Modular Datacenter Energy Efficiency and Thermal Research Overview

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Abstract

Datacenter designs continue to evolve rapidly as both industry thermal requirements and deployment configurations change to support demands for improved energy efficiency. This demand for improved efficiency is driven in part by the fact that IT equipment accounts for about 2% of U.S. and global energy consumption[1]. With rapidly increasing demand for cloud computing, including headend services, this percentage can increase to unsustainable levels if efficiency improvements are not realized.

The need for higher efficiency is also driven by the desire for reduced carbon emissions and OPEX savings that result from reduced energy consumption.

In this paper improvements to data center efficiency through highly efficient hybrid cooling methods will be discussed. The cooling methods reviewed will include evaporative cooling and air economizers. Because air quality is critical to data center uptime and reliability, the paper will also discuss the air filtration effectiveness of evaporative cooling systems. The type of data center considered in the study will be Modular Data Centers.

Introduction

A key driver in datacenter efficiency is the power consumed by the cooling system. For more traditional datacenters that use CRAC units or chilled water, cooling systems can account for 30% of facility power consumption[2]. For a 30 megawatt facility, that's 79,000,000 kilowatt-hrs per year, which is equivalent to 54,000 metric tons of CO_2 emissions. Also, at $0.10/killow-hr, this amount of energy would represent a $7.9 million annual expense for cooling system energy.

CommScope has been working through an industry/academia consortium with oversight by the NSF to research datacenter cooling efficiency improvements. Through the consortium, known as I/UCRC[3] (or Industry and University Cooperative Research program), CommScope and its consortium partners are investigating the following methods for improving datacenter cooling efficiency:

- Modular datacenter configurations
- Air-side economizers
- Direct evaporative cooling
- Indirect evaporative cooling
- Particulate and gaseous contamination filtering

This paper will present an overview of datacenter industry cooling research done to date by a sub-team of the overall consortium:

- Potential energy savings for economization and evaporative cooling
- Examples of CFD cooling system simulation
- Filtration benefits of certain cooling techniques

Global Impact of Datacenter Energy Consumption

Total datacenter global energy use for the year 2012 was 322 Twh[1]. This value represents 1.8% of all global energy consumption[1]. The U.S. accounts for 25% of global datacenter energy usage[1]. As mentioned previously, cooling systems currently account for approximately 30% of datacenter energy usage[2].

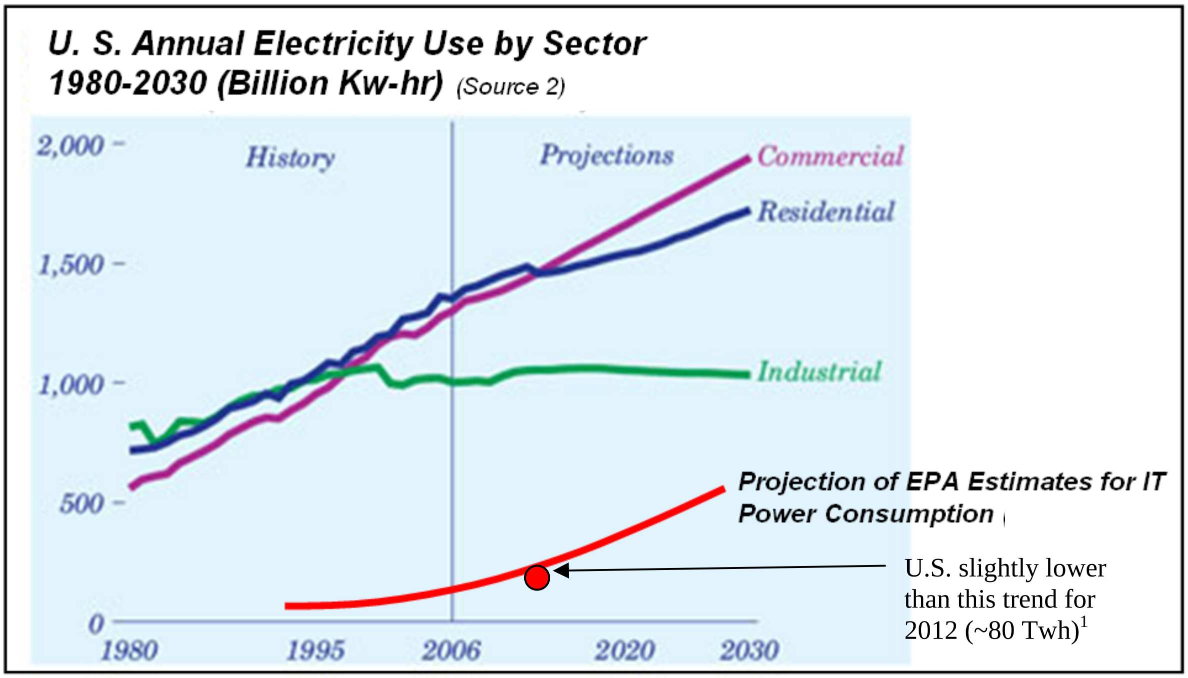

Figure 1: Projected U. S. annual electricity use by sector, 1980-2030
(references 4, 5)

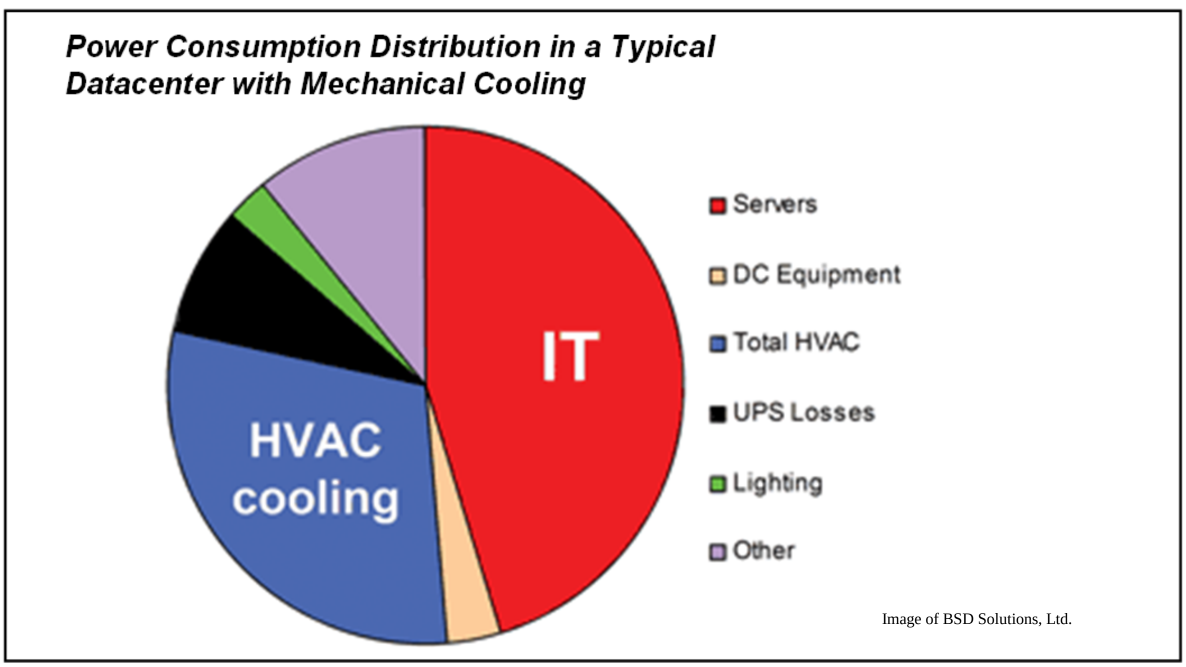

Figure 2: Power consumption distribution in a typical datacenter
(reference 2)

