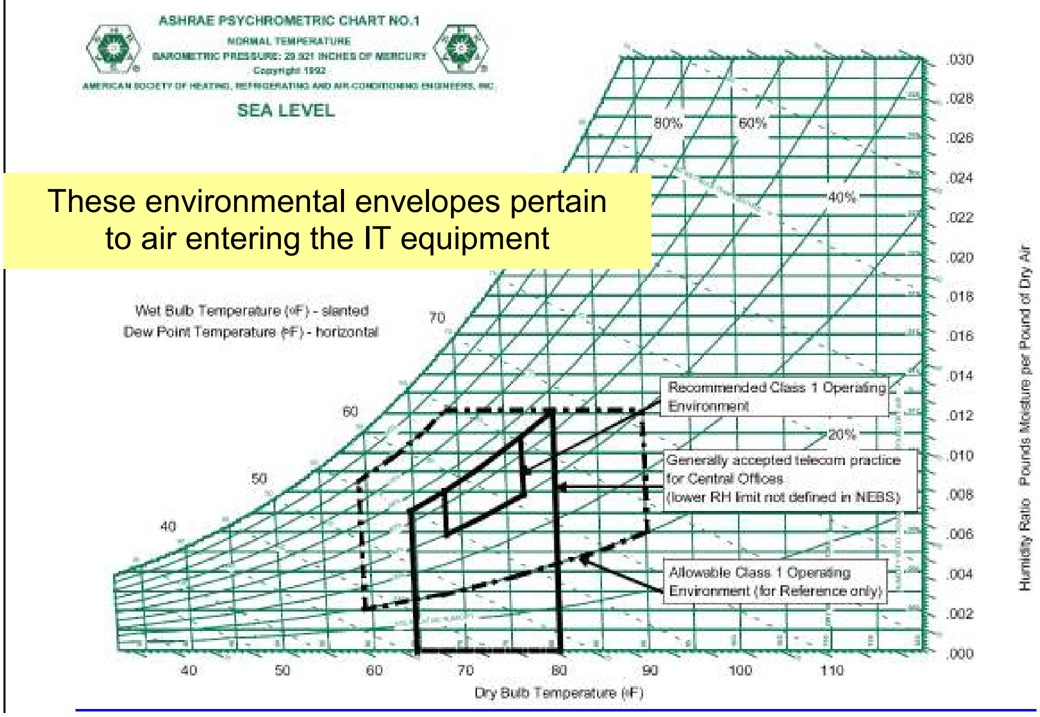
2008 ASHRAE Environmental Guidelines for Datacom Equipment

-Expanding the Recommended Environmental Envelope-

Overview:

The current recommended environmental envelope for IT Equipment is listed in Table 2.1 of the 2004 referenced ASHRAE Datacom book [1]. These recommended conditions as well as the allowable conditions refer to the inlet air entering the datacom equipment. Specifically, it lists for data centers in ASHRAE classes 1 and 2 (refer to the referenced ASHRAE book for details on data center type, altitude, recommended vs allowable, etc.) a recommended environment range of 20 to 25 °C (68 to 77 °F) (dry bulb temperature) and a relative humidity (RH) range of 40 to 55%. (See the allowable and recommended envelopes for class 1 in the psychrometric chart below.).



To provide greater flexibility in facility operations, particularly with the goal of reduced energy consumption in data centers, TC 9.9 has undergone an effort to revisit these recommended Equipment Environmental Specifications, specifically the recommended envelope for classes 1 and 2 (the recommended envelope is the same for both of these environmental classes). The result of this effort, detailed below, is to expand the recommended operating environment envelope. The purpose of the recommended envelope is to give guidance to data center operators on maintaining high reliability and also operating their data centers in the most energy efficient manner. The allowable envelope is where IT manufacturers test their equipment in order to verify that the equipment will function within those environmental boundaries. Typically manufacturers will perform a number of tests prior to announcement of a product to verify that their product meets all the functionality requirements within this environmental envelope. This is not a statement of reliability but one of functionality of the IT equipment. However, the recommended envelope **is** a statement on reliability. For extended periods of time, the IT manufacturers recommend that data center operators maintain their environment within the recommended envelope. Exceeding the recommended limits for short periods of time should not be a problem, but running near the allowable limits for months could result in increased reliability issues. In reviewing the available data from a number of IT manufacturers the 2008 expanded recommended operating envelope is the agreed-upon envelope that is acceptable to all the IT manufacturers, and operation within this envelope will not compromise overall reliability of the IT equipment.

