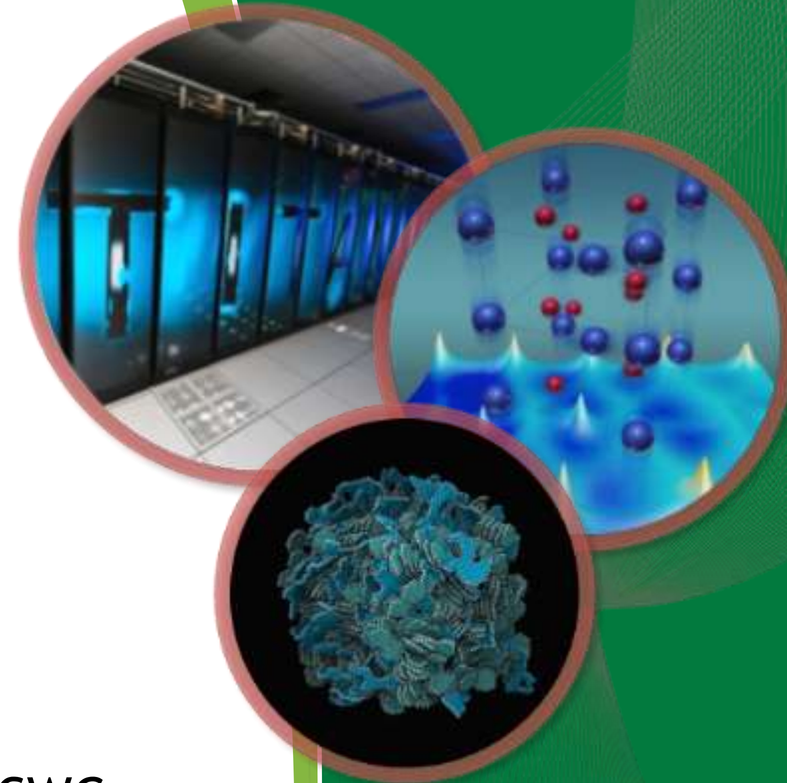
HPC Data Center Cooling Design Considerations



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+
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Corresponding Member of ASHRAE TC9.9

U.S. DEPARTMENT OF ENERGY

OAK RIDGE National Laboratory

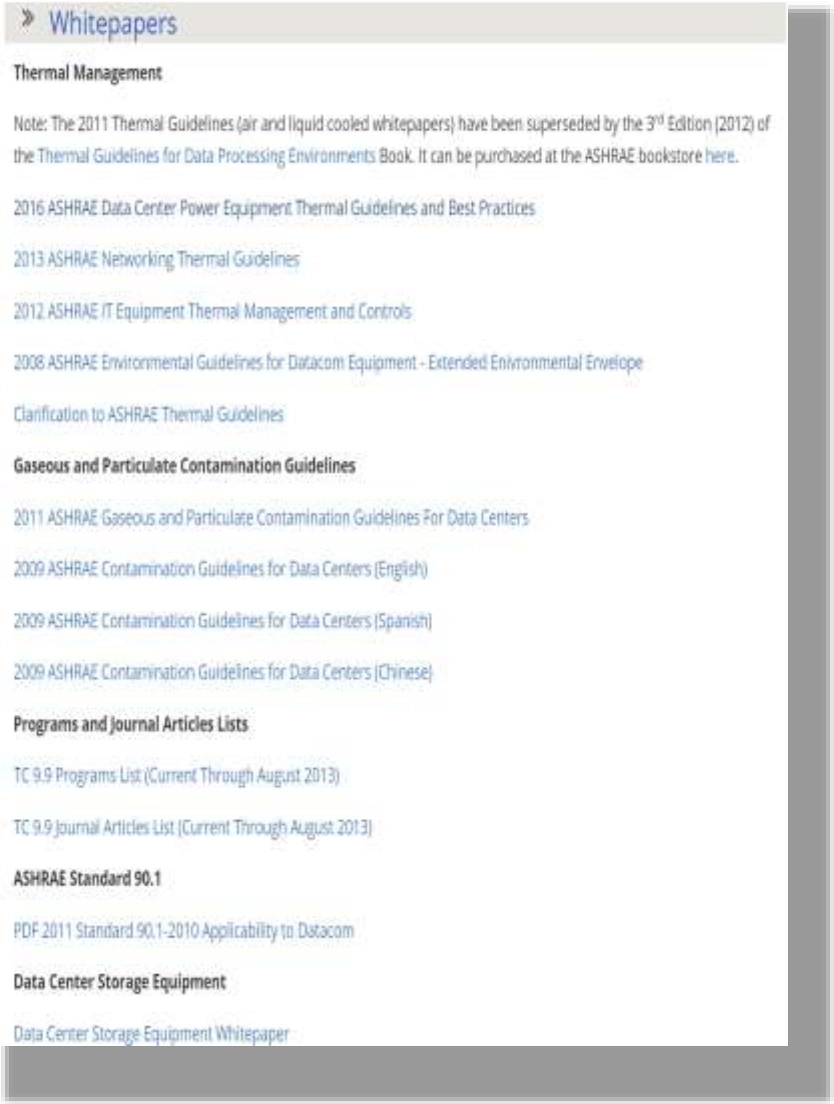
Data Center Efficiency

Today's discussion will cover:

1) ASHRAE Activities
2) Fundamentals of the design of data centers
3) Typical Equipment involved in cooling Data Centers
4) Best Practices/Lessons Learned
5) Summit Design Overview

ASHRAE – TC9.9 Activities

- Meetings cover – Website, Handbook updates, Programs, Research (High Humidity, CFD, and DC Energy Modeling), Liaison Reports, and new/updated publications
- Subgroups for data center energy calculations
  - Data center zone/space, air flow, solution/simulation model
  - Prototype correlation based data center HVAC systems spreadsheet model based on Comnet
  - Prototype TC 4.7 secondary and primary toolkit spreadsheet model using callable Fortran from Excel


» Whitepapers

Thermal Management

Note: The 2011 Thermal Guidelines (air and liquid cooled whitepapers) have been superseded by the 3rd Edition (2012) of the Thermal Guidelines for Data Processing Environments Book. It can be purchased at the ASHRAE bookstore here.

2016 ASHRAE Data Center Power Equipment Thermal Guidelines and Best Practices

2013 ASHRAE Networking Thermal Guidelines

2012 ASHRAE IT Equipment Thermal Management and Controls

2008 ASHRAE Environmental Guidelines for Datacom Equipment - Extended Environmental Envelope

Clarification to ASHRAE Thermal Guidelines

Gaseous and Particulate Contamination Guidelines

2011 ASHRAE Gaseous and Particulate Contamination Guidelines For Data Centers

2009 ASHRAE Contamination Guidelines for Data Centers (English)

2009 ASHRAE Contamination Guidelines for Data Centers (Spanish)

2009 ASHRAE Contamination Guidelines for Data Centers (Chinese)

Programs and Journal Articles Lists

TC 9.9 Programs List (Current Through August 2013)

TC 9.9 Journal Articles List (Current Through August 2013)

ASHRAE Standard 90.1

PDF 2011 Standard 90.1-2010 Applicability to Datacom

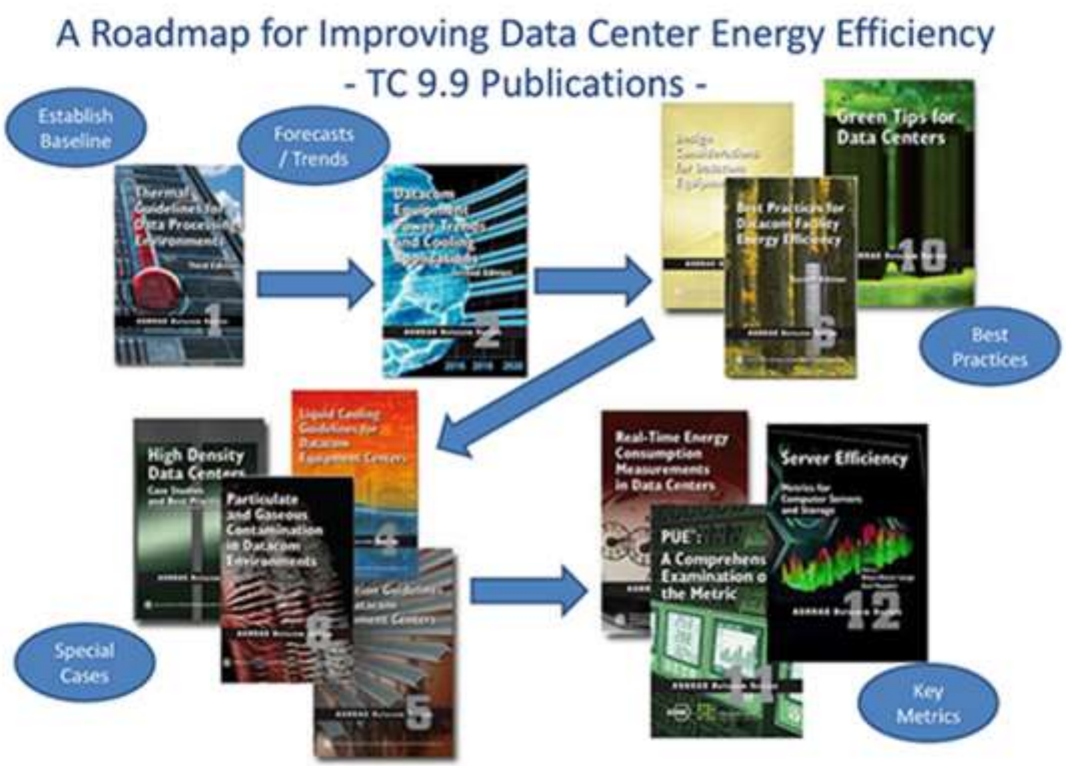
Data Center Storage Equipment

Data Center Storage Equipment Whitepaper

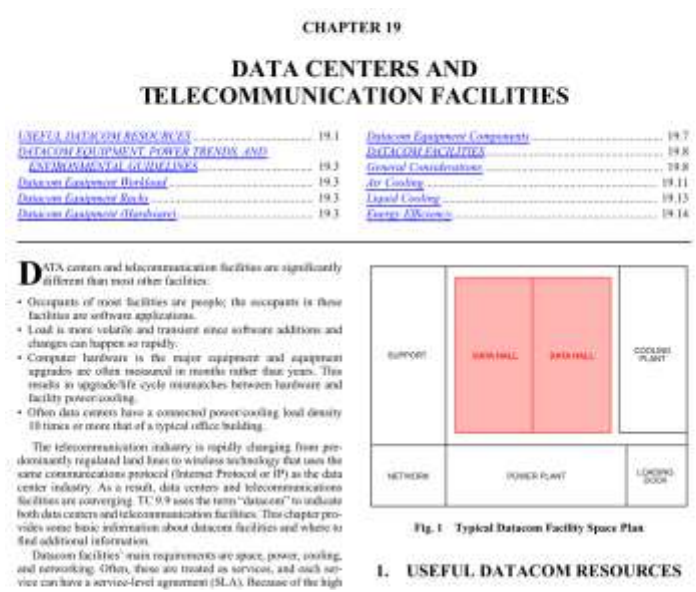
ASHRAE

- ASHRAE TC 9.9 – Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment

- TC 9.9 is concerned with all aspects of mission critical facilities, technology spaces, and electronic equipment/systems. This includes data centers, computer rooms/closets, server rooms, raised floor environments, high-density loads, emergency network operations centers, telecom facilities, communications rooms/closets, and electronic equipment rooms/closets.



