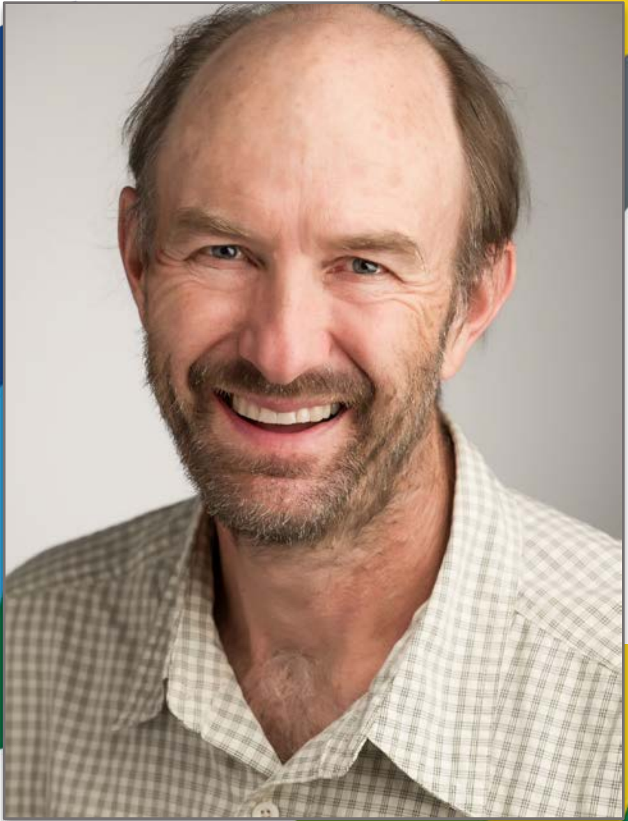
Best Practices to Design, Retrofit, and Operate Efficient Data Centers

Energy Exchange



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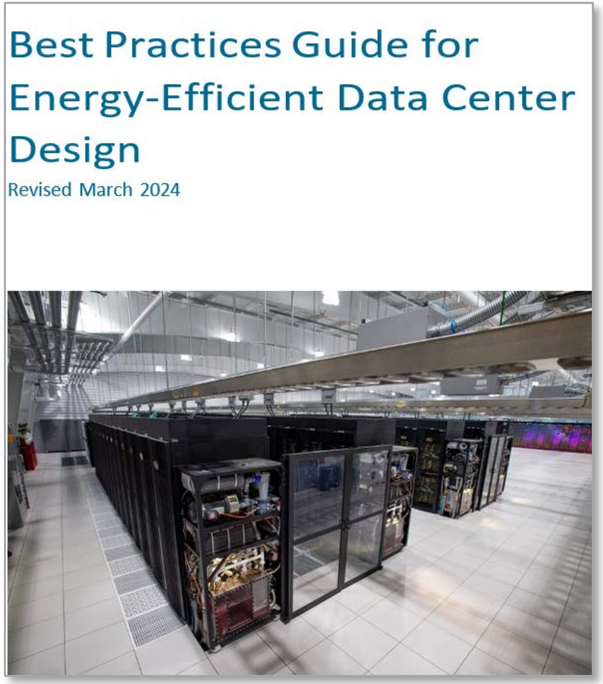
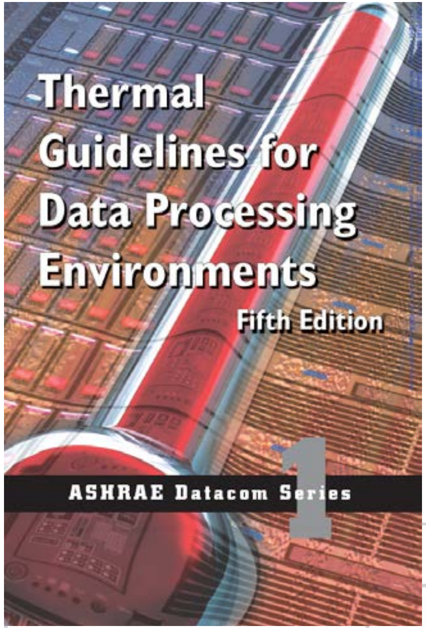
Energy Efficient Data Center Strategies

