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# *Blade Servers and Beyond: Adaptive Cooling for the Next Generation of IT Systems*

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## Executive Summary

***In enterprise data centers, designers face the challenge of having to create facilities with a 20-year lifespan when they are unsure how technology will change in the next three to five years*.**

High-density servers and communications switches, increased emphasis on business continuity, the convergence of voice and data, and new support system technologies are all driving change in the traditional data center.

In enterprise data centers, designers face the challenge of having to create facilities with a 20-year lifespan when they are unsure how technology will change in the next three to five years. In addition, with server replacement cycles averaging three to four years, heat load diversity within the data center is introducing a major challenge of its own: how to efficiently cool a heterogeneous environment. This challenge is compounded by dramatic increases in energy costs. Traditional approaches to cooling are only effective and efficient to a point. They lack the scalability, adaptability and precision required to effectively cool the high-density blade server racks being deployed today, let alone those coming in the future.

As a result, data center managers are commissioning facilities that optimize current approaches to cooling while supplementing these systems with new zone- and spot-based cooling systems. This adaptive, hybrid approach provides a cost-effective, energy-efficient solution to the requirements of today's systems while enabling the flexibility to adapt to whatever the future brings.

Adaptive cooling principles provide new and existing facilities a roadmap for dealing with heat densities that are increasing unpredictably and unevenly. Adaptive cooling provides maximum flexibility and scalability with the lowest cost of ownership while maintaining or improving availability.

## Equipment Trends

New high-performance equipment, such as dual-processor servers and high-speed communications switches, are raising rack densities well above 30 kW. Figure 1 illustrates the rising heat load of electronics equipment and predicts future heat loads.

With server power requirements exceeding projections, cooling strategies must adapt at a faster pace than anticipated to avoid downtime, equipment failure and reduced lifespan of electronics.

And with continued pressure to drive down data center operating costs, many organizations are attempting to pack as much equipment into as small a space as possible.

As a result, rooms are heating up and organizations are feeling the effects. Already, many of today's data centers require more than 100 Watts of power per square foot.

The latest generation of blade servers pushes power and heat levels even higher. A single rack loaded with four fully configured IBM BladeCenter™ H Chassis, each drawing 5.8 kW, creates a load of almost 24 kW in an enclosure that takes just seven square feet of data center floor space. This shows a sharp contrast with the state of the industry in 2000 when the average rack consumed just 1 kW of power.

Communications equipment is progressing in the same direction. Depending on its power supply configuration, the Cisco CRS-1 router creates a heat load of 15 to 16.6 kW per rack.

To further complicate the challenge, the average server replacement cycle is three to

