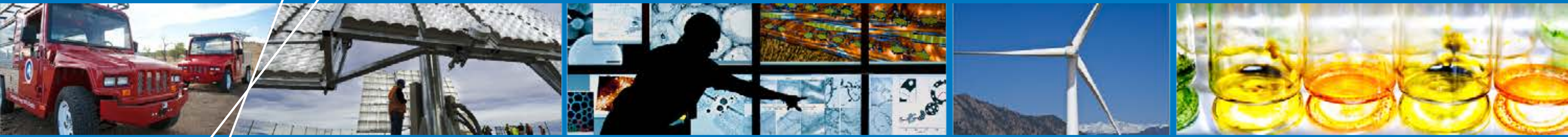
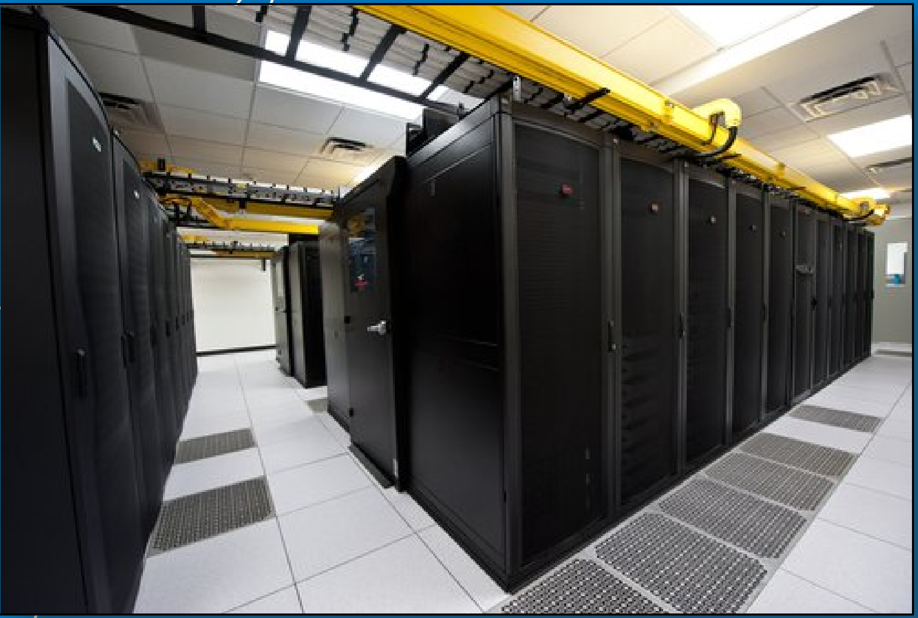
Trends in Data Center Design – ASHRAE Leads the Way to Large Energy Savings





ASHRAE Conference, Denver
Otto Van Geet, PE
June 24, 2014

NREL/PR-6A40-58902

Data Center Energy

Data centers are energy intensive facilities.

- 10-100x more energy intensive than an office
- Server racks well in excess of 30 kW
- Surging demand for data storage
- EPA estimate: 3% of U.S. electricity
- Power and cooling constraints in existing facilities.

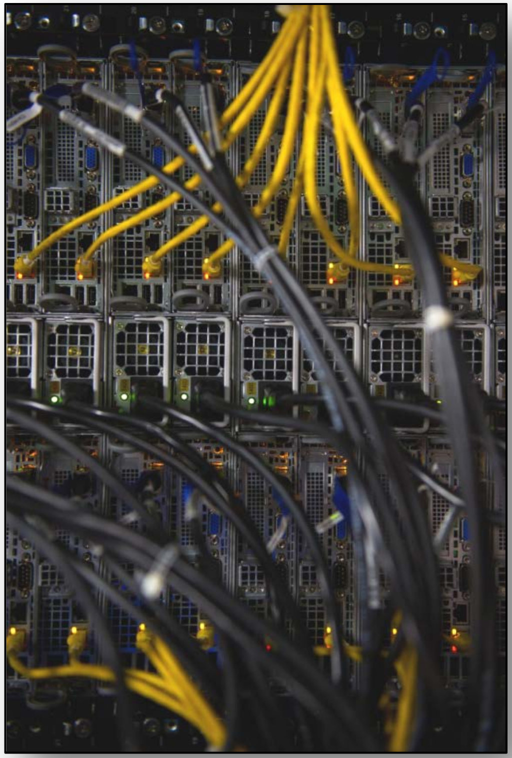


Photo by Steve Hammond, NREL

Data center inefficiency steals power that would otherwise support compute capability.

BPG Table of Contents

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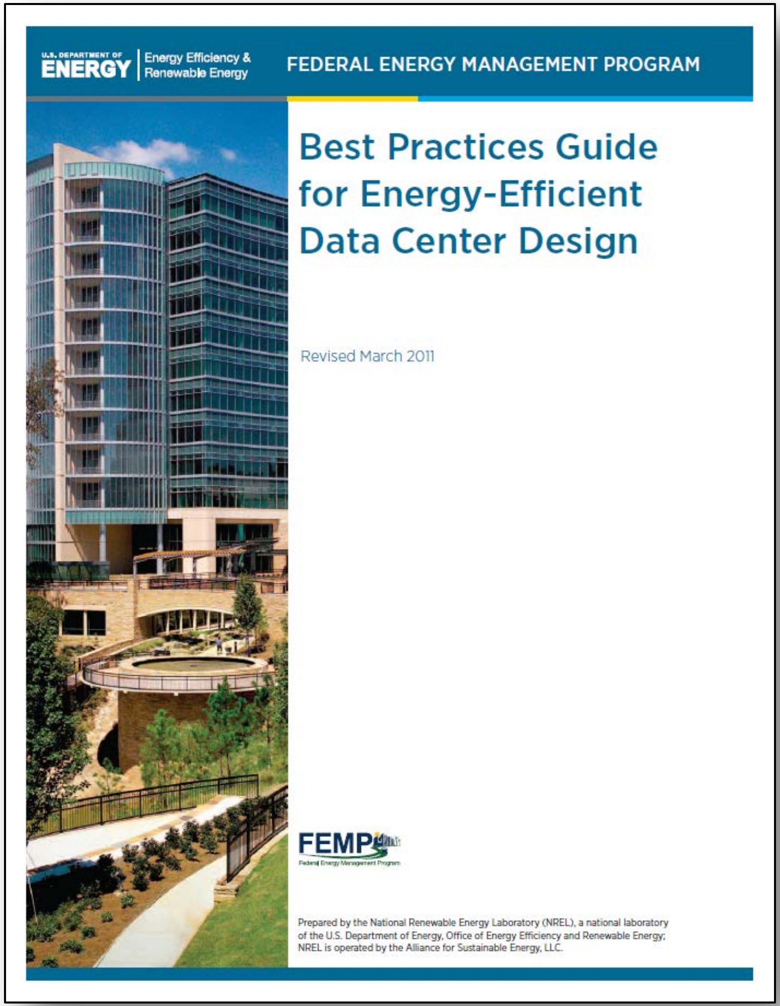
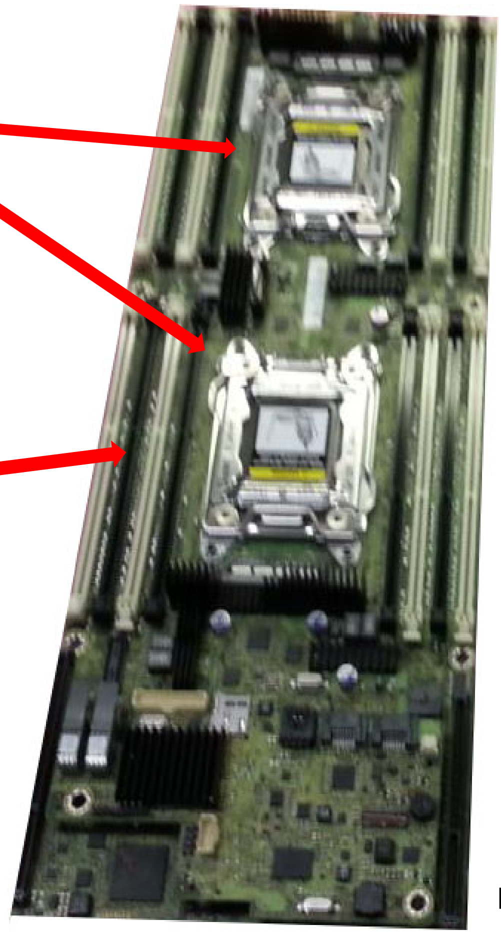


Safe Temperature Limits

CPUs
~65C
(149F)

Memory
~85C
(185F)



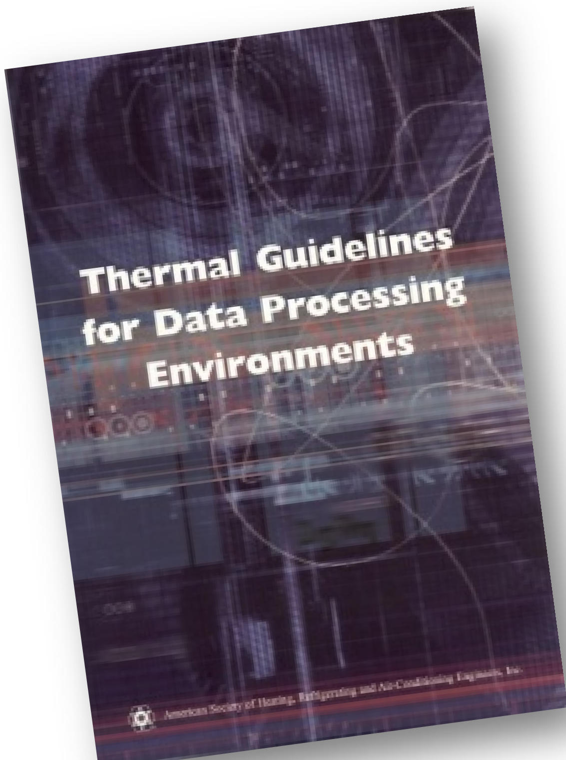
GPUs
~75C
(167F)

