

Best Practices for Data Center Energy Efficiency **Lab21 Workshop**

San Jose, California

October 1, 2012

Presented by:

Dale Sartor, P.E.

Applications Team Leader, Building Technologies
Lawrence Berkeley National Laboratory

(Version: 8/29/12)



U.S. Department of Energy
Energy Efficiency and Renewable Energy



This Presentation is Available for download at:
<http://datacenterworkshop.lbl.gov/>

- Introduction
- Performance metrics and benchmarking
- IT equipment and software efficiency
- Use IT to save IT (monitoring and dashboards)
- Data center environmental conditions
- Airflow management
- Cooling systems
- Electrical systems
- Resources
- Workshop summary

Conventional Approach

- Data centers need to be cool and controlled to tight humidity ranges
- Data centers need raised floors for cold air distribution
- Data centers require highly redundant building infrastructure

Need Holistic Approach

- IT and Facilities Partnership



Introduction

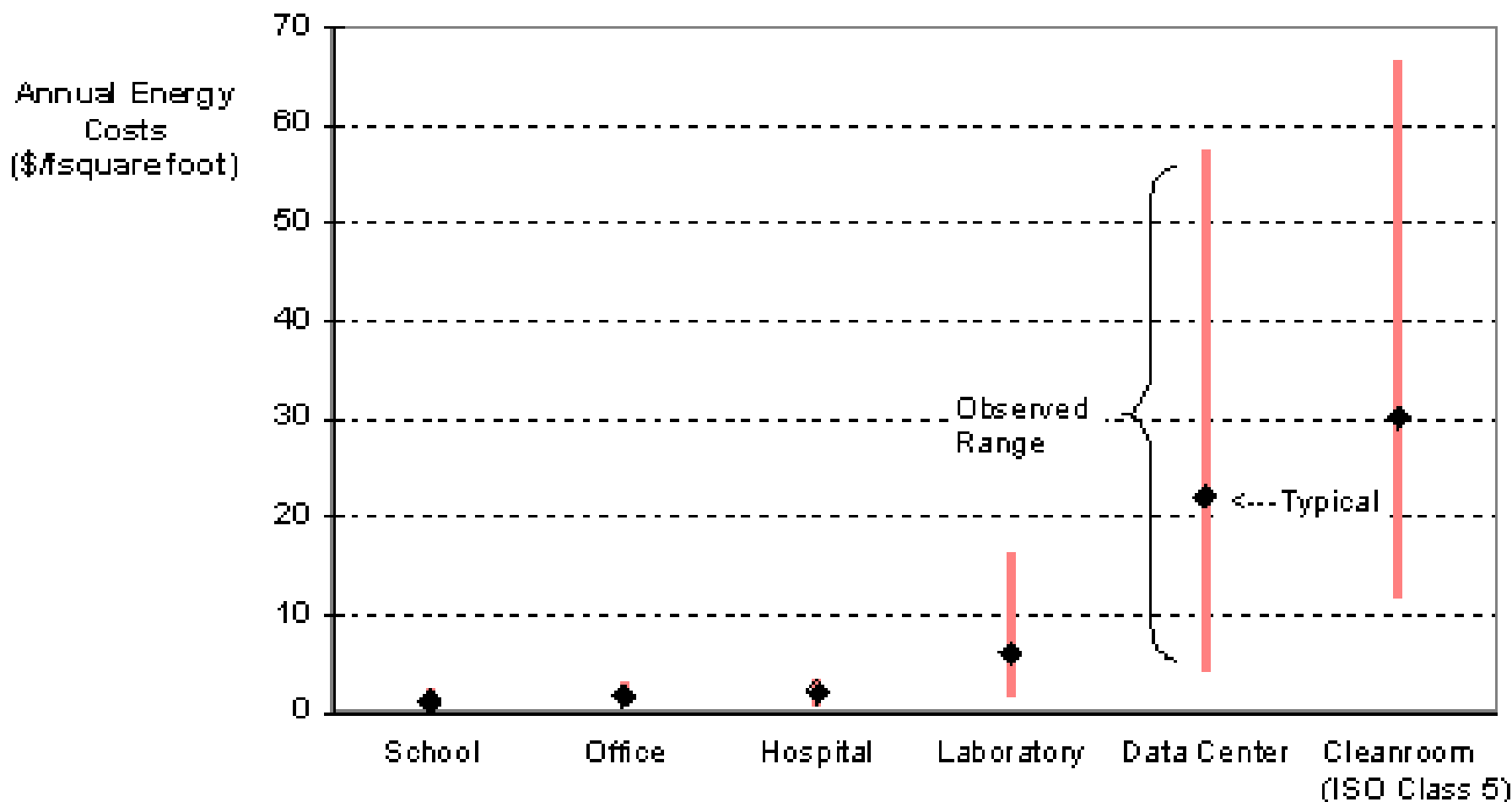


U.S. Department of Energy
Energy Efficiency and Renewable Energy



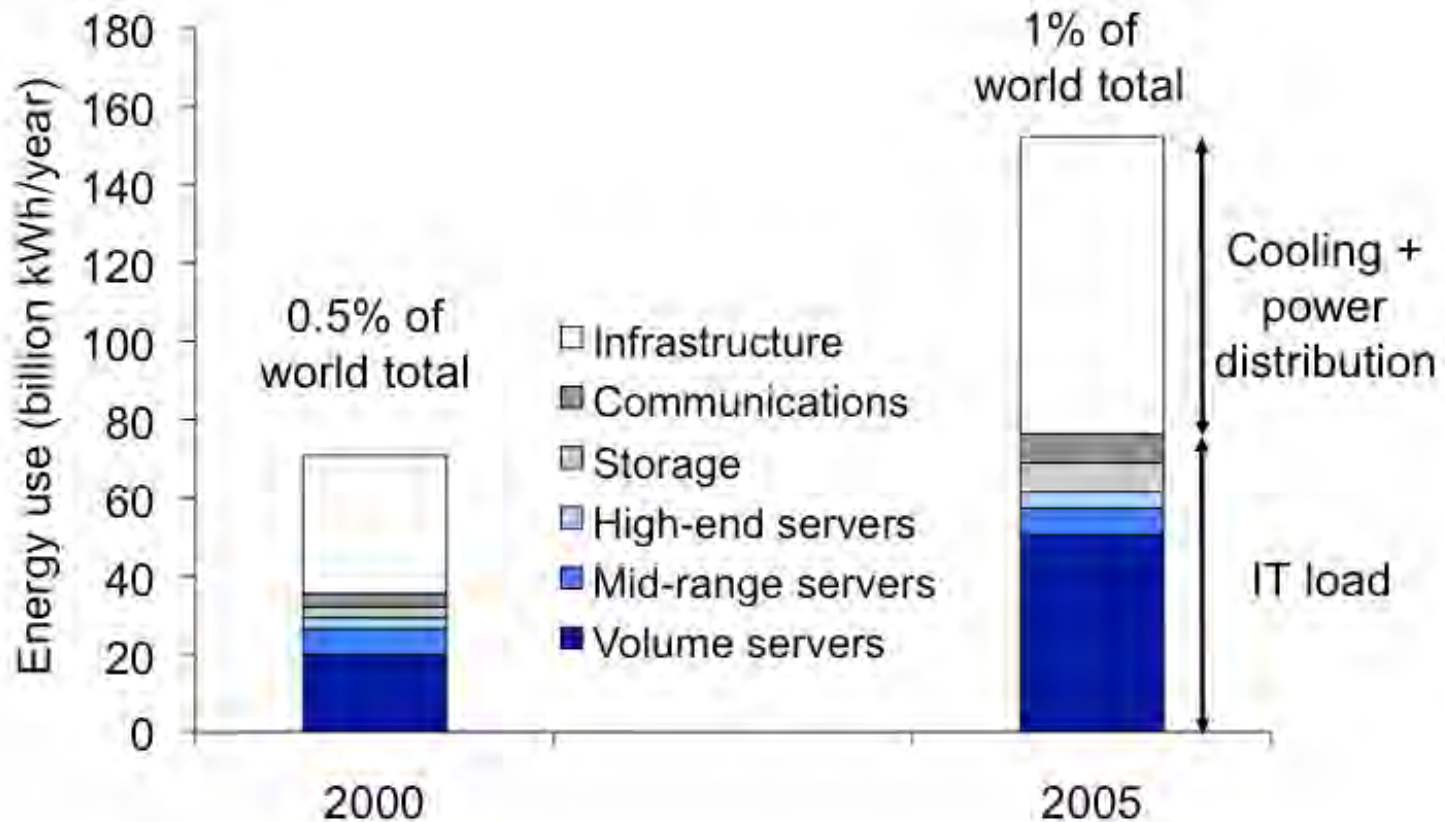
- **Provide background on data center efficiency**
- **Raise awareness of efficiency opportunities**
- **Develop common understanding between IT and Facility staff**
- **Review of data center efficiency resources**
- **Group interaction for common issues and solutions**

Comparative Energy Costs High-Tech Facilities vs. Standard Buildings



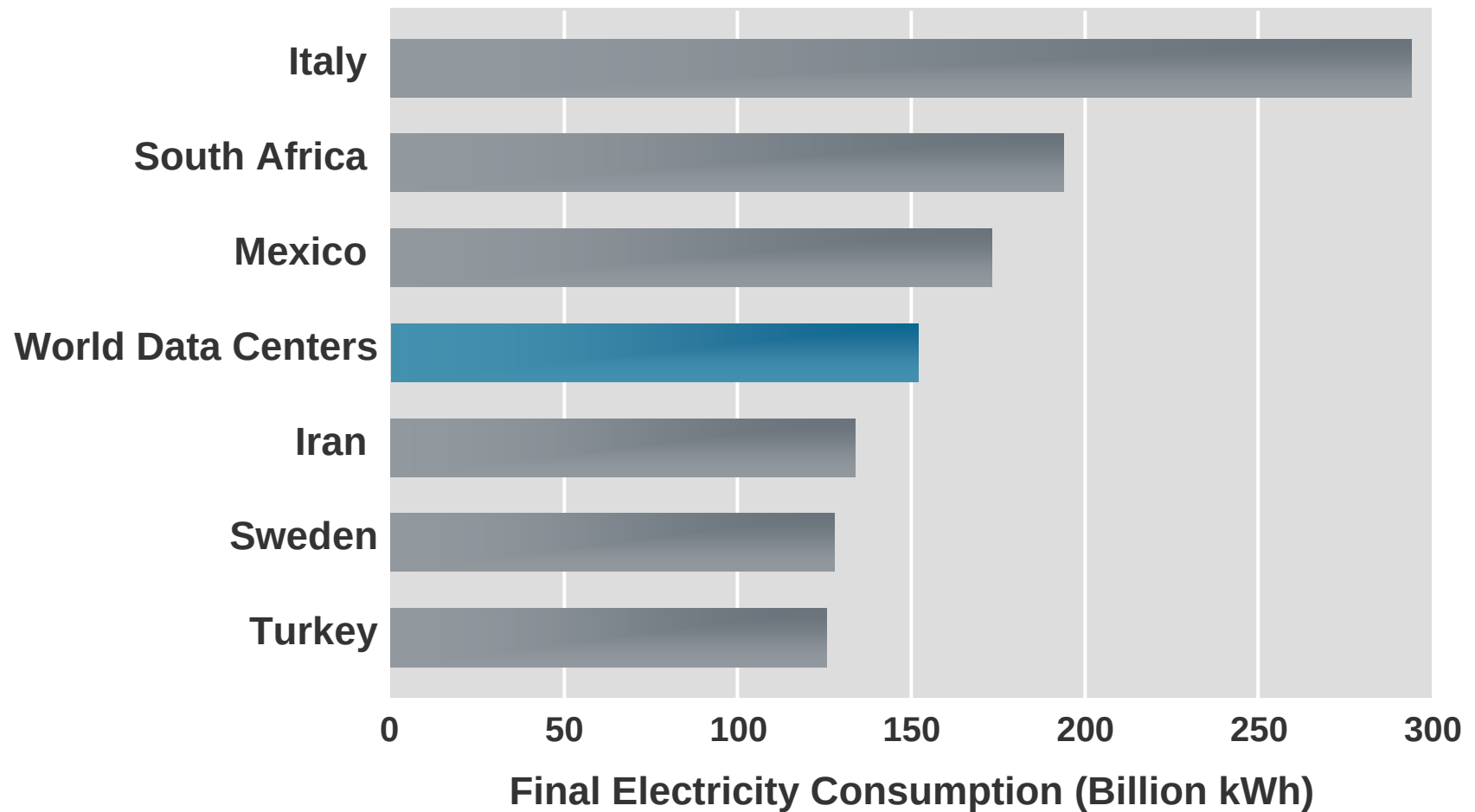
- Data centers are energy intensive facilities
 - 10 to 100 times more energy intensive than an office
 - Server racks now designed for more than 25+ kW
 - Surging demand for data storage
 - 1.5% of US Electricity consumption
 - Projected to double in next 5 years
 - Power and cooling constraints in existing facilities

World Data Center Electricity Use - 2000 and 2005



Source: Koomey 2008

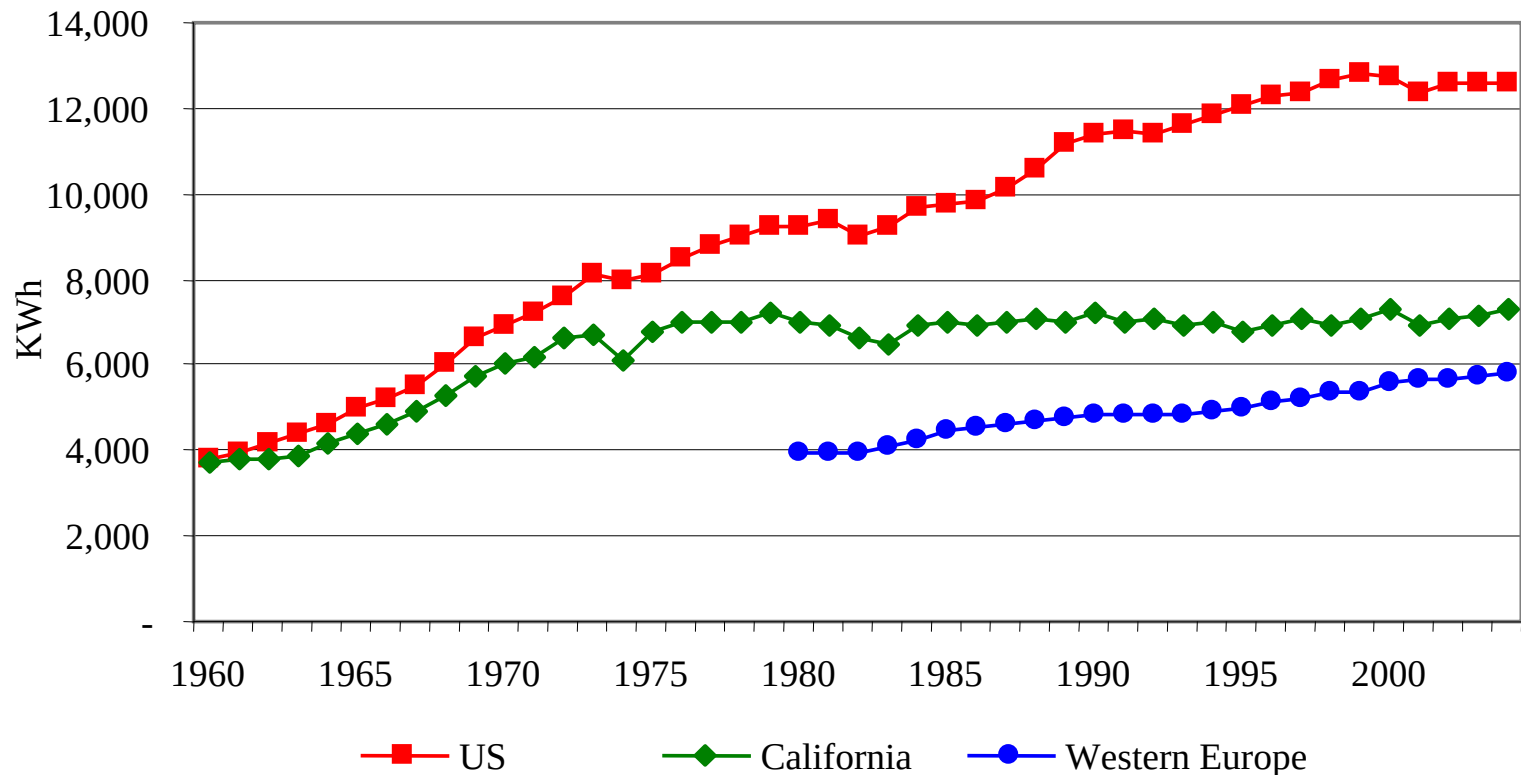
How Much is 152B kWh?



