Data Center Environments
ASHRAE’s Evolving Thermal Guidelines

By Robin A. Steinbrecher, Member ASHRAE; and Roger Schmidt, Ph.D., Member ASHRAE

Over the last decade, data centers housing large numbers of servers have become significant power consumers. Manufacturers of information technology equipment (ITE) continue to increase compute capability while at the same time improving compute efficiency. On the support side, various parties including ITE manufacturers, physical infrastructure manufacturers, data center designers and operators have focused on reducing power consumption from the non-compute part of the overall power load, which is the power and cooling infrastructure that supports the ITE.

ASHRAE Technical Committee 9.9, Mission Critical Facilities, Technology Spaces and Electronic Equipment, brings together the disparate interests in the data center industry in the area of data center cooling technologies. Thermal Guidelines for Data Processing Environments helped create a framework to enable the industry to speak a common language and better understand the implications of ITE cooling requirements on the data center and vice versa. Since ASHRAE first issued the Thermal Guidelines in 2004 and updated them in 2008, data center efficiency improvements have become an even higher priority.

The original Thermal Guidelines were written by representatives from the ITE manufacturers who understood the limits of the components in the ITE. The objective at the time was to create a common set of environmental parameters that would ensure adequate reliability and performance within reasonable cost constraints.

To address the growing concerns about energy efficiency, particularly the cooling component, TC 9.9 has been evolving the Thermal Guidelines toward wider temperature and humidity ranges.

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Case studies in recent years have demonstrated significant savings in cooling plant energy when the data center is allowed to operate with economizers and a wider environmental envelope. The 2011 Thermal Guidelines enable these practices to transition from niche to mainstream in mixed-manufacturer data centers.

Data center infrastructure energy efficiency is quantified using power usage effectiveness (PUE) as defined in the following equation:

\[
PUE = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}}
\]

The stringency of the ITE’s environmental operating parameters drives the facility power consumption. To enable improved PUEs and overall operational efficiency, ASHRAE TC 9.9 has added two new ITE environmental classes that are more compatible with chiller-less cooling to its Thermal Guidelines, which also provide detailed guidance on how to specify an optimum environmental range for a given data center. And for the first time, TC 9.9 has created liquid-cooling environmental classes along with usage guidance, primarily to support high density data centers.

Air Cooling Thermal Guidelines
The environmental classes and their associated limits define the boundaries in which ITE is designed to operate. The original Thermal Guidelines were created to clearly state the environmental ranges, create commonality among the ITE manufacturers and define a metrology within the data center to ensure that the data center's cooling system was delivering properly conditioned air to the inlets of the ITE. Data center cooling could then be designed appropriately to ensure that ITE would be adequately cooled.

The original 2004 Thermal Guidelines defined allowable and recommended temperature ranges. Compliant ITE was designed to fully function within the allowable range, while the data center had to be capable of always meeting these parameters. Operating outside the allowable range could result in unsupported operation of the ITE, possibly leading to data errors, reduced performance, shutdown, and permanent damage to the equipment.

The recommended range defined the envelope in which ITE would have the highest reliability. Excursions outside the recommended range were acceptable, but little information was provided on what high reliability meant or how overall data center energy consumption could be optimized. In 2008 the recommended range for temperature and humidity were expanded, enabling reduced mechanical cooling and increased economizer hours.

Since 2008, innovators in data center infrastructure have created many cooling technologies that compete to successfully address the needs of data centers. The industry now recognizes that outside air can be used with economizers to vastly decrease mechanical cooling in data center implementations, that there is room to expand the application of economizers, and that there are caveats and implications associated with using outside air to cool ITE.

To address these topics, TC 9.9 has issued a white paper, “2011 Thermal Guidelines for Data Processing Environments—Expanded Data Center Classes and Usage Guidance.” This paper defines two new environmental classes and provides guidance to data center operators on how to move their normal operating environmental range outside the recommended envelope and closer to the allowable extremes.

Environmental Classes
Table 1 describes the class definitions, including the previous 2008 class names. The names were changed to more easily identify those classes pertaining to data centers, the 'A' classes. Compliance with a particular environmental class requires full operation of the equipment over the entire allowable environmental range based on non-failure conditions.

