The ASHRAE Thermal Guidelines for Data Centers
Past, Present, and Future

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April 16, 2025

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Learning Objectives

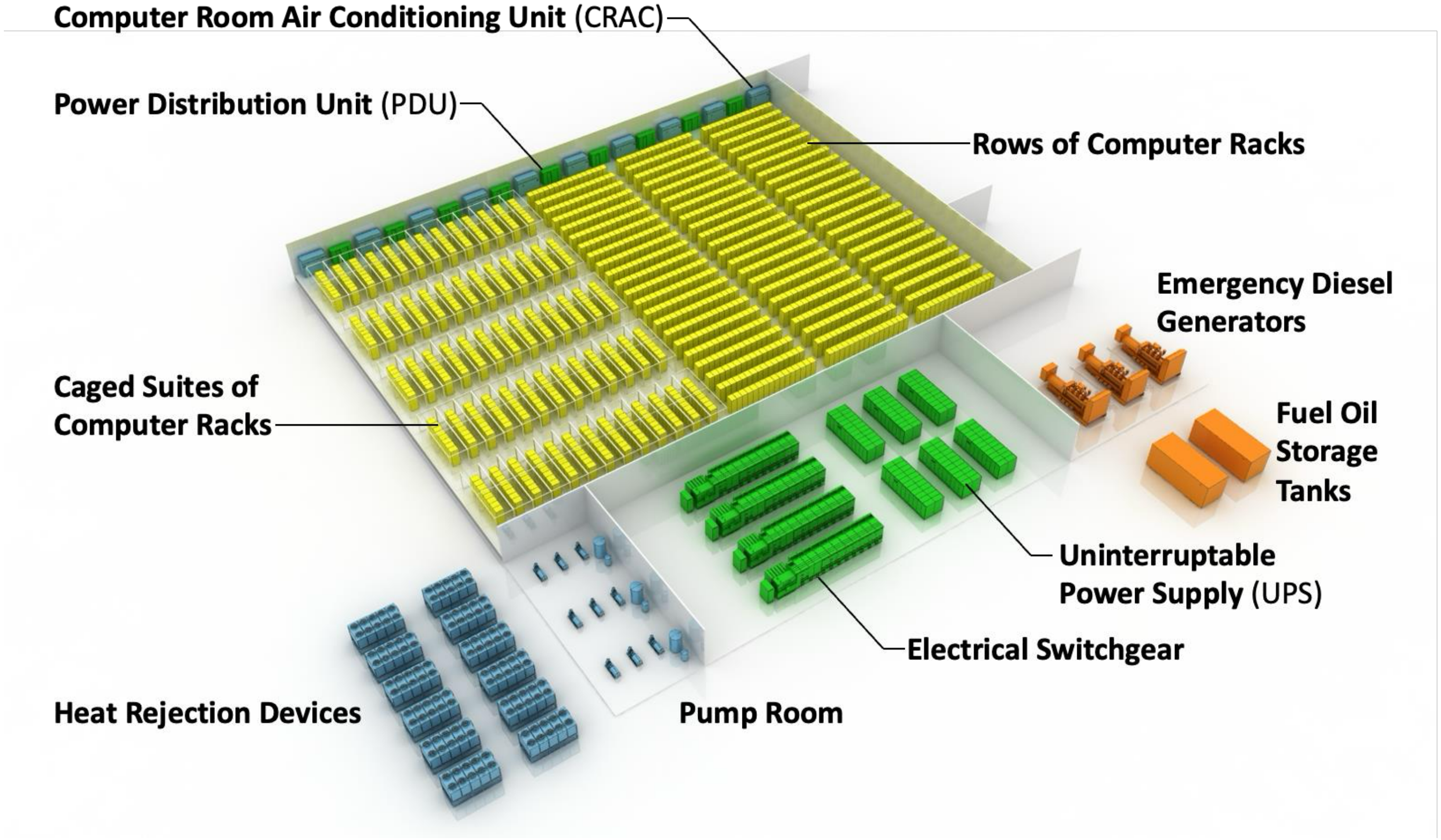
1. Understand how the ASHARE Thermal Guidelines for Data Processing environments have evolved over time and their significance to the data center industry.

2. Describe the changes to the recommended envelope as a result of ASHRAE research into the impact of low and high humidity.

3. Understand high density trends of IT equipment, the addition of a new high density air-cooled environmental envelope, and its impact of data center efficiency.

4. Understand the ASHRAE liquid cooling classes and why a dedicated set of classes for the Technology Cooling Systems (TCS) was needed to support the data center industry.

