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Improving Data Center Energy Efficiency Through Environmental Optimization

How Fine-Tuning Humidity, Airflows, and Temperature Dramatically Cuts Cooling Costs

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Data center operators are under increasing pressure to control and often reduce operating costs. An obvious focus of such efforts is energy costs and more specifically, the costs of cooling the data center. Today, data center operators face a wide and at times bewildering array of products that claim to reduce cooling costs in the data center. However, data center operators, particularly those in legacy data centers, have the means to realize substantial cooling cost reductions without investing in exotic measures. Substantial energy savings can be achieved by implementing the right combination of air temperature set points, humidity levels, and air flows. We call this process environmental optimization. Environmental optimization can cut cooling costs by over 40%, often with minimal investment.

Scope extends to operating cost – GOOD
ensure that wide scope doesn't detract from detail of energy efficiency study

This paper discusses the significant operating cost savings that can be realized by optimizing humidity set points, air flow rates, and air temperature set points. By lowering humidity in the data center and adjusting the methods by which it is controlled, CRAC/CRAH units' increased capacity for sensible cooling (lowering the temperature of air) can dramatically minimize compressor and humidifier power usage. By tuning the air flow rates supplied to server inlets through perforated tiles, air temperature set points can be raised. CRAC/CRAH units' cooling capacity improves and compressor power usage is further reduced. Tuning any one of the aforementioned parameters without careful consideration of the others can have undesirable effects. Raising rack inlet temperatures without ensuring adequate supply air flows will almost certainly lead to server inlet hot spots due to recirculation. Raising air temperature set points without adjusting humidity levels can actually result in higher energy costs. Similarly, adjusting humidity levels without accounting for temperature set points will preclude efficient operation and possibly damage data processing equipment. However, by optimizing humidity levels, air flows, and temperature set points together, the aggregate effect can yield substantial energy savings.

In addition to quantifying the energy savings that can be realized through low-cost optimization of environmental parameters, this paper describes technologies used for assessing humidity levels, rack inlet temperatures, and air flows in the data center.

Fine Tuning The Humidity Set Point For BIG Efficiency Gains

Dry air in the data center can result in damaging electrostatic discharges. Humidity levels must be maintained sufficiently high to avoid this threat. On the other hand, excessive humidity levels can result in damage if water vapor condenses inside data processing equipment. This is why data processing equipment manufacturers typically provide recommended ranges of safe humidity levels for their products. According to the *2011 ASHRAE Thermal Guidelines for Data Processing Equipment [1]*, the allowable range for relative humidity in data centers is 20%-80%. The recommended range is a dew point between 41.9°F and 59°F with a maximum of 60% relative humidity.

this is good as a rule for the logic engine on how general humidity in the data centre should be represented

READ CITATION [1]

another good potential logic engine rule

Optimizing humidity set points within the manufacturer specified range in a data center can boost efficiency significantly. Safely lowering the humidity level will decrease the amount of latent cooling or inherent dehumidification by the CRAC/CRAH cooling coil. This means that a greater share of compressor energy will be used for sensible cooling (decreasing the air temperature). The result is a reduction in compressor loading and thus reduced power use.

During normal operation in a properly sealed data center (no exterior air infiltration), any humidity that is removed by the cooling coils must be replaced by humidifiers. Safely dropping humidity levels in the data center can reduce or even eliminate humidification energy expenditure. Remember: excessive humidity is paid for twice- once for removal and once for replacement! Reduced humidity levels will result in energy savings for both compressors and humidifiers. These savings can be significant. For CRAH units using building chilled water, the same principles apply to chiller operation but on a larger, data-center-sized scale.

make this into a rule regarding CRAC/CRAH systems

To get the best energy savings from humidity set point tuning, the local return air temperatures must be accounted for. Picking set points and tweaking control systems accordingly involves psychrometric calculations that become increasingly complicated for data centers with multiple zones. However, if done right, optimizing humidity level set points in the data center can be an extremely inexpensive way to drop your PUE and produce substantial energy savings.

