ASHRAE's Data Center Thermal Guidelines—Air-Cooled Evolution

BY DAVID QUIRK, P.E., MEMBER ASHRAE; TOM DAVIDSON, P.E., MEMBER ASHRAE; ROGER SCHMIDT, PH.D., P.E., FELLOW ASHRAE

Data centers have always had unique HVAC requirements because rather than serving primarily people, they cool information technology equipment (ITE). In addition, the equipment is typically high density, resulting in high HVAC energy consumption. Prior to 2004, guidance on the allowable environmental envelope varied from one manufacturer to another, and energy density trends, essential for "future-proofing" a facility, were not available to design engineers. Given this lack of guidance, IT industry leaders started to talk about standardization, first through an informal industry consortium, and eventually in the formation of ASHRAE Technical Committee (TC) 9.9, Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment, in 2003.

The first publication of ASHRAE TC 9.9 was *Thermal Guidelines for Data Processing Environments (First Edition)* in 2004.[1] Information on the history leading up to that guideline can be found in the 2004 paper "Evolution of Data Center Environmental Guidelines."[2] Since that initial publication, the *Thermal Guidelines* book has been revised four times. While the initial guideline only covered air-cooled ITE, the *Fourth Edition* and *Fifth Edition* cover liquid-cooling technology guidelines as well.

This column summarizes the changes to the air-cooled technology guidelines over the past 18 years. The evolution of the guidelines for liquid-cooled, and other aspects of the guidelines, will be covered in subsequent columns.

Note that the temperature/humidity ranges listed in this column refer to the ITE *inlet* conditions and should not be confused with "space" conditions, discharge air conditions from cooling equipment or return air conditions to cooling equipment. For new data centers, CFD modeling is likely the best way to estimate ITE inlet conditions. For existing data centers, Chapter 4 of the *Thermal Guidelines,* titled "Facility Temperature and Humidity Measurement," provides additional guidance.

David Quirk, P.E., is a managing principal, and Tom Davidson, P.E., is a senior mechanical engineer at DLB Associates. Roger Schmidt, Ph.D., P.E., is an IBM Fellow Emeritus and a professor at Syracuse University.

FIGURE 1 Recommended and allowable environmental envelope for Classes A1, A2, A3, and A4 with low levels of gaseous pollutants.[3]

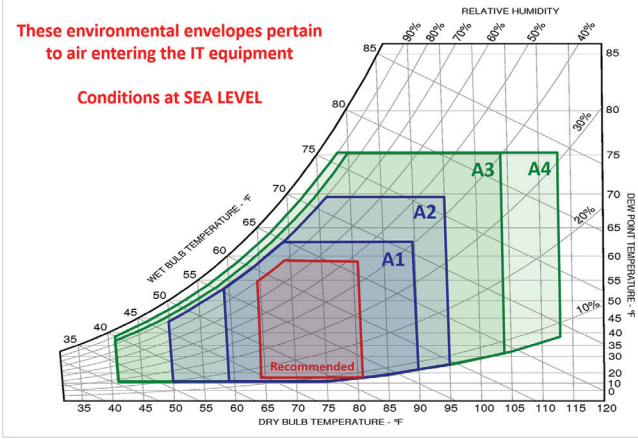
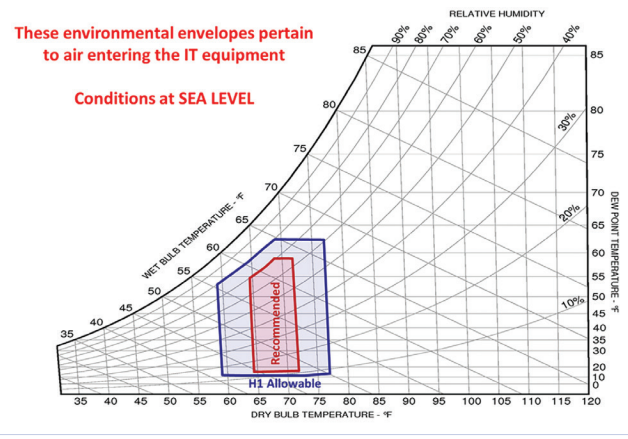


FIGURE 2 Recommended and allowable environmental envelope for Class H1 with low levels of gaseous pollutants.[3]



Recommended vs. Allowable Envelopes

The thermal guidelines publication has both *recommended* and *allowable* ranges. While other parameters (such as air pollution and elevation) are also limiting factors, the primary environmental operating conditions are related to temperature and humidity (both relative and absolute) and are displayed on sea level psychrometric charts in the guidelines.

The *recommended* range is likely the most important range for data center designers and operators. Facilities should be designed and operated to target the recommended range for most hours of the year.