Photo by Steve Hammond, NREL

CPU, GPU & Memory, represent ~75-90% of heat load …

Environmental Conditions

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

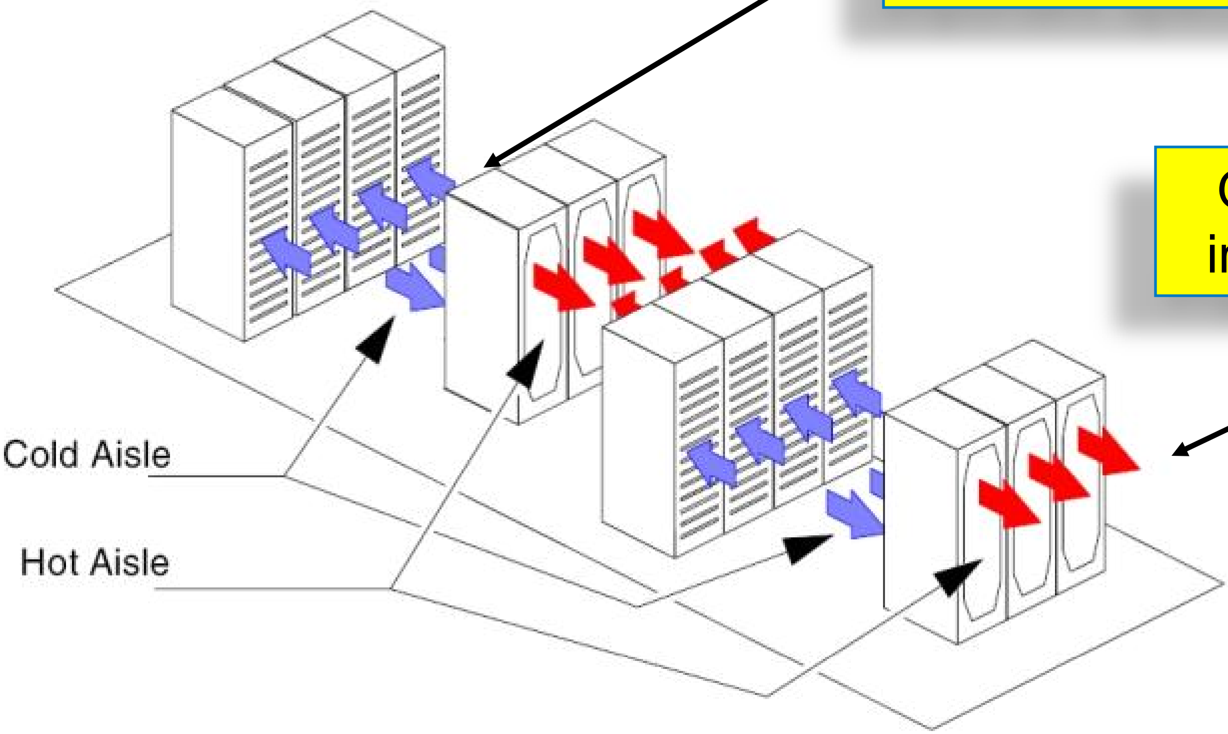


Environmental Specifications (°F)

(@ Equipment Intake)	Recommended	Allowable
Temperature Data Centers ASHRAE	65° – 80°F	59° – 90°F (A1) 41° – 113°F (A4)
Humidity (RH) Data Centers ASHRAE	42°F DP – 60% or 59°F DP	20% – 80% & 63°F DP

ASHRAE Reference: ASHRAE (2008), (2011)

Equipment Environmental Specification



<u>Air inlet</u> to IT equipment **is** the important specification to meet

Outlet temperature is *not* important to IT equipment

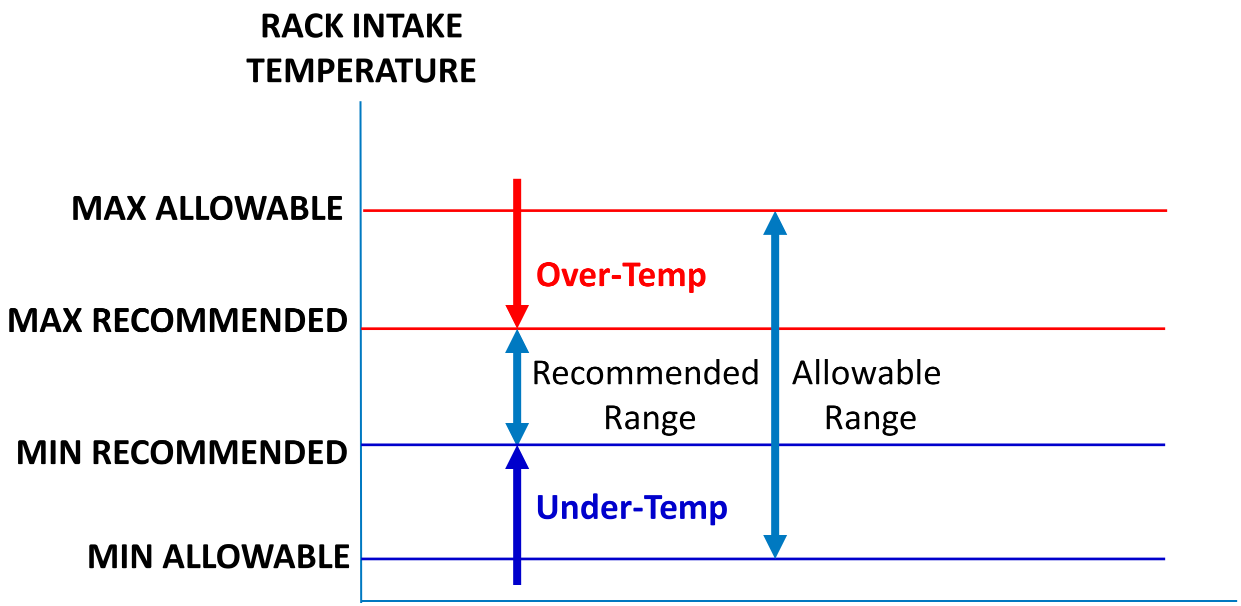
Key Nomenclature

Recommended Range (Statement of Reliability)

Preferred facility operation; <u>most</u> values should be within this range.

Allowable Range (Statement of Functionality)

Robustness of equipment; <u>no</u> values should be outside this range.

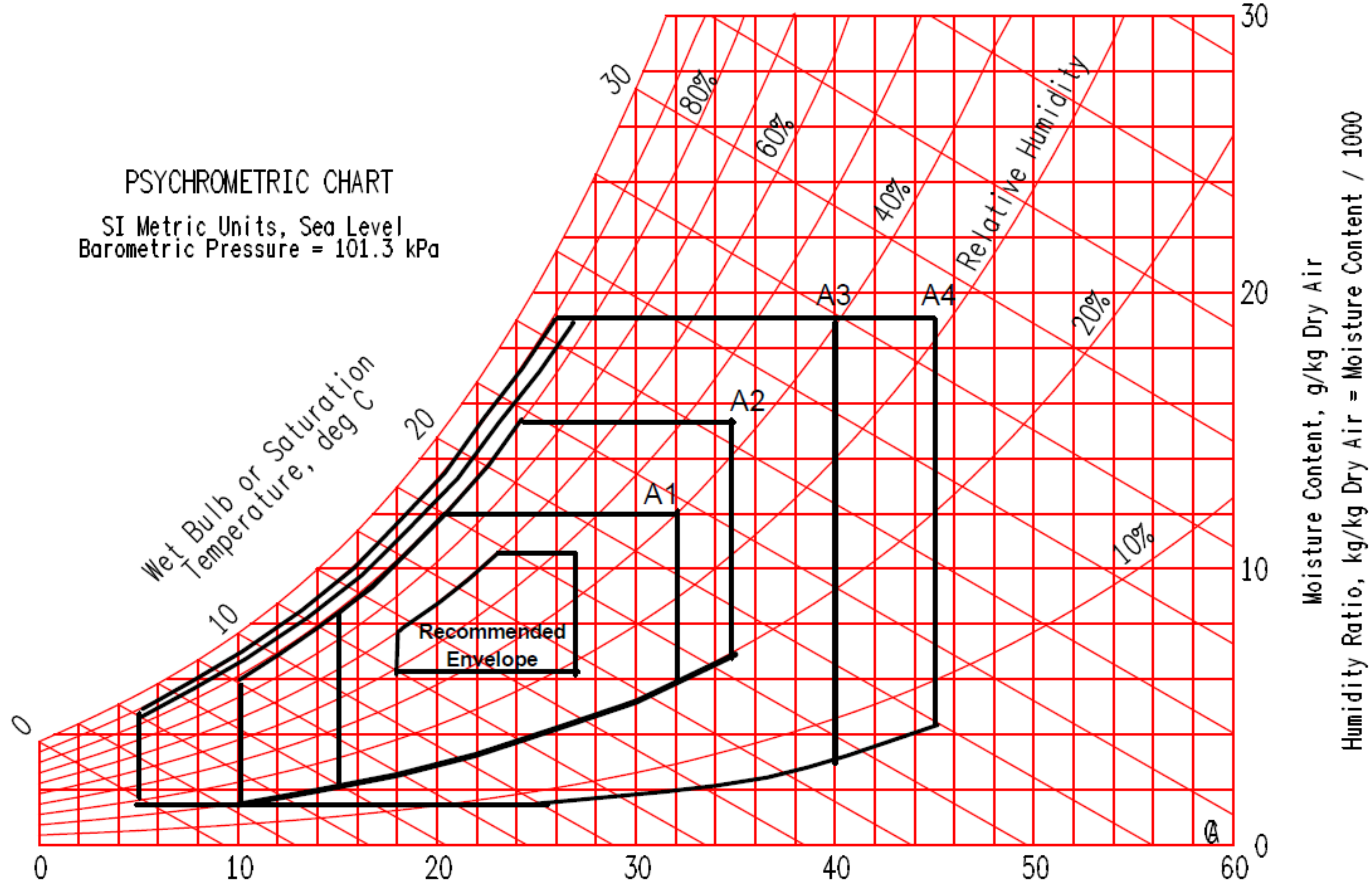


2011 ASHRAE Thermal Guidelines

Classes (a)	Equipment Environmental Specifications							
	Product Operations (b)(c)					Product Power Off (c) (d)		
	Dry-Bulb Temperature (˚F) (e) (g)	Humidity Range, non-Condensing (h) (i)	Maximum Dew Point (˚F)	Maximum Elevation (f)	Maximum Rate of Change(˚F/hr) (f)	Dry-Bulb Temperature (˚F)	Relative Humidity (%)	Maximum Dew Point (˚F)
Recommended (Applies to all A classes; individual data centers can choose to expand this range based upon the analysis described in this document)								
A1 to A4	64.4 to 80.6	41.9°F DP to 60% RH and 59°F DP						
Allowable								
A1	59 to 89.6	20 to 80% RH	62.6	10,000	9/36	41 to 113	8 to 80	80.6
A2	50 to 95	20 to 80% RH	69.8	10,000	9/36	41 to 113	8 to 80	80.6
A3	41 to 104	10.4˚F DP & 8% RH to 85% RH	75.2	10,000	9/36	41 to 113	8 to 85	80.6
A4	41 to 113	10.4˚F DP & 8% RH to 90% RH	75.2	10,000	9/36	41 to 113	8 to 90	80.6
B	41 to 95	8% RH to 80% RH	82.4	10,000	NA	41 to 113	8 to 80	84.2
C	41 to 104	8% RH to 80% RH	82.4	10,000	NA	41 to 113	8 to 80	84.2