Optimizing Air Temperature Set Points and Air Flows Can Shrink PUE Numbers

It is widely acknowledged that substantial energy savings can be achieved by raising air temperature set points in the data center. This occurs because of the physics of compressor operation. In a DX CRAC unit, improved efficiency from increased air temperature set point occurs due to compressor unloading. Raising the temperature of returning air to the unit, allows an increase in coil temperature (really an increase in the temperature of the refrigerant in the evaporator). Meanwhile, the condenser temperature stays fairly constant. As the temperature difference between the evaporator and condenser decreases, the compressors gains cooling capacity and the Coefficient of Performance (COP) goes up. This means that the compressors will be able to run under less load more of the time and consume less energy. The bottom line is this: raising the air temperature means lowering compressor energy use. The same goes for Data Centers using CRAH units and chillers. With a central chiller, raising the air temperature set points allows raising the chilled water temperature set point. The effect is the same on a chiller's compressor as it is on a DX CRAC unit compressor, the main difference being that the chiller evaporator has water running through it instead of air. No matter the type of cooling system in the data center, raising the air temperature set point can bring about considerable cuts in energy use.

How high can the temperature set point be?

According to the *2011 ASHRAE Thermal Guidelines for Data Processing Equipment [1]*, the allowable range for equipment inlet air temperature is 59°F to 89.6°F. ASHRAE's recommended inlet air temperature range is 64.4°F to 80.6°F. This is the supply air temperature range, so in data centers where CRAC/CRAH units measure return air temperature, the set points should be anywhere from 7 to 20 degrees higher than these numbers depending on data center air flows. We recommend selecting as high an air temperature set point as possible using three primary constraints:

1) The manufacturer recommended high air temperature limit for the specific equipment in the data center.
2) The temperature at which server fan speeds begin to ramp up due to elevated inlet temperatures. Many servers incorporate control schemes that increase fan speed as inlet temperature increases or once inlet temperature exceeds a certain value. Increased fan speeds can cut into efficiency gains and create excessive noise although this typically occurs at inlet temperatures greater than 80.6°F.
3) Available air flow from perforated tiles. <u>If supplied air flow does not meet server fan requirements, recirculation will occur.</u> As air temperatures are increased, the recirculation will cause server inlet hot spots to develop. This will be discussed in greater detail, below.

The greatest energy savings from higher air temperature set points can be realized only if air flow supply from the perforated tiles meets server air flow demand. The closer that the flow rate of supply air from the perforated tiles matches the flow rate of the air moved by server fans, the higher the temperature set point can be. When adequate air flow is not provided from the floor, the servers will meet their cooling needs using ambient air in the data center instead. Supplemental cooling from ambient air, rather than the supply air from the raised floor is known as hot air recirculation. When hot air recirculation occurs, ambient air (typically in part, made up from the hot rack exhaust air) is drawn into the cold aisles from around the sides of the racks and over the tops of the racks. This phenomenon results in server hotspots. This is illustrated below using real world data, below.

We have developed techniques that create infrared mosaics that allow us produce quantitative measurement of rack inlet temperatures over entire rows. With this technique, we can actually see recirculation as well as over-cooling or under-cooling across large areas.

We observe infrared mosaic images of two different rows below. Each row consists of 10 racks, each with 44 servers for a total of 440 servers.