ITE, on the other hand, should be designed to operate within the extremes of the applicable *allowable* environmental classes. *Figure 1* provides an example chart from the *Fifth Edition*; it shows both the recommended and allowable conditions for environmental Classes A1 to A4 under conditions with low gaseous pollutants and corresponding ITE corrosion potential.[3] As a second example, *Figure 2* shows the recommended and allowable envelopes for the new high-density H1 air-cooled class, again with low corrosion potential. If the corrosion potential is high, the maximum recommended relative humidity (RH) is lowered from 70% to 50%. Similar charts are available in the *Fifth Edition* for all classes with both low and high levels of gaseous pollutants, in both SI and I-P units.

Environmental Class Definitions

As shown in *Figures 1* and *2*, not all ITE is designed for the same environmental conditions (i.e., the Allowable envelopes). Several classes of environmental envelopes are specified in the *Thermal Guidelines* book. The *First Edition* and *Second Edition* each had four Classes: 1, 2, 3 and 4. Among them, Class 1 had the most restrictive allowable environmental envelope, while Class 4 had the widest specification.

TABLE 1 *Thermal Guidelines* environmental classes.

FIRST EDITION ENVIRONMENTAL CLASS	*FIFTH EDITION* ENVIRONMENTAL CLASS	CLASS DESCRIPTION
1 Renamed Class A1 in *Third Edition*	A1	Typically a data center with tightly controlled environmental parameters (dew point, temperature, and RH) and mission-critical operations
2 Renamed Class A2 in *Third Edition*	A2	Typically an information technology space with some control of environmental parameters
N/A	A3	Similar to Class A2, but with a wider allowable range that will likely allow for chiller-less cooling with a water-cooled heat rejection system in most climates
N/A	A4	Similar to Class A2/A3, but with a wider allowable range that will likely allow for chiller-less cooling with an outdoor air-cooled system in most climates
N/A	H1	High-density air-cooled servers (see *Fifth Edition*, Section 2.2.2 for more information)

In the *Third Edition*, industry pressure to increase the efficiency of data center operation led to the addition of two new classes, A3 and A4. There was a co-incident renaming of the original classes with this publication. To help avoid confusion, *Table 1* provides a correspondence between the class naming convention used in the *First Edition* and the *Fifth Edition*.

From *Table 1*, the current classes (in the *Fifth Edition*) are A1, A2, A3, A4 and H1. Classes A1 and A2 correspond

TABLE 2 Evolution of recommended air-cooled data center environmental conditions.

CLASS	*FIRST EDITION* 2004	*SECOND EDITION* 2008	*THIRD EDITION*[a] 2012	*FOURTH EDITION* 2015	*FIFTH EDITION* 2021
Recommended Temperature (A1 to A4)	68°F to 77°F	64.4°F to 80.6°F	64.4°F to 80.6°F	64.4°F to 80.6°F	64.4°F to 80.6°F
Recommended Temperature (H1)[c]	N/A	N/A	N/A	N/A	64.4°F to 71.6°F
Recommended Relative Humidity (All Classes)[d]	40% to 55% RH	60% RH Max. (See Dew Point for Min.)	60% RH Max. (See Dew Point for Min.)	60% RH Max. (See Dew Point for Min.)	70% RH Max.[b] Or 50% Max.[b]
Recommended Dew Point (All Classes)[d]	N/A	41.9°F to 59°F	41.9°F to 59°F	15.8°F to 59°F	15.8°F to 59°F

[a]The *Third Edition* did not have any changes to the recommended or Class A1 allowable conditions. Rather, environmental classes A3 and A4 were added to the guidelines, with broader operating ranges.

[b]If testing with silver or copper coupons results in values less than 200 and 300 Anstroms/month, respectively, then operating up to 70% RH is acceptable. If testing shows corrosion levels exceed these limits, then catalyst-type pollutants are probably present and RH should be driven to 50% or lower.

[c]Class H1 has a recommended temperature operating range that is different than all other equipment classes.

[d]Recommended Relative Humidity and Dewpoint are only applicable to Class H1 in the *Fifth Edition*, since Class H1 was not defined earlier.

to the original Class 1 and 2, respectively. Classes A3 and A4 were added in the *Third Edition* to facilitate wider adoption of cooling without mechanical refrigeration. In the *Fifth Edition*, a new high-density class H1 was added to align with new high-density ITE products entering the market. The original Class 3 and Class 4 (renamed Class B and Class C in the *Third Edition*) are not "data center environments" and are not addressed in this column.

Description of Air-Cooled Changes for Subsequent Editions

Second Edition Changes

The environmental envelope changes in the *Second Edition*[4] can be found outlined in blue in the third column of *Table 2*. Changes were made to both the recommended temperature and humidity ranges. For temperature, the recommended range was expanded from 68.0°F to 77.0°F (20°C to 25°C) to 64.4°F to 80.6°F (18°C to 27°C). The recommended humidity range was also adjusted. For relative humidity, the low-end RH threshold was eliminated and the high end was raised from 55% to 60% RH. A recommended dew-point temperature range was also added, with a range from 41.9°F to 59.0°F (5.5°C to 15°C) The most restrictive of the RH vs. dew-point temperatures defines the envelope. No changes to the allowable envelopes were made in the *Second Edition*.

