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Out of all the major facets that keep a data center running and performing at optimum levels, thermal management is often considered a low priority compared to other functions, and it is often ignored unless problems develop. For those that work within the confines of a facility and understand the ramifications of the thermal environment upon highly sensitive, hot running equipment, having an efficient and effective thermal management strategy has become an important aspect of data center management.

The method of cooling the equipment inside the data hall has always been a critical piece in any data center’s design. However, what is different today is that data center facilities managers are under more scrutiny to cut costs and improve equipment reliability while supporting a growing IT demand. In order to meet those challenges, data centers are now being designed to grow with the business' needs. This includes the cooling system, which is being designed to scale as needed.

However, there are thousands of existing facilities out there that were designed 10, 15 and even 20 years ago, which still support their businesses and that need to adapt at a reasonable cost. This is where airflow management best practices can have an impact by making those environments more efficient and reliable to support today’s IT equipment for a minimal investment.

In a 2014 report titled Trends in Data Centers, over 220 professionals were asked to describe one area they would change about their data centers. 19 percent cited more energy efficient and 15 percent stated a better cooling/HVAC system\(^1\). However, many facilities already have the cooling capacity on hand; it is poor airflow management that is not allowing the cooling system’s full capacity to be used effectively. This report tackles the challenges, standards and best approaches to thermal efficiency in existing facilities largely due to them being more prevalent when compared to a new facility. You will be introduced to four best practices that are absolutely critical to achieving an optimal thermal environment. The report also explores the future of data center cooling and introduces emerging technologies.

The approach to thermal management in the data center is holistic, and each individual piece has a substantial effect on the entire ecosystem. The different variables that go into cooling a data center are inextricably interrelated on a constant basis – even a brief lapse in the performance of one system can result in a breakdown in the rest of the areas. The many facets of thermal management will be explored from this all-inclusive perspective.

\(^1\) Insights Into What’s Next: Trends in Data Centers 2014 – Mortenson
WHAT’S DRIVING COOLING AS A PRIORITY

A lot has changed in data center cooling in the last few decades. While once considered a simple design consideration akin to any building’s comfort system, today’s data centers now require a highly specialized approach to cooling, mainly driven by the overall increase in IT computing demands. However, there are several other driving forces that make thermal efficiency a high priority:

› In legacy data centers, the cooling system consumes a large amount of energy.
› Imbalanced room temperatures increase the likelihood of equipment failures.
› Increasing server rack densities can create unique thermal challenges.
› Changing IT requirements require cooling to be available on demand.
› High-availability environments need well-controlled temperature ranges for reliable performance.

Figure 1: E.U. Data Center Power Consumption

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling fans, pumps and compressors</td>
<td>32%</td>
</tr>
<tr>
<td>Lighting and small power</td>
<td>2%</td>
</tr>
<tr>
<td>Ventilation (fresh air)</td>
<td>2%</td>
</tr>
<tr>
<td>Communications</td>
<td>0%</td>
</tr>
<tr>
<td>Security, NOC, BMS and outdoor lighting</td>
<td>2%</td>
</tr>
<tr>
<td>Distribution and conversion lossess</td>
<td>4%</td>
</tr>
<tr>
<td>IT terminal load</td>
<td>59%</td>
</tr>
</tbody>
</table>

2 Data Center Alliance Project.
Before diving into today’s thermal management challenges and solutions, it’s important to create some historical context around data center cooling. As data centers continue to evolve, the approach to cooling is often, unfortunately, based on outmoded cooling theories and methodologies, making some historical perspective essential.

A BRIEF HISTORY OF DATA CENTER COOLING

From the first data center built in the 1960s – mainly limited to space technologies for defense and other government entities – designers understood the two factors needed for successful operation were power and cooling. However, of these two factors, power most often took the hefty share of the limelight and attention, as facility owners focused on the quality, availability and reliability of power. Cooling was left to the IT equipment manufacturers to control through water-cooled CPUs.

As data centers evolved alongside advancing power grids throughout the next two decades, the dependability and quality of power became less of a concern. Even though cooling started as a secondary issue, it evolved into a greater and greater challenge, especially as computing demands ramped up exponentially.

In the early 1990s, individual servers were introduced into the computer rooms, coming from offices and data closets. This move resulted in a shrinking form factor and an extraordinary increase in data center power densities. The explosion of IT demands exacerbated the problem. No longer could a cooling system built for comfort also accommodate these new heat loads. To address this trend, more and more data centers were designed with massive chillers and air handlers. Because of the loud noise and other environmental issues this cooling equipment caused, isolated stand-alone computer rooms were developed to protect the sensitive IT equipment. This has forced facility, IT and maintenance staff to move to offices outside the computer rooms.

In taking a closer look at how data centers were designed 15 to 20 years ago, there have been a number of factors that have contributed to a lack of efficient cooling. One common issue that often arose during the planning of a facility was the selection of an architectural and engineering firm that fully understood HVAC design practices but didn't have a complete understanding of the best practices around controlling airflow throughout the data hall itself.

As facilities evolved, the initial planning that went into building data centers has become more highly specialized. As with many other aspects of data center design, engineers and planners without this specialized data center airflow management training could forgo tuning the cooling system for maximum efficiency from the beginning.

In addition, with the many foreboding forecasts of dramatic data loads exploding, data centers were often designed to cram as much hardware onto a raised floor as possible. Maximizing the footprint was the mantra, and cooling systems were designed to handle the maximum anticipated heat load. All perimeter cooling units were generally turned on once initially deployed, with cold inlet temperatures, which meant the room was getting far more cooling than the IT equipment required and which added significantly to the operational cost of the facility.

In terms of the type of cooling systems used most typically by data centers in the past, these are generally limited to two perimeter methods:

› Direct expansion (DX)
› Chilled water

DX cooling systems use a heat removal process that uses a liquid similar to what is used to cool a car or refrigerator. In the past, a majority of data centers have been cooled by packaged DX systems, which are often referred to as computer room air conditioners (CRAC). They were attractive to facility owners due to easy off-the-shelf options, the relatively small form factor and straightforward operation.

As data center cooling technologies have advanced and became larger with higher total heat loads, more and more owners and operators during the past decade have chosen other technologies over DX that are capable of producing the same amount of cooling more efficiently.

Nevertheless, DX systems are still a viable option for many computer rooms. DX systems are now being configured to take advantage of economizer (free) cooling. However, this requires extra equipment to be installed with the cooling units, which increases the system’s cost.
CHILLED WATER COOLING SYSTEMS

Chilled water designs use a centralized chiller to produce cold water. The chilled water is then piped to computer room air handlers (CRAH) with heat dissipation being handled by the cooling towers. Chilled water in the past was often the choice for large, multistory facilities, mainly because it was more efficient and – for the size of the facility – was less expensive.

CHAOS AIR DISTRIBUTION

The methodology of chaos air distribution is simple: arrange cooling units around the perimeter of the server room and produce a large volume of chilled air. The thought was that the turbulence of the air movement under the raised floor would create a homogenous supply air temperature. This approach had the intention of cooling IT equipment while pushing out hot server exhaust air toward the facility’s return air ducts. What was later discovered was the cooling units ended up creating a confounded airflow system under the floor, which resulted in no control over supply side temperature throughout the data hall.

Other air distribution inefficiencies associated with chaos air distribution include:

› Bypass airflow
  Cool supply air never enters the IT equipment. The supply air either is lost before it gets to the cold aisle, or it does enter the cold aisle but travels past the IT equipment.

› Recirculation
  Hot exhaust air re-enters the server intakes prior to being reconditioned by the cooling system. This is the leading cause of data center hot spots.

› Air stratification
  Trying to direct cool air to the top of the rack face creates air masses in different temperature-based layers, which may force the lowering of set points on the cooling equipment.

› Multiple underfloor temperatures
  With each cooling unit being controlled locally, each unit could provide a different supply air temperature; these variations confound the ability to control the input air temperatures across the computer room.

› Wasted cooling capacity
  The additional cooling required to satisfy the heat load in the room is primarily due to the large amount of bypass airflow in the room.