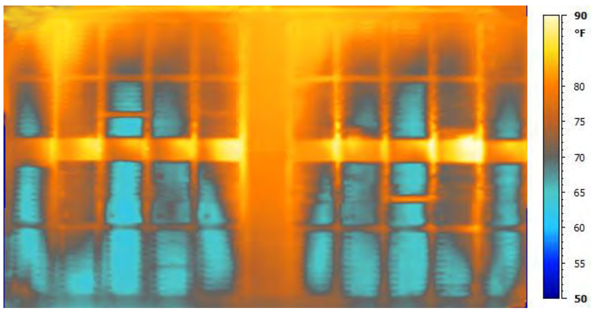


Fig. 1

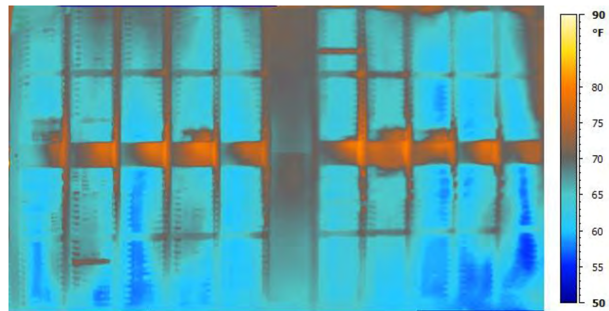


Fig. 2

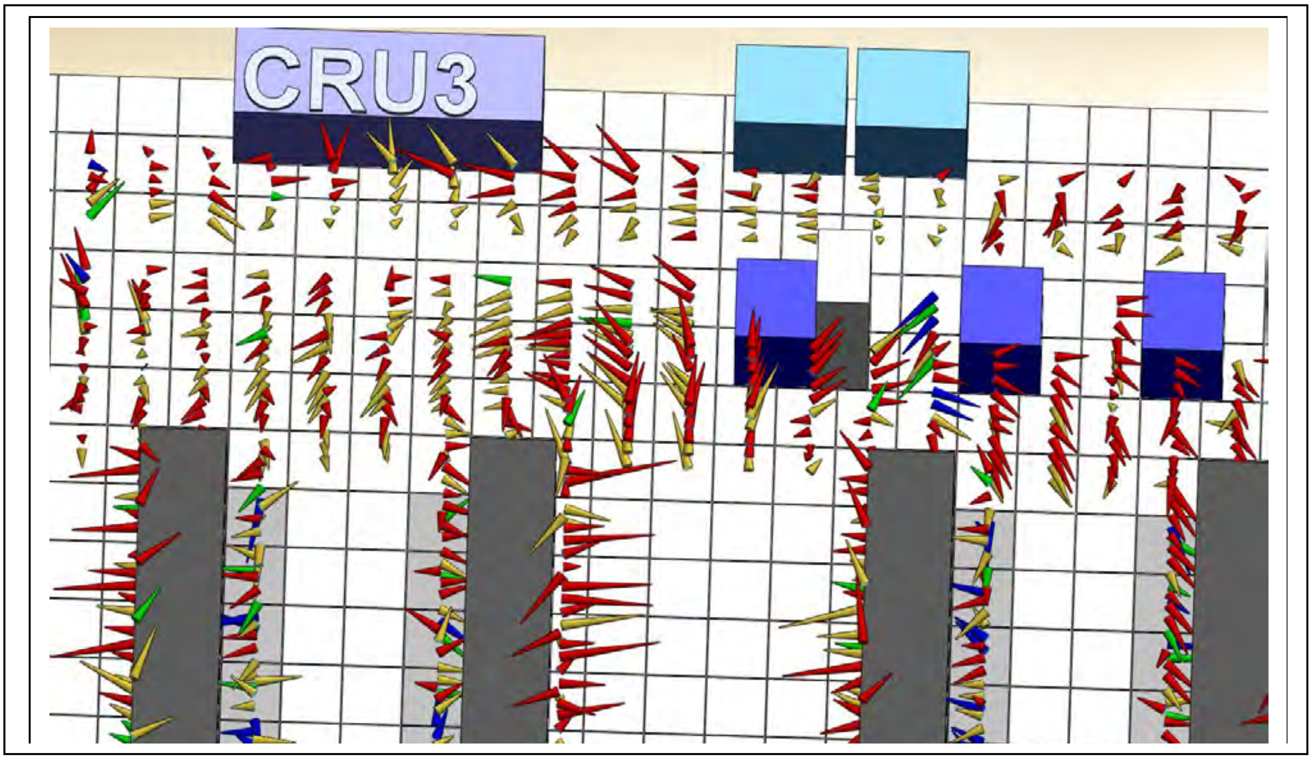
The loads on each row are about 66 kW. The Fig. 1 racks have 26% of inlet temperatures above ASHRAE recommended maximum (80.6°F) and the Fig. 2 racks have .03% of inlet surfaces above ASHRAE maximum. The thermal patterns in Fig. 1 demonstrate that recirculation air is coming over the top of the racks, producing elevated inlet temperatures. The thermal patterns in Fig. 2 show that server cooling requirements are better met by cooling air from the perforated tiles. What accounts for the difference in inlet temperatures? The supply air flows differ from row to row. The Fig. 1 racks are receiving 4,878 CFM from the perforated tiles. The Fig. 2 racks are receiving 5,948 CFM of air from the perforated tiles. The average supply air temperature (from the perforated tiles) for each set of racks is 61.2°F.

Hot spots and recirculation are eliminated in the Fig. 2 rack due to increased supply air flows from the perforated tiles. However, this arrangement is still wasting energy. The rack inlet temperatures are substantially cooler than necessary as evidenced by the large portion of over-cooled inlets (31% below ASHRAE minimum). Increased supply air temperature to the Fig. 2 racks will enable the same cooling to be accomplished at a lower cost.

The result of hot air recirculation will be elevated server inlet temperatures. As air temperatures are raised, the probability of developing hot spots in excess of ASHRAE guidelines will also rise. The way to ensure success when raising set points is to ensure adequate air flow to the servers.

We have a variety of analytical procedures used to “tune” air flow in the data center. In addition to evidence of air flow deficiencies identified by our thermal mosaics, we can actually produce air flow maps that depict measured, not modeled, air flows. The image below is produced by our Data Center Airflow Measurement and Mapping (DAMM) Tool (patent pending).