HVAC Applications Handbook



CHAPTER 19

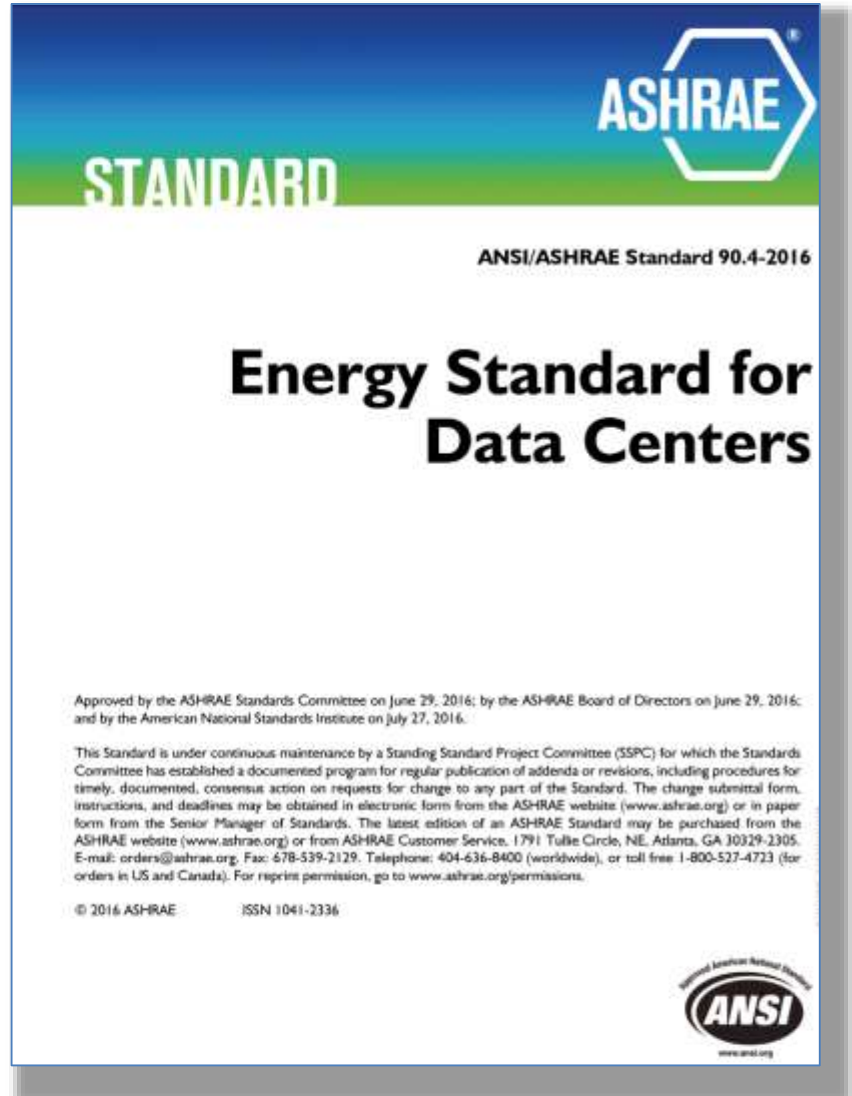
DATA CENTERS AND TELECOMMUNICATION FACILITIES

Fig. 1 Typical Datacom Facility Space Plan

1. USEFUL DATACOM RESOURCES

ASHRAE – 90.4 Approved/Published

- ASHRAE 90.4 – Energy Standard for Data Centers
- Data Center – a room or building, or portions thereof, including computer rooms being served by the data center systems, serving a total ITE load greater then 10 kW and 20 W/ft^2 (215 W/m^2) of conditioned floor area.
- Performance Based
  - Mechanical and Electrical
  - Trade-off Method
- Compliance requires calculations at 100% and 50% of the design ITE load.
- Refers to 90.1 for envelope, lighting, service water heating, and equip. eff.


STANDARD

ASHRAE

ANSI/ASHRAE Standard 90.4-2016

Energy Standard for Data Centers

Approved by the ASHRAE Standards Committee on June 29, 2016; by the ASHRAE Board of Directors on June 29, 2016; and by the American National Standards Institute on July 27, 2016.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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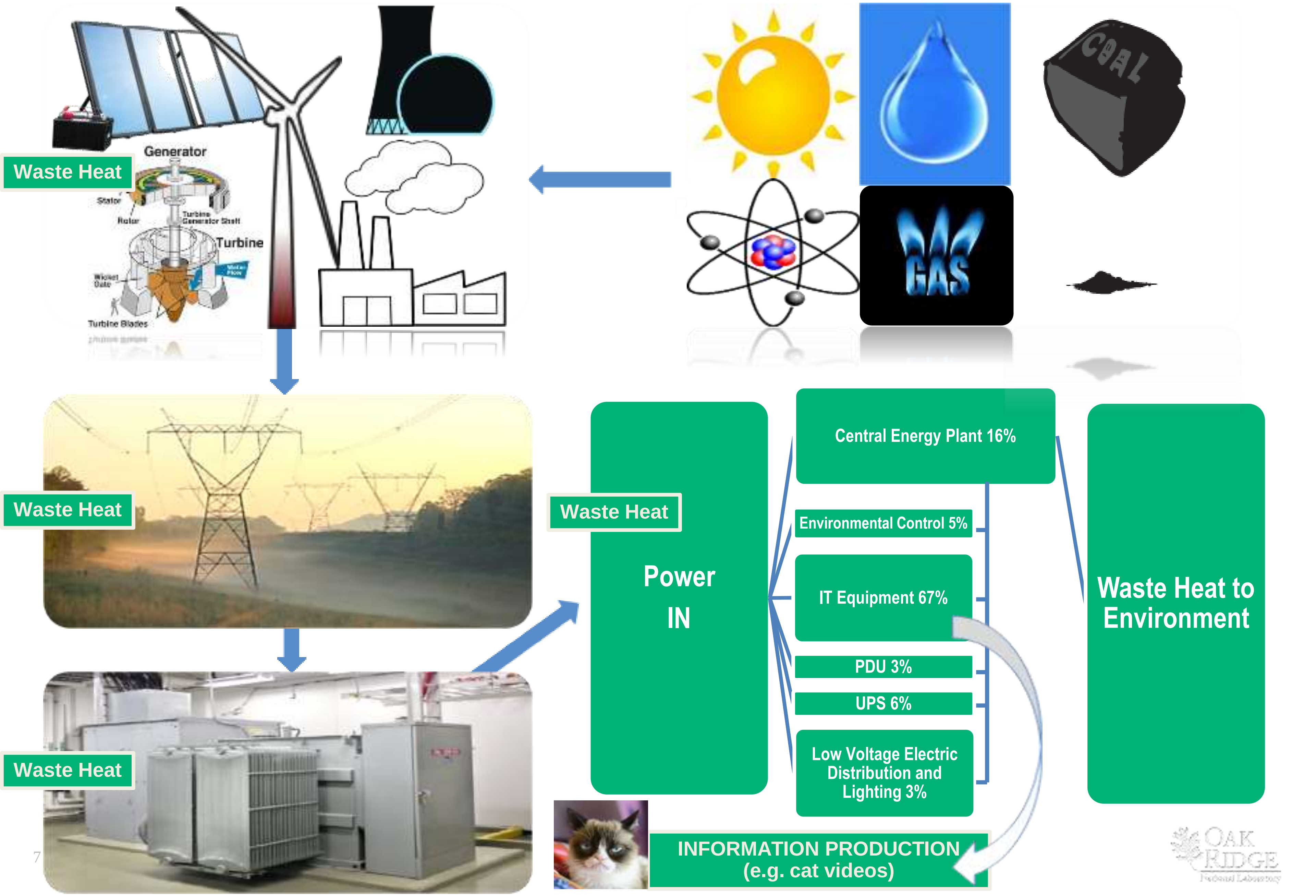
ANSI

Data Center Efficiency

According to DOE

- How many data centers are in the U.S.?
  - ~3,000,000
  - ~1 for every 100 people
  - Spread all over the country
- What is a data center? – depends on who you ask…
  - A repository (closet, room, floor, or building) for the storage, management, and dissemination of data and information. Data centers house computing systems and associated components, such as telecommunications and storage systems.
- Why does it matter?
  - In 2014, U.S. data centers consumed ~70 billion kWh, or about 1.8% of total US electrical consumption. **The number of data centers is growing and total energy use is expected to grow 4% from 2014-2020.** (Source: Lawrence Berkley National Laboratory).

Data Center Cooling – Fundamentals



Data Centers and Mechanical Efficiency

- Measures of Efficiency
  - kW/ton, kW/cfm, etc.
- Technologies (Inherent Efficiencies)
  - Within the Data Center
    - Humidity Control
    - Air Cooling
      - Perimeter
      - In-row
      - Cabinet Based
      - Air Side Economizers
    - Liquid Cooling
  - Central Energy Plants
    - Air Cooled
    - Water Cooled
    - Water Side Economizers

Data Center Efficiency
What impacts efficiency in data centers?

- Electrical
  - Individual component/equipment efficiency
  - System efficiency
- **Mechanical**
  - **Individual component/equipment efficiency**
  - **System efficiency**
    - **Controls**
- IT
  - Individual component/equipment efficiency
    - Energy Star
  - System efficiency
    - Policy
    - Virtualization
    - Cloud

Data Center Efficiency

Measures of Efficiency

- It’s how much do you have to put in compared to what you get out
- Power Usage Effectiveness (PUE) ratio of total data center energy consumed annually to the total IT energy consumed annually. **Lower the better.**

$$PUE = (E_{FACILITY} + E_{IT}) / E_{IT}$$

$E_{FACILITY}$ = Energy consumed by the IT supporting systems annually

E_{IT} = Energy consumed by the IT equipment annually

2.0 Standard, 1.4 Good, 1.1 Better, 1.0 Best

1/PUE=DCiE (Data Center Infrastructure Efficiency)

Data Center Efficiency

Measures of Efficiency

- It's how much do you have to put in compared to what you get out
- kW/ton – commonly used in cooling plants

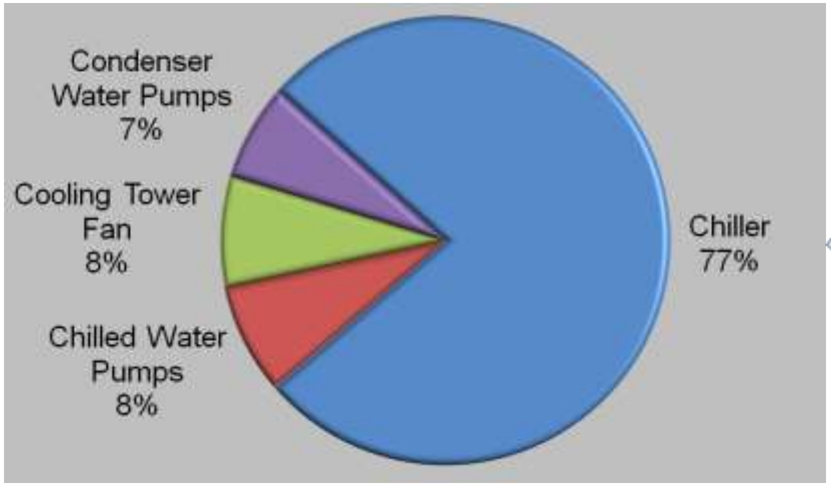
$$\textbf{Plant Eff.} = \textbf{kW}_{\textbf{CONSUMED}}/\textbf{tons of cooling}$$

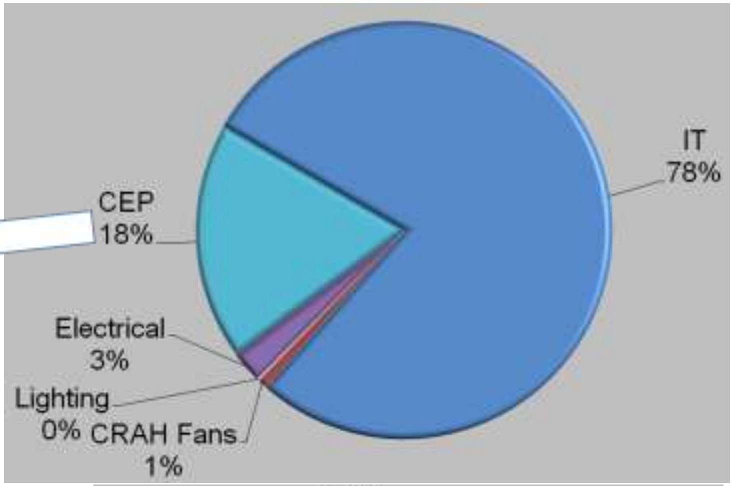
kW= Power consumed by the facility

Tons = Rate at which heat is removed from the system

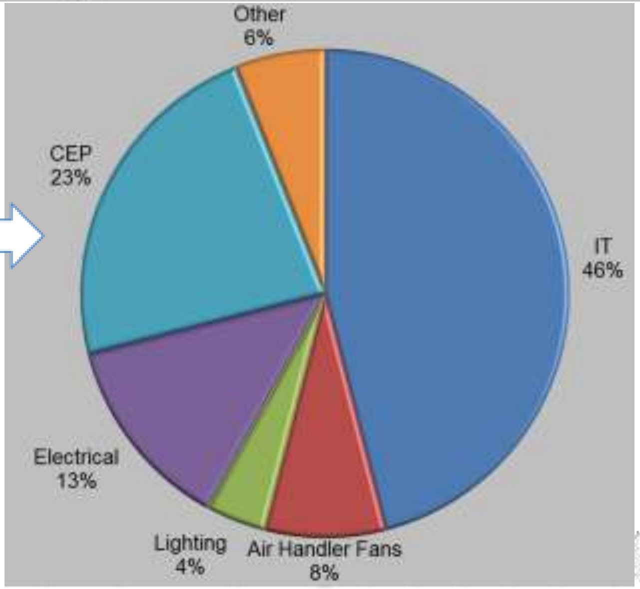
Data Center Efficiency

- Measurements taken while a 6600 ton chiller plant had a <u>HPC</u> <u>IT</u> load of ~8.1MW (2300 tons or 35% load). Chiller Plant efficiency = 0.75kW/ton