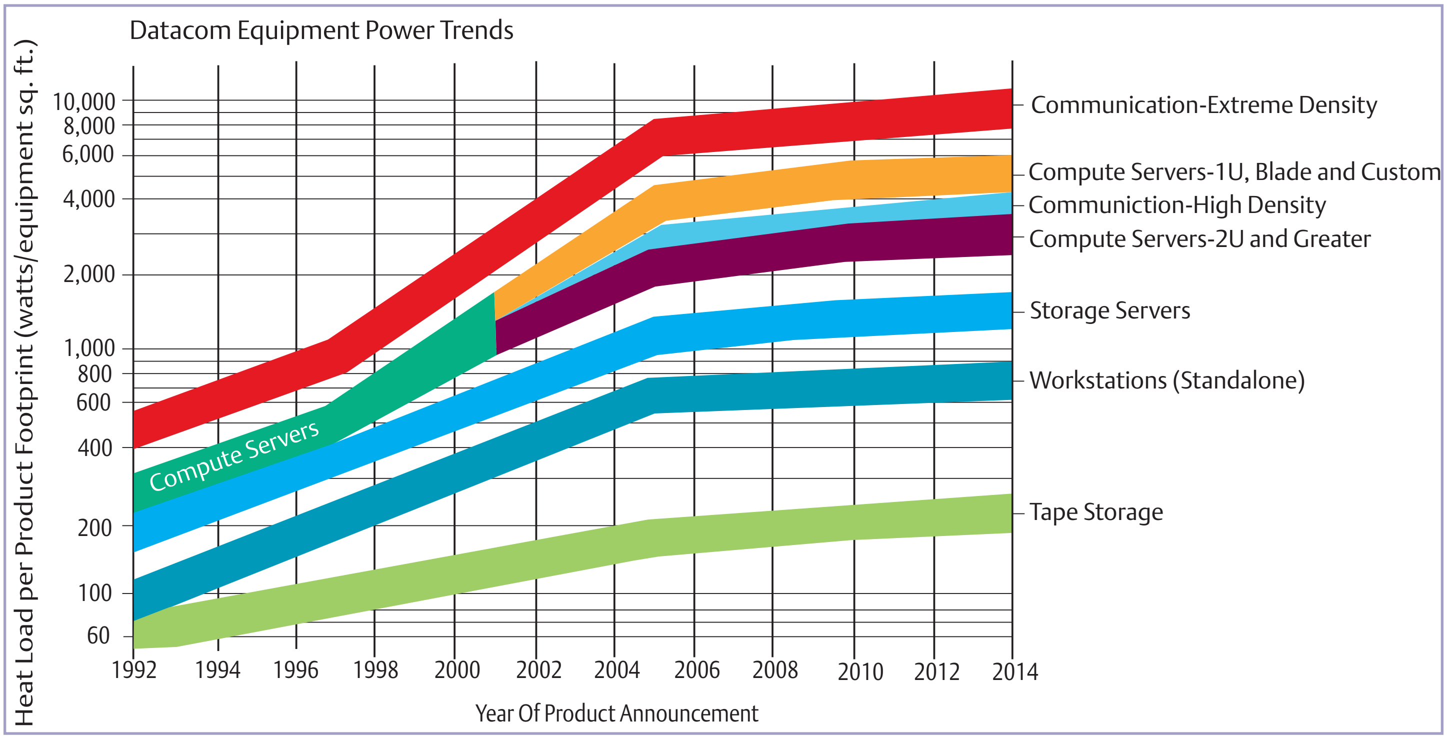


**Figure 1. Equipment densities are rising even faster than once predicted.**
© 2005 ASHRAE TC 9.9 Datacom Equipment Power Trends & Cooling Applications

*The Uptime Institute reports that equipment located in the top third of a data center rack fails twice as often as equipment in the bottom two-thirds of the same rack.*

four years, producing a diverse per-rack heat emission throughout the data center. While a rack of servers bought four years ago may use 2 kW of power per rack, the rack of IBM BladeCenters referenced previously has a power draw — and corresponding heat load — of almost 24 kW.

To approach cooling such a room by sizing a traditional precision air conditioning system to address the hot spots would mean vastly over-sizing your system and wasting a significant amount of energy, not to mention threats to availability posed by hot zones.

If the heat from a rack is not effectively removed, the performance, availability and lifespan of the equipment in the rack will be reduced significantly. Increasingly, as organizations adopt the latest server technologies into their existing data centers, they are exposed to higher failure rates, especially in the top third of the rack. As cooling air is supplied from the raised floor, it is fully consumed by high-density equipment at the bottom of the rack, while the top of the rack is deprived of the cooling air it requires. This is compounded by the fact that high densities also cause hot air to be recirculated back through the top third of the rack, as illustrated by the red plume in Figure 2.

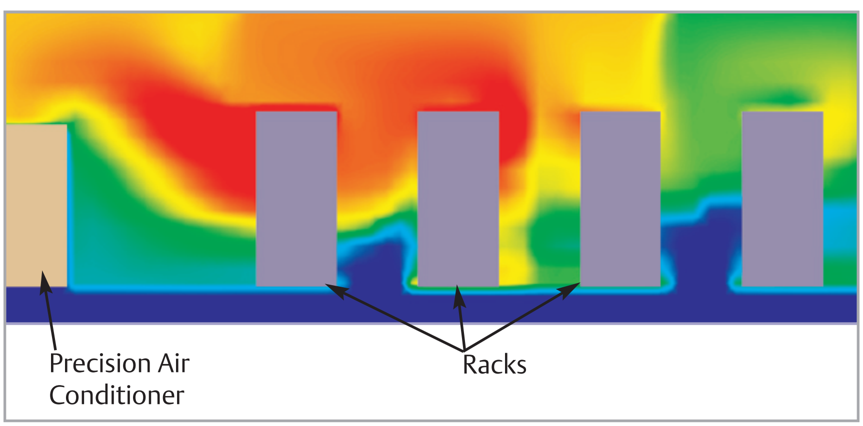


**Figure 2. As heat densities rise, equipment at the bottom of the rack consumes the cold air from the floor, causing hot air to be recirculated through the top of the rack.**

This is why failure rates are higher for equipment at the top of the rack. The Uptime Institute reports that equipment located in the top third of a data center rack fails twice as often as equipment in the bottom two-thirds of the same rack. The organization also estimates that, for every increase of 18 degrees F above 70 degrees F, long-term electronics reliability falls by 50 percent.

The increasing failure rate at the top of racks is occurring because current air delivery through a raised floor is generally limited to cooling an average room load of about 150 Watts per square foot, or racks with 2 to 3 kW load. Beyond that point, the volume of air that can be effectively delivered to the equipment in the upper part of the rack is insufficient.

## Responding to Equipment Trends

As equipment heat densities have risen faster than many expected, and as heat loads have become increasingly diverse within the data center, data center managers have been forced to consider new approaches to data center cooling. Among those that have been tried:

Increased Spacing
Some data center managers have responded to the problem by spreading out the load. They've made sure that racks are only partially populated and that aisles are wider between high-density racks. This spreads the heat over a larger area, but consumes valuable floor space as well as energy.

Data center managers are now deploying racks with power densities of more than 20 kW per rack. Based on field measurements at various sites, the average actual airflow in raised floor sites creates the ability to dissipate about 2 kW of heat. Spacing the equipment in a way that will allow existing airflow to dissipate 20 kW would require aisle widths of more than 16 feet.

