2008 ASHRAE Environmental Guidelines for Datacom Equipment—Expanding the Recommended Environmental Envelope[1]

The recommended environmental envelope for IT equipment is listed in Table 2.1 of ASHRAE's *Thermal Guidelines for Data Processing Environments* (2004). 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 *Thermal Guidelines* for details on data center type, altitude, recommended vs. allowable, etc.) a recommended environment range of 20°C to 25°C (68°F 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 Figure 1 below.)

To provide greater flexibility in facility operations, particularly with the goal of reduced energy consumption in data centers, ASHRAE Technical Committee (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 in this supplement, 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 it will function within those environmental boundaries. Typically, manufacturers perform a number of tests prior to the announcement of a product to verify that it 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 of reliability. IT manufacturers recommend that data center operators maintain their environment within the recommended envelope for extended periods of time. Exceeding the recommended limits for short periods of

1. This supplement modifies the first edition of *Thermal Guidelines for Data Processing Environments* (ASHRAE 2004).

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 environmental envelope is the agreed-upon envelope that is acceptable to all IT manufacturers, and operation within this envelope will not compromise overall reliability of IT equipment. The previous and 2008 recommended envelope data are shown in Table 1.

Neither the 2004 nor the 2008 recommended operating environments ensure that the data center is operating at 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 increase the speeds of 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 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 result in latent cooling (condensation) on refrigerated coils, especially in direct expansion (DX) 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 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 computer room air conditioners (CRACs). This warmer air also affects the RH, resulting in lower values at the top portion of the rack.

Table 1 Comparison of 2004 and 2008 Recommended Environmental Envelope Data

	2004	2008
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	69% RH and 15°C (59°F DP)

The air temperature generally follows a horizontal line on the psychrometric chart, where the absolute humidity remains constant but the RH 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 acoustical noise levels in the data center. See the section "Acoustical Noise Levels" later in this supplement for a discussion of these effects.

The 2008 recommended environmental envelope is shown in Figure 1. 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 stemmed from the generally accepted practice for the telecommunication industry's central office, based on NEBS GR-3028-CORE (Telcordia 2001), 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.

Low End

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) results in about a 2°C (3.6°F) drop in all component temperatures. Even if variable-speed air-moving devices are deployed, typically no change in speed occurs in this temperature range, so component temperatures 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 noneconomizer-based cooling system running at 18°C (64.4°F) will most likely carry an energy penalty. (One reason to use a noneconomizer-based cooling system 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 toward 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 setpoint, the lower end of the range (18°C to 20°C) (64.4°F to 68°F) increases the risk of freezing the coils in a DX cooling system.