Industry/University Datacenter Efficiency Consortium

Through the I/UCRC consortium, CommScope and other consortium members are undertaking a varied list of projects directed at improving datacenter efficiency. A partial listing of these projects is as follows:

1. Energy-aware Scheduling and Synergistic Management of Server Workloads
2. Compact Models for Rapid Thermal Modeling of Data Centers
3. Efficient Air-Side Economization and Evaporative Cooling in Modular Data Centers
4. Cold Aisle Containment Systems for Room-Level Air Cooled Data Centers
5. 3-D Simulation Models for Data Centers Heat Exchangers
6. Energy-Aware Virtualization for Data Centers
7. Impact Of Particulate and Gaseous Contamination on Data Center Servers
8. Data Center Waste Energy Recovery and Reuse

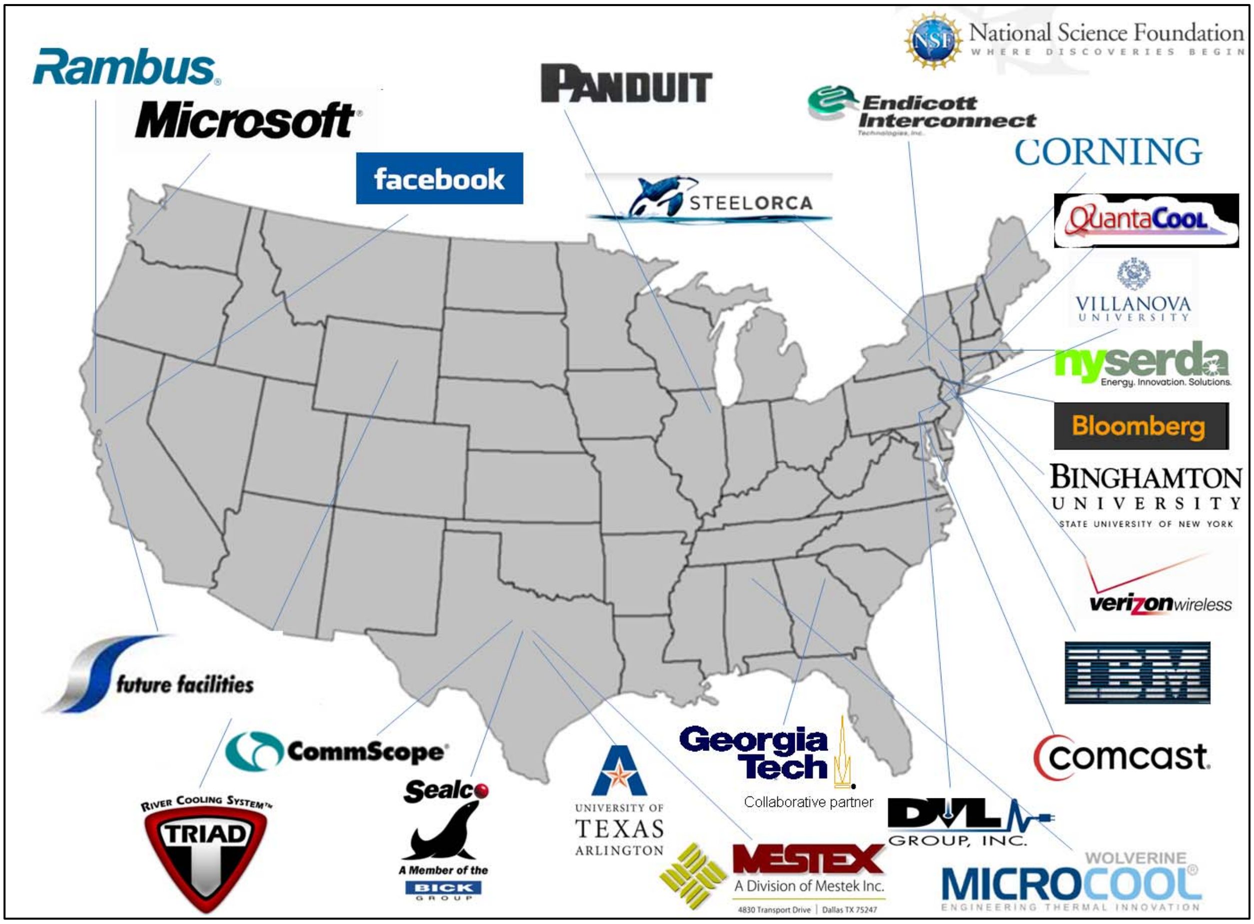

Figure 3: Datacenter Efficiency consortium
(reference 3)

CommScope has partnered with a subset of consortium members to work specifically on projects #3 and #7 on the above list. A partial list of these partners can be found in figure 4. For projects #3 and #7, research focus has been applied to the following methods for improving datacenter cooling efficiency:

- Effectiveness of air side economizers
- Effectiveness of direct evaporative cooling
- Effectiveness of combined air side economizers and evaporative cooling (hybrid cooling)
- Effects of mixing exhaust with intake to control server temps
- Best practices for combining these cooling methods

Figure 4: Data center cooling efficiency project sub-team
(reference 3)

Modular Datacenter Architecture Examples

In a modular data center, a sub-module of the total datacenter is pre-fabricated, assembled, and tested in a factory environment away from the data center construction site. These "sub-modules" are typically 20-40ft long, 8-11ft wide, and 9-20ft high. IT capacity, or IT load, supported by a sub-module commonly ranges from 200Kw to 1.2 Mw. Because these units represent a pre-assembled "sub-module" of the total datacenter, they are known as "modular data centers" or "MDC's".

Once an MDC has been assembled and tested, it is readied for shipment to the customer site via truck. Because they are similar in size and form factor to standard ISO shipping containers, MDC's can also be transported by boat overseas.

Once the unit arrives at the data center build site, it is placed and connected to power, communication, and cooling water sources. It is then commissioned for server and network switch operation. Because MDC's can be pre-cabled and servers installed at the factory, they can be placed on site, connected, and commissioned in a matter of days. This method can significantly reduce the deployment time for a data center.

Regarding MDC configurations, three types are common:

1. Stand alone MDC with remote chilled water supply
2. Stand alone MDC with side placement of cooling and power systems (beside the IT module)
3. Stand alone MDC with top placement of cooling and power systems (above the IT module)

For the purposes of this paper, we will only study configurations 2 and 3. Some examples of these types of data center architectures are shown in figures 5 and 6. An example of an MDC IT Module is shown in figure 7.