Source for country data in 2005: International Energy Agency, *World Energy Balances* (2007 edition)

Aggressive Programs Make a Difference

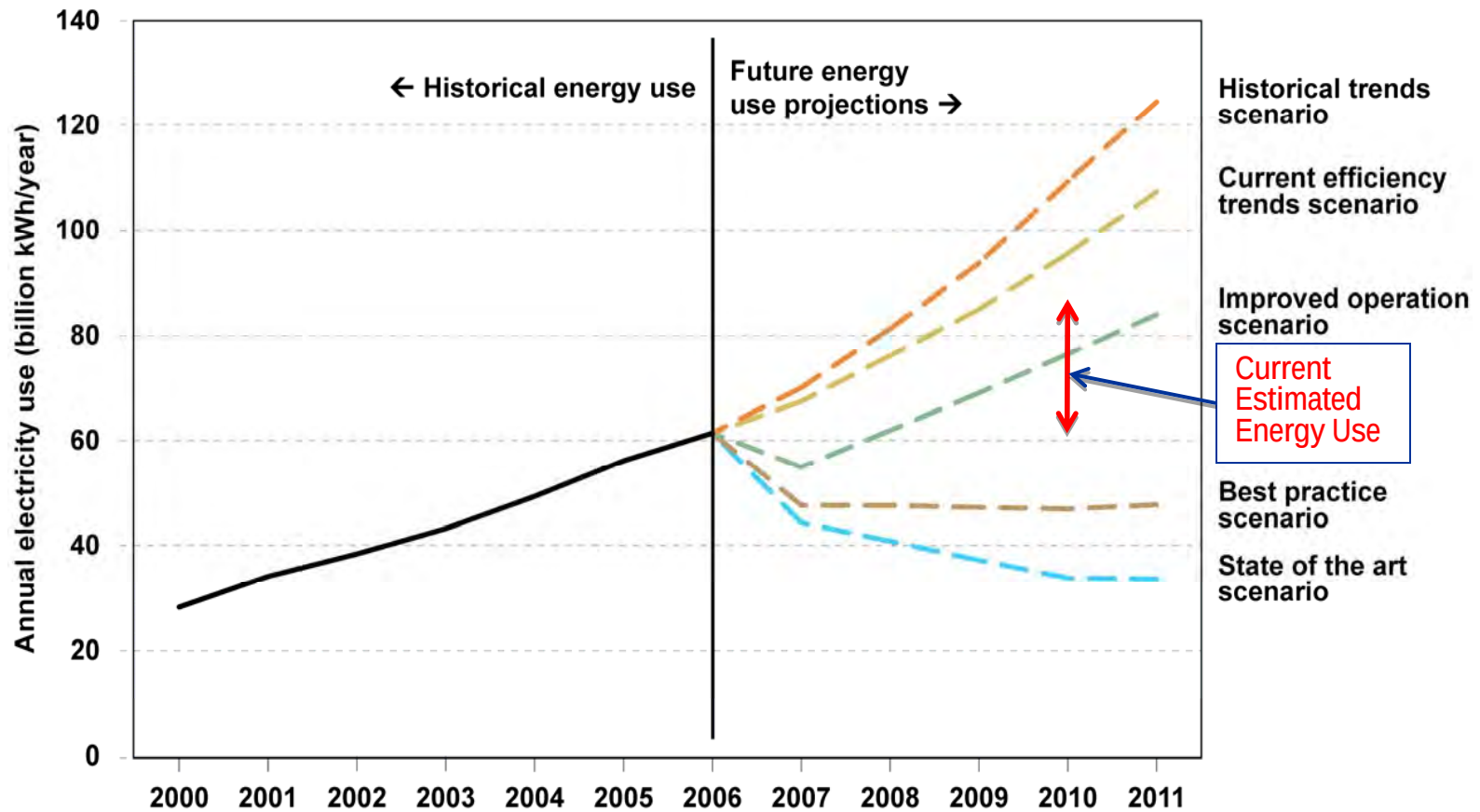
Energy efficiency programs have helped keep per capita electricity consumption in California flat over the past 30 years



Projected Data Center Energy Use

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

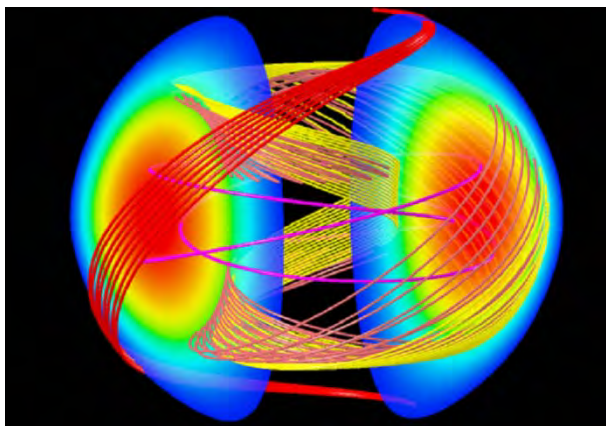


EPA Report to Congress 2008

- From 2000 – 2006, computing performance increased 25x but energy efficiency only 8x
 - Amount of power consumed per \$1,000 of servers purchased has increased 4x
- Cost of electricity and supporting infrastructure now surpassing capital cost of IT equipment
- Perverse incentives -- IT and facilities costs separate

Source: The Uptime Institute, 2007

LBNL operates large systems along with legacy systems

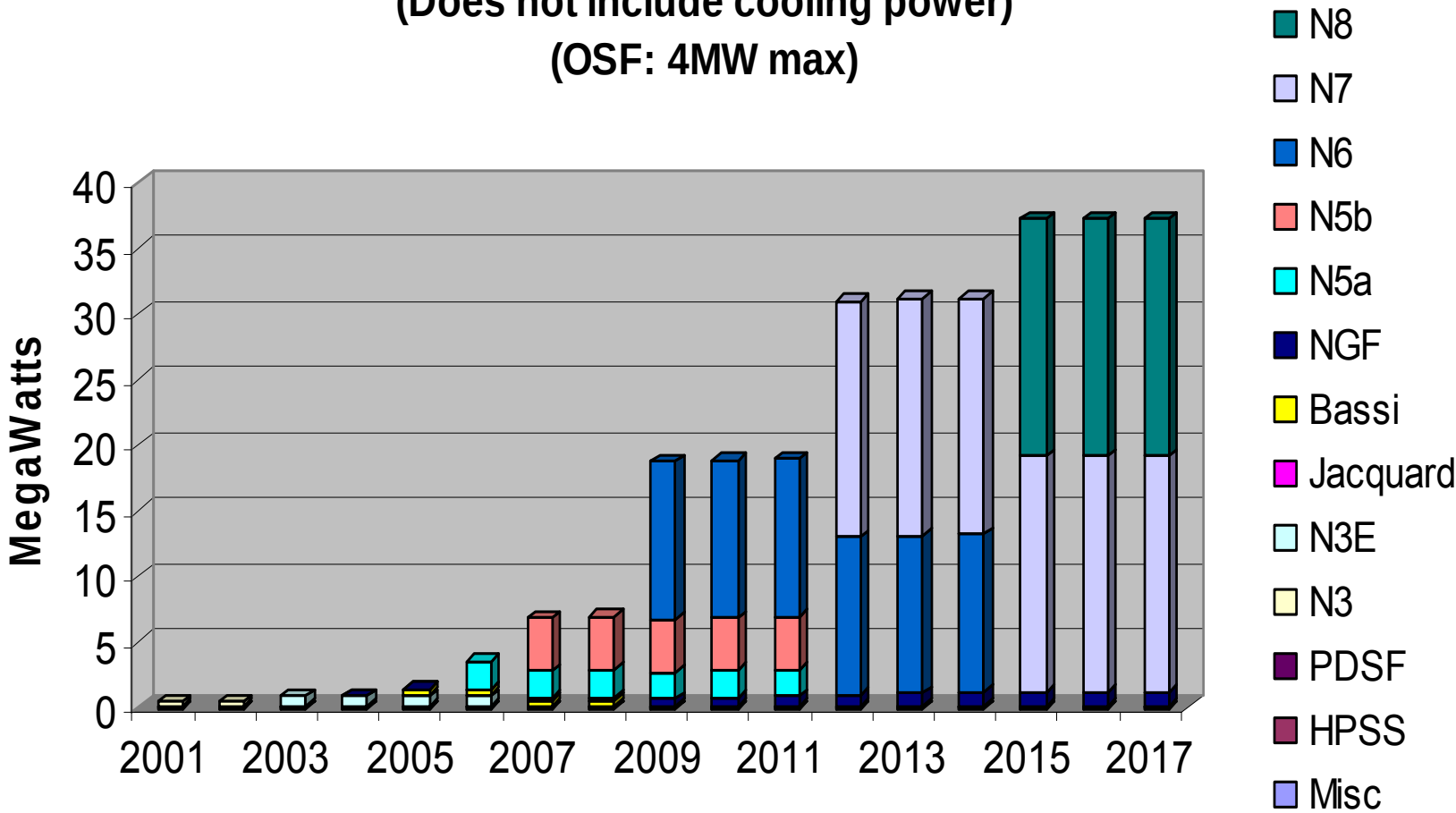


We also research energy efficiency opportunity and work on various deployment programs

LBNL Feels the Pain!

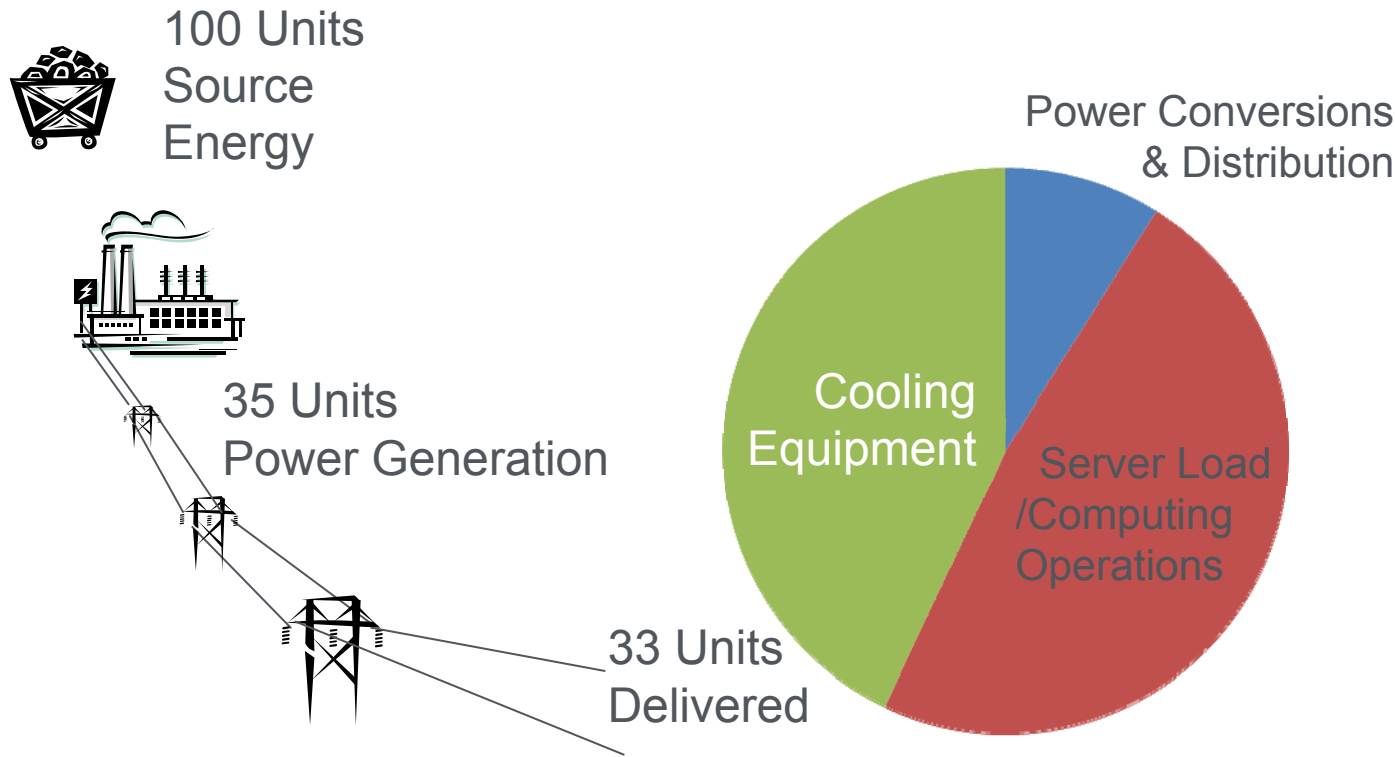


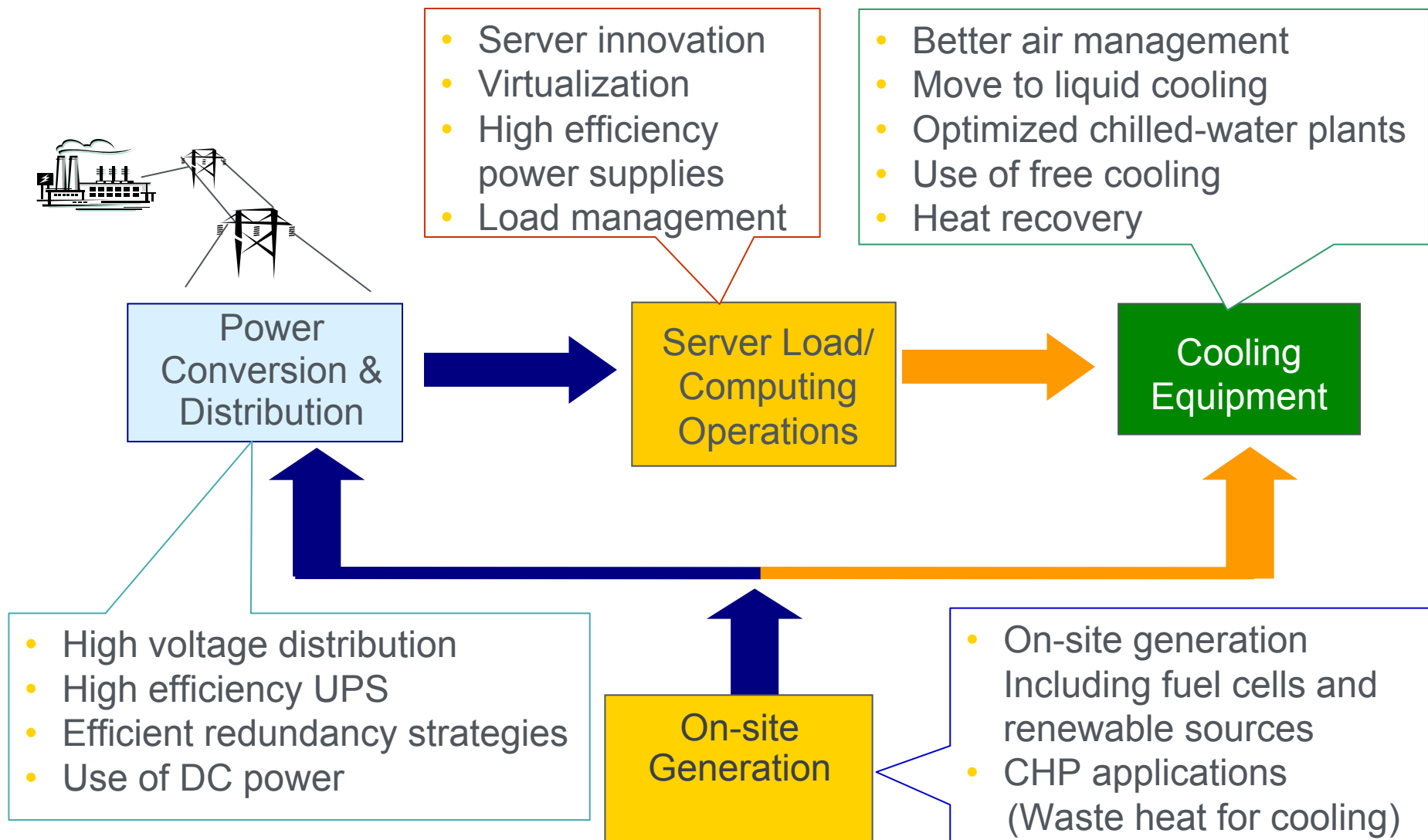
NERSC Computer Systems Power
(Does not include cooling power)
(OSF: 4MW max)



Energy Efficiency = Useful computation / Total Source Energy

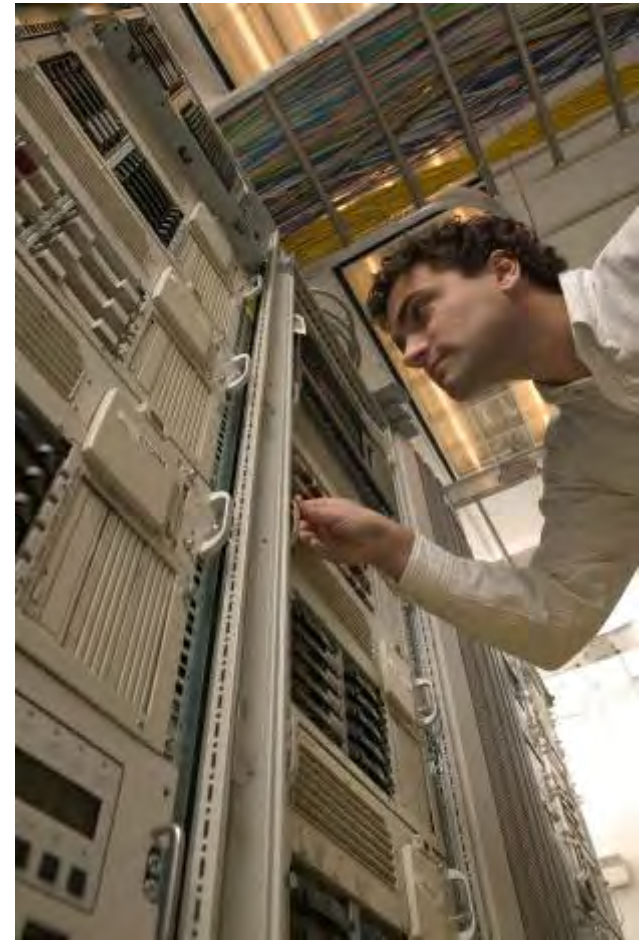
Typical Data Center Energy End Use





Potential Benefits of Data Center Energy Efficiency

- 20-40% savings typical
- Aggressive strategies can yield 50+% savings
- Extend life and capacity of infrastructures



Questions?