Resolving cooling capacity via rack spacing drastically reduces the number of racks the data center can accommodate. Using traditional under-floor cooling, and spacing racks in a hot aisle/cold aisle configuration, a 10,000-square-foot data center can support only 50 racks if average rack density is 10 kW.

Turner Construction recently analyzed construction and cooling costs to accommodate a 4,000 kW load. To demonstrate the impact of different levels of heat density, three facility densities were selected and total data center costs (construction, security, cooling, power and UPS) were examined for each density (see Figure 3).

The first option, designing the cooling to support 50 Watts per square foot, requires 80,000 square feet of space to accommodate the 4,000 kW load. This facility would cost approximately $6,250 per kW of load. By increasing cooling capacity to 400 Watts per square foot, the same load can be condensed into a 10,000 square-foot facility. The cost for this facility would be about $4,750 per kW of load.

Clearly, facility costs vastly outweigh any premium required for cooling higher density loads. By opting for a smaller facility, enabled by extreme density cooling options, the facility in this example saves 24 percent of capital costs.

Adding Exhaust Fans

Another common fix is to add exhaust fans to the racks. It's important to remember, however, that fans do not remove heat — they just move it around. In fact, fans actually add to the room's power requirements, heat load and noise level. For example, if fans that draw between 200 and 500 Watts per blower assembly are added to 500 racks in a room, one to three additional 30-ton air conditioning units are required just to remove the heat generated by the fans.

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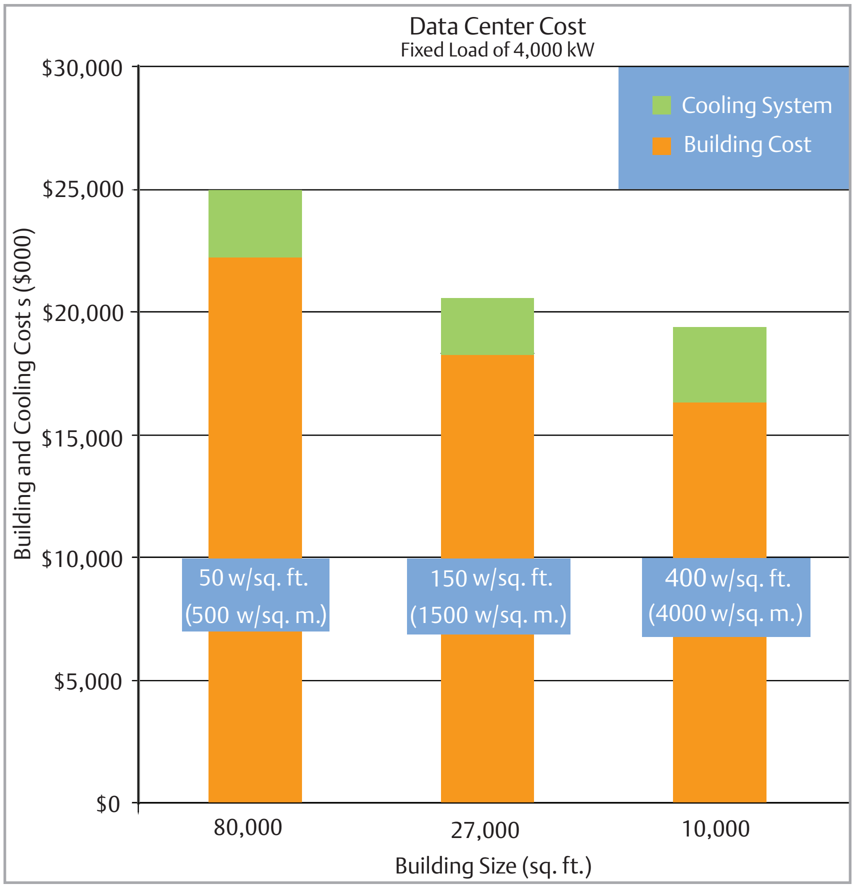


**Figure 3. Cooling at higher capacities per square foot makes better use of space and reduces total data center costs significantly.**

*A new, adaptive approach to cooling is replacing traditional measures as a best practice because the constant in data center heat loads has been rapid, unpredictable change,*

Figure 4 shows how quickly various density systems can overheat without cooling. This is compounded in close-coupled systems where the room is not used as a buffer against overheating.

## Answering Uncertainty With Adaptability

Rather than approaching the challenge of exploding heat removal requirements using limited, traditional measures, what's needed is a shift in approach. Because the constant in data center heat loads has been rapid, unpredictable change, a new, adaptive approach to cooling is replacing traditional measures as a best practice.

A survey of nearly 100 members of the Data Center Users' Group revealed that data center managers' top three concerns were density of heat and power (83 percent), availability (52 percent), and space constraints/growth (45 percent).