- Thermal (environmental) guidelines
- Air management
- Free cooling
- Performance metrics
- Liquid-based cooling
- www.energy.gov/femp/articles/best-practices-guide-energy-efficient-data-center-design





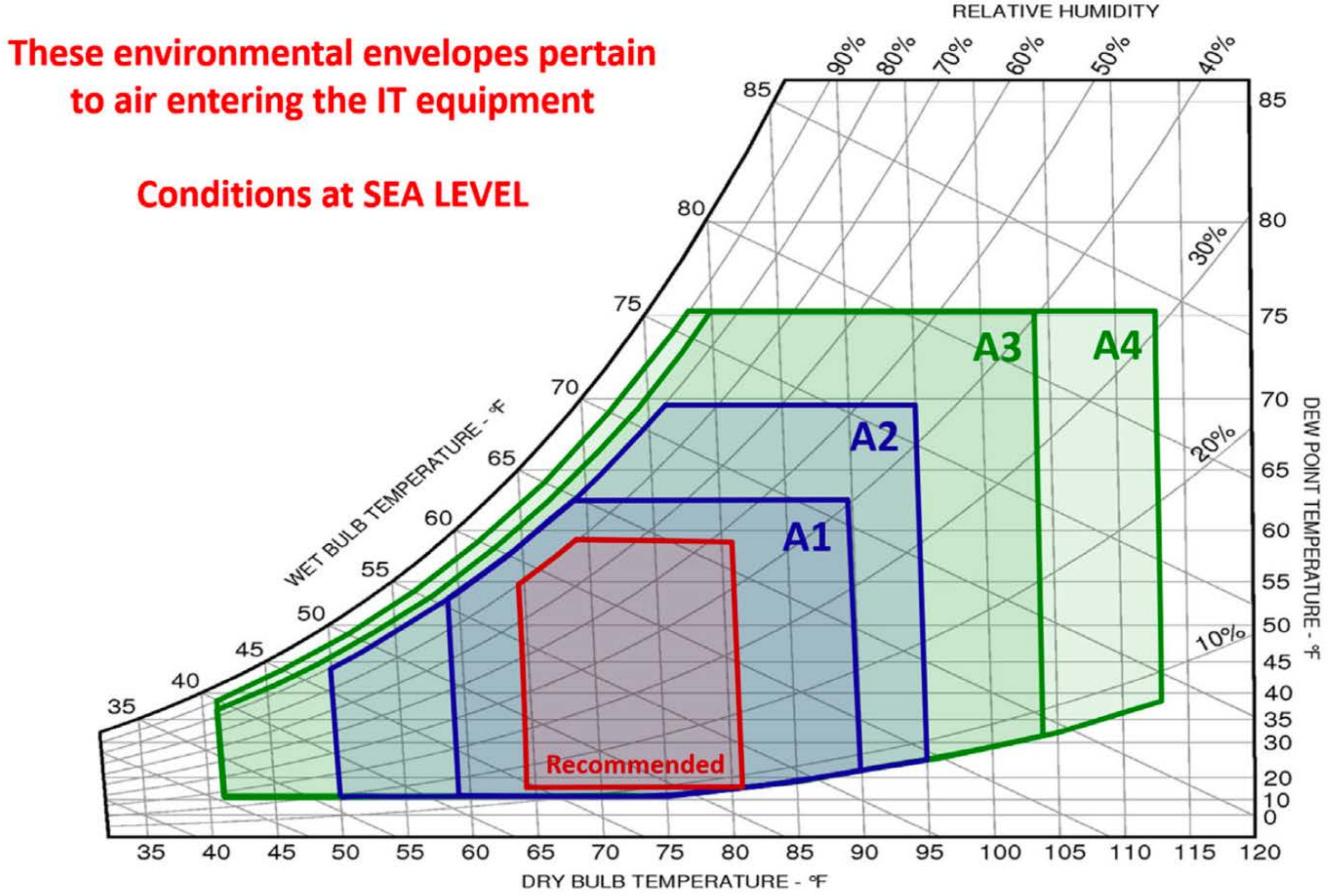
Data center equipment's environmental conditions should fall within the ranges established by ASHRAE as published in the *Thermal Guidelines*.