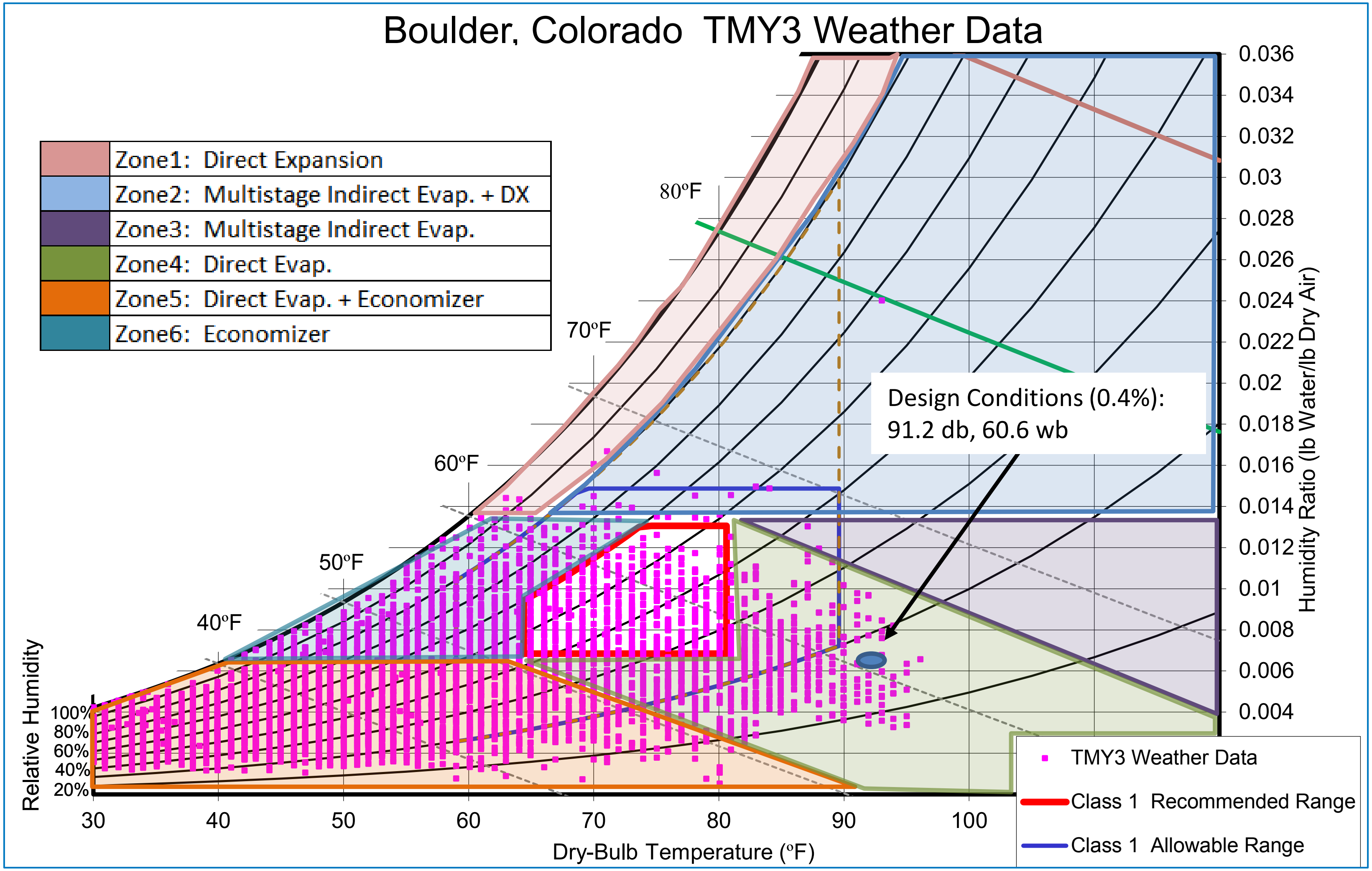
2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance. White paper prepared by ASHRAE Technical Committee TC 9.9

2011 ASHRAE Allowable Ranges



Dry Bulb Temperature

Psychrometric Bin Analysis



Estimated Savings

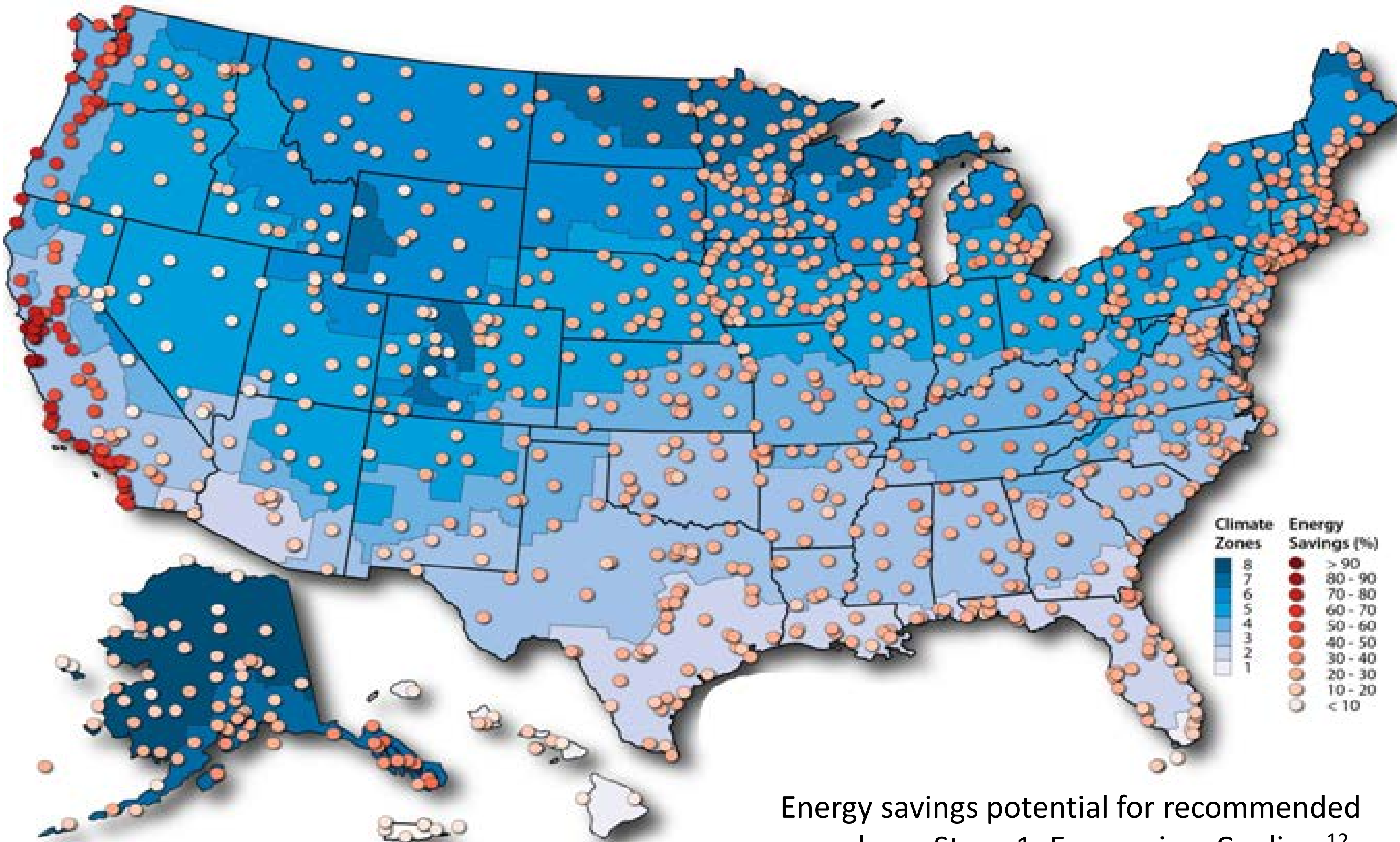
Baseline

System	DX Cooling with no economizer
Load	1 ton of cooling, constant year-round
Efficiency (COP)	3
Total Energy (kWh/yr)	**10,270**