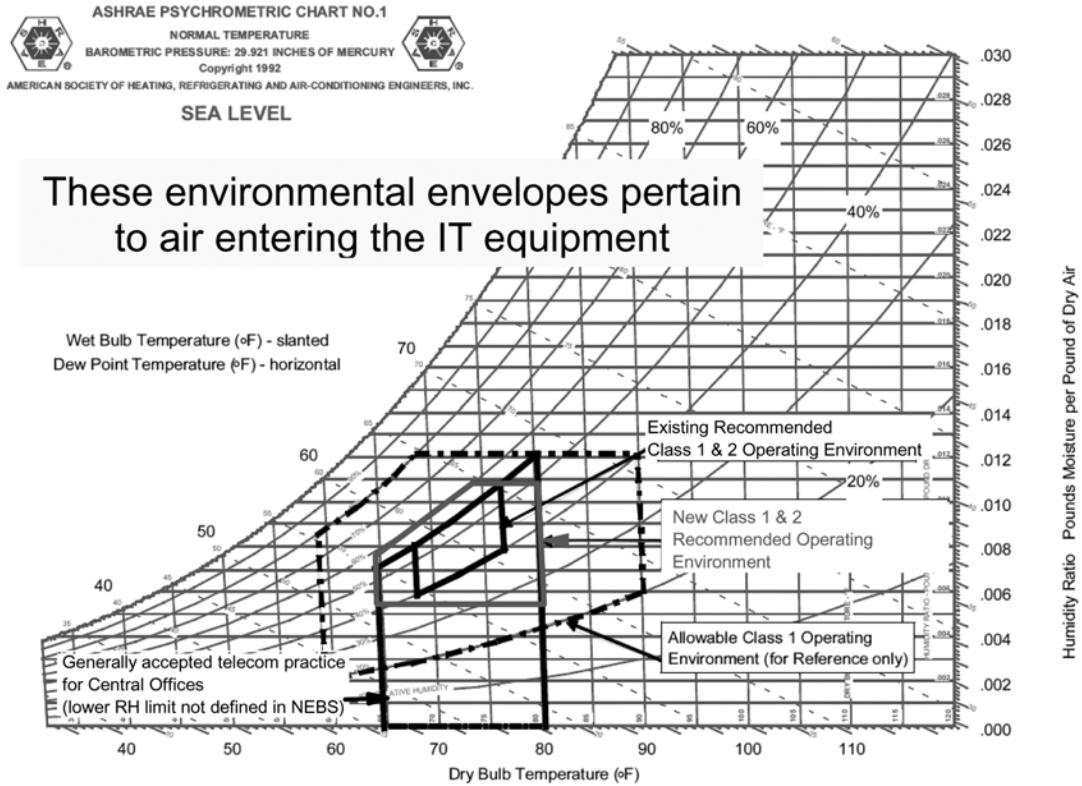

Figure 1 2008 recommended environmental envelope (new Class 1 and 2).

High End

The greatest justification for increasing high-side temperature is to increase hours of economizer use per year. For noneconomizer systems, there may be an energy benefit by increasing the supply air or chilled-water temperature setpoints. 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 graph in Figure 2 showing a typical component temperature relative to an increasing ambient temperature for an IT system with constant-speed fans.

In Figure 2, 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 Figure 3. Variable-speed fans decrease the fan flow rate at lower temperatures to save energy. Ideal fan control optimizes the reduction

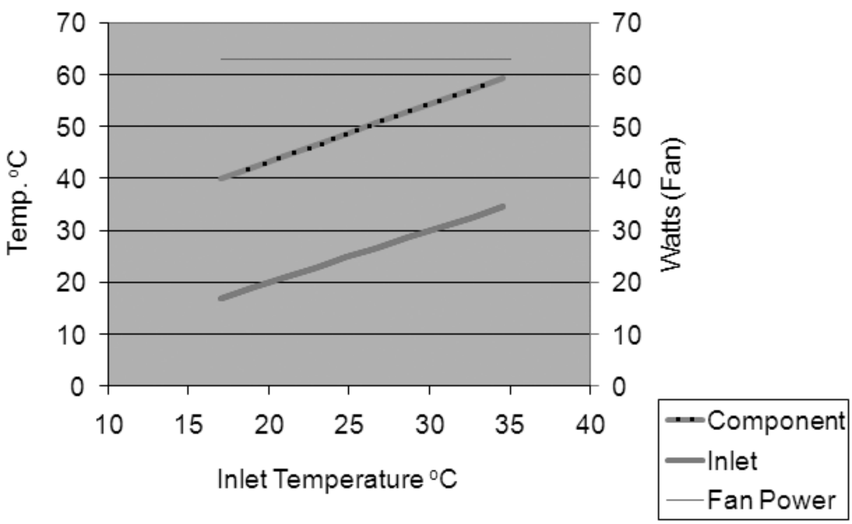

Figure 2 Inlet and component temperatures with fixed fan speed.

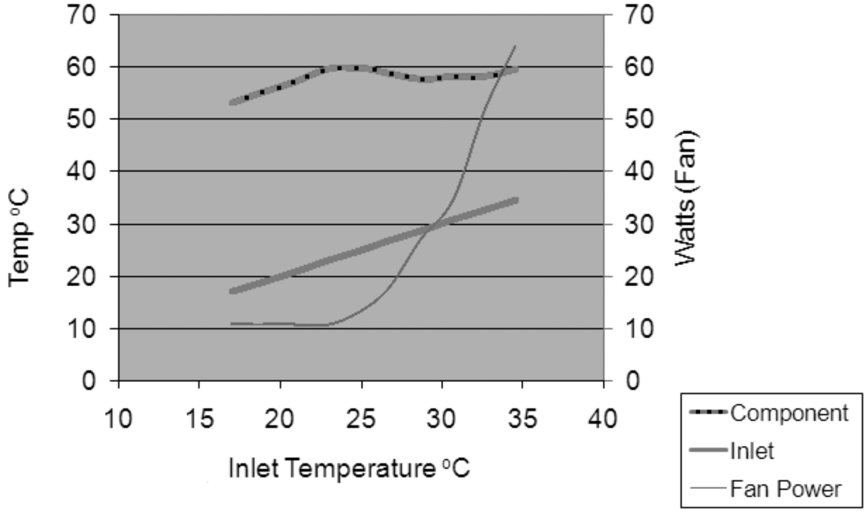

Figure 3 Inlet and component temperatures with variable fan speed.

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 track fairly closely to ambient temperature changes. Systems that don't employ variable-speed air-moving devices track ambient air temperatures over the full range of allowable ambient temperatures.
- Above a certain inlet temperature (23°C in the case described above), the speed of the air-moving device increases 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 Figure 3, the IT fan power can increase dramatically as it ramps up 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 temperature to over 60 watts at 35°C inlet temperature. The inefficiency in the power supply results in an even larger system power increase. The total room power (facilities + IT) may actually increase at warmer temperatures. IT manufacturers should be consulted when considering system ambient temperatures approaching the upper recommended ASHRAE temperature specification. See Patterson (2008) 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 ft) above 1800 m (5906 ft).

