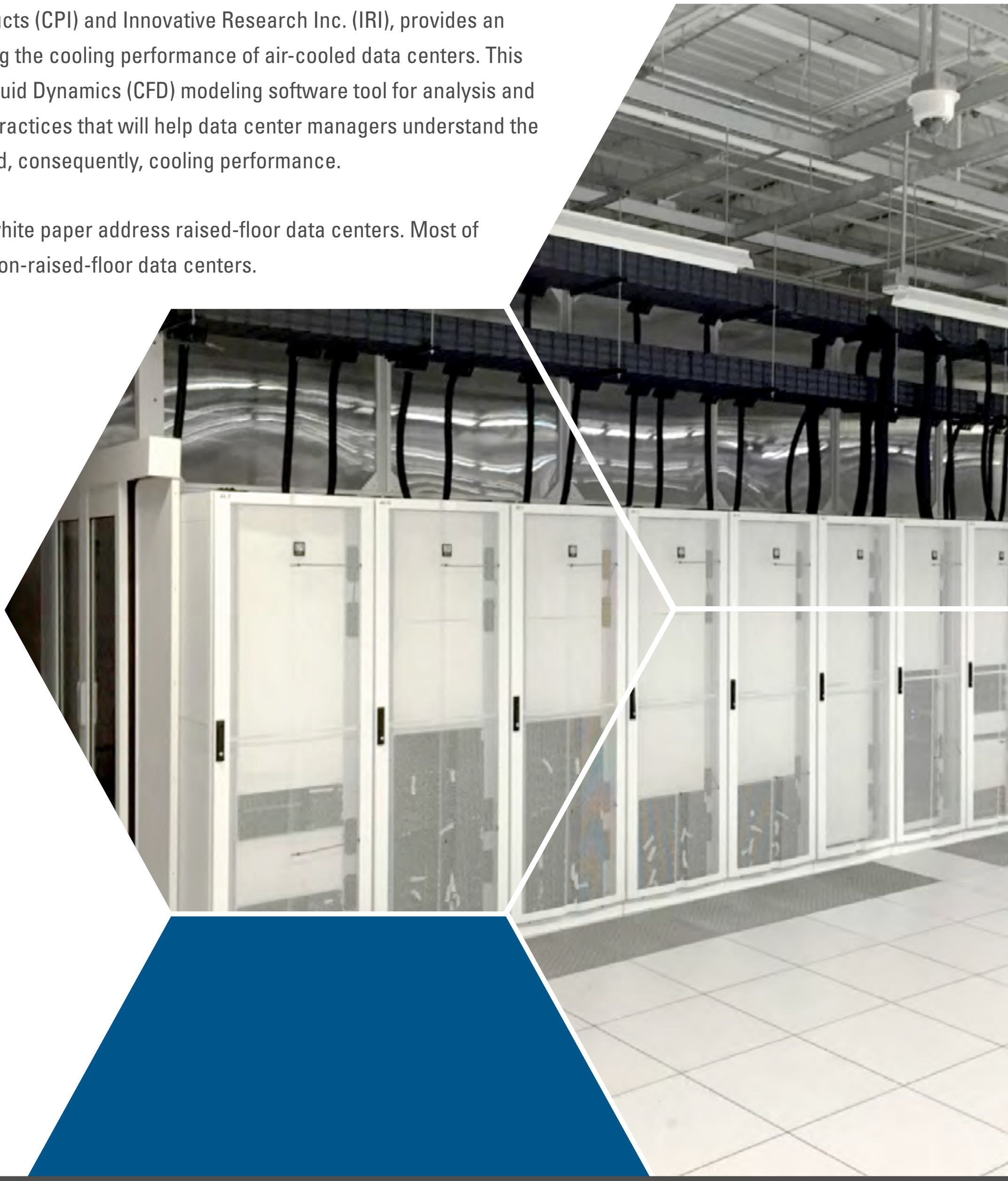
Introduction

One of the main operational challenges in data centers is optimizing cooling performance. Optimizing cooling performance improves capacity utilization and may allow cooling system adjustments that reduce cooling costs and OPEX. In air-cooled data centers, the key is to understand how changes in the site impact cooling, and how airflow management can be used as a tool for optimization.

There are practical limits to how much power or air can be delivered to a cabinet depending on each room design. However, today's average cabinet density of 8-10 kW[1] is well within the cooling capacity of typical airflow supplied to the cabinet. With this in mind, it is likely many organizations still have some unused or possibly wasted cooling capacity in their air-cooled data center, especially if they do not practice a comprehensive airflow management strategy.

This white paper, by Chatsworth Products (CPI) and Innovative Research Inc. (IRI), provides an overview of the key steps for optimizing the cooling performance of air-cooled data centers. This includes employing a Computational Fluid Dynamics (CFD) modeling software tool for analysis and exercising airflow management best practices that will help data center managers understand the what and how of optimizing airflow and, consequently, cooling performance.

Note: The steps and solutions in this white paper address raised-floor data centers. Most of the steps and solutions also apply to non-raised-floor data centers.



Key Steps for Optimizing Cooling Performance

Airflow management is the principle method of optimizing cooling performance in air-cooled data centers. Airflow management allows data centers to closely match the supply and demand of conditioned air. Not focusing on this relationship, will add unnecessary capacity, which just drives cooling costs up.