Environmental Specifications (°F, °C)

		Recommended	Allowable			
		A1 - A4	A1	A2	A3	A4
Dry-Bulb Temp	Degree F	64.4 to 80.6	59 to 89.6	50 to 95	41 to 104	41 to 113
	Degree C	18 to 27	15 to 32	10 to 35	5 to 40	5 to 45
Humidity	RH	8% to 70% *	8% to 80% *	8% to 80% *	8% to 85% *	8% to 90% *

Source: ASHRAE. 2021. *Thermal Guidelines for Data Processing Environments, Fifth Edition.* https://www.ashrae.org/technical-resources/bookstore/datacom-series.

- Refer to ASHRAE for the high-level pollutants and max. rate of change for tape storage.
- If testing shows corrosion levels exceed these limits, then drops to 50% max.

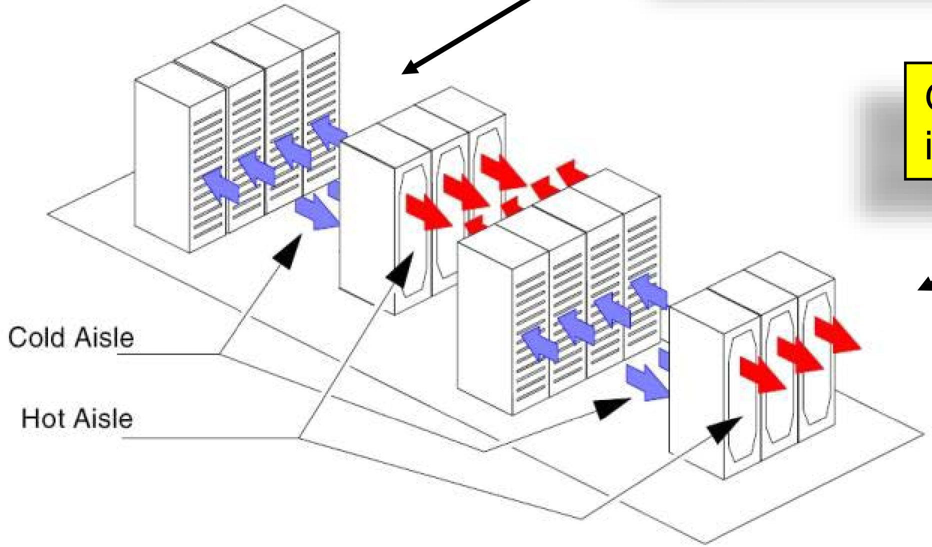


Source: ASHRAE. 2021. *Thermal Guidelines for Data Processing Environments, Fifth Edition.* https://www.ashrae.org/technical-resources/bookstore/datacom-series.

