

Thermal Guidelines for Data Processing Environments

Third Edition

ASHRAE Datacom Series

1

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Third Edition

Thermal Guidelines for Data Processing Environments is authored by ASHRAE Technical Committee (TC) 9.9, Mission Critical Facilities, Technology Spaces and Electronic Equipment. ASHRAE TC 9.9 is composed of a wide range of industry representatives, including but not limited to equipment manufacturers, consulting engineers, data center operators, academia, testing laboratories, and government officials who are all committed to increasing and sharing the body of knowledge related to data centers.

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Thermal Guidelines for Data Processing Environments

Third Edition

ASHRAE Datacom Series
Book 1



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Preface to the Third Edition

Prior to the 2004 publication of the first edition of *Thermal Guidelines for Data Processing Environments*, there was no single source in the data center industry for ITE temperature and humidity requirements. This book established groundbreaking common design points endorsed by the major IT OEMs. The second edition, published in 2008, created a new precedent by expanding the recommended temperature and humidity ranges.

This third edition breaks new ground through the addition of new data center environmental classes that enable near-full-time use of free-cooling techniques in most of the world's climates. This exciting development also brings increased complexity and tradeoffs that require more careful evaluation in their application due to the potential impact on the IT equipment to be supported.

The newly added environmental classes expand the allowable temperature and humidity envelopes. This may enable some facility operators to design data centers that use substantially less energy to cool. In fact, the classes may enable facilities in many geographical locations to operate year round without the use of mechanical refrigeration, which can provide significant savings in capital and operating expenses in the form of energy consumption.

The recommended operating range has not changed from the second edition of the book. However, a process for evaluating the optimal operating range for a given data center has been introduced for those owners and operators who have a firm understanding of the benefits and risks associated with operating outside the recommended range. The third edition provides a method for evaluating ITE reliability and estimating power consumption and airflow requirements under wider environmental envelopes while delineating other important factors for further consideration. The most valuable update to this edition is the inclusion for the first time of IT equipment failure rate estimates based on inlet air temperature. These server failure rates are the result of IT OEMs evaluating field data, such as warranty returns, as well as component reliability data. These data will allow data center operators to weigh the potential reliability consequences of operating in various environmental conditions versus the cost and energy consequences.

A cornerstone idea carried over from previous editions is that inlet temperature is the only temperature that matters to IT equipment. Although there are reasons to want to consider the impact of equipment outlet temperature on the hot aisle, it does not impact the reliability or performance of the IT equipment. Also, each manufacturer balances design and performance requirements when determining their equipment design temperature rise. Data center operators should expect to understand the

equipment inlet temperature distribution throughout their data centers and take steps to monitor these conditions. A facility designed to maximize efficiency by aggressively applying new operating ranges and techniques will require a complex, multi-variable optimization performed by an experienced data center architect.

Although the vast majority of data centers are air cooled at the IT load, liquid cooling is becoming more commonplace and likely will be adopted to a greater extent due to the enhanced operational efficiency, potential for increased density, and opportunity for heat recovery. Consequently, the third edition of *Thermal Guidelines for Data Processing Environments* for the first time includes definitions of liquid-cooled environmental classes and descriptions of their applications. Even a primarily liquid-cooled data center may have air-cooled IT within. As a result, a combination of an air-cooled and liquid-cooled classes will typically be specified.

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ASHRAE TC 9.9 would like to thank the following members of the IT subcommittee for their groundbreaking work and willingness to share it in order to further the understanding of the entire data center industry, and for their active participation, including numerous conference calls, writing/editing, and reviews: Jason Matteson, Mike Ellsworth, and Roger Schmidt (IBM); Robin Steinbrecher and Mike Patterson (Intel); Jon Fitch and Dave Moss (Dell); David Copeland (Oracle/Sun Microsystems); Tim McCann (SGI); David Moore and Declan O'Riordan (Hewlett-Packard); Marlin Vogel (Juniper); Dave Redford (AT&T); Mike Fabray (Seagate); Lionel Coutancier (Bull); Greg Pautsch (Cray); Lang Yuan (Fujitsu); Bill French (EMC); and David Wang (Teradata).

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Finally, special thanks to Mike Mangan of DLB Associates for creating a consistent set of graphics in this updated version.

