

De-Risking Data Center Temperature Increases, Part 1

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Since the introduction of *Thermal Guidelines for Data Processing Environments*, industry consultants have had answers for energy savings in the palm of their hands. Furthermore, each subsequent edition to the *Thermal Guidelines* has included additional energy savings opportunities through the expansion of the envelopes, publication of the X-factor, and inclusion of several resources and tools implementing these changes. The question remains why so many owners have yet to implement higher IT equipment intake temperatures within their data centers.

Perhaps the answer lies in the fact that few widely published end-to-end procedures exist for safely and reliably raising temperatures in the data center. Simply adjusting a thermostat or temperature controls setting in the building automation system (BAS) is typically not the right answer, as many data center operators know.

Each data center is unique. The combinations of their air management approach, the HVAC systems used, their operating boundary conditions, types of IT hardware, and geographic areas make for unique conditions.

These unique conditions need to be evaluated for each data center to determine *if* and what magnitudes of energy savings are possible through the increase in the temperatures.

In this column, we'll explore *how* to raise the temperatures in the data center using a systematic engineering and commissioning approach that removes the risks and uncertainty from raising the temperatures and capturing the associated energy savings.

Review Air Management

Before ever considering making temperature adjustments in a data center, the airflow management approach needs to be characterized and understood for each data center.

Airflow management in data centers can consist of one or more of the following approaches:

- Underfloor;
- Overhead;

Close-coupled with:

- Rear-door heat exchangers (passive or active type);
- Overhead heat exchangers in the aisles (*Figure 1*);

and

- Cooling in the equipment rows.

Aisle containment can be considered in addition to the above methods of airflow management. In all, the purpose of all airflow management is to optimize the amount of airflow being provided by the HVAC to closely match that required by the IT equipment. Said another way, the goal is for the HVAC return temperature to exactly match the IT exhaust temperatures.

In theory, this will minimize excess energy consumption from the HVAC equipment through:

- A reduction in the fan energy; and
- Increase in the ΔT across the HVAC.

The following mathematical ratios depict the bypass and recirculation airflows as a function of temperatures measured at the IT equipment intake or cold aisle (T_c) and exhaust or hot aisle (T_h), and the HVAC equipment supply (T_s) and return (T_r) (refer to *Figure 2*).

$$\text{Bypass Airflows: } B_p = (T_h - T_r) / (T_h - T_c)^1$$

$$\text{Recirculation Airflows: } R = (T_c - T_s) / (T_c - T_h)^1$$

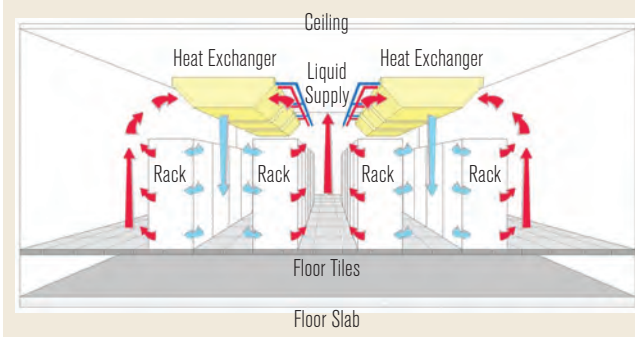
Where

$$B_p = \text{HVAC } \Delta T > \text{Server } \Delta T$$

$$R = \text{HVAC } \Delta T < \text{Server } \Delta T$$

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FIGURE 1 Overhead in the aisle air distribution.



The ideal air management approach is one where the ΔT s are equal, though this is impractical in real applications due to the sensitivity mismatch. Represented mathematically, this occurs when the bypass airflow ratio and recirculation airflow ratio are equal to zero (Figure 3). Any numeric value greater than zero, up to 1, represents losses and inefficiency in the airflow management of the data center.

At a basic level, the airflow management should be characterized as good, poor, or unknown. The next step is measuring the temperatures as described previously (according to the *Thermal Guidelines*, third edition) to determine the bypass and recirculation airflow factors.