Answering these concerns requires an approach that delivers the required reliability and the flexibility to grow, while providing the lowest cost of ownership possible. That means:

- solutions that can effectively and efficiently address high-density zones
- flexible options that are easily scalable
- technologies that improve energy efficiency, and
- systems that are easy to maintain and support.

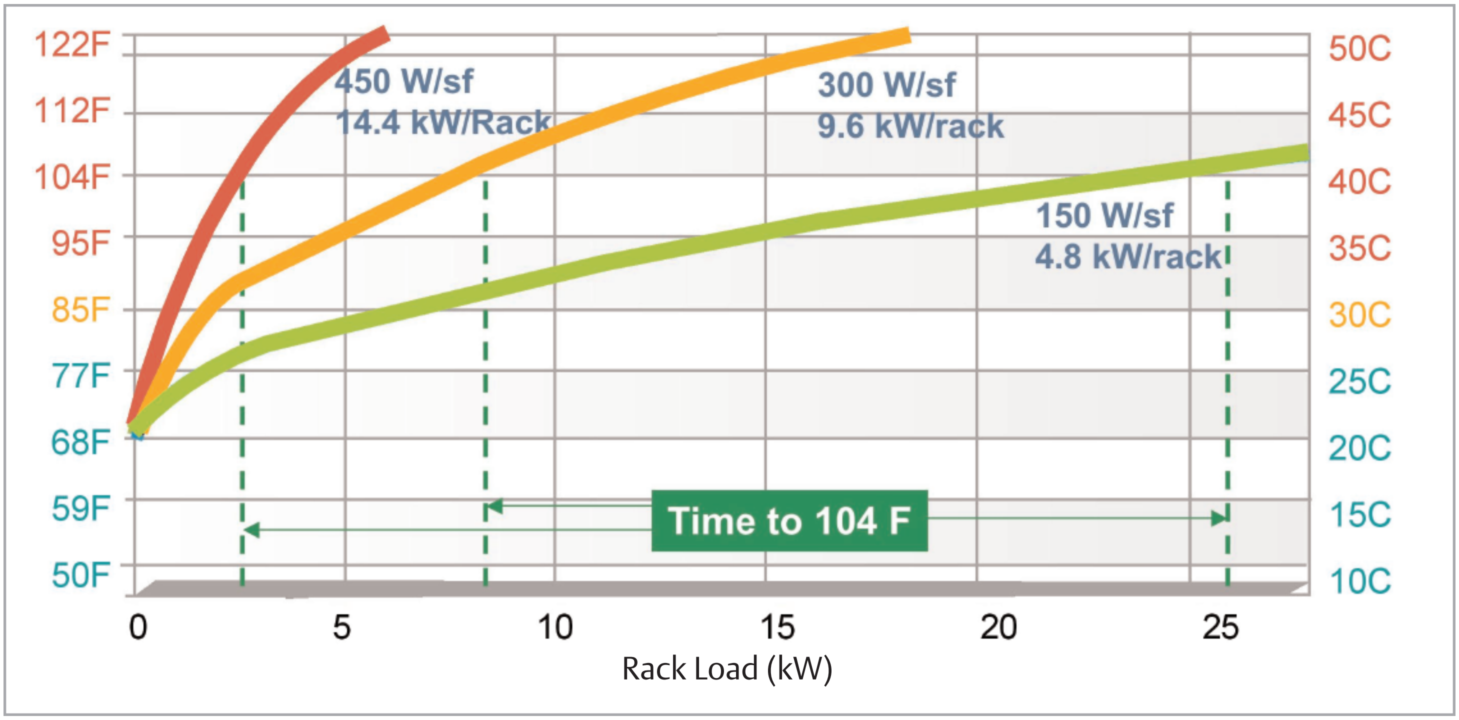


**Figure 4. Time to thermal shutdown by density.**

These requirements can be achieved by optimizing the cooling infrastructure and carefully selecting the two components of adaptive cooling: traditional under-floor cooling and supplemental cooling.

## Physical Infrastructure Optimization

The following areas should be evaluated when optimizing the cooling infrastructure.

Raised Floor
Today's data centers are typically built on an 18- to 36-inch raised floor. The higher the raised floor, the greater the volume of air that can be evenly distributed under the floor and the higher the potential capacity of the cooling system.

In existing data centers, however, increasing floor height presents an impractical answer to rising heat densities as it introduces a major disruption to data center operations, which not many organizations can endure. Even if a data center can manage the disruption, and if ceiling height allows for more space to be taken up under the floor, there is a limit to what can be accomplished with floor height alone. For example, a floor height of nearly 5 feet would be required to accommodate cooling for heat loads of 400 Watts per square foot.