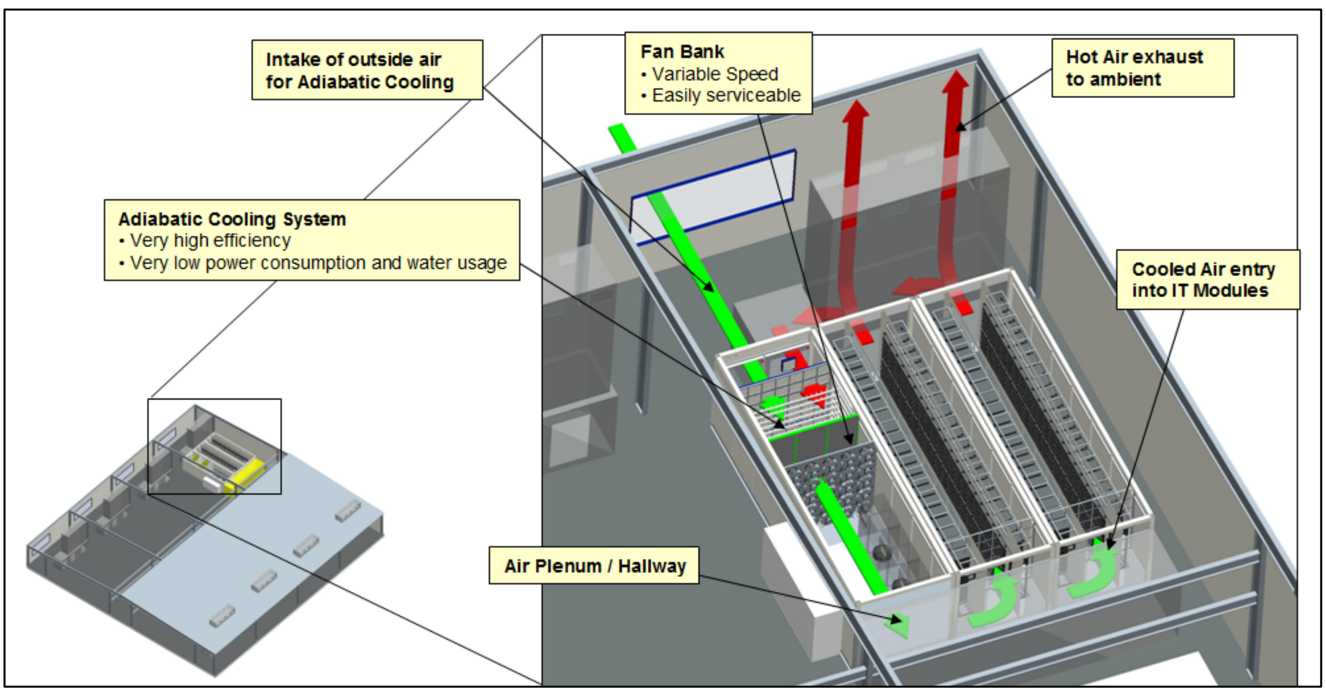

Figure 5: "Side placement" Modular Datacenter architecture
(reference 6)

For the side placement architecture of figure 5, the cooling and power systems reside in a separate module placed next to one or more IT modules. Cooling air is transferred to the IT modules via a plenum system, while power bus systems deliver power. For the purposes of our consortium study, the type of cooling system is assumed to be air economizer coupled with direct evaporative cooling.

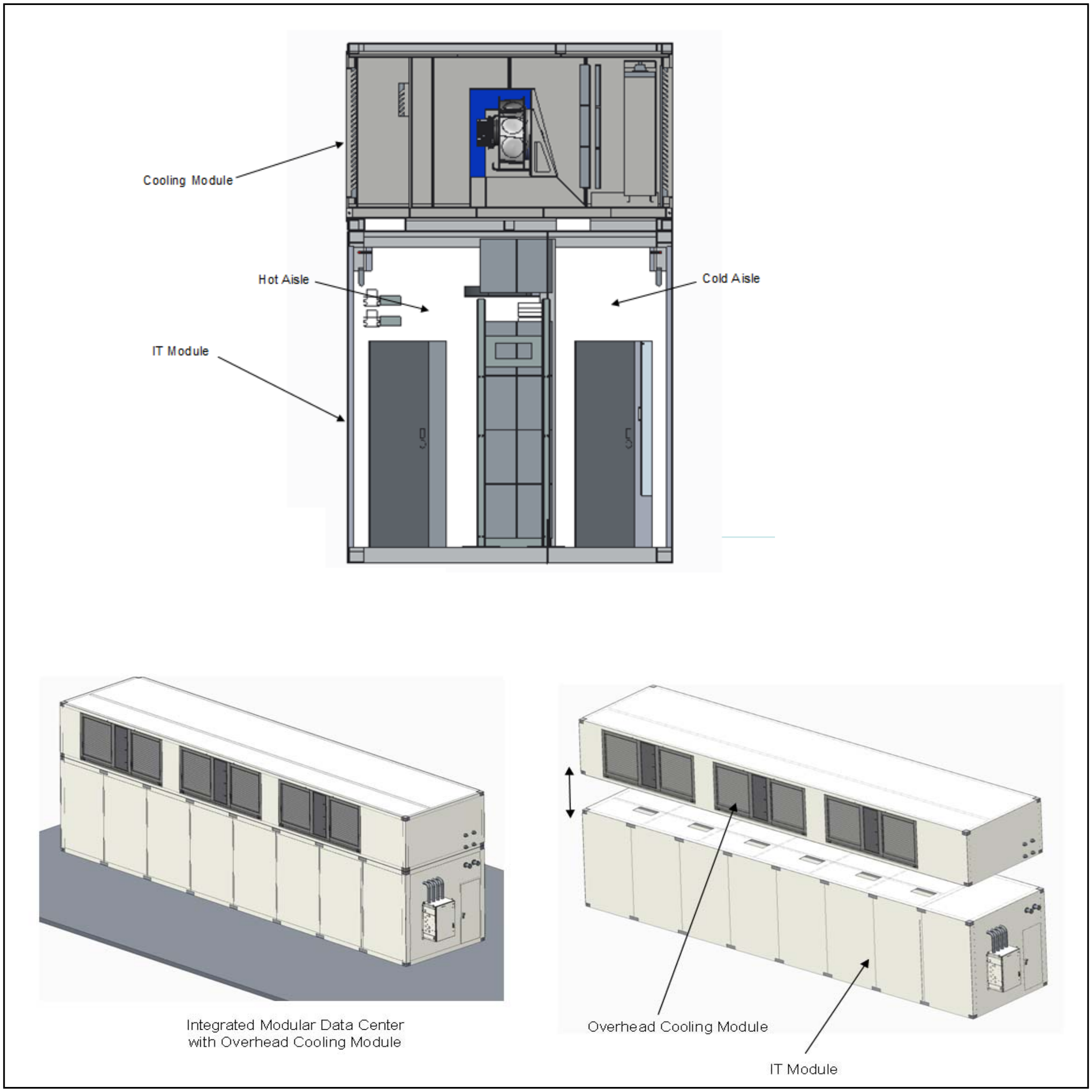

Figure 6: "Top placement" Modular Datacenter architecture
(reference 6)

For the top placement architecture of figure 6, the cooling system is lifted and mounted on top of the IT module at the data center build site.