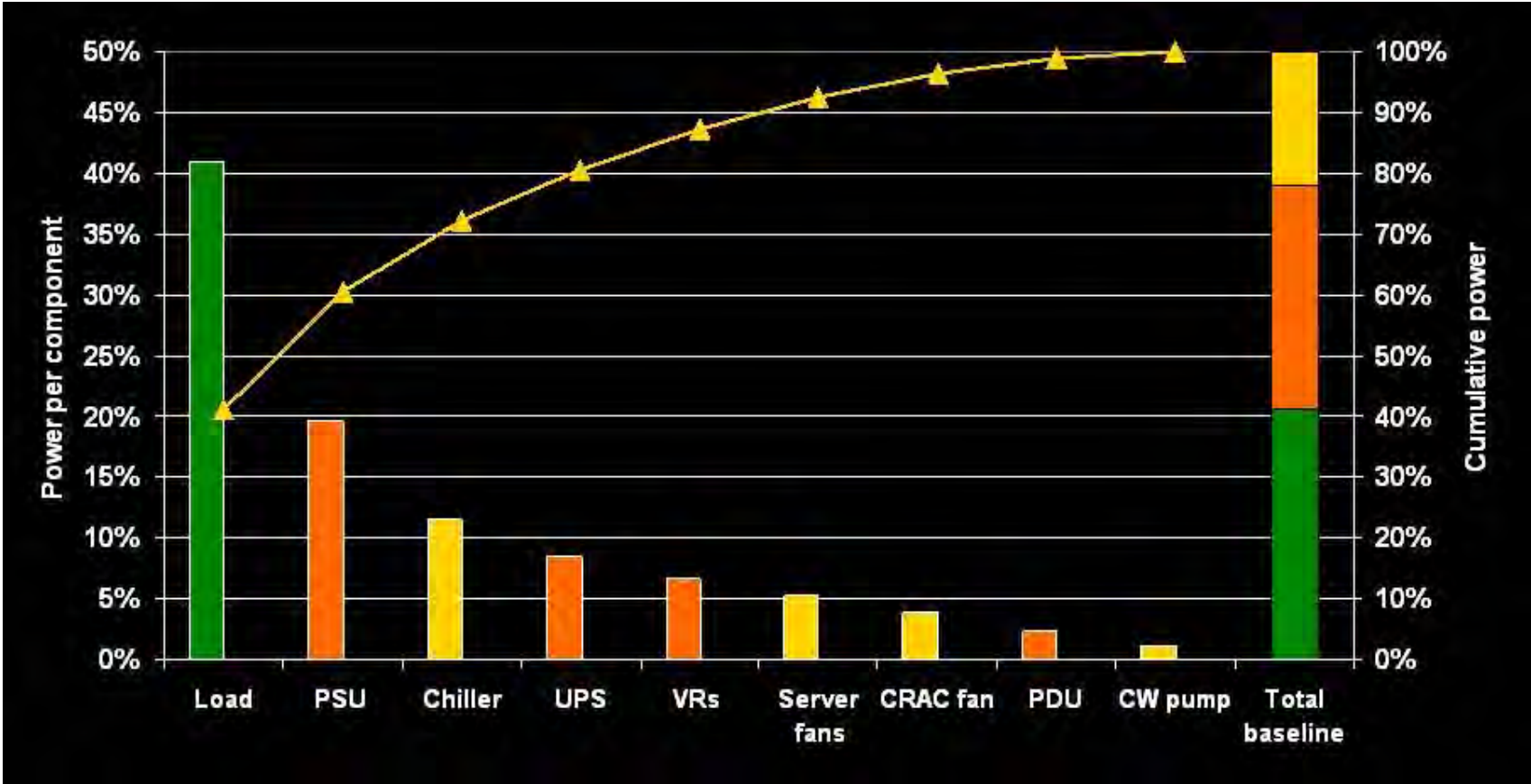
Performance metrics and benchmarking



U.S. Department of Energy
Energy Efficiency and Renewable Energy



Electricity Use in Data Centers



Courtesy of Michael Patterson, Intel Corporation

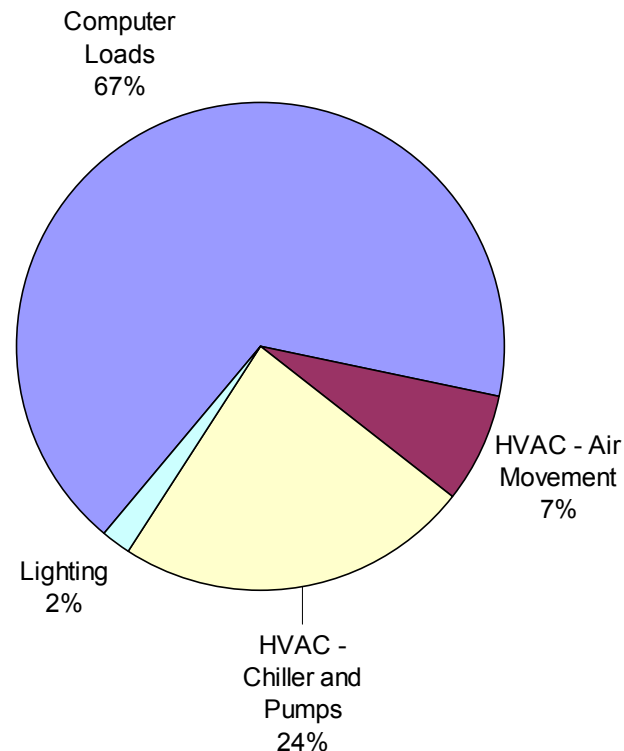
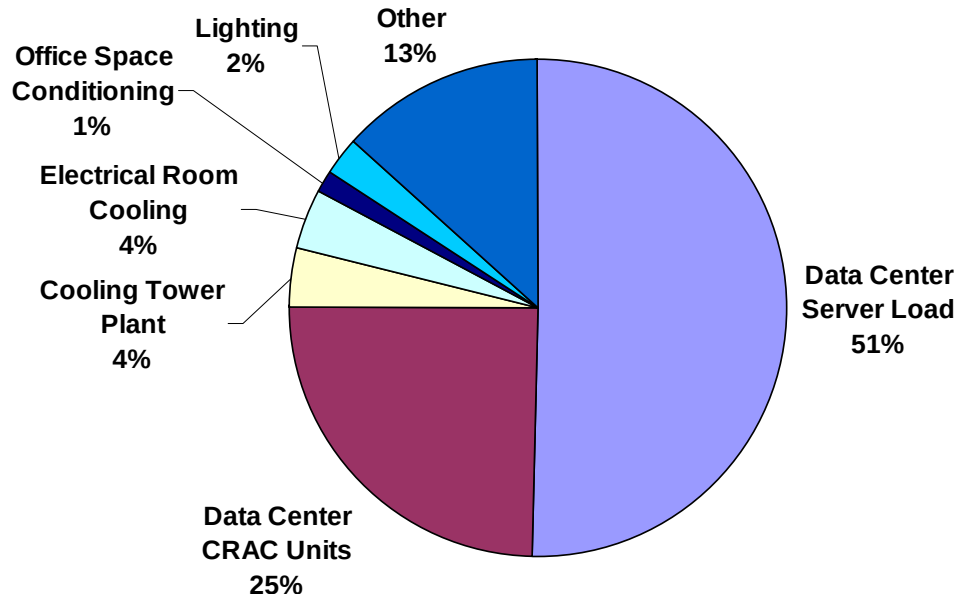
Benchmarking for Energy Performance Improvement:

- Energy benchmarking can allow comparison to peers and help identify best practices
- LBNL conducted studies of over 30 data centers:
 - Wide variation in performance
 - Identified best practices
- Can't manage what isn't measured

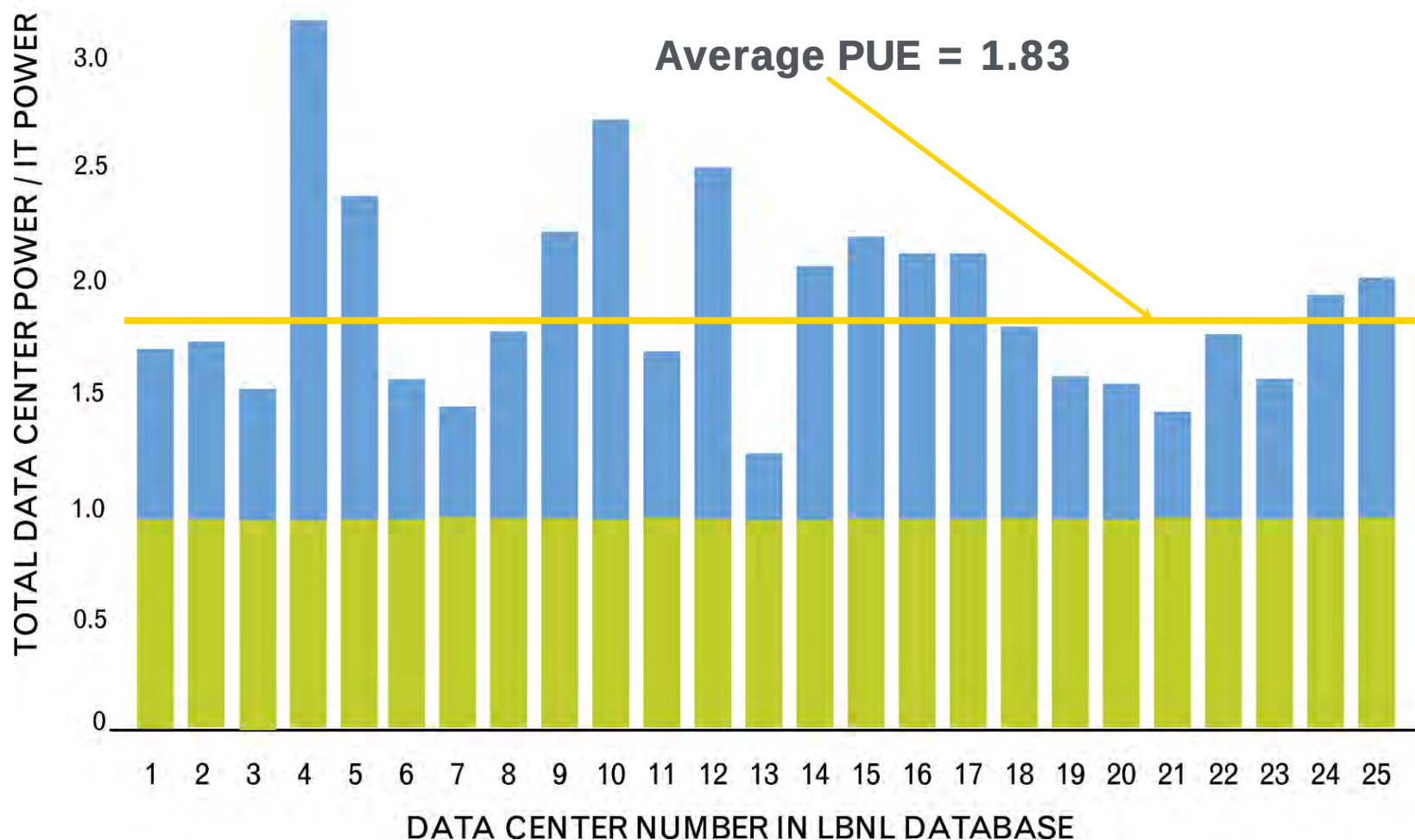


Your Mileage Will Vary

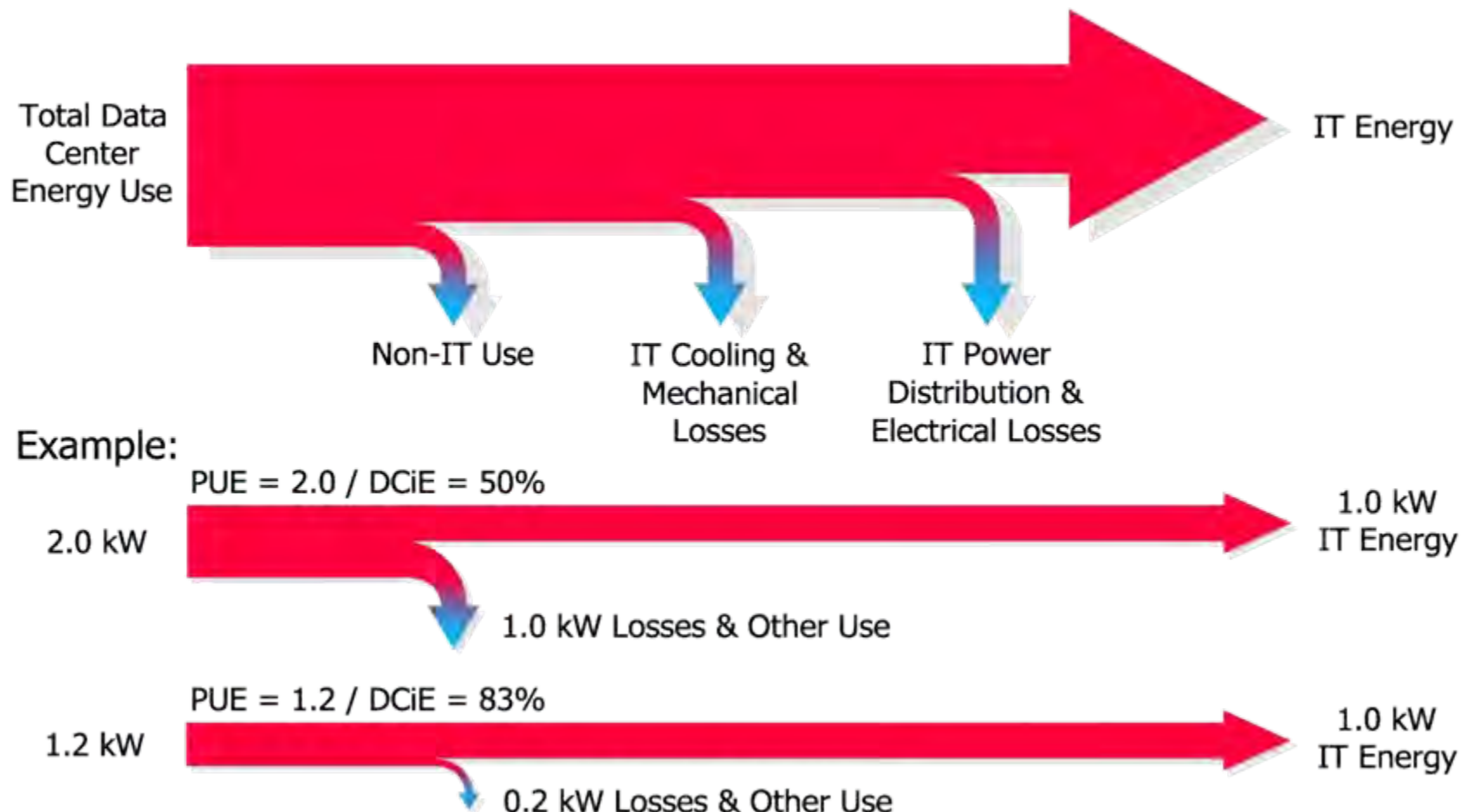
The relative percentages of the energy doing computing varies considerably.



High Level Metric: Power Utilization
Effectiveness (PUE) = Total Power/IT Power



PUE and Energy Savings



40% Energy Savings going from PUE = 2.0 to 1.2

- **Key Metrics:**
 - PUE and partial PUEs (e.g. HVAC, Electrical distribution)
 - Utilization
 - Energy Reuse (ERF)
- **The future: Computational Metrics (e.g. peak flops per Watt; transactions/Watt)**

The private sector has a better handle on data center efficiency metrics

What Do They Know*?		
	Private sector*	Public sector
PUE?	82%	23%
Average load?	94%	31%
Average server power density?	95%	29%

% of respondents who can provide data on these metrics for their organizations.
MeriTalk Study released June 2011

- Watts per square foot, Watts per rack
- Power distribution: UPS efficiency, IT power supply efficiency
 - Uptime: IT Hardware Power Overhead Multiplier (IT_{ac}/IT_{dc})
- HVAC
 - Fan watts/cfm
 - Pump watts/gpm
 - Chiller plant (or chiller or overall HVAC) kW/ton
- Air Management
 - Rack cooling index (fraction of IT within recommended temperature range)
 - Return temperature index $(RAT-SAT)/IT\Delta T$
- Lighting watts/square foot

Power Usage Effectiveness

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

Standard	Good	Better
2.0	1.4	1.1

Airflow Efficiency

$$\frac{\text{Total Fan Power (W)}}{\text{Total Fan Airflow (cfm)}}$$

Standard	Good	Better
1.25W/cfm	0.75 W/cfm	0.5 kW/cfm

Cooling System Efficiency

$$\frac{\text{Average Cooling System Power (kW)}}{\text{Average Cooling Load (ton)}}$$

Standard	Good	Better
1.1 kW/ton	0.8 kW/ton	0.6 kW/ton

Questions?