Hot-Aisle/Cold-Aisle Configuration
Most equipment manufactured today is designed to draw in air through the front and exhaust it from the rear. This allows equipment racks to be arranged to create hot aisles and cold aisles. As recommended by ASHRAE TC 9.9 (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Technical Committee 9.9) in its Special Publication "Thermal Guidelines for Data Processing Environments," this approach arranges racks front-to-front so the cooling air rising into the cold aisle is pulled through the front of the racks on both sides of the aisle and exhausted at the back of the racks into the hot aisle (see Figure 5). Only cold aisles have perforated floor tiles, and floor-mounted cooling is placed at the end of the hot aisles — not parallel to the row of racks. Parallel placement can cause air from the hot aisle to be drawn across the top of the racks and to mix with the cold air, causing insufficient cooling to equipment at the top of racks and reducing overall energy efficiency, as was seen in Figure 2.

Cable Management
With the hot-aisle/cold-aisle approach, improved cable management, both within the rack and under the floor, can also yield increased efficiency. As much as possible, cable management should be limited to the raised floor space below the hot aisle so cables do not impede cooling air's path to equipment.

Additionally, some racks now feature expansion channels that improve cable management and ease heat removal for high-density racks. In some cases, existing racks can be retrofitted with these expansion channels. Running cables above or through racks is also becoming more popular to reduce the number of cables under the floor. Many organizations are taking power distribution closer to the load by using advanced power strips at the rack-level, dramatically reducing the number of cables coming into the rack.

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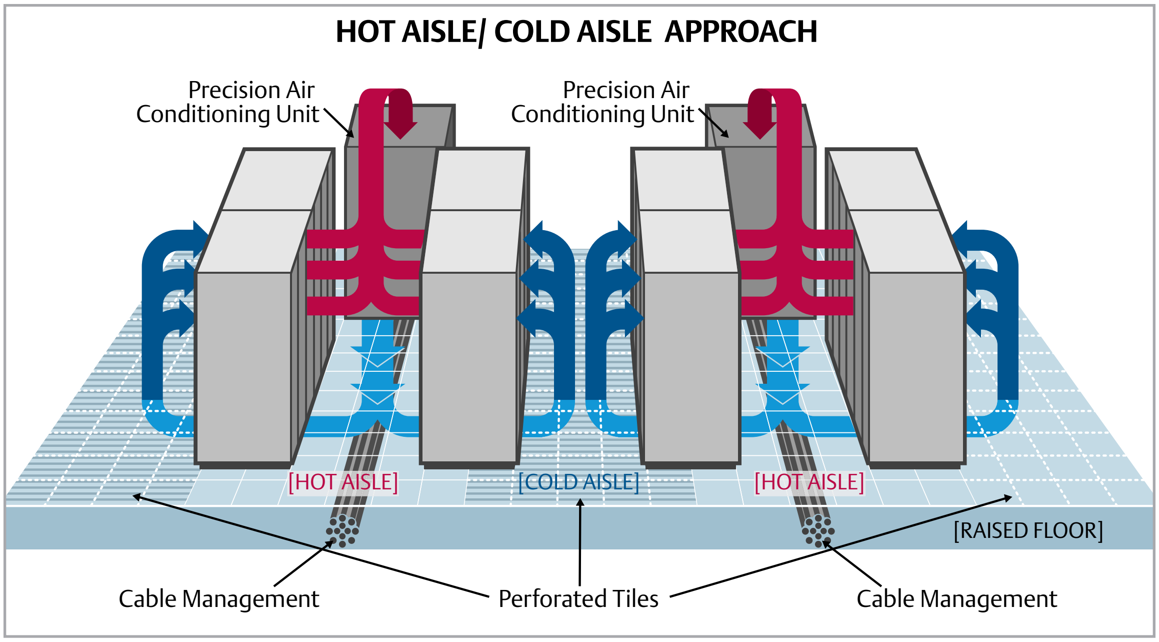


**Figure 5. Racks arranged in a hot aisle/cold aisle configuration.**

Vapor Seal

As equipment densities increase, a vapor barrier that isolates the controlled environment from the building environment becomes even more critical. Without a good vapor seal, humidity will migrate into the data center during the hot summer months and escape during the cold winter months. An effective vapor seal minimizes the energy required to either dehumidify or re-humidify.

## Responding to Changing Requirements

Traditional floor-mounted cooling systems with under-floor air delivery will continue to play an essential role in data center cooling. It's recommended that traditional systems be configured to deliver the required cooling for the first 100 to 150 Watts per square foot of the data center heat load as well as the room's full humidification and filtration requirements. With floor-mounted cooling systems optimized, the next element of adaptive cooling is supplemental cooling, which can take a data center beyond the 150 Watts per square foot (3 to 5 kW per rack) limit of traditional cooling solutions to well beyond 30 kW per rack.

First though, traditional cooling should be maximized to ensure it provides an efficient, flexible and reliable foundation for adaptive cooling.

## Optimizing Traditional Under-Floor Cooling

As demands grow, floor-mounted systems are changing to better meet new requirements. Features that will deliver the highest reliability and efficiency and the lowest total cost of ownership include:

Variable Capacity
ASHRAE has determined that the maximum cooling load occurs less than 5 percent of the time. Accordingly, cooling systems should effectively operate at varying loads. Units' compressors should be capable of stepped unloading — or total variable capacity — to deliver the desired cooling requirements without cycling the compressor off and on. For example, a system operating with two compressors partly loaded will consume approximately 50 percent of the energy of a fully loaded system, but will deliver 76 percent capacity because the condenser and evaporator are sized for full load. New variable capacity systems provide even more precise control of capacity.