Review Existing Thermal Conditions

ASHRAE TC 9.9's forthcoming fourth edition of *Thermal Guidelines for Data Processing Environments* (to be published early this year) covers the "defacto standards" for:

- Environmental guidelines for air- and liquid-cooled equipment;
- Taking measurements for facility and intake temperature and humidity measurements;
- Equipment placement and airflow patterns;
- Equipment manufacturers' heat and airflow reporting requirements; and
- X-factor: a reliability metric used to determine the effects of higher entering temperatures on hardware failure rates.

One of the most important first steps when reviewing the existing thermal conditions is to acknowledge that the temperatures vary *greatly* within the data center environment. In fact, if it does *not*, energy is being wasted. Not all high temperatures are created equal or are considered potentially harmful to IT equipment. In fact, two considerations matter more:

1. The locations of the high temperatures.
2. The type of IT hardware.

FIGURE 2 Temperature measurement conditions.

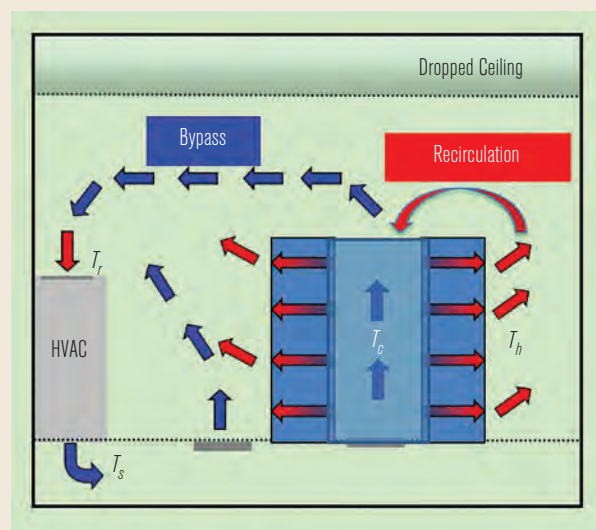
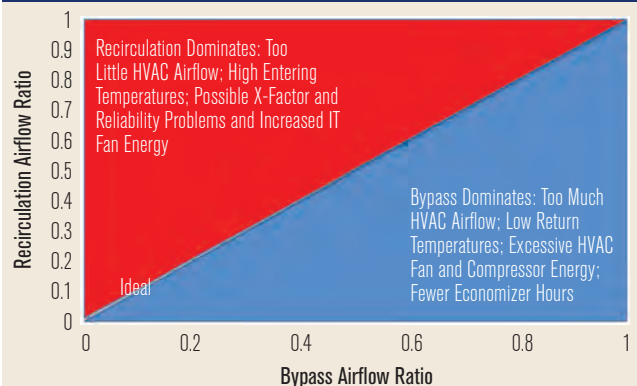


FIGURE 3 Airflow ratios.



As described in *Thermal Guidelines*, third edition, the Class of electronic hardware does matter. Class A1 hardware has a different Allowable upper range of intake temperatures than A4 or B, for examples.

Also, as mentioned in previous columns, the intakes of the IT hardware are the most critical points for the measurement of the temperatures in consideration. *Thermal Guidelines* provides further details on the measurement locations and protocols that should be followed when taking these measurements. Typically, the approach and instrumentation to perform this step necessitates a data center consultant with expertise in air temperature measurements (not surface temperature measurements).

The other part of reviewing existing thermal conditions is determining the classes of hardware in the data center. Often, this may be unknown, particularly in colocation

facilities where the customer's hardware is unknown. In those instances, the lowest common denominator will dictate, which is Class 1 Recommended (81°F [27°C]) or Allowable (90°F [32°C]) conditions.

Defining Boundary Conditions

The boundary conditions for this energy optimization problem primarily focus on two factors:

1. IT equipment ΔT ; and
2. HVAC ΔT .

The IT equipment ΔT is not something that can be modified by the design engineer or the data center operator. The ΔT is a function of many variables and control algorithms established by the IT equipment manufacturer as follows:

- Type of IT hardware;
- Configuration of that hardware; and
- Software that runs on the hardware (type, intervals, frequency, loads, etc.).