Third Edition Changes

The environmental envelope changes in the *Third Edition*[5] can be found outlined in blue in the fourth column of *Table 3*. There were no changes to the recommended range in the *Third Edition*. For Class A1 and A2, there were also no changes to the allowable environment, but two new environmental classes were added: A3 and A4. Class A3 had an allowable temperature range from 41°F to 104°F (5°C to 40°C), while Class A4 had an allowable range from 41°F to 113°F (5°C to 45°C). The allowable humidity environment for Classes A3 and A4 was broader than for existing Classes A1 and A2.

These new classes were created in large part due to the desire to provide data center cooling without mechanical refrigeration. The thought was that equipment designed to Class A3 could be placed in a data center that could be cooled without mechanical refrigeration—using water evaporation through cooling towers or other adiabatic heat rejection pathways to the atmosphere. Similarly, equipment designed to Class A4 could be placed in an air-cooled data center that uses outdoor air (with appropriate filtration and humidity control) to provide 100% of the cooling and heat rejection.

While not specifically covered in this column, the *Third Edition* also provided industry data on ITE failure rates as a function of ITE inlet temperature. This could

TABLE 3 Evolution of Allowable air-cooled data center environmental conditions.

CLASS	*FIRST EDITION* 2004	*SECOND EDITION* 2008	*THIRD EDITION*[a] 2012	*FOURTH EDITION* 2015	*FIFTH EDITION* 2021
1/A1[a] Temperature (Allowable)	59°F to 89.6°F	59°F to 89.6°F	59°F to 89.6°F	59°F to 89.6°F	59°F to 89.6°F
1/A1 RH (Allowable)	20% to 80%	20% to 80%	20% to 80%	8% to 80%	8% to 80%
1/A1 Dew Point (Allowable)	Max of 62.6°F	Max of 62.6°F	Max of 62.6°F	10.4°F to 62.6°F	10.4°F to 62.6°F
2/A2[b] Temperature (Allowable)	50°F to 95°F	50°F to 95°F	50°F to 95°F	50°F to 95°F	50°F to 95°F
2/A2 RH (Allowable)	20% to 80%	20% to 80%	20% to 80%	8% to 80%	8% to 80%
2/A2 Dewpoint (Allowable)	Max of 69.8°F	Max of 69.8°F	Max of 69.8°F	10.4°F to 69.8°F	10.4°F to 69.8°F
A3 Temperature (Allowable)	N/A	N/A	41°F to 104°F	41°F to 104°F	41°F to 104°F
A3 RH (Allowable)	N/A	N/A	8% to 85%	8% to 85%	8% to 85%
A3 Dewpoint (Allowable)	N/A	N/A	10.4°F to 75.2°F	10.4°F to 75.2°F	10.4°F to 75.2°F
A4 Temperature (Allowable)	N/A	N/A	41°F to 113°F	41°F to 113°F	41°F to 113°F
A4 RH (Allowable)	N/A	N/A	8% to 90%	8% to 90%	8% to 90%
A4 Dewpoint (Allowable)	N/A	N/A	10.4°F to 75.2°F	10.4°F to 75.2°F	10.4°F to 75.2°F
H1 Temperature (Allowable)	N/A	N/A	N/A	N/A	41°F to 77°F
H1 RH (Allowable)	N/A	N/A	N/A	N/A	8% to 80%
H1 Dewpoint (Allowable)	N/A	N/A	N/A	N/A	10.4°F to 62.6°F

[a]Class 1 (Editions 1,2) renamed Class A1 (Editions 3,4,5)

[b]Class 2 (Editions 1,2) renamed Class A2 (Editions 3,4,5)

allow for "floating setpoint" control of the data center environment, with lower cooling energy consumption without higher ITE failure rates on an annualized basis. Appendices H and I (of the *Third*, *Fourth* or *Fifth Edition*) provide more detailed analysis and examples.

Fourth Edition Changes

The environmental envelope changes in the *Fourth Edition*[6] can be found outlined in blue in the fifth column of *Tables 2* and *3*. These changes were made after completion of ASHRAE Research Project RP-1499.

For RP-1499, ASHRAE funded the Electromagnetic Compatibility (EMC) Laboratory at the Missouri University of Science and Technology from 2011 to 2014 to investigate the risk of upsets or damage to electronics related to electrostatic discharge (ESD). Emphasis was placed on the increase in risk with reduced humidity. The results from this study showed that a data center with a low incident rate of ESD-induced damage operating at 25% RH will maintain a low incident rate if the relative humidity is reduced to 8%.[7] As a result of this research, the recommended humidity range was expanded as shown in *Table 2*, and the allowable humidity range for Classes A1 and A2 was expanded, as noted in *Table 3*.