Optimizing cooling performance (in raised floor data centers) has five key steps:

1. Identifying the causes of cooling issues
2. Sealing openings
3. Balancing airflow
4. Adding containment to isolate hot and cold air
5. Adjusting the cooling system

Step 1: Identifying Causes of Cooling Issues

There are many factors that impact airflow in the data center white space, including:

- The shape and size of the room
- Raised floor and ceiling heights
- Locations, types, and settings of cooling units
- Location and open area of perforated tiles
- Location and open area of cutouts
- Location and size of under-floor obstructions
- Location, orientation, heat load, and airflow of cabinets
- Location and size of above-floor obstructions

Computational Fluid Dynamics (CFD) modeling software simulates all these factors to help data center managers visualize temperature distribution, airflow patterns, and pressure differentials in computer rooms. With careful modeling, it is possible to quickly see where conditioned air is wasted and how airflow management methods, like sealing cable openings in raised floors and aisle containment, improve operating conditions and allow cost-saving adjustments to cooling equipment.

Every site is unique, which makes CFD modeling software a crucial tool for identifying causes of cooling issues. Use it to create a digital twin of your data center and to analyze the impacts of changes prior to deployment in order to maintain optimal conditions for the site.

The goals and techniques of airflow management are universal: to deliver the correct amount and condition of air to the front of equipment in the cabinets. The techniques are to seal openings that leak cooled air, to add/remove perforated tiles, and to isolate hot and cold air to help reduce the volume of cooled air required by the equipment

CFD modeling illuminates a mismatch between airflow demand and supply, as equipment load typically varies across the room (Figure 1).

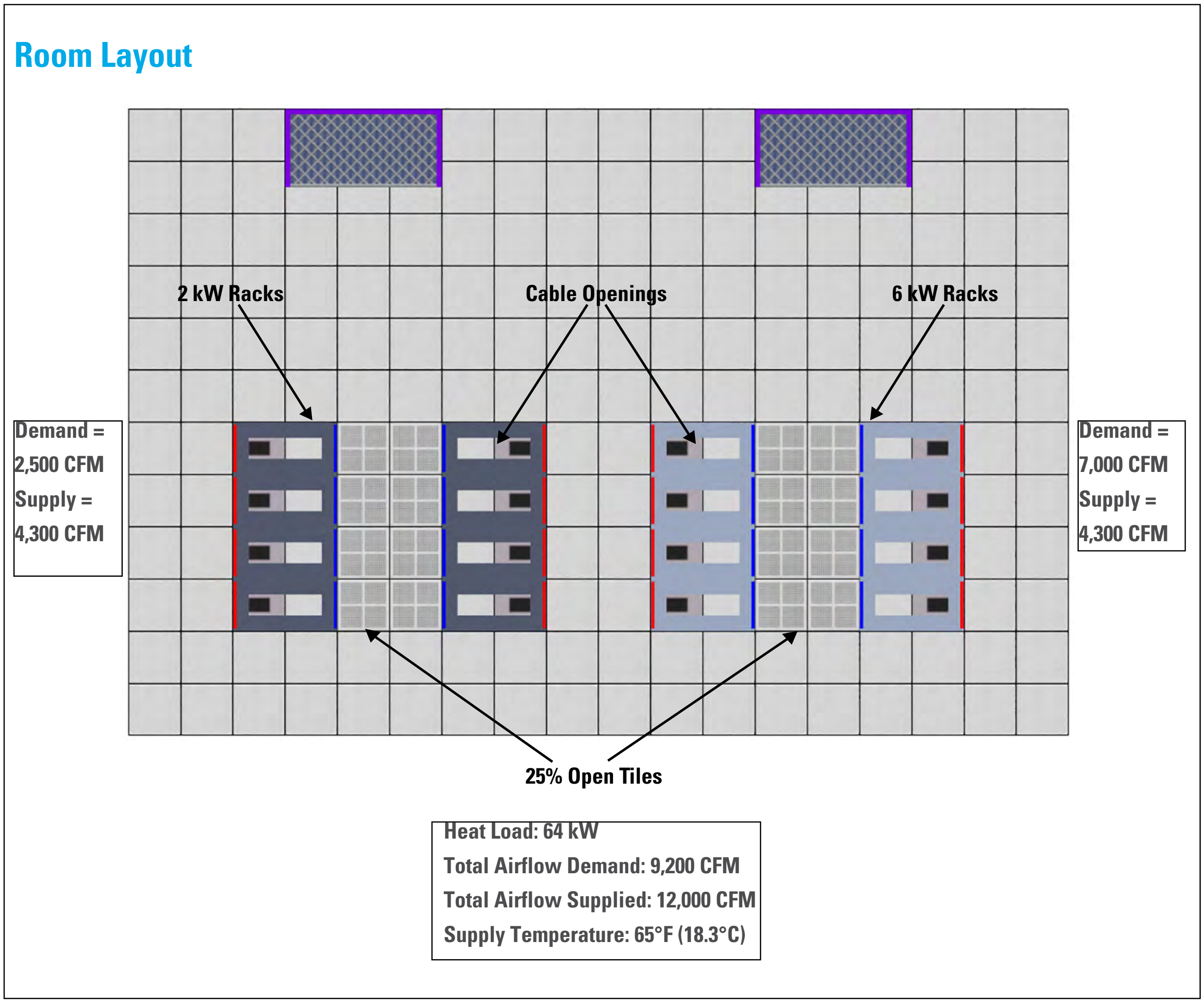


Figure 1: This is a typical symmetrical room layout, but note the difference in heat load between cabinets on the left and right side of the room. The heat load difference translates into a difference in airflow demand, but the uniform room design will deliver the same amount of air to all racks.

Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

Another factor that affects cooling efficiency in raised floor environments is unsealed openings in raised floor tiles. Unsealed openings cause a significant amount of conditioned supply air to be lost, resulting in wasted energy cost (Figure 2).

Airflow From Perforated Tiles and Cable Openings

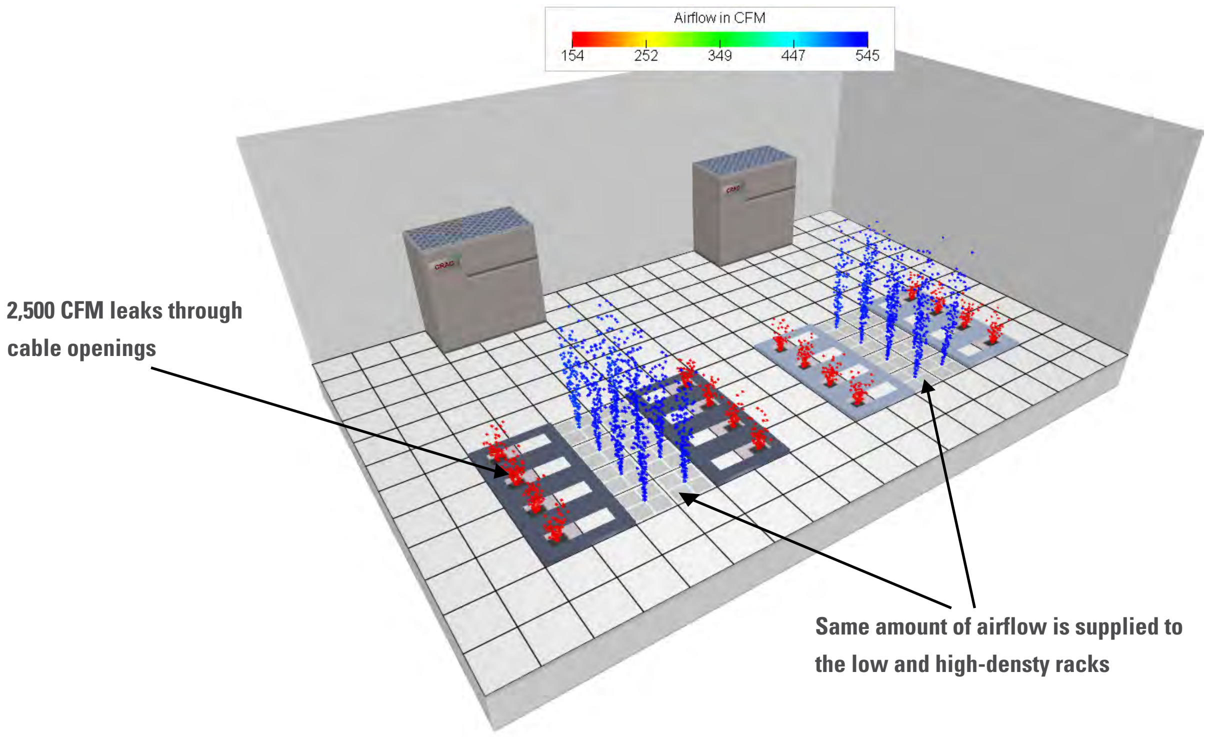


Figure 2: The red plumes in the screenshot of the CFD model above show conditioned air leaking through unsealed cable openings at the back of cabinets and, therefore, not contributing to cooling equipment directly.

In this example, 2,500 CFM is lost through unsealed cable openings. Refer to Figure 1, and note that there is 9,200 CFM required, 12,000 CFM supplied and 2,500 CFM leaking. That leaves only 300 CFM of extra supply (unused capacity).

Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

The combination of mismatched airflow for high density cabinets and raised floor openings that are not properly sealed is uneven temperature in the room, wasted chilled air on one side of the room and an insufficient amount of chilled air on the other side of the room. The result is recirculation of high temperature air on the other side of the room (Figure 3).