Results

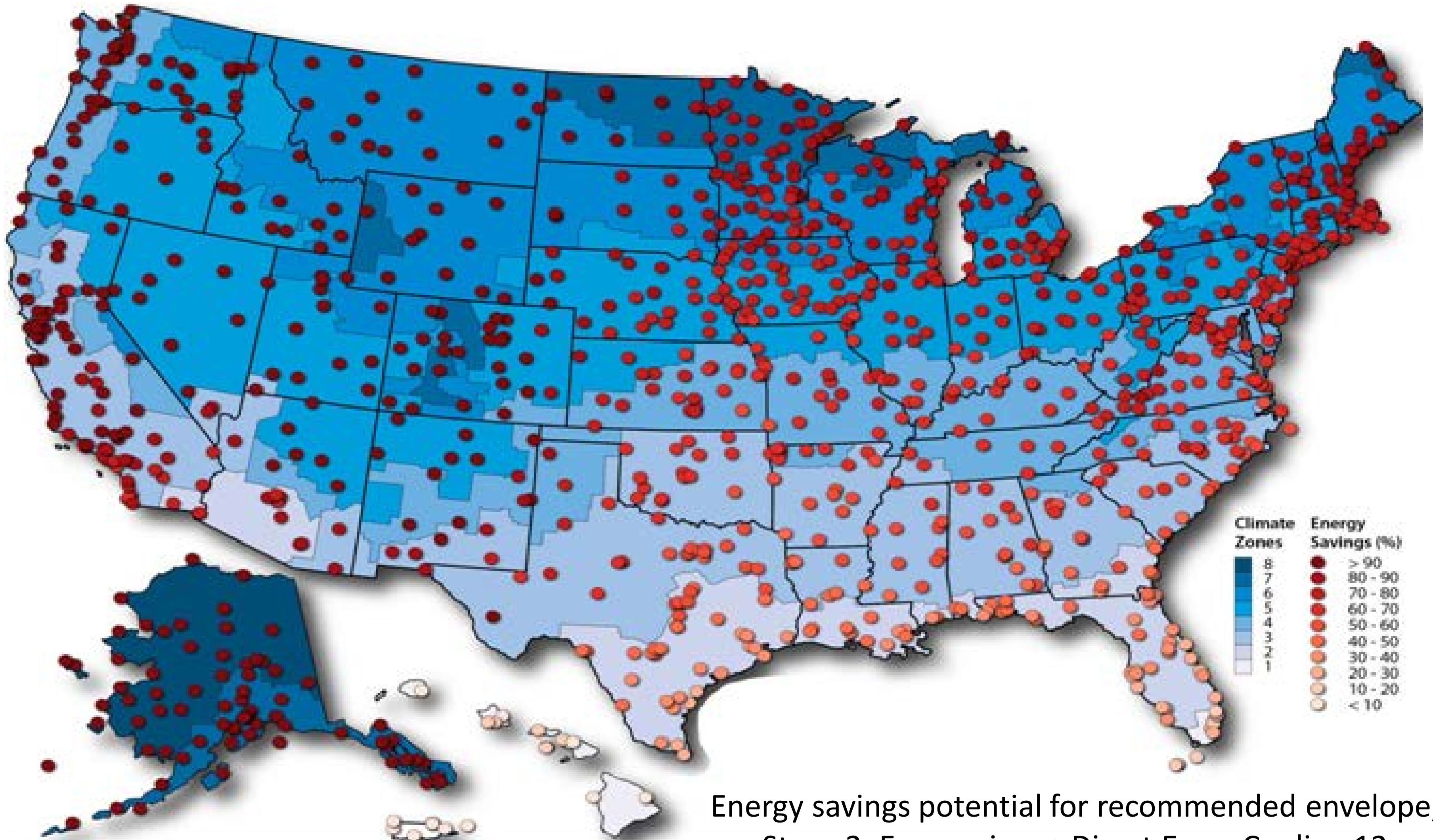
	Recommended Range		Allowable Range	
	Hours	Energy (kWh)	Hours	Energy (kWh)
Zone1: DX Cooling Only	25	8	2	1
Zone2: Multistage Indirect Evap. + DX (H80)	26	16	4	3
Zone3: Multistage Indirect Evap. Only	3	1	0	0
Zone4: Evap. Cooler Only	867	97	510	57
Zone5: Evap. Cooler + Economizer	6055	417	1656	99
Zone6: 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%***

Energy Savings Potential: Economizer Cooling



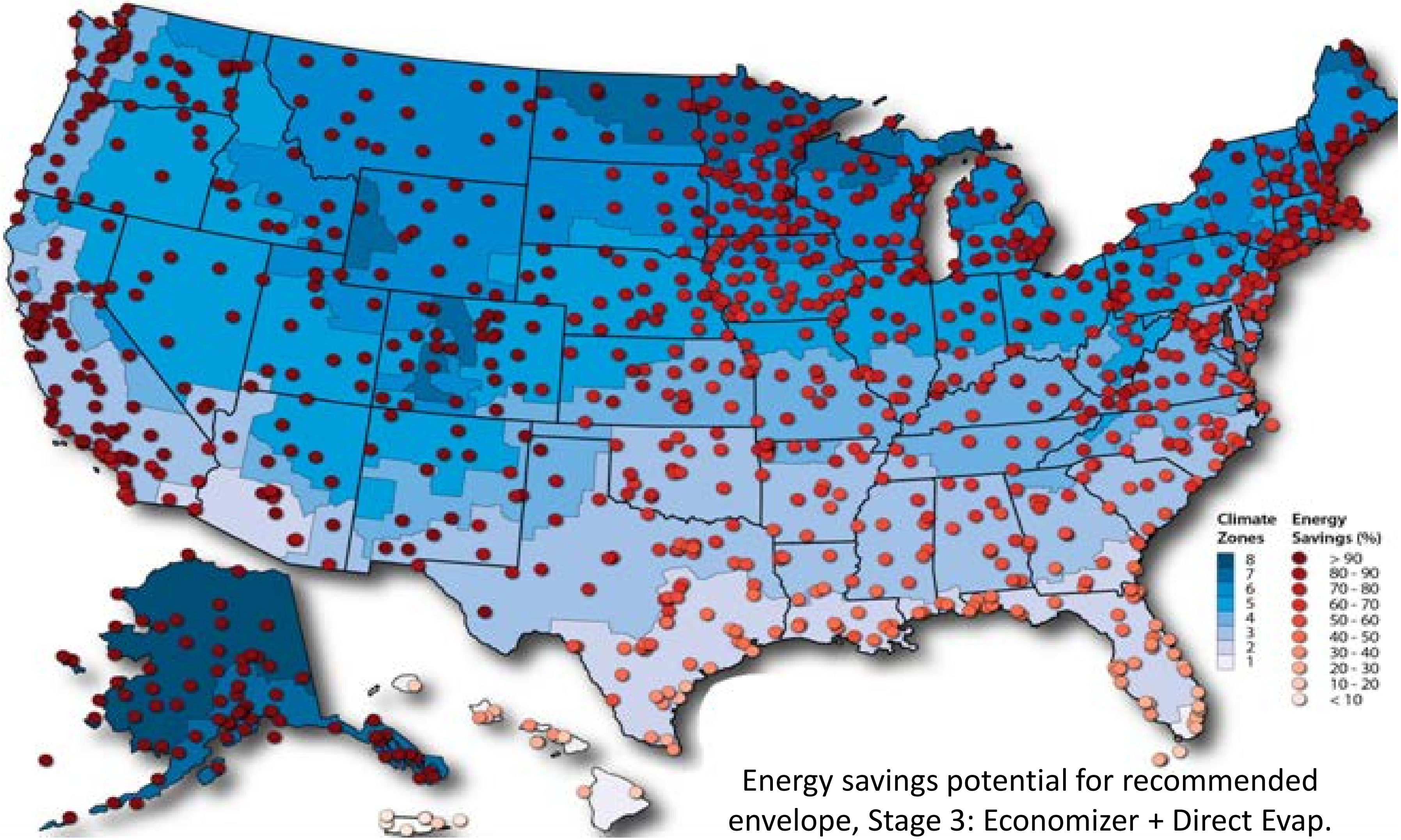
Energy savings potential for recommended envelope, Stage 1: Economizer Cooling.[12] (Source: Billy Roberts, NREL)

Energy Savings Potential: Economizer + Direct Evaporative Cooling



Energy savings potential for recommended envelope, Stage 2: Economizer + Direct Evap. Cooling.12
(Source: Billy Roberts, NREL)

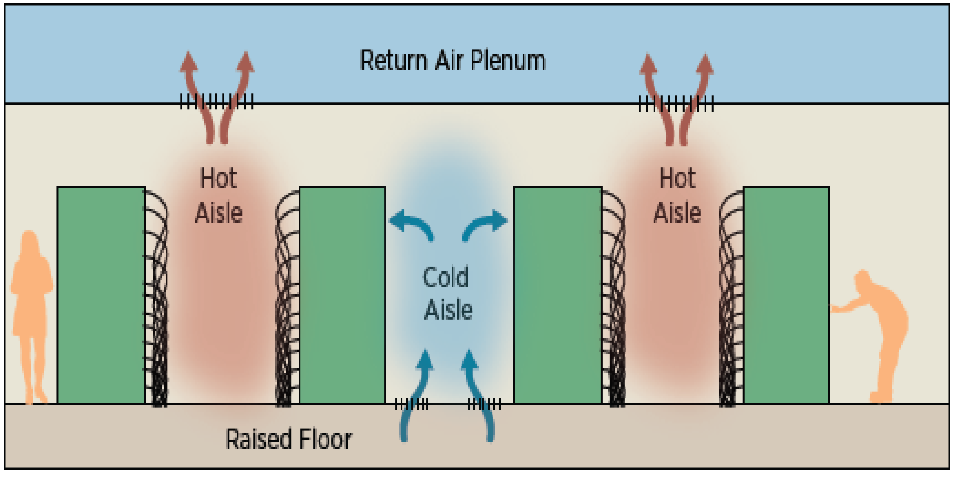
Energy Savings Potential: Economizer + Direct Evap. + Multistage Indirect Evap. Cooling



Energy savings potential for recommended envelope, Stage 3: Economizer + Direct Evap. + Multistage Indirect Evap. Cooling.12 (Source: Billy Roberts, NREL)

Improve Air Management

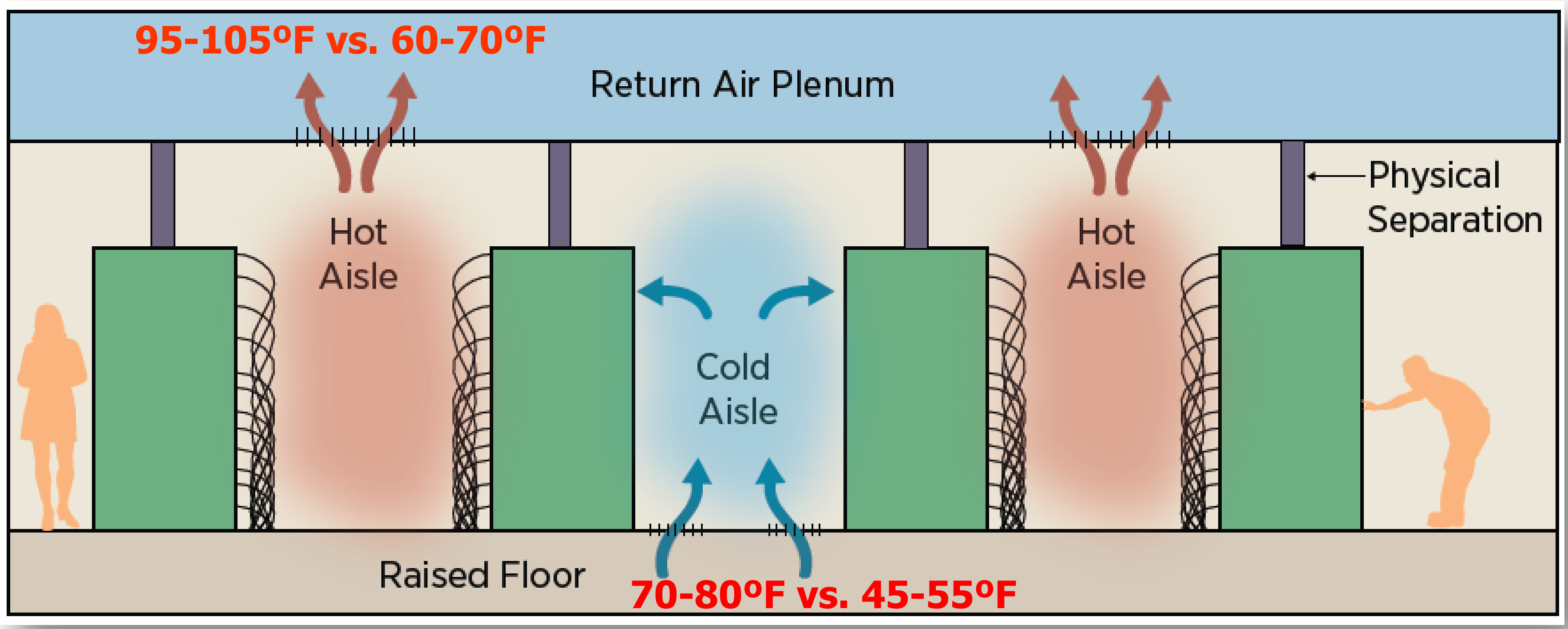
- **Typically, more air circulated than required**
- **Air mixing and short circuiting leads to:**
  - Low supply temperature
  - Low Delta T
- **Use hot and cold aisles**
- **Improve isolation of hot and cold aisles**
  - Reduce fan energy
  - Improve air-conditioning efficiency
  - Increase cooling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