The previous and 2008 recommended envelope data is shown in table 1.

	2004 Version	2008 Version
Low End Temperature	20°C (68 °F)	18°C (64.4 °F)
High End Temperature	25°C (77 °F)	27°C (80.6 °F)
Low End Moisture	40% RH	5.5°C DP (41.9 °F)
High End Moisture	55% RH	60% RH & 15°C DP (59 °F DP)

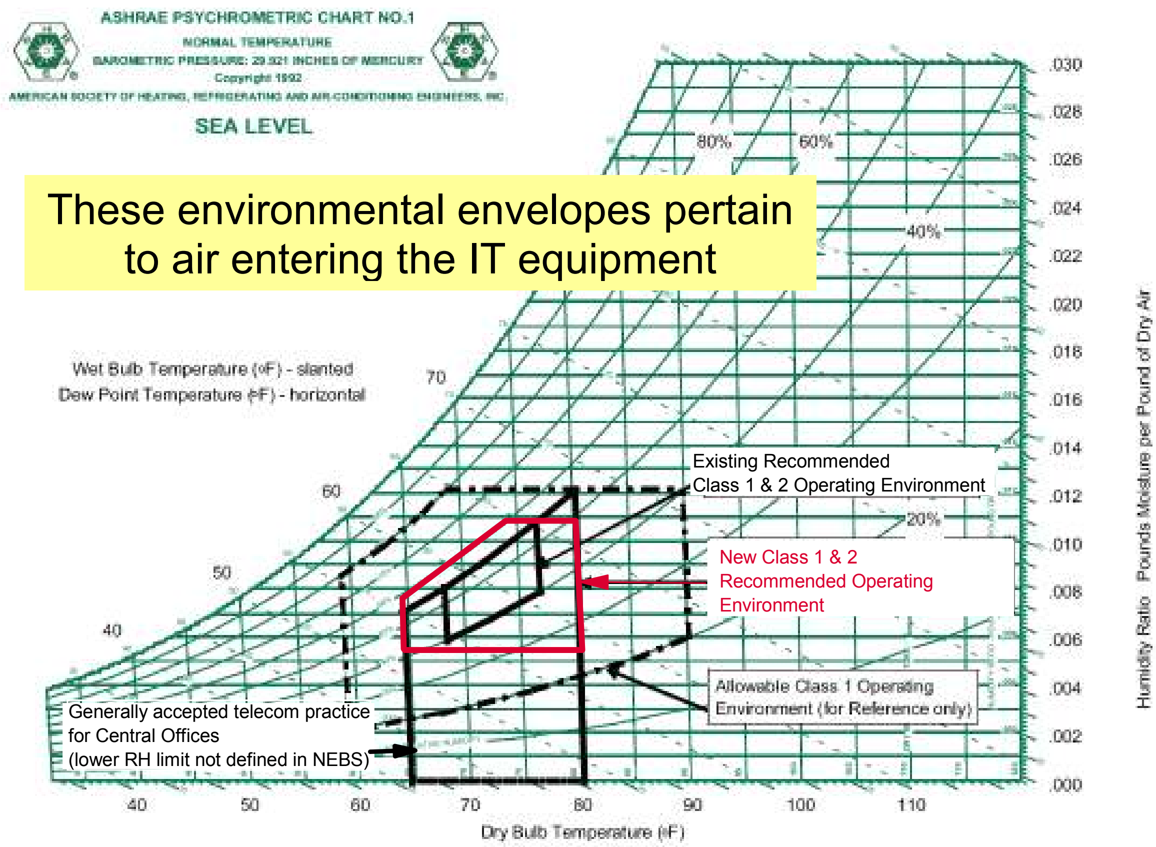
Table 1 Comparison of 2004 and 2008 recommended operating envelope