Room Temperatures Map

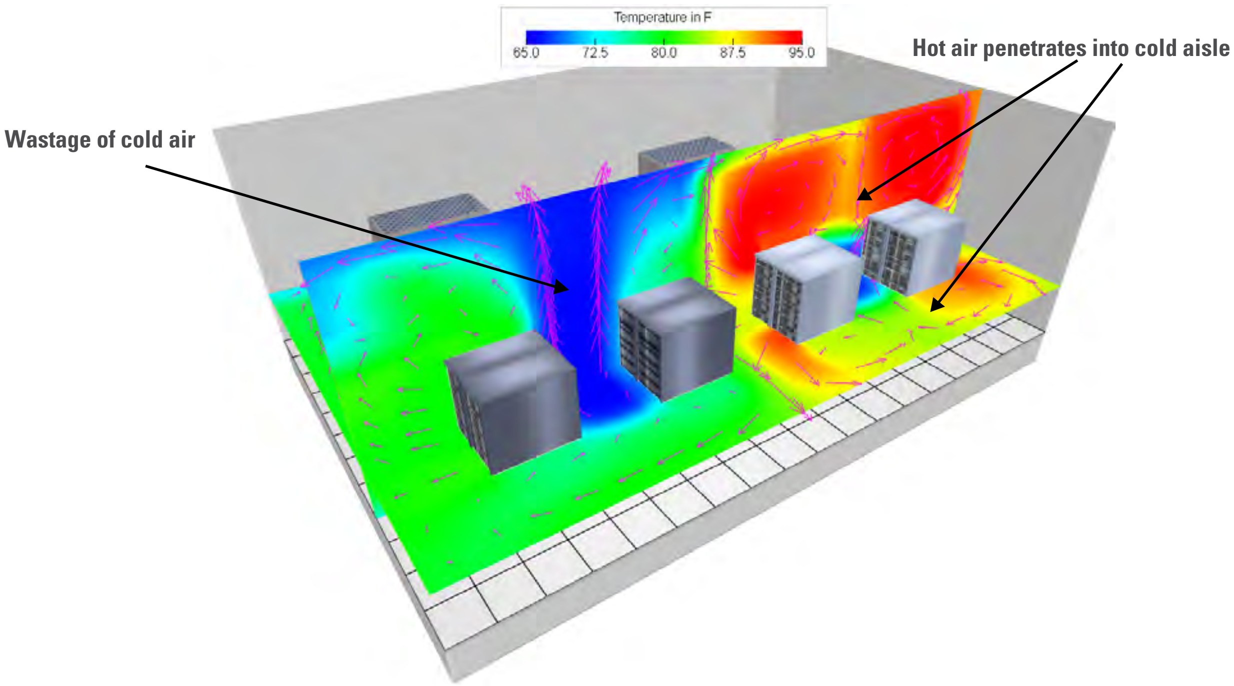


Figure 3: Result of poor airflow in a space that should have sufficient cooling. Blue shows an overcooled area. Red shows an undercooled area. Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

Obviously, individuals would be able to feel the temperature variations in the room. But, in a large and complex data center, how would data center managers know the most effective steps to fix the problem? Is more cooling capacity necessary? Is moving equipment needed? Is airflow containment appropriate? If so, where?

The good news is that it is possible to make changes in the CFD model and see the impact before taking action. The CFD model works as a digital twin and is a fundamental planning and optimization tool.

Step 2: Sealing Openings

The example site shown in Figures 1-3 above can be improved by controlling airflow with airflow management accessories in the room and inside the cabinets. There is no need for additional cooling capacity or equipment.

Start by modeling the effects of sealing openings in the raised floor (Figure 4). If the effect is positive, then seal the openings with brush-sealed or gasketed grommets. These protective grommets cover openings in raised floor tiles and have a seal that blocks most of the airflow through the opening. Individual cables, cable bundles, power cords or piping can then pass through the opening in the grommet with minimal leakage of conditioned air (Figure 5).

Figure 5: Raised Floor Grommets are available in various sizes and shapes. They seal openings in raised floor tiles with brushes or rubberized gaskets to reduce air leaks around cables, conduit and piping. Use these grommets to seal openings in raised floor tiles when the interstitial space under the floor is used as a supply air plenum.

Airflow from Perforated Tiles and Cable Openings

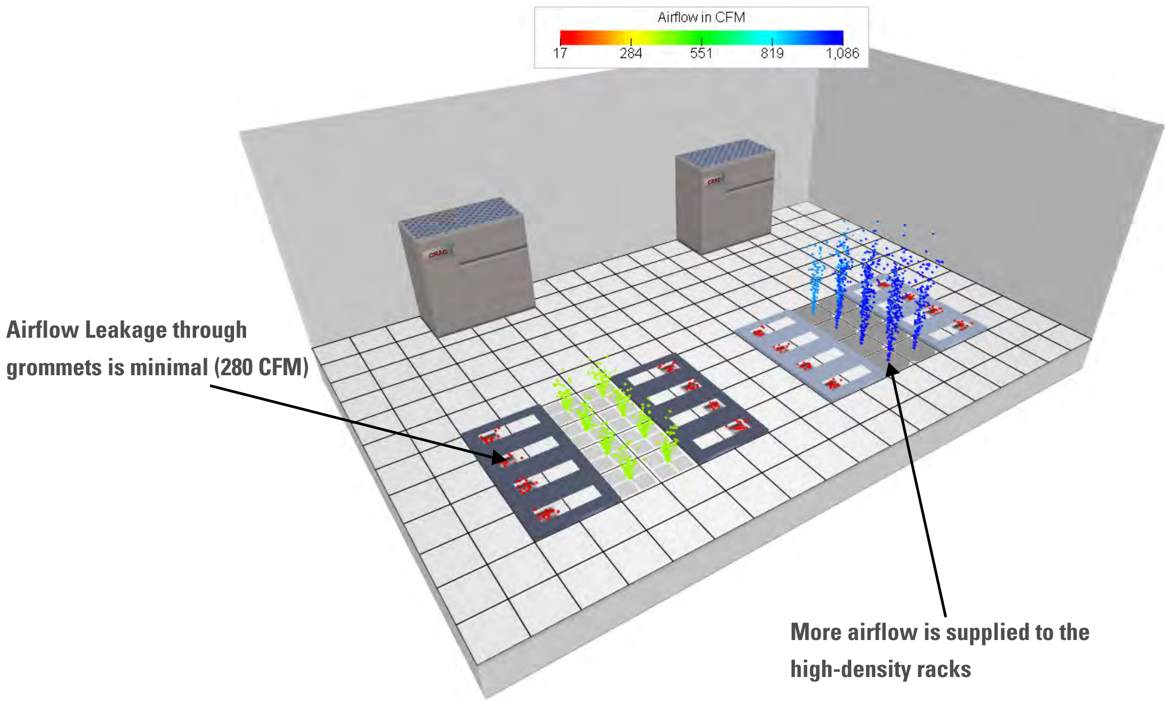


Figure 4: CFD modeling shows that sealing cable openings reduces wasted air from 2,500 CFM to 280 CFM. That provides an additional 2,220 CFM for cooling equipment. Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

Next, create a top-to-bottom seal within each cabinet. Use filler panels to seal open rack-mount spaces in cabinets between rack-mount equipment. Use air dam kit to seal the space between the equipment mounting rails and the top, bottom and side panels of the cabinet. This creates a front-rear separation within the cabinet that requires conditioned air to pass though equipment and prevents heated air from circulating back to the front of the cabinet. (Figure 6).