Figure 1 shows the previously existing data center classes now named A1 and A2 and the two new data center classes, A3 and A4, along with the recommended range for all the classes. (Table 2 summarizes the same limits.)

Most locations around the world will be able to support class A3 or A4 ranges nearly year-round using free-cooling techniques. New data centers may go chiller-less, thereby re-

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**Table 1: 2008 and 2011 ASHRAE environmental class definitions.**

<table>
<thead>
<tr>
<th>2008 Classes</th>
<th>2011 Classes</th>
<th>Applications</th>
<th>Information Technology Equipment</th>
<th>Environmental Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1</td>
<td>Data Center</td>
<td>Enterprise Servers, Storage Products</td>
<td>Tightly Controlled</td>
</tr>
<tr>
<td>2</td>
<td>A2</td>
<td></td>
<td>Volume Servers, Storage Products, Personal Computers, Workstations</td>
<td>Some Control</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td></td>
<td></td>
<td>Free Cooling Techniques When Allowable</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td></td>
<td></td>
<td>Some Control Near Full-Time Usage Of Free-Cooling Techniques</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>Office, Home, Transportable Environment, etc.</td>
<td>Personal Computers, Workstations, Laptops, and Printers</td>
<td>Minimal Control</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>Point-of-Sale, Industrial, Factory, etc.</td>
<td>Point-of-Sale Equipment, Ruggedized Controllers, or Computers and PDAs</td>
<td>No Control</td>
</tr>
</tbody>
</table>
ducing capital expenditure, while others may have chillers installed to ensure year-round availability. The additional classes accommodate different applications and priorities of ITE operation. Each data center must be optimized based upon the owner’s or operator’s own criteria. Although there are great potential efficiency benefits associated with classes A3 and A4, one must weigh the benefits versus the detriments.

**Setting the Operational Envelope**

The intent of the recommended range is to define the range where the most reliable and power-efficient operation of the ITE can be achieved based upon ITE manufacturers’ input. The recommended range was never intended to define the absolute limits of inlet air temperature and humidity for ITE. To clarify, the recommended range should be viewed as the starting point for the operational envelope when no evaluation has been performed to understand the optimal limits for the specific data center of interest. The upcoming third edition of Thermal Guidelines and the white paper provide guidance for performing this evaluation for different types of data centers: existing, retrofit and new construction.

Operation outside of the recommended range requires a balance between the cooling system energy savings and the various deleterious effects shown in Figure 2. The evaluation to determine which class is optimal for any individual data center should include each of the following factors:

**Reliability.** Long-term reliability of ITE components will degrade with higher temperature. Using economizer techniques will not necessarily cause reduced reliability. The white paper describes how to evaluate long-term reliability using time and temperature weighting factors.

**ITE Power.** The major goal of widening the allowable ranges is to reduce overall data center power. As inlet temperature rises, ITE fans typically speed up to keep components within their temperature limits. This increase depends upon how close the components are to their limits. Light workloads will cause minimal fan speed increase while heavy workloads cause more substantial increases. Fan power increases non-linearly with speed. Although some opportunity exists for ITE manufacturers to reduce or eliminate the need for higher fan airflows with increased inlet temperatures, it comes at the expense of modifying the ITE form factors, which will increase ITE first costs and space requirements. Also, as the temperature goes up, some silicon devices will consume more power.

<table>
<thead>
<tr>
<th>Range</th>
<th>Class</th>
<th>Dry-Bulb Temperature</th>
<th>Humidity Range, Non-Condensing</th>
<th>Maximum Dew Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended</td>
<td>All A</td>
<td>64.4°F to 80.6°F</td>
<td>41.9°F DP to 60% RH and 59°F DP</td>
<td>59°F</td>
</tr>
<tr>
<td>Allowable</td>
<td>A1</td>
<td>59°F to 89.6°F</td>
<td>20% to 80% RH</td>
<td>62.6°F</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>50°F to 95°F</td>
<td>20% to 80% RH</td>
<td>69.8°F</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>41°F to 104°F</td>
<td>10.4°F DP and 8% RH to 85% RH</td>
<td>75.2°F</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td>41°F to 113°F</td>
<td>10.4°F DP &amp; 8% RH to 90% RH</td>
<td>75.2°F</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>41°F to 95°F</td>
<td>8% RH to 80% RH</td>
<td>82.4°F</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>41°F to 104°F</td>
<td>8% RH to 80% RH</td>
<td>82.4°F</td>
</tr>
</tbody>
</table>

Table 2: 2011 ASHRAE environmental classes for data center applications.
due to leakage currents. The white paper shows the potential power impact of increasing the inlet temperature.