Neither the 2004 nor the 2008 recommended operating environments ensure that the data center is operating at the optimum energy efficiency. Depending on the cooling system design and outdoor environmental conditions there will be varying degrees of efficiency within the recommended zone. For instance, when the ambient temperature in the data center is raised, the thermal management algorithms within some datacom equipment will increase the speeds of the air moving devices to compensate for the higher inlet air temperatures, potentially offsetting the gains in energy efficiency due to the higher ambient temperature. It is incumbent upon each data center operator to review and determine, with appropriate engineering expertise, the ideal operating point for their system. This will include taking into account the recommended range and their site specific conditions. Using the full recommended envelope is not the most energy efficient environment when a refrigeration cooling process is being used. For example, the high dew point at the upper areas of the envelope will result in latent cooling (condensation) on refrigerated coils, especially in DX (direct expansion) units. Latent cooling decreases the available sensible cooling capacity for the cooling system and in many cases leads to the need to humidify to replace the moisture removed from the air.

The ranges included in this document apply to the inlets of all equipment in the data center (except where IT manufacturers specify other ranges). Attention is needed to make sure the appropriate inlet conditions are achieved for the top portion of IT equipment racks. The inlet air temperature in many data centers tends to be warmer at the top portion of racks, particularly if the warm rack exhaust air does not have a direct return path to the CRACs. This warmer air also affects the relative humidity resulting in lower values at the top portion of the rack. The air temperature generally follows a horizontal line on the psychometric chart where the absolute humidity remains constant but the relative humidity decreases.

Finally, it should be noted that the 2008 change to the recommended upper temperature limit from 25°C to 27°C (77 °F to 80.6 °F) can have detrimental effects on the acoustical noise levels in the data center. See the section on "Acoustical Noise Levels" near the end of this document for a discussion of these effects.

The 2008 recommended environmental envelope is shown in red in the figure below.



The reasoning behind the selection of the boundaries of this envelope are described below:

Dry bulb temperature limits

Part of the rationale in choosing the new low and high temperature limits was based on the generally accepted practice for the telecommunication industry's Central Office, based on NEBS GR-63-CORE, which uses the same dry bulb temperature limits as specified here. In addition, this choice provides a precedence for reliable operation of telecommunication electronic equipment based on a long history of Central Office installations all over the world.

Dry bulb Low side limit:
From an IT point of view, there is no concern in moving the lower recommended limit for dry bulb temperature from 20 °C to 18 °C. (68 °F to 64.4 °F) In equipment with constant speed air moving devices, a facility temperature drop of 2 °C (3.6 °F) will result in about a 2 °C (3.6 °F) drop in all component temperatures. Even if variable speed air moving devices were deployed, typically no change in speed occurs in this temperature range so that component temperatures would again experience a 2 °C (3.6 °F) drop.

One reason for lowering the recommended temperature is to extend the control range of economized systems by not requiring a mixing of hot return air to maintain the previous 20 °C (68 °F) recommended limit. The lower limit should not be interpreted as a recommendation to reduce operating temperatures as this could increase hours of chiller operation and increase energy use. A non-economizer based cooling system running at 18 °C (64.4 °F) will most likely carry an energy penalty. (One reason to do this would be a wide range of inlet rack temperatures due to poor airflow management, however fixing the airflow would likely be a good first step towards reducing energy)

Where the setpoint for the room temperature is taken at the return to cooling units, the recommended range should not be applied directly as this could drive energy costs higher from overcooling the space. The recommended range is intended for the inlet to the IT equipment. If the recommended range is used as a return air set-point, the lower end of the range (18 to 20°C) (64.4 to 68 °F) increases the risk of freezing the coils in a DX cooling system.

Dry Bulb High side limit:
The greatest justification for increasing high side temperature is to increase hours of economizer use per year. For non-economizer systems there may be an energy benefit by increasing the supply air or chilled water temperature set points. However, the move from 25 °C to 27 °C (77 °F to 80.6 °F) can have an impact on the IT equipment's power dissipation. Most IT manufacturers start to increase air moving device speed around 25 °C (77 °F) to improve the cooling of the components and thereby offset the increased ambient air temperature. Therefore care should be taken before operating at the higher inlet conditions.

The concern that increasing the IT inlet air temperatures might have a significant effect on reliability is not well founded. An increase in inlet temperature does not necessarily mean an increase in component temperatures. Consider the following graph showing a typical component temperature relative to an increasing ambient temperature for an IT system with constant speed fans.