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4 Energy Consumption of Information Technology Data Centers - Madhusudan Iyengar 2010
5 Properly Deployed Airflow Management Devices – ENERGY STAR

Figure 2: Chilled Water Cooling System (Simplified)™

Figure 3: Imbalanced Supply Temperature™
LEGACY AIRFLOW DESIGN

One of the hallmarks of legacy data center airflow design is a proliferation of holes, gaps and obstructions in the supply air pathway, creating bypass airflow. Some examples include:

› Open cable cutouts
› Open holes underneath the cabinet
› Holes at the perimeter walls of the room under the raised floor
› Holes behind the air handling units
› Holes above the drop ceiling
› Additional perforated tiles than needed to properly cool the IT equipment

What is the impact of these tactics? All of these openings are the vehicles that produce bypass airflow, which represents conditioned air that never enters the IT equipment. In order to make up for the air that never reaches the intended heat load, the cooling units have to work harder to deliver enough air, which creates inefficiencies and can lead to unstable temperatures throughout the data hall. According to a 2013 Upsite Technologies survey, the average data hall had 48 percent bypass airflow.6

Much of these inefficient tactics in legacy data centers can be attributed to a lack of specialized knowledge on the science of airflow by data center designers, mechanical engineers and facilities technicians.

LEGACY COOLING MENTALITIES STILL AROUND TODAY

You’ll discover in the remainder of this report the importance of proper airflow management and the negative impact it can have on the cooling system.

Yet, despite more informed approaches and the availability of better solutions, data centers take an approach that results in overprovisioning data center cooling resources, instead of looking at the airflow throughout the rack, row and room. Why?

› Lack of knowledge
  Cooling data centers is a specialized field, and many facility owners simply aren’t aware of the many subtleties and implications.

› Aversion to risk
  Many data center managers avoid taking the risk of trying a new approach.

› Complacency
  Unless systems go down as a direct result of lack of cooling, many managers are hesitant to rethink their systems.

› Fear
  Many data center managers simply do not want to risk modifying a cooling system for fear failures could lead to systems going down.

› Apathy
  This can be the case when the facility manager’s function does not own the energy portion of the budget.

6 Lars Strong – Myths of Data Center Containment – 2015

Inevitably, advances in cooling systems specifically designed to address the unique challenges of the data center environment will force legacy data centers to address thermal efficiency. If not, increasing outages, simple economics, the need to cut costs and the trend toward environmentalism will certainly force data centers to embrace better thermal management practices. Fortunately, there is much that can be done in many existing data centers with a relatively minimal investment to improve the reliability and efficiency of the cooling system.
COMMON COOLING CHALLENGES

There are several challenges that make it difficult to keep data centers at an ideal temperature.

› **Increasing cabinet densities**  
Cabinet densities are on the rise for many data centers today. Although they aren’t rising as much as once thought, there are several applications that require a large investment of power. These cabinets can require a different approach to cooling than the rest of the environment.

› **Operational budget cuts**  
Many data center managers are being asked to reduce operational expenses and think that increased thermal efficiency requires significant capital investment.

› **Lack of knowledge of airflow management best practices**  
Just understanding the right techniques can be a challenge. The impact of deploying blanking panels, removing cabling from under the floor and using cable-sealing grommets can pay huge dividends.

› **Matching cooling to IT requirements**  
An efficient cooling system means that the right amount of cooling is being delivered to satisfy the IT equipment’s demands. Because IT’s requirements change dynamically, the cooling system should be adjusted frequently, but the information required to do that isn’t always provided or accessible.

› **Overwhelming thermal design considerations**  
There are a lot of options and methodologies out there to cool a data center. In addition, there are several options to separate supply and return air. In light of this, choosing the best approach can be difficult.
THE COST OF COOLING A DATA CENTER

There is growing evidence to support the fact that IT equipment is no longer the primary cost driver of running a data center. Operational expenses related to powering and cooling the facilities infrastructure are fast overtaking hardware costs. According to ASHRAE, part of the reason for this is the fact that server performance and efficiency has increased substantially in recent years while their costs have remained relatively constant. According to a report conducted by Christian Belady, during an eight year period server performance increased 75 times for the same hardware cost. In the same study, the performance per watt was shown to increase by 16 times in a typical server during that same period.

This is a paradigm shift in terms of how the C-suite perceives the economics of running a data center, impacting operational decisions as they relate to power and cooling. It’s all about reducing the overall total cost of ownership (TCO) and having an efficient thermal environment is becoming a huge factor in achieving that goal.

On average, the energy cost to cool a data center is substantial. On the low end of the spectrum are estimates in the range of 30 percent or less, even though many data centers lacking efficient cooling systems and tactics can consume nearly 50 percent of energy costs.

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7 In the data center, power and cooling costs more than the IT equipment it supports – Christian L. Belady 2007
HOW POOR COOLING AND AIR DISTRIBUTION STRATEGIES CAN IMPACT OPERATING EXPENSES

The cost of the cooling system can be greater than 30 percent of the total energy used in the data center. The main culprit within the cooling unit is generally the compressor and fans. There are two ways to reduce the energy being consumed by the cooling units:

- Increase supply-side temperature (compressor energy)
- Decrease the volume of air being delivered to the IT equipment (fan energy)

Before any of those actions can be taken, best practices around airflow management must be implemented. If there is considerable bypass airflow and recirculation happening in the data hall, then increasing the supply-side temperature and decreasing the air volume being delivered can have devastating effects. The good news is that many existing data centers can implement these best practices and see significant gains in improvement of their systems.

In 2002, an Uptime Institute study found that an average of 60 percent of computer room cooling was going to waste through bypass air not passing through the IT equipment. In a 2013 follow-up study, Upsite Technologies found little improvement, estimating that an average of 48 percent of supply air is bypass airflow. What was also interesting was that in 2002 there was approximately 2.8 times the required cooling capacity available and in 2013 that figure rose to 3.9. Cooling capacity isn’t the issue: it is inefficient cooling systems and poor airflow management practices.  

Table 1: The State of Airflow Management

<table>
<thead>
<tr>
<th>2002 UPTIME INSTITUTE RESEARCH</th>
<th>2013 UPSITE TECHNOLOGIES RESEARCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass Airflow</td>
<td>Bypass Airflow</td>
</tr>
<tr>
<td>60%</td>
<td>48%</td>
</tr>
<tr>
<td>Hot Spots</td>
<td>Hot Spots</td>
</tr>
<tr>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Cooling Capacity</td>
<td>Cooling Capacity</td>
</tr>
<tr>
<td>2.6x</td>
<td>3.9x</td>
</tr>
</tbody>
</table>

Cooling capacity isn’t the issue. It is inefficient cooling systems and airflow management that is the problem.
COOLING AND AIRFLOW MANAGEMENT GOALS

When talking about the cost of cooling (and thermal management in general), it’s important to note the concrete differences between two concepts: active cooling and airflow management.

Active cooling systems and equipment are actually cooling the return air from the IT equipment. These systems generally include perimeter cooling such as CRAC or CRAH systems, close-coupled cooling (in-row) and rear door heat exchangers (in-rack). The goal of any cooling system is to supply enough conditioned air at as high a temperature as possible to allow for a reliable equipment operating environment.

Airflow management manages the supply air that comes from the cooling equipment to the IT load, and the return air that exits the IT load and goes back to the cooling equipment. Tactics include aisle containment systems, perforated floor tiles, blanking panels, airflow sensors and more. Airflow management’s goal is to deliver the conditioned supply air required by the IT equipment, ensure it only passes through once and get it back to the cooling unit so it can be reconditioned.

A data center manager knows when he has achieved an optimized thermal environment when:

› Bypass airflow is less than 10 percent
› The temperature measured at top and bottom of the IT equipment cabinet has a delta of less than 5 degrees Fahrenheit.

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9 Room-Level Energy and Thermal Management in Data Centers: The DOE Air Management Tool – Magnus K. Herrlin 2010
EFFECTS OF GEOGRAPHY ON FACILITY COOLING

While looking at aspects of data center cooling, it’s worth exploring the impact of the physical location of a facility on cooling performance and costs. Whether you own or manage an existing facility and are looking to take advantage of the potential cooling benefits that its climate may afford, or actually determining a location for a greenfield data center, geography can play a major role in achieving a cost-effective thermal environment.

Chief among the geographical opportunities is the potential for a data center to leverage free cooling systems, such as economizers. These systems rely on outside air, provided the conditions are right.

There are four primary climate-related variables that can affect data center cooling:

› Temperature: average outside air temperatures that are low enough to allow for the use of an economizer cooling system to be employed
› Humidity: ideal level is not so high as to require continuous dehumidification, and low enough to allow for adiabatic cooling
› Contamination: due to air quality issues
› Corrosion: due to poor air quality

AN IMPORTANT NOTE ON GEOGRAPHY

Of course, besides these four climate-related factors, it’s worth noting that the geographic location of a data center as it relates to thermal management also hinges on the availability and quality of power today and in the future. Local energy rates are an important factor. Proper vetting of the power grid should be conducted before choosing a location or a cooling system.