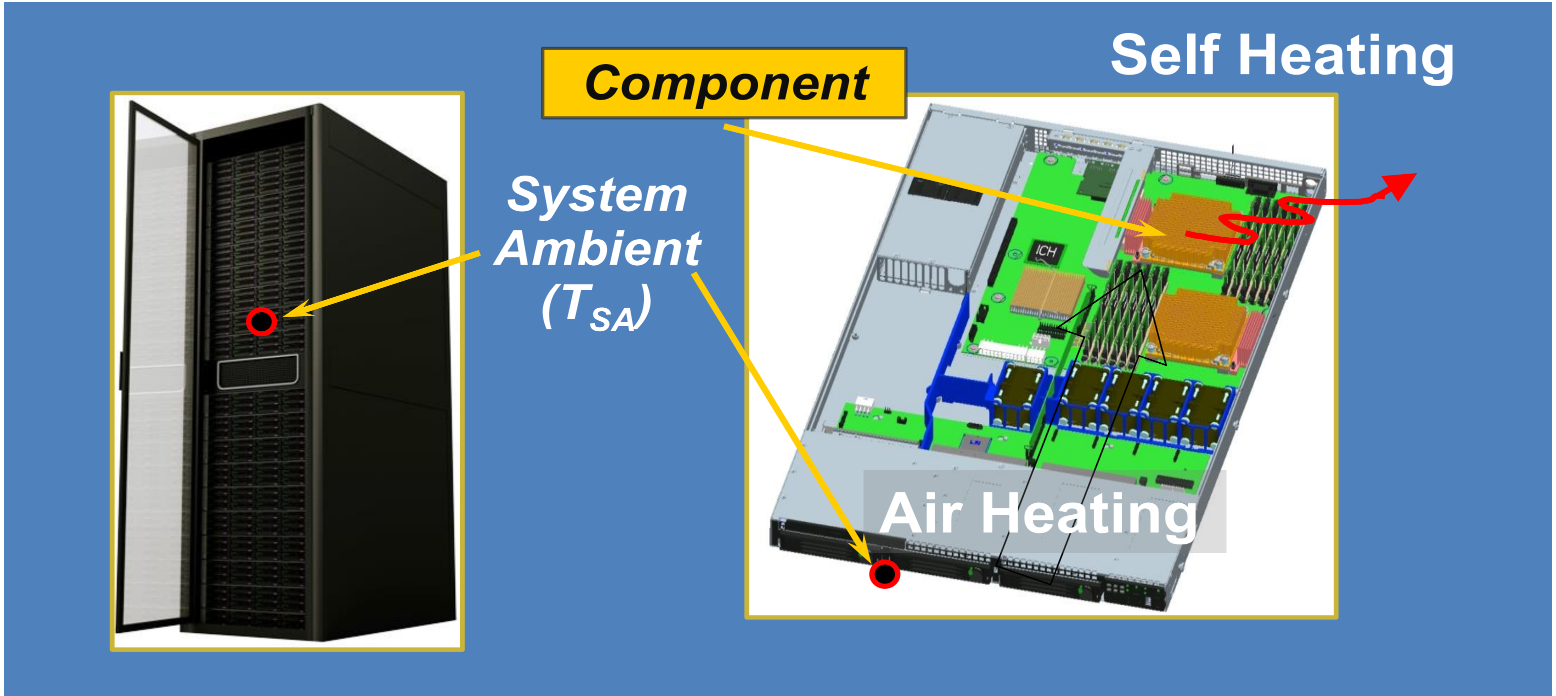
The Generic Data Center



The Occupants of the Data Center

The Information Technology Equipment (ITE) hardware and software are the occupants of the data center and must be maintained with acceptable environmental limits to guarantee performance, reliability, and energy efficiency.

Influence of Environment on Component Temperatures



Self Heating

Component

System Ambient (T_{SA})

Air Heating

$T_{Component}$ = Self Heating + Air Heating + System Ambient

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Objective of the Thermal Guidelines

- 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
- Provide a basis for measuring the effect of any changes intended to save energy in the data center

A Brief History of the ASHRAE Thermal Guidelines for Datacom Equipment

No temperature and humidity standards prior to the first ASHRAE Thermal Guidelines Book (2004).

- Common temperatures were 18°C–20°C (64°F–68°F).

ASHRAE’s Thermal Guidelines

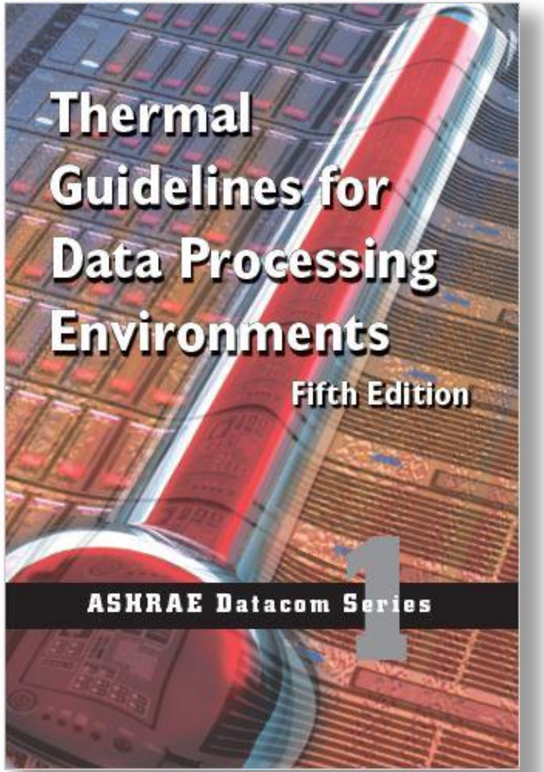
- Recommended 18°C (64.4°F) up to 27°C (80.6°F)
- Allowable temperatures even higher.

4th Edition Update

- Lower recommended relative humidity.

5th Edition Update

- Higher recommended relative humidity based on corrosive gas monitoring.



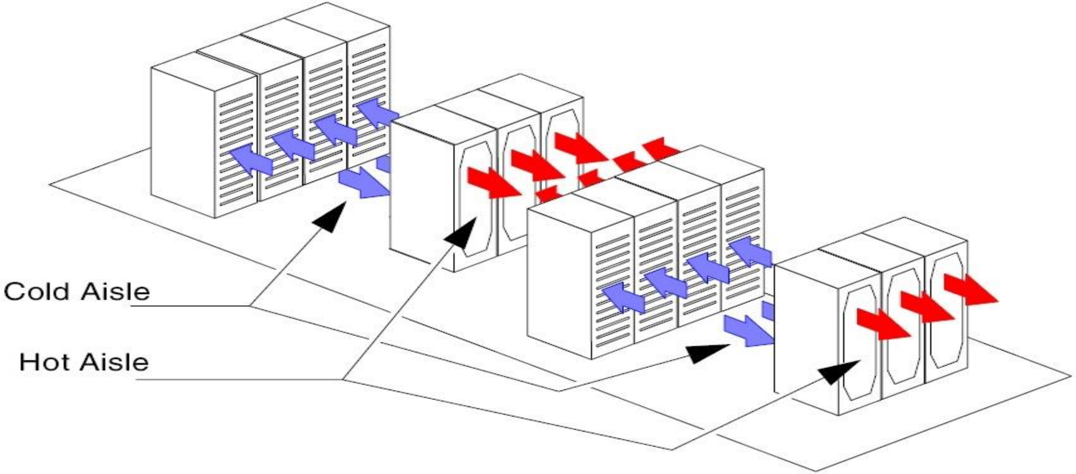
IT Equipment Environmental Measurements

AIR INLET to datacom equipment IS the important specification to meet.

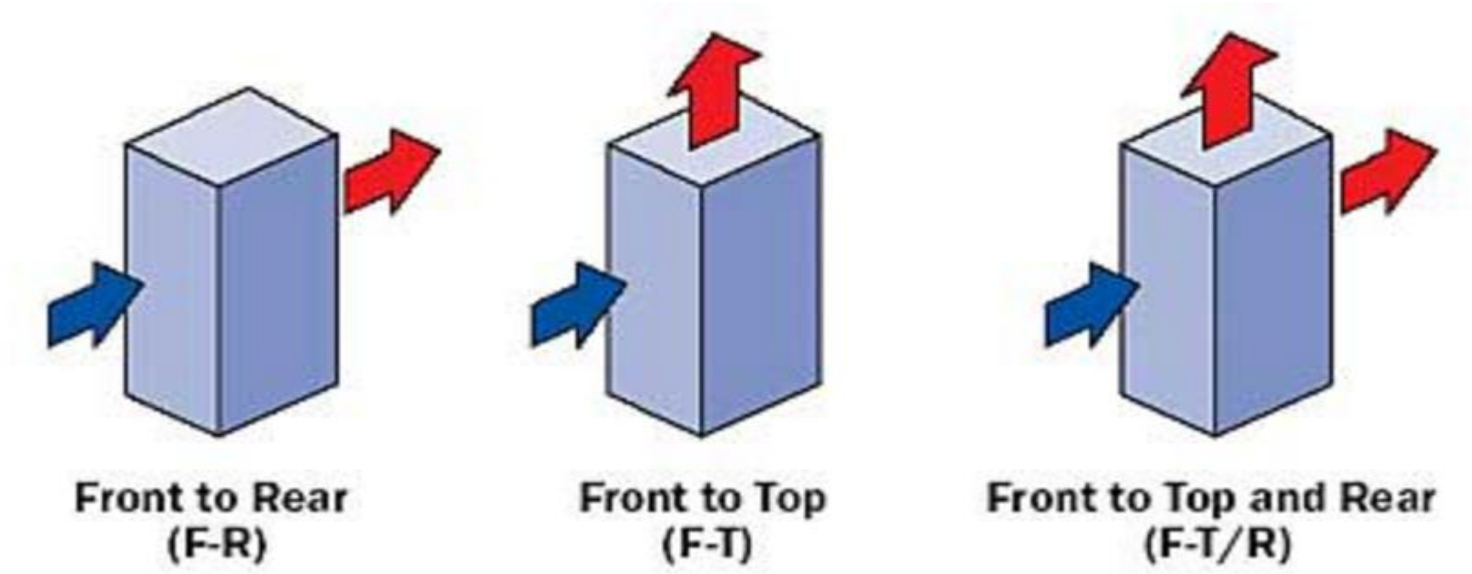
OUTLET temperature is NOT of concern to the datacom equipment (but is limited by safety and other concerns).