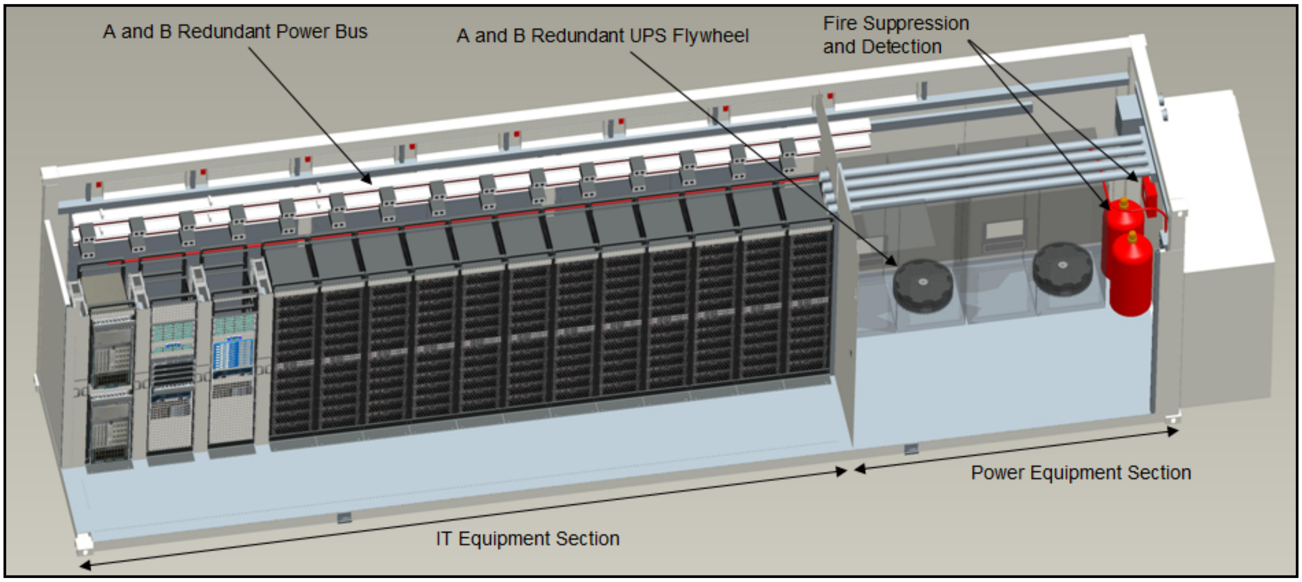

Figure 7: Example of IT Module detail
(reference 6)

Thermal Research Key Findings

Evaporative and Economizer Combined Cooling

Use of mechanical cooling, such as CRAC coolers or chiller systems, can be significantly reduced by using a combination of evaporative cooling and air side economization. This combination of cooling methods will be referred to as a hybrid cooling system in this paper.

For this hybrid cooling system it is possible to tailor cooling system performance to optimally support different climate regions. In the Dallas / Ft. Worth area, for example, evaporative cooling and economizers can be used for more than 90% of the year (see figures 8 and 9). During this time, mechanical cooling, such as CRAC systems, and their associated high energy consumption, can be avoided.

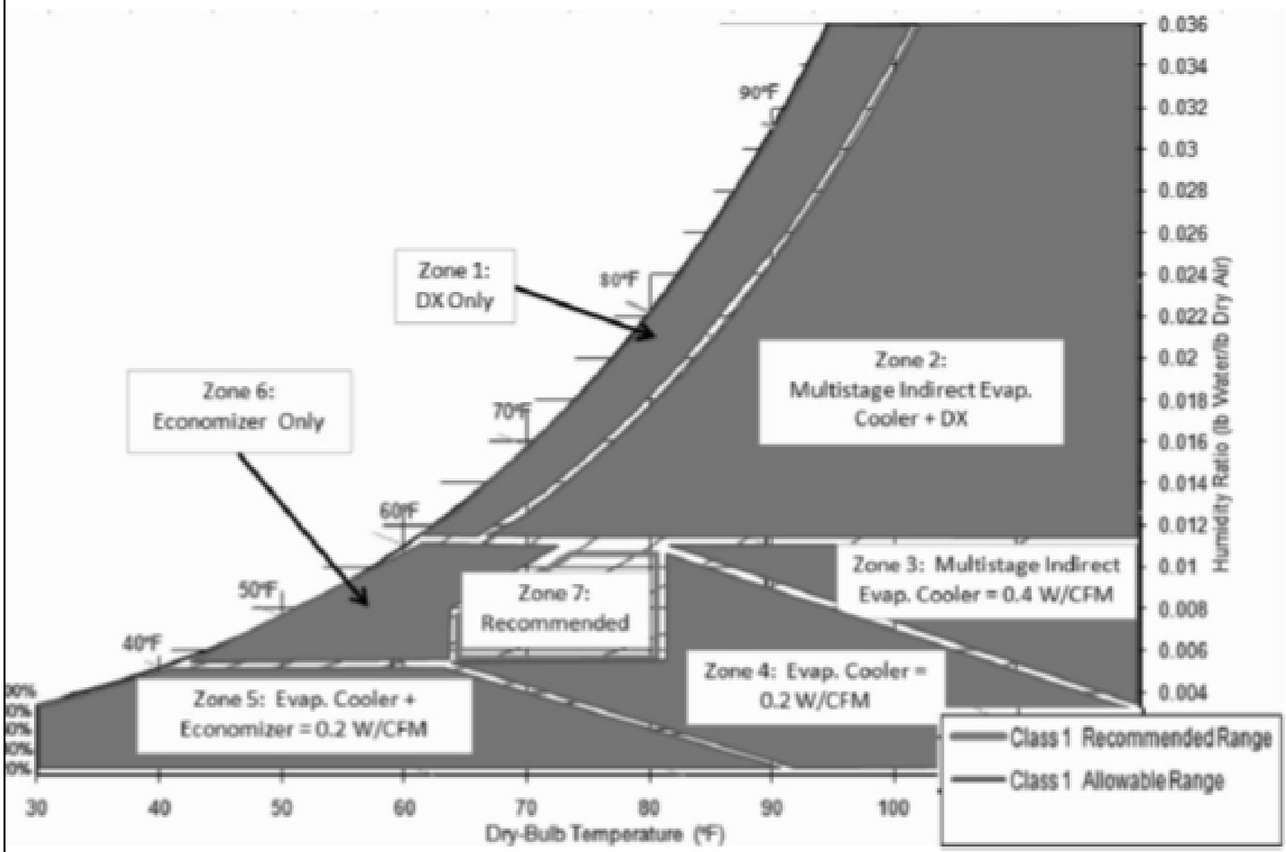

Figure 8: Psychometric Bin Analysis and Chart Zones with associated cooling methods to support ASHRAE levels (reference 7)

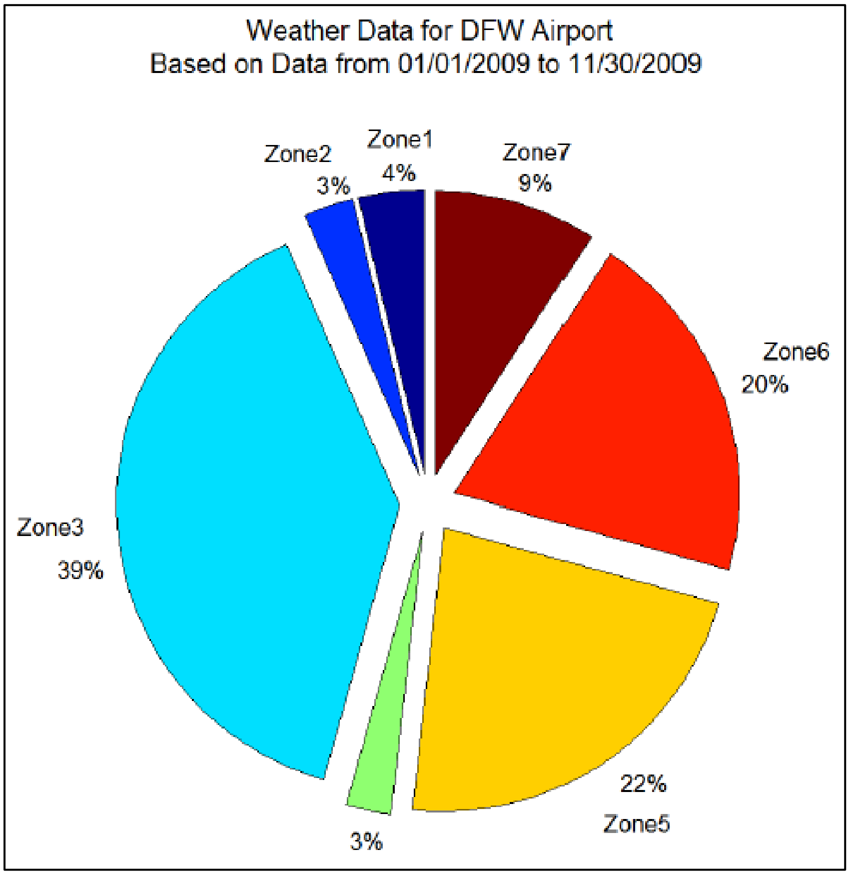

Figure 9: ASHRAE “recommended” cooling methods for Dallas, TX based on weather bin data (Reference 8)

Further efficiency improvements can be achieved by allowing data center temperature excursions beyond the somewhat conservative ASHRAE “recommended” thermal requirements. For data center providers and server manufacturers, acceptance of the ASHRAE “allowable” standard broadens the minimum and maximum acceptable temperatures and humidity levels allowed in the data center. The associated wider temperature and humidity ranges can further reduce required run time for mechanical cooling units. The temperature and humidity levels associated with each standard can be seen in the psychometric chart of figure 10.