Source: http://www1.eere.energy.gov/femp/pdfs/eedatacenterbestpractices.pdf

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

Isolate Cold and Hot Aisles



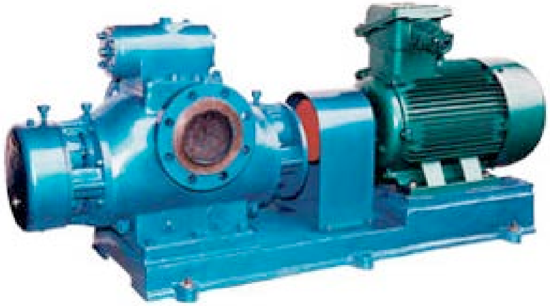
Source: http://www1.eere.energy.gov/femp/pdfs/eedatacenterbestpractices.pdf

Adding Air Curtains for Hot/Cold Isolation

Photo used with permission from the National Snow and Ice Data Center. http://www.nrel.gov/docs/fy12osti/53939.pdf

Move to Liquid Cooling

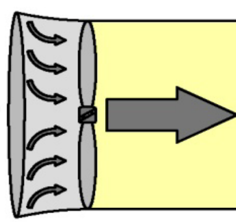
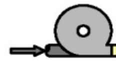
- **Server fans are inefficient and noisy.**
  - Liquid doors are an improvement but we can do better!
- **Power densities are rising making component-level liquid cooling solutions more appropriate.**
- **Liquid benefits**
  - Thermal stability, reduced component failures.
  - Better waste heat re-use options.
  - Warm water cooling, reduce/eliminate condensation.
  - Provide cooling with higher temperature coolant.
- **Eliminate expensive & inefficient chillers.**
- **Save wasted fan energy and use it for computing.**
- **Unlock your cores and overclock to increase throughput!**



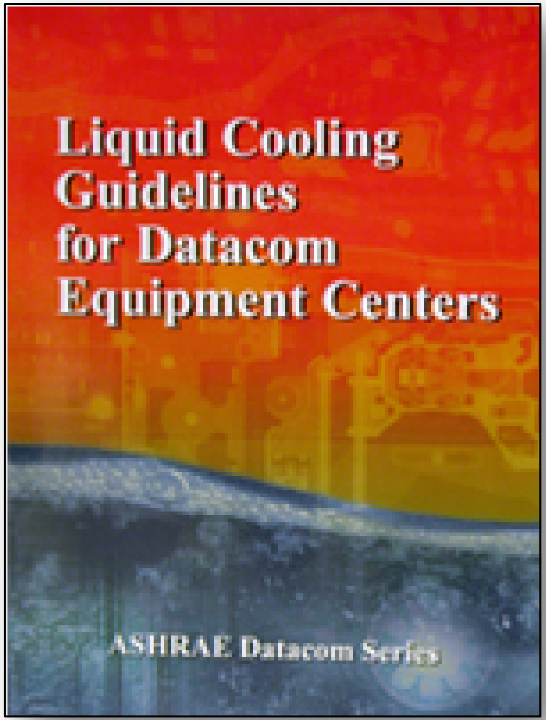
Liquid Cooling – Overview

Water and other liquids (dielectrics, glycols and refrigerants) may be used for heat removal.

- Liquids typically use LESS transport energy
  (14.36 Air to Water Horsepower ratio for example below).
- Liquid-to-liquid heat exchangers have closer approach temps than Liquid-to-air (coils), yielding increased economizer hours.

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

Liquid Cooling – New Considerations



- **Air Cooling**
  - Humidity
  - Fan failures
  - Air side economizers, particulates
- **Liquid Cooling**
  - pH & bacteria
  - Dissolved solids
  - Corrosion inhibitors, etc.
- **When considering liquid-cooled systems, insist that providers adhere to the latest ASHRAE water quality spec or it could be costly.**

2011 ASHRAE Liquid Cooling Guidelines

ASHRAE TC 9.9

2011 Thermal Guidelines for Liquid Cooled Data Processing Environments

Whitepaper prepared by ASHRAE Technical Committee (TC) 9.9 Mission Critical Facilities, Technology Spaces, and Electronic Equipment

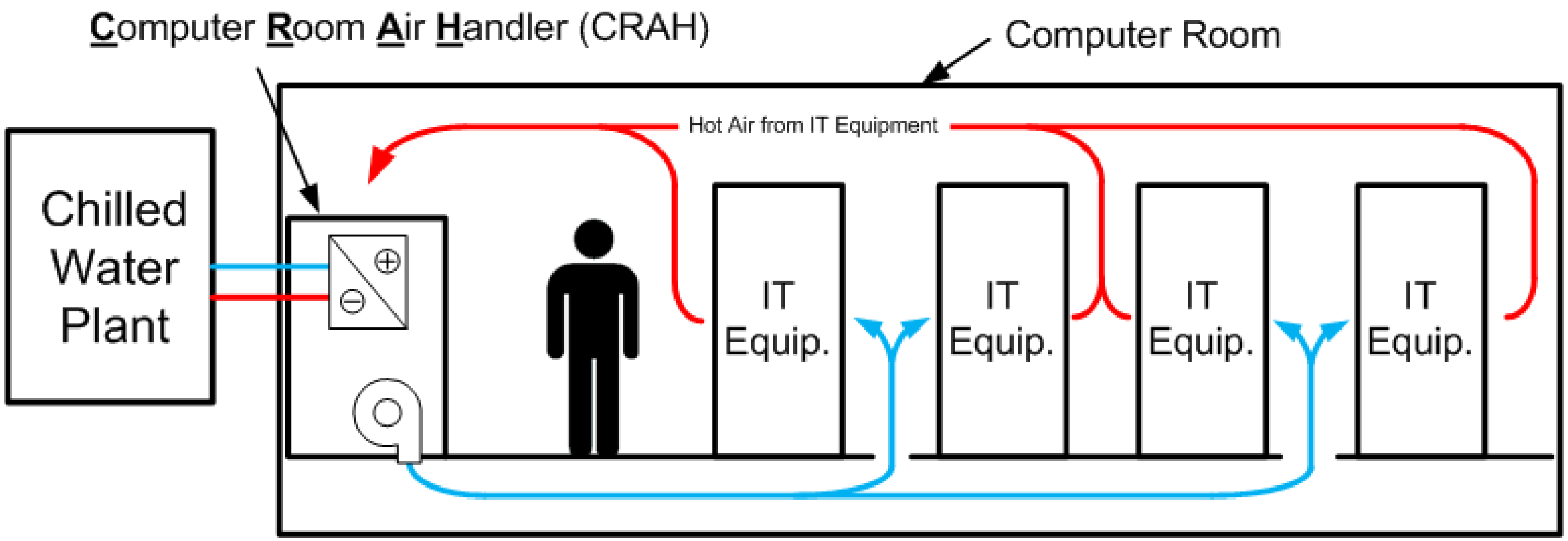
2011 ASHRAE Liquid Cooling Guidelines

Table A-1: 2011 ASHRAE Liquid Cooled Guidelines (SI Version in Main Body)

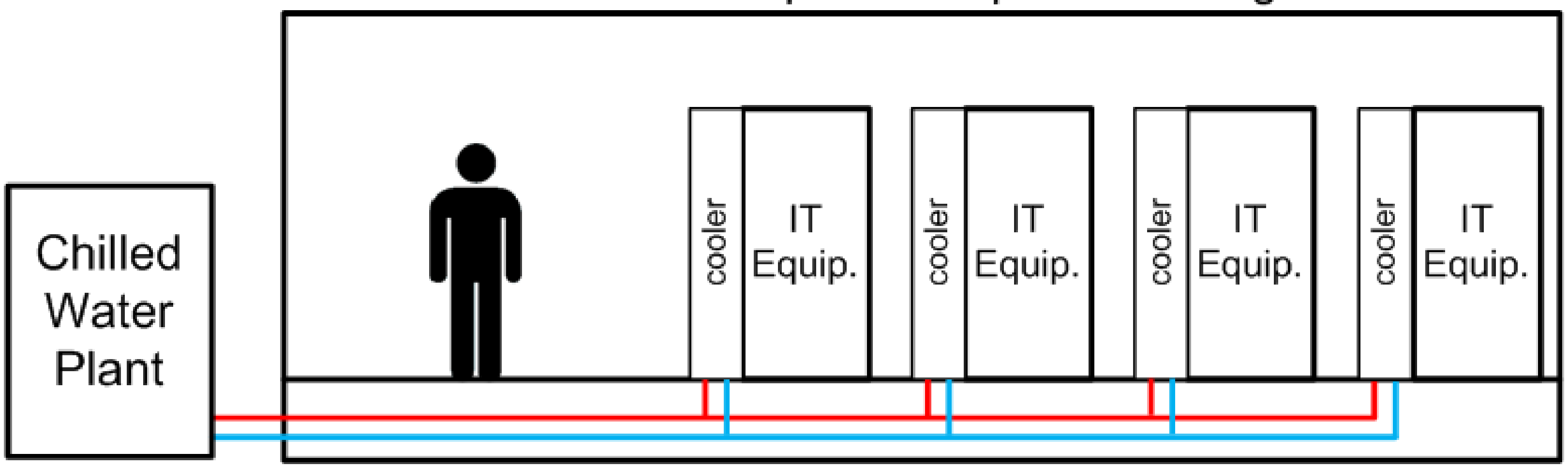
	Typical Infrastructure Design		
Liquid Cooling Classes	Main Cooling Equipment	Supplemental Cooling Equipment	Facility Supply Water Temp(F)
W1(see Figure A-a)	Chiller/Cooling Tower	Water-side Economizer (w drycooler or cooling tower)	35.6-62.6
W2(see Figure A-a)			35.6-80.6
W3(see Figure A-a)	Cooling Tower	Chiller	35.6-89.6
W4(see Figure A-b)	Water-side Economizer (w drycooler or cooling tower)	N/A	35.6-113.0
W5(see Figure A-c) See Operational Characteristics	Building Heating System	Cooling Tower	>113.0