Four Key Environmental Requirements

- Inlet Air Temperature
- Inlet Humidity
- Inlet Particulate Contamination
- Inlet Gaseous Contamination



Acceptable Airflow Directions



ASHRAE Thermal Guidelines Definitions

Recommended

- The recommended envelope gives ***guidance*** to data center operators on maintaining ***high reliability*** and also operating their data centers in the ***most energy-efficient manner***.

Allowable

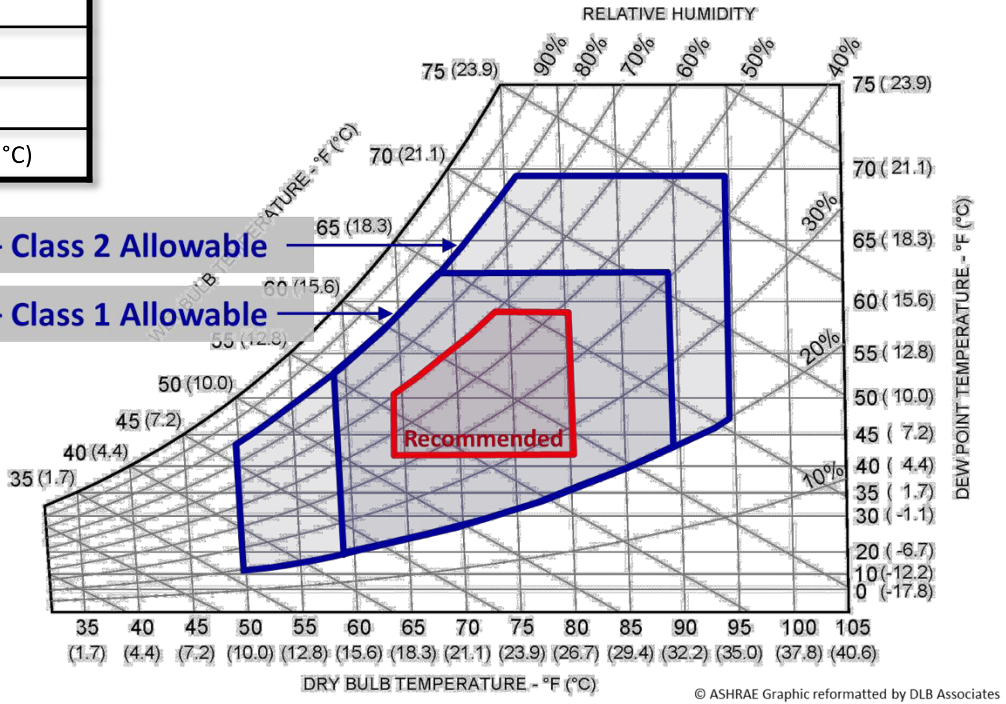
- The allowable envelope is where the IT manufacturers test their equipment in order to verify that the equipment will ***function*** within those environmental boundaries. Peak performance at upper extreme may not be guaranteed

Practical Application

- Optimal range for a given data center based on operational goals including performance, power efficiency, computing efficiency, etc.
- Operating outside of the recommended range for extended periods ***may*** impact equipment reliability

Thermal Guidelines 1st (2004) and 2nd Editions (2008)

Recommended Envelopes		
Criteria	**2004**	**2008**
Low End Temp.	**68°F** (20°C)	**64.4°F** (18°C)
High End Temp.	**77°F** (25°C)	**80.6°F** (27°C)
Low End Moisture	**40% RH**	**41.9°F DP** (5.5°C)
High End Moisture	**55% RH**	**60% RH & 59°F DP** (15°C)



ASHRAE 2004/2008 – Class 2 Allowable

ASHRAE 2004/2008 – Class 1 Allowable

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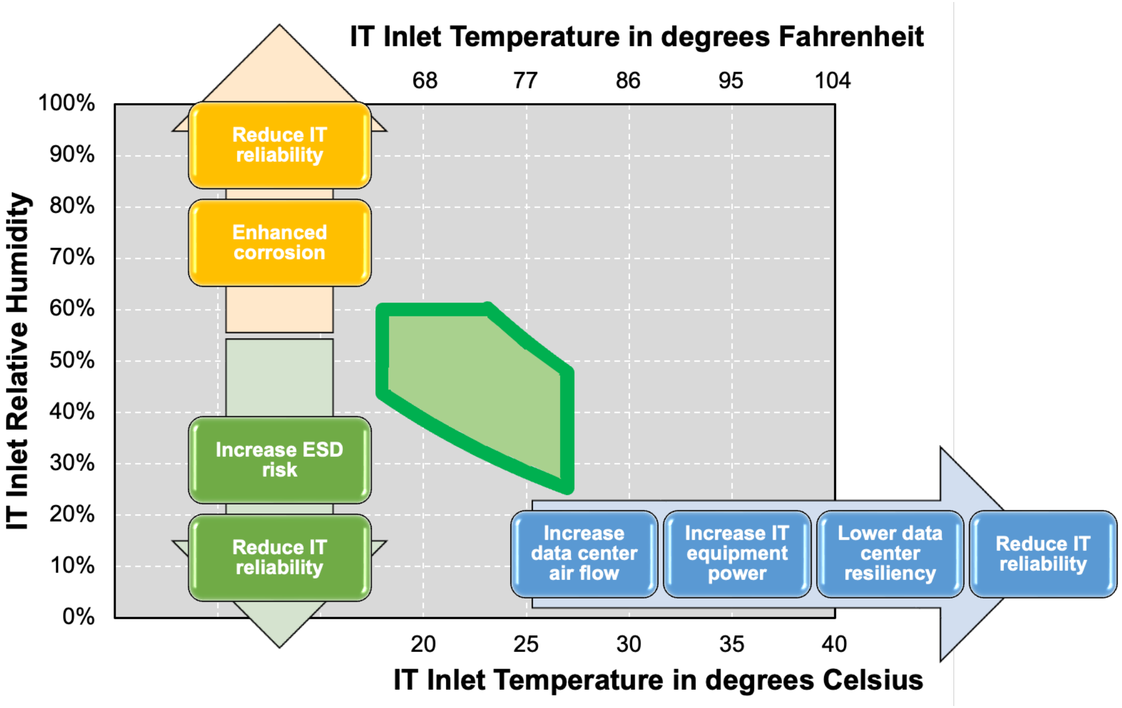
Note: Refer to the ASHRAE Thermal Guidelines for Data Processing Environments for important footnotes associated with the guidelines