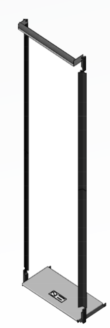


Figure 6: Air Dam Kit and Snap-In Filler Panels create a top-to-bottom seal within the cabinet so that conditioned supply air goes through equipment and not around it.

Step 3: Balancing Airflow

Once floor and cabinet openings are sealed, the correct amount of airflow needs to be delivered to cabinets. Most data centers arrange cabinets around hot and cold aisles. First, it is important to ensure there are no vented floor tiles in the hot aisles. The airflow supplied to the hot aisle does not directly cool racks. Vented floor tiles should only be placed in the cold aisles so that supply air is delivered to the front of cabinets and equipment.

The amount of air required will increase as cabinet power/heat load increases. So, it is beneficial to model the effects of varying the amount of perforation on floor tiles to determine the correct combination of floor tiles needed to deliver more air in front of high-density cabinets (Figure 7).

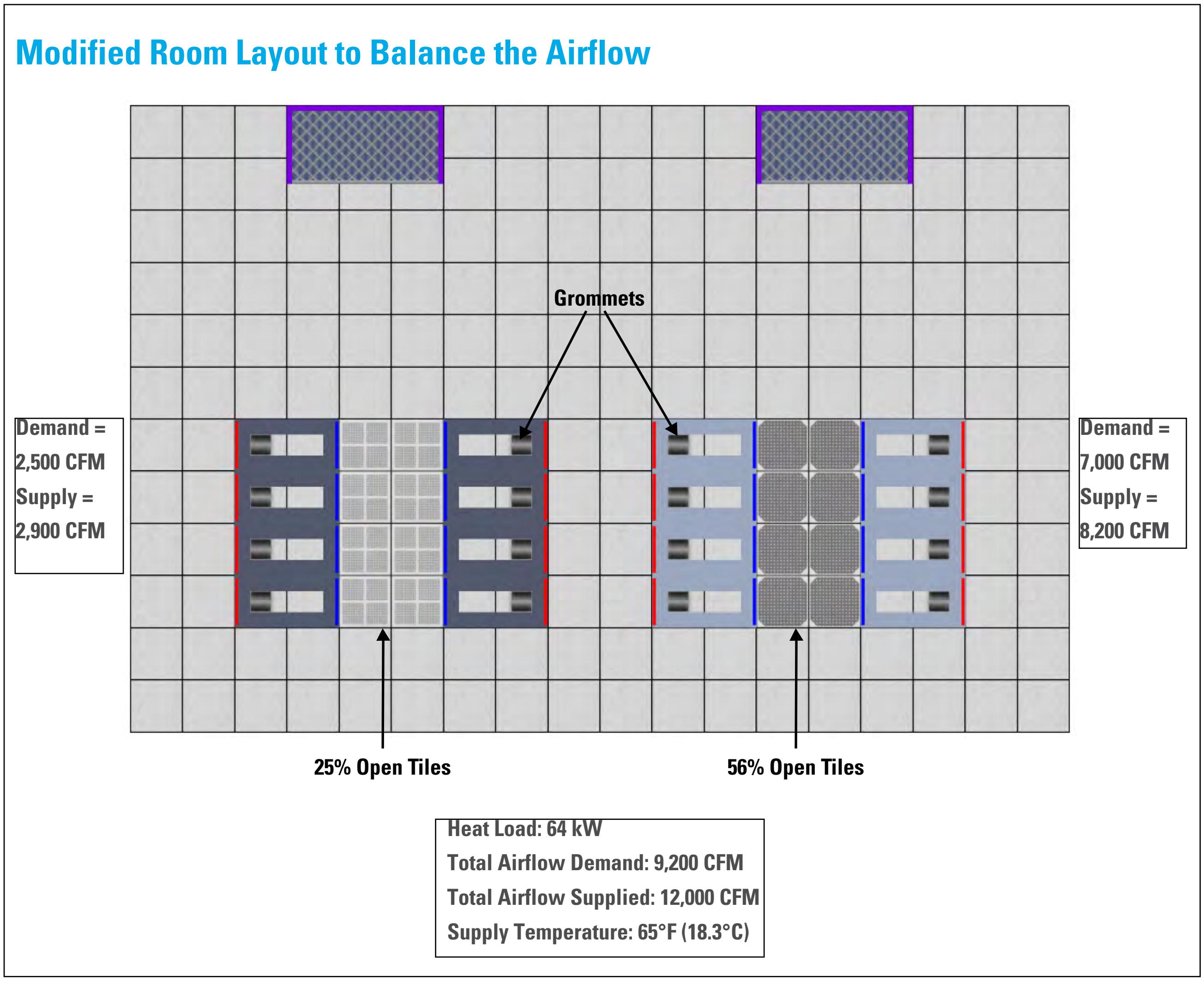


Figure 7: To balance airflow so that airflow supply more closely matches airflow demand, 25% open tiles are placed in front of 2 kW cabinets and 56% open tiles are placed in front of 6 kW cabinets. Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

Step 4: Adding Containment to Isolate Hot and Cold Air

The next step is to execute the CFD model of the room with the proposed enhancements to ensure sufficient airflow and acceptable rack inlet temperatures (Figure 8). Air cooled rack-mount equipment uses internal fans to draw air through the equipment chassis. If it is not possible to deliver enough cold air to the front of the cabinet, heated air will be pulled under, over and around to the front of the cabinets. The CFD model will show the extent of recirculation and the impact on temperature and airflow in the room.