By reducing compressor cycling, variable capacity systems reduce compressor starts and stops (on/off), one of the leading causes of compressor wear.

Unit-to-Unit Communication
Communication between units operating as a system (team) also enhances total cooling efficiency. This is even more critical in rooms with high-density loads, as zones within the room may be operating at a significantly higher temperature than other areas.

This ensures that units are not countering each other by dehumidifying while others are humidifying and provides the ability to direct specific cooling to the high-heat zone, thus improving the energy efficiency of the data center.

Service Organization Availability
As the heat load increases, the margin of error in a cooling system design becomes more critical. Available 24-hour local service and regular preventive maintenance by trained professionals are required to counteract mechanical wear-and-tear.

In addition, new technologies exist that improve communication functions to provide increased support for maintenance programs. Options include diagnostic and support tools, maintenance notification triggers and internal logging of maintenance events, including predictive diagnostics.

## Adding Supplemental Cooling

To effectively supplement traditional cooling and address high density areas, cooling must move closer to the source of heat. There are three major choices to be made when deciding what technology to employ in addressing high density cooling needs: cooling fluid, system architecture and future capabilities.

Cooling Fluid: Water vs. Refrigerant
While water is regularly used in floor-mounted cooling, when the source of cooling moves close to sensitive electrical equipment, safety becomes a key concern. That's why pumped R134a refrigerant is an ideal choice for high-density applications. Because refrigerant turns into a gas when it reaches the air, a leak would not damage IT equipment or pose a safety hazard. Pumped

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*An open architecture allows greater flexibility to reconfigure as needs change and additional cooling capacity is needed.*

refrigerant solutions also provide an incremental energy efficiency savings of between 25 percent and 35 percent, based on kilowatts of cooling capacity per kW of heat load.

System Architecture: Open vs. Closed
Cooling can be brought close to the load through either an open or closed cooling system architecture.

In a closed architecture, the electronics and cooling equipment are located together in a sealed environment. This approach provides high-capacity cooling at the expense of flexibility and fault tolerance if failure-mode precautions are not built in. While this approach is appropriate for small implementations, assuming failure mode ventilation, an open architecture approach is preferred for cooling in a data center environment. In a data center, closed cooling offers limited flexibility of rack combinations and often no backup emergency cooling. If the cooling fails, racks are isolated from room cooling and the temperature in the enclosure can reach the server over-temperature limit condition in less than 15 seconds. This is a risk that's unnecessary in a room environment.

In an open architecture, where modules are on or near racks, but not part of an enclosure, room air is used as a buffer in the event of a failure, making it a safer alternative in many cases. Additionally, an open architecture allows greater flexibility to reconfigure as needs change and additional cooling capacity is needed.

Future Capabilities: Scalability of Cooling Solutions
Choosing a technology platform that can scale to future needs is an important part of selecting a solution, given the projections for continued dramatic increases in power draws and heat loads. Most of the major server manufacturers are currently working on solutions that bring refrigerant-based cooling modules into the rack to answer future heat densities of 30 kW and beyond, making refrigerant-based systems compatible with

| ADVANTAGES | DISADVANTAGES |
|---|---|
| **Refrigerant-Based System**<br>No water in data center<br>No electrical hazards<br>Micro-channel coil efficiency and low pressure drop results in lower operating costs.<br>Smaller piping requirements<br>More compact heat exchanges | **Refrigerant-Based System**<br>Some compatibility issues with small rooms<br>Higher fluid cost |
| **Chilled Water-Based System**<br>Lowest fluid cost<br>No limitation to room size | **Chilled Water-Based System**<br>Electrical hazard<br>Operating efficiency<br>May require fluid treatment to prevent fouling<br>Limited overhead cooling options |

**Figure 6. The decision of a fluid medium affects capacity, reliability and efficiency.**

the next generation of cooling. Figure 7 charts the capacity limit of each major cooling technology.

Overhead Supplemental Cooling

An open architecture approach to high-density cooling that uses R134a refrigerant as a cooling medium is overhead supplemental cooling. The as-needed addition of supplemental cooling units offers maximum flexibility, reliability and efficiency. Overhead supplemental units are the final building block of the adaptive cooling approach.

Overhead supplemental cooling solutions work in concert with traditional under-floor cooling systems for both existing and new data centers by providing effective cooling where the under-floor system leaves off.

Reliability

High reliability is accomplished by placing the supplemental units close to the high density source, either in the ceiling, above the rack or next to the rack. This configuration supplies the necessary cold air to the top sections of the rack to "supplement" the air delivered from under the floor. Using R134a rather than water also improves reliability and eliminates the risk that would accompany the introduction of water.