The image is a top-down view that demonstrates recirculation over the tops of server racks. The DAMM Tool allows us to analyze air flow patterns, temperature distributions, and humidity variations throughout an entire data center environment in three dimensions. The output is similar to a CFD model, however it uses actual measured data. In the image, we see warm air flowing from the hot aisle over the top and around the sides of the racks and into the server inlets. Arrow color indicates air temperature: All red arrows show air temperatures above 80.6°F. All blue arrows show air below 64.4°F.The length of the arrow corresponds to velocity. Of course, the direction of the arrow shows the direction of air flow.



The Numbers: How Much Can You Really Save Through Environmental Optimization?

A CFD model of a small raised-floor/drop-ceiling server room is used to evaluate the effects of various operating conditions on power usage of one 52.5 kW direct-expansion (DX) CRAC unit ducted to the room. DX CRAC unit performance is simulated using CRACSYM, our proprietary thermodynamic CRAC/CRAH simulation model. Model outputs have been verified with manufacturer data to reflect similar performance to commonly used DX CRAC units. The modeled server room contains 5 55U server racks with 35 kW of heat dissipation (7 kW per rack). A perforated tile is placed directly in front of each rack to deliver cold supply air from the DX CRAC unit located in an adjacent room. A grate is installed in the dropped ceiling directly behind the racks for return of hot exhaust air to the DX CRAC unit. Server fans in the model move a total 7875 CFM. This value remains constant unless inlet air temperatures exceed 80.6°F at which

add this before DAMM image in explanation paragraph

What is a CFD model!

point server fan speeds increase. Figures 3 and 4 below show the CFD model layout in a dimetric view and a side view with flow trajectories to demonstrate cold and hot air flows.