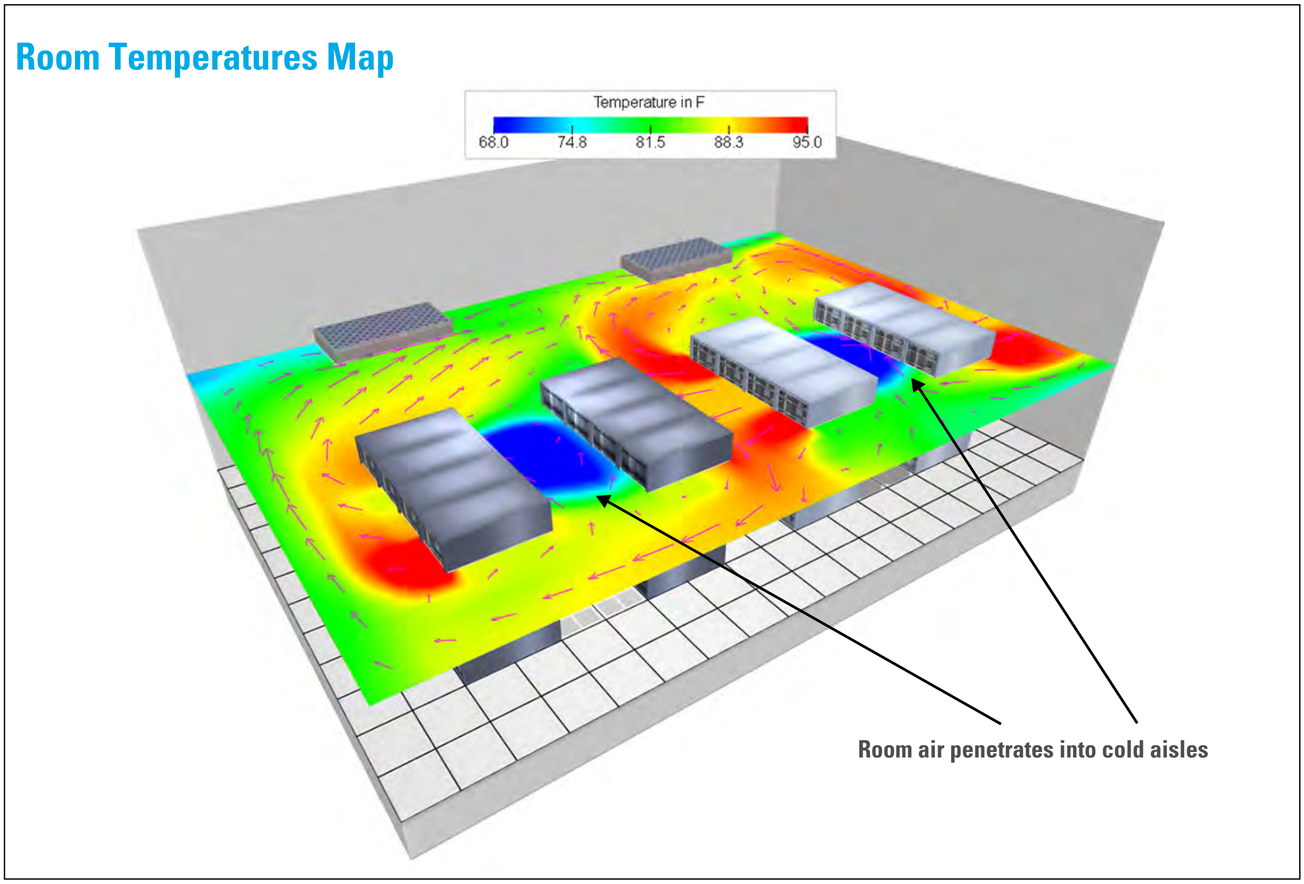


Figure 8: CFD modeling shows good cabinet temperatures in the center of each aisle with some recirculation of hot air over and around cabinets. Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

If inlet temperatures are still too high in the cold aisles, then the recommendation is to add containment to block hot airflow under, over and around cabinets. Each component should be modeled individually and in combinations to understand the impact to the data center. Most cabinets are placed on leveler feet when installed into the data center, so there is a gap between the floor and the base of the cabinet. It is possible to block the airflow under cabinets using bottom panels. To block airflow over and around cabinets, aisle containment doors (Figure 9) are the solution. If necessary, the entire aisle can be sealed with either a ceiling (Figure 10) to keep air in the aisle, or a duct (Figure 11) to exhaust air from the room. Alternately, cabinets with vertical exhaust ducts can be used instead of aisle containment (Figure 12). To maximize performance, the containment method should provide a strong seal between components to minimize leakage.

Figure 9: Aisle containment doors are available in various styles and widths. Ensure a good seal between the door frame and the sides of the adjoining cabinets. Consider a door that includes a mechanism to return and maintain it in a closed position.