Figure 7: Biggest Factors That Drive New Data Center Investments

<table>
<thead>
<tr>
<th>Factor</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Expenses (Power/Cooling Costs)</td>
<td>32%</td>
</tr>
<tr>
<td>Low Natural Disaster Risk</td>
<td>3%</td>
</tr>
<tr>
<td>Least Network Latency</td>
<td>3%</td>
</tr>
<tr>
<td>Tax Credits and Local Incentives</td>
<td>3%</td>
</tr>
<tr>
<td>Caliber of Workforce</td>
<td>9%</td>
</tr>
<tr>
<td>Quality of Life</td>
<td>10%</td>
</tr>
<tr>
<td>Proximity to Fiber</td>
<td>11%</td>
</tr>
<tr>
<td>Proximity to Existing Operation/Headquarters Staff</td>
<td>29%</td>
</tr>
</tbody>
</table>

10 Insights Into What’s Next: Trends in Data Centers 2014 – Mortenson
MEASURING COOLING SYSTEM EFFICIENCY

There are several different ways to measure the efficiency of a data center’s use of power, the most popular being Power Usage Effectiveness (PUE). However, while the use of PUE measurements are accurate for measuring power efficiency overall, there are several additional steps that need to be taken to accurately define the efficiency of the specific cooling system within a data center. Below are some common methodologies to measure the effectiveness of the cooling system.

**POWER USAGE EFFECTIVENESS**

In 2007, the Green Grid Association published an energy-efficiency metric called Power Usage Effectiveness\(^1\). It is measured by dividing the amount of power entering a data center by the power used to run the IT infrastructure. It’s expressed as a ratio, with overall efficiency improving as the number is closer to one.

The challenge with PUE as it relates specifically to the cooling system is that it measures overall energy efficiency of the entire facility. This makes it difficult to quantify exactly how efficient or inefficient the cooling system is. Nevertheless, capturing and recording PUE can be a benchmark metric that will help gauge the effectiveness of any step taken to increase the cooling system’s efficiency.

**COOLING CAPACITY FACTOR (CCF)**

Cooling Capacity Factor or CCF\(^2\) is a metric that was developed by Upsite Technologies to estimate the utilization of the cooling system within the data hall. This metric allows a data center manager to benchmark the rated cooling capacity versus how it is being utilized. Having this information allows data center managers to understand if their cooling issues are due to a lack of available cooling capacity or poor airflow management practices.

**OTHER IMPORTANT THERMAL EFFICIENCY METRICS**

Here is a list of other metrics that are important to know when evaluating the overall efficiency of the cooling system\(^3\):

- Raised floor bypass open area
- Percent of data center cabinets experiencing hot and cold spots
- Percent of perforated tiles properly placed in the cold aisle versus the hot aisle
- Ratio of supply air volume to IT equipment airflow volume

\(^{13}\) Cooling Capacity Factor (CCF) Reveals Stranded Capacity and Data Center Cost Savings – Kenneth G. Brill and Lars Strong 2013
\(^{14}\) Lars Strong – Myths of Data Center Containment – 2015
DATA CENTER COOLING STANDARDS

Standards for data center thermal management have evolved substantially in the last few years, particularly in the areas of optimal temperature range as it relates to IT equipment. There are several organizations with useful published standards and guidelines, with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) being highly prominent globally. As data center owners and operators aim to achieve the best possible thermal environment, these organizations can be a valuable resource with well-researched, documented and methodical standards.

ASHRAE

ASHRAE is heavily involved with the development of modern data center facilities. The ASHRAE Technical Committee 9.9 created an initial set of thermal guidelines for the data center in 2004 with two follow-up editions in 2008 and 2011. Each new set of guidelines provided guidance on the different classes of servers and other data center equipment that could function in higher acceptable levels of operating temperature and humidity for greater cost savings and efficiency. However, it’s important to note that the standards have to be properly implemented in order to avoid heat-related outages and other potential issues.

THE GREEN GRID

The Green Grid is not a standard per se, but it is an international consortium dedicated to improving energy efficiency in data centers and business computing ecosystems. PUE and its reciprocal, DCiE, are widely accepted benchmarking standards proposed by the Green Grid and the Department of Energy respectively to help IT professionals understand how efficient their data centers are and to monitor the impact of their improvement efforts.

DIN EN 1377

DIN EN 13779 is a European standard, and encompasses ventilation for nonresidential buildings, as well as performance requirements for ventilation and room-conditioning systems. This standard focuses on achieving a comfortable and healthy indoor environment in all seasons with acceptable installation and running costs. It also specifies the required filter performance in a system to achieve good indoor air quality (IAQ).
EUROPEAN COMMITTEE FOR ELECTROTECHNICAL STANDARDIZATION (CENELEC)

The European Committee for Electrotechnical Standardization developed a series of European standards for data centers. This document specifies recommendations and requirements to support the various parties involved in the design, planning, procurement, integration, installation, operation and maintenance of facilities and infrastructures within data centers.

The EN 50600-2-3 standard focuses specifically on environmental control and specifies requirements and recommendations for such factors as:

- Temperature control
- Relative humidity control
- Particulate control
- Ventilation
- Energy-saving practices

ENERGY STAR

ENERGY STAR is a U.S. Environmental Protection Agency (EPA) voluntary program that helps businesses and individuals save money and protect the climate through superior energy efficiency. ENERGY STAR has collaborated with other data center standards organizations to establish guidelines and best practices in the area of energy management. The organization has published recommendations specific to cooling in the areas of temperature and humidity adjustments, hot- and cold aisle layouts, air-side economizer, proper airflow management and more.

OTHER STANDARDS AND RESOURCES

There are a number of other applicable standards, guidelines and best practice documents and research related to data center cooling that may be helpful to designer, engineers, owners and operators:

- BREEAM
- 80 Plus
- Code of Conduct Data Centers
- BICSI
- Uptime Institute
- CEEDA
- US Department of Energy
- OSHA
- VDI 2054 (Germany)
DATA CENTER COOLING APPROACHES

Data center owners, designers and engineers have many choices when it comes to methodologies and the cooling topologies of their facilities. This section is not intended to provide heavily technical details or comparisons between these different choices, but rather a snapshot of each method and a few of their chief advantages. This informed perspective of the current data center cooling landscape will provide the basis for the solutions and technologies that can be layered to further increase efficiency and cost-effectiveness.

**METHODOLOGIES**

There are many different methods for cooling data centers, some being a hybrid of technologies such as traditional systems with an economizer option or mode of operation. Here’s a quick overview of choices broken down into a few major categories.

**WATER**

Chilled water systems are generally used in data centers with a critical IT load of 200 kW and larger with moderate- to high-availability needs. They may also be used as a high-availability dedicated solution. In many facilities, chilled water systems are often used to cool entire buildings, even though the data center uses only a small portion of the total cooling capacity. These systems use large chillers to produce cold water which cools the supply air. The chilled water is pumped into the CRAHs in the computer room, while the heat is transferred to the cooling tower through condenser piping.

**AIR**

Air-cooled systems are two-piece designs that include an air-cooled CRAC and a condenser, which is also known as an air-cooled CRAC DX (direct expansion) system. Air-cooled CRAC units are widely used in data centers, and are considered the norm for small and medium rooms. In this type of system, refrigerant circulates between the indoor and outdoor components in pipes. Heat is transferred outdoors by using this circulating flow of refrigerant.

Air-cooled self-contained systems are AC units that are joined within an air duct. Usually these systems feature all the components of the refrigeration cycle in one enclosure, most typically within an IT environment. Heat exits this system as a stream of exhaust air, which is routed away from IT spaces to the outdoors or unconditioned spaces.
FREE COOLING

The term “free cooling” is a misnomer. It refers to the ability to cool a data center without using a refrigeration cycle. There are still pumps and fans operating in these systems which consume energy. Free cooling takes advantage of local ambient conditions to cool the supply side air that feeds the IT equipment.

According to a report by IHS, the market for free cooling technologies will grow faster than any other cooling method over the next four years. Additionally, many of these technologies are being added on to existing DX or chilled water systems as an optional operating mode.

There are three main types of free cooling systems:

Air-Side Systems
Outside air is brought into the data center directly through filters or indirectly through heat exchangers. In direct air-side systems, filtering of the outside air is important in order to avoid particulate or gaseous contamination as well as to provide some form of humidity control.