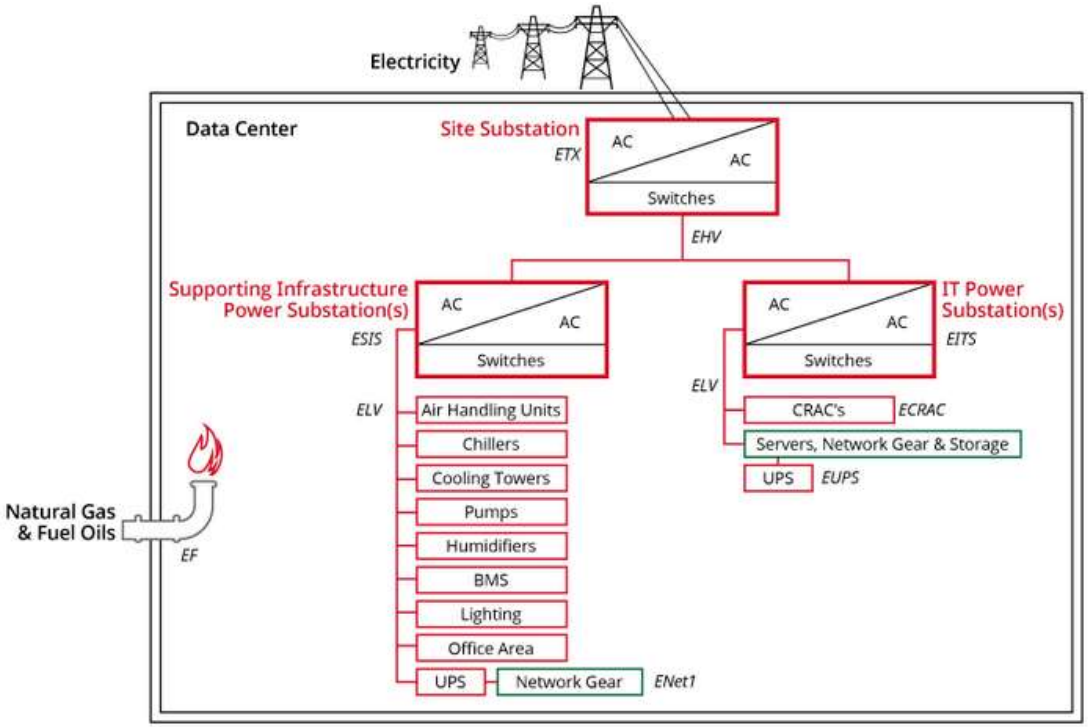




- For a "typical" data center



Data Center Efficiency



Key

Red = Overhead Energy
Green = IT Energy
ESIS - Supporting Infrastructure Substation Energy
EITS - IT Substation Energy
ETX - Medium/High Voltage Transformer Losses
EHV - High Voltage Cable Losses
ELV - Low Voltage Cable Losses
EF - Fuel Oil & Natural Gas Energy
ECRAC - CRAC Energy
EUPS - UPS Losses
ENet1 - Network Room Energy

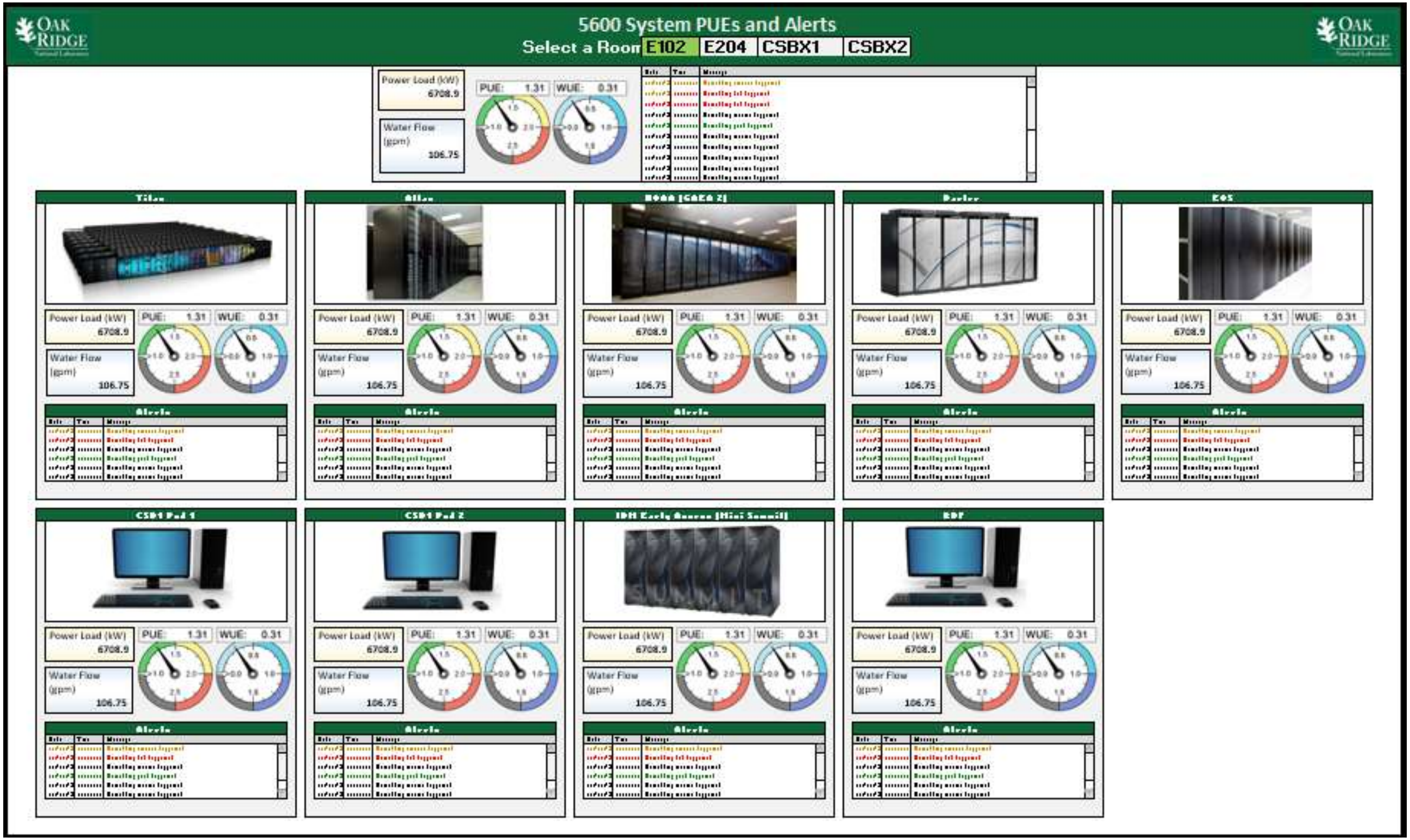
Figure 3: Google includes servers, storage, and networking equipment as IT equipment power. We consider everything else overhead power.

Equation for PUE for our data centers

$$PUE = \frac{ESIS + EITS + ETX + EHV + ELV + EF}{EITS - ECRAC - EUPS - ELV + ENet1}$$

Monitoring & Metering Strategy

System PUE Dashboard

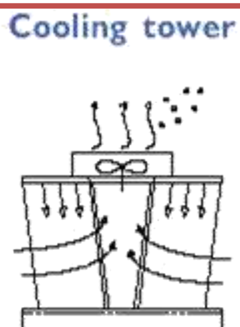


Data Center Cooling

Final Heat Rejection

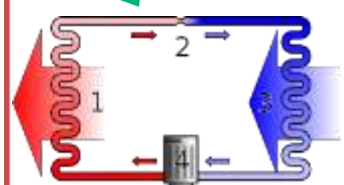
- Dry Cooler
- Air Cooled
- Evaporatively Cooled
- Water Cooled w/ HX
- Water Cooled Direct

Water to Outside Air (Cooling Tower)



Central Energy Plant

- Refrigerant DX
- Chiller
- Economizer
- Heat Exchanger
  - Can be integrated with chiller for partial use.



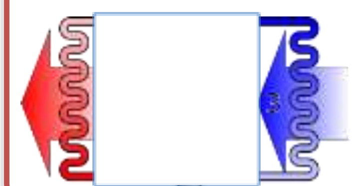
Refrigerant to Water (Chiller Condenser)

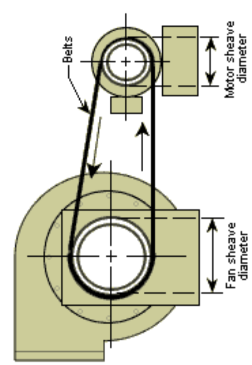
Water to Refrigerant (Chiller Evaporator)

Distributor of Cooling

- CRAC
- CRAH
- Central AHU
- *Liquid Cooling*
- *CDU W/ RDHx*

Air to Water (CRAH)

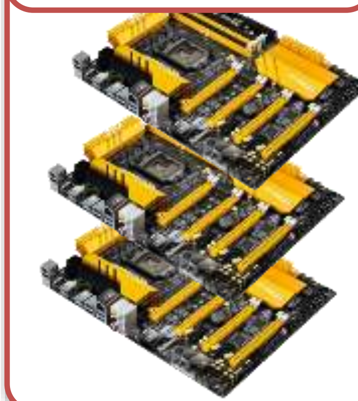




Distribution Method

- Raised Floor
- Over Head
- In Row
- In Rack
- On Board

Circuitry to Air and/or Liquid (Rack)

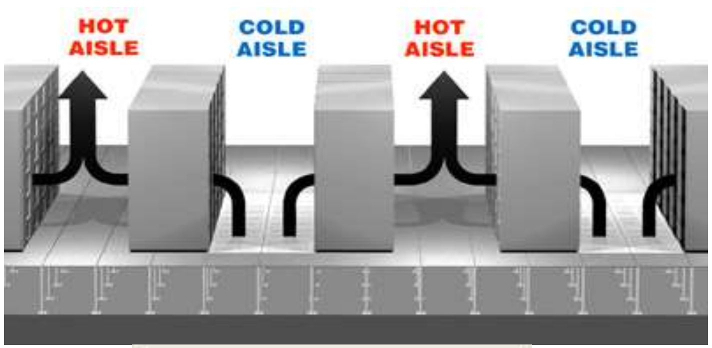


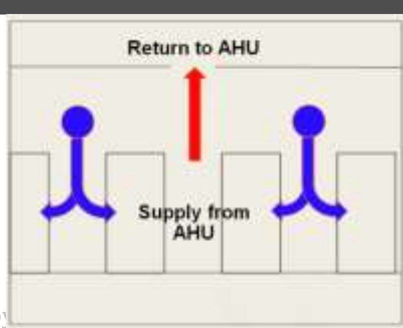
NEED TO SPECIFY HOW THE HEAT GETS FROM THE CIRCUITRY TO THE ENVIRONMENT PROVIDE EQUIPMENT SPECIFICATIONS