I Introduction

Over the years, the power density of electronic equipment has steadily increased, as shown and projected in Figure 1.1. In addition, the mission critical nature of computing has sensitized businesses to the health of their data centers. The combination of these effects makes it obvious that better alignment is needed between equipment manufacturers and facility operations personnel to ensure proper and fault-tolerant operation within data centers.

This need was recognized by an industry consortium in 1999 that began a grass-roots effort to provide a power density road map and to work toward standardizing power and cooling of the equipment for seamless integration into the data center. The Industry Thermal Consortium produced the first project of heat density trends. The IT subcommittee of ASHRAE Technical Committee (TC) 9.9 is the successor of that industry consortium. Figure 1.1 shows the latest projection from the IT subcommittee and is based on best estimates of heat release for fully configured systems. An updated set of power trend charts is published in the second edition of *Datacom Equipment Power Trends and Cooling Applications*, Second Edition (ASHRAE 2012). These updated equipment power trends extend to 2020 as shown for the 1U server, in Figure 1.2.

The objective of *Thermal Guidelines for Data Processing Environments*, Third Edition is to

- provide standardized operating environments for equipment,
- provide and define a common environmental interface for the equipment and its surroundings,
- provide guidance on how to evaluate and test the operational health of the data center,
- provide a methodology for reporting the environmental characteristics of a computer system,
- guide data center owners and operators in making changes in the data center environment, and
- provide the basis for measuring the effect of any changes intended to save energy in the data center.

This book, which was generated by ASHRAE TC 9.9, provides equipment manufacturers and facility operations personnel with a common set of guidelines for environmental conditions. It is important to recognize that the IT subcommittee is made up of subject matter experts from the major IT equipment manufacturers. It is the intent of ASHRAE TC 9.9 to update this document regularly.

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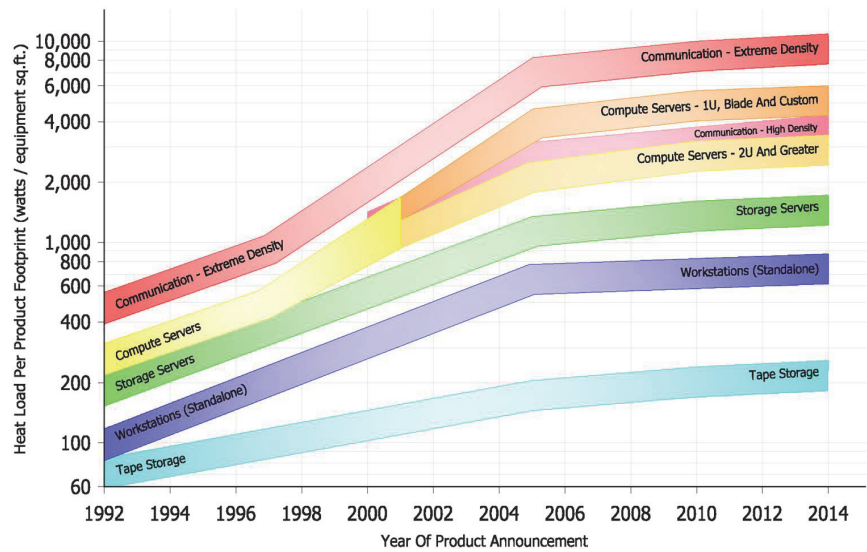


Figure I.1 Heat density trends, projections for information technology products (ASHRAE 2005a).

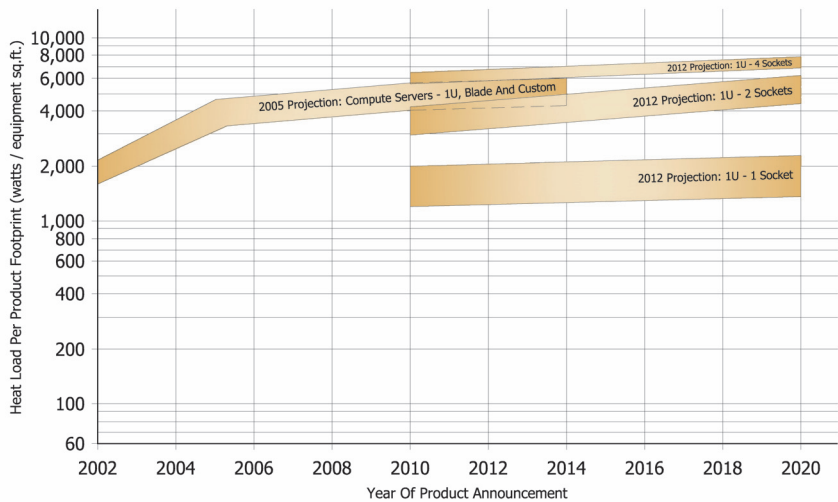


Figure I.2 1U server trends showing 2005 and new 2011 projections (ASHRAE 2012).