IT Equipment and Software Efficiency

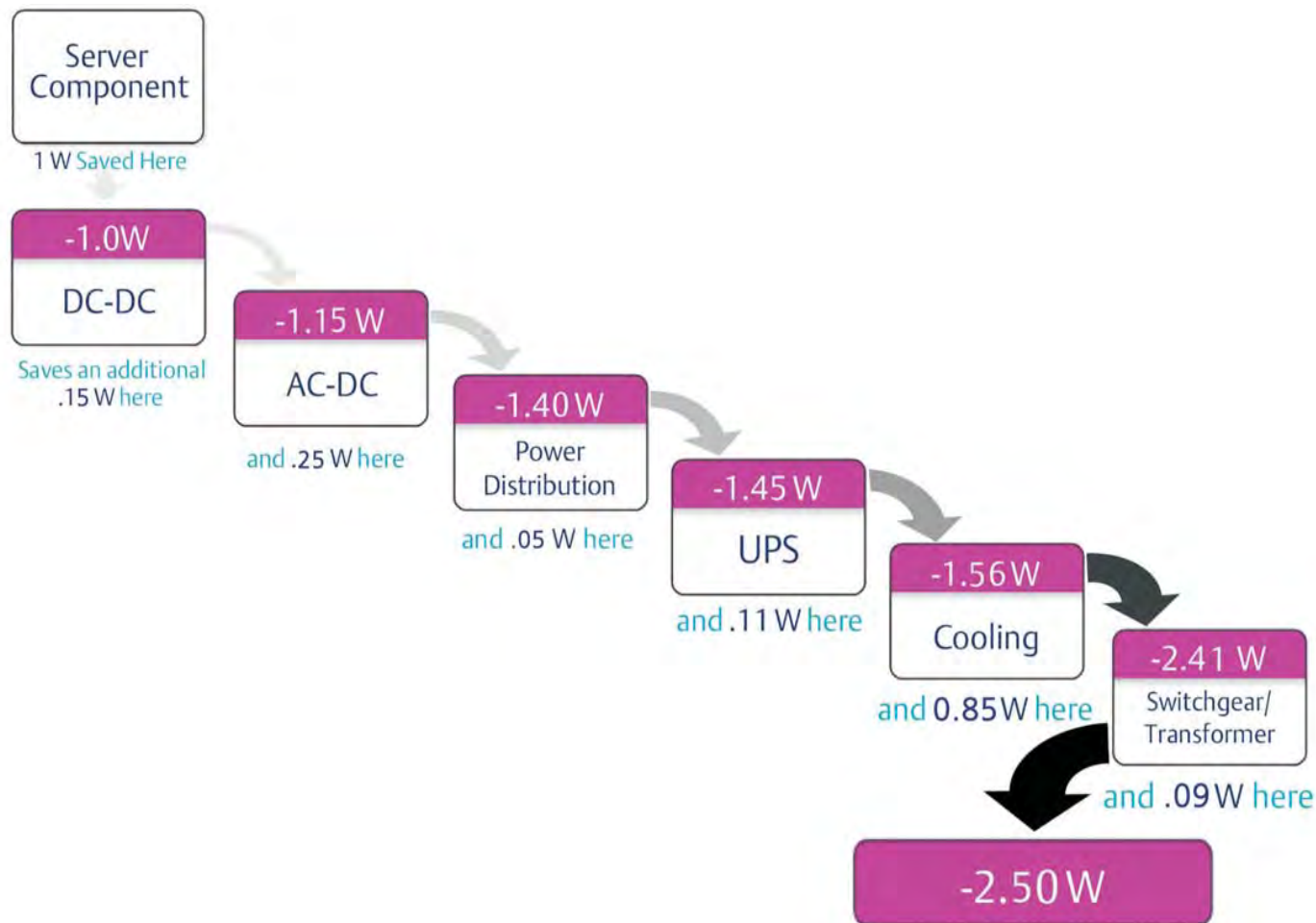


U.S. Department of Energy
Energy Efficiency and Renewable Energy

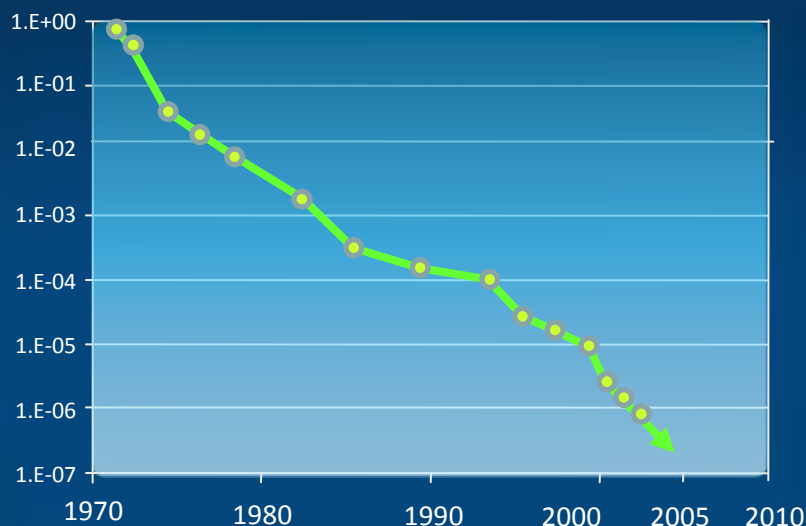


IT Server Performance - Saving a Watt...

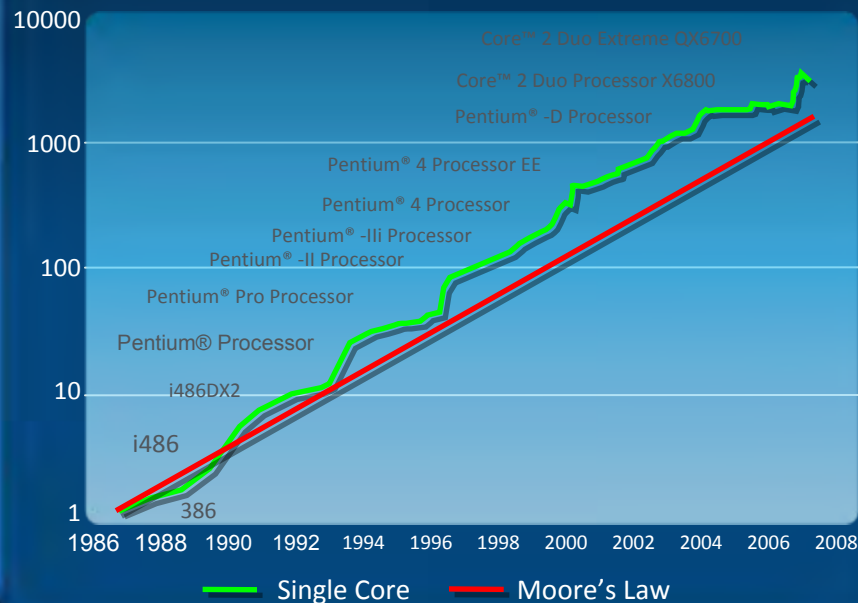
The value of one watt saved at the IT equipment



Power reduction Over Time*



Core Integer Performance Over Time*

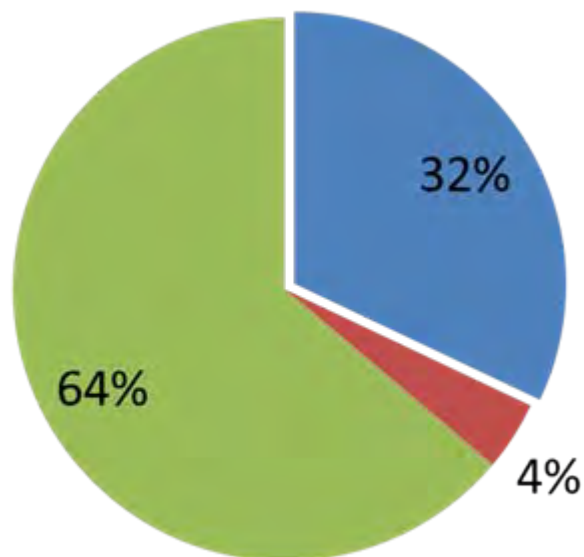


- Every year Moore's Law is followed, smaller, more energy-efficient transistors result
- Miniaturization provides 1 million times reduction in energy/transistor size over 30+ years.
- Benefits: Smaller, faster transistors => faster AND more energy-efficient chips.

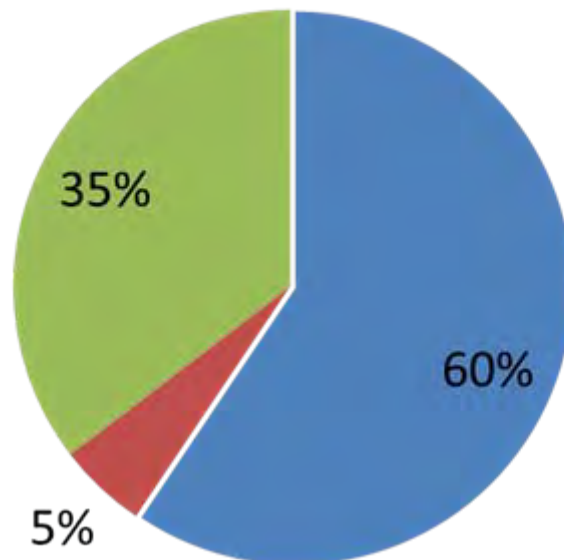
Source: Intel Corp.

IT Equipment Age and Performance

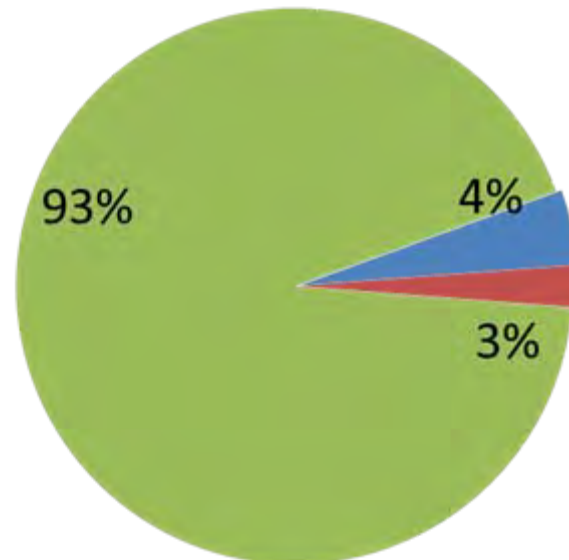
Age Distribution
of Servers



Energy Consumption
of Servers



Performance Capability
of Servers



Old Servers consume 60% of Energy, but deliver only 4% of Performance Capability.

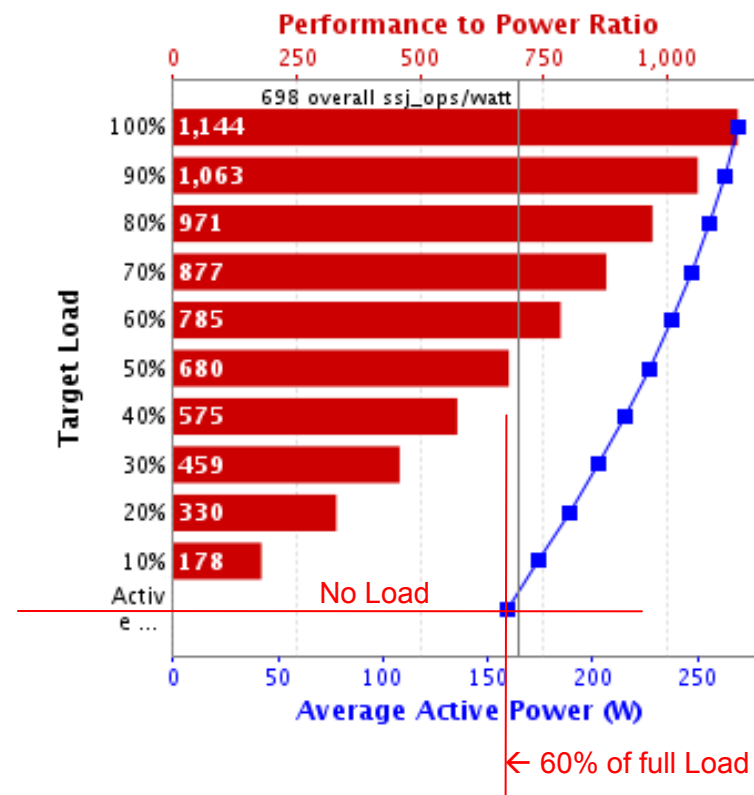
Data collected recently at a Fortune 100 company; courtesy of John Kuzma and William Carter, Intel

Perform IT System Energy Assessments

IT Energy Use Patterns: Servers

Idle servers consume as much as 50-60% of power @ full load as shown in SpecPower Benchmarks.

Performance			Power	Performance to Power Ratio
Target Load	Actual Load	ssj_ops	Average Active Power (W)	
100%	99.2%	308,022	269	1,144
90%	90.2%	280,134	264	1,063
80%	80.0%	248,304	256	971
70%	69.9%	217,096	247	877
60%	60.1%	186,594	238	785
50%	49.6%	154,075	227	680
40%	39.9%	123,805	215	575
30%	29.9%	92,944	203	459
20%	20.1%	62,364	189	330
10%	10.0%	31,049	174	178
Active Idle		0	160	0
$\Sigma \text{ssj_ops} / \Sigma \text{power} =$				698

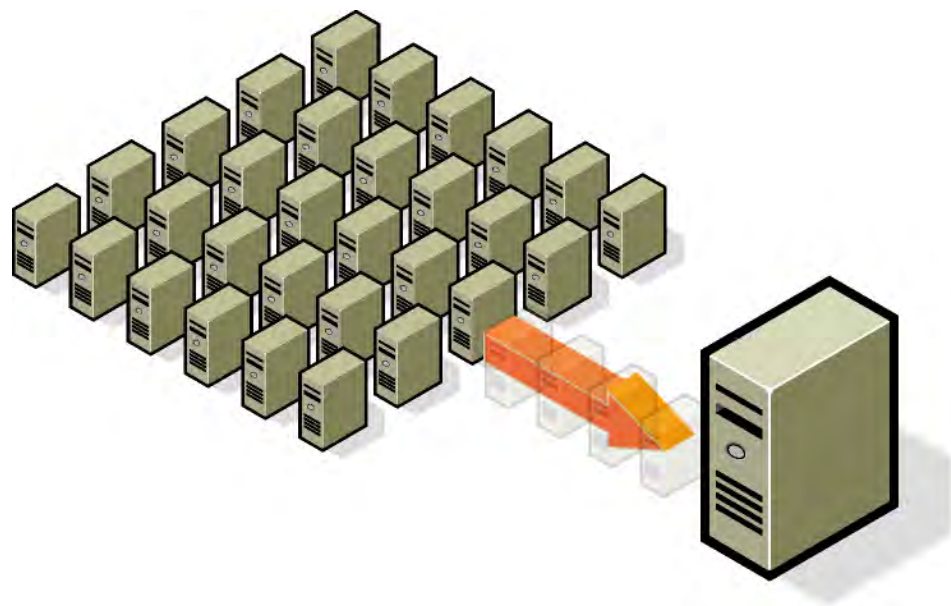


PHYSICALLY RETIRE AN INEFFICIENT OR UNUSED SYSTEM

- **Uptime Institute reported 15-30% of servers are on but not being used**
- **Decommissioning goals include:**
 - Regularly inventory and monitor
 - Consolidate/retire poorly utilized hardware

Virtualize and Consolidate Servers and Storage

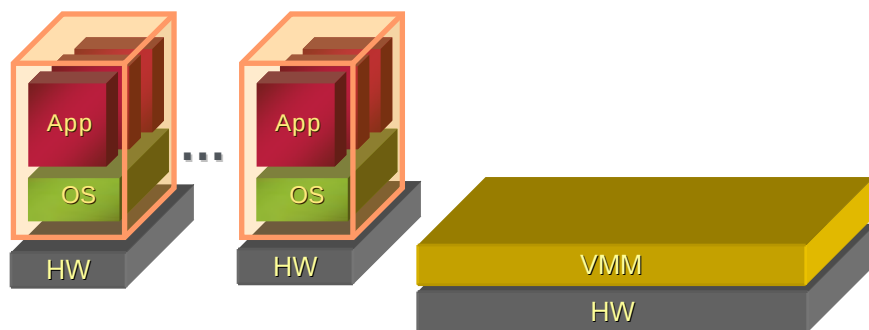
- Run many “virtual” machines on a single “physical” machine
- Developed in the 1960s to achieve better efficiency
- Consolidate underutilized physical machines, increasing utilization
- Energy saved by shutting down underutilized machines