For example, a rack can contain 42U of the same server type, yet one set of servers is running virtualization

software for an e-commerce website, and the remaining servers are not running virtualization, but rather some enterprise IT software for email. In each case, the physical heat loads and ΔT across the servers will be very different, and at different times of the day.

The HVAC equipment also has boundary conditions that define the limit on the HVAC coil ΔT as follows:

- Coil design (fluid used, fins per inch, materials of construction, etc.); and
- Sensible heat ratio.

Upon a detailed review of these ΔT s, there may be a fundamental mismatch in the potential maximum ΔT that can be achieved across the IT and HVAC coils. In such instances, this may predetermine whether raising temperatures is a worthwhile cause or not.

Raising the Right Temperatures

A clear understanding of *how* energy is saved in the HVAC plant is necessary before identifying the right temperatures.

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Exercise caution to review the impacts of increased intake temperatures on server fans' energy when an HVAC economizer is not present. Depending on a host of variables, that change alone could result in higher total site energy consumption. While the power usage effectiveness (PUE) may improve, the total electric bill may increase.

Fundamentally, three ways to save HVAC energy in a data center (improve the PUE) include:

1. Better air management (reduced mixing of supply and return airflows) leads to less dilution of return air temperatures from the IT exhaust. The ideal condition exists when the HVAC return temperature matches the exhaust temperature from the IT equipment. This will enable maximizing the economizer hours, if present.
2. Decreasing flows due to increased ΔT s and return temperatures (both air and water). Reduced HVAC airflow is a common strategy when excessive bypass airflow is present.
 - Lower water flows (pumping energy).
 - Lower airflow (fan energy).
3. Increasing the supply air temperature control and

chilled water supply control setpoints, once higher return temperatures are achieved (decrease compressor energy).

By understanding *how* we can save energy, we can now focus on what temperatures to raise for a given data center application.

Typically, the temperatures to raise in the data center are the IT equipment intake temperatures, as noted previously. However, that alone will not save energy. Exceptions to this exist that are beyond the realm of this column.

To save energy through the increase in temperatures, we must carefully review the type of HVAC systems present. At the most basic level, we can hone in on one of two strategies based on the presence of an economizer.

If an economizer is present, typically it is best to raise the HVAC return temperatures. If *no* economizer is present, then raising the HVAC supply temperatures is typically the most important.

In an ideal world, both supply and return would be raised together, but this may not happen and may not be true in all cases. For example, the return air temperatures

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can be raised through better air management, yet also be accompanied by an increase in HVAC coil ΔT , resulting in the same HVAC supply temperature. If no economizer is present, this may not result in as significant an energy savings as anticipated, especially if the HVAC does not include a means of fan speed control, too.

How Much Energy Is Saved?

How much energy can be saved is the ultimate question we want answered. As mentioned previously, three primary mechanisms exist for saving energy by raising temperatures:

1. Increased economizer hours of operation (less compressor operation).
2. Reduced motor energy for moving fluids (pumps and fans) through the offsets gained in increased ΔT s.
3. Higher evaporator temperatures on compressors (lower compressor lift conditions, resulting in less work input according to the vapor-compression cycle).

For compressor energy savings, the theoretical maximum is defined by the vapor compression coefficient of performance (COP) using the Reversible Carnot Cycle.

In general, over the Recommended range (64°F to 81°F [18°C to 27°C]) of temperatures (evaporative and condenser) under consideration here, the theoretical maximum savings is 7.4% per degree Celsius or Kelvin. Over the range of refrigerant temperatures (42°F to 120°F [5.5°C to 49°C]) under consideration here, the theoretical maximum savings drops to 2% per degree Celsius or Kelvin. Reality of actual HVAC equipment is typically less than 1% per degree Celsius or Kelvin.

The economizer savings will be dependent upon geographical climate zone (including microclimate considerations), type of economizer, type of economizer control, and the return temperatures on the HVAC system (air or water, as applicable).