Figure 10: Cold Aisle Containment (CAC) typically uses a ceiling to cover the contained aisle. Cold air is delivered to and isolated within the contained aisle.

Figure 11: Hot Aisle Containment (HAC) typically uses a duct to surround the contained aisle. Hot air is isolated within and exhausted from the room through the duct.

Figure 12: Cabinets with vertical exhaust ducts have a solid rear door and top-mounted duct. Hot air is isolated and exhausted from the room through the duct. These "chimney" cabinets are an alternative to aisle containment.

Step 5: Adjusting the Cooling System

Adding containment with a good seal and maintaining strong airflow management discipline result in eliminating hot spots, more uniform room and cabinet temperatures (Figure 13), and more reliable control when adjusting room conditions. Once the airflow and containment steps are in place, data center managers can model and then make small adjustments to room temperature and airflow to optimize cooling conditions. As a rule of thumb, every 1-degree increase in supply temperature will reduce 2-4% energy consumption.

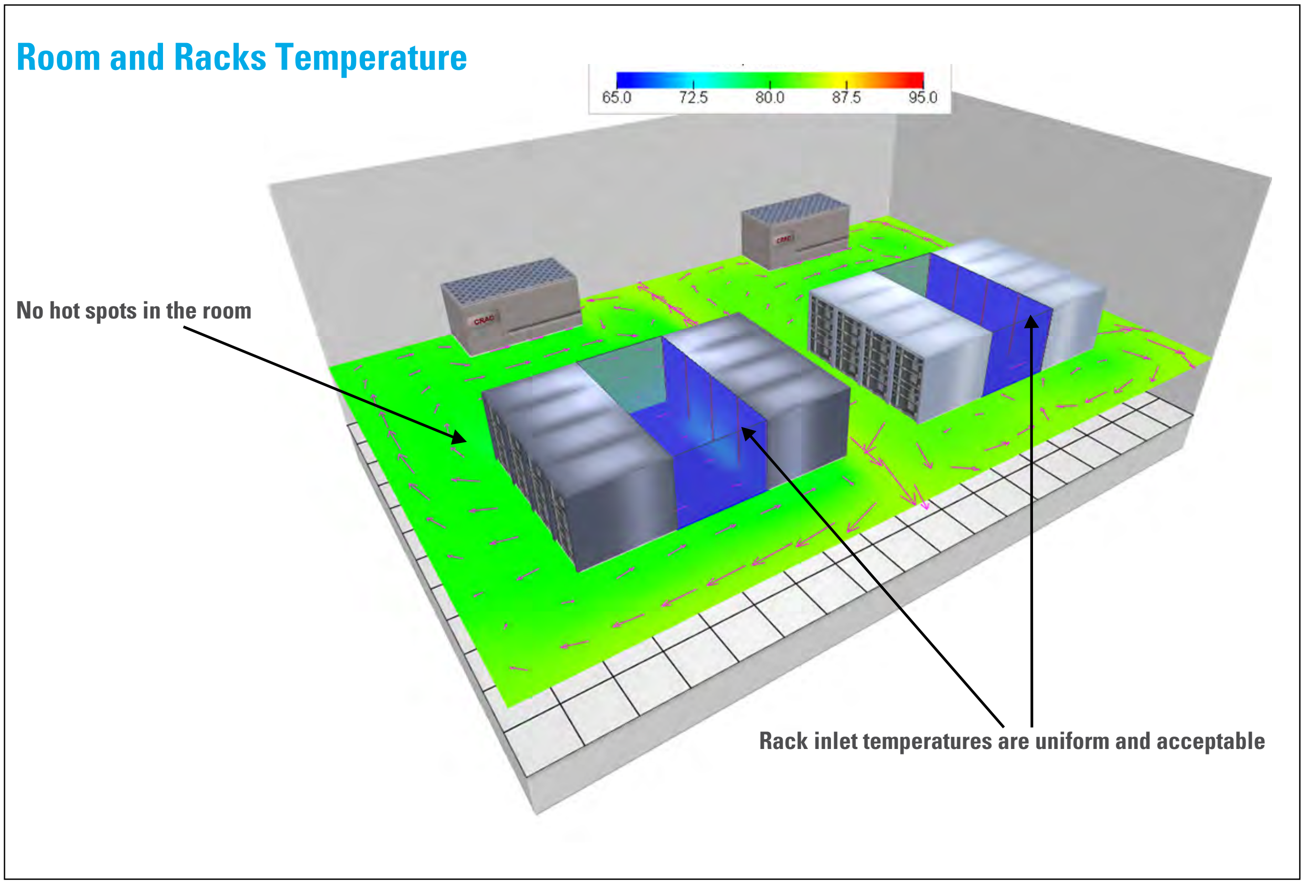


Figure 13: CFD modeling shows CAC with uniform temperature and no hot spots. Supply temperature can now be raised to lower cooling costs.

HAC and cabinets with vertical exhaust ducts deliver similar results. The type of containment that is used depends on the architectural constraints of the space and amount of heat load variation in the racks.

Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

CFD modeling also shows the pressure differences between the room and contained spaces which will help managers, engineers, and technicians adjust airflow to minimize the pressure differences while maintaining correct airflow (Figure 14). Reduction in airflow allows them to reduce the number of air handling units or operate units with variable-speed fans at lower speeds, further reducing cooling cost.