Equipment Environmental Specification

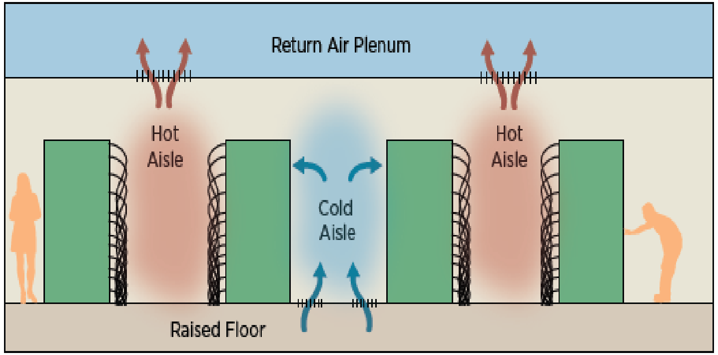
Air inlet to information technology (IT) equipment **is** the important specification to meet

Outlet temperature is *not* important to IT equipment



Improve Air Management

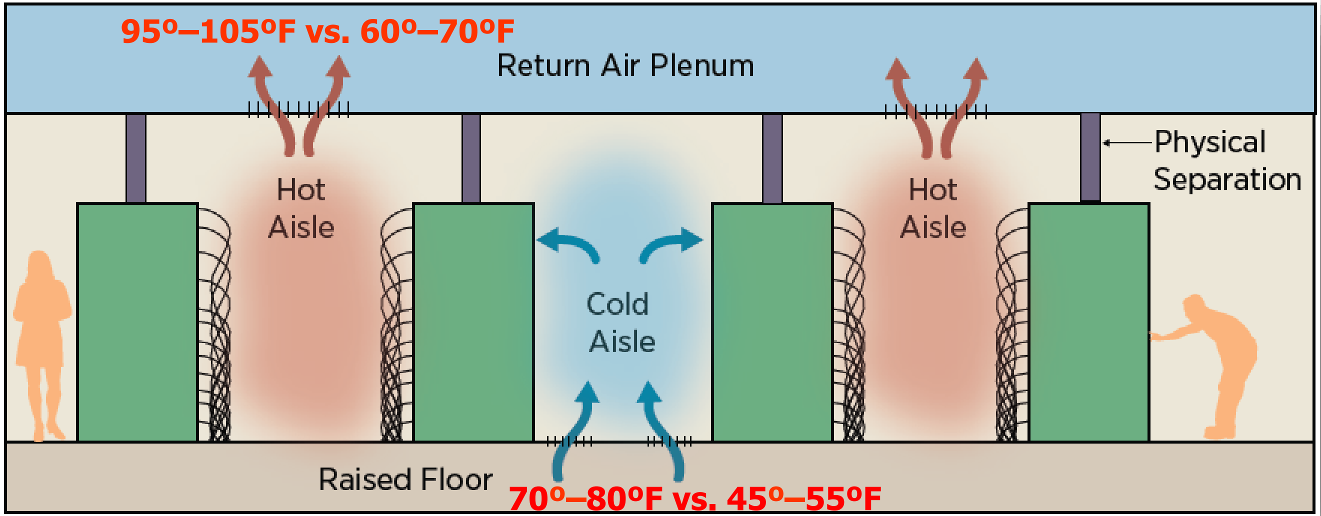
- Typically, more air circulated than required
- Air mixing and short-circuiting leads to:
  - Low supply temperature
  - Low Delta T
- Use hot and cold aisles
- Improve isolation of hot and cold aisles
  - Reduce fan energy
  - Improve air-conditioning efficiency
  - Increase cooling capacity



Source: www.energy.gov/femp/articles/best-practices-guide-energy-efficient-data-center-design