How Can We Improve Energy Efficiency?

As the data center industry pursued energy efficiency and lower Power Usage Effectiveness (PUE) the obvious question became "How do we continue to expand the environmental envelopes to enable economization and the elimination of mechanical (refrigeration) systems?"



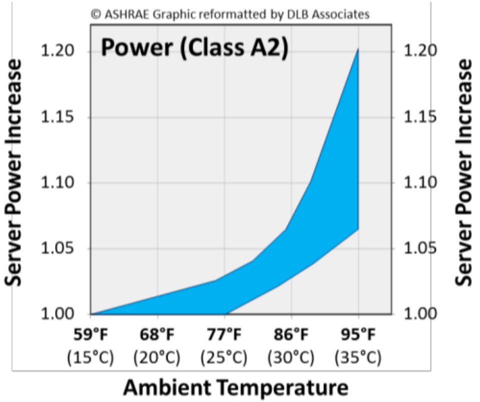
Impact of Higher Temperatures

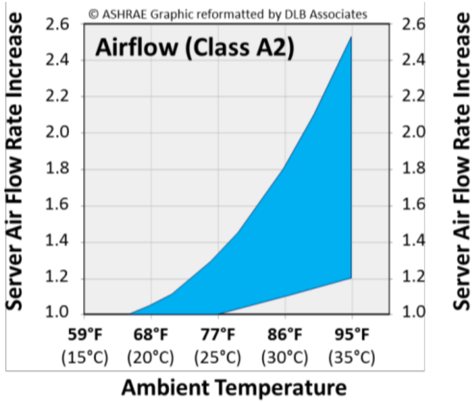
Temperature can impact electronic component reliability

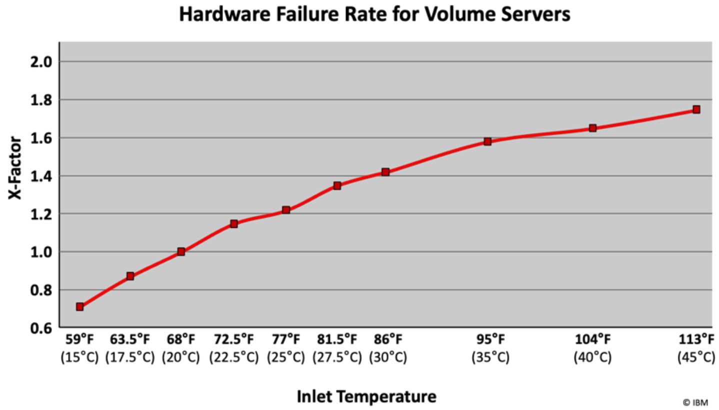
ITE typically responds to higher temperature by increasing cooling

- Result: fan failure rate increases but not necessarily the rest of the ITE – up to a point

ITE manufacturers characterize reliability vs. temperature and can predict field failure rates for ITE



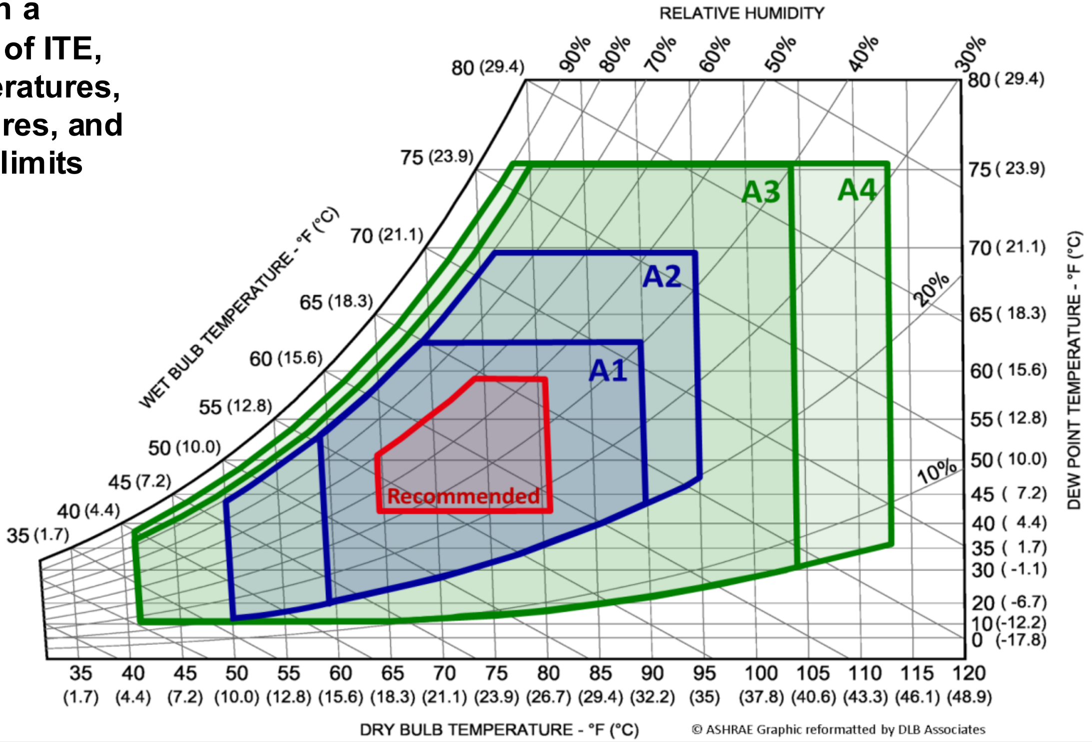




Thermal Guidelines 3rd Edition

Motivation: Increased free-cooling hours

The recommended envelope was chosen based on a number of inputs, the primary being the reliability of ITE, power increases of ITE with higher ambient temperatures, acoustical impacts with higher ambient temperatures, and providing a buffer for excursions to the allowable limits caused by facility cooling fails.