Water-Side Systems
This system leverages a cooling medium, such as water or a glycol water mixture that circulates directly through cooling towers and/or condensers rather than the chillers or compressors. Water-side systems segregate outside from inside air, providing cooling through a heat exchanger. Depending on the location of the data center, there is opportunity to leverage cold water from rivers, lakes or oceans instead of using traditional closed-loop water chiller systems. Evaporative cooling systems use a number of methods to evaporate water into the airflow path of the airside economizing systems in order to lower the air temperature entering the computer room. This system is used to extend the hours of free cooling in areas with hot and dry climates.

Higher Temperatures for Chiller Set Points
Raising chilled water set points is more of a retooling tactic than an actual methodology, but it’s a growing trend for facilities that use chillers. Raising the cooling set point in the data center allows operators to also raise the temperature of the water in the chillers, reducing the amount of energy required to cool the water and increasing the amount of free cooling hours.

It was widely reported that Facebook retooled its cooling system in one of its existing data centers and reduced its annual energy bill by $229,000. Some of the ways Facebook was able to do this was by:

- Raising the temperature at the CRAH return from 72 to 81 degrees Fahrenheit.
- Raising the temperature of chiller water supply by 8 degrees, from 44 to 52 degrees Fahrenheit.

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15 Facebook Saves Big By Retooling its Cooling – Data Center Knowledge – 2010
COOLING TOPOLOGIES

When designing a cooling system, there are three main topologies or layouts to consider: room, row and rack. Each topology has benefits and drawbacks, but the important thing to remember is that there isn’t one method that is necessarily more efficient than the other. Any system can be made efficient with proper airflow management techniques. Selecting one topology over the other comes down to the physical layout of the room and the power requirements of the individual IT racks. It is also important to note that these topologies can be mixed in the same environment, so the cooling system is more tuned to the IT application requirements.

ROOM COOLING

Room or perimeter cooling is the traditional and most prevalent topology used in data centers today. It involves using a cooling unit such as a CRAC or CRAH system that delivers the supply air to the IT load with or without a plenum to the cold aisle.

There are two main floor designs that will affect the delivery of the supply-side air from a perimeter cooling unit: raised floor and slab.

RAISED FLOOR DESIGNS

Delivering supply air through perforated floor tiles can be easily arranged. This design tends to allow for much easier execution of an efficient air distribution strategy and gives greater control of where the supply air is going.

According to data center thermal efficiency expert Dr. Robert F. Sullivan, some tips that might increase efficiency in a raised floor environment include:

› Keeping the underfloor as clean as possible
› Removing any power and data cables from under the floor and move them overhead
› Removing any items being stored under the floor
› Matching the number of perforated tiles properly to the airflow, which is matched to the heat load
› Sealing and plugging all cable cutouts using grommets and foam blocks

SLAB FLOOR DESIGNS

These designs offer flexibility in the location of the computer room, but it makes it harder to distribute air properly. According to Dr. Robert F. Sullivan, when distributing air into a computer room built on a slab the benefit of going to contained aisles occurs at a much lower power dissipation level (e.g., 5 kW per cabinet).

PLENUM AND DUCTWORK

Plenum and ductwork costs need to be considered when looking at a thermal management status. Plenum spaces are the open spaces above the ceiling or below the floor that are used for air circulation. Attention to these spaces is crucial for optimum air circulation in data centers. Inadequate ceiling heights, poor ductwork design or an undersized hot air return plenum can cause airflow management issues.
**ROW-BASED COOLING**

Row-based cooling goes by several different names including close-coupled cooling, row-oriented architecture and in-row cooling.

The true purpose of row cooling is to capture hot IT exhaust air, neutralizing the potential negative impact before it can mix with surrounding air or recirculate to the front of the IT rack. Row cooling units that can capture 100 percent of hot air can improve energy efficiency and eliminate hot spots. Another benefit of row cooling is that the supply and return air doesn’t have to travel as long a distance as it would have to in a perimeter- or room-cooled environment, which means smaller, more energy-efficient fans can be used to reduce the operational costs of the system.

Some important points to keep in mind when designing a row-based cooling topology:

- **It does not require a raised floor**
  One of the benefits of row-based cooling is that it can be installed in environments that lack a raised floor. Because the cooling system is located in the same row as the IT equipment, a supply air plenum isn’t required.

- **It needs overhead or under floor piping**
  Row-based cooling still requires chilled water or refrigerant to operate, which means pipes will need to be installed overhead or under the floor for each cooling unit, which creates additional cost and complexity.

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**Figure 9: Example of Row-Based Cooling**

*It’s good for high-density applications and targeted cooling*
In environments that have high-density cabinet configurations, row-based cooling can be used to target those areas that can help alleviate strain on the perimeter cooling systems.*
RACK COOLING

Rack cooling is when the cooling unit is brought inside the IT rack itself. There are two main drivers that relate to the implementation of rack cooling methodologies:

› High-density equipment cabinets
› Data centers built in nontraditional data center environments

Sometimes high-density equipment cabinets produce too much heat for traditional methods used to cool the data center. In those cases, rather than add additional perimeter cooling units, it might be more beneficial to add rack cooling.

Data centers that are constructed in rooms that might not be designed to support IT equipment can also benefit from in-rack cooling because like row cooling a raised floor isn’t required. Additionally, the heat is largely contained within the rack itself and the exhaust air produced is conditioned air, which makes the rest of the room a comfortable temperature.

One method of rack cooling is the use of a rear door heat exchanger. Rear door heat exchangers use water or refrigerant to cool the IT exhaust air by passing it through a heat exchanger mounted directly to the rear of the cabinet. Fans then blow cool air out the rear of the cabinet and back into the data hall. By close coupling the rear door heat exchanger to the rack, the hot air is contained within the cabinet.
The goal of any data center thermal management strategy is to make sure the room that the equipment resides in is at a temperature that is within range of the required operating temperatures specified by the equipment manufacturer. As stated previously, the old method of doing this is to flood the room with cold air, and if the room became too hot, add more perforated tiles, lower the temperature set points and finally add cooling capacity until the desired temperature is achieved. Due to the cost of operating a data center and the rise in cabinet densities, data center managers today are looking for a more efficient, reliable way of delivering air to the equipment in the cabinet.

Conditional environmental control is the process of delivering the exact amount of supply air at an ideal temperature and moisture content to maximize the cooling system’s efficiency and improve equipment uptime.

There are several key drivers as to why a data center would want to adopt this approach in a new or existing environment:

- Reduces the likelihood of hot spots and cold spots that can lead to equipment failure and added energy usage
- Regains stranded cooling and energy capacity, which allows for additional IT growth to support the business while minimizing unnecessary capital expenditures
- Reduces operational expenses through the reduction in energy consumption by the cooling equipment
- Enhances the business’ environmental image

The following sections will explain in detail these four best practices to achieve conditional environmental control:

1. Supply pressure
2. Supply temperature
3. Airflow segregation
4. Airflow control
A difficult thermal management challenge that many data center operators have to face is how to deliver the proper amount of cooling that the IT load requires without oversupplying. Achieving a balance means the cooling system is using the minimum amount of energy required to deliver the supply air to where it needs to go, thereby reducing cost.

One reason why supply pressure is such a challenge is that the IT load is constantly in motion. Any change that takes place in the data center — whether it is addition or subtraction of cabinets, IT equipment workload variation, containment systems, etc. — will have an impact on the airflow pressure within the data center. Additionally, obstructions in the room, cabling under the floor in a raised floor environment and poor cable management inside of a cabinet can affect airflow pressure throughout the room. However, it is important that the amount of air being delivered by the cooling system is tuned to the environment so there isn’t an over- or undersupply of air, which can lead to wasted cooling capacity or, worse yet, hot spots that can cause equipment failures through airflow recirculation.

Having a better understanding of the airflow pressure throughout the data hall will allow better identification of trouble spots, redirection of cooling to areas that might need it more, such as high-density equipment cabinets and verification of the effects of improvements made throughout the thermal management system.

This section of the report identifies some of the thermal management challenges that have an impact on supply pressure.
Bypass airflow is conditioned air from a cooling unit that does not pass through the IT equipment before returning back to a cooling unit. This is a problem because it reduces the static pressure under the raised floor, which means the cooling unit fans need to spin faster to deliver the same amount of air. This leads to excess cooling capacity because the actual heat load is being generated by the equipment to compensate.