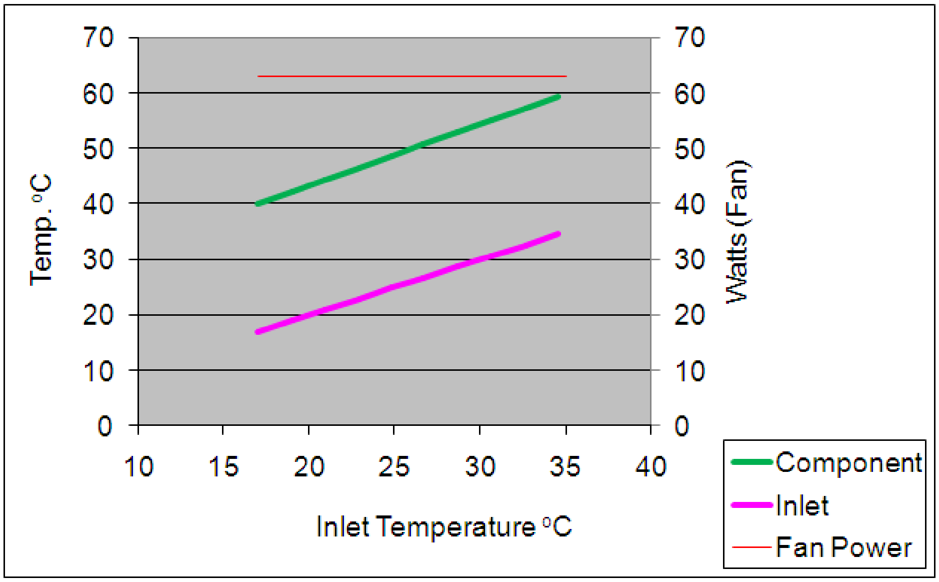
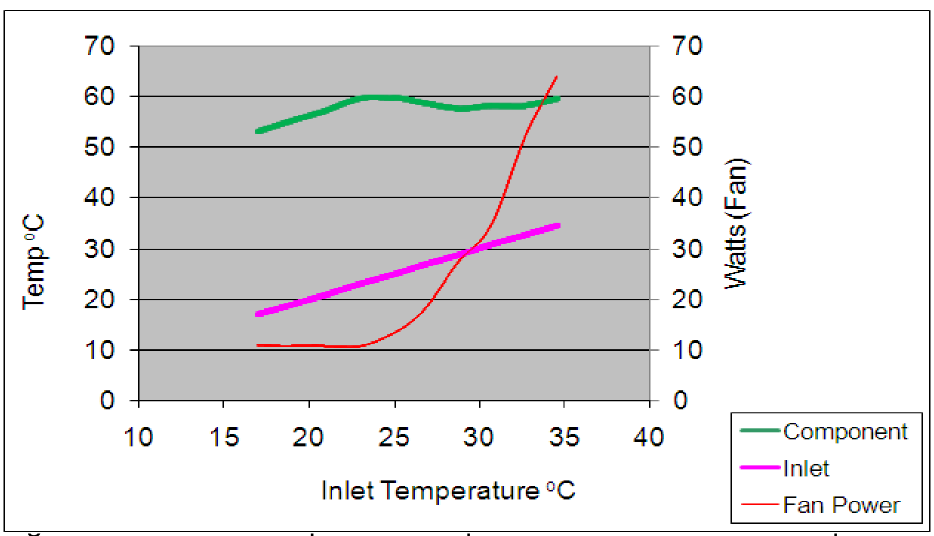


Figure 2: Inlet and Component Temperatures with fixed fan speed

In this example, the component temperature is 21.5 °C above the inlet temperature of 17 °C; it is 23.8 °C above an inlet ambient temperature of 38°C. The component temperature tracks the air inlet ambient temperature very closely.

Now consider the response of a typical component in a system with variable speed fan control as depicted in the figure below. Variable speed fans decrease the fan flow rate at lower temperatures to save energy. Ideal fan control optimizes the reduction in fan power to the point that component temperatures are still within vendor temperature specifications (i.e. the fans are slowed to the point that the component temperature is constant over a wide range of inlet air temperatures).



This particular system has a constant fan flow up to approximately 23°C. Below this inlet air temperature, the component temperature tracks closely to the ambient air temperature. Above this inlet temperature, the fan adjusts flow rate such that the component temperature is maintained at a relatively constant temperature.