Virtualize and Consolidate Servers and Storage

Virtualization: Workload provisioning

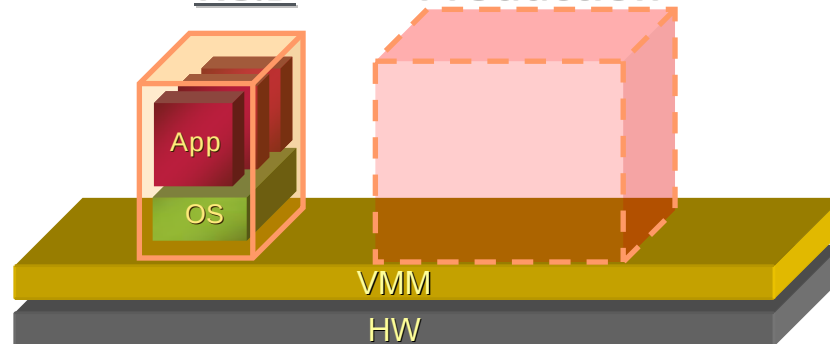
Server Consolidation



10:1 in many cases

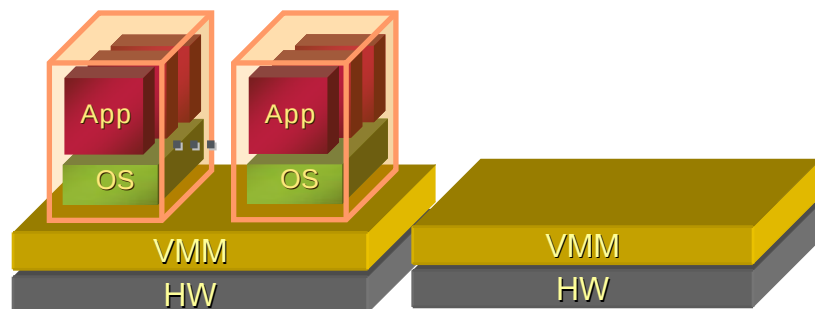
R&D

Production



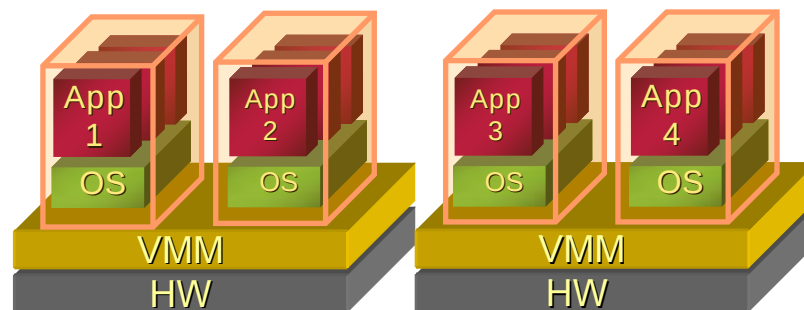
Enables rapid deployment,
reducing number of idle, staged servers

Disaster Recovery



- Upholding high-levels of business continuity
- One Standby for many production servers

Dynamic Load Balancing



CPU Usage



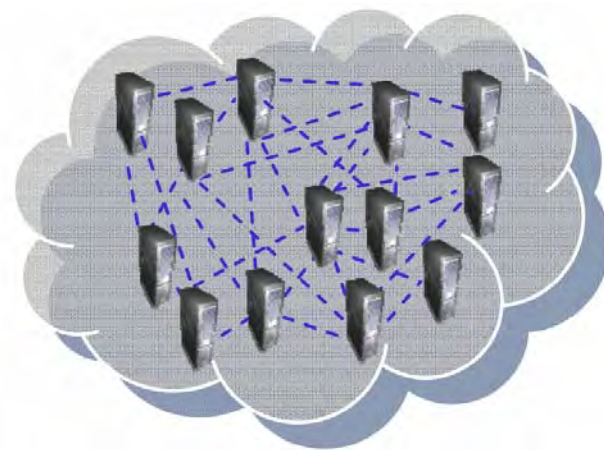
CPU Usage



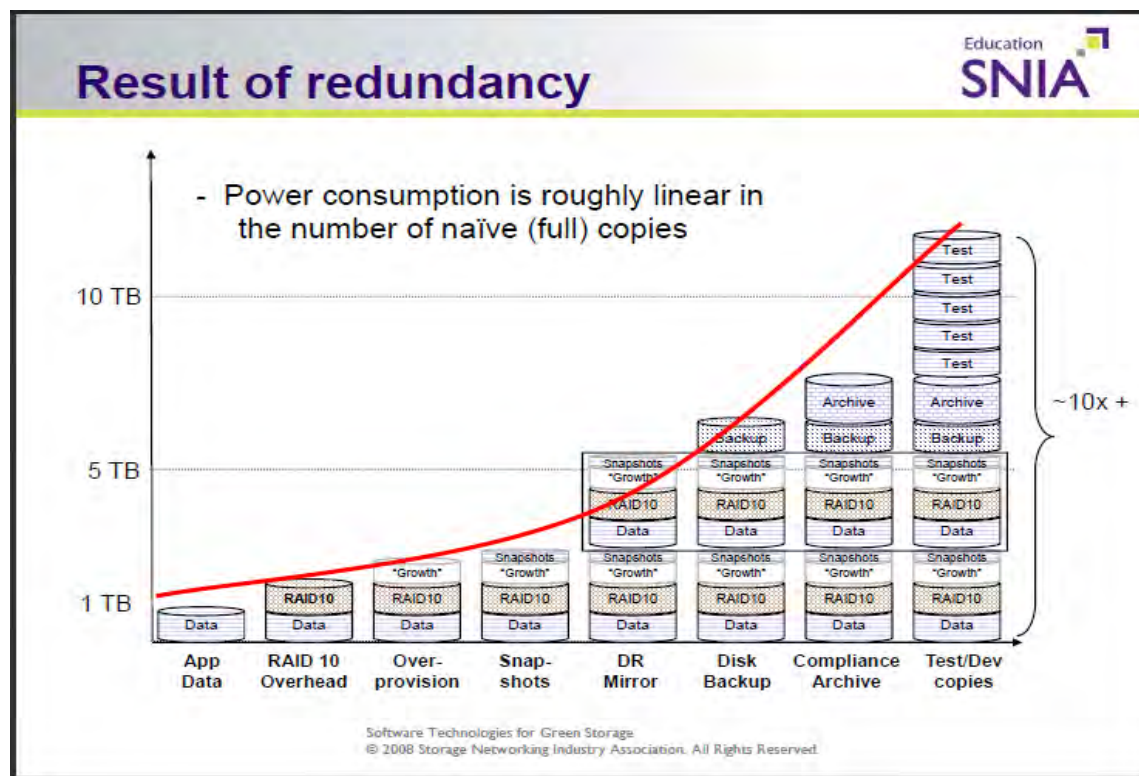
Balancing utilization with head room

Virtualized cloud computing can provide...

- Dynamically scalable resources over the internet
- Can be internal or external
- Can balance different application peak loads
- Typically achieves high utilization rates

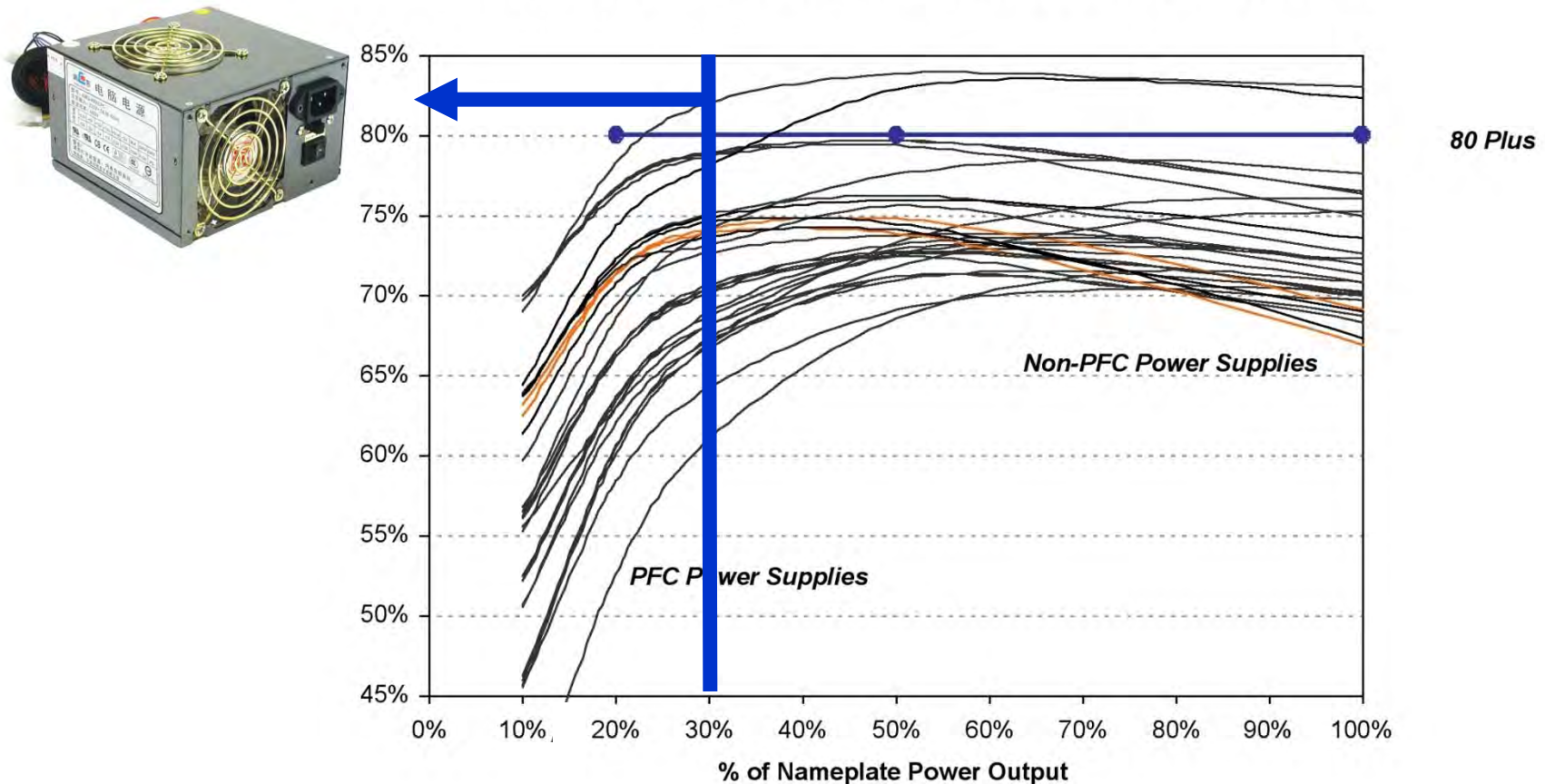


- Power roughly linear to storage modules
- Storage redundancy significantly increases energy
- Consider lower energy hierarchal storage
- Storage De-duplication - Eliminate unnecessary copies



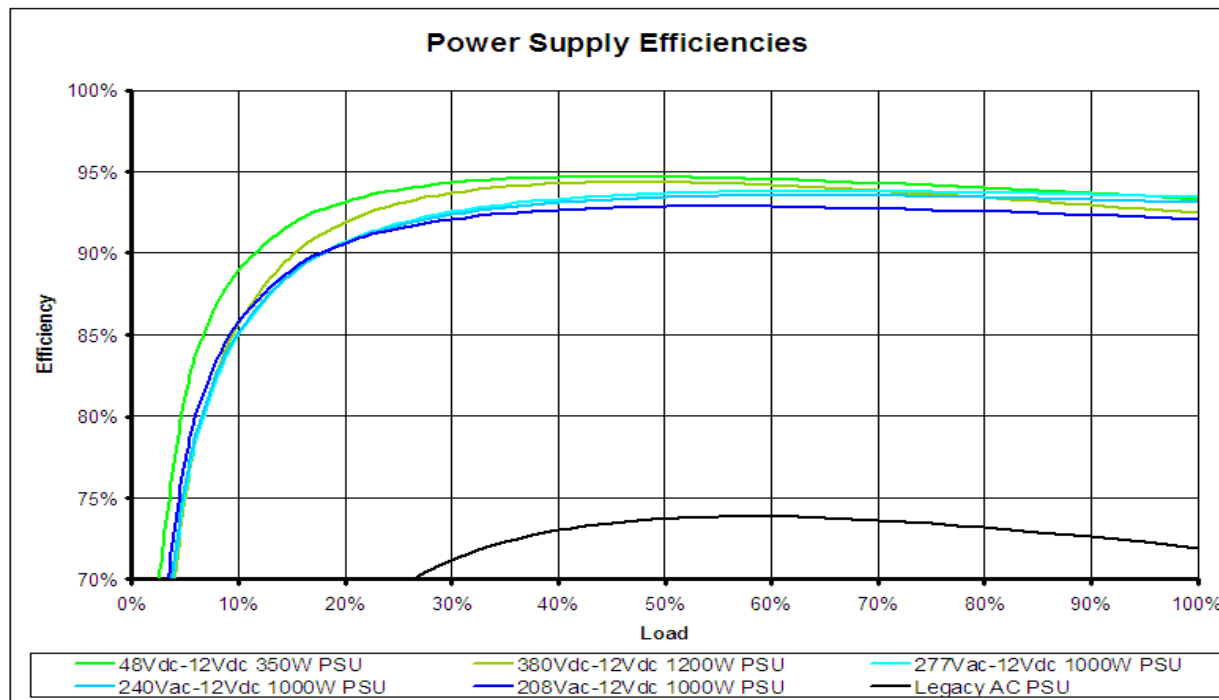
LBNL/EPRI measured power supply efficiency

Measured Server Power Supply Efficiencies (all form factors)



Power Supply Units

- Most efficient in the mid-range of performance curves
- Right-size for load
- Power supply redundancy puts operation lower on the curve
- Use Energy Star or Climate Savers power supplies

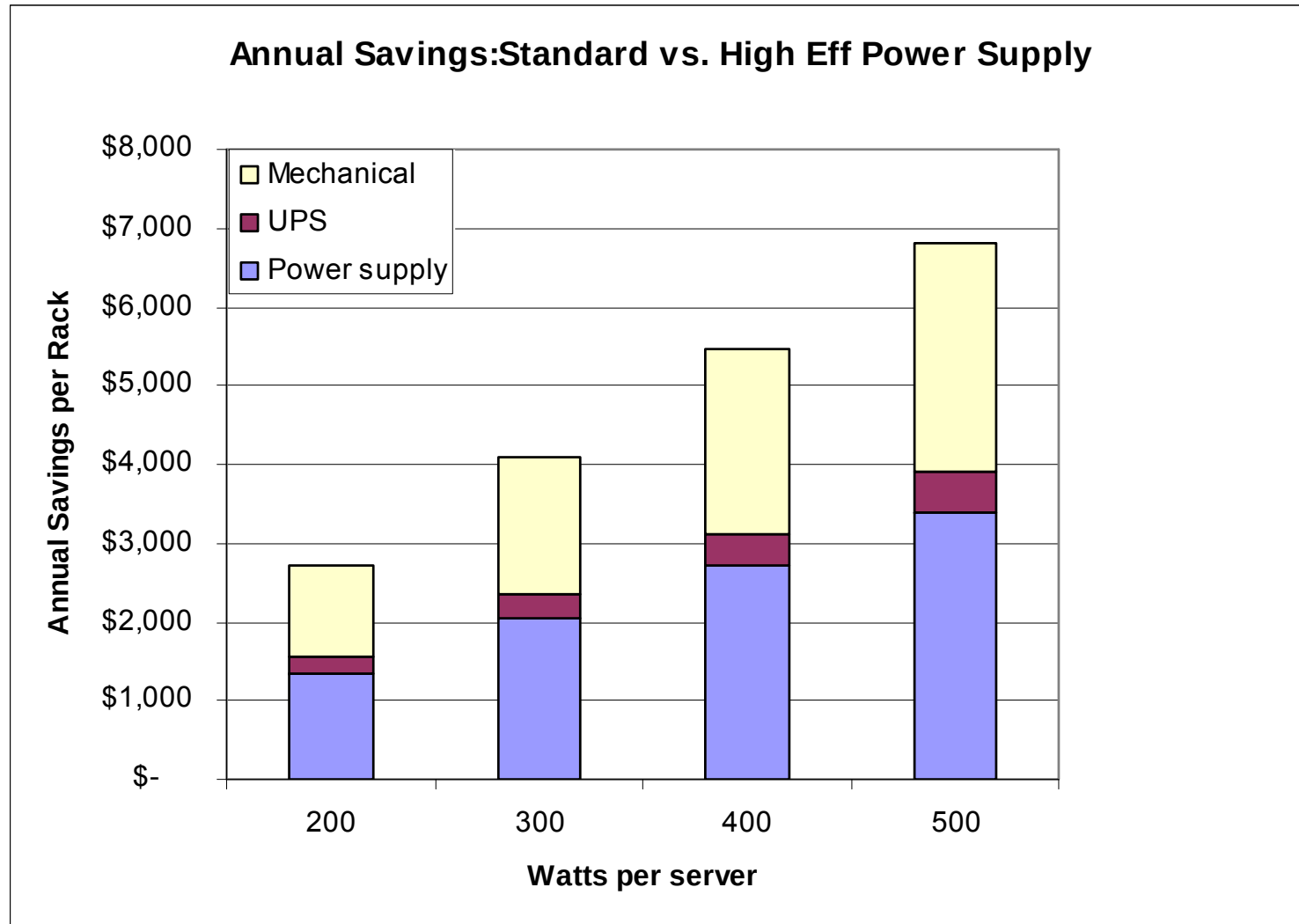


Source: The Green Grid

80 PLUS Certification Levels

Level of Certification	Efficiency at Rated Load					
	115V Internal Non-Redundant			230V Internal Redundant		
	20%	50%	100%	20%	50%	100%
80 PLUS	80%	80%	80%	n/a	n/a	n/a
80 PLUS Bronze	82%	85%	82%	81%	85%	81%
80 PLUS Silver	85%	88%	85%	85%	89%	85%
80 PLUS Gold	87%	90%	87%	88%	92%	88%
80 PLUS Platinum	n/a	n/a	n/a	90%	94%	91%

Power supply savings add up...