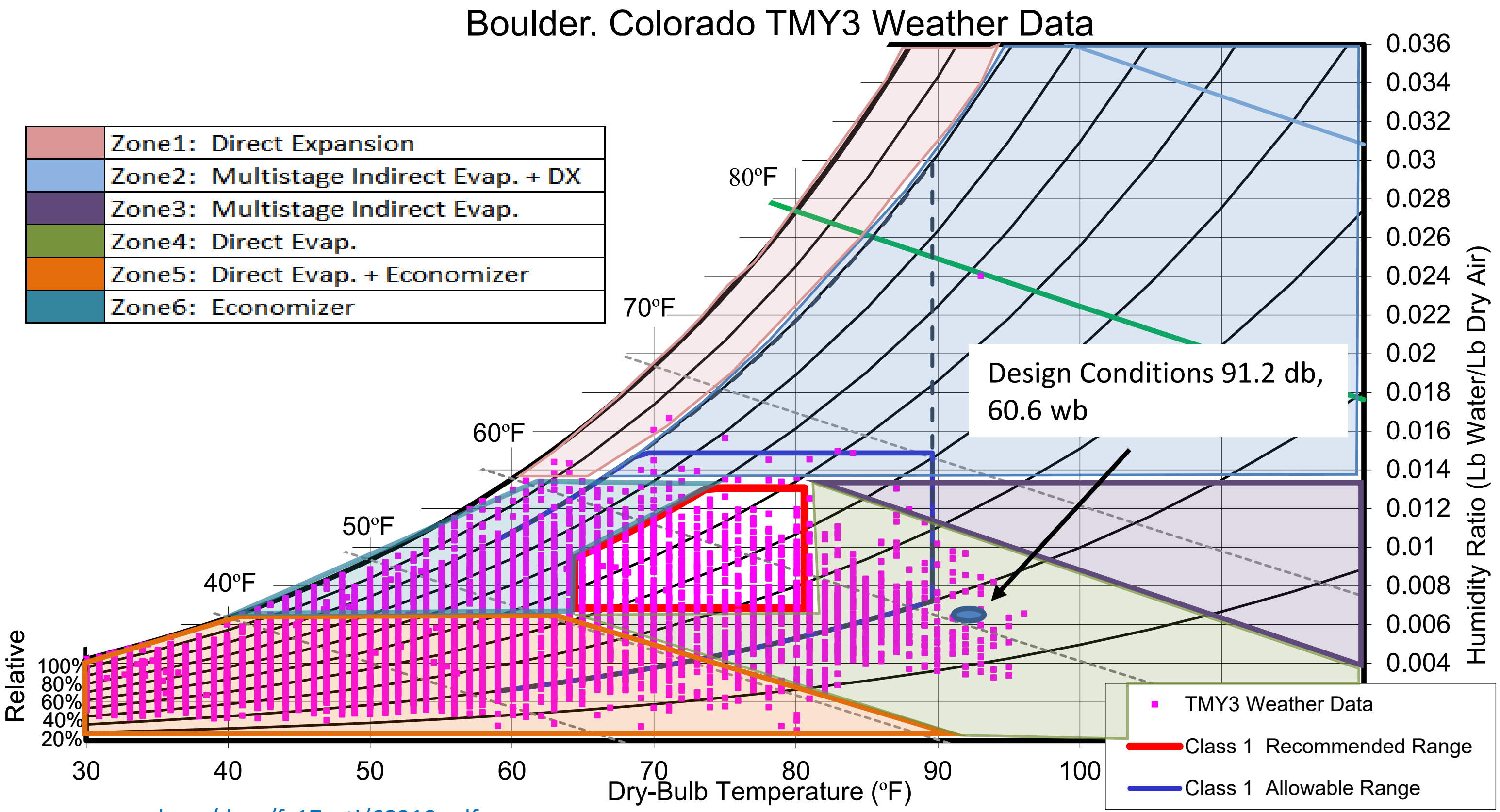
Hot aisle/cold aisle configuration decreases mixing of intake and exhaust air, promoting efficiency.

Isolate Cold and Hot Aisles



Source: www.energy.gov/sites/prod/files/2013/10/f3/eedatacenterbestpractices.pdf

Psychrometric Bin Analysis



Source: www.nrel.gov/docs/fy17osti/68218.pdf

Estimated Savings

Baseline

System	Direct expansion (DX) cooling with no economizer
Load	1 ton of cooling, constant year-round
Efficiency (Coefficient of Performance)	3
Total Energy (kWh/yr)	10,270