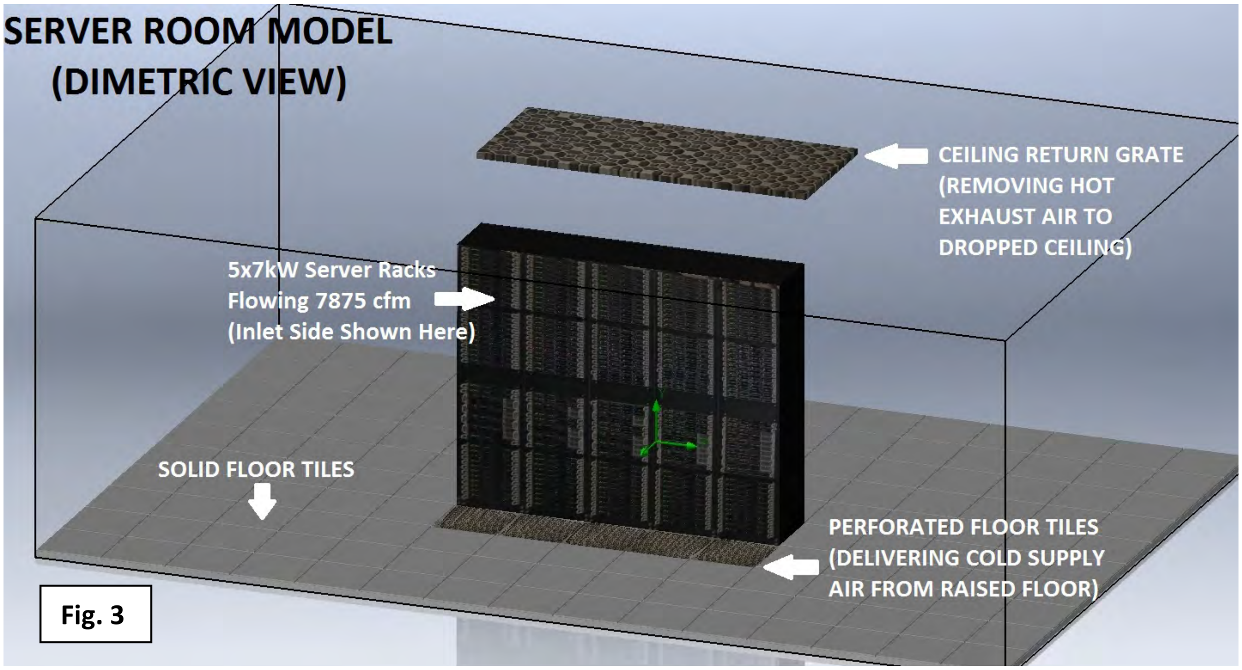


Fig. 3

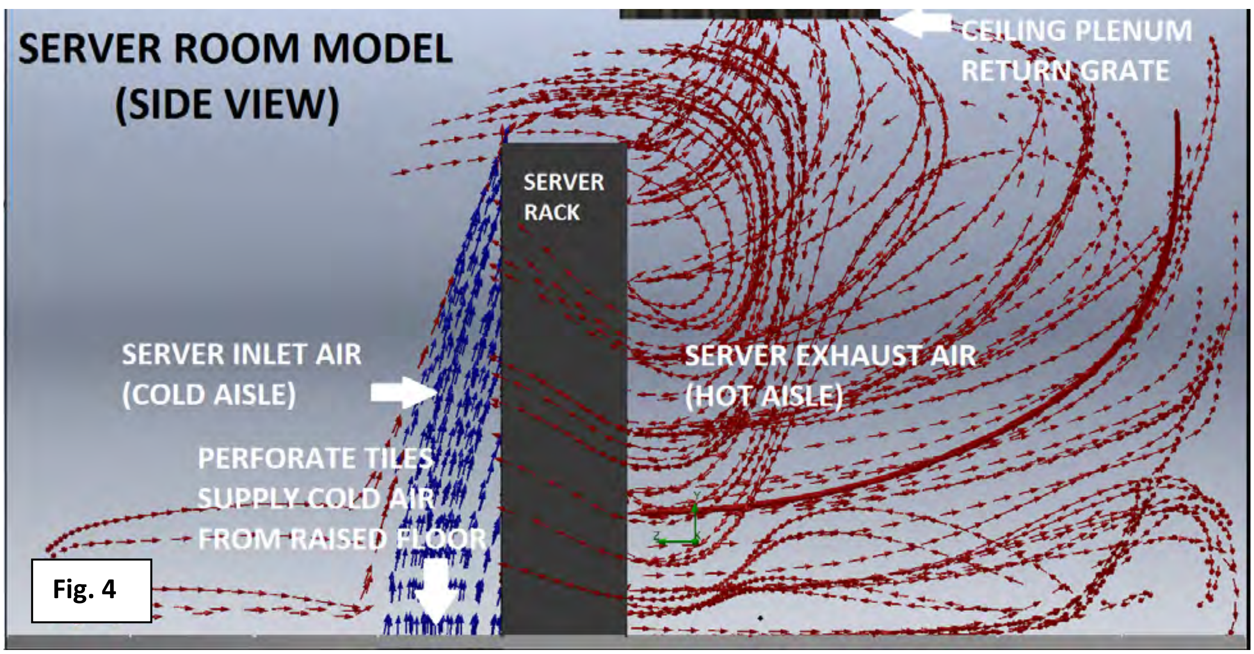


Fig. 4

We will use CFD and CRACSYM to evaluate several issues:

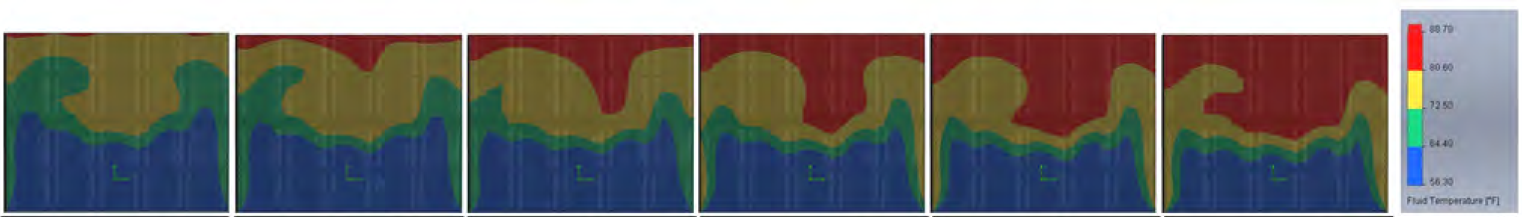
1) The impact of air flow from perforated tiles on maximum CRAC return air temperature set point.

2) The impact on annual operating costs of simply raising the CRAC return air temperature set point while providing increased air flows.
3) The impact of optimizing humidity levels while raising the return air temperature set point while providing increased air flows.

Impact of Air Flow

From the earlier discussion, we know that improved efficiency can be achieved as CRAC return air temperatures set points are raised. However, we also know that in the absence of adequate supply air flow from the perforated tiles, server inlet hot spots will result from increased return air temperatures set points.