Steps to reduce bypass airflow include:

- Measuring current bypass airflow by using weighted average temperatures from the cooling unit, server racks and ceiling return points — making sure to record measurements for each functional cooling unit.
- Walking through the data center to visually identify the sources of bypass airflow, which can include cable openings in the raised floor, unsealed holes in the perimeter walls under the raised floor and holes behind the air handling units and at the bottom of building columns.
- Sealing all identified sources of bypass airflow with floor grommets or fire-rated material for holes in the perimeter walls underneath the raised floor.
- Ensuring the correct number of perforated tiles are only placed in the cold aisle, not in the hot aisle.
- Remeasuring bypass airflow.

By reducing bypass airflow in the computer room, one can expect to achieve the following benefits:

- Reduced number of cooling units operating and the reduction in the operating expense of the cooling systems.
- Improved equipment reliability through a reduction in hot spots.
- Reduction in new cooling unit capital expenses.
- Cooling system capacity gains for future expansion needs.

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16 Improving Data Center Air Management – Munther Salim and Robert Tozer February 2010
17 Opportunities to Improve Cooling Capacity and Operating Costs – Upsite Technologies
18 Upsite technologies research study
19 Operational Intelligence Ltd, 2015
AIRFLOW RECIRCULATION

Airflow recirculation can be defined as hot exhaust air that passes through the IT equipment multiple times before it travels back to the cooling system. Recirculation is a problem because the supply air coming from the cooling equipment will heat up to a level that threatens the availability of the equipment, which can cause an outage or failure. These areas are generally referred to as hot spots. Some causes of airflow recirculation include:

› Absence of blanking panels in equipment cabinets
› Gaps in sides, tops and bottoms of cabinets
› Leakage through spaces left between cabinets
› Poorly designed airflow panels
› Noncontinuous rows
› Circulation over the tops of cabinets and rows
› Poor cable management inside the rack or cabinet.

HOW TO DETECT AIRFLOW RECIRCULATION

The best way to detect if a data center is experiencing airflow recirculation is to verify if there are any hot spots. To do that:

› Use an IR thermometer to identify a cold aisle with a wide range of temperatures or where temperatures are too hot
› Measure temperature at the top, middle and bottom of the rack by using sensors or a thermal heat gun
› Record the supply temperature from the cooling unit feeding that row (the best place to do this is under the raised floor in each cold aisle or at the base of the cabinet)
› Determine if there is more than a 5 degree Fahrenheit difference between cooling system set point and the warmest temperature at the rack, which means there is energy waste.

Temperature sensors should be permanently deployed every third cabinet with one at the top, middle and bottom rack unit (RU). This allows a user to monitor the difference in temperature on a continuous basis. Ideally, the difference should be less than or equal to five degrees Fahrenheit. If the temperature variance is higher than that, then chances are there is airflow recirculation (mixing) or the perforated tiles are inefficient.
REDUCING AIRFLOW RECIRCULATION

Steps to reduce airflow recirculation include:

- Filling in all gaps inside the cabinet with blanking panels
- Plugging all gaps in between cabinets
- Adopting a hot and cold aisle layout
- Segregating supply and return air
- Using perforated tiles designed for heat dispersion
- Increasing Cubic Feet per Minute (CFM) to the cold aisle
- Replacing inefficient perforated tiles with tiles designed for higher heat transfer capability.

MONITORING AIRFLOW PRESSURE

After improving overall airflow pressure throughout the data hall, it is important to continue to tune the system. Monitoring the static pressure and airflow at different points in the data center will help prevent significant pressure differentials, which could be a sign of bypass airflow or recirculation that ultimately lead to hot spots and equipment failure. It is recommended that the differential air pressure trends be monitored over a period of time to establish a baseline.

DIFFERENTIAL AIRFLOW PRESSURE SENSOR PLACEMENT

If the data center is built on a raised floor or a slab, monitoring airflow pressure is still important. In order to collect accurate data, deploying sensors correctly is critical. The ideal placement for pressure sensors depends on the size and layout of the room, but here are some general best practices:

- Place sensors every 1,000 square feet
- Install a few feet above the floor
- Position sensor tubes in different pressure areas (e.g., above and below the raised floor and in the hot and cold aisle)
- When under the raised floor, install them no closer than 12 feet from a cooling unit

When collecting the information, use the lowest pressure reading as a guide because it is an indication of where the most air is required. In a nonraised floor environment, measure the static pressure difference between the hot and cold aisle.
The importance of achieving the right temperature is to help maximize the efficiency of the cooling system. It has been well documented that increasing the operating temperature will reduce the energy required to operate the cooling equipment thus providing substantial operational savings.

As stated earlier, the traditional method to cool server rooms in the past was to flood them with cool air and operate within the temperature range of 68 degrees Fahrenheit (20 degrees Celsius) to 71 degrees Fahrenheit (22 degrees Celsius). In 2004, ASHRAE increased the operating temperature range to 68 degrees Fahrenheit (20 degrees Celsius) to 77 degrees Fahrenheit (25 degrees Celsius) based on its findings and the advice from various IT equipment manufacturers. In 2008, ASHRAE added another change in the form of an addendum titled “Environmental Guidelines for Datacom Equipment” in which it expanded the recommended operating range to 64.4 degrees Fahrenheit (18 degrees Celsius) to 80.6 degrees Fahrenheit (27 degrees Celsius).

In 2011, ASHRAE published the third edition of the book, which contained two major additions. The first was guidance on server metrics that would assist data center operators in creating a different operating envelope that matched their business values. Essentially, ASHRAE was providing the decision criteria and steps that data center operators should take if they wanted to go beyond the recommended temperature envelope for additional energy savings. The second change was in the data center classes. Previously, there were two classes that applied to IT equipment: classes 1 and 2. The new guidelines provided additional classes to accommodate different applications and priorities of IT equipment operation.

Studies have shown that for every 1 degree Fahrenheit increase in server inlet temperature data centers can save 2 percent in energy costs.21

SUPPLY TEMPERATURE

21 Dr. Robert Sullivan – Anixter Interview 2015
Table 2: ASHRAE 2011 and 2008 Thermal Guideline Comparisons

<table>
<thead>
<tr>
<th>2011 CLASSES</th>
<th>2008 CLASSES</th>
<th>APPLICATIONS</th>
<th>IT EQUIPMENT</th>
<th>ENVIRONMENTAL CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>Data center</td>
<td>Enterprise servers, storage products</td>
<td>Tightly controlled</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
<td></td>
<td>Volume servers, storage products, personal computers, workstations</td>
<td>Some control</td>
</tr>
<tr>
<td>A3</td>
<td>NA</td>
<td></td>
<td>Volume servers, storage products, personal computers, workstations</td>
<td>Some control</td>
</tr>
<tr>
<td>A4</td>
<td>NA</td>
<td></td>
<td>Volume servers, storage products, personal computers, workstations</td>
<td>Some control</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>Office, home, transportable environment, etc</td>
<td>Personal computers, workstations, laptops and printers</td>
<td>Minimal control</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>Point-of-sale, industrial, factory, etc</td>
<td>Point-of-sale equipment, ruggedized controllers, or computers and PDAs</td>
<td>No control</td>
</tr>
</tbody>
</table>

Based upon self-reported DCD intelligence census data, the global average of inlet air temperature is 72.5 degrees Fahrenheit (22.5 degrees Celsius). The proportion below ASHRAE’s minimum recommended level of 64.4 degrees Fahrenheit (18 degrees Celsius) is higher (9.8 percent) than the proportion above the maximum level (2 percent), which means there still is capacity for data centers to reduce energy consumption and costs by raising air inlet temperatures.

THE DESIRE TO KEEP THINGS THE SAME

If raising the inlet temperature in the data center has been proven to reduce energy thereby significantly reducing operational expenses, why aren’t more data centers doing it? Some of the reasons that have been stated by various data center operators are:

› The current data center is operational without any issues
› Legacy IT systems might not be able to cope with temperature changes
› The working environment will be hotter, and that isn’t worth the savings
› Feeling it is difficult to change thermal management strategies in an existing data center
› If there is a cooling system failure, IT equipment will shut down faster.