Unless otherwise stated, the thermal guidelines in this document refer to data center and other data-processing environments. Telecom central offices are discussed in detail in Telcordia NEBS1™ documents GR-63-CORE (2012) and GR3028-CORE (2001), as well as ANSI T1.304 (1997) and the European ETSI standards (1994, 1999). The NEBS documents are referenced when there is a comparison between data centers and telecom rooms. These two equipment environments have historically been very different. Nevertheless, it is important to show the comparison where some convergence in these environments may occur in the future.

1.1 DOCUMENT FLOW

Following this introductory chapter, this guide continues as follows:

1. **Chapter 2, “Environmental Guidelines for Air-Cooled Equipment”** provides
 - descriptions of the six environmental classes and the temperature and humidity conditions that information technology (IT) equipment must meet,
 - the recommended operating environment for four of the information technology equipment (ITE) classes,
 - the opportunity for facility operators to plan excursions into the allowable range or modify the recommended operating envelope based on details provided in this book on the effect of data center environmentals on server operation and reliability,
 - the effect of altitude on each data center class, and
 - a comparison with the NEBS1 environment for telecom equipment.
2. **Chapter 3, “Environmental Guidelines for Liquid-Cooled Equipment”** provides information on five environmental classes for supply water temperature and other characteristics.
3. **Chapter 4, “Facility Temperature and Humidity Measurement”** provides a recommended procedure for measuring temperature and humidity in a data center.

Different protocols are described depending on whether the purpose of the measurement is to perform

- an audit on the data center,
 - an equipment installation verification test, or
 - an equipment troubleshooting test.
4. **Chapter 5, “Equipment Placement and Airflow Patterns”** examines
 - recommended airflow protocols,
 - hot-aisle/cold-aisle configurations, and
 - recommended equipment placement.
 5. **Chapter 6, “Equipment Manufacturers Heat and Airflow Reporting,”** provides the manufacturer with a methodology to report sufficient dimensional, heat load, and airflow data to allow the data center to be adequately designed

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to meet equipment requirements but not be oversized, as might be the case if nameplate equipment ratings were used to estimate heat loads.

6. **Appendix A, “2008 ASHRAE Environmental Guidelines for Datacom Equipment—Expanding the Recommended Environmental Envelope,”** describes some of the methodology used in determining the recommended envelope and also some scenarios for how the recommended and allowable envelopes can be applied in an operational data center.
7. **Appendix B, “Air-Cooled Equipment Thermal Guidelines (I-P)”** shows the new air-cooled equipment classes in I-P units.
8. **Appendix C, “Detailed Flowchart for the Use and Application of the ASHRAE Data Center Classes”** provides, in detailed flowcharts, guidance for data center operators to achieve data center operation within a specific environmental envelope.
9. **Appendix D, “Static Control Measures”** discusses the need for minimum humidity levels and basic electrostatic discharge (ESD) protection protocols in the data center.
10. **Appendix E, “OSHA and Personnel Working in High Air Temperatures”** provides some information and guidance on personnel working in high-temperature environments.
11. **Appendix F, “Psychrometric Charts”** shows various psychrometric charts for the air-cooled classes in different units.
12. **Appendix G, “Altitude Derating Curves”** shows the envelopes of temperature and elevation for Classes A1–A4, B, C, and NEBS.
13. **Appendix H, “A Practical Example of the Impact of Compressorless Cooling on Hardware Failure Rates”** uses a hypothetical data center implementation in the city of Chicago to guide the reader through assessing the impact of a compressorless cooling design on hardware failure rates using the information in this book.
14. **Appendix I, “IT Equipment Reliability Data for Selected Major U.S. and Global Cities”** uses ASHRAE *Weather Data Viewer* software (2009d) and the relative hardware failure rate information in this book to provide localized metrics on net hardware failure rates and annual hours per year of compressorized cooling needed in selected major U.S. and global cities to comply with the various environmental envelopes.
15. **Appendix J, “Most Common Problems in Water-Cooled Systems”** describes the most common water-cooling problems and failures.
16. **References and Bibliography** provides references as cited throughout this book.