Below is a string of CFD runs showing the server inlet temperature plots that resulting from increasing CRAC return air temperature set points. Supply air flow is held constant at 3000 CFM. Each image shows the impact of raising the CRAC set point by two degrees. Blue indicates air temperatures that fall below the ASHRAE recommended minimum of 64.4°F. Red indicates air temperatures above the ASHRAE recommended maximum of 80.6°F. Green indicates air temperatures within the lower half of ASHRAE's recommended range. Yellow indicates air temperatures within the upper half of ASHRAE's recommended range.

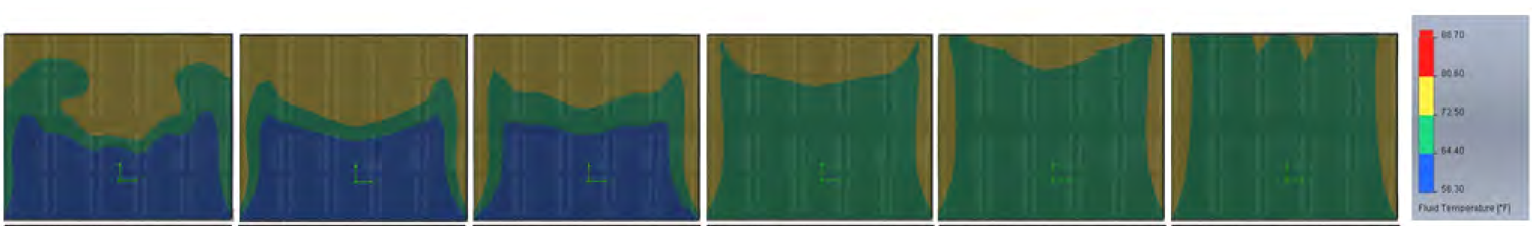


Supply: 3000 CFM RATS: 70°F	Supply: 3000 CFM RATS: 72°F	Supply: 3000 CFM RATS: 74°F	Supply: 3000 CFM RATS: 76°F	Supply: 3000 CFM RATS: 78°F	Supply: 3000 CFM RATS: 80°F

Fig. 5

As we can see, with the air supply held constant and CRAC setpoint is raised at 2^{o}F increments, we develop ever increasing hot spots from recirculation.

Next, we provide another string of CFD runs. In each run, we add 1000 CFM of air flow. We then increase the CRAC Return Air Temperature Setpoint (RATS) to the highest value before ASHRAE values are exceeded.