Table 3: Inlet Air Temperature 201422

<table>
<thead>
<tr>
<th>TEMPERATURE RANGE</th>
<th>PERCENT SPECIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>64.4 °F (18 °C) or cooler</td>
<td>9.8%</td>
</tr>
<tr>
<td>64.4 °F (18 °C) &gt; 68 °F (20 °C)</td>
<td>15.8%</td>
</tr>
<tr>
<td>68 °F (20 °C) &gt; 69.8 °F (21 °C)</td>
<td>20.6%</td>
</tr>
<tr>
<td>69.8 °F (21 °C) &gt; 71.6 °F (22 °C)</td>
<td>24.1%</td>
</tr>
<tr>
<td>71.6 °F (22 °C) &gt; 75.2 °F (24 °C)</td>
<td>12.4%</td>
</tr>
<tr>
<td>75.2 °F (24 °C) &gt; 77 °F (25 °C)</td>
<td>5.6%</td>
</tr>
<tr>
<td>77 °F (25 °C) &gt; 78.8 °F (26 °C)</td>
<td>2.0%</td>
</tr>
<tr>
<td>80.6 °F (27 °C) or warmer</td>
<td>2.0%</td>
</tr>
<tr>
<td>Unable to specify</td>
<td>16.6%</td>
</tr>
</tbody>
</table>

22 DCD Intelligence Census Survey – 2014
CONSIDERATIONS WHEN INCREASING OPERATIONAL TEMPERATURE

Server Reliability
There is a perception in the industry that higher operating temperatures in the data hall can lead to a higher number of failure rates with the IT equipment. These concerns do hold some weight as it has been shown that there is a greater likelihood of failure when equipment is exposed to high temperatures caused by data center hot spots. However, what isn’t as widely understood is the long-term effect of temperature change on servers.

In 2011, ASHRAE released a paper titled 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance. One of the studies presented in the paper focused on relative server failure rates evaluated against temperature based on data from a variety of different hardware manufacturers. What was found was that at 68 degrees Fahrenheit (20 degrees Celsius), which was the baseline measurement one could expect roughly 10 servers to fail in a 1,000 server environment per year. If the inlet temperature was slowly increased to 80.6 degrees Fahrenheit (27 degrees Celsius), which is at the high end of ASHRAE’s recommended temperature range, there would be an average increase of 2.5 server failures per year, for a total of 12.5 server failures for that same year. In other words, 10 failed servers out of 1,000 means 1 percent of the total servers failed; if 12.5 servers fail out of 1,000, that means 1.25 percent of the servers failed, or just a 0.25 percent difference. This data shows there isn’t a significant increase in server failures over the long term when increasing inlet temperatures within ASHRAE’s recommended guidelines.

There isn’t a significant increase in server failures over the long term when increasing inlet temperatures within ASHRAE’s recommended guidelines.

24 The Green Grid: Data Center Efficiency and IT Equipment Reliability at Wider Operating Temperature and Humidity Ranges
25 ASHRAE, 2011 Thermal Guidelines for Data Processing Environments – Appendix C, reformatted
Cooling System Ride-Through Time
Another commonly held misconception by data center operators is that if they maintain a lower operating temperature in their server rooms they would increase the ride-through time of the cooling system. Ride-through time is the speed a data center would heat up to reach a critical temperature causing IT equipment to shut down and/or fail during a cooling system failure. There is some validity to this depending on the thermal strategy and cabinet densities residing in the current data center. Data centers that have deployed hot or cold aisle containment have a smaller contained air volume, so the temperature to the racks would rise faster. Additionally, higher rack power densities will shorten the time for the environment to get to a critical temperature in the event of an outage. In data centers that operate in an open environment with no containment and lower cabinet densities, the ride-through time will be longer, but only by a few seconds. In environments where server densities are 6 kW or greater, the Uptime Institute recommends continuous cooling where the heat removal system is uninterrupted during the transition from utility power to generator power.27

All things being equal, comparing server inlet temperatures with an operating temperature of 55 degrees Fahrenheit (13 degrees Celsius) versus an ideal operating temperature of 77 degrees Fahrenheit (25 degrees Celsius) would only buy seconds if there wasn’t a UPS backup on the cooling system. The amount of operating expense difference that would be incurred by running at the cooler temperature generally outweighs the 12 seconds that would be gained in that scenario.

Working Environment
There should be some consideration given to the working environment when deciding whether to raise the operating temperature in the data center. The Occupational Safety and Health Administration (OSHA) and the International Organization for Standardization (ISO) both have guidelines for working in high-temperature environments. OSHA calculates temperature exposure limits on the wet bulb globe temperature (WBGT), which also takes humidity into account. Because much of the hot aisle work is classified by OSHA as light work (adding removing cabling to servers), at 86 degrees Fahrenheit (30 degrees Celsius) continuous work is allowed. However, as temperatures start to climb past that, OSHA regulations could require employees working in the hot aisle to work less time and have more rest. For more detailed information on this, please refer to the OSHA technical manual Section III, Chapter 4.

In a traditional uncontained work environment where the IT equipment inlet air temperature is between 56-81 degrees Fahrenheit (13-21 degrees Celsius) where there is a rough assumed 40 percent bypass airflow (leakage) and 20 percent recirculation, the rest of the server room (outside the cold aisle) should be roughly 75 degrees Fahrenheit (24 degrees Celsius). At these temperatures the OSHA high-temperature guidelines wouldn’t apply.

Comparing server inlet temperatures with an operating temperature of 55 degrees Fahrenheit (13 degrees Celsius) versus an ideal operating temperature of 77 degrees Fahrenheit (25 degrees Celsius) would only buy seconds if there wasn’t a UPS backup on the cooling system.

26 Focused Cooling Using Cold aisle Containment – Emerson Network Power
### SIX STEPS TO ADJUST SUPPLY TEMPERATURE
There are a few steps that need to take place in order to safely increase the supply temperature in the data center to the desired level.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>DEPLOY TEMPERATURE SENSORS</strong> There needs to be a baseline reading collected, and in order to do that, temperature sensors should be deployed across the data hall. Per ASHRAE guidelines, temperature and humidity sensors should be deployed every third rack, at the supply side with one sensor aligned with the top U, one in the middle U and one at the bottom.</td>
</tr>
<tr>
<td>2</td>
<td><strong>MONITOR EXISTING TEMPERATURE</strong> When collecting data from the sensors, it is important to establish a baseline of information and to understand the thermal dynamic of the current space. If there are hot spots currently in the data center, it is important to get those issues resolved before turning up the set point. Temperature data should be monitored for at least a few days to account for swings in IT equipment utilization throughout the day.</td>
</tr>
<tr>
<td>3</td>
<td><strong>CORRECT AIRFLOW MANAGEMENT PROBLEMS</strong> Bypass airflow and recirculation problems must be corrected and the proper number and distribution of perforated tiles need to be deployed before changing the temperature set points.</td>
</tr>
<tr>
<td>4</td>
<td><strong>MOVE AIR HANDLER CONTROL POINT</strong> With many legacy air handlers, the control point was located on the return air side. Moving the control to the supply side will give the data center manager more control over the temperature that is being supplied to the IT equipment. There are kits available from various cooling system manufacturers to accomplish this.</td>
</tr>
<tr>
<td>5</td>
<td><strong>ADJUST TEMPERATURE SET POINT</strong> It is important that raising the temperature set point is done gradually, 1 degree Fahrenheit per week, until the desired inlet temperature has been achieved. It is important to watch for additional hot spots that could form throughout this process. The input air temperature should not exceed 80.6 degrees Fahrenheit (27 degrees Celsius). If there are areas where the temperature has been exceeded then the airflow volume from the air handlers needs to be increased or additional perforated floor tiles need to be placed in the cold aisle, always maintaining the proper number of perforated tiles for the total airflow volume in the computer room.</td>
</tr>
<tr>
<td>6</td>
<td><strong>ADJUST CHILLED WATER TEMPERATURE</strong> Raising the set point of the air handler generally means that chilled water temperature can be increased as well. Many data centers have chilled water set points between 42-45 degrees Fahrenheit (6-7 degrees Celsius) that have been raised in some facilities to 50 degrees Fahrenheit (10 degrees Celsius) or up to 18 degrees Celsius for substantial energy savings(^\text{29}). It is best to consult with the manufacturer of the chiller and air handler for guidance on the ideal temperature balance.</td>
</tr>
</tbody>
</table>

WHAT IS THE RIGHT TEMPERATURE FOR MY DATA CENTER?

The short answer is: it depends. There are several considerations that go into understanding what the right temperature is for any particular data center. Server manufacturers have agreed that inlet temperatures that fall within the range of 64-80.6 degrees Fahrenheit (18-27 degrees Celsius) have little effect on the reliability or performance, pending the temperature is not a sudden, but a gradual increase. ASHRAE has provided recommended and allowable guidelines, and classes within the data center environment for additional guidance. It all comes down to what makes the particular data center manager feel comfortable. A general rule of thumb is that temperature in the cold aisle should be even from the bottom of the rack to the top of the rack, and as warm as possible not to exceed ASHRAE recommended guidelines.