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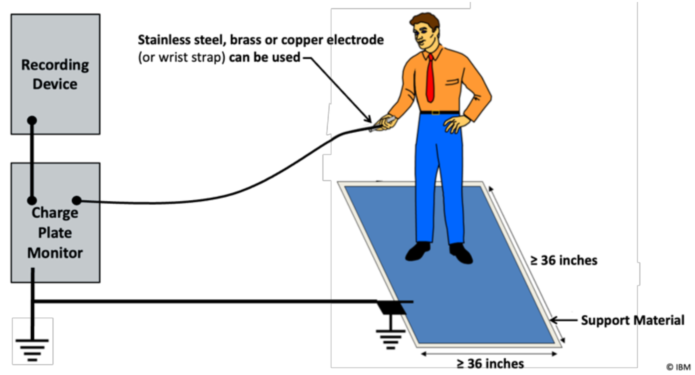
Note: Refer to the ASHRAE Thermal Guidelines for Data Processing Environments for important footnotes associated with the guidelines

Can We Eliminate Humidification?

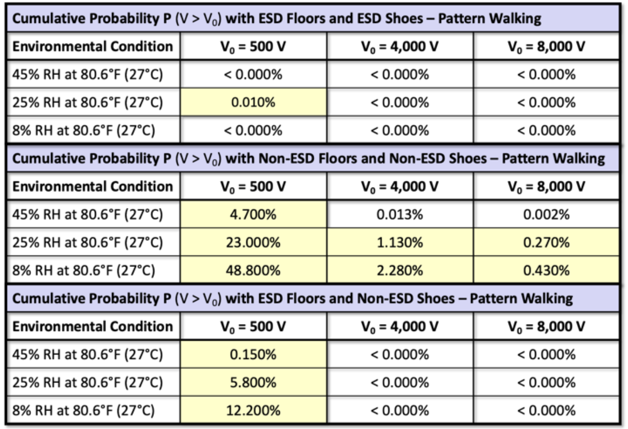
TC 9.9 research (RP-1499) concluded that low humidity has less impact on hardware reliability than originally thought

The research showed that there is a significant reduction of electrostatic charge accumulation on personnel if ESD control shoes are worn, regardless of the flooring, and there is significant benefit in charge accumulation reduction if a good conductive floor is installed, regardless of footwear.

The best overall results are with a combination of a low resistance range (conductive) flooring and ESD control footwear (shoe grounding straps or low range dissipative shoes), and highly recommended for use of the 2015 / 2021 thermal guidelines.



ANSI / ESD STM 97.2 Test Procedure
The induced voltage on the body of a person is measured and recorded while he is walking.



Cumulative Probability P (V > V_0) with ESD Floors and ESD Shoes – Pattern Walking			
Environmental Condition	V_0 = 500 V	V_0 = 4,000 V	V_0 = 8,000 V
45% RH at 80.6°F (27°C)	< 0.000%	< 0.000%	< 0.000%
25% RH at 80.6°F (27°C)	0.010%	< 0.000%	< 0.000%
8% RH at 80.6°F (27°C)	< 0.000%	< 0.000%	< 0.000%
Cumulative Probability P (V > V_0) with Non-ESD Floors and Non-ESD Shoes – Pattern Walking			
Environmental Condition	V_0 = 500 V	V_0 = 4,000 V	V_0 = 8,000 V
45% RH at 80.6°F (27°C)	4.700%	0.013%	0.002%
25% RH at 80.6°F (27°C)	23.000%	1.130%	0.270%
8% RH at 80.6°F (27°C)	48.800%	2.280%	0.430%
Cumulative Probability P (V > V_0) with ESD Floors and Non-ESD Shoes – Pattern Walking			
Environmental Condition	V_0 = 500 V	V_0 = 4,000 V	V_0 = 8,000 V
45% RH at 80.6°F (27°C)	0.150%	< 0.000%	< 0.000%
25% RH at 80.6°F (27°C)	5.800%	< 0.000%	< 0.000%
8% RH at 80.6°F (27°C)	12.200%	< 0.000%	< 0.000%

Thermal Guidelines 4th Edition

Lower end humidity for recommended, A1 and A2 envelopes reduced

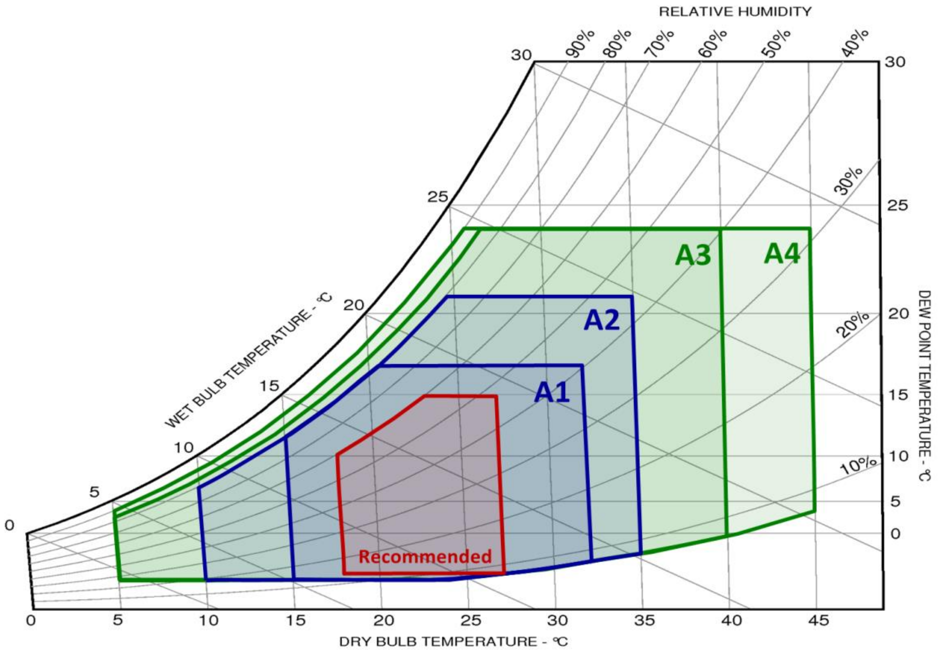
- Recommended lowered to -9°C dew point
- Allowable lowered to -12°C dew point & 8% relative humidity

Temperature rate of change for ITE updated to 20°C in an hour and no more than 5°C in any 15-minute period

Increased focus on minimum requirements for ESD mitigation in data centers

- Data centers with non-ESD floors and where people are allowed to wear non-ESD shoes may want to consider increasing humidity given that the risk of generating 8 kV increases slightly from 0.27% at 25% RH to 0.43% at 8% RH
- All mobile furnishing/equipment must be made of conductive or static dissipative materials and connected to ground
- Wrist straps must be used by personnel who contact ITE during maintenance on any hardware.