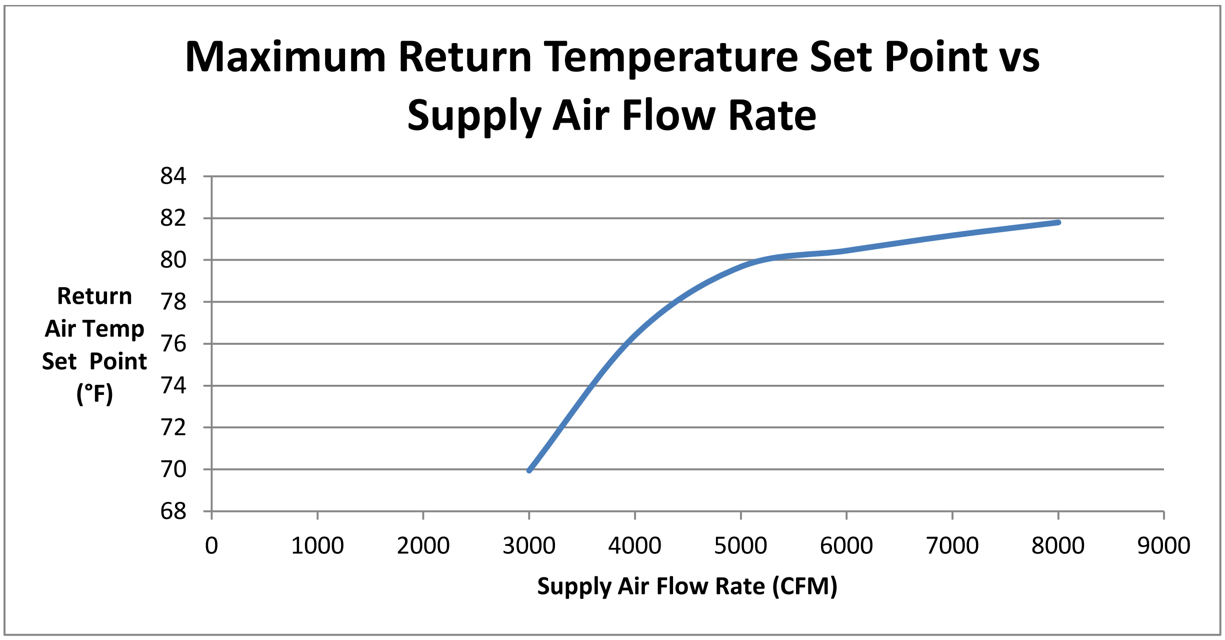


Supply: 3000 CFM RATS: 69.95°F	Supply: 4000 CFM RATS: 76.4°F	Supply: 5000 CFM RATS: 79.68°F	Supply: 6000 CFM RATS: 80.45°F	Supply: 7000 CFM RATS: 81.18°F	Supply: 8000 CFM RATS: 81.8°F

Fig. 6

We can infer from Figure 6 that the amount of hot air recirculation declines as the supplied air flow increases. This allows the return air temperature set point to be increased. It should be noted that it is nearly impossible to completely eliminate hot air recirculation without implementation of some type of barrier or aisle containment. However, the tremendous reduction of hot air recirculation with increased air flow is evident.

Plot 1 portrays the relationship between the maximum possible return air temperature set point for various supplied air flow rates. This plot shows diminishing impacts of set point adjustment when supply air flow exceeds 5,000 CFM. This means there may be economic tradeoffs to be considered when there is a cost to achieving increased air flow.



Plot 1

<u>Impact of Increased Air Flow and Increased CRAC Return Temperature on Operation Costs</u>

Next, we will use our CRACSYM model to simulate performance as the temperature set point is raised. Instead of changing CRAC blower speed to modify supply air flow, we will vary the leakage rate from 60% to 15% of the CRAC's blower capacity.

Leakage air is defined as any air supplied by the CRAC/CRAH unit that flows into the room through openings other than perforated tiles. The unnoticeably small gaps between solid floor tiles in a typical raised floor data center can allow 5-15% of the CRAC/CRAH air escape [6]. As solid tiles age, they can leak even more. We have seen large scale computing facilities with leakage rates as high as 60%.

The model is configured so that all leakage air is short cycled back to the CRAC air return and mixes with all exhaust air from the room. The CRAC unit flow rate matches the server rack demanded flow rate, so at best we will come within 15% of meeting the server air demands. We will maintain a returning air relative humidity set point of 50%. The table below compares the simulated values for the two extreme cases: 60% leakage and 15% leakage.

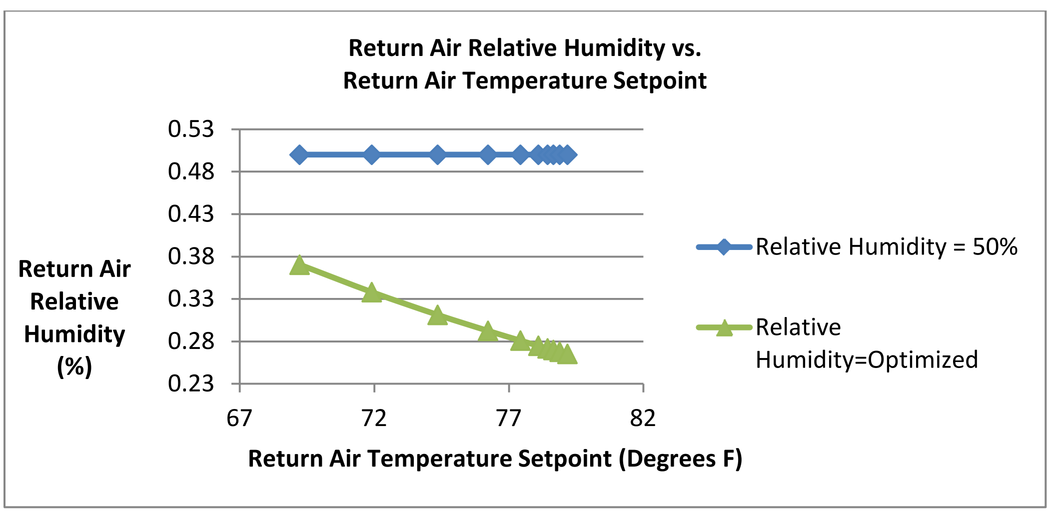
Operating Condition	Case 1	Case 2
% Air Leakage	60	15
Actual Supply Air Flow Rate (CFM)	3150	6693
Return Air Temperature Setpoint (°F)	69.2	79.2
Relative Humidity (%)	50	50
CRAC Sensible Cooling Capacity Fully Loaded (kW)	38.8	43.6
CRAC Latent Cooling Capacity Fully Loaded (kW)	5.3	12.4
Compressor Total Power Consump. Fully Loaded (kW)	13.3	13.4
Humidifier Avg. Power Consumption Fully Loaded (kW)	1.6	3.8
Total CRAC Power Consumption Fully Loaded (kW)	19.7	22
CRAC Sensible COP- Actual Load	2.05	2.12
Annual CRAC Energy Consumption (kWh)	149350	144507
% Energy Savings from Case 1	**0**	**3.2**