A good start is to set a guideline, adjust gradually, monitor the change and report back the results. From there, if the equipment is still within the recommended temperature range, there have been no major complications and the employees are comfortable with the working conditions, the temperature can continue to be gradually raised. Remember, for every 1 degree Fahrenheit increase, there is roughly a 2 percent savings in energy cost.
The main purpose of any airflow segregation strategy is to isolate the cool supply air from the hot exhaust air, which prevents airflow recirculation. The less airflow recirculation there is in the room, the better temperature control the data center operator will have and the less likelihood there will be any data center hot spots. Airflow segregation, along with following the other best practices of conditional environmental control outlined in this paper allows for the following benefits:

› Prevents airflow recirculation, which reduces the risk of hot spots
› Allows for higher temperature return air to the HVAC equipment which increases efficiency
› Provides more consistent equipment rack inlet temperatures with the use of top rack units across the computer room

It is important to note that airflow segregation doesn’t provide any efficiency gains on its own. What it does is allow for greater energy savings and control over supply and return temperatures. In order for those efficiencies to be realized, data center managers still need to increase rack inlet temperatures and reduce the volume of air being delivered to the IT load by reducing fan speeds or turning off cooling units.
DIFFERENT METHODS OF AIRFLOW SEGREGATION

There are three main types of airflow segregation strategies available today:

› Hot aisle containment
› Cold aisle containment
› Vertical exhaust ducts

Each of these methods has multiple variations of how it can be constructed and deployed. For instance, hot aisle containment can be deployed with or without a roof, with one row or two rows of equipment cabinets, or with curtains or sliding doors. The following sections explain the differences between the three methods and considerations when selecting one versus the other.

Hot Aisle Containment
In a hot aisle containment deployment, the hot aisle is enclosed to capture the IT equipment airflow discharge with the rest of the data hall acting as the cold aisle. Generally in a hot aisle deployment, two rows of racks are set up with the “rear” of the racks facing each other so the IT equipment discharge flows into a hot aisle. From there, the hot air travels either through grates into a drop ceiling plenum, can be fully contained with a roof, or if the room has a high ceiling (greater than or equal to 24 feet), vertical walls can be constructed so the hot air is released back into the room well above the cabinets.

Cold Aisle Containment
In a cold aisle containment deployment, the cold aisle is enclosed to capture the supply air that comes from the active cooling equipment with the rest of the data hall acting as the hot aisle. In this environment, two rows of racks are set up with the “front” of the racks facing each other so the supply air from the cold aisle can flow into the IT equipment in each row. Generally, cold aisle containment has a cap or roof structure installed at the top of the cabinets.

Vertical Exhaust Ducts
Vertical exhaust ducts (VED), or chimney systems as they are sometimes referred to, is another hot aisle containment approach. The difference, however, is that each cabinet has an exhaust duct (or chimney) mounted directly to the top rear to allow for the heat exhausted from rack-mounted equipment to flow directly into an overhead ceiling plenum or if the ceiling is high enough into the data hall and pulled back into the cooling unit(s). With this system the entire room becomes a cold aisle.

Table 4: Containment Physical Assessment Checklist

<table>
<thead>
<tr>
<th>FACILITY PHYSICAL ASSESSMENT</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the data center arranged in a hot/cold aisle alignment?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Are the cabinets a uniform height/width?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Is there a drop ceiling installed?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>If no, is there clearance to install a drop ceiling?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Is the data center installed on a raised floor?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Is the data center installed on a slab?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Is there overhead cabling installed?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Is there an overhead bus way system installed?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Are there any columns inside a row of racks?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Is perimeter cooling system installed?</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Is a close-coupled coupled cooling system installed?</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
THERMAL EFFICIENCY
BEST PRACTICES

HOW TO SELECT THE RIGHT FORM OF CONTAINMENT

Research has shown that from an efficiency standpoint hot, cold or chimney containment does not hold one advantage over the other. So the question becomes, how do you know what is best for your data center? The first step is to assess the current facility. Table four on page 35 contains a checklist that will provide the key information needed to better determine the right form of airflow segregation in an existing data center.

Once the facility has been assessed, then the data center operator can begin to evaluate one form of containment versus the other.

WHEN TO CONSIDER COLD AISLE CONTAINMENT

✓ It’s generally the simplest solution to deploy in a retrofit.
✓ There is a raised floor already installed.
✓ The data center is installed in a hot and cold aisle configuration.
✓ There are few stand-alone cabinets, and most cabinets are in uniformed aisles and have similar levels of power dissipation.
✓ Higher overall data center working conditions are acceptable.

WHEN TO CONSIDER HOT AISLE CONTAINMENT

✓ There is a drop ceiling with a return air plenum installed
✓ There are many stand-alone IT cabinets.
✓ The data center is installed in a hot and cold aisle configuration.
✓ Cooler overall working conditions are preferred.
✓ With hot aisle containment, a single airflow control can be implemented for a normal size computer room. For large rooms, multiple control zones might have to be implemented.

WHEN TO CONSIDER VERTICAL EXHAUST DUCTS

✓ There is a drop ceiling with a return air plenum installed.
✓ Building columns interfere and make aisle containment impractical.
✓ There are limited overhead obstructions.
✓ High-density cabinets are scattered around the data hall.
✓ There is no raised floor installed.

30 DataCenter 2020: hot aisle and cold aisle containment reveal no significant differences
MEETING FIRE CODE COMPLIANCE

One of the challenges with aisle containment is understanding the impact of the fire and safety requirements on retrofits and new construction data center deployments. Many data centers are implementing containment solutions due to the energy-efficiency benefits, but they are unaware of the potential risks as it relates to the fire and safety standards.

The National Fire Protection Association (NFPA), while being focused mainly in North America, can provide guidance globally and has two standards that address aisle containment fire protection in data centers:

› NFPA Standard 75 (2013), Standard for Fire Protection of Information Technology Equipment
› NFPA Standard 76 (2012), Standard for the Fire Protection of Telecommunications Facilities

It is highly encouraged that data center managers purchase both copies of the standard and review them in their entirety. Here are some highlights from the standards:

› Elements of the containment system must be constructed with materials that have a flame spread index less than 50 and smoke development less than 450 in accordance with one or more of the following: ASTM E 84 and UL723.
› Smoke detectors need to be rated for the intended temperatures of the hot aisles if they are located there.
› Aisle containment systems are no longer considered plenums, so plenum-rated construction materials are unnecessary.
› In a retrofit environment, if automatic sprinklers are present and the aisle containment creates an obstruction to the sprinklers, they need to be modified to comply with NFPA 13.
› No longer are fusible links (heat activated/temperature sensitive) compliant; the roof of the containment system needs to be removed via smoke or fire system activation.
› Panels can no longer drop into the aisle, which can potentially obstruct egress.

Having a better understanding of these requirements before designing an aisle containment solution can help reduce costs that would be incurred through additional labor should the original design not pass a local fire code.

SIDE BREATHING EQUIPMENT

Equipment that does not breathe front to rear or rear to front can have a detrimental impact on any containment system or the equipment itself. As data center managers start to raise the set points and contain their aisles, ensuring this type of equipment gets adequate cooling becomes even more critical. For these types of situations here are some recommendations:

› Deploy a cabinet with adjustable side intake ducts that support mixed airflow equipment in the same cabinet.
› In existing cabinets that cannot support side breathing equipment, deploy rack mountable intake devices matched to the type of airflow required by the device. These are available in active (fan assisted) or passive models.

31 Complying With NFPA’s Aisle Containment Requirements – ASHRAE Journal, September 2015
Airflow control can be defined as the process of directing airflow from the cooling unit to the IT equipment and back. Air flows much like water and will generally take the path of least resistance. That is the reason it is so critical to help guide the air to where it needs to go. Making sure the supply pressure is balanced, the temperature is at an ideal level and the supply and return air are segregated, which will improve overall efficiency and make for a more reliable environment for the IT equipment. Control over the airflow will ultimately provide data center managers the stability they need for the entire thermal management system. This area of evaluation compared to the other three best practices is probably the simplest and most overlooked.

New studies being conducted by several universities funded by the National Science Foundation (NSF) are showing significant effect on airflow and temperature control by the geometric design of airflow panels. For the past 50 years, the method of cooling data centers has been to determine the full BTU (kW) load generated from the electrical usage and provide enough CFM of cold air to offset the heat generation.

The current way to classify perforated tiles is based on the flow area offered. Typically tiles with a 25 percent open area are used for low-density applications that require flow rates less than 1,000 CFM/tile (1,667 cubic meters/hour), and tiles with up to 60 percent open area are used for higher rack densities that require flow rates greater than 1,200 CFM/tile (2000 cubic meters/hour).