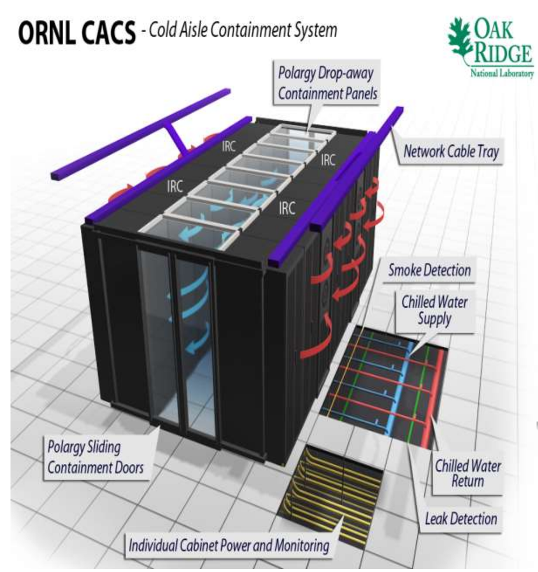
Data Center Efficiency – Air Management

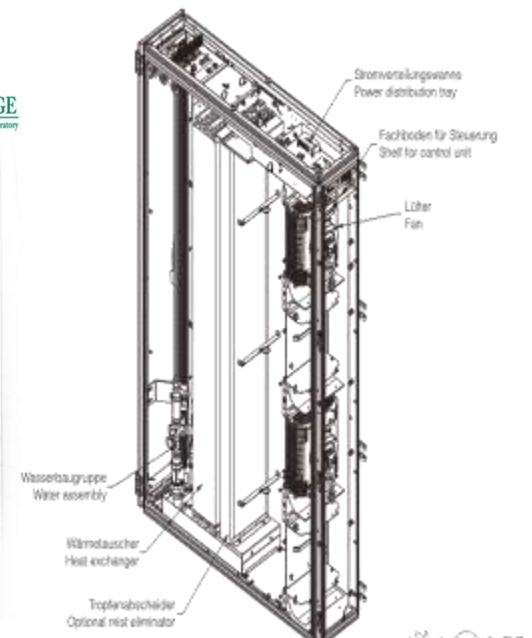
General Air Side Cooling Design Using Facility Fans

- Make air flow management a priority from the beginning and make it visible, so it is more likely to be maintained. Keep the supply and return air paths separate!
- Use premium efficiency motors with variable frequency drives (VFDs) or electronically commutated (EC) direct drive fans
- Use filters with low pressure drop
- Minimize pressure drop in the air distribution
- Minimize air flow volume and length of air flow path to the IT equipment and back to the air handler



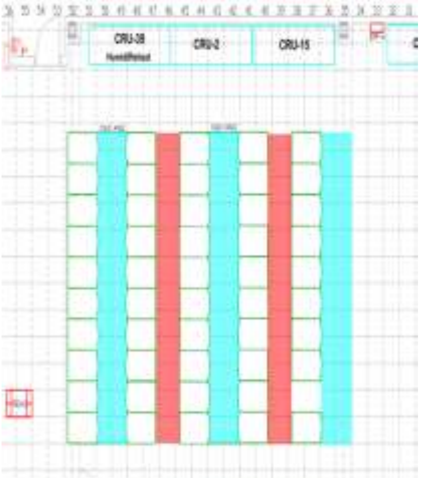






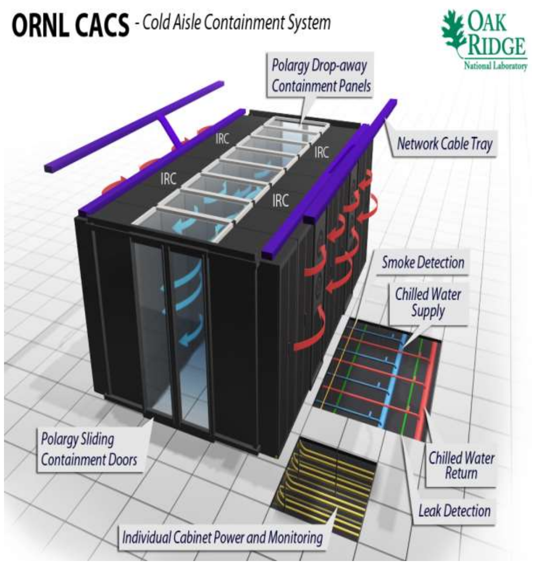
Data Center Efficiency - Perimeter

- Automatic backflow damper with fail closed position (if redundancy allows)
- Include VFD
- Control air flow based on underfloor pressure or rack inlet temperatures
- Return air from the highest point possible above the CRAH/CRAC
- Run the fewest number of CRAHs/CRACs possible at minimum VFD speed needed
- Locate down flow air handlers at the ends of hot aisle if possible
- Avoid installing down flow air handlers too close to cold aisles
- Maintain clearances around the air handlers to allow proper maintenance



Data Center Efficiency – In-Row Coolers

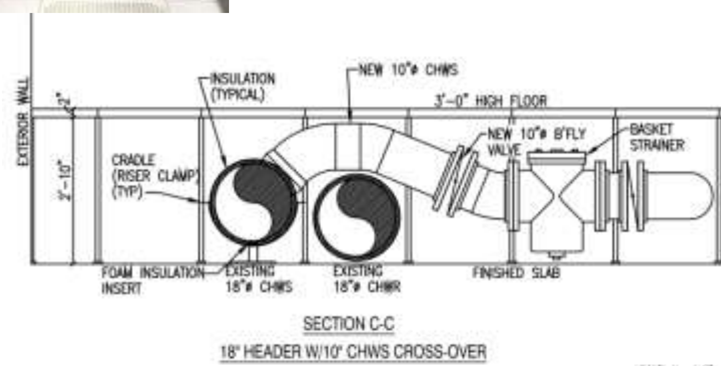
- Require EC Fans
- Control air flow based on CAC pressure or rack inlet temperatures
- Control supply air temperature on an individual unit basis
- Run the fewest number of IRCs possible at minimum EC fan speed needed
- Locate throughout the row for best air flow distribution
- Avoid installing IRCs too close to the ends of the aisles
- Calibrate sensors periodically



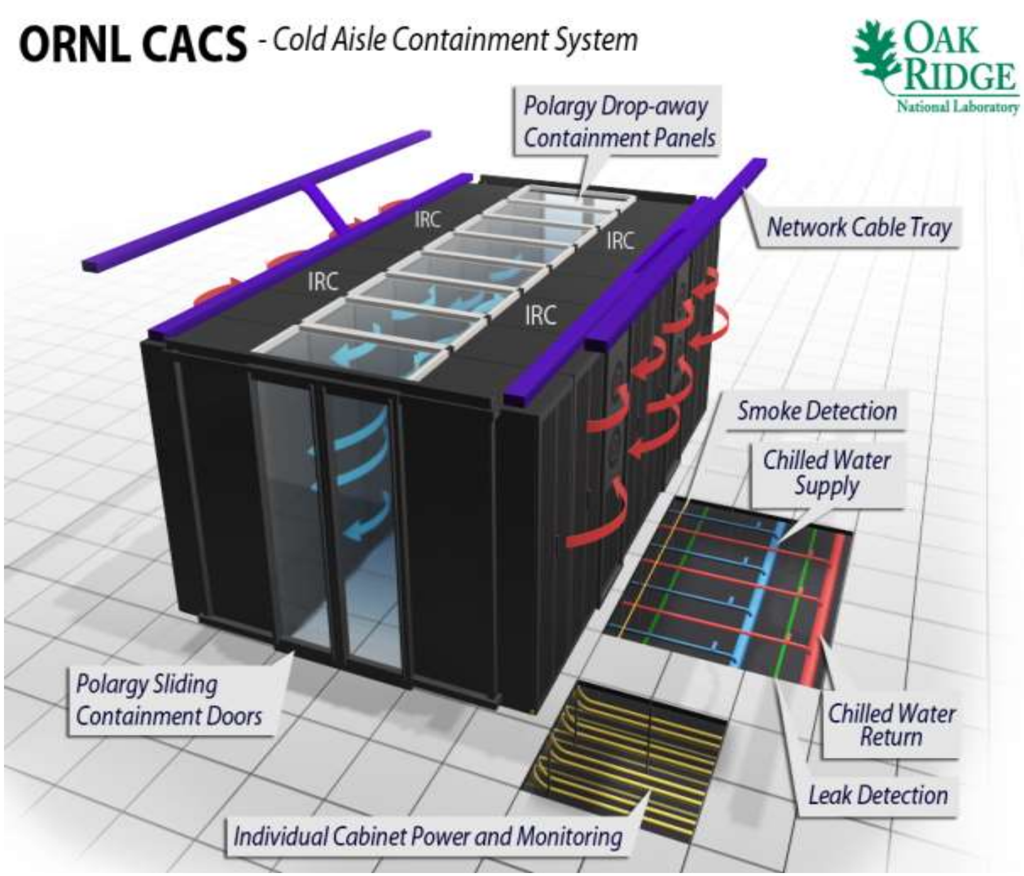
Data Center Efficiency – Air Flow Management – Air Distribution

CRU Return Temperatures Study - Before and After Installing Top Hats

	Before	After Top Hats	Difference
CRU 3	64.4	68.3	3.9
CRU 2	65.7	70.1	4.4
CRU 1	73.8	76.2	2.3
CRU 38	65.4	70.7	5.3
CRU 21**	67.3	71.9	4.6
CRU 20	72.7	71.9	-0.8
CRU 15	66.6	75.2	8.5
Average	68.0	72.1	**4.4**



Data Center Efficiency – Air Flow Management – Hot/Cold Aisle Containment

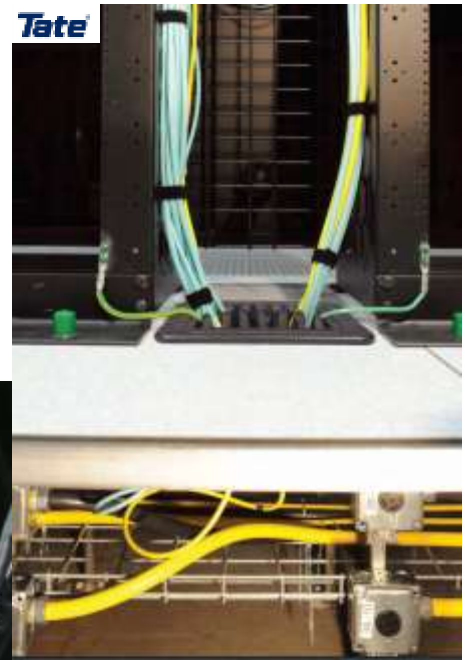


POLARGY

PolarFlex™ 42U Blanking Panels

PolarBlock™ Air Separation Skirts and Barriers

Data Center Efficiency – Air Flow Management – Floor Penetrations



Tate®

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National Laboratory

Data Center Efficiency – Air Flow Management – Active Tiles

Data Center Efficiency – Air Flow Management Metrics

- Airflow efficiency - Air Handler Fan Power (W)/Total Air Flow (cfm)
  - **1.25W/cfm Standard**
  - **0.75W/cfm Good**
  - **0.5W/cfm Better**
- Return Temperature Index (RTI)
  - RTI is a measure of the efficiency of air flow in the data center. The results of this calculation show how much improvement the air flow system can have. The desired result is 90%-110%. An RTI value of less than 100% indicates that the some of the supply air is by-passing the racks, and a value greater than 100% indicates that there is recirculation of air from the hot aisle.

$$RTI = \left(\frac{Return_{AT} - Supply_{AT}}{Outlet_{RT} - Inlet_{RT}}\right)$$

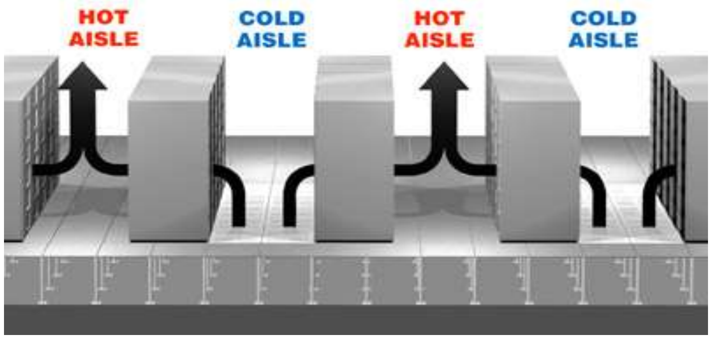
Where

$Return_{AT}$ . . .= CRAH Return Air Temperature

$Supply_{AT}$ . . .= CRAH Supply Air Temperature

$Outlet_{RT}$ . . .= Rack Outlet Mean Temperature

$Inlet_{RT}$ . . . . .= Rack Inlet Mean Temperature



Data Center Efficiency – Air Flow Management Metrics

- Rack Cooling Index (RCI)
  - The RCI is a measure of compliance with ASHRAE/NEBS temperature specifications. RCI_{HI} = 100%: no temperature above max recommended, RCI_{LO} = 100%: no temperature above max recommended. Below 90% is poor in this index.