Results

	Recommended Range		Allowable Range	
	Hours	Energy (kWh)	Hours	Energy (kWh)
Zone1: DX Cooling Only	25	8	2	1
Zone2: Multistage Indirect Evap. + DX (H80)	26	16	4	3
Zone3: Multistage Indirect Evap. Only	3	1	0	0
Zone4: Evap. Cooler Only	867	97	510	57
Zone5: Evap. Cooler + Economizer	6055	417	1656	99
Zone6: Economizer Only	994	0	4079	0
Zone7: 100% Outside Air	790	0	2509	0
Total	***8,760***	***538***	***8,760***	***160***
Estimated % Savings	-	***95%***	-	***98%***

Data Center Metrics

Data Center Metrics: The Green Grid PUE "Family"

Energy

$$Power\ Usage\ Effectiveness\ PUE = \frac{\text{"Facility energy"} + \text{"IT energy"}}{\text{"IT energy"}} = \frac{\text{"Total energy"}}{\text{"IT energy"}}$$

$$IT\text{-}power\ Usage\ Effectiveness\ ITUE = \frac{\text{"IT energy"}}{\text{Total energy into the "Compute Components"}}$$

$$Total\text{-}power\ Usage\ Effectiveness\ TUE = PUE \times ITUE$$

$$Energy\ Reuse\ Effectiveness\ ERE = \frac{\text{"Facility energy"} + \text{"IT energy"} - \text{"Reuse energy"}}{\text{"IT energy"}}$$

Sustainability (*water and carbon*)

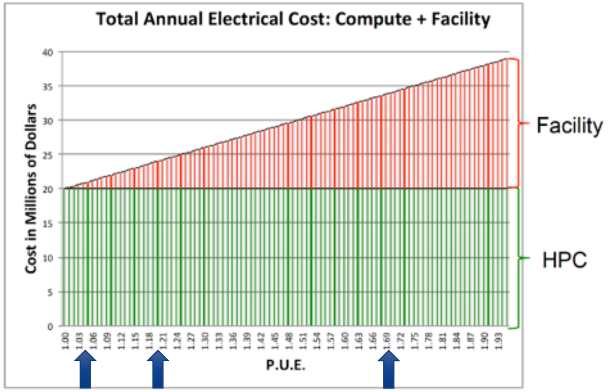
$$Water\ Usage\ Effectiveness\ WUE = \frac{\text{"Annual site water usage"}}{\text{"IT energy"}} \quad \left(units\ \frac{L}{kWh}\right)$$

$$WUE_{source} = \frac{\text{"Annual site water usage" + "Annual source energy water usage"}}{\text{"IT energy"}}$$

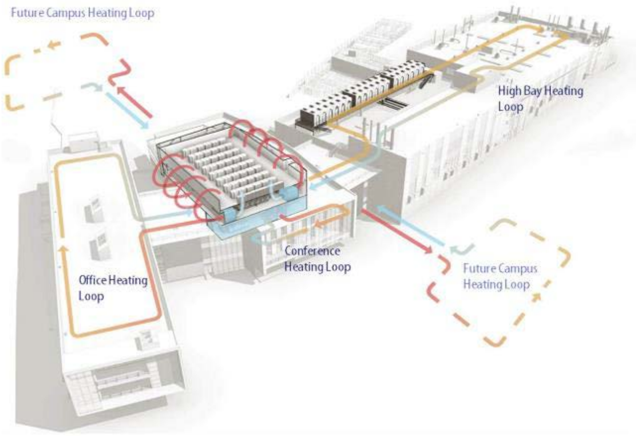
$$Carbon\ Usage\ Effectiveness\ CUE = \frac{\text{"Total } CO_2 \text{ emissions caused by total energy"}}{\text{"IT energy"}} \quad \left(units\ \frac{kgCO_2eq}{kWh}\right)$$

Utilization (*based on industry*)

$$\{Gflops,\ Transaction\}\ per\ Watt$$



Assume ~20MW HPC system & $1M per MW year utility cost.