In general, the determination of potential energy savings is something best left to a detailed energy audit and associated analysis since so many variables may apply to any given data center.

The key with this step is understanding *how* the energy will be saved before embarking too far on the journey of raising temperatures.

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Categorize Conditions

To this point, we've taken the following steps toward raising temperatures:

- Reviewed the airflow management approaches: Possibly determined the bypass and recirculation airflow metrics (temperature conditions).
- Reviewed the existing thermal conditions and possibly the type of IT hardware class: Measured the inlet temperature conditions on the IT hardware.
- Reviewed and defined the boundary conditions on the HVAC system and IT hardware.
- Determined which temperatures to raise to save HVAC energy.
- Possibly evaluated the order of magnitude of energy that could be saved and potential ROI of a more thorough review.

Even if no detailed measurements have been taken to this point, *Table 1* can be used to determine the appropriate next steps.

This table generally characterizes the airflow management conditions, temperature variability conditions, average IT inlet temperature conditions, and the next steps. Generally speaking, if the airflow management condition is good, there will be little variability on the IT intake temperature conditions.

For example, with the inlet temperature conditions in hand and no other information, we can determine that we have Cases A3, B3, C3, or D3. For each of these cases, proposed next steps include measurement and monitoring of the airflows and bypass/recirculation metrics.

All cases require further actions and next steps except Case C1. This assumes that the objective is to operate all IT intakes within the Recommended range of the *Thermal Guidelines*. If the objective is other than the Recommended range, next steps can be modified accordingly.

Final Thoughts

In this column, we've covered Part I of raising temperatures in the data center. Raising temperatures is

TABLE 1 Characterizing environmental conditions.²

CASE	AIRFLOW MANAGEMENT	TEMPERATURE VARIABILITY	AVERAGE INLET TEMPERATURE	WHAT'S NEXT?
A1	Good	Known—Little Variability	<64.4°F	Adjust Temperatures!!
A2	Poor	Known—Wide Range of Inlet Conditions	<64.4°F	Correct Airflows, Then A1
A3	Unknown	Unknown	<64.4°F	Measure & Monitor Airflow; A1 or A2?
B1	Good	Known—Little Variability	Lower End of ASHRAE Range—64.4°F to 80.6°F (18°C to 27°C)	Evaluate Being at Upper End of ASHRAE Range
B2	Poor	Known—Wide Range of Inlet Conditions	Lower End of ASHRAE Range—64.4°F to 80.6°F	Correct Airflows, Then B1
B3	Unknown	Unknown	Lower End of ASHRAE Range—64.4°F to 80.6°F	Measure & Monitor Airflow; B1 or B2?
C1	Good	Known—Little Variability	Upper End of ASHRAE Range—64.4°F to 80.6°F	No Action Likely Required
C2	Poor	Known—Wide Range of Inlet Conditions	Upper End of ASHRAE Range—64.4°F to 80.6°F	Correct Airflows
C3	Unknown	Unknown	Upper End of ASHRAE Range—64.4°F to 80.6°F	Measure & Monitor Airflow; C1 or C2?
D1	Good	Known—Little Variability	>80.6°F	Consult Manufacturer For Suitability
D2	Poor	Known—Wide Range of Inlet Conditions	>80.6°F	Consult Manufacturer & Correct Airflows
D3	Unknown	Unknown	>80.6°F (28°C)	Measure & Monitor Airflow; D1 or D2?

rarely as simple as adjusting the thermostat or temperature controls setting on the building automation system (BAS).

It requires a systemic engineering and commissioning approach because each data center, its IT hardware, HVAC systems, etc., are unique.

The process for raising the temperatures was introduced in this column. It begins with characterizing the temperatures, airflow management, boundary conditions, and determining how to save energy and the order of magnitude of energy to be saved.

In next month's column, we continue with the remaining steps necessary to de-risk the process of raising temperatures in the data center. Those steps will include identifying the objectives, identifying the system limits, implementing and reviewing trade-offs, and how to measure, monitor and adjust conditions thereafter to ensure sustainable results.

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