NREL ESIF HPC (HP hardware) using 75 F supply, 113 F return –W4/W5

Conventional Computer Room Cooling



Close Coupled Computer Cooling

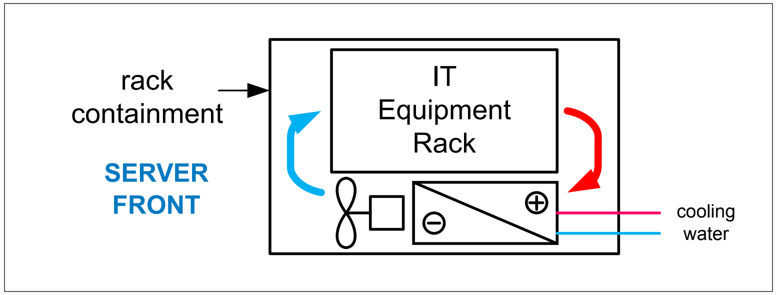


Courtesy of Henry Coles, Lawrence Berkeley National Laboratory

Three Cooling Device Categories

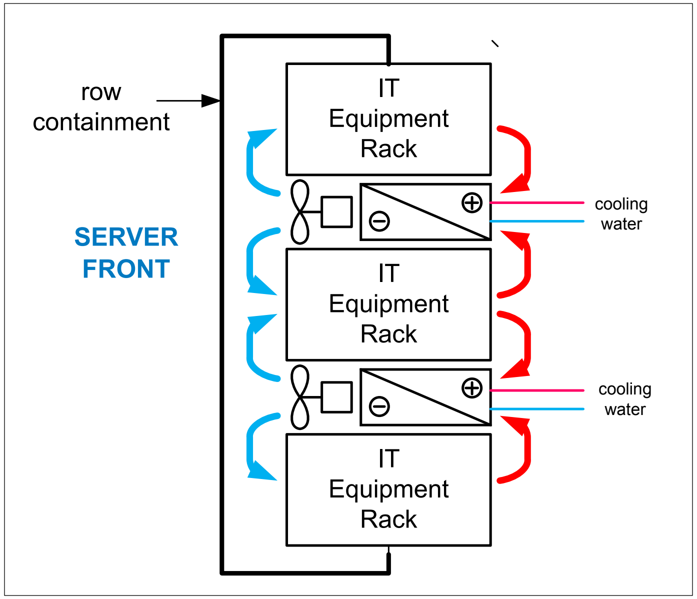
1 - Rack Cooler

- APC-water
- Knürr(CoolTherm)-water
- Knürr(CoolLoop)-water
- Rittal-water



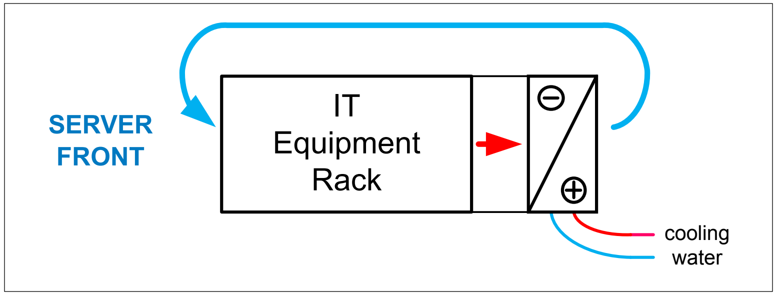
2 - Row Cooler

- APC(2*)-water
- Liebert-refrigerant



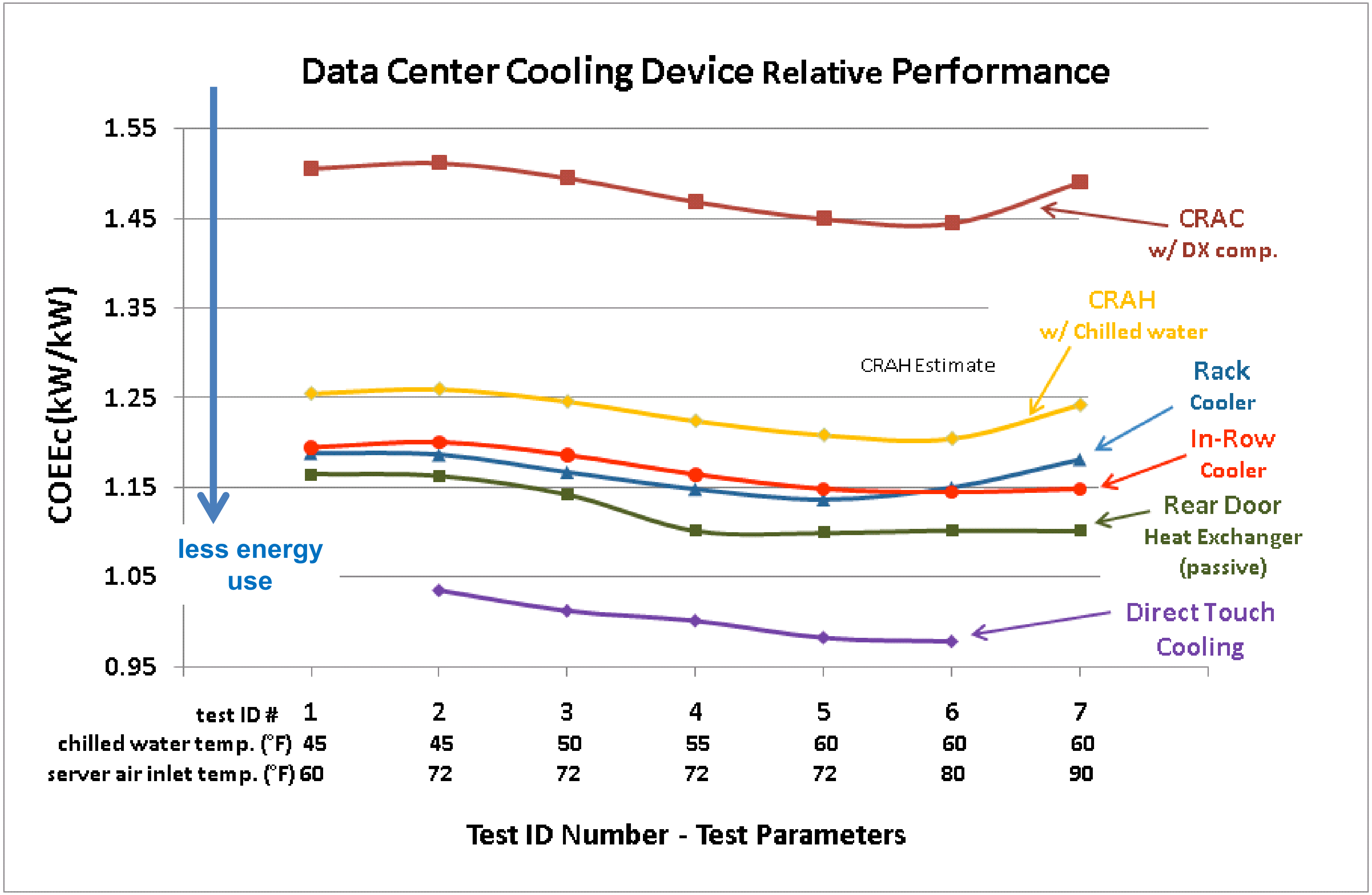
3 - Passive Door Cooler

- IBM-water
- Vette/Coolcentric-water
- Liebert-refrigerant
- SUN-refrigerant



Courtesy of Henry Coles, Lawrence Berkeley National Laboratory

"Chill-off 2" Evaluation of Close-coupled Cooling Solutions



Courtesy of Geoffrey Bell and Henry Coles, Lawrence Berkeley National Laboratory

Cooling Takeaways…

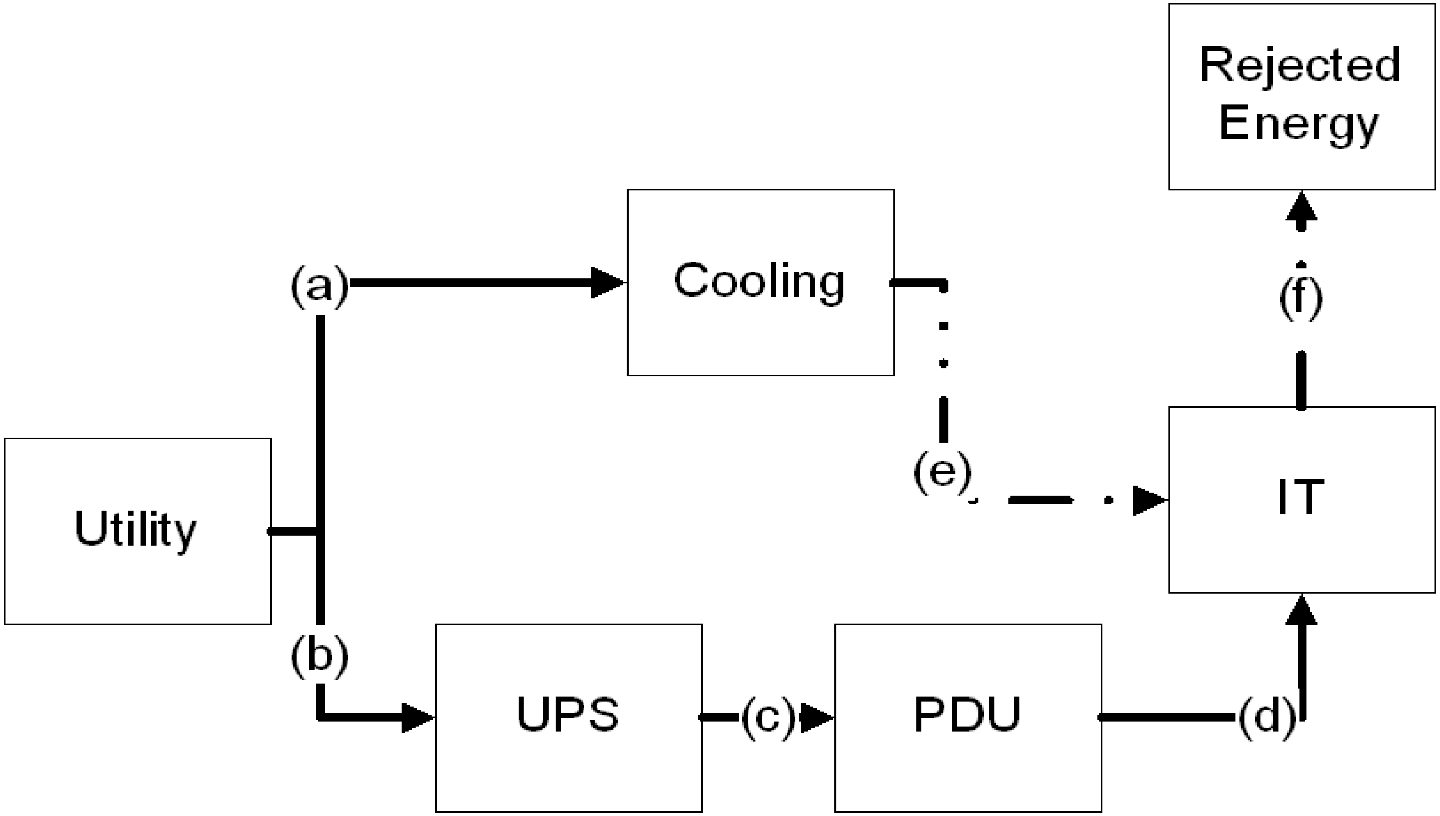
- Use a central plant (e.g., chiller/CRAHs vs. CRAC units)
- Use centralized controls on CRAC/CRAH units to prevent simultaneous humidifying and dehumidifying
- Move to liquid cooling (room, row, rack, chip)
- Consider VSDs on fans, pumps, chillers, and towers
- Use air- or water-side economizers
- Expand humidity range and improve humidity control (or disconnect)