**Performance and Allowable Envelope.** Many ITE designs include power management features that engage based upon component temperatures. For a given operating temperature, some systems may perform better than others, depending upon the ITE’s power and thermal design points. A system designed to handle any potential workload compared with one that is tuned for a specific workload may be capable of better overall performance in wider environmental ranges.

**Corrosion.** Expanding the high end of the humidity envelope increases the opportunity for corrosion problems to occur. Moisture may exacerbate corrosion problems in data centers where corrosive gases are present. Different locations around the world have different ambient levels of potentially corrosive pollutants, and the designer must be cognizant of these pollution levels on a site-specific basis. Even when ambient levels are known to be low, the potential still exists for short-term transient conditions of potentially corrosive pollutants of which the designer must be aware.

**Acoustical Noise and Airflow.** As mentioned previously, higher inlet temperatures will cause ITE air movers to operate at higher speeds. This causes substantial increases in acoustic output. Measures to protect personnel hearing in compliance with government regulations must be taken into account.

**Cost.** To support higher inlet temperatures, more costly thermal solutions may be required. Larger, more expensive heat sinks may be required to maintain acceptable levels of compute performance, temperature rises, and ITE power consumption.

**Electrostatic discharge (ESD).** Due to the lower allowable humidity ranges in classes A3 and A4, there may be increased probability of ESD events. ITE manufacturers design their equipment based upon international standards to prevent ESD problems. Good ESD practices in the data center can eliminate most concerns.

**Liquid Cooling Thermal Guidelines**

Liquid Cooling Guidelines for Datacom Equipment Centers by TC 9.9 was published in 2006, focusing mostly on the design options for liquid-cooled equipment. This book did not address the various facility water temperature ranges possible for supporting liquid-cooled equipment. TC 9.9 recently posted the white paper “2011 Thermal Guidelines for Liquid Cooled Data Processing Environments” to describe classes for the temperature ranges of facility water supplied to liquid-cooled ITE. In addition, this document reinforces some of the information provided in Liquid Cooling
Guidelines on the interface requirements between the ITE and infrastructure in support of the liquid cooled ITE.

With the focus areas of performance, energy efficiency and use of the waste energy, several ranges of facility supply water temperatures have been specified to accommodate the business and technical requirements of the data center operator. Since the classes cover a wide range of facility water temperatures supplied to the ITE, a brief description is provided for the possible infrastructure equipment that could be deployed between the liquid-cooled ITE and the outside environment.

By creating these new facility water cooling classes and not mandating the use of any one of these classes, server manufacturers can develop products for the classes depending on the customer needs and requirements for products within each class.

**ITE Liquid Cooling**

The increasing heat density of modern electronics is stretching the ability of air to adequately cool the electronic components within servers, as well as the datacom facilities that house these servers. To meet this challenge, the use of direct water or refrigerant cooling at the rack or server level is being deployed. The ability of water and refrigerant to carry larger amounts of heat per unit volume or mass also offers tremendous advantages. Because of the operating temperatures involved with liquid cooling solutions, water-side economizers fit in well.

In the past, high-performance mainframes were often water-cooled with the internal piping supplied by the ITE manufacturer. Components are becoming available today that have similar factory-installed and leak-tested piping that can accept the water from the facility mechanical cooling system, which may also employ a water-side economizer. Increased standardization of ITE liquid-cooled piping connection methods could also help expand the use of liquid cooling.

Several implementations of liquid cooling could be deployed, such as the coolant removing a large percentage of the waste heat via a rear door heat exchanger, or a heat exchanger located above or on the side of a rack.
Figures 3a and 3b show the defined interface for a liquid-cooled rack with remote heat rejection. The interface is located at the boundary of the facility water system loop and does not impact the datacom equipment cooling system loops, which will be controlled and managed by the ITE manufacturers. However, the definition of the interface at the loop affects both the ITE manufacturers and the facility operator. As an option, Figure 3a could be extended so that a larger building-level CDU is deployed, thereby eliminating modular CDUs.