Additionally, because the cooling module is not directly "close-coupled" with the heat load, the air in the room is used as a buffer in the event of a power failure to the cooling system, providing the necessary ride-through until back-up power is restored. To verify the performance, this adaptive cooling method was modeled with Computational Fluid Dynamics (CFD) to over 30 kW per rack.

Energy Efficiency

Overhead supplemental systems that are currently on the market utilize up to 32 percent less power than traditional floor-mounted precision air conditioners to cool 1 kW of sensible heat. One reason for this savings is the fan horsepower required to move the air is 64 percent less, since it has to move the air less than 3 feet against zero static pressure.

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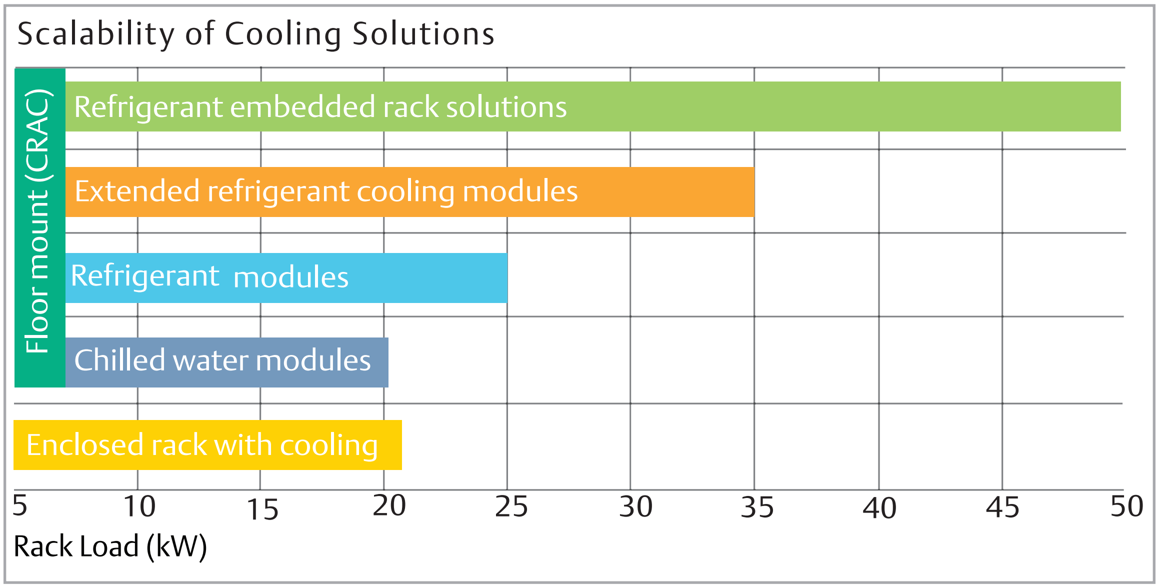


**Figure 7. Limits of cooling solutions (standard 24-inch rack).**

***Refrigerant use reduces chiller capacity requirements by more than .2 kW per 1 kW of sensible heat load.***

Because these cooling modules provide 100 percent sensible cooling, there is no wasted energy in controlling humidity.

Additionally, refrigerant use reduces chiller capacity requirements by more than .2 kW per 1 kW of sensible heat load (See Figure 8). Not only does this reduce the amount of energy consumed, in large implementations, it also enables additional cooling capacity without adding additional chillers or reduces the number of chillers on a new build.

Maximum Flexibility

Finally, overhead supplemental cooling provides the end user maximum flexibility in both growth and arrangement of the data center. Because valuable raised floor space is not consumed, it does not constrain the end user with unnecessary rack orientations, condensation removal, ducting or equipment placements. In addition, today's supplemental cooling conforms to any rack manufacturer's equipment. With available pre-piping options, the facility can be equipped with the necessary piping in the ceiling that permits the end user to add or move 16 kW modules at a time by a simple “plug-and-play” connection while the other cooling modules continue to operate.

This adaptive cooling approach permitted Virginia Tech to solve the space, heat density and energy requirement challenges for its Supercomputer site, which was initially configured to accommodate over 200 Watts per square foot. But with flexibility in mind, Virginia Tech reconfigured the data center in half the space and reallocated the cooling modules in the final space to accommodate well over 350 Watts of heat per square foot, preserving their initial investment while scaling to meet new needs.

Pomona Valley Hospital Medical Center in California is another example of an organization benefiting from supplemental cooling. When the cooling capacity delivered through its six-inch raised floor limited their ability to adopt technology that would help it automate medical records, the organization added rack-mounted supplemental cooling units. The data center temperature dropped more than 30 degrees — bringing the environment within safe operating temperatures — and heat-related failures stopped. Pomona estimates cost savings in the first year at $300,000 based solely on preventing heat-related equipment loss. Further, the system's flexibility allows for a 100 percent increase in capacity.