What the game-changing discovery has been is that the vent design of the perforated floor tile plays a critical role in the distribution of cold air to the rack. Depending on the vent design, the distribution of cold air can vary significantly across tiles that have an identical open area. In other words, it’s not the volume of air that comes out through the floor tiles that matters. What is most important is deploying floor tiles that can create a turbulent airflow which has a greater impact on heat transfer.

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32 Complying With NFPA’s Aisle Containment Requirements – ASHRAE Journal, September 2015
TYPES OF AIRFLOW DISPERSION IN THE COLD AISLE

› **Puddle effect**
  Airflow distribution has poor velocity or is short cycling at the front edge of the panel. This is normally seen with 25 percent airflow panels but may also be seen in some high-density designs due to geometrical design of panel construction.

› **Jet stream effect**
  Airflow distribution is moving at too fast of a velocity. This is seen quite often in high-density (50 percent or more open area) panels that are streaming the air and lacking turbulent flow characteristics.

› **Heat transference effect**
  Airflow is directed toward a rack but with a designed turbulence and speed that allows cooler air to be pulled in effectively by server fans. This type of airflow dispersion is created by perforated tiles designs that have a lower anterior direction fin protruding below the bottom surface of panel.

SELECTING THE RIGHT PREFORATED FLOOR TILE

› Constructed in a way that ensures positive flow out of every part of the tile (no short cycling)
› Diverts air to the servers so it can penetrate the boundary air of heat on the front side of the cabinet or rack
› Should be able to stratify the air to the top of the cold aisle
› Contains fins underneath, which help to create a heat transfer flow
› Correct load rating to prevent damage from cabinet installations

ELECTRONICALLY COMMUNICATED (EC) AND VARIABLE SPEED DRIVES (VSDs)

After the mechanical cooling system, fans are the next largest energy consumer on computer room air conditioning units (CRACs). In traditional cooling systems, the fans are often operating at a fixed capacity — 100 percent. Moving to a variable speed fan technology can save fan energy consumption by as much as 76 percent by enabling cooling systems to throttle fan speed up or down to meet the changing IT heat load.

Energy consumption by the fans is related to the cube of the speed of the fan. For example:

› A 10 percent reduction in fan speed would result in a 27 percent energy savings
› A 20 percent reduction in fan speed would result in a 49 percent energy savings

![Figure 16: Comparing Heat Transfer, Puddle and Jet Stream Airflows in the Data Center Cold aisle](image-url)
COMPARING THE DIFFERENCE BETWEEN VARIABLE FREQUENCY DRIVES AND EC FANS

In order to evaluate what would be best for a particular environment, it is important to know the difference between a VFD and an EC fan. Both have particular benefits, but it comes down to the amount of capital that can be invested up front and the type of cooling system currently in place. Most manufacturers have retrofit kits that can be purchased; however, it is recommended that they be installed by the manufacturer or a certified mechanical contractor. Below are the major differences between the two solutions:

VFDs
› Drives added to current centrifugal fans in CRAC system
› Achieves speed control by varying the frequency of the electrical current
› Enables fan speed to be adjusted based on IT heat load demands

EC Fans
› Replaces the fans and motor assemblies in an existing CRAC
› Provides a different, more efficient design when compared with traditional centrifugal fans
› Achieves speed control by varying DC voltage delivered to the fan
› Enables fan speed to be adjusted based on IT heat load demands

Table 5: VFD and EC Fans Comparison

<table>
<thead>
<tr>
<th></th>
<th>VARIABLE FREQUENCY DRIVES</th>
<th>ELECTRONICALLY COMMUNICATED FANS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Savings</td>
<td>Save energy when operated below full speed</td>
<td>Save energy at any speed due to more efficient design</td>
</tr>
<tr>
<td>Cooling Unit Type</td>
<td>Better suited for larger systems with ducted up flow cooling units</td>
<td>Better suited for down-flow units</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Similar to traditional fans</td>
<td>Reduces maintenance due to no fan belts and less dust creation</td>
</tr>
<tr>
<td>Installation</td>
<td>Can be retrofitted on existing cooling units</td>
<td>Can be retrofitted on existing cooling units</td>
</tr>
<tr>
<td>ROI</td>
<td>Faster payback due to lower upfront cost</td>
<td>Lowest total cost of ownership, but higher upfront cost</td>
</tr>
</tbody>
</table>

34 Choosing Between VSDs and EC Fans – Emerson Network Power
The cooling systems of today might not be what the cooling systems of tomorrow look like. As data centers continue to grow and evolve, there will be new technologies that come to the forefront. As resources such as water become more expensive, cooling system manufacturers are continuing to come up with new, more efficient ways to cool the data center. Here is a look at some future technologies that might be used more in the future.

**LIQUID COOLING**

There are different approaches to liquid cooling. The two main approaches are to either bring a liquid into the server itself via an enclosed system that features pipes and plates or by immersing the entire server chassis into a fluid.

One challenge with liquid cooling is the high upfront cost associated with it. If the cost doesn’t come down, then many data center managers are likely to avoid it. Another challenge is simply the fear of bringing a liquid closer to the IT equipment itself. This has been something generally avoided so there are some negative perceptions with doing such.

**HEAT WHEEL COOLING**

Heat wheels have been around for years, but recently heat wheels are starting to find their way into some data centers. A heat wheel is generally made out of aluminum honeycomb. Hot air from the servers is pulled into the heat wheel by fans. The wheel absorbs the heat from the air as it passes through. The cooled air is then sent back into the data hall. In a separate plenum, outside air is pulled into the cooling unit by fans, passes through the wheel absorbing the heat and discharges it back outside. The wheel rotates between plenums to effectively transfer the heat.

Heat wheel cooling systems are efficient, are an indirect airside cooling system and have been installed in a variety of different geographies around the world. There have been predictions of a total energy savings (cooling plus IT) for a 2.5 MW data center in New York, Boston, Philadelphia or Toronto in the 30 percent range for annual power savings based on $0.10/kWh, of more than 500,000 USD.35

Some of the drawbacks to heat wheel cooling are the amount of space it requires cost; as conventional cooling is still required if outside temperatures are too high.

**FREE COOLING ADOPTION**

Gartner defines free cooling as any technique used to reduce the energy consumed by the cooling systems or the time that the cooling units run by using the outside temperature of air or water to cool the data center or other facilities. Free cooling solutions are being adopted all over the world today. IHS forecasts strong growth globally for the free cooling market through 2018.

There are two main types of free cooling technologies: air-side and water-side economizers. As data centers start to run warmer, it allows for more hours that a free cooling system can be used, which reduces the overall operational expense of the cooling system and making free cooling systems more attractive to data center managers.
This report covered a wide spectrum of variables that impact the data center thermal environment. Increasing efficiency, reducing total operating costs and avoiding costly outages are top of mind for all data center operators and managers, and cooling is an area that directly impacts all these objectives. Using the foundation set forth in this paper provides a better understanding of today’s challenges, methods, standards and more. Additionally, having knowledge of the four best practices for optimizing a data center’s thermal environment provides a clear roadmap for a more efficient and reliable facility.

This report covered a lot of ground with this complex topic, trying to bring some important – though not always obvious – flash points to the forefront. On the surface, keeping hot-running IT equipment cool seems pretty straightforward that data center owners and facilities managers can solve by simply purchasing additional cooling equipment and pumping in large volumes of conditioned air. However, what has been discovered in many data centers, is that not following the best practices of airflow management has a detrimental impact on the entire cooling system. Additionally, most existing data centers have a surplus of cooling capacity that can be reclaimed by reducing bypass airflow and preventing recirculation.

The key takeaway is that thermal management needs to be addressed as an integrated, holistic and ongoing effort, not in a piecemeal, disparate and short-term way. The good news is that once these four key areas are addressed properly in the data center, it’s possible to achieve an energy-efficient, cost-saving, high-performing thermal environment.
Contact Anixter to learn about how thermal efficiency works with the other building blocks of Anixter’s Infrastructure as a Platform solution. Infrastructure as a Platform focuses on helping you create an agile and scalable data center by addressing the five key building blocks for data center interoperability:

› Risk management
› Network migration
› Power optimization
› Thermal efficiency
› DCIM enablement

For more information on how achieving conditional environmental control in your data center can reduce operational expenses, allow for better capacity management, and reduce the risk of outages, visit anixter.com/datacenterdcd or contact your local Anixter representative.
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