1.2 PRIMARY USERS OF THIS DOCUMENT

Primary users of this book are those involved in the design, construction, commissioning, operating, implementation, and maintenance of equipment rooms. Others who may benefit from this guide are those involved in the development and design

of electronic equipment. Specific examples of the book's intended audience include the following:

- computer equipment manufacturers—research and development, marketing, and sales organizations;
- infrastructure equipment manufacturers—cooling and power;
- consultants;
- general and trade contractors;
- equipment operators, IT departments, facilities engineers, and chief information officers.

1.3 COMPLIANCE

It is the hope of TC 9.9 that many equipment manufacturers and facilities managers will follow the guidance provided in this document. Data center facilities managers can be confident that these guidelines have been produced by the IT manufacturers.

Manufacturers can self-certify the compliance of specific models of equipment as intended for operation in data processing Air-Cooling Environmental Classes A1, A2, A3, A4, B, and C and Liquid Cooling Environmental Classes W1–W5.

1.4 DEFINITIONS AND TERMS

air:

conditioned air: air treated to control its temperature, relative humidity, purity, pressure, and movement.

supply air: air entering a space from an air-conditioning, heating, or ventilating apparatus.

ANSI: American National Standards Institute.

cabinet: frame for housing electronic equipment that is enclosed by doors and is stand-alone; this is generally found with high-end servers.

CDU: coolant distribution unit.

data center: a building or portion of a building whose primary function is to house a computer room and its support areas; data centers typically contain high-end servers and storage products with mission-critical functions.

DP: dew point.

equipment: refers, but is not limited to, servers, storage products, workstations, personal computers, and transportable computers; may also be referred to as *electronic equipment* or *IT equipment*.

equipment room: data center or telecom central office room that houses computer and/or telecom equipment; for rooms housing mostly telecom equipment, see Telcordia GR-3028-CORE (2001).

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ESD: electrostatic discharge.

ETSI: European Telecommunications Standards Institute.

frameworks: structural portion of a frame.

heat:

total heat (enthalpy): a thermodynamic quantity equal to the sum of the internal energy of a system plus the product of the pressure-volume work done on the system.

$$h = E + pv$$

where

h = enthalpy or total heat content

E = internal energy of the system

p = pressure

v = volume

For the purposes of this document, h = sensible heat + latent heat.

sensible heat: heat that causes a change in temperature.

latent heat: change of enthalpy during a change of state.

heat load per product footprint: calculated by using product measured power divided by the actual area covered by the base of the cabinet or equipment.

HPC: high-performance computing.

humidity:

absolute humidity: the mass of water vapor in a specific volume of a mixture of water vapor and dry air.

relative humidity (RH):

- Ratio of the partial pressure or density of water vapor to the saturation pressure or density, respectively, at the same dry-bulb temperature and barometric pressure of the ambient air.
- Ratio of the mole fraction of water vapor to the mole fraction of water vapor saturated at the same temperature and barometric pressure; at 100% RH, the dry-bulb, wet-bulb, and dew-point temperatures are equal.

humidity ratio: the ratio of the mass of water to the total mass of a moist air sample; it is usually expressed as grams of water per kilogram of dry air (gw/kg_{da}) or as pounds of water per pound of dry air (lb_w/lb_{da}).

IEC: International Electrotechnical Commission; a global organization that prepares and publishes international standards for all electrical, electronic, and related technologies.

ITE: information technology (IT) equipment.

IT OEM: information technology original equipment manufacturer (OEM).

IT space: a space dedicated primarily to computers and servers but with environmental and support requirements typically less stringent than those of a data center.

liquid cooled: the use of direct water or refrigerant for cooling ITE (as opposed to using air).

Liquid Cooling Guidelines: TC 9.9 publication, *Liquid Cooling Guidelines for Datacom Equipment Centers* (ASHRAE 2006).

NEBS: formerly Network Equipment-Building System; provides a set of physical, environmental, and electrical requirements for a central office of a local exchange carrier.

OSHA: Occupational Safety and Health Administration.