Data Center Efficiency Metric

- **Power Usage Effectiveness (PUE) is an industry standard data center efficiency metric.**
- **The ratio of power used or lost by data center facility infrastructure (pumps, lights, fans, conversions, UPS…) to power used by compute.**
- **Not perfect, some folks play games with it.**
- **2011 survey estimates industry average is 1.8.**
- **Typical data center, half of power goes to things other than compute capability.**

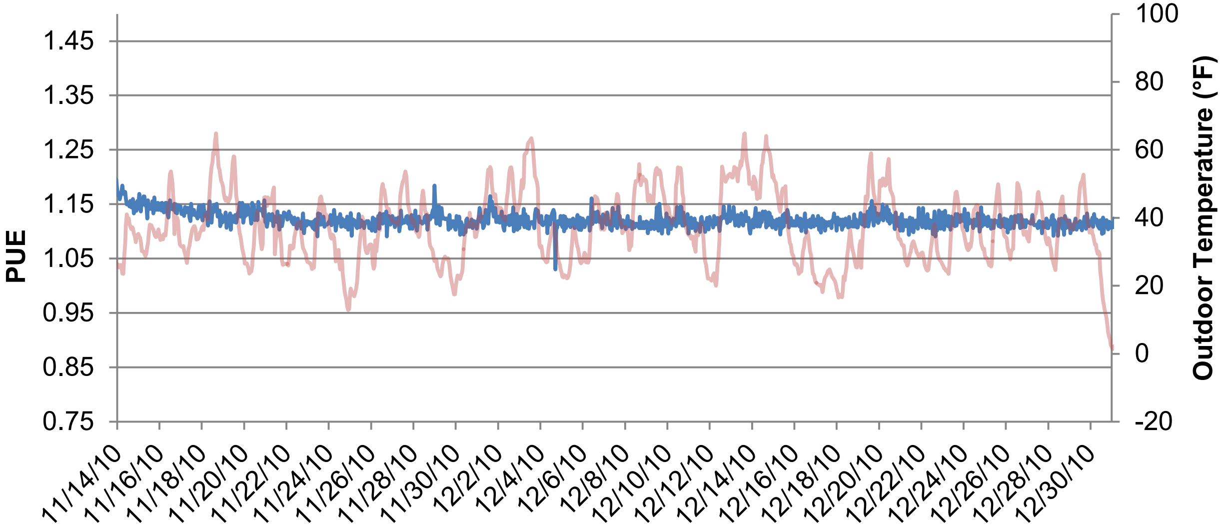
$$P.U.E. = \frac{\text{“IT power”} + \text{“Facility power”}}{\text{“IT power”}}$$

PUE – Simple and Effective

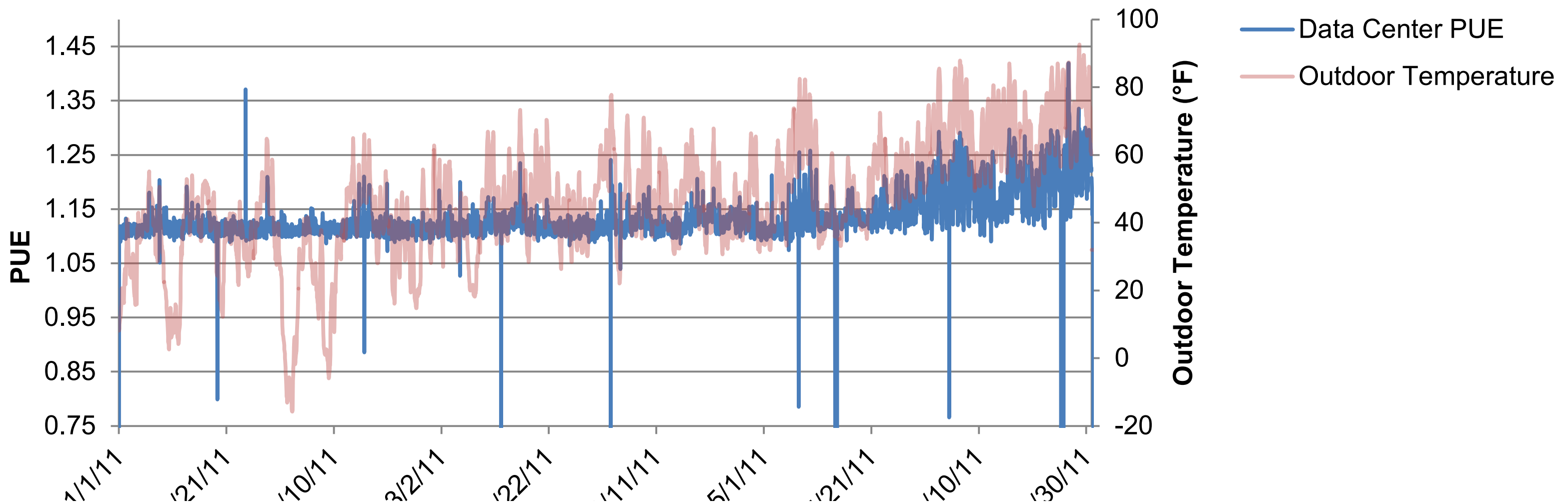


$$PUE = \frac{Total\ Energy}{IT\ Energy} = \frac{Cooling + PowerDistribution + Misc + IT}{IT} = \frac{a+b}{d}$$

Data Center PUE



NREL PIX 17828



"I am re-using waste heat from my data center on another part of my site and my PUE is 0.8!"

http://www.thegreengrid.org/en/Global/Content/white-papers/ERE

“I am not using waste heat from my data center on another part of my site and my PUE is 0.8!”

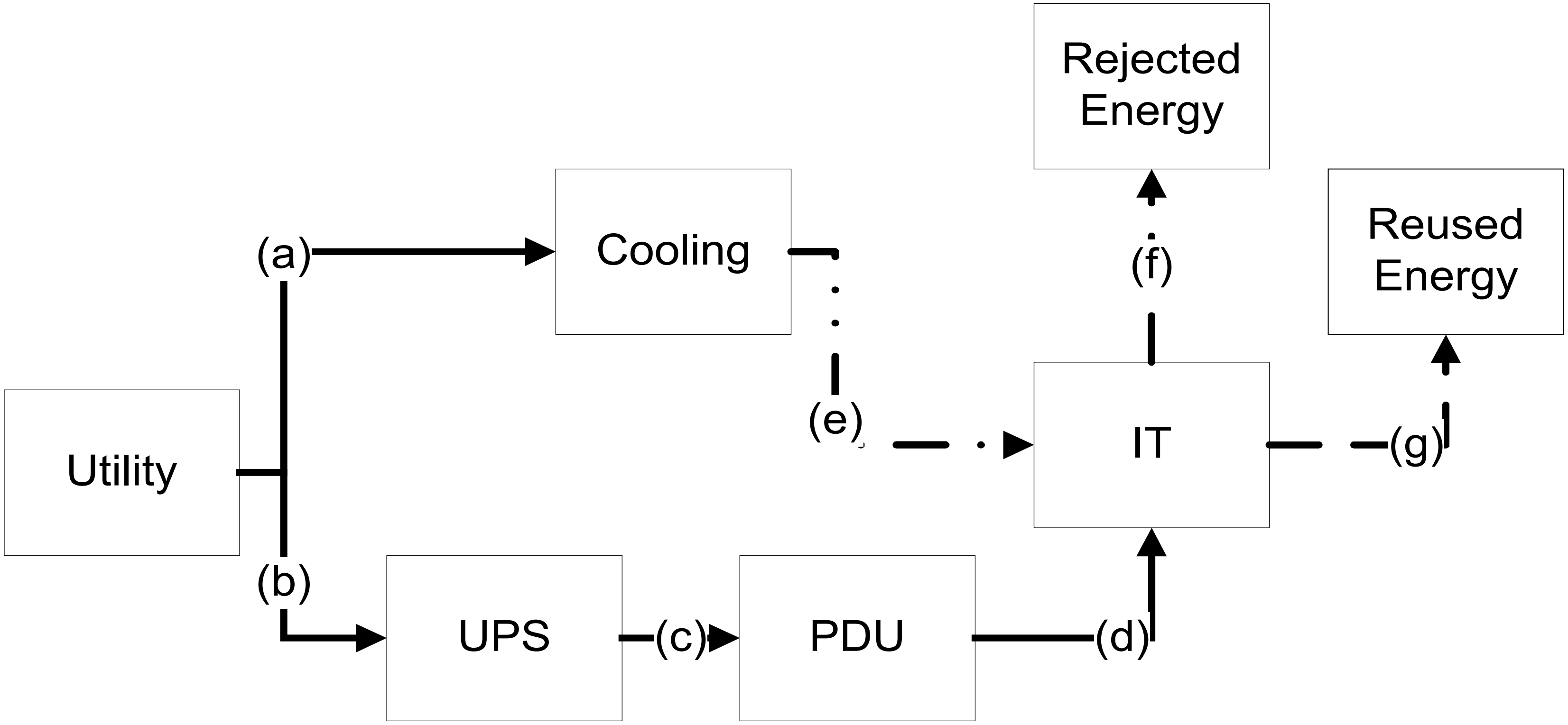
http://www.thegreengrid.org/en/Global/Content/white-papers/ERE

ASHRAE & friends (DOE, EPA, TGG, 7x24, etc..) do not allow reused energy in PUE & PUE is always >1.0.