Note: Refer to the ASHRAE Thermal Guidelines for Data Processing Environments for important footnotes associated with the guidelines



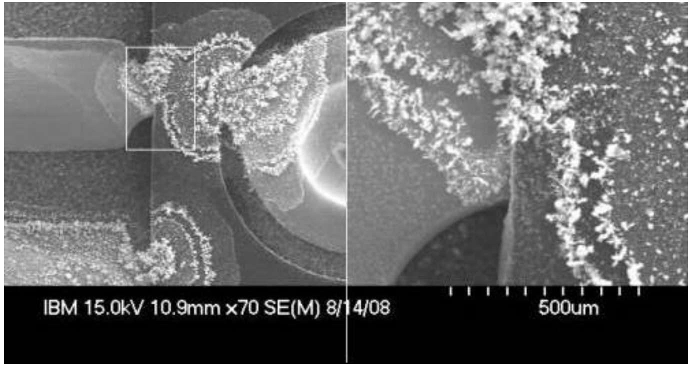
Can We Eliminate Dehumidification?

TC 9.9 research (RP-1755) concluded that high humidity in the presence of some gaseous contaminants can have a significant impact on corrosion

O_3, NO_2 and SO_2 are pervasive pollutants in a data center environment, while the presence of Cl_2 and H_2S are due to local phenomenon depending on the activities inside and surrounding a specific data centers.

Significant increase in corrosion for copper near 80% RH. The recommended RH level should not exceed 70 % at 21°C regardless of the gaseous contaminants present in the data center.

For data center environments tested and suspected to have Cl_2 and/or H_2S (or other corrosive catalysts) present, then moisture levels should be kept lower than 60% RH levels and even lower than 50% RH if possible, given the very corrosive nature of these catalysts.



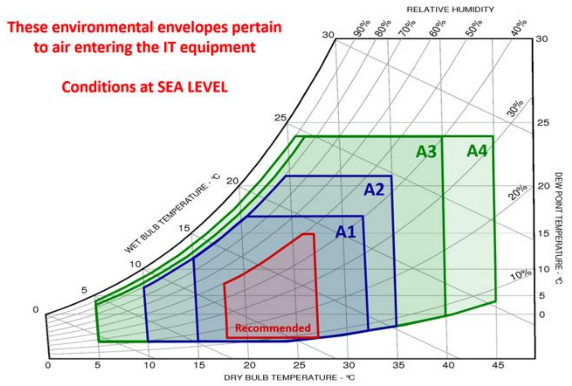
Thermal Guidelines 5th Edition

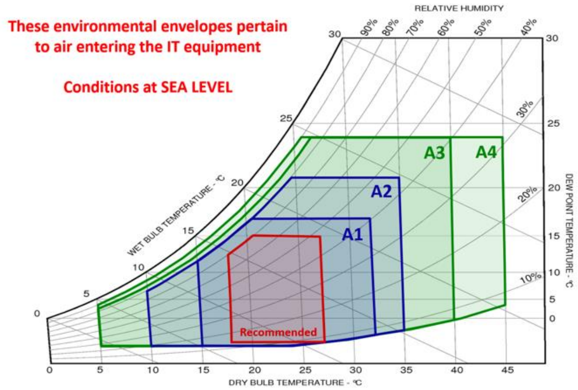
At least twice a year (once in the winter and once in the summer) data center operators should use silver and copper coupons to detect the level of corrosion

Recommended thermal envelope changes depending on the level of gaseous pollutants in the data center

- For low levels of pollutants, recommended range upper humidity increased to 70%

- For high levels of pollutants or no monitoring, recommended range upper humidity limited to 50%

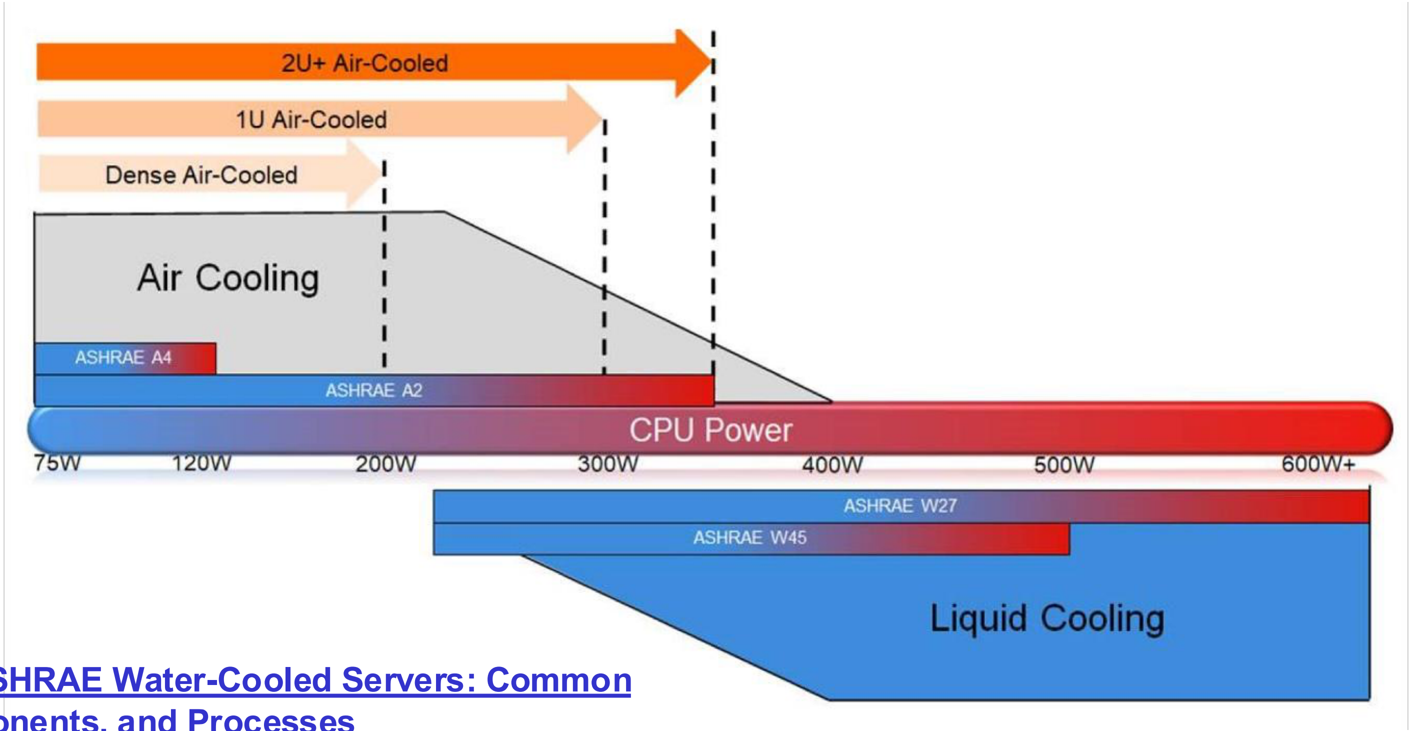




Note: Refer to the ASHRAE Thermal Guidelines for Data Processing Environments for important footnotes associated with the guidelines

Air Cooling vs. Liquid Cooling: Transitions and Temperatures

The latest generation of chips are pushing the limits on air cooling and driving the adoption of liquid cooling technologies.