$$RCI_{HI} = \left[1 - \frac{Average\ Over\ Temp}{Max\ Allowed\ Over\ Temp}\right] * 100(\%)$$

Where

Max Allowed Over Temp . . . . . . =32°C or 89.6°F

Max Recommended . . . . =27°C or 80.6°F

$Average\ Over\ Temp = Average\ Temp - Max\ recomended$

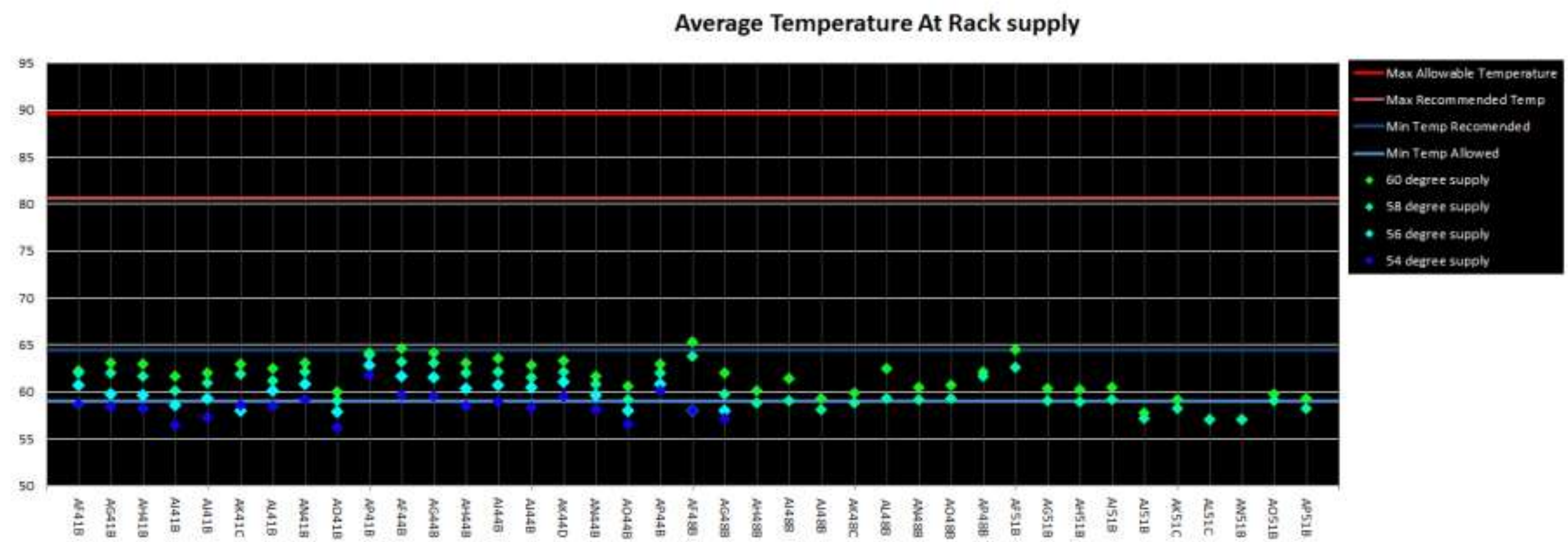
$$RCI_{LOW} = \left[1 - \frac{Average\ Under\ Temp}{Min\ Allowed\ Under\ Temp}\right] * 100(\%)$$

Where

Min Allowed Under Temp . . . . . =15°C or 59.0°F

Min Recommended . . . . =18°C or 64.4°F

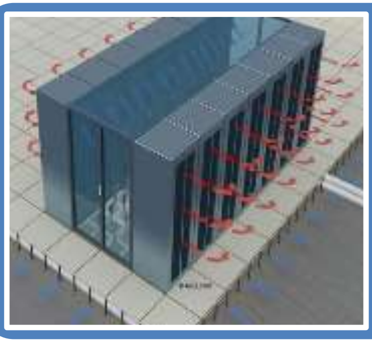
$Average\ Under\ Temp = Min\ Recommended - Average\ Temp$



Energy Efficiency Best Practices

Water Cooled Computing

- Trend is towards elevated chilled water temps (dedicated systems?)
- Water side economizers
- Possible to eliminate or reduce chiller use in some climates
- Lake or seawater cooling



In Row Cooling

- Reduces floor space requirements
- Allows for increased rack density
- 30-40% more efficient that perimeter cooling

Air Flow Management

- Hot/cold isle containment
- Blanking panels in racks
- Seal raised floor openings

Energy Efficiency Best Practices

Variable Frequency Drives (VFDs)

- Utilized on chillers, towers, pumps
- Significant partial load savings
- Allows for higher chilled water temps
- Sensitive to power quality events, may require UPS power

Transformers near loads

- Reduces line loses
- Climate controlled electrical rooms improve reliability and maintainability
- Reduces copper costs for distribution to loads

Metering

- Recommend metering power, chilled water, potable water usage on per system and data center total basis
- Allows for metrics (PUE) and measuring impact of efficiency upgrades
- Useful in determining available capacity for future systems

Energy Efficiency Best Practices

High Efficiency UPS

- Energy Efficient UPS Mode
- Allows for higher energy efficiency to load
- Long Battery life

Data Center Efficiency

Best Practice Features in the Data Center

- Dew Point Control with supervisor control preventing simultaneous dehumidification and humidification. Have dedicated system for controlling humidity if possible.
- Aisle containment – CAC, HAC for row or perimeter based cooling
- Floor penetration seals – grommets, brushes
- Pressurization air – conditioned and filtered
- Install vapor barrier around the data center
- Turn off reheat (part of dehumidification process)
- Control supply air temperature

Data Center Efficiency

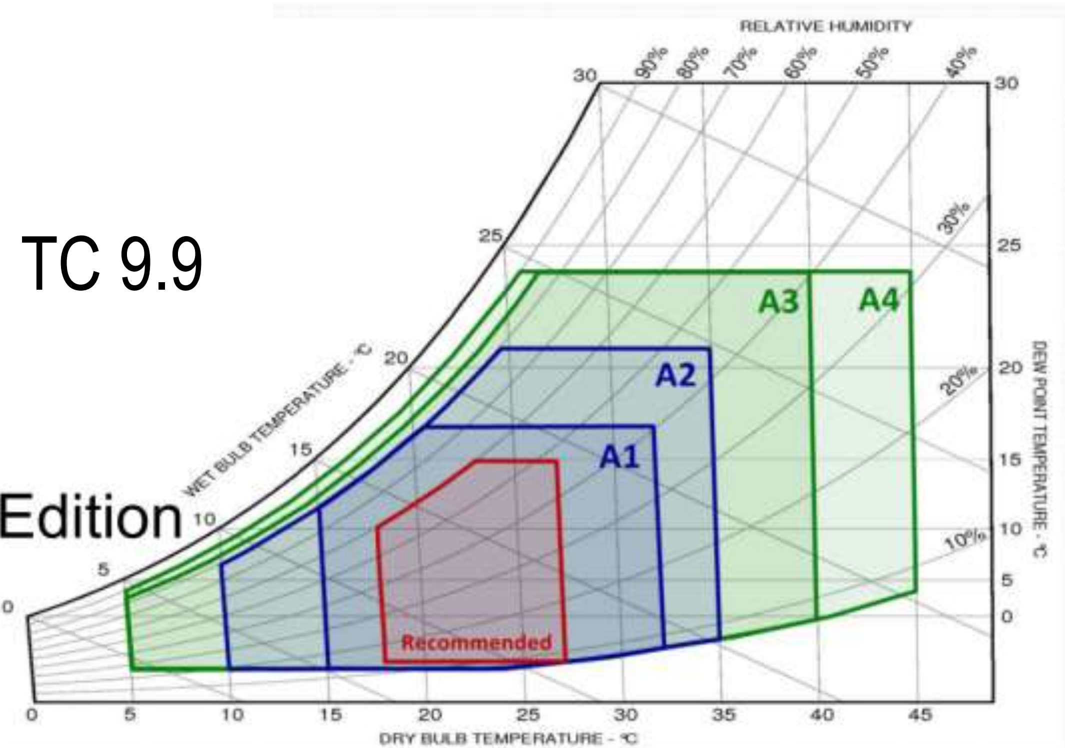
Best Practice Features in the Data Center

- Maximize supply and return temperatures at air handlers
- Maximize allowable ranges of environmental conditions
- Calibrate Sensors
- Economize!

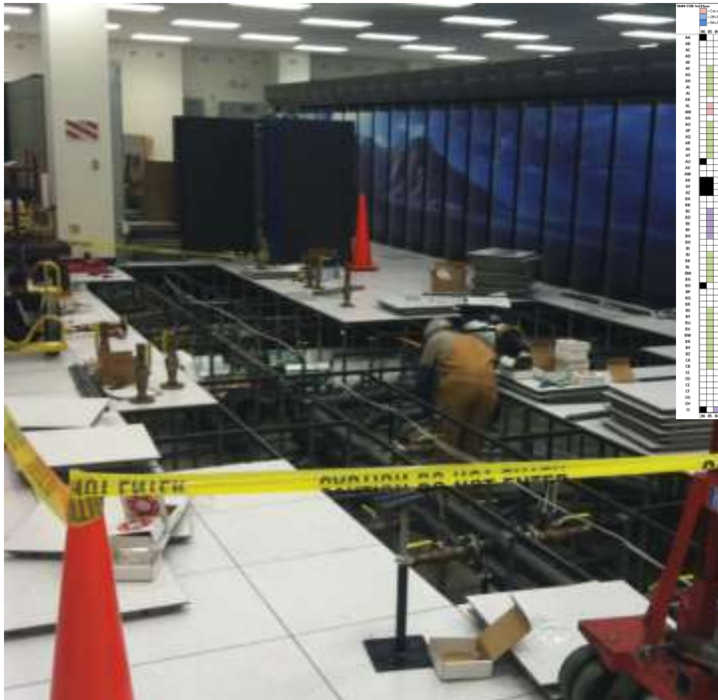
To the right – ASHRAE TC 9.9

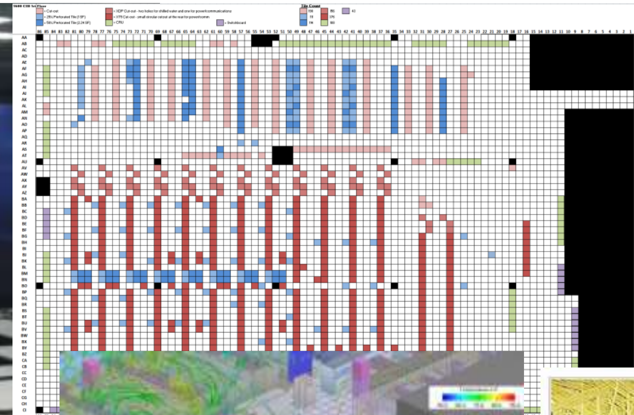
Inlet Conditions

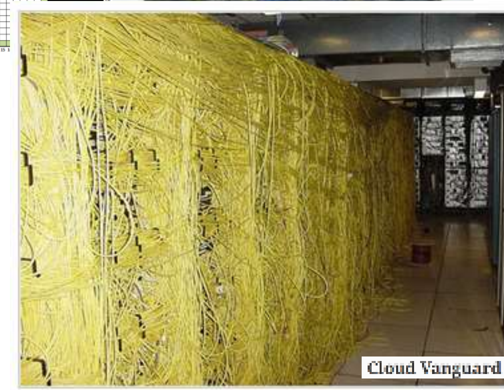
2015 4th Edition

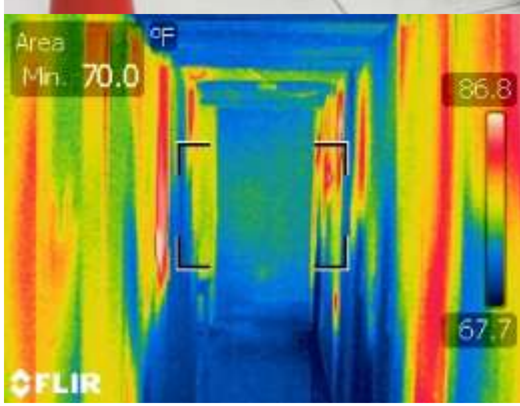


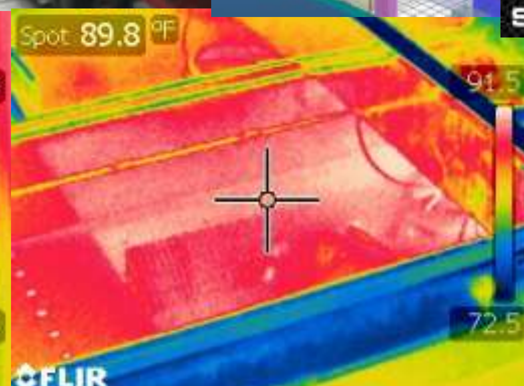
Data Center Efficiency – Air Flow Management – Air Distribution