Another metric has been developed by The Green Grid +; ERE – Energy Reuse Effectiveness.

http://www.thegreengrid.org/en/Global/Content/white-papers/ERE

ERE – Adds Energy Reuse



$$ERE = \frac{Total\ Energy - Reuse\ Energy}{IT\ Energy}$$

$$= \frac{Cooling + PowerDistribution + Misc + IT - Reuse}{IT} = \frac{a + b - g}{d}$$

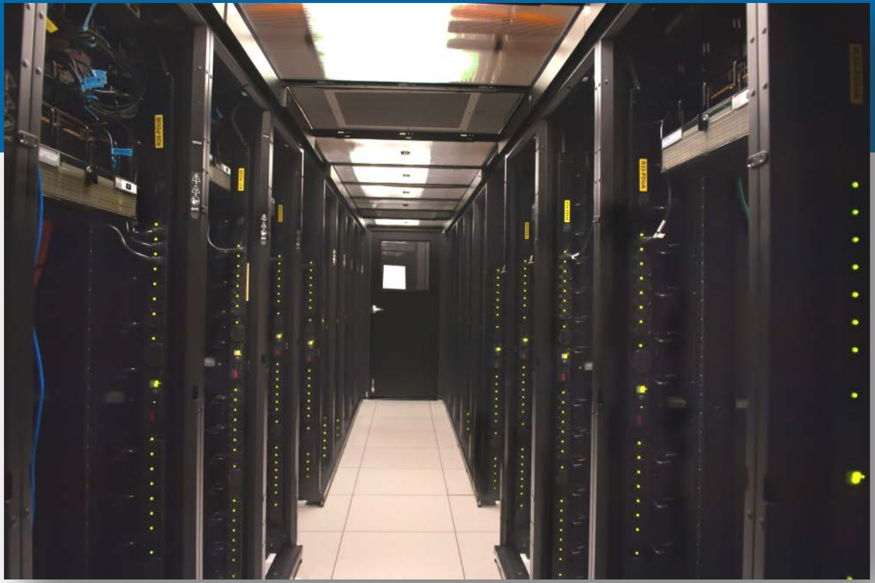
DOE/NREL Research Support Facility

- **More than 1300 people in DOE office space on NREL's campus**
- **360,0,000 ft^2**
- **Design/build process with required energy goals**
  - 25 $kBtu/ft^2$
  - 50% energy savings
  - LEED Platinum
- **Replicable**
  - Process
  - Technologies
  - Cost
- **Site, source, carbon, cost ZEB:B**
  - Includes plugs loads and **datacenter**
- **Firm fixed price - $246/ft^2 construction cost (not including $27/ft^2 for PV from PPA/ARRA)**
- **Opened June 10, 2010 (First Phase)**

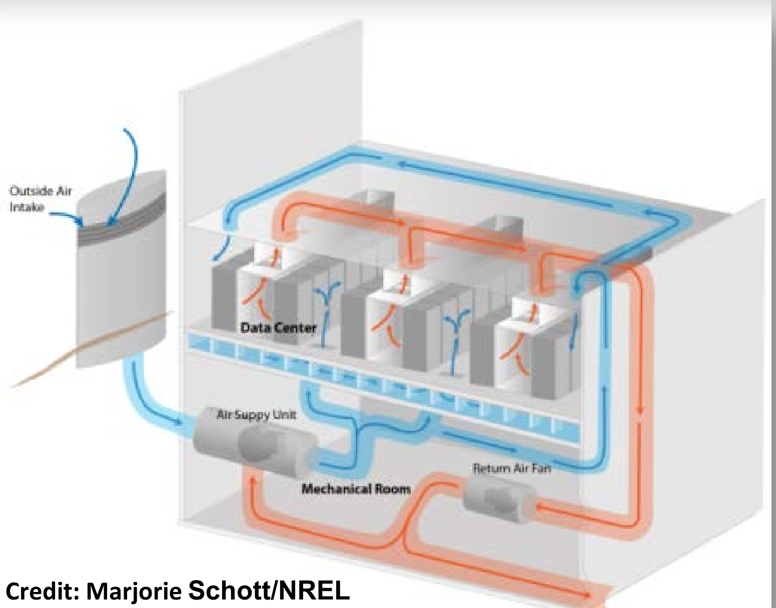
Credit: Haselden Construction

RSF Datacenter

- **Fully containing hot aisle**
  - Custom aisle floor and door seals
  - Ensure equipment designed for cold
    aisle containment
    - And installed to pull cold air
      - Not hot air…
  - 1.18 annual PUE
  - ERE = 0.9
- **Control hot aisle based on return temperature of ~90F.**
- **Waste heat used to heat building.**
- **Economizer and Evaporative Cooling**
- **Low fan energy design**
- **1900 ft^2**



NREL PIX 25417



Credit: Marjorie Schott/NREL

NREL HPC Data Center

Leveraged expertise in energy efficient buildings to focus on showcase data center

Chips to bricks approach

Showcase Facility

- 10MW, 10,000 ft^2
- Leverage favorable climate
- Use evaporative rather mechanical cooling.
- Waste heat captured and used to heat labs & offices.
- **World's most energy efficient data center, PUE 1.06!**
- **Lower CapEx and OpEx.**

High Performance Computing

- Petascale+ HPC Capability in 2013
- 20-year planning horizon
  - 5 to 6 HPC generations.
  - Insight Center
    - Scientific data visualization
    - Collaboration and interaction.

Critical Data Center Specs

- **Warm water cooling, 75F (24C)**
  - Water much better working fluid than air - pumps trump fans.
  - Utilize high quality waste heat, 95F (35C) or warmer.
  - +90% IT heat load to liquid.
- **High power distribution**
  - 480VAC, Eliminate conversions.
- **Think outside the box**
  - Don’t be satisfied with an energy efficient data center nestled on campus surrounded by inefficient laboratory and office buildings.
  - Innovate, integrate, optimize.

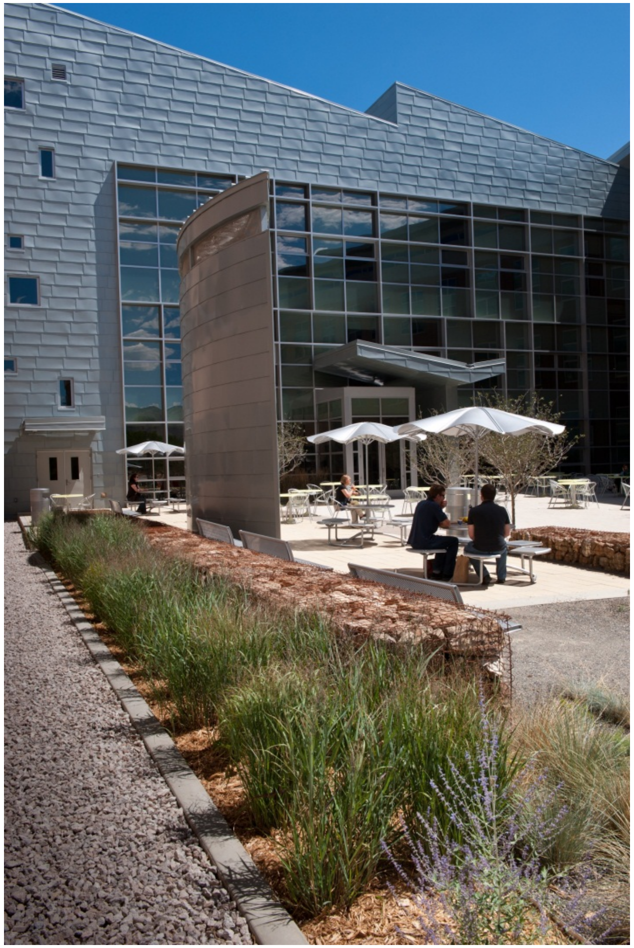
Photo by Steve Hammond, NREL

Dashboards report instantaneous, seasonal, and cumulative PUE values.

Water Considerations

"We shouldn't use evaporative cooling, water is scarce."

- **Thermoelectric power generation (coal, oil, natural gas and nuclear) consumes about 1.1 gallon per kW hour, on average.**
- **This amounts to about 9.5M gallons per MW year.**
- **We estimate about 2.0M gallons water consumed per MW year for on-site evaporative cooling at NREL.**
- **If chillers need 0.2MW per MW of HPC power, then chillers have an impact of 2.375M gallons per year per MW.**
- **Actuals will depend on your site, but evap. cooling doesn't necessarily result in a net increase in water use.**



NREL PIX 17828

Data Center Energy Efficiency

- **ASHRAE 90.1 2011 requires economizer in most data centers.**
- **ASHRAE Standard 90.4P, *Energy Standard for Data Centers and Telecommunications Buildings***
- **PURPOSE: To establish the minimum energy efficiency requirements of data centers and telecommunications buildings for:**
  - Design, construction, and a plan for operation and maintenance
- **SCOPE: This standard applies to:**
  - New, new additions, and modifications to data centers and telecommunications buildings or portions thereof and their systems
- **Will set minimum PUE based on climate**
- **More details at https://www.ashrae.org/news/2013/ashrae-seeks-input-on-revisions-to-data-centers-in-90-1-energy-standard-scope**

Energy Conservation Measures

1. **Reduce the IT load - Virtualization & Consolidation (up to 80% reduction).**
2. **Implement contained hot aisle and cold aisle layout.**
   - Curtains, equipment configuration, blank panels, cable entrance/exit ports,
3. **Install economizer (air or water) and evaporative cooling (direct or indirect).**
4. **Raise discharge air temperature. Install VFD's on all computer room air conditioning (CRAC) fans (if used) and network the controls.**
5. **Reuse data center waste heat if possible.**
6. **Raise the chilled water (if used) set-point.**
   - Increasing chiller water temperature by 1° F reduces chiller energy use by 1.4%
7. **Install high efficiency equipment including UPS, power supplies, etc.**
8. **Move chilled water as close to server as possible (direct liquid cooling).**
9. **Consider centralized high efficiency water cooled chiller plant**
   - Air-cooled = 2.9 COP, water-cooled = 7.8 COP.

QUESTIONS?

RSF II
21 kBtu/ft2
$246/ft2 Construction Cost

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