PCB: printed circuit board

power:

measured power: the heat release in watts, as defined in Section 5.1, "Providing Heat Release and Airflow Values."

nameplate rating: term used for rating according to nameplate (IEC 60950 [1999], under clause 1.7.1): "Equipment shall be provided with a power rating marking, the purpose of which is to specify a supply of correct voltage and frequency, and of adequate current-carrying capacity."

rated voltage: the supply voltage as declared by the manufacturer.

rated voltage range: the supply voltage range as declared by the manufacturer.

rated current: "The input current of the equipment as declared by the manufacturer" (IEC 1999); the rated current is the absolute maximum current that is required by the unit from an electrical branch circuit.

rated frequency: the supply frequency as declared by the manufacturer.

rated frequency range: the supply frequency range as declared by the manufacturer, expressed by its lower- and upper-rated frequencies.

PUE: power usage effectiveness.

rack: frame for housing electronic equipment.

rack-mounted equipment: equipment that is to be mounted in an Electronic Industry Alliance (EIA 1992) or similar cabinet; these systems are generally specified in EIA units, such as 1U, 2U, 3U, etc., where 1U = 44 mm (1.75 in.).

RH: see *humidity, relative*.

room load capacity: the point at which the equipment heat load in the room no longer allows the equipment to run within the specified temperature requirements of the equipment; Chapter 4, “Facility Temperature and Humidity Measurement,” defines where these temperatures are measured. The load capacity is influenced by many factors, the primary factor being the room theoretical capacity; other factors, such as the layout of the room and load distribution, also influence the room load capacity.

room theoretical capacity: the capacity of the room based on the mechanical room equipment capacity; this is the sensible capacity in kW (tons) of the mechanical room for supporting the computer or telecom room heat loads.

TCO: total cost of ownership.

temperature:

dew point: the temperature at which water vapor has reached the saturation point (100% RH).

dry bulb: the temperature of air indicated by a thermometer.

wet bulb: the temperature indicated by a psychrometer when the bulb of one thermometer is covered with a water-saturated wick over which air is caused to flow at approximately 4.5 m/s (900 ft/min) to reach an equilibrium temperature of water evaporating into air, where the heat of vaporization is supplied by the sensible heat of the air.

Thermal Guidelines: TC 9.9 publication, *Thermal Guidelines for Data Processing Environments*.

ventilation: the process of supplying or removing air by natural or mechanical means to or from any space; such air may or may not have been conditioned.

x-factor: a dimensionless metric that measures the relative hardware failure rate at a given constant equipment inlet dry-bulb temperature when compared to a baseline of the average hardware failure rate at a constant equipment inlet dry-bulb temperature of 20°C (68°F).

x-factor, time-weighted (or net): a dimensionless metric indicating a statistical equipment failure rate over a defined range of environmental temperatures when compared to a constant baseline temperature of 20°C (68°F). It is calculated by summing individual time-at-temperature bins multiplied by their associated x-factor.

2

Environmental Guidelines for Air-Cooled Equipment

Chapters 2 and 3 summarize data center environmental guidelines developed by members of the TC 9.9 committee representing the IT equipment (ITE) manufacturers. These environmental guidelines are for terrestrial-based systems and do not cover electronic systems designed for aircraft or spacecraft applications. In this document the term *server* is used to generically describe any ITE, such as servers, storage, network products, etc., used in data-center-like applications.

2.1 BACKGROUND

TC 9.9 created the original publication *Thermal Guidelines for Data Processing Environments* in 2004 (ASHRAE 2004). At the time, the most important goal was to create a common set of environmental guidelines that ITE would be designed to meet. Although computing efficiency was important, performance and availability took precedence. Temperature and humidity limits were set accordingly. Progressing through the first decade of the 21st century, increased emphasis has been placed on computing efficiency. Power usage effectiveness (PUE) has become the new metric by which to measure the effect of design and operation on data center efficiency. To improve PUE, free-cooling techniques, such as air- and water-side economization, have become more commonplace with a push to use them year-round. To enable improved PUE capability, TC 9.9 created additional environmental classes, along with guidance on the use of the existing and new classes. Expanding the capability of ITE to meet wider environmental requirements can change the equipment's reliability, power consumption, and performance capabilities; this third edition of the book provides information on how these capabilities are affected.