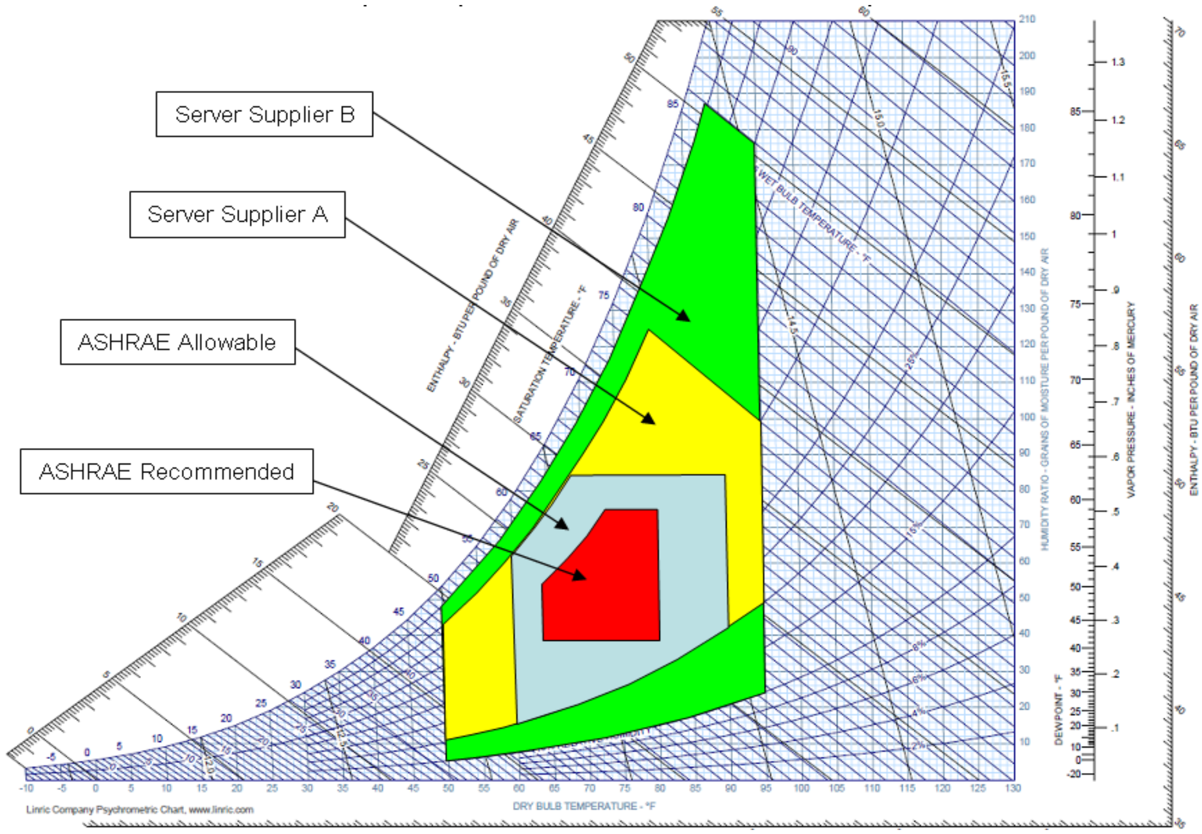

Figure 10: Psychometric chart showing expanded temperature and humidity levels for "allowable" ASHRAE spec (Reference 9)

A detailed example of how the expanded "allowable" range can impact cooling efficiency is shown in figure 11. Here it can be seen that in the Chicago area, an economizer alone can provide all cooling needs for 30% of the year for the "recommended" ASHRAE envelope, but this increases to almost 70% of the year using the "allowable" envelope. Also, it can be seen that the "allowable" envelope enables non-mechanical cooling for 84% of the year, versus 79% for the "recommended" envelope.

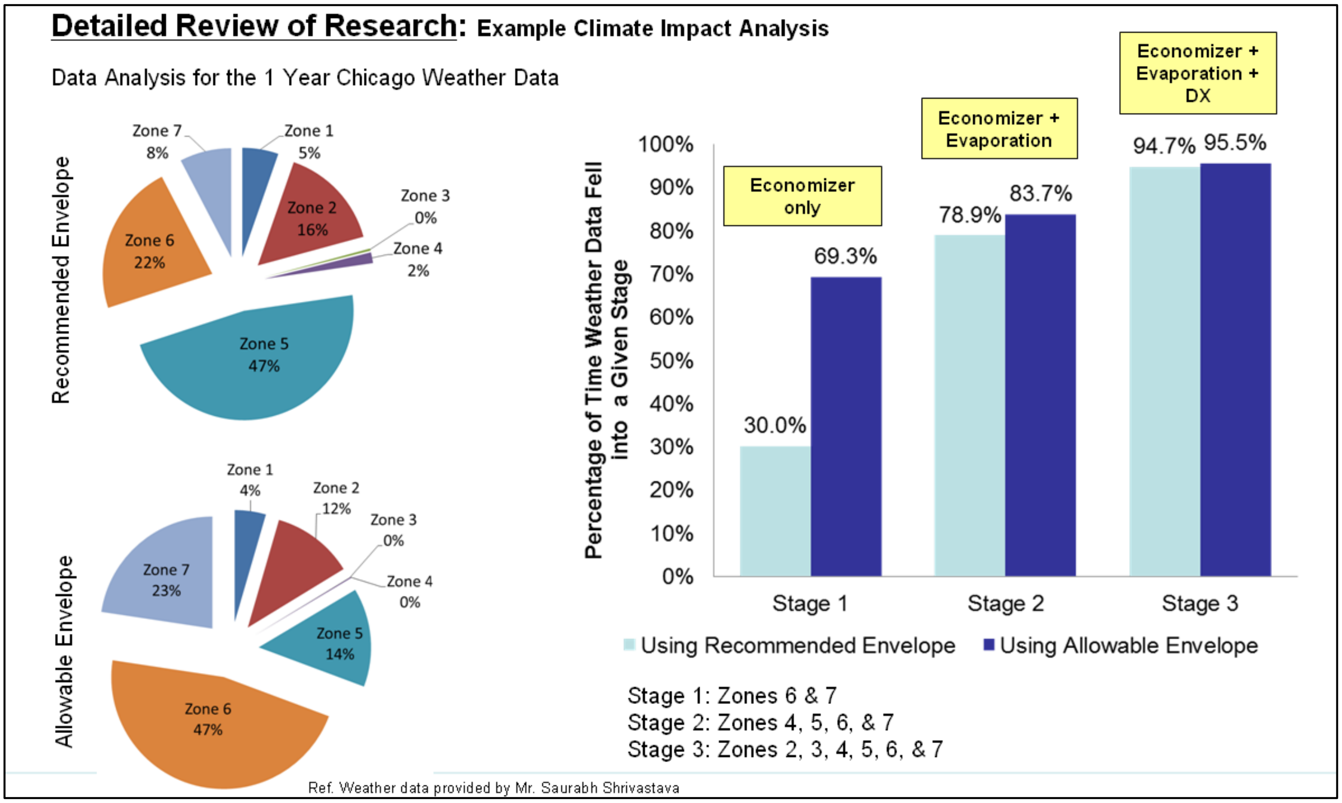

Figure 11: Impact of Recommended vs. Allowable ASHRAE Data Center Temperature/Humidity Requirements: Chicago Area Example.
(reference 8)

An example of a hybrid cooling system with a combination of direct evaporative cooling and economizer is shown in figure 12. In this system, a series of dampers direct air to either enter the evaporative cooler section, or bypass the evaporative system and enter directly into the datacenter electronics area. For this type of cooling system, filtration of incoming cooling air is very important.