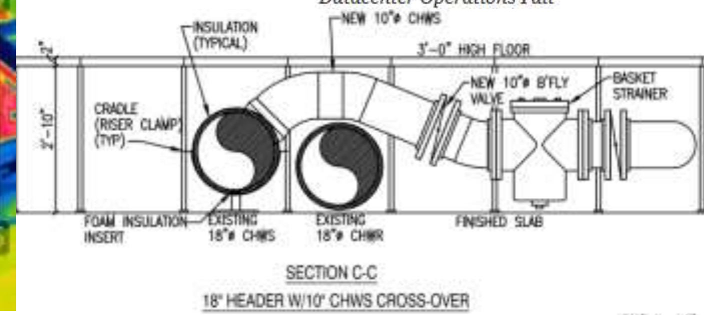




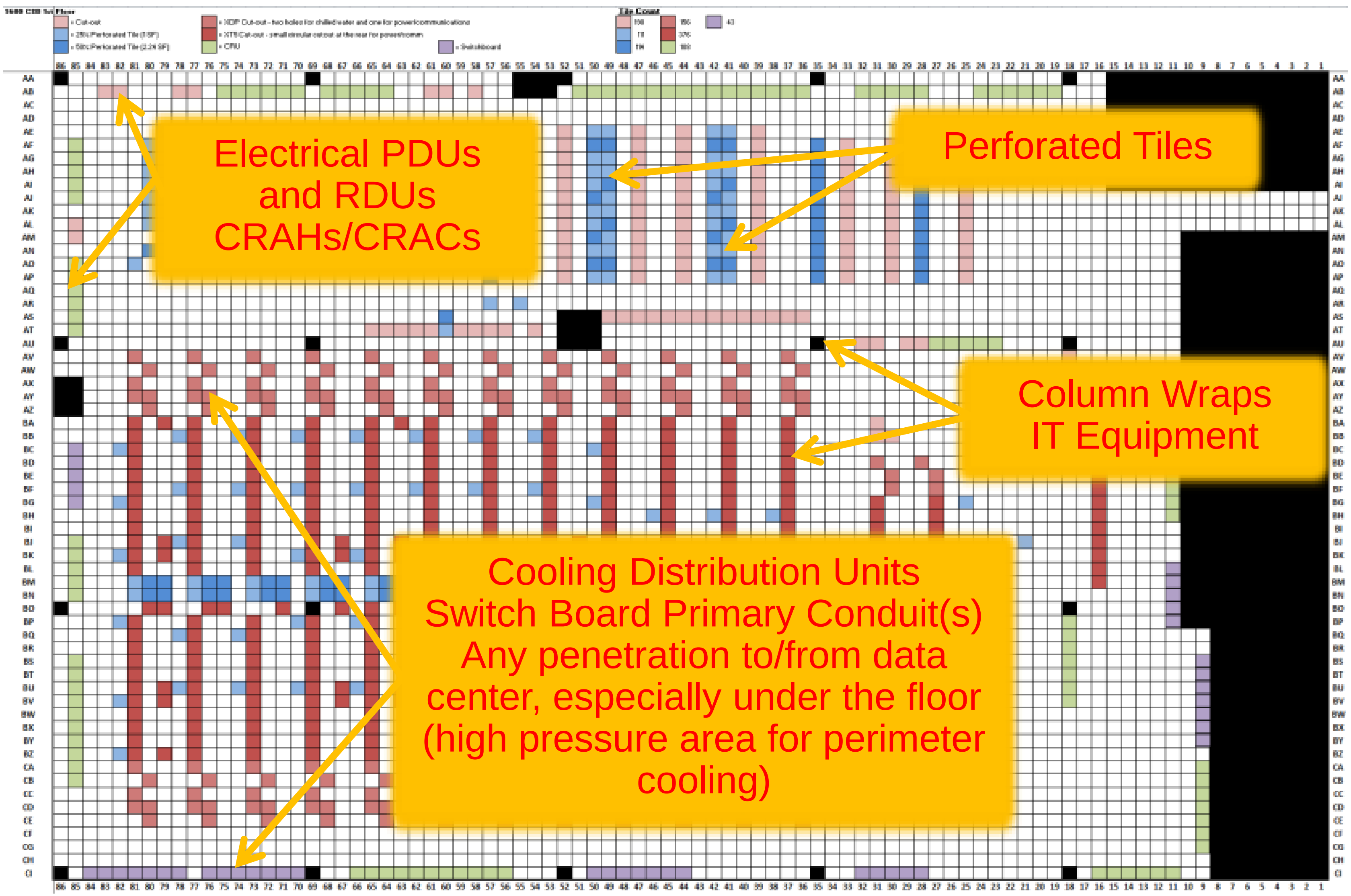




Datacenter Operations Fail



Data Center Efficiency – Floor Openings

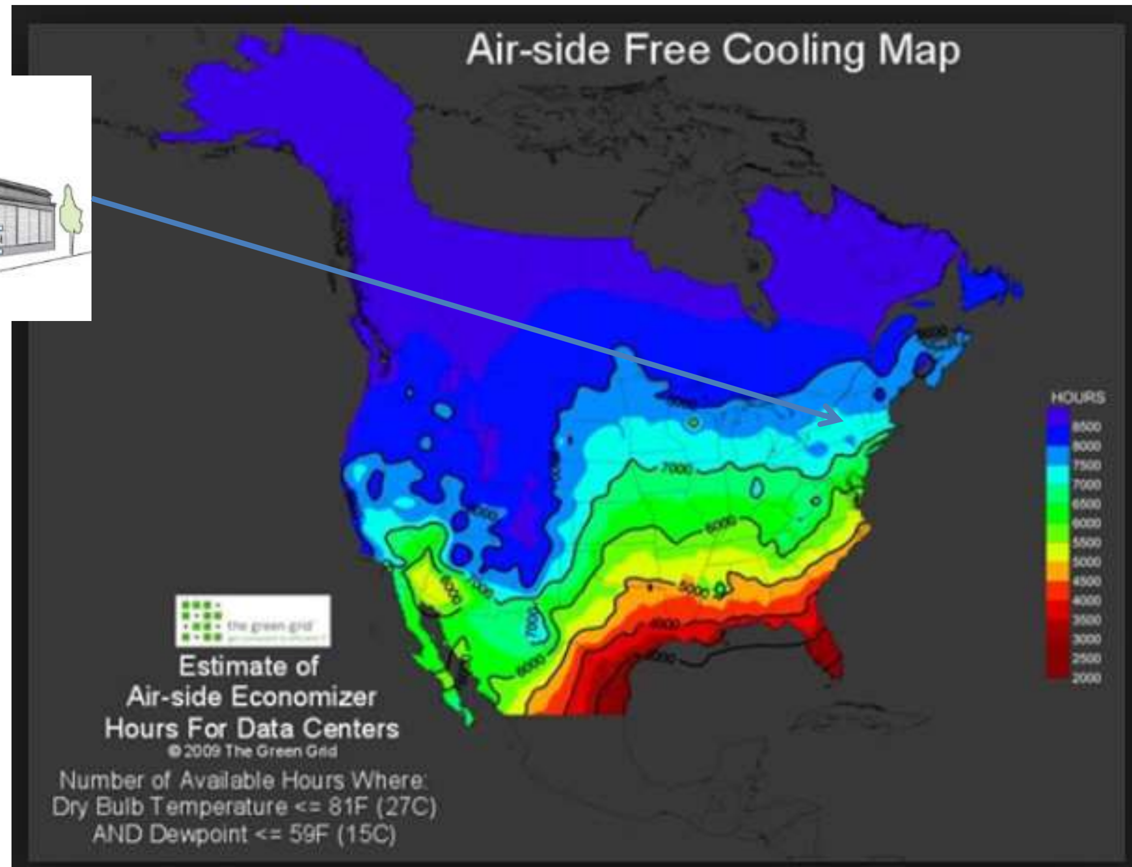


Data Center Efficiency – Air-Side Econo

Good if you are away from the coast, have clean air and the real-estate for the filters, duct, and air handlers.

Usage depends on air supply temperatures and geographic location

Yahoo "Chicken Coops"



PUE =1.1

Data Center Efficiency – Air Cooled Chiller Plants

Generally small data centers.

Digital Scroll Compressors and pumped refrigerant technologies with economizers are bringing kW/ton more toward water cooled centrifugal plant efficiencies.

kW/ton – 0.95-1.2

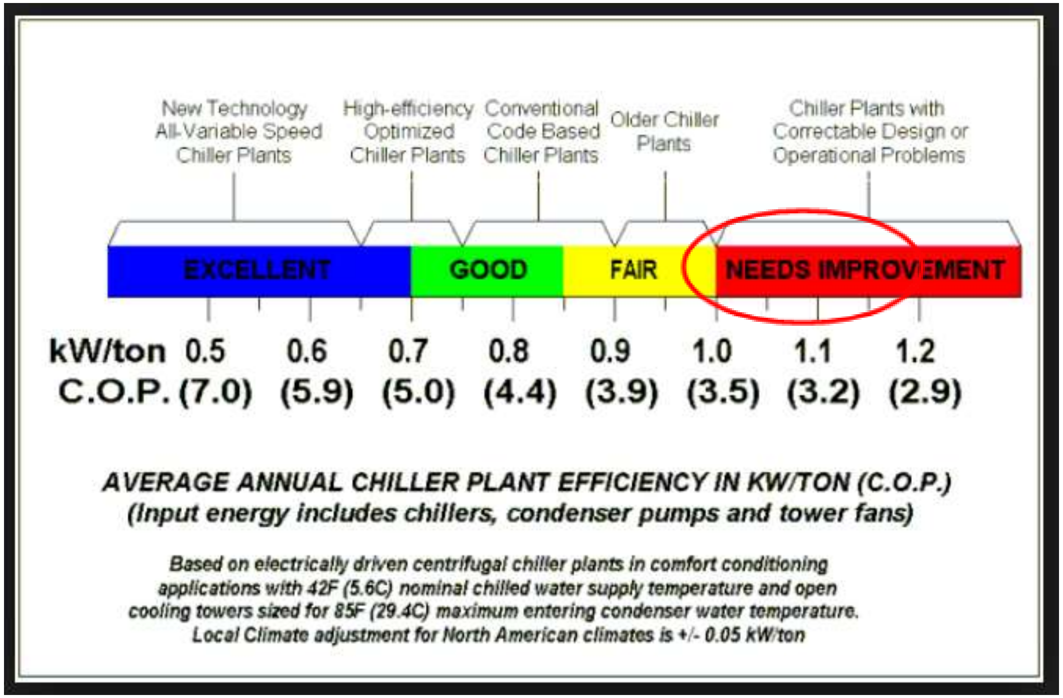
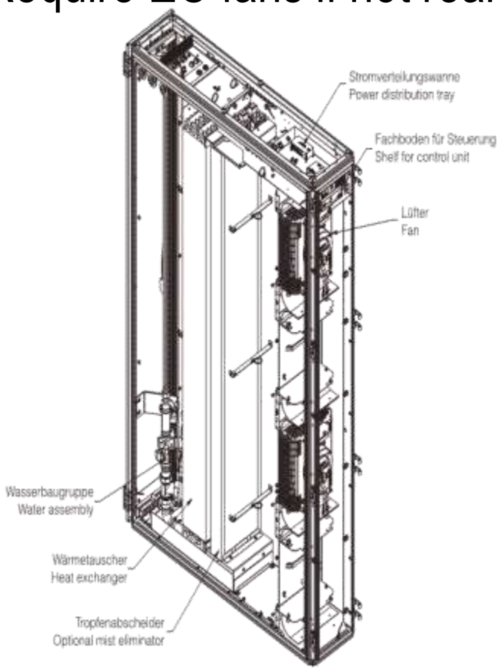