Cooling Efficiency

- Liquid conduits require 250 to 1,000 times less space than air conduits for transporting the same quantity of heat energy.
- Liquids require 10 to 20 times less energy to transport energy.
- Liquid-to-liquid heat exchangers have closer approach temperatures than liquid-to-air (coils), yielding greater efficiency and increased economizer hours.
- ASHRAE Technical Committee 9.9 liquid standards provide an excellent guide.

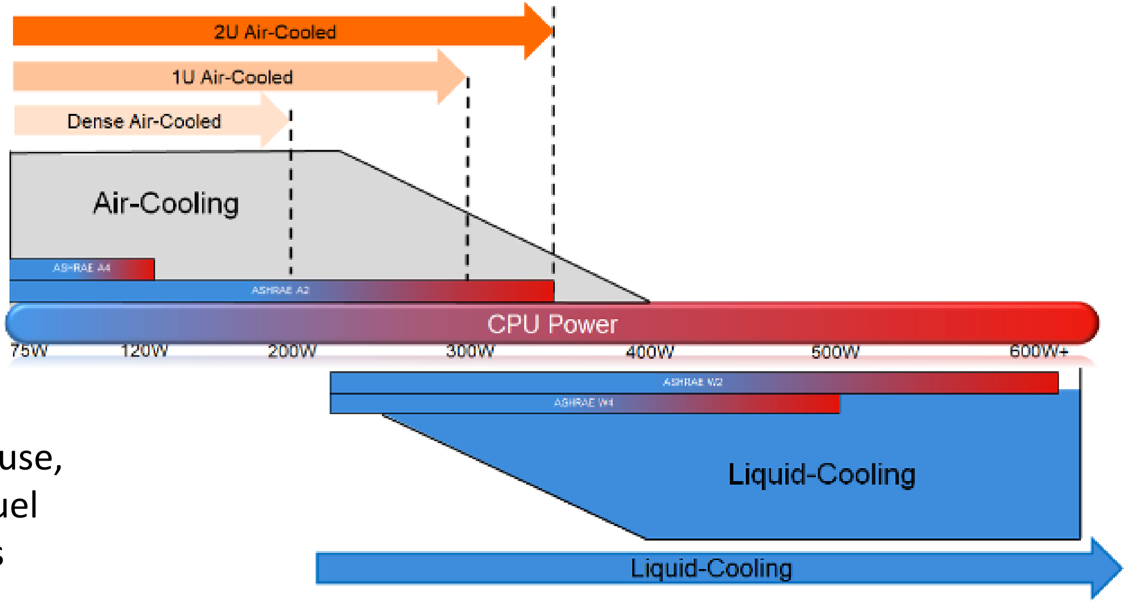
Heat Transfer		Resultant Energy Requirements			
Rate	ΔT	Heat Transfer Medium	Fluid Flow Rate	Conduit Size	Theoretical Horsepower
10 Tons	12°F	Forced Air	9217 cfm	34" Ø	3.63 Hp
		Water	20 gpm	2" Ø	.25 Hp

Source: ASHRAE Technical Committee 9.9: Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment. https://tpc.ashrae.org/?cmtKey=fd4a4ee6-96a3-4f61-8b85-43418dfa988d.

Increasing CPU Power – Transition to Warm Water Cooling

NREL believes increasing CPU power will:

- Drive transition to warm water cooling
- Transition from fans to pumps, saving energy
- Eliminate chillers for cooling
- Enable much greater waste heat reuse, saving water and displacing fossil fuel heating, reducing carbon emissions
- Reducing water usage through reduction of cooling towers and lowering overall system cooling infrastructure and operating costs.



Soft Limits & Temperature Regression of Air and Water.
Source: Draft figure from ASHRAE TC 9.9, found on slide 43 of https://tpc.ashrae.org/FileDownload?idx=2779ca57-3cbc-4f16-8484-bab38f9c1771.