In the second edition of *Thermal Guidelines* (ASHRAE 2008), the purpose of the recommended envelope was to give guidance to data center operators on maintaining high reliability and also operating their data centers in the most energy efficient manner. This envelope was created for general use across all types of businesses and conditions. However, different environmental envelopes may be more appropriate for different business values and climate conditions. Therefore, to allow for the potential to operate in a different envelope that might provide even greater energy savings, this third edition provides general guidance on server metrics that will assist data center operators in creating an operating envelope that matches their business values. Each of these metrics is described. Through these guidelines, the user will be able to determine what environmental conditions best meet their technical and business needs. Any choice outside of the recommended region will be a balance between the additional energy savings of the cooling system versus the deleterious effects that may be created on total cost of ownership (TCO) (total site energy use, reliability, acoustics,

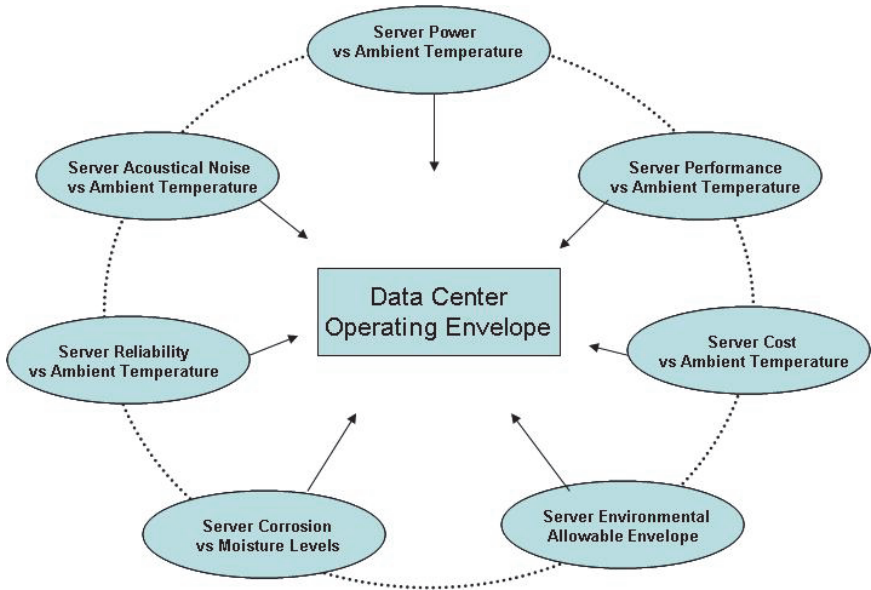


Figure 2.1 Server metrics for determining data center operating environment envelope.

or performance). A simple representation of this process is shown in Figure 2.1 for those who decide to create their own envelope rather than use the recommended envelope for operation of their data center.

A flow chart is also provided to help guide the user through the appropriate evaluation steps. Many of these metrics center around simple graphs that describe the trends. However, the use of these metrics is intended for those who plan to go beyond the recommended envelope for additional energy savings. Their use will require significant additional analysis to understand the TCO impact of operating beyond the recommended envelope.

The other major change in the environmental specification is to the data center classes. Previously there were two classes (Classes 1 and 2) that applied to ITE used in data center applications. The new environmental guidelines have more data center classes to accommodate different applications and priorities of ITE operation. This is critical because a single data center class forces a single optimization, whereas each data center needs to be optimized based on the operator's own criteria (e.g., TCO, reliability, performance, etc.).

2.2 NEW AIR-COOLED EQUIPMENT ENVIRONMENTAL SPECIFICATIONS

Prior to the formation of TC 9.9, each commercial information technology (IT) manufacturer published its own independent temperature specification. Typical data centers were operated in a temperature range of 20°C to 21°C (68°F to 69.8°F) under

the common notion that colder is better. Most data centers deployed ITE from multiple vendors. This resulted in designing for ambient temperatures based on the ITE with the most stringent temperature requirements (plus a safety factor). TC 9.9 obtained informal consensus from the major commercial ITE manufacturers for both recommended and allowable temperature and humidity ranges and for four environmental classes, two of which were applied to data centers.

Another critical accomplishment of TC 9.9 was to establish ITE air inlets as the common measurement point for temperature and humidity compliance; requirements in any other location within the data center were optional.