This data brings up several important observations:

- Below a certain inlet temperature (23 °C in the case described above), IT systems that employ variable speed air moving devices have constant fan power, and their component temperatures will track fairly closely to ambient temperature changes. Systems that don't employ variable speed air moving devices would track ambient air temperatures over the full range of allowable ambient temperatures.
- Above this air inlet temperature (23 °C in the case described above), the speed of the air moving device increases in speed to maintain fairly constant component temperatures and in this case inlet temperature changes have little-to-no effect on component temperatures and thereby no affect on reliability since component temperatures are not affected by ambient temperature changes
- The introduction of IT equipment that employs variable speed air moving devices has:
  - Minimized the effect on component reliability as a result of changes in ambient temperatures, and
  - Allowed for potential of large increases in energy savings especially in facilities that deploy economizers

As shown in the figure 3 the IT fan power can increase dramatically as it starts ramping up in speed to counter the increased inlet ambient temperature. The graph shows a typical power increase that results in the near constant component temperature. In this case the fan power increased from 11 watts at ~23°C inlet to over 60 watts at 35°C inlet. The inefficiency in the power supply results in an even larger system power increase. The total room power (facilities + IT) may actually go up at warmer temperatures. IT manufacturers should be consulted when considering system ambient temperatures approaching the upper recommended ASHRAE temperature specification. See reference [2] for a technical evaluation of the effect of increased environmental temperature, where it was shown that an increase in temperature can actually increase energy use in a standard data center, but reduce it in a data center with economizers in the cooling system.

Because of the derating of the maximum allowable temperature with altitude for classes 1 and 2, the recommended maximum temperature is derated by 1 °C/300 m (1.8 °F/984.25 ft.) above 1800 m (5905.51 ft.).

Upper moisture limit

Based on extensive reliability testing of Printed Circuit Board (PCB) laminate materials, it has been shown that conductive anodic filament (CAF) growth is strongly related to relative humidity [3]. As humidity increases, time to failure rapidly decreases. Extended periods of relative humidity exceeding 60% can result in failures, especially given the reduced conductor to conductor spacings common in many designs today. The CAF mechanism involves electrolytic migration after a path is created. Path formation could be due to a breakdown of inner laminate bonds driven by moisture which supports the electrolytic migration, explaining why moisture is so key to CAF formation.

The upper moisture region is also important for disk and tape drives. In disk drives, there are head fly-ability and corrosion issues at high humidity. In tape drives, high humidity can increase frictional characteristics of tape, head wear and head corrosion. High relative humidity in combination with common atmospheric contaminants is required for atmospheric corrosion. The humidity forms monolayers of water on surfaces, thereby providing the electrolyte for the corrosion process. 60% RH is associated with adequate monolayer buildup for monolayers to start taking on fluid-like properties. Combined with humidity levels exceeding the critical equilibrium humidity of a contaminant's saturated salt, hygroscopic corrosion product is formed, further enhancing the buildup of acid-electrolyte surface wetness and greatly accelerating the corrosion process. Although disk drives do contain internal means to control and neutralize pollutants, maintaining humidity levels below the critical humidity levels of multiple monolayer formation retards initiation of the corrosion process.

A maximum recommended dew point of 15 °C (59 °F) is specified to provide an adequate guard band between the recommended and allowable envelopes.

Lower moisture limit

The motivation for lowering the moisture limit is to allow a greater number of hours per year where humidification (and its associated energy use) is not required.

The previous recommended lower limit was 40% RH. This correlates on the psychrometric chart to 20 °C (68 °F) dry bulb temperature and a 5.5 °C (41.9 °F) dew point (lower left) and a 25 °C (77 °F) dry bulb and a 10.5 °C (50.9 °F) dew point (lower right). The dryer the air, the greater the risk of electrostatic discharge (ESD). The main concern with decreased humidity is that the intensity of static electricity discharges increases. These higher voltage discharges tend to have a more severe impact on the operation of electronic devices, causing error conditions requiring service calls and, in some cases, physical damage. Static charges of thousands of volts can build up on surfaces in very dry environments. When a discharge path is offered, such as a maintenance activity the electric shock of this magnitude can damage sensitive electronics. If the humidity level is reduced too far, static dissipative materials can lose their ability to dissipate charge and then become insulators.