IT System Efficiency Summary...

Servers



- Enable *power management capabilities!*
- Use EnergyStar® Servers

Power Supplies



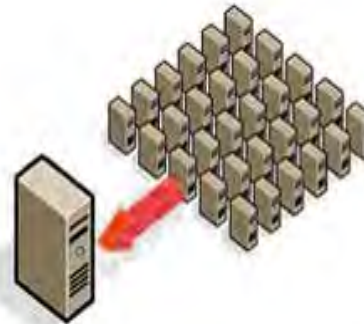
- Reconsider Redundancy
- Use 80 PLUS or Climate Savers products

Storage Devices



- Take superfluous data offline
- Use thin provisioning technology

Consolidation



- Use virtualization
- Consider cloud services

Server System Infrastructure

Managing Component Interfaces

- www.ssiforums.org
- www.80plus.org
- www.climatesaverscomputing.org
- <http://tc99.ashraetcs.org/>



ASHRAE
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
ASHRAE Technical Committee 9.9



Questions?





Using IT to Manage IT

Innovative Application of IT in Data Centers for Energy Efficiency



U.S. Department of Energy
Energy Efficiency and Renewable Energy

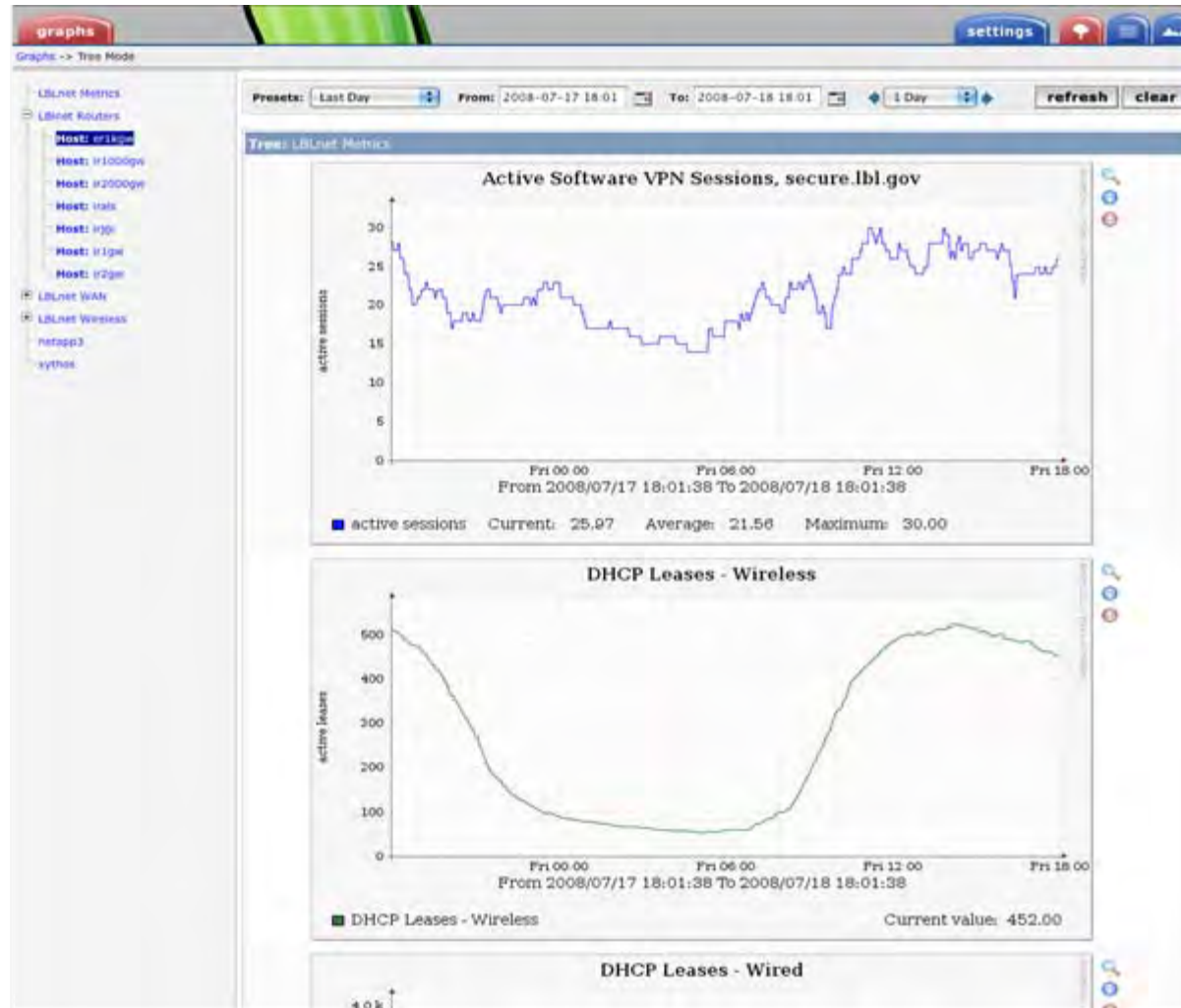


Using IT to Save Energy in IT:

- Most operators lack “visibility” into their data center environment.
- An operator can’t manage what they don’t measure.
- Goals:
 - Provide the same level of monitoring and visualization of the physical space that exists for monitoring the IT environment.
 - Measure and track performance metrics.
 - Spot problems before they result in high energy cost or down time.

The Importance of Visualization

- IT Systems & network administrators have tools for visualization.
- Useful for debugging, benchmarking, capacity planning, forensics.
- Data center facility managers have had comparatively poor visualization tools.



- ✓ LBNL installed 800+ point sensor network.
- ✓ Measures:
 - Temperature
 - Humidity
 - Pressure (under floor)
 - Electrical power
- ✓ Presents real-time feedback and historic tracking
- ✓ Optimize based on empirical data, not intuition.

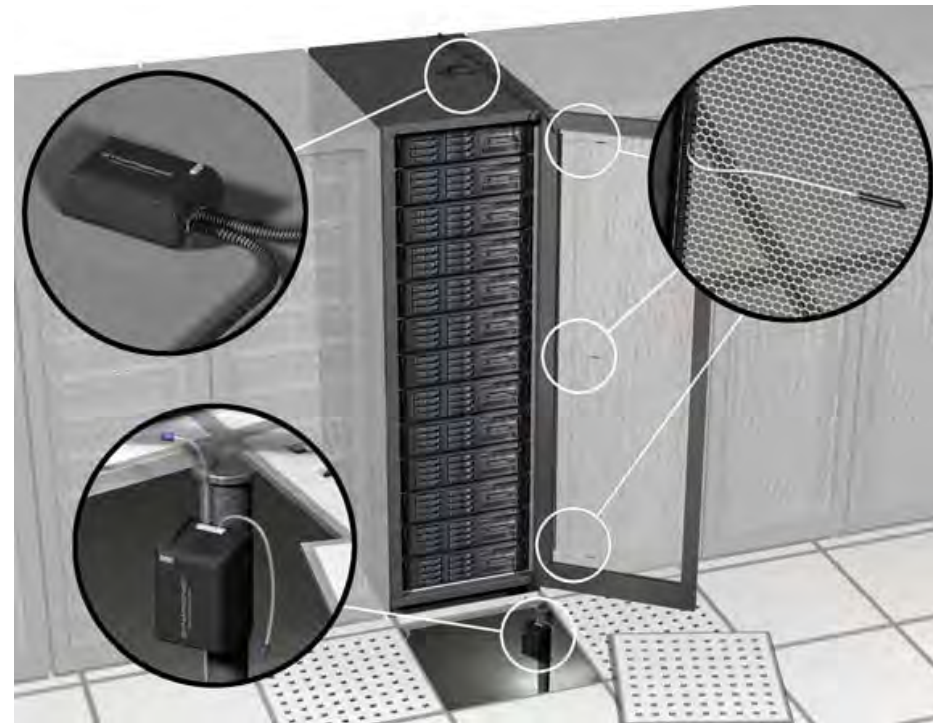
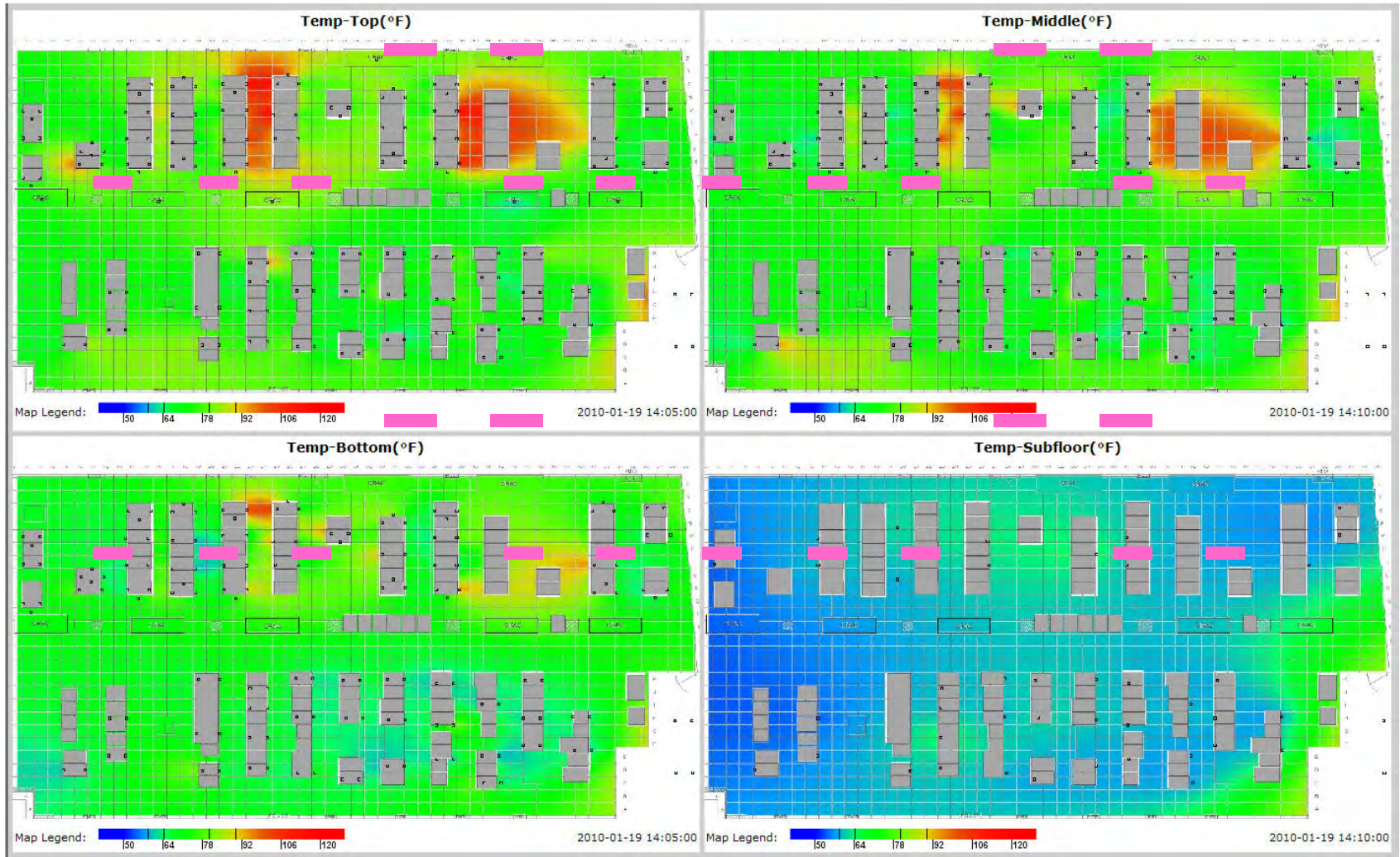
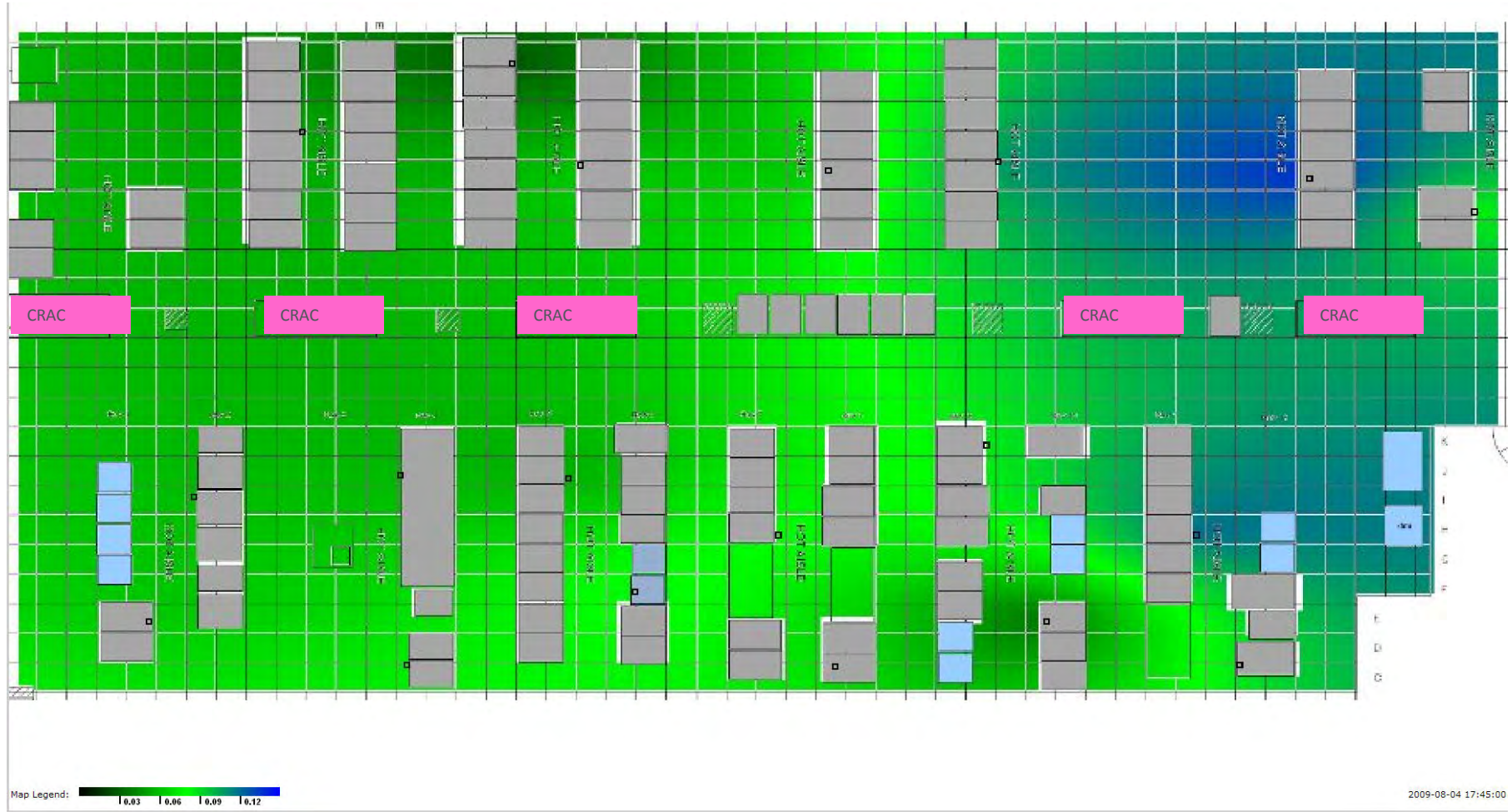


Image: SynapSense

Real-time Temperature Visualization by Level



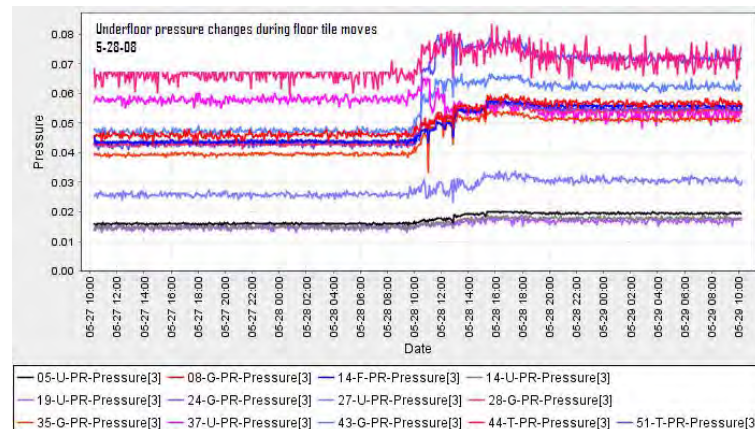
Displayed Under-floor Pressure Map...