Room Pressure Map

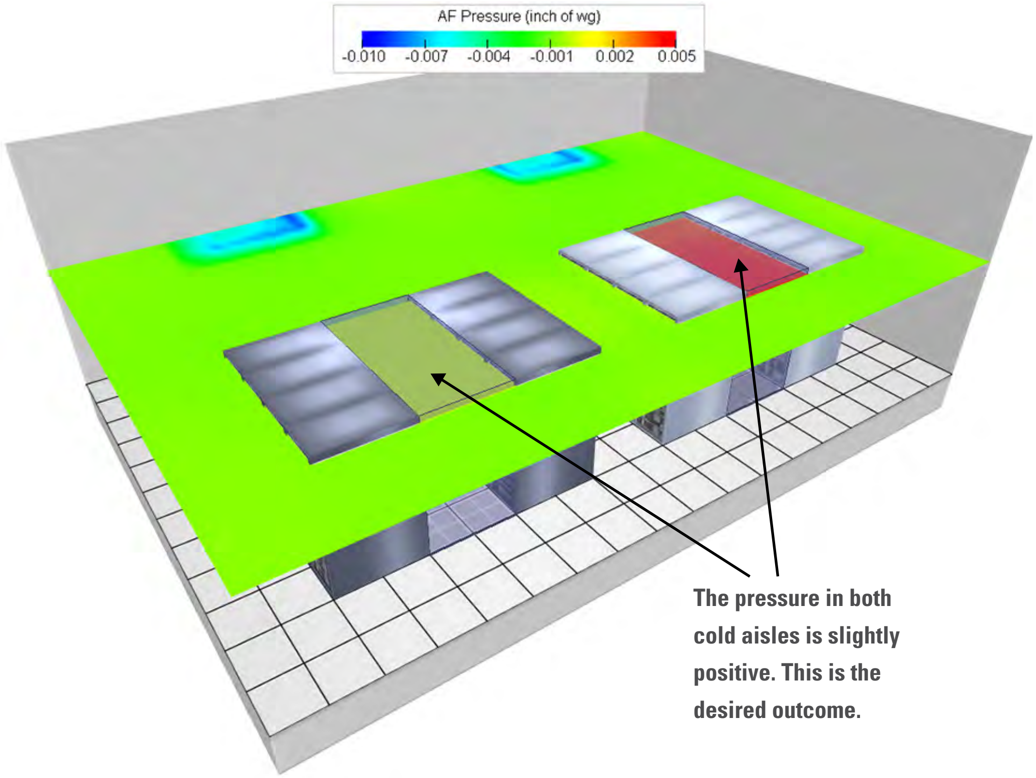


Figure 14: CFD modeling shows CAC with slightly positive pressure in both cold aisles. This maintains cold-to-hot airflow direction and eliminates leakage of hot air into the cold aisle, but allows adjustment of air handlers to minimal fan speeds.

Conversely, HAC and cabinets with vertical exhaust ducts would have slightly negative pressure in the contained aisle or duct to maintain cold-to-hot airflow direction and eliminate leakage.

Image from TileFlow CFD modeling software by Innovative Research, Inc. tileflow.com

Conclusion

CFD modeling and airflow management are critical to operating a highly efficient data center and optimizing cooling performance. CFD modeling allows data center managers to create a digital twin of their facility and simulate effects of new equipment and changes in airflow management and cooling system settings. Airflow management provides a toolkit of methods for controlling airflow and preventing the mix of supply and return air.

The five key steps to optimizing cooling performance discussed in this paper provide a simple guideline for optimizing data center white spaces. For assistance identifying opportunities to optimize cooling performance and possibly lower cooling costs, contact CPI's Field Applications Engineers today.

Additional Information on Containment

For a deeper explanation of CFD modeling software and how customers are using it to plan and optimize site utilization, watch the on-demand webinar *Improving Data Center Cooling Using Computational Fluid Dynamics, available here:* https://www.chatsworth.com/en-us/training-center/webinars

For more details on the three basic types of containment systems, including a comparison of the architectural and design considerations for each system, read the companion paper, *Data Center Airflow Management Basics: Comparing Containment Systems, available here:* https://www.chatsworth.com/en-us/resources/product-information/cpi-white-papers

For more details on how containment allows data center managers to reduce the volume of air delivered to cool equipment and raise room temperatures, resulting in several improved efficiencies and reduction in cooling energy costs, read the white paper, *Data Center Airflow Management Basics: Economics of Containment Systems, available here:* https://www.chatsworth.com/en-us/resources/product-information/cpi-white-papers

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Contributors

John Thompson – Field Applications Engineer

John Thompson has more than 30 years of technical experience in the telecommunications industry and has been a BICSI-certified RCDD since 1997. As a contractor, John owned and operated a structured cabling installation company in the Mid-Atlantic region. Before joining CPI, John was a consultant for a special systems design firm in Baltimore, MD that teamed with architects, MEP firms and worked directly with end users. In addition to assisting with AutoCAD design, John not only developed new construction specification documents, but served as a project manager for health care and higher education facilities projects across the United States. Since joining Chatsworth more than 10 years ago, John has assisted in the design of both new and existing data centers ranging in size from just a few cabinets to many hundreds of cabinets.

Amir Radmehr – Director and Member of Technical Staff

Dr. Amir Radmehr has worked at IRI since 1997. He has over 28 years of experience in developing and utilizing CFD software products. In the past twenty years, he has been working on IRI's CFD product "TileFlow". He has used both measurements and computational modeling to identify and resolve cooling issues in data centers. He holds a Ph.D. in Mechanical Engineering from the University of Minnesota. He has written more than 30 research publications.

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