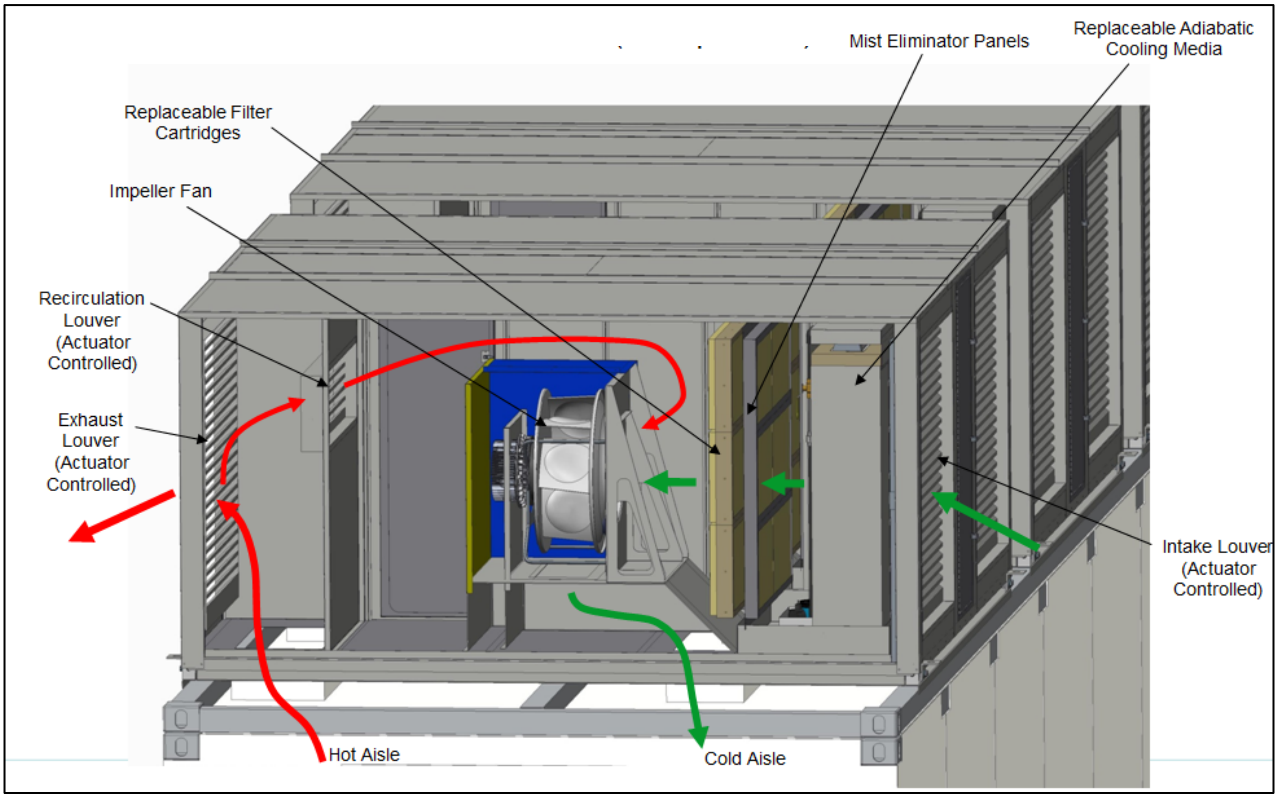

Figure 12: Example of a combined direct evaporative cooling system and economizer (not detailed is a bypass for economizer-only operation)
(reference 6)

CFD Simulation for Optimizing MDC Cold Aisle Air Flow

It is critical that air flow and pressure be evenly balanced across the cold aisle for all racks in an IT Module. Air plenum design and cooling air inlet configurations can have a surprisingly significant impact on cooling performance by disrupting balanced flow and starving isolated racks from required air flow.

Figure 13 shows an example of how CFD modeling can identify disrupted flow and starved rack air intake caused by directional intake louvers. With an initial design of 45° angled louvers, air is directed upward causing a swirl pattern in front of rack position 9. The result is stagnant air flow and a 6° C increase in inlet temperature for rack position 9.

When the louver angle is changed to 0° in the CFD model air flow becomes uniform across the entire line up of 20 IT racks. Consequently, the 6° C increase in inlet temperature for rack position 9 is eliminated.