**Facility Water Supply Characteristics for ITE**

The facility water supplied to the ITE is anticipated to support any liquid cooled ITE using water, water plus additives, refrigerants, or dielectrics. Compliance with a particular environmental class requires full operation of the equipment within the class specified based on non-failure conditions. Different ITE designs from the same class may still have different design points for the cooling components (cold plates, thermal interface materials, liquid flow rates, piping sizes, etc.). For ITE designs that meet the higher supply temperatures as referenced by the ASHRAE classes in Table 3, enhanced thermal designs will be required to maintain the liquid cooled components within the desired temperature limits. Generally, the higher the supply water temperature, the higher the cost of the ITE cooling solutions.

**Classes W1/W2.** Typically, a data center that is cooled using chillers and a cooling tower, but, depending on the data center location, uses an optional water-side economizer to improve energy efficiency (Figure 4a).

**Class W3.** For most locations, these data centers may be operated without chillers. Some locations will still require chillers (Figure 4a).

**Class W4.** To take advantage of energy efficiency and reduce capital expense, these data centers are operated without chillers (Figure 4b).

**Class W5.** To take advantage of energy efficiency, reduce capital expense with chiller-less operation and also make use of the waste energy, the water temperature is high enough to make use of the water exiting the ITE for heating local buildings during the heating season and also potentially using technologies such as adsorption chillers for space cooling during the cooling season (Figure 4c).

ASHRAE Classes W1 - W3 were developed in concert with the Energy Efficient High Performance Computing Working Group, which is part of Lawrence Berkeley National Laboratory. Currently, no ITE is available in liquid cooling classes W3-W5. Product availability in these ranges in the future will be based upon market demand. It is anticipated that future designs in these classes may involve trade-offs between IT cost and performance. At the same time these classes would allow lower cost data center infrastructure in some locations. The choice of the IT liquid-cooling class should involve a total cost of ownership evaluation of the combined infrastructure and IT capital and operational costs.

To avoid condensation, the ITE shown in Figures 4a and 4b would include a CDU if facility water temperature has the potential to fall below the facility dew point.
Operational Characteristics

For Classes W1 and W2 the actual chilled water loop temperature may be set by a campus-wide operational requirement. It may also be the optimum of a balance between lower operational cost using higher temperature chilled water systems versus a lower capital cost with low temperature chilled water systems.

For Classes W3, W4, and W5, the infrastructure will likely be specific to the data center and, therefore, the water temperature supplied to the water-cooled ITE will depend on the climate zone in which the data center is located. In these classes running without an installed chiller may be required, so it becomes critical to understand the limits of the water-cooled ITE and its integration with the infrastructure designed to support the ITE. This is important so that those extremes in temperature and humidity allow for uninterrupted operation of the data center and the liquid-cooled equipment.

For Class W5, the infrastructure will be such that the waste heat from the warm water can be redirected to nearby buildings. Accommodating water temperatures nearer the upper end of the temperature range will be more critical to those applications where retrieving a large amount of waste energy is critical. The water supply temperatures for this class are specified as greater than 113°F (45°C) since the water temperature may be depend on many parameters such as the climate zone, building heating requirements, distance between data center and adjacent buildings, etc. Of course, the electronic components within the IT server need to be cooled to their temperature limits and still use the hotter water as the sink temperature. In many cases, the hotter water temperature will be a challenge to the ITE thermal designer.

Summary

The thermal design of ITE involves a delicate balance of ITE compute performance, ITE reliability, ITE cost, as well as ITE power consumption. In addition, the facility design must optimize overall power consumption between ITE and HVAC in the data center. Understanding the trade-offs between these objectives is critical to making energy savings decisions.

With increased emphasis on data center energy optimization, TC 9.9 has responded by creating expanded ITE air-cooling environmental classes and defining liquid-cooling environmental classes. Along with these new classes, they have provided information necessary to make the critical trade-off decisions between ITE compute performance, ITE reliability, ITE cost, ITE power consumption, and HVAC power consumption. The two 2011 Thermal Guidelines white papers provide information that will enable more data center operators to achieve significant cooling plant energy savings and lower PUEs.

References