Table 1

While total cooling capacity of the CRAC unit increases from changing the temperature set point from Case 1 to Case 2, the sensible cooling capacity does not improve much. This is due to the fact that the relative humidity set point was not adjusted along with the temperature set point. Excessive humidification and dehumidification negatively affects the efficiency of the CRAC unit as the temperature rises, almost canceling out any improvement in COP from temperature rise alone. Because of this, raising the temperature set point without tuning humidity set point along with it allows only 3.24% energy savings in a year.

<u>Impact of Increased Air Flow, Increased CRAC Return Temperature and Optimized Humidity Level on Operation Costs</u>

Now we will optimize humidity level while raising air temperature and observe the change in CRAC unit performance. Humidity level will be maintained at the lower end of ASHRAE's recommended range but adjusted for each temperature set point change. Plot 2 shows relative humidity as temperature is raised for the cases used in the simulation. Table 2 below contains CRAC unit performance results for the varying temperature AND humidity levels.



Plot 2

Operating Condition	Case 3	Case 4
% Air Leakage	60	15
Actual Supply Air Flow Rate (CFM)	3150	6694
Return Air Temperature Setpoint (°F)	69.2	79.2
Relative Humidity (%)	37	26.5
CRAC Sensible Cooling Capacity Fully Loaded (kW)	48.2	63.2
CRAC Latent Cooling Capacity Fully Loaded (kW)	0	0
Compressor Total Power Consump. Fully Loaded (kW)	13.2	13.3
Humidifier Power Consumption Fully Loaded (kW)	0	0
Total CRAC Power Consumption Fully Loaded (kW)	18	18.1
Compressor Total COP Fully Loaded	3.66	4.76
CRAC Sensible COP- Actual Load	3.15	3.63
Annual CRAC Energy Consumption (kWh)	97406	84600
% Energy Savings from Case 1	**34.78**	**43.35**

Table 2

As can be seen from the table, CRAC unit operating costs can be reduced by 34.78% through humidity optimization alone and no set point adjustment. This figure increases to 43.35% after reducing leakage to 15% and raising the temperature by 10°. These large energy savings can be attributed to three factors.

1) CRAC unit cooling capacity is used for sensible or actual cooling only instead of moisture removal. We can see that by optimizing humidity levels, latent cooling drops to 0 kW.
2) Since no moisture is removed, the humidifier no longer must run to replace any moisture.
3) CRAC unit cooling capacity is increased in the above cases from 48.2 kW to 63.15 kW from raising the return air temperature set point.

It is clear that relative humidity must be optimized to take full advantage of the temperature set point changes. Now that we have established that there is potential for substantial savings from environmental optimization in the data center, we can discuss the methods for actually achieving them.

The Path To Greater Efficiency

Through environmental optimization, substantial energy efficiency improvements can be achieved by simply making the best use of existing facilities. Extensive investment to achieve significant savings is often not required.

This approach requires that all obstacles to efficient operation are systematically identified. These obstacles will then become the opportunities for energy savings.

Our optimization service uses a variety of tools and techniques to measure cooling demand and cooling performance in the data center. All systems are included: rack power requirements are measured, rack inlet temperatures are mapped with infrared mosaics, data center air flow patterns are determined using the DAMM cart, CRAC/CRAH performance is quantitatively measured (air flow, COP, CRAC control calibration and more), air flow distribution through perforated tiles and resulting leak rates are determined. Envelope studies are completed to identify infiltration sources that increase humidification/ dehumidification costs. This comprehensive assessment of data center operation will identify all cooling deficiencies in the data center and provide a basis for the design of operational solutions.

After we have effectively characterized cooling in the data center, we then use engineering assessments, CFD and our CRACSYM model to design improved air flow schemes and determine optimal CRAC/CRAH temperature and humidity set points.

The end result: The data center will enjoy the highest possible efficiencies with minimal investment cost

References and Relevant Articles

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