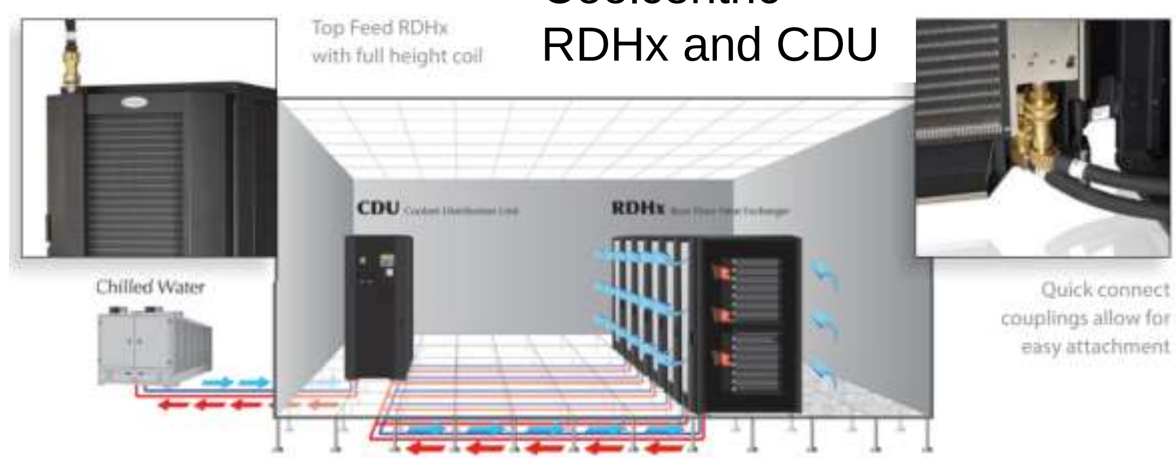
Image - ASHRAE

Data Center Efficiency – Rack Level

- Must have separate air filtration system for balance of the data center space.
- Must have separate humidity control system if rack coolers can't handle condensate (and cooling fluid temperatures must remain about dew point.
- Rack coolers are best if designed for sensible cooling only (no wet coils) with supply temperatures as low as an economizer can do while being above the dew point temperature in the space.
- Require EC fans if not rear door heat exchangers



Coolcentric
RDHx and CDU



Data Center Efficiency

Liquid Cooling – Allows higher cooling temperatures

Remember why water is better than air?

Higher heat capacity per unit volume

Higher pumping efficiency

Higher rate of heat transfer

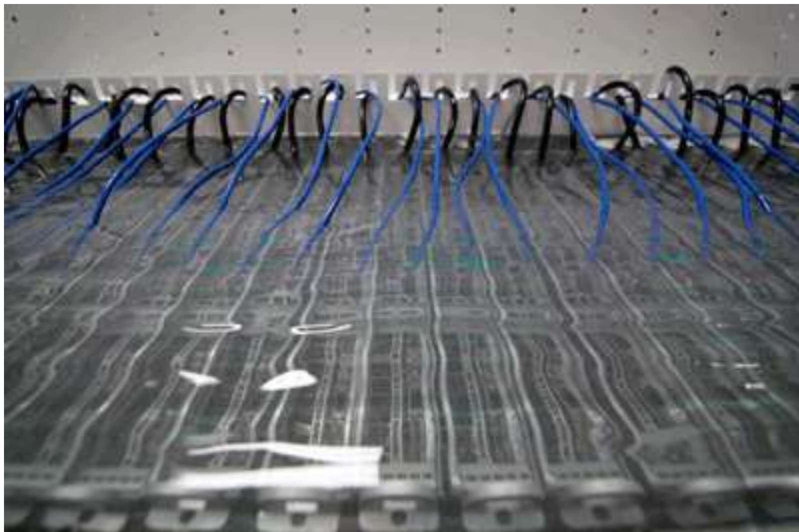
Most of the time you still have heat to remove on the air side

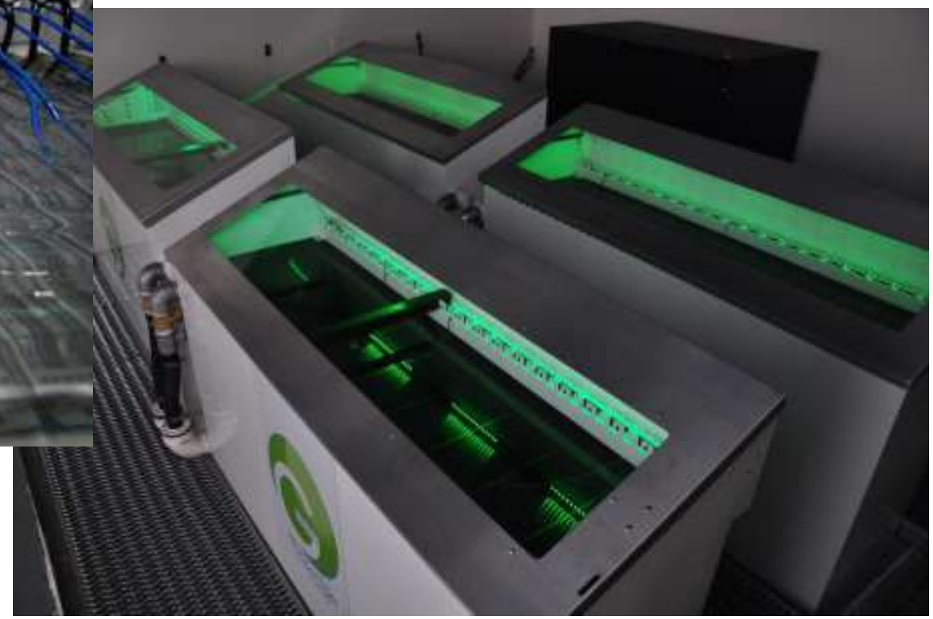
HP

ASE

Data Center Efficiency

Liquid Cooling – Immersion





Geek.com (above)

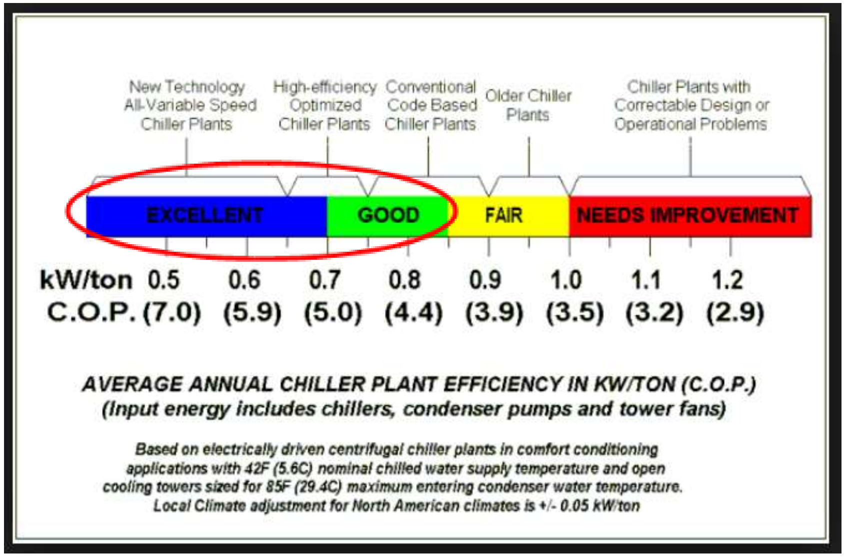
GRC (right)

3M - https://www.youtube.com/watch?v=a6ErbZtpL88

Data Center Efficiency – Water Cooled Chiller Plants

Best Practices in the CEP

- VFDs on chilled water, condenser water pumps, and cooling tower fans
- VFDs on centrifugal chillers
- Premium Efficiency Motors
- Optimized controls
  - Utilize turn down on cooling towers
  - Coolest condenser water temperature – run towers in parallel
  - Head pressure control on chillers
  - Base load constant speed chillers and trim with VFD chiller if chiller plant is mixed
- Water side economize
- Supply highest chilled water supply temperature possible
- Water cooled is more efficient than air cooled systems

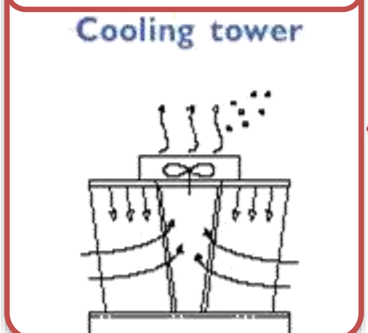


Data Center Cooling – Water-side Econo

Final Heat Rejection

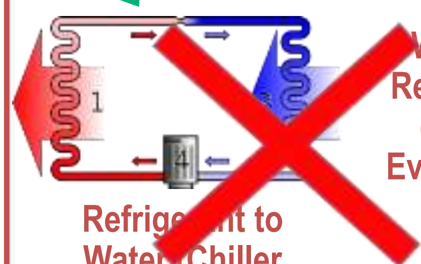
- Dry Cooler
- Air Cooled
- Evaporatively Cooled
- Water Cooled w/ HX
- Water Cooled Direct

Water to Outside Air (Cooling Tower)



Central Energy Plant

- ~~Refrigerant DX~~
- ~~Chiller~~
- Economizer
- Heat Exchanger
    - Can be integrated with chiller for partial use.



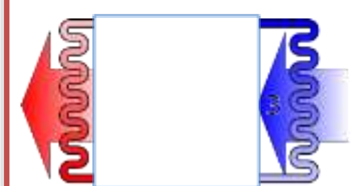
Water to Refrigerant (Chiller Evaporator)

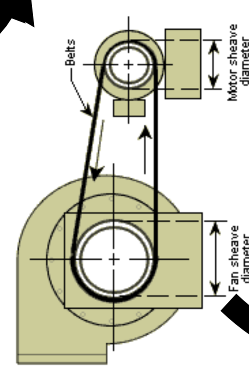
Refrigerant to Water (Chiller Condenser)

Distributor of Cooling

- CRAC
- CRAH
- Central AHU
- Liquid Cooling

Air to Water (CRAH)