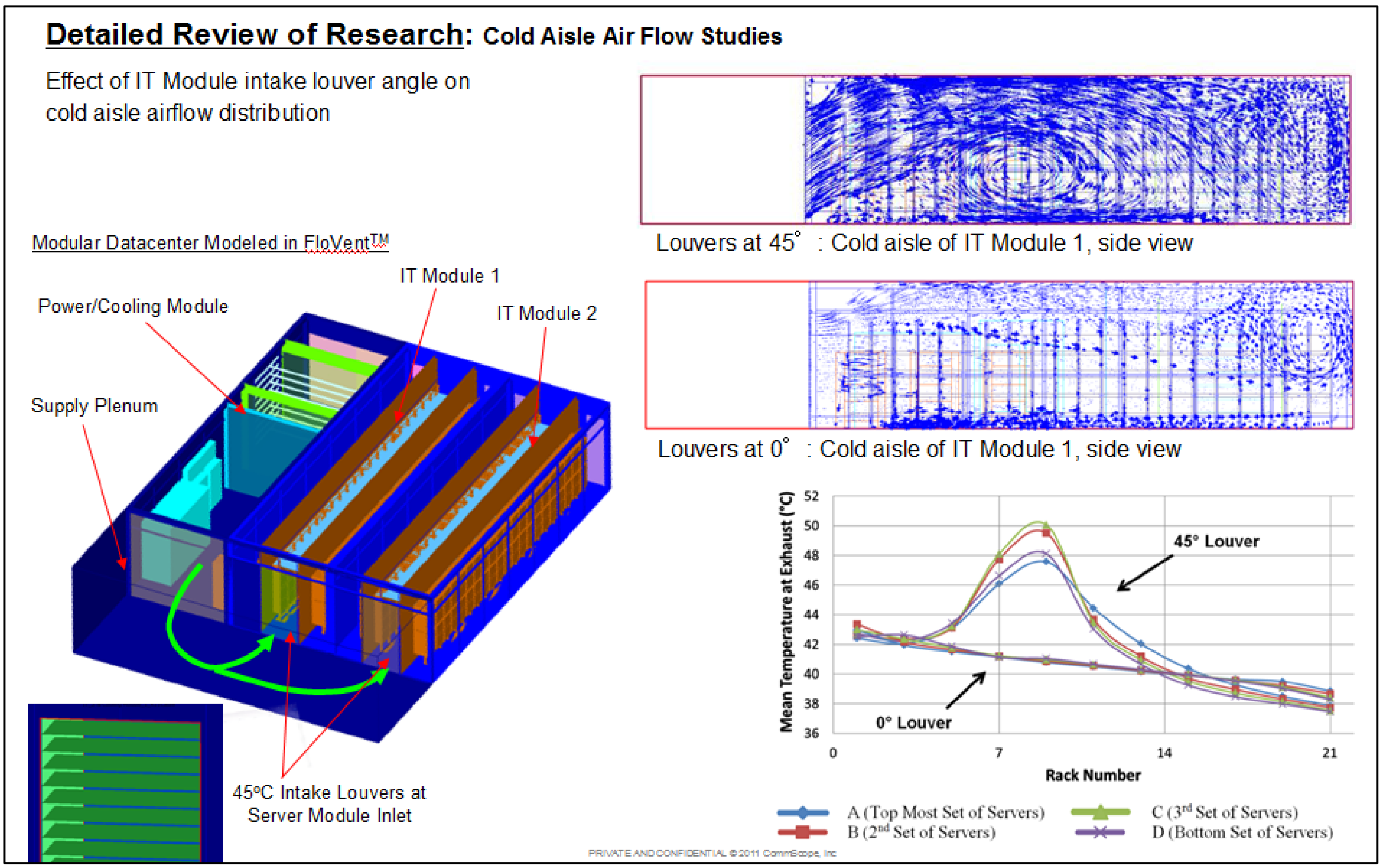

Figure 13: CFD evaluation of the impact of intake air louver angle for an MDC IT Module (reference 8)

Filtration Qualities of Evaporative Cooling Systems

Testing has proven that evaporative cooling media pads can be an effective filter for incoming cooling air. In addition to having many of the filtration qualities of a typical filter, evaporative cooling media is also partially self-cleaning. When operating, water washes through the evaporative media removing some of the particles that have been filtered from the air. For this reason, the evaporative media typically lasts much longer than filters. However, the media still must be maintained and changed, though at much less frequent intervals. Some examples of evaporative cooling media pads are shown in figure 14.

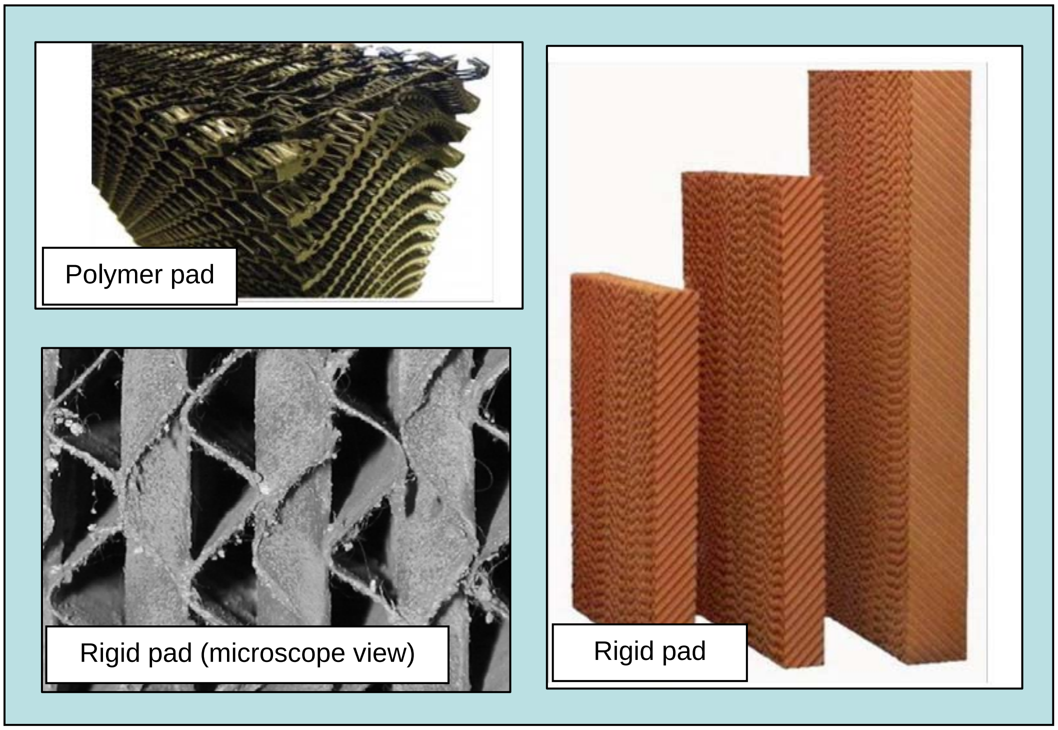

Figure 14: Examples of evaporative media pads used in evaporative cooling systems (reference 8)

Test data is available for the filtration effectiveness of evaporative media pads. The data shows that particles are trapped and filtered by the cooling media pads via the phenomena shown in figure 15.

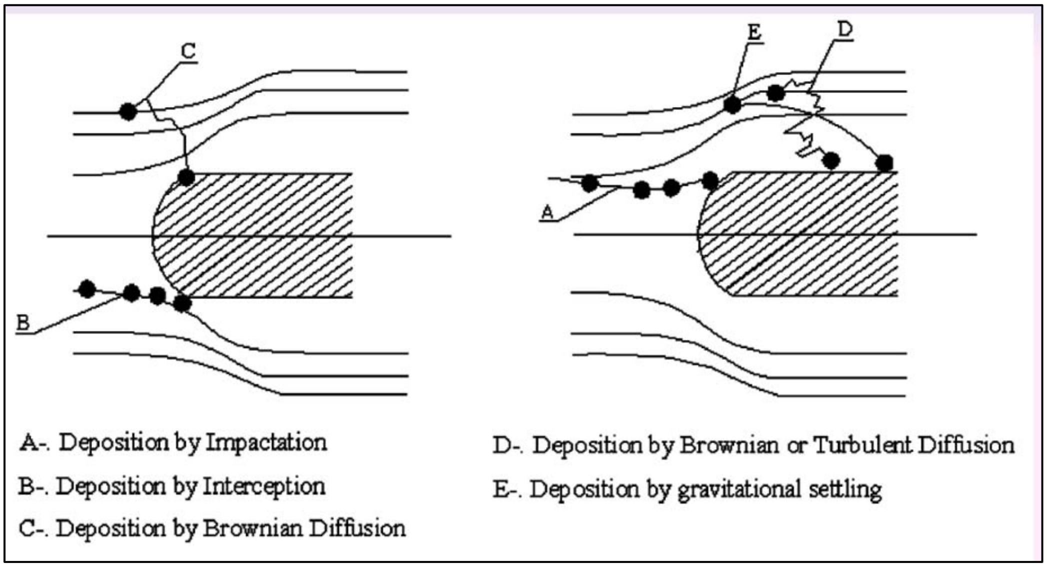

Figure 15: Methods by which particles are trapped and filtered by evaporative cooling media pads (reference 10)

Actual filtration effectiveness of evaporative cooling media pads has been determined through testing (reference X). Figure 16 shows the filtering impact of rigid cooling pads during operation (wet condition). A summary of the filtration impact for wet media pads as a function of the indoor/outdoor ratio is as follows:

Particle Size	% Reduction	Notes
PM1.0	0%	Particles this small are not effectively filtered by evaporative media
PM2.5	10%	Tested value
PM10.0	50%	Tested value

Note: PM2.5 = Particulate Matter 2.5 microns in size
(reference 10)