Source: [2019 ASHRAE Water-Cooled Servers: Common Designs, Components, and Processes]()

High Density Products

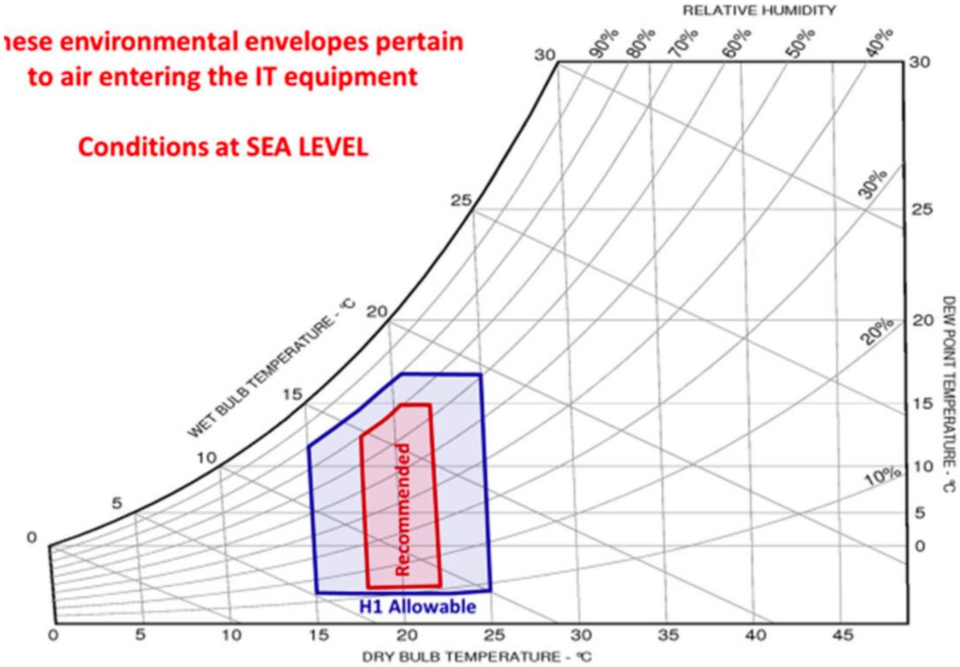
The consequence of the exponential rise in chip powers is the need to move to liquid cooling.

The alternatives to not transitioning to liquid cooling

- Lower data center air temperature (the H-class)
- Reduced compute performance
- Less space efficient servers (4U vs. 2U)
- And/or a dramatic increase in required data center air flow and a substantial increase in server fan power

High-density products that use high-powered components such as CPU, GPU, and memory require increased cooling. New H Classes defined

Note: Refer to the ASHRAE Thermal Guidelines for Data Processing Environments for important footnotes associated with the guidelines



hese environmental envelopes pertain to air entering the IT equipment

Conditions at SEA LEVEL

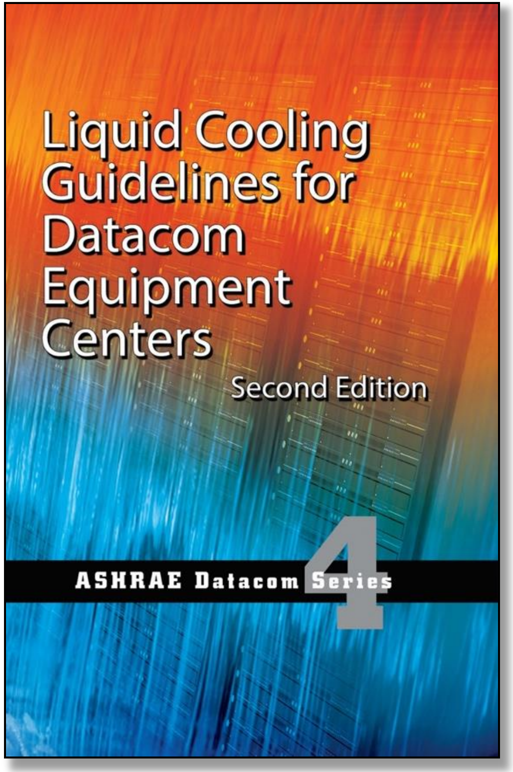
Liquid Cooling Guidelines for Datacom Equipment Centers

Air-Cooled System Definition:

- Air is supplied to the rack inlets for convection cooling of the heat rejected (from ITE components).
- The rack transport heat from the actual source component (e.g., processor) can be either liquid or air based.
- The rack heat rejection media to the terminal cooling device outside of the rack is air.

Liquid Cooled System Definition:

- Liquid (e.g., water, usually above the dew point) is channeled to the actual heat-producing ITE components.
- Liquid transports heat from those components and rejected via a heat exchanger (air-to-liquid or liquid-to-liquid) or extended to the terminal cooling device outside of the rack.



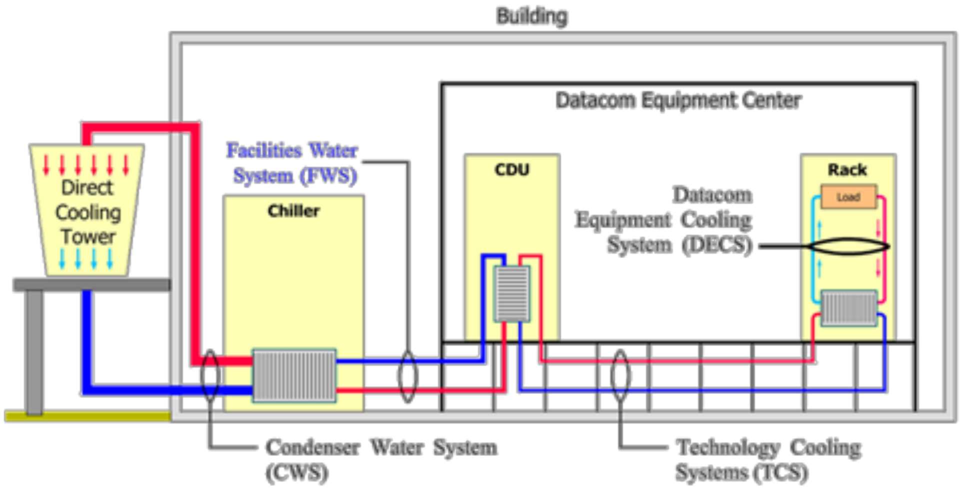
ASHRAE Liquid Cooling Thermal Guidelines