Fanless Direct Liquid-Cooled Server Options

Fixed Cold Plate

Photo by Werner Slocum, NREL 77629

Data Center Metrics: The Green Grid PUE "Family"

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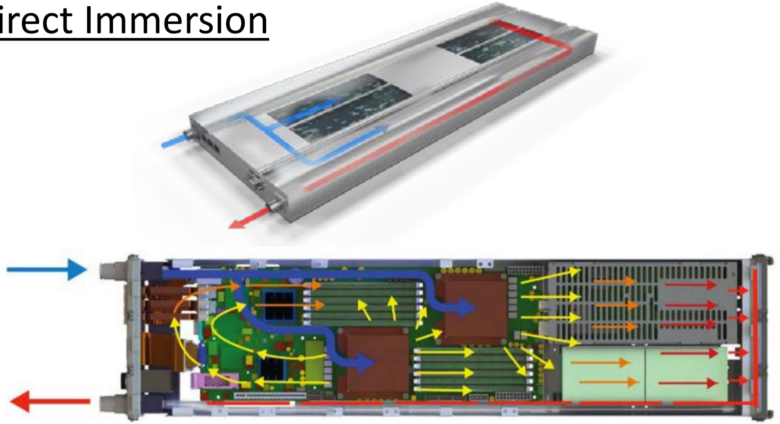
$$PUE = \frac{\text{"Facility energy"} + \text{"IT energy"}}{\text{"IT energy"}} = \frac{\text{"Total energy"}}{\text{"IT energy"}}$$

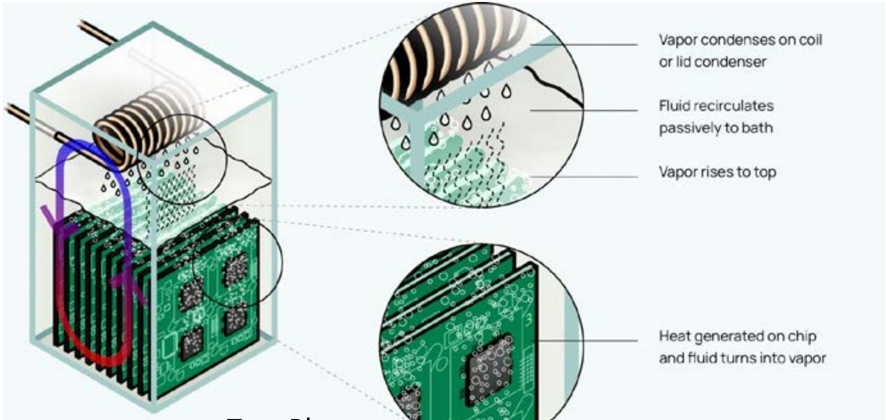
$$ITUE = \frac{\text{"IT energy"}}{\text{Total energy into the "Compute Components"}}$$

$$TUE = PUE \times ITUE$$

Direct Immersion



Single Phase



Two Phase

Image from Liquid Stack

FEMP/NREL's Key Approach to Sustainable Data Centers

1. PUE: Reduce energy use by making systems as efficient as possible.
   - ***Maximize compute entering temperature while avoiding IT overheating to maximize energy efficiency!***
   - "Free" cooling to reduce or eliminate compressor (chiller, DX) based cooling:
     a) Install direct liquid cooled computers that use warm water
     b) Capture as much heat as possible directly to the liquid cooling system
   - Optimizing fan/pump speeds and UPS
2. ERE: Heat reuse – achieve lowest Energy Reuse Effectiveness possible
   - ***Maximize compute leaving temperature to maximize energy reuse!***
3. WUE: Reject as much remaining heat to dry coolers as possible
   - ***Maximize compute leaving temperature to maximize heat rejected dry!***
4. CUE: Maximize energy from renewable systems on site or within grid region
   - ***With the goal of 100% renewable energy 100% of the time.***

Questions?

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Energy Exchange℠

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