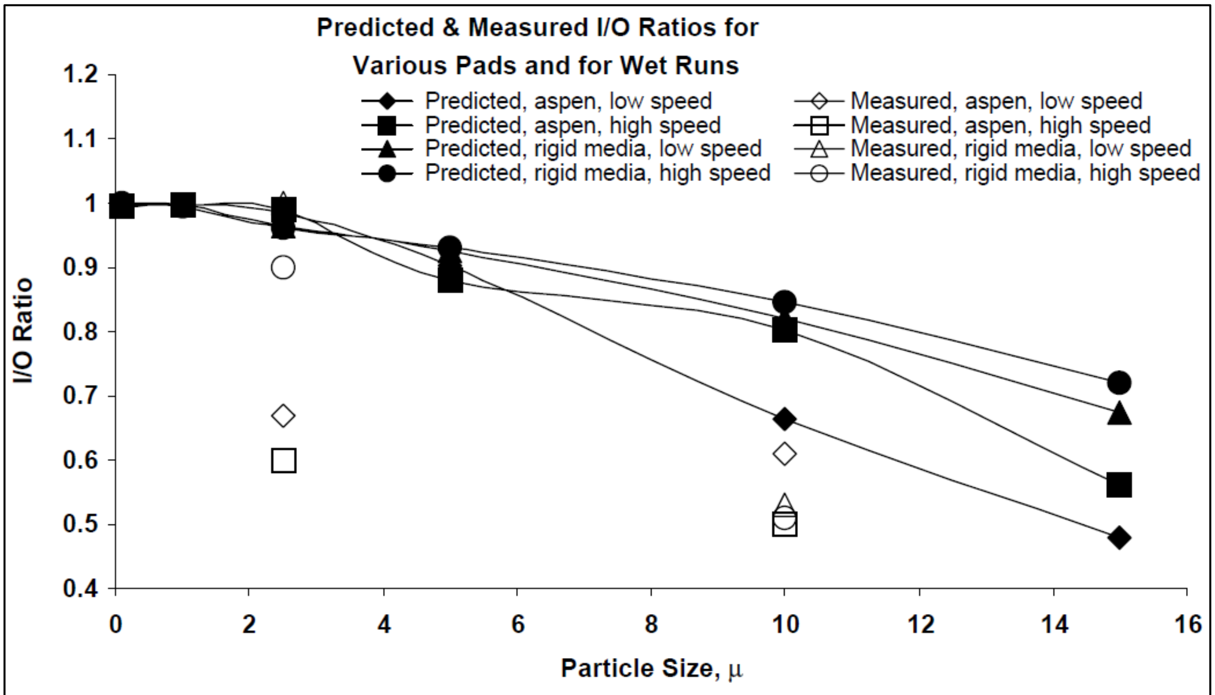

Fig. 11. Comparison of predicted and measured I/O ratios for wet runs.

Figure 16: Filtration effectiveness of evaporative cooling pads in wet condition
(reference 10)

Filtration effectiveness for evaporative media pads in the dry condition (evaporative system not operating) is not quite as effective as for the wet condition, but still significant as seen in figure 17

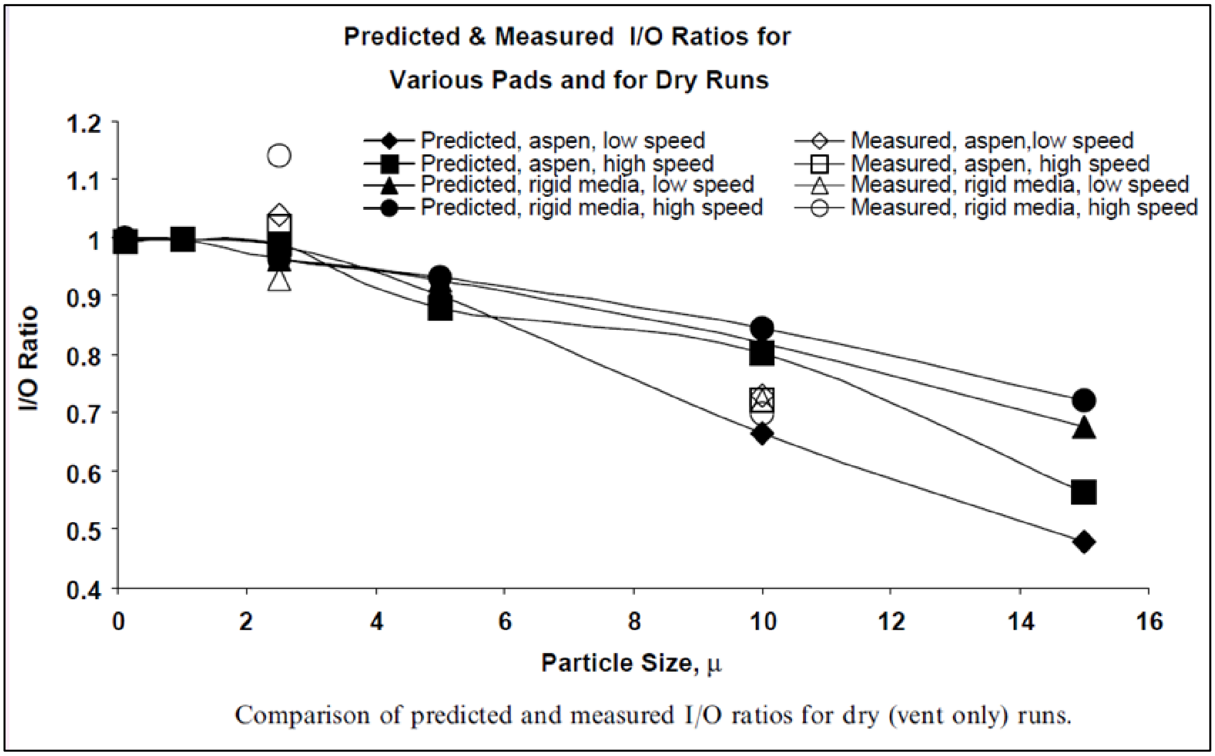

Figure 17: Filtration effectiveness of evaporative cooling pads in dry condition (reference 10)

Summary

Addressing energy efficiency in data centers is important as the growth of cloud computing continues to push energy consumption higher for the data center industry. In 2012 data centers consumed over 320 Twh energy, or approximately 2% of total global energy consumption. Improving data center efficiency can help to reduce overall global energy demand. Such improvements can also reduce carbon emissions and provide significant OPEX savings to data center operators.

CommScope is working with other consortium members of the I/UCRC (Industry/ University Cooperative Research Center) to research energy efficiency improvements in data centers. The consortium, which includes four major universities and over 20 companies, is addressing data center efficiency through a number of major projects. In this paper, the two key projects being addressed by CommScope and some of its consortium partners are:

- Efficient Air-Side Economization and Evaporative Cooling in Modular Data Centers
- Impact Of Particulate and Gaseous Contamination on Data Center Servers

In the two above projects, research and analysis work has been focused on Modular Data Centers, or MDC’s. In a modular data center, a sub-module of the total datacenter is pre-fabricated, assembled, and tested in a factory environment away from the data center construction site. Because MDC’s can be pre-cabled and servers installed at the factory, they can be placed, connected, and commissioned in a matter of days. This method can significantly reduce the deployment time for a data center site.

Key research findings identified in this paper include:

- Annual run times for mechanical cooling can be reduced 90% or more using a hybrid system of economizers and evaporative cooling
- Efficiency improvements are geographic dependent and the hybrid system can be optimized for specific geographic climate conditions
- Taking advantage of the more relaxed requirements of the ASHRAE “allowable” temperature and humidity ranges can significantly improve data center cooling efficiency
- CFD simulation has proven significant value in optimizing air flow design
- Evaporative cooling pad media can act as an effective air filter and require less frequent maintenance than filters

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