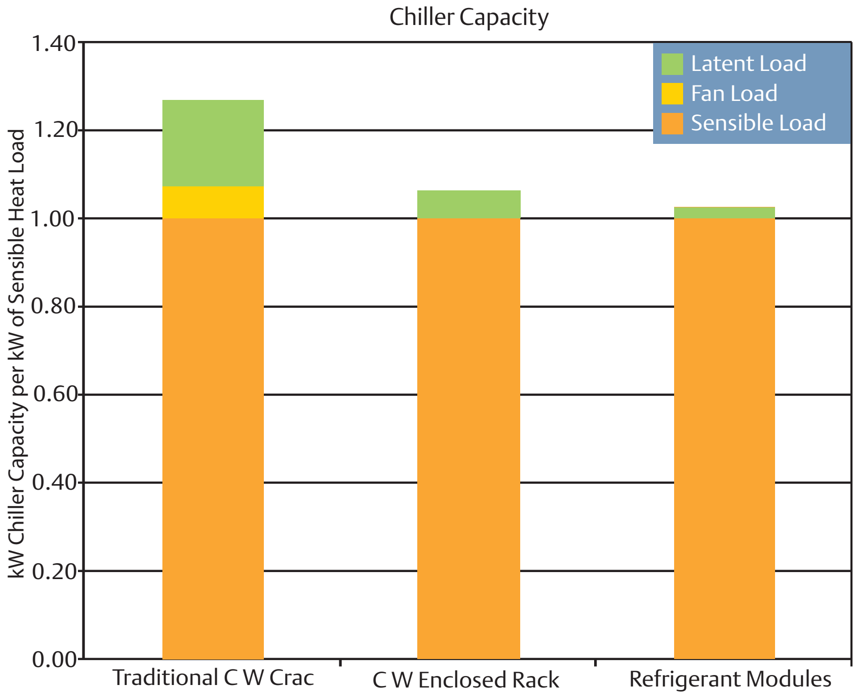


**Figure 8. Fluid cooling with refrigerant at the source requires less chiller capacity than traditional cooling.**

## Conclusion

An adaptive cooling architecture permits the flexibility to grow with constantly changing electronics systems. With proper planning and the use of next-generation equipment, the total costs of operating a data center can hold steady or even decrease, even as network availability becomes more critical.

Components of adaptive systems incorporate the latest generation of floor-mounted cooling in a raised-floor environment, extreme-density cooling over hot zones, and rack-mounted cooling to address hot spots.

Adaptive cooling offers a roadmap to help data center managers progress toward supporting loads that are consistently rising in excess of predictions and introducing increased diversity into the data center environment. The adaptive approach is flexible, scalable, reliable and efficient in terms of energy, cost and space. Unlike other approaches, it does not sacrifice floor space or reliability.

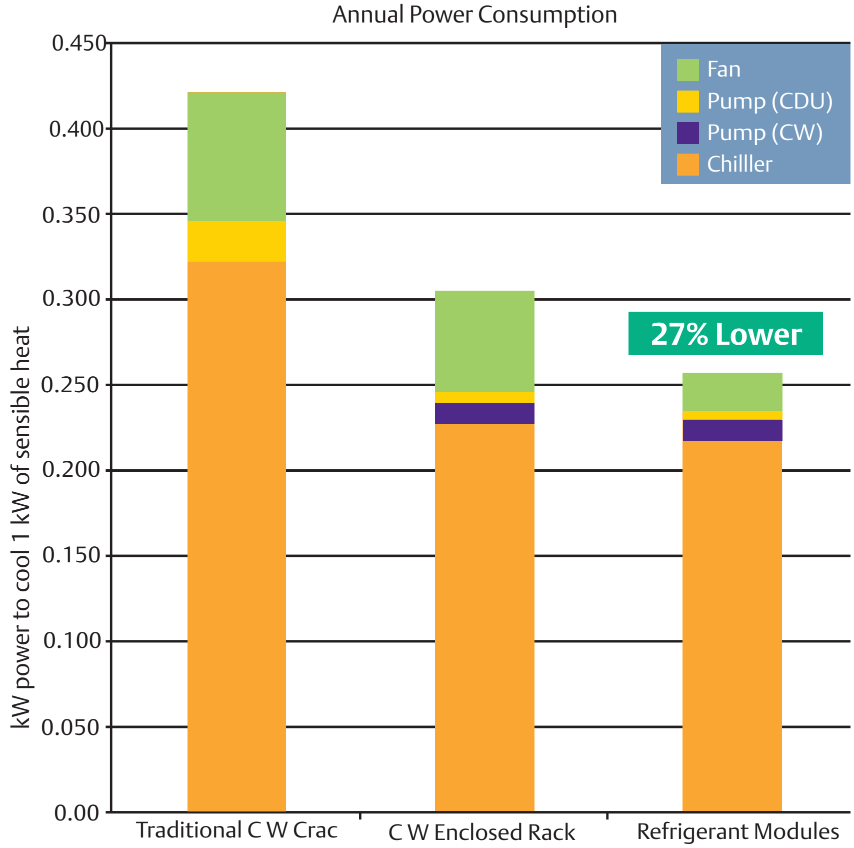


**Figure 10. Supplemental cooling with refrigerant provides increased efficiency.**

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