In 2011 liquid cooling classes were created in collaboration with HPC EE WG for the facility water temperature (W-Classes)

ASHRAE W Temperature Classes define Facility Water Supply Temperature (FWS) and not the Technology Cooling System (TCS)

Large CDU Approach Temperature ranges result in ITE inlet temperatures 3-15°+ C higher than FWS

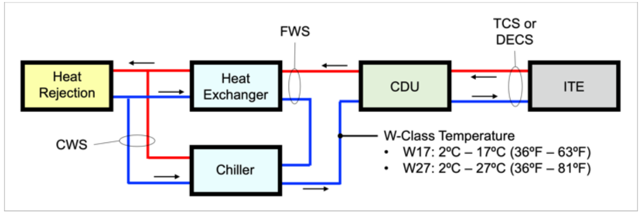
- ITE thermal requirement are based the inlet fluid temperature to the liquid loop: Not the FWS
- For silicon and data center planning Technology Cooling Systems (TCS) Classifications to ITE need to be defined

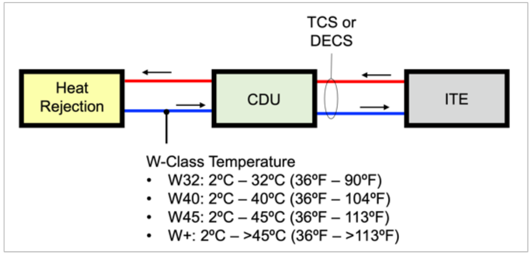


Facility Water System (FWS) Thermal Guidelines

Liquid Cooling Classes	Typical Infrastructure Design		Facility Supply Water Temp.
	Main Cooling Equipment	Supplemental Cooling Equipment	
W17	Chiller/Cooling Tower	Water-Side Economizer (Cooling Tower)	62.6°F (17°C)
W27			80.6°F (27°C)
W32	Cooling Tower	Chiller or district heating system	89.6°F (32°C)
W40			104.0°F (40°C)
W45	Cooling tower or dry cooler	District heating system	113°F (45°C)
W+			>113°F (>45°C)

a) Minimum water temperature for all classes is 2°C (35.6°F)

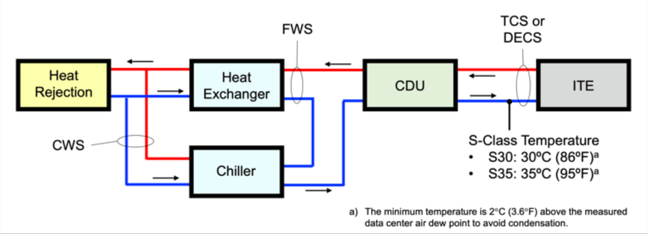




Technology Cooling System (TCS) Thermal Guidelines

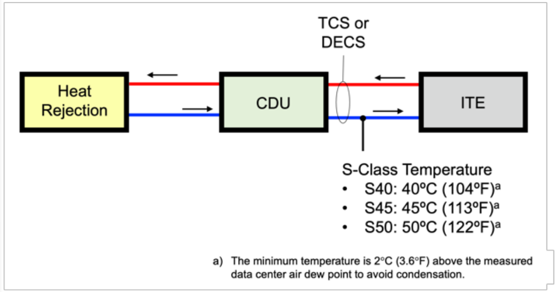
TCS Fluid Class	Typical Infrastructure Design		Facility Supply Water Temp.
	Common FWS Facilities	TCS Facilities	
S30	Chiller/Cooling Tower	CDU	**86°F** (30°C)
S35			**95°F** (35°C)
S40	Cooling Tower / Dry Cooler		**104°F** (40°C)
S45			**113°F** (45°C)
S50	Dry cooler		**122°F** (50°C)

a) Minimum water temperature for all classes is 2°C above room dew point (3.6°F)



S-Class Temperature
- S30: 30°C (86°F)[a]
- S35: 35°C (95°F)[a]

a) The minimum temperature is 2°C (3.6°F) above the measured data center air dew point to avoid condensation.



S-Class Temperature
- S40: 40°C (104°F)[a]
- S45: 45°C (113°F)[a]
- S50: 50°C (122°F)[a]

a) The minimum temperature is 2°C (3.6°F) above the measured data center air dew point to avoid condensation.

What’s Next with ASHRAE TC 9.9

Liquid cooling resiliency

- **Tech Brief released** highlighting the critical nature of redundant design on the TCS and FWS loops.
- Air-cooled had the benefit of having large volumes of cool air in the data center that gave minutes of ride through time during a failure. With liquid cooling, a loss of flow will result in ITE overheating within seconds.
- Research Work Statement approved by TC 9.9 to established guidance for data center resiliency and x-factor for liquid cooling

Coolant Distribution Units

- **Tech Brief released** highlighting how CDUs are the most important element of a liquid cooling system and isolation of the TCS and the FWS is of critical importance for reliability
- Significant challenges of designing large CDU loops that serve diverse IT equipment

CDU Testing

- No Method of Test or ratings for most liquid cooling equipment.
- ASHRAE Standard 127, Method of Test for Data Center Cooling equipment updated its TPS, and has out for public review an addendum that included liquid-to-liquid CDUs

ASHRAE Technical Committee 9.9 Datacom Encyclopedia

Evolved in 2024 from the ASHRAE Datacom Book Series

Contents

- New Liquid Cooling Book
- Design Considerations Book
- Thermal Guidelines 5th Edition Book
- PDFs of all 14 books
- White papers

Subscription based access

- $33 non-member / $24 member

ASHRAE Data Center Resources

https://www.ashrae.org/technical-resources/bookstore/datacom-series

Conclusions

ASHRAE TC 9.9’s Thermal Guidelines for Datacom Equipment Centers

- Gave a common set of criteria that IT manufacturers design to, but that doesn’t guarantee that end users use equipment that can all be designed to be energy efficient at the extremes.

- In the age of Artificial Intelligence, data centers are going to have to deal with equipment across the range of environmental envelopes – including both air- and liquid-cooling.

- Expanded thermal envelopes (both air and liquid) allow for more hours of free cooling, reduction or elimination of mechanical equipment, and opportunities for heat reuse but overall sustainability of data centers must focus on computational performance per watt (not just energy).

- Data center optimization is a complex, multivariable problem and requires a detailed engineering evaluation for any significant changes to be successful. An alternative operating envelope should be considered only after appropriate data are collected and interactions within the data center are understood.

- The Guidelines has enabled HVAC equipment manufacturers and installers, data center designers, and facility operators to find common solutions and standard practices that facilitate ITE interchangeability while preserving industry innovation

- The guidelines have continuously evolved, based on the latest industry research, to promote energy efficiency and the high availability of data centers.