The mechanism of the static discharge and the impact of moisture in the air are not widely understood. Montoya [4] demonstrates through a parametric study that ESD charge voltage level is a function of dew point or *absolute* humidity in the air and not *relative* humidity. Simonic [5] studied ESD events over various temperature and moisture conditions over a period of a year and found significant increases in ESD events (20x) depending on the level of moisture content (winter vs summer months). It was not clear whether the important parameter was absolute humidity or relative humidity. Blinde and Lavioe[6] studied electrostatic charge decay (vs discharge) of several materials and have shown that it is not sufficient to specify environmental ESD protection in terms of absolute humidity; nor is a relative humidity specification sufficient since temperature effects ESD parameters other than atmospheric moisture content.

The 2004 recommended range includes a dew point temperature as low as 5.5 °C (41.9 °F). Discussions with the IT equipment manufacturers indicated that there have been no known reported ESD issues within the current recommended environmental limits. In addition the referenced information on ESD mechanisms [4-6] do not suggest a direct relative humidity correlation with ESD charge creation or discharge, but reference 4 does demonstrate a strong correlation of dewpoint to charge creation, a lower humidity limit based upon a minimum dewpoint(rather than minimum relative humidity) is proposed. Therefore the 2008 recommended lower limit is a line from 18 ^{o}C (64.4 °F) dry bulb and 5.5 ^{o}C (41.9 °F) dew point temperature to 27 ^{o}C (80.6 °F) dry bulb and a 5.5 ^{o}C (41.9 °F) dew point temperature. Over this range of dry bulb temperature and a 5.5 ^{o}C (41.9 °F) dew point the relative humidity varies from approximately 25% to 45%.

Another practical benefit of this change is that process changes in data centers and their HVAC systems, in this area of the psychrometric chart, are generally sensible only (i.e. horizontal on the psychrometric chart). Having a limit of relative humidity greatly complicates the control and operation of the cooling systems and could require added humidification operation at a cost of increased energy in order to maintain an RH when the space is already above the needed dew point temperature. To avoid these complications, the hours of economizer operation available using the 2004 guidelines were often restricted.

ASHRAE is developing a research project to investigate moisture levels and ESD with the hope of driving the recommended range to a lower moisture level in the future. In addition to ESD, low moisture levels can result in drying out of lubricants which can adversely affect some components. Possible examples include motors, disk drives, and tape drives. While manufacturers have indicated acceptance of the environmental extensions documented here, some have expressed concerns about further extensions. Another concern for tape drives at low moisture content is the increased tendency to collect debris on the tape, around the head, and tape transport mechanism due to static buildup.

Acoustical Noise Levels

The ASHRAE proposal to expand the operating envelope for datacom facilities may have an effect on acoustical noise levels. Noise levels in high-end data centers have steadily increased over the years and have become, or at least will soon become, a serious concern to data center managers and owners. For background and discussion on this, see Chapter 9 "Acoustical Noise Emissions" in the ASHRAE datacom book [7] . The increase in noise levels is the obvious result of the significant increase in cooling requirements of new, high-end datacom equipment. The increase in concern results from noise levels in data centers approaching or exceeding regulatory workplace noise limits, such as those imposed by OSHA in the U.S. or by EC Directives in Europe. Empirical fan laws generally predict that the sound power level of an air moving device increases with the 5^{th} power of rotational speed. This means that a 20% increase in speed (e.g., 3000 to 3600 rpm) equates to a 4 dB increase in noise level. While it is not possible to predict *a priori* the effect on noise levels of a potential 2°C (3.6 °F) increase in data center temperatures, it is not unreasonable to expect to see increases in the range of 3-5 dB. Data center managers and owners should therefore weigh the trade-offs between the potential energy efficiencies with the proposed new operating environment and the potential increases in noise levels.

With regard to the regulatory workplace noise limits, and concern to protect their employees against potential hearing damage, data center managers should check whether potential changes in the noise levels in their environment will cause them to trip various "action level" thresholds defined in the local, state, or national codes. The actual regulations should be consulted, because these are complex and beyond the scope of this document to explain fully. For instance, when levels exceed 85 dB(A), hearing conservation programs are mandated, which can be quite costly, generally involving baseline audiometric testing, noise level monitoring or dosimetry, noise hazard signage, and education and training. When levels exceed 87 dB(A) (in Europe) or 90 dB(A) (in the US), further action such as mandatory hearing protection, rotation of employees, or engineering controls must be taken. Data center managers should consult with acoustical or industrial hygiene experts to determine whether a noise exposure problem will result from increasing ambient temperatures to the upper recommended limit proposed here.