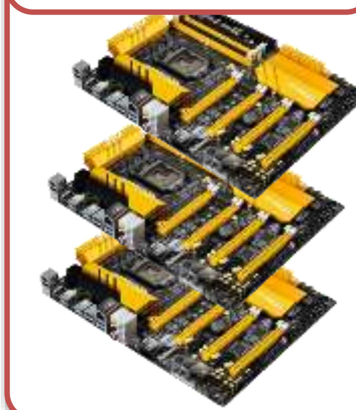




Distribution Method

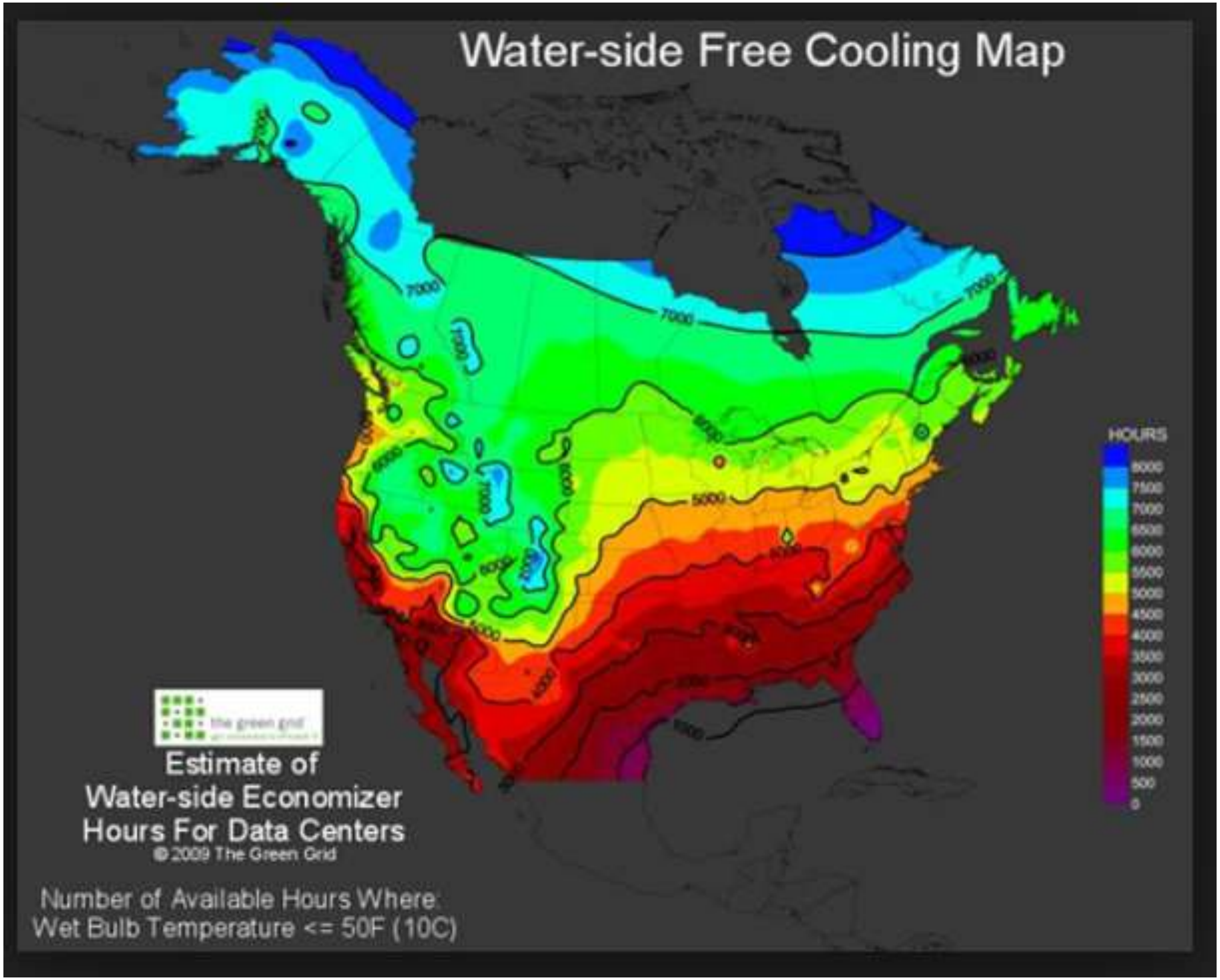
- Raised Floor
- Over Head
- In Row
- In Rack
- On Board

Circuitry to Air and/or Liquid (Rack)



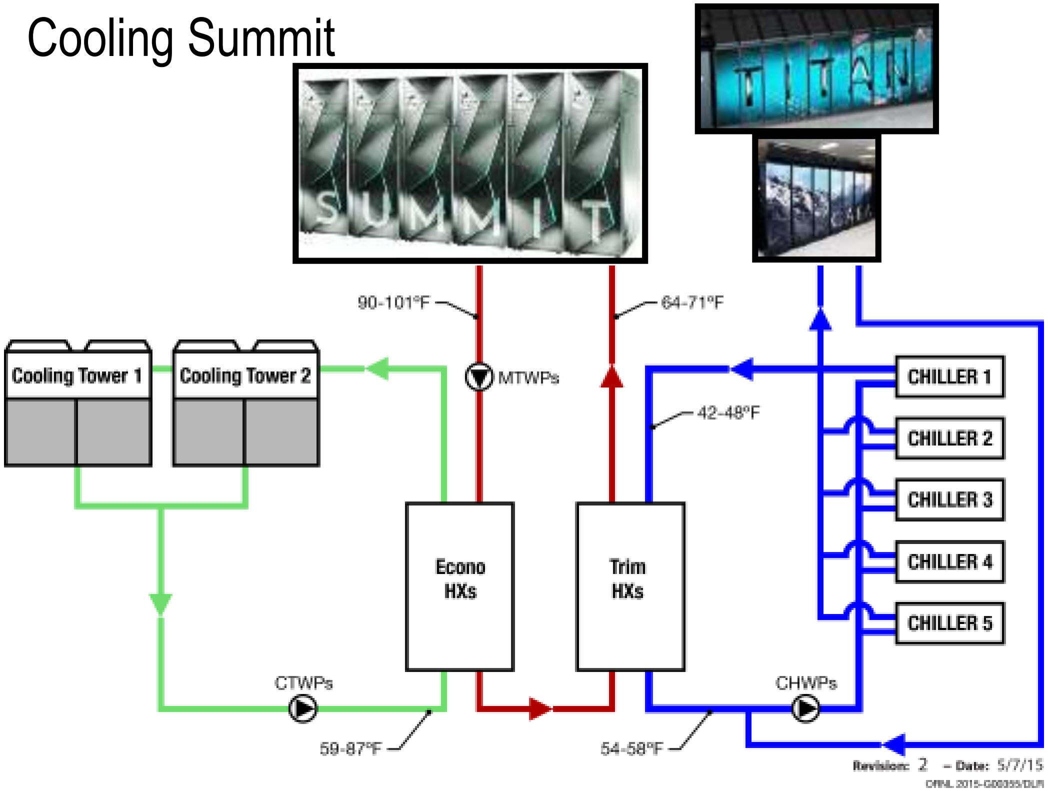
NEED TO SPECIFY HOW THE HEAT GETS FROM THE CIRCUITRY TO THE ENVIRONMENT
PROVIDE EQUIPMENT SPECIFICATIONS

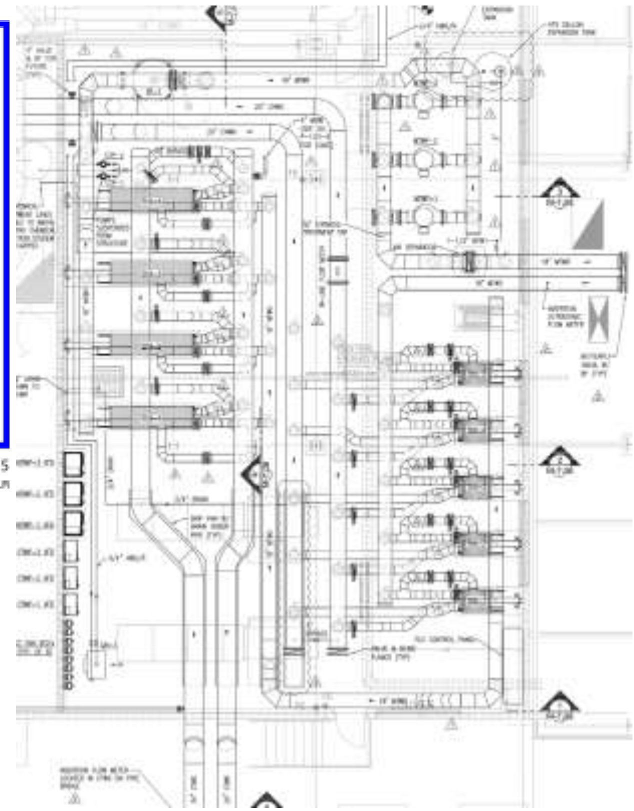
Data Center Efficiency – Water-Side Econo



Data Center Efficiency – Water-Side Econo

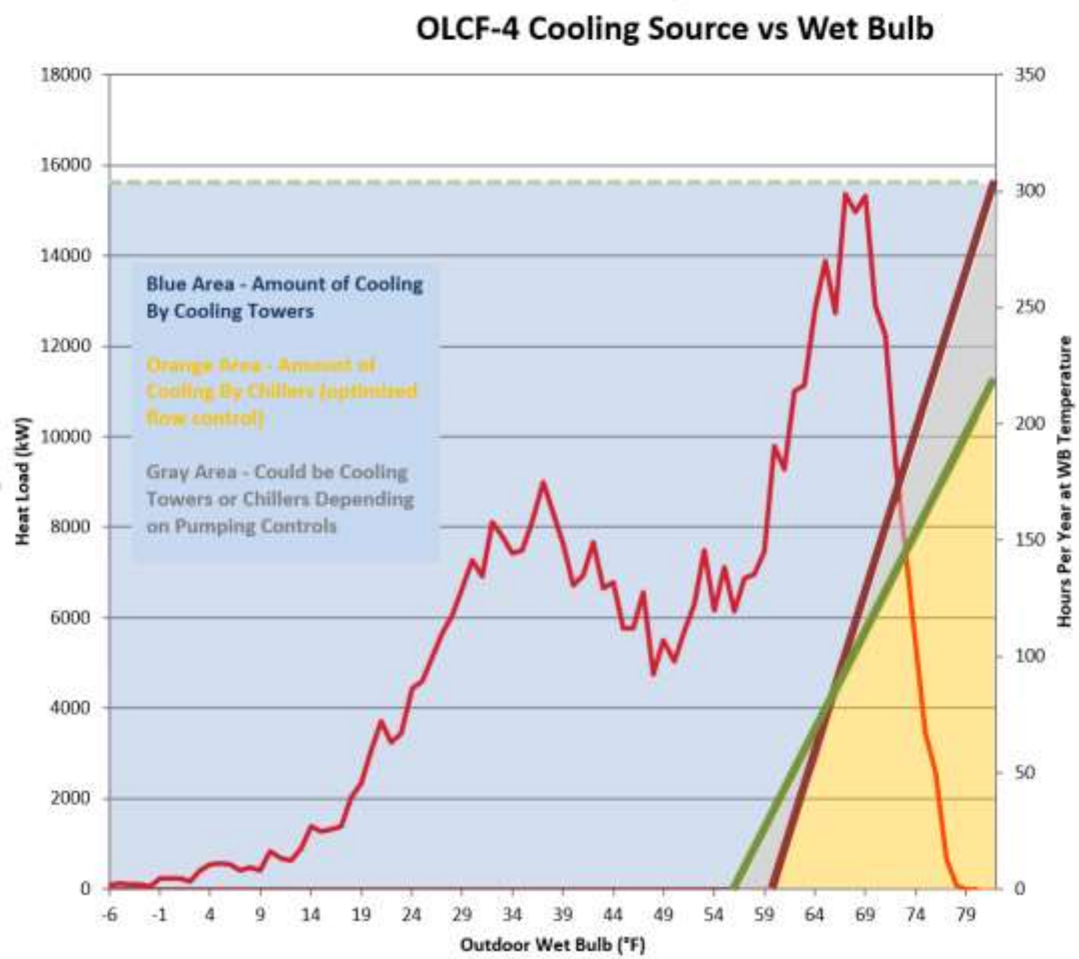
Cooling Summit





Summit - Expected Cooling Source

- Variables
  - System Size (changes the slope of CHW demand)
  - Cabinet Load (changes the overall load)
  - Cabinet Cooling Supply Temperature (shifts the demand line left/right)
  - Approach Temperatures of HXs and Cooling Towers (shifts the demand line left/right)
  - Outside Air Wet Bulb Temperature



Data Center Efficiency - Resources

DOE FEMP

- DC Pro 3 Profiling Tool for Data Centers Software
- Data Center Air Management Tool

- https://datacenters.lbl.gov/technologies

Data Center Efficiency

- Resources

- http://www.apc.com/prod_docs/results.cfm?DocType=White+Paper&Query_Type=10
- Vendor sites have great information about general data center related topics
- Webinars!
- https://datacenters.lbl.gov/
- http://tc99.ashraetcs.org/index.html
- http://www.thegreengrid.org/
  - http://www.thegreengrid.org/~/media/WhitePapers/WP49-PUE%20A%20Comprehensive%20Examination%20of%20the%20Metric_v6.pdf?lang=en
- http://www.datacenterknowledge.com
- http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency
- https://uptimeinstitute.com/
- http://energy.gov/eere/femp/resources-data-center-energy-efficiency
- LBNL Data Center Energy and Water Usage Report 2016

HPC Data Center Cooling Design Considerations

Questions & Discussion