MOISTURE LIMITS

High End

Based on extensive reliability testing of printed circuit board laminate materials, it was shown that conductive anodic filament (CAF) growth is strongly related to RH (Sauter 2001). As humidity increases, time to failure rapidly decreases. Extended periods of RH 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 and explains 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 flyability and corrosion issues at high humidity. In tape drives, high humidity can increase frictional characteristics of tape and increase head wear and head corrosion. High RH, 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. Sixty percent 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.

Low End

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 (2002) demonstrates, through a parametric study, that ESD charge voltage level is a function of dew point or absolute humidity in the air and not a function of RH. Simonic (1982) studied ESD events across various temperature and moisture conditions over a period of a year and found significant increases in the number of events (20×) depending on the level of moisture content (winter vs. summer months). It was not clear whether the important parameter was absolute humidity or RH.

Blinde and Lavioe (1981) studied electrostatic charge decay (vs. discharge) of several materials and showed that it is not sufficient to specify environmental ESD protection in terms of absolute humidity; nor is a RH specification sufficient, since temperature affects 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 IT equipment manufacturers indicated that there have been no known reported ESD issues within the 2004 recommended environmental limits. In addition, the referenced information on ESD mechanisms (Montoya 2002; Simonic 1982; Blinde and Lavio 1981) does not suggest a direct RH correlation with ESD charge creation or discharge, but Montoya (2002) does demonstrate a strong correlation of dew point to charge creation, and a lower humidity limit, based upon a minimum dew point (rather than minimum RH), is proposed. Therefore, the 2008 recommended lower limit is a line from 18°C (64.4°F) dry-bulb temperature and 5.5°C (41.9°F) dew-point temperature to 27°C (80.6°F) dry-bulb temperature and a 5.5°C (41.9°F) dew-point temperature. Over this range of dry-bulb temperatures and a 5.5°C (41.9°F) dew point, the RH 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 RH 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. ESD and 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 indicated acceptance of the environmental extensions documented here, some expressed concerns about further extensions. Another concern for tape drives at low moisture content is the increased tendency to collect debris on the tape and around the head and tape transport mechanism due to static buildup.

ACOUSTICAL NOISE LEVELS

The ASHRAE 2008 recommendation to expand the environmental 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 are becoming a serious concern for data center managers and owners. For background and discussion on this, see Chapter 9, "Acoustical Noise Emissions," in ASHRAE's *Design Considerations for Datacom Equipment Centers* (2005). 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 fifth 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 recommended new operating environment and the potential increases in noise levels.

With regard to the regulatory workplace noise limits, and to protect employees against potential hearing damage, data center managers should check whether potential changes in noise levels in their environments will cause them to trip various "action level" thresholds defined in local, state, or national codes. The actual regulations should be consulted, because they 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 and generally involve 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 U.S.), 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 2008 upper recommended limit.

Data Center Operation Scenarios for ASHRAE's 2008 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 allowable extremes. 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 the period of warmer inlet air temperatures to the datacom equipment does not exceed several days each year; otherwise, 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 the 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, is a business decision of 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 the 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 normal industry times for these types of 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 the 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

ASHRAE. 2004. *Thermal Guidelines for Data Processing Environments*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2005. *Design Considerations for Datacom Equipment Centers*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Blinde, D., and L. Lavoie. 1981. Quantitative effects of relative and absolute humidity on ESD generation/suppression. *Proceedings of EOS/ESD Symposium,* vol. EOS-3, pp. 9–13.

Montoya. 2002. Sematech electrostatic discharge impact and control workshop, Austin Texas. http://ismi.sematech.org/meetings/archives/other/20021014/montoya.pdf.

Patterson, M.K. 2008. The effect of data center temperature on energy efficiency. *Proceedings of Itherm Conference, Orlando, Florida*.

Sauter, K. 2001. Electrochemical migration testing results—Evaluating printed circuit board design, manufacturing process and laminate material impacts on CAF resistance. *Proceedings of IPC Printed Circuits Expo, Anaheim, CA*.

Simonic, R. 1982. ESD event rates for metallic covered floor standing information processing machines. *Proceedings of the IEEE EMC Symposium, Santa Clara, CA,* pp. 191–98.

Telcordia. 2001. GR-3028-CORE, Thermal management in telecommunications central offices. *Telcordia Technologies Generic Requirements*, Issue 1. Piscataway, NJ: Telcordia Technologies, Inc.