Data Center Operation scenarios for ASHRAE's new recommended environmental limits

The recommended ASHRAE guideline is meant to give guidance to IT data center operators on the inlet air conditions to the IT equipment for the most reliable operation. Four possible scenarios where data center operators may elect to operate at conditions that lie outside the recommended environmental window are listed as follows:

1. Scenario #1: Expand economizer use for longer periods of the year where hardware fails are not tolerated

For short periods of time it is acceptable to operate outside this recommended envelope and approach the extremes of the allowable envelope. All manufacturers perform tests to verify that the hardware functions at the allowable limits. For example if during the summer months it is desirable to operate for longer periods of time using an economizer rather than turning on the chillers, this should be acceptable as long as this period of warmer inlet air temperatures to the datacom equipment does not exceed several days each year where the long term reliability of the equipment could be affected. Operation near the upper end of the allowable range may result in temperature warnings from the IT equipment.

2. Scenario #2: Expand economizer use for longer periods of the year where limited hardware fails are tolerated

All manufacturers perform tests to verify that the hardware functions at the allowable limits. For example if during the summer months it is desirable to operate for longer periods of time using the economizer rather than turning on the chillers and if your data center operation is such that periodic hardware fails are acceptable then operating for extended periods of time near or at the allowable limits may be acceptable. This, of course, would be a business decision on where to operate within the allowable and recommended envelopes and for what periods of time. Operation near the upper end of the allowable range may result in temperature warnings from the IT equipment.

3. Scenario # 3: Failure of cooling system or servicing cooling equipment

If the system was designed to perform within the recommended environmental limits it should be acceptable to operate outside this recommended envelope and approach the extremes of the allowable envelope during the failure. All manufacturers perform tests to verify that the hardware functions at the allowable limits. For example if a modular CRAC unit fails in the data center and the temperatures of the inlet air of the nearby racks increase beyond the recommended limits but are still within the allowable limits, this is acceptable for short periods of time until the failed component is repaired. As long as the repairs are completed within industry norm times for these type failures this operation should be acceptable. Operation near the upper end of the allowable range may result in temperature warnings from the IT equipment.

4. Scenario # 4: Addition of new servers that push the environment beyond the recommended envelope

For short periods of time it should be acceptable to operate outside this recommended envelope and approach the extremes of the allowable envelope. All manufacturers perform tests to verify that the hardware functions at the allowable limits. For example if additional servers are added to the data center in an area that would increase the inlet air temperatures to the server racks above the recommended limits but adhere to the allowable limits, this should be acceptable for short periods of time until the ventilation can be improved. The length of time operating outside the recommended envelope is somewhat arbitrary but several days would be acceptable. Operation near the upper end of the allowable range may result in temperature warnings from the IT equipment.

References:

1. ASHRAE Publication, "Thermal guidelines for Data Centers and other Data Processing Environments", Atlanta, 2004

2. Patterson, Micheal K., "The Effect of Data Center Temperature on Energy Efficiency" Itherm Conference, Orlando, Florida, May 28 – June 1, 2008.

3. Sauter, Karl, "Electrochemical Migration Testing Results - Evaluating Printed Circuit Board Design, Manufacturing Process and Laminate Material Impacts on CAF Resistance", IPC Printed Circuits Expo Proceedings, March 2001.

4. Montoya, 2002,
http://ismi.sematech.org/meetings/archives/other/20021014/montoya.pdf
from the Sematech Electrostatic Discharge Impact and Control Workshop, Austin Texas, October, 2002.

5. Simonic, R, "ESD Event Rates for metallic Covered Floor Standing Information Processing Machines," IEEE EMC Symp. 1982, p.191-198.

6. Blinde, D. and Lavoie, L., "Quantitative effects of relative and absolute humidity on ESD generation/suppression," in Proc. EOS/ESD Symp., vol. EOS-3, Sept. 1981, pp. 9-13.

7. ASHRAE Publication, "Design considerations for Datacom Equipment Centers", Atlanta, 2005.