Fifth Edition Changes

The environmental envelope changes in the *Fifth Edition*[3] can be found in bold in the sixth column of *Table 2*. These changes were made after completion of ASHRAE Research project RP-1755.

For RP-1755, ASHRAE funded the Syracuse University Mechanical and Aerospace Engineering Department from 2015 to 2018 to investigate the risk of operating at higher levels of moisture when high levels of gaseous pollutants exist.[8] The objective was to evaluate the impact of increasing the recommended moisture level in support of reducing energy required by data centers. Five gaseous pollutants were tested under a variety of temperature and RH conditions—three pollutants that are pervasive throughout the planet (SO_2, NO_2 and O_3) and two catalyst pollutants (H_2S and Cl_2). Pollutant levels tested were at or near the maximum common concentration levels existing around the world. The following changes were made to the recommended envelope based on this research study:

- For data center environments, tested with silver and copper coupons, shown to have corrosion levels *less than* ***300 Å/month*** *for copper and* ***200 Å/month*** *for silver, suggesting that only the pervasive pollutants (SO_2, NO_2, and O_3)* may be present, the recommended moisture limit is raised from 60% to 70% RH. The upper moisture limit will now be 70% RH or 59°F (15°C) dew point, whichever is the minimum moisture content. These changes are reflected in the environmental envelopes for Low Levels of Gaseous Pollutants.
- For data center environments, tested with silver and copper coupons, shown to have levels of corrosion *greater than* ***300 Å/month*** *for copper or* ***200 Å/month*** *for silver, suggesting that Cl_2 and/or H_2S (or other corrosive catalysts)* may be present, then the recommended moisture levels should be kept below 50% RH. The upper moisture limit is 50% RH or 59°F (15°C) dew point, whichever is the minimum moisture content. Chemical filtration should be considered. These changes are reflected in the environmental envelopes for High Levels of Gaseous Pollutants.

In addition, a new high-density environmental class was added to the *Fifth Edition*: H1. Both the recommended (*Table 2*) and the allowable (*Table 3*) temperature ranges for Class H1 are more restrictive than for Class A1. For Class H1, the recommended temperature range is 64.4°F to 71.6°F (18°C to 22°C), and the allowable range is 41°F to 77°F (5°C to 25°C). The recommended humidity range for Class H1 is the same as for Classes A1 to A4, as shown in *Table 2*.

Closing Comments

ASHRAE's *Thermal Guidelines for Data Processing Environments* has been a dynamic document serving the data center community (facility designers, operators and IT manufacturers) for the past 18 years. The recommended and allowable operating environments have been adjusted several times in response to the needs of society at large for increased energy efficiency, the needs of the IT manufacturers to produce equipment meeting the necessities of the IT community and research carried out by ASHRAE.

This is the first of several columns on the *Thermal Guidelines for Data Processing Environments* publications. The next column will focus on the most recent changes to the guideline, the *Fifth Edition*, published in 2021. Reference to the full guideline (*Thermal Guidelines for Data Processing Environments (Fifth Edition)*, available from the ASHRAE Bookstore) is recommended to provide significantly more instruction, guidance and context.

References

1. ASHRAE. 2004. *Thermal Guidelines for Data Processing Environments (First Edition)*. Atlanta: ASHRAE.
2. Schmidt, R.R., C. Belady, A. Classen, T. Davidson, et al. 2004. "Evolution of data center environmental guidelines." *ASHRAE Transactions* 110(1).
3. ASHRAE. 2021. *Thermal Guidelines for Data Processing Environments (Fifth Edition)*. Peachtree Corners: ASHRAE.
4. ASHRAE. 2008. *Thermal Guidelines for Data Processing Environments (Second Edition)*. Atlanta: ASHRAE.
5. ASHRAE. 2012. *Thermal Guidelines for Data Processing Environments (Third Edition)*. Atlanta: ASHRAE.
6. ASHRAE. 2015. *Thermal Guidelines for Data Processing Environments (Fourth Edition)*. Atlanta: ASHRAE.
7. Wan, F., D. Swenson, M. Hillstrom, D. Pommerenke, C. Stayer. 2014. "The effect of humidity on static electricity induced reliability issues of ICT equipment in data center—motivation and setup of the study." *ASHRAE Transactions* 119(2).
8. Zhang, J., R. Zhang, R. Schmidt, J. Gilbert, B. Guo. 2019. "Impact of Gaseous Contamination and High Humidity on the Reliable Operation of Information Technology Equipment in Data Centers." ASHRAE Research Project RP-1755, Final Report. ■