The environmental guidelines/classes are really the domain and expertise of IT OEMs. TC 9.9's IT subcommittee is exclusively composed of engineers from commercial IT manufacturers; the subcommittee is strictly technical.

The commercial IT manufacturers' design, field, and failure data are shared (to some extent) within the IT subcommittee, which enables greater levels of disclosure and ultimately lead to the decision to expand the environmental specifications. Prior to TC 9.9, there were no organizations or forums to remove the barriers to sharing information among competitors. This is critical because some manufacturers conforming while others do not results in a multivendor data center where the most stringent requirement plus a safety factor would most likely prevail.

From an end-user perspective, it is also important that options, such as the following, are provided for multivendor facilities:

- Option 1—Use of ITE optimized for a combination of attributes, including energy efficiency and capital cost, with the dominant attribute being reliability.
- Option 2—Use of ITE optimized for a combination of attributes, including some level of reliability, with the dominant attribute being energy and compressorless cooling.

The industry needs both types of equipment but also needs to avoid having Option 2 inadvertently increase the acquisition cost of Option 1 by increasing purchasing costs through mandatory requirements not desired or used by all end users. Expanding the temperature and humidity ranges can increase the physical size of the ITE (e.g., more heat-transfer area required), increase ITE airflow, etc. This can impact embedded energy cost, power consumption, and ITE purchase cost but enables peak performance under high-temperature operation.

By adding new classes and not mandating all servers conform to something such as an air inlet temperature of 40°C (104°F), the increased server packaging cost for energy optimization becomes an option rather than a mandate. Before the new classes are described and compared to their 2008 version, several key definitions need to be highlighted.

recommended environmental range: Facilities should be designed to achieve, under normal circumstances, ambient conditions that fall within the recommended range. This recommended range may be as defined either in Table 2.3 or by the process outlined later in this chapter whereby the user can apply the metrics in Figure 2.1 (described in more detail in this book) to define a different recommended range more appropriate for particular business objectives.

allowable environmental range: The allowable envelope is where IT manufacturers test their equipment in order to verify that it will function within those environmental boundaries. Typically, IT manufacturers perform a number of tests prior to the announcement of the product to verify that it meets all the functional requirements within the environmental envelope. This is not a statement of reliability but one of functionality of the ITE. In addition to the allowable dry-bulb temperature and relative humidity (RH) ranges, the maximum dew point (DP) and maximum elevation values are part of the allowable operating environment definitions.

practical application: Prolonged exposure of operating equipment to conditions outside its recommended range, especially approaching the extremes of the allowable operating environment, can result in decreased equipment reliability and longevity (server reliability values versus inlet air temperatures are now provided in this 2011 version to provide some guidance on operating outside the recommended range). Exposure of operating equipment to conditions outside its allowable operating environment risks catastrophic equipment failure. With equipment at high power density, it may be difficult to maintain air entering the equipment within the recommended range, particularly over the entire face of the equipment. In these situations, reasonable efforts should be made to achieve conditions within the recommended range. If these efforts prove unsuccessful, operation within the allowable environment is likely to be adequate, but facility operators may wish to consult with the equipment manufacturers regarding the risks involved.

The primary difference between the first edition of the *Thermal Guidelines* published in 2004 and the second edition, published in 2008, were in the changes to the recommended envelope shown in the Table 2.1. The 2008 recommended guidelines have not changed in the third edition, as shown in Table 2.3. However, as stated above there is an opportunity to define a different recommended envelope based on the metrics shown in Figure 2.1 and documented later in this chapter. More information is provided later on this subject. For more background on the changes made in 2008 to the recommended envelope, refer to Appendix A.

To enable improved operational efficiency, ASHRAE TC 9.9 has added two new ITE environmental classes to *Thermal Guidelines* that are more compatible with chillerless cooling. The naming conventions have been updated to better delineate the types of ITE. Old and new classes are now specified differently (comparisons are shown in Table 2.2). The 2008 version shows two data center classes (Classes 1 and 2) which have been kept the same in this update but are now referred to as Classes A1 and A2. The new data center classes are referred to as Classes A3 and A4.

Environmental Class Definitions for Air-Cooled Equipment

Compliance with a particular environmental class requires full operation of the equipment over the entire allowable environmental range, based on nonfailure conditions.

Class A1: Typically a data center with tightly controlled environmental parameters (dew point, temperature, and RH) and mission critical operations; types of