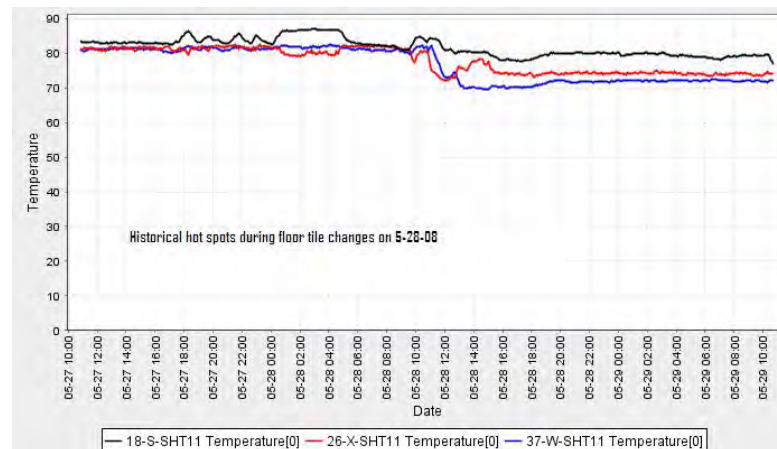
Provided Real-time Feedback During Floor-tile Tuning

- ✓ Removed guesswork by monitoring and using visualization tool.

Under-Floor Pressure



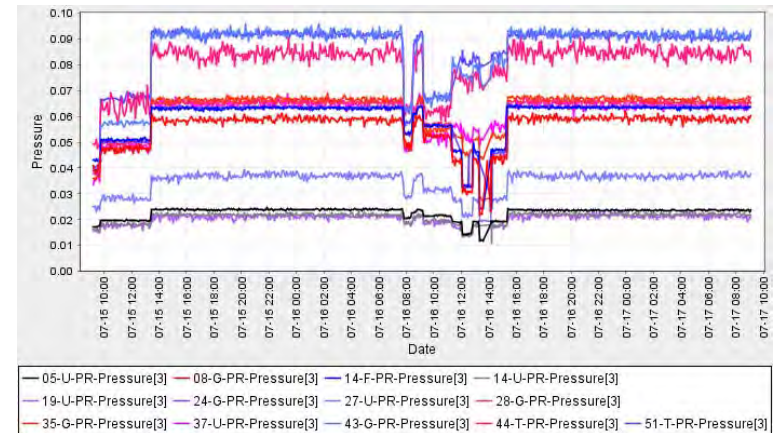
Rack-Top Temperatures



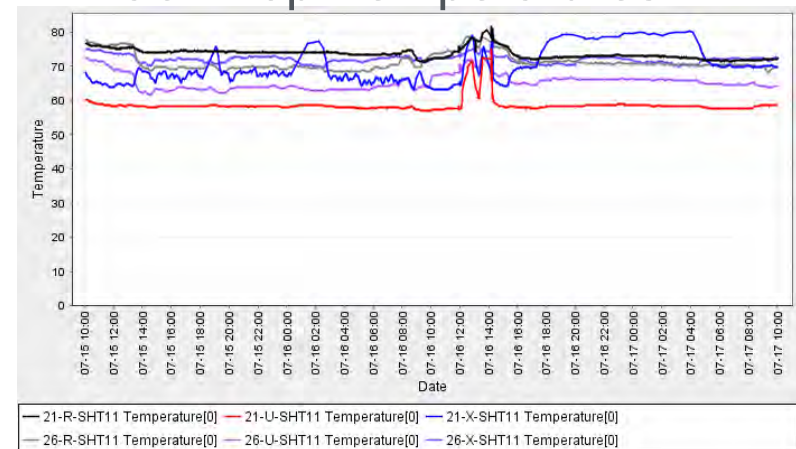
Determined Relative CRAC Cooling Energy Impact

- Enhanced knowledge of data center redundancy.
- Turned off unnecessary CRAC units to save energy.

Under-Floor Pressure

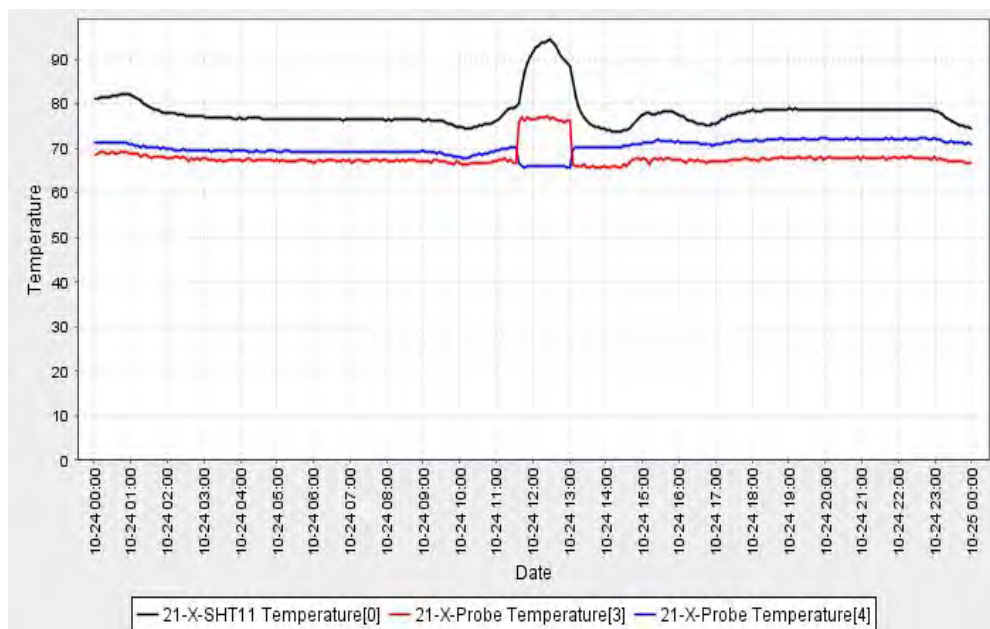


Rack-Top Temperatures

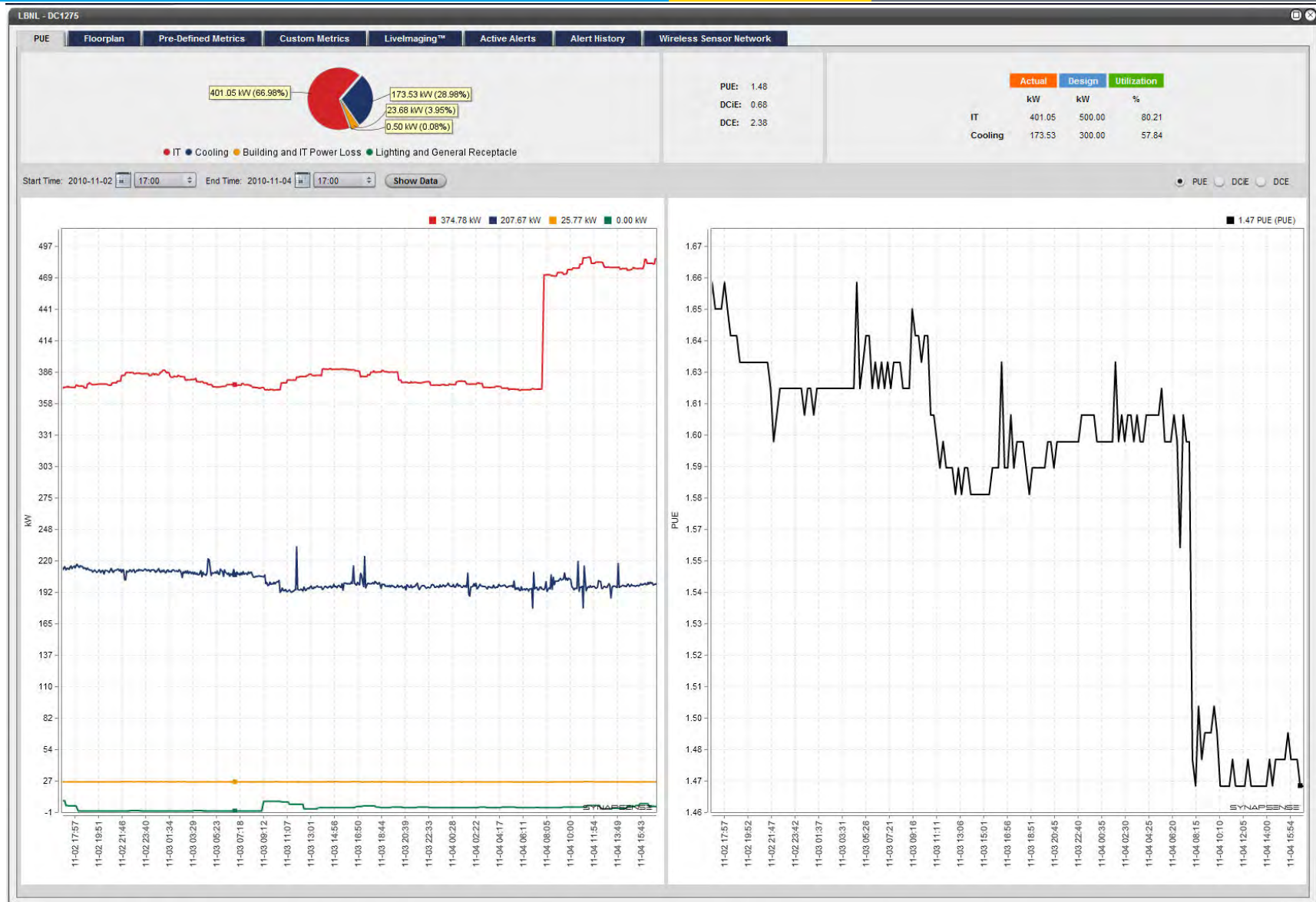


Feedback Continues to Help: Note impact of IT cart!

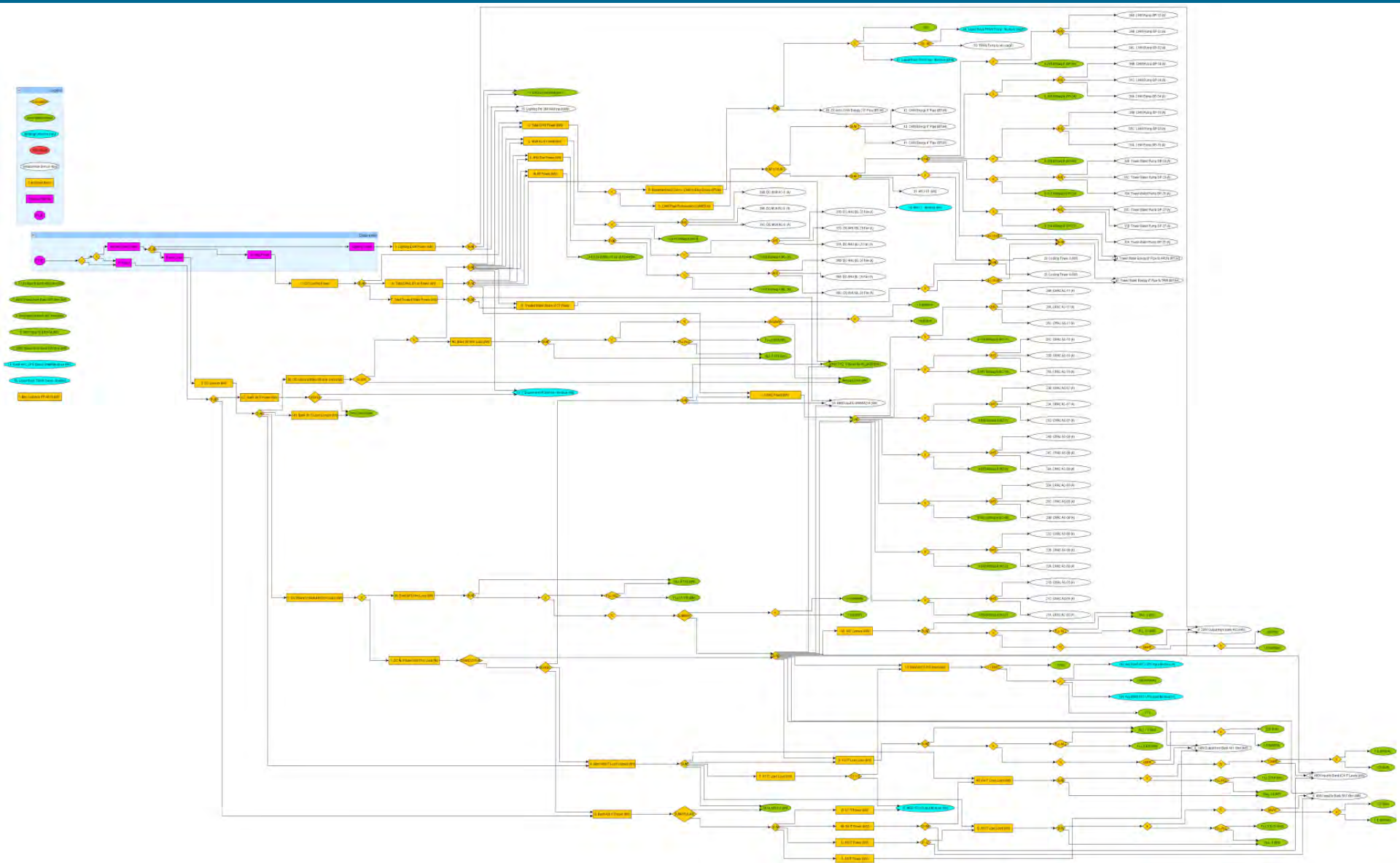
Real-time feedback identified
cold aisle air flow obstruction!



Real-time PUE Display



PUE Calculation Diagram



Franchise Tax Board (FTB) Case Study

Description:

- 10,000 Sq Ft
- 12 CRAH cooling units
- 135 kW load

Challenges:

- Over-provisioned
- History of fighting
- Manual shutoff not successful

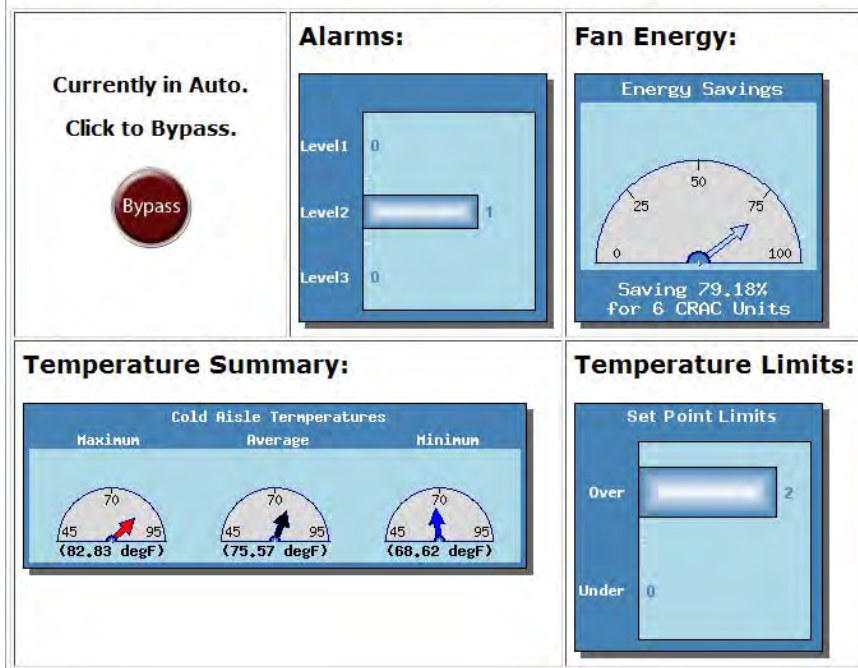
Solution:

- Intelligent supervisory control software with inlet air sensing



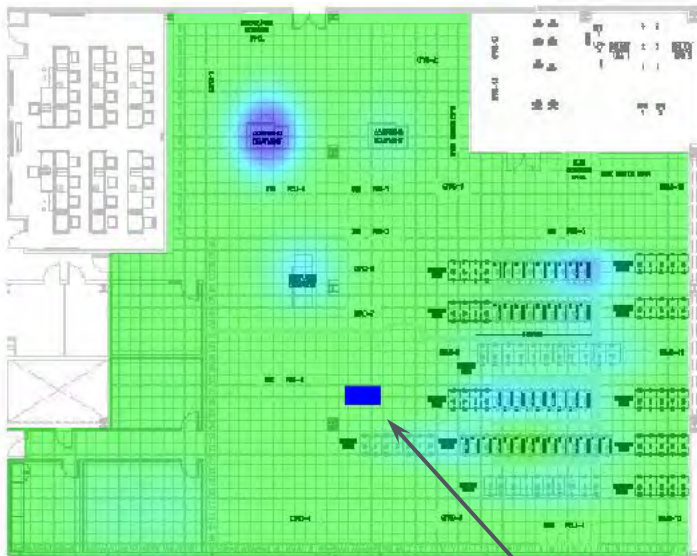
- WSN included 50 wireless temperature sensors (Dust Networks radios)
- Intelligent control software

FACS Dashboard:

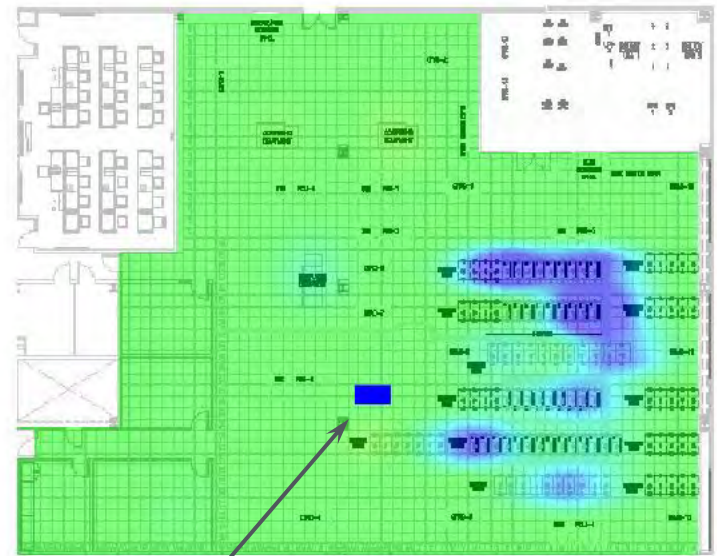


WSN Smart Software: learns about curtains

CRAH 3 influence at start

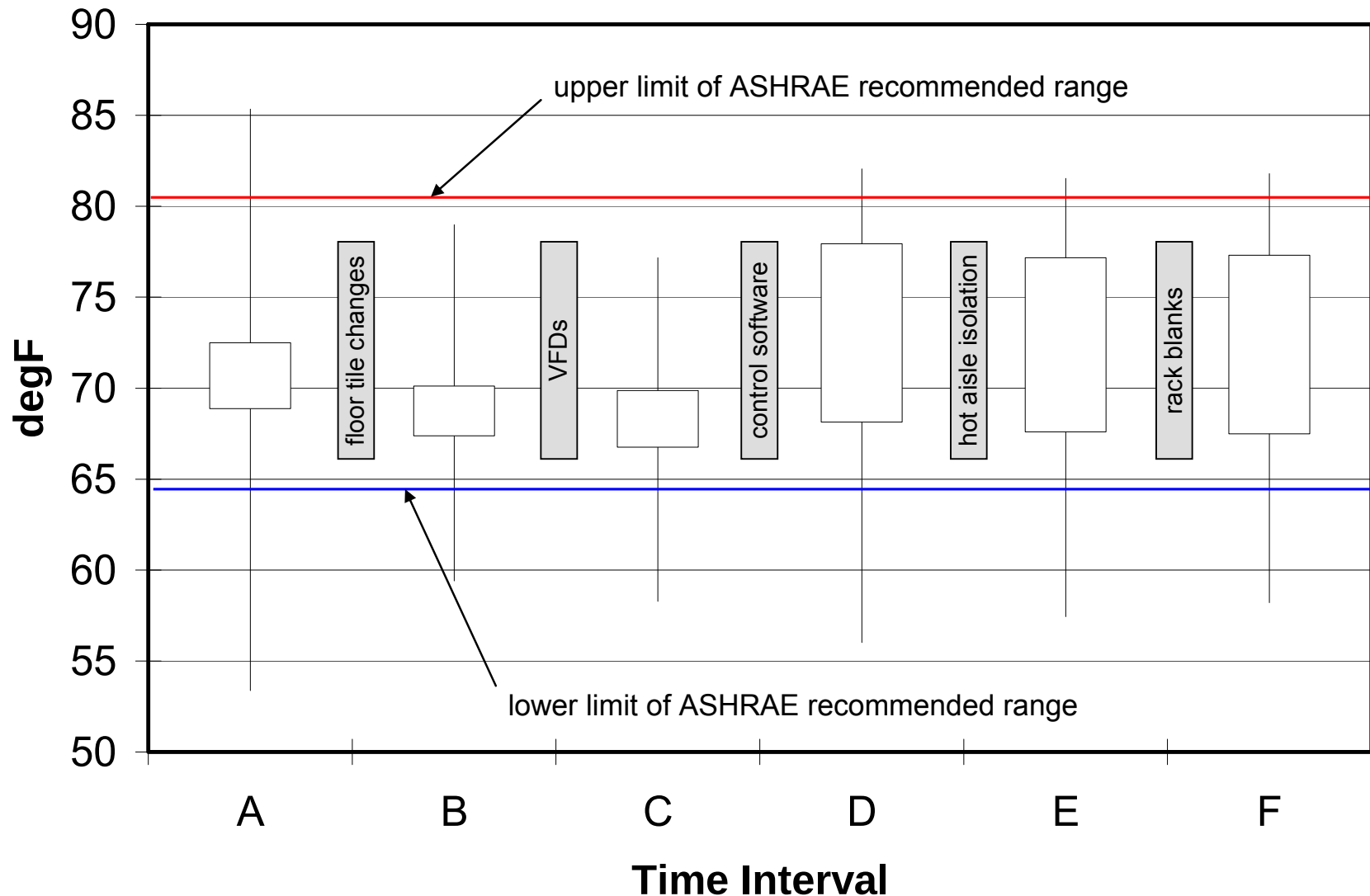


CRAH 3 influence after curtains

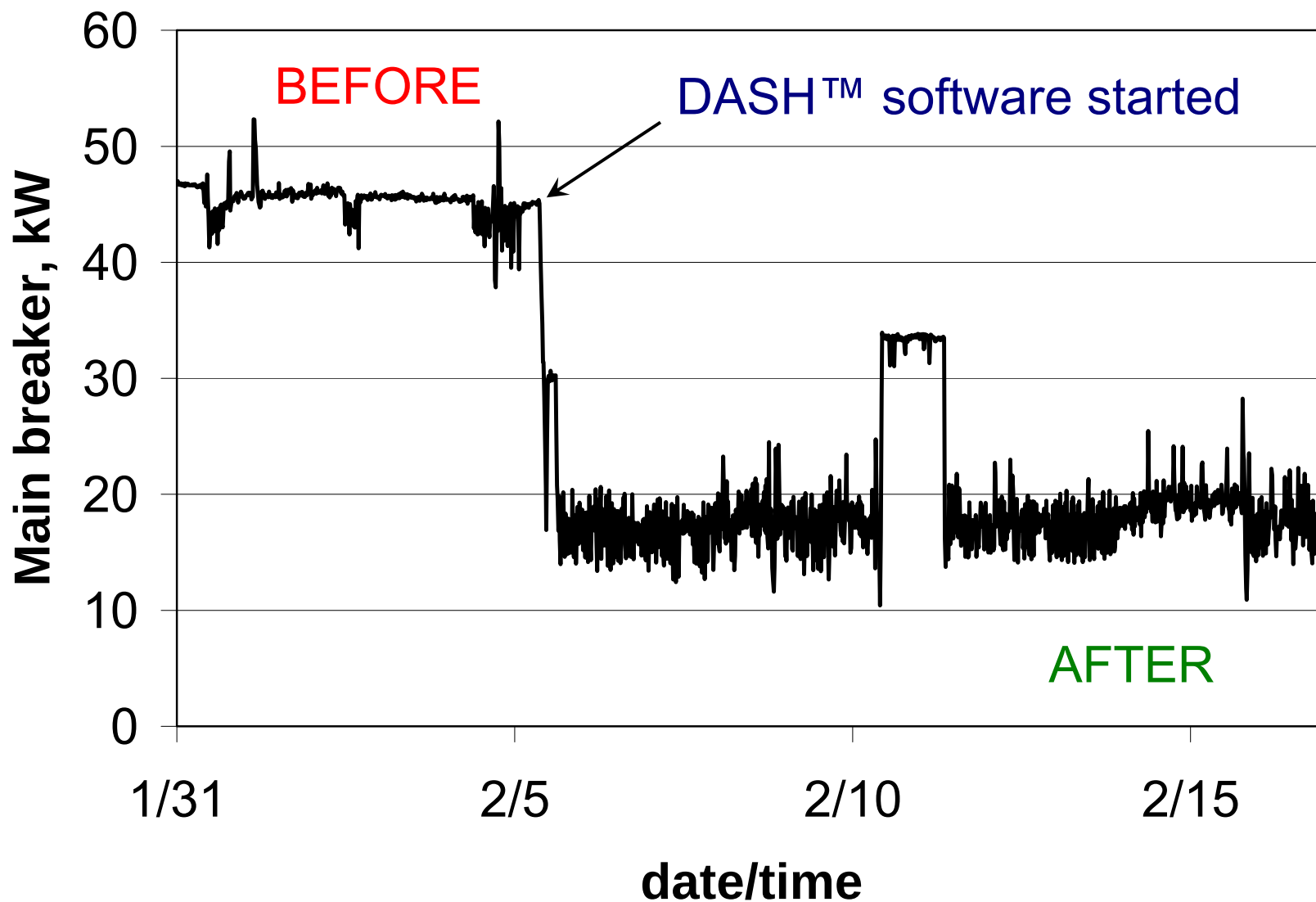


CRAH-03

WSN Provided Effect on Cold-aisle Temperatures:



WSN Software = Dramatic Energy Reduction...



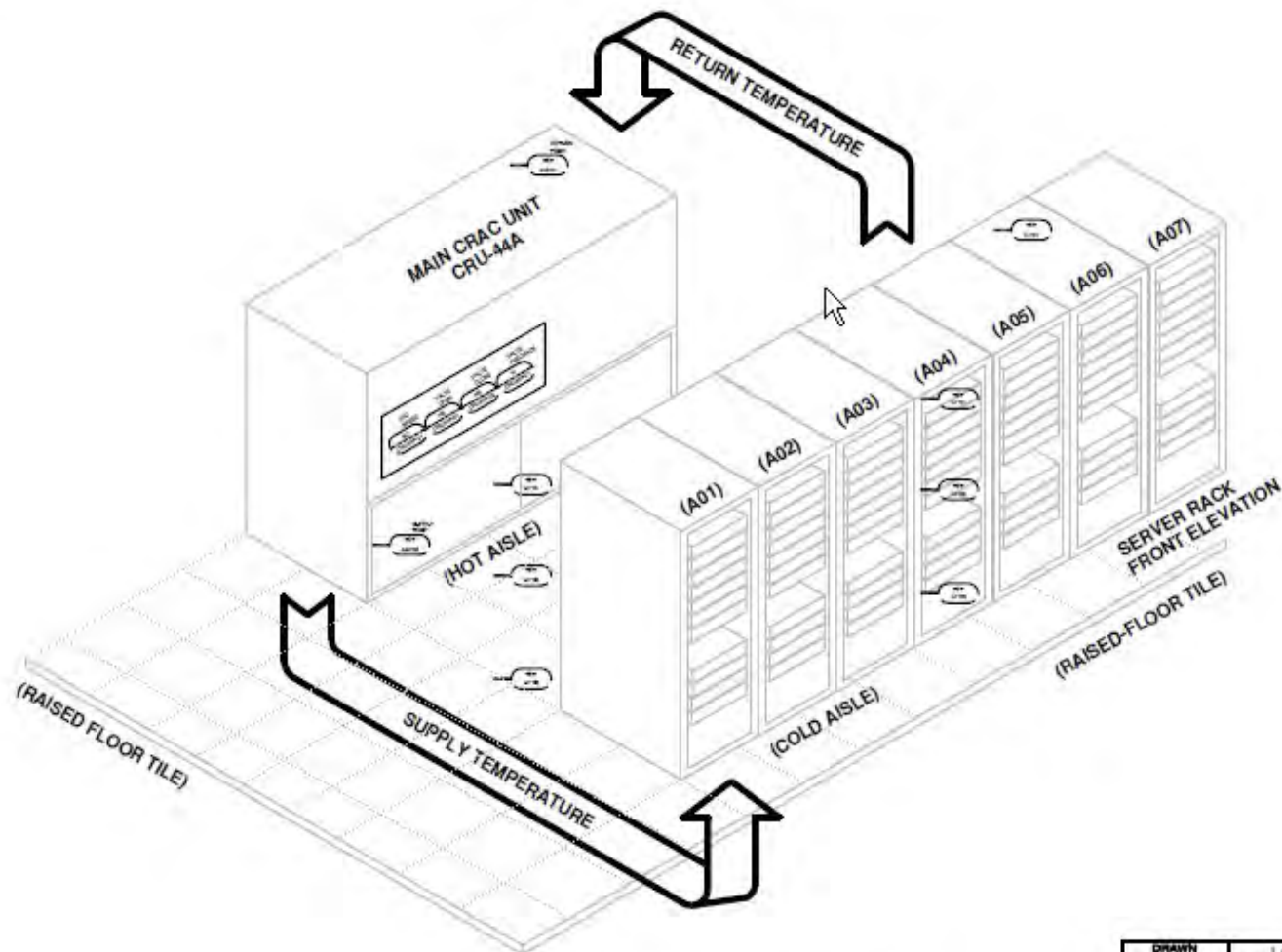
- DASH cost-benefit (sensors and software)
 - Cost: \$56,824
 - Savings: \$30,564
 - Payback: 1.9 years
- Total project cost-benefit
 - Cost: \$134,057
 - Savings: \$42,772
 - Payback: 3.1 years

Control data center air conditioning using the *built-in* IT server-equipment temperature sensors



- **Typically**, data center cooling devices use *return air temperature* as the primary control-variable
 - ASHRAE and IT manufacturers agree IT equipment inlet air temperature is the key operational parameter
 - Optimum control difficult
- Server inlet air temperature is available from ICT network
 - Intelligent Platform Management Interface (IPMI) or
 - Simple network management protocol (SNMP)

Intel Data Center HVAC:

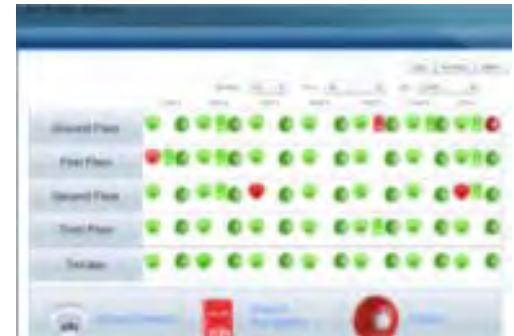


SC11 DATA CENTER HVAC MECHANICAL DIAGRAM

DRAWN RJM	LAWRENCE BERKELEY NATIONAL LABORATORY INTEL CORPORATION
CHECKED DS	
DATE 03/07/2006	HVAC CONTROLS DEMONSTRATION PROJECT
DATE, NO. LBNL-DIAG-1	

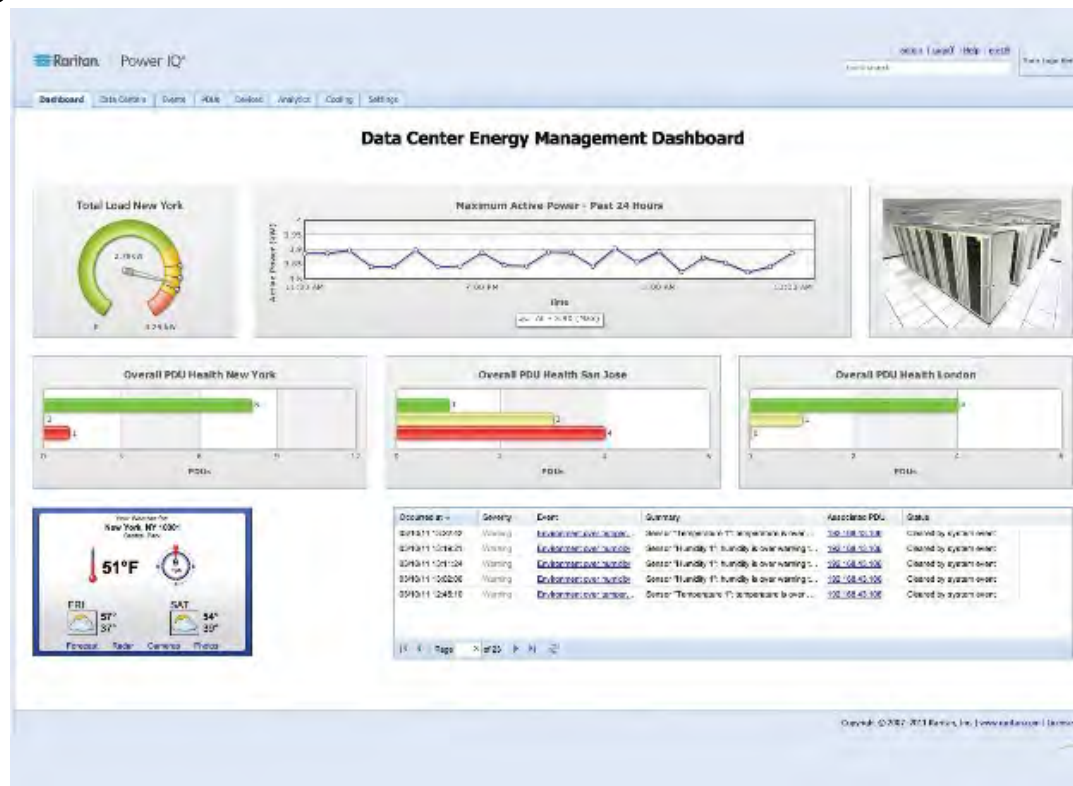
- Demonstration showed:
 - Servers can provide temperature data to facilities control system
 - Given server inlet temperature, facility controls improved temperature control and efficiency
 - Effective communications and control accomplished without significant interruption or reconfiguration of systems

Dashboards can display multiple systems' information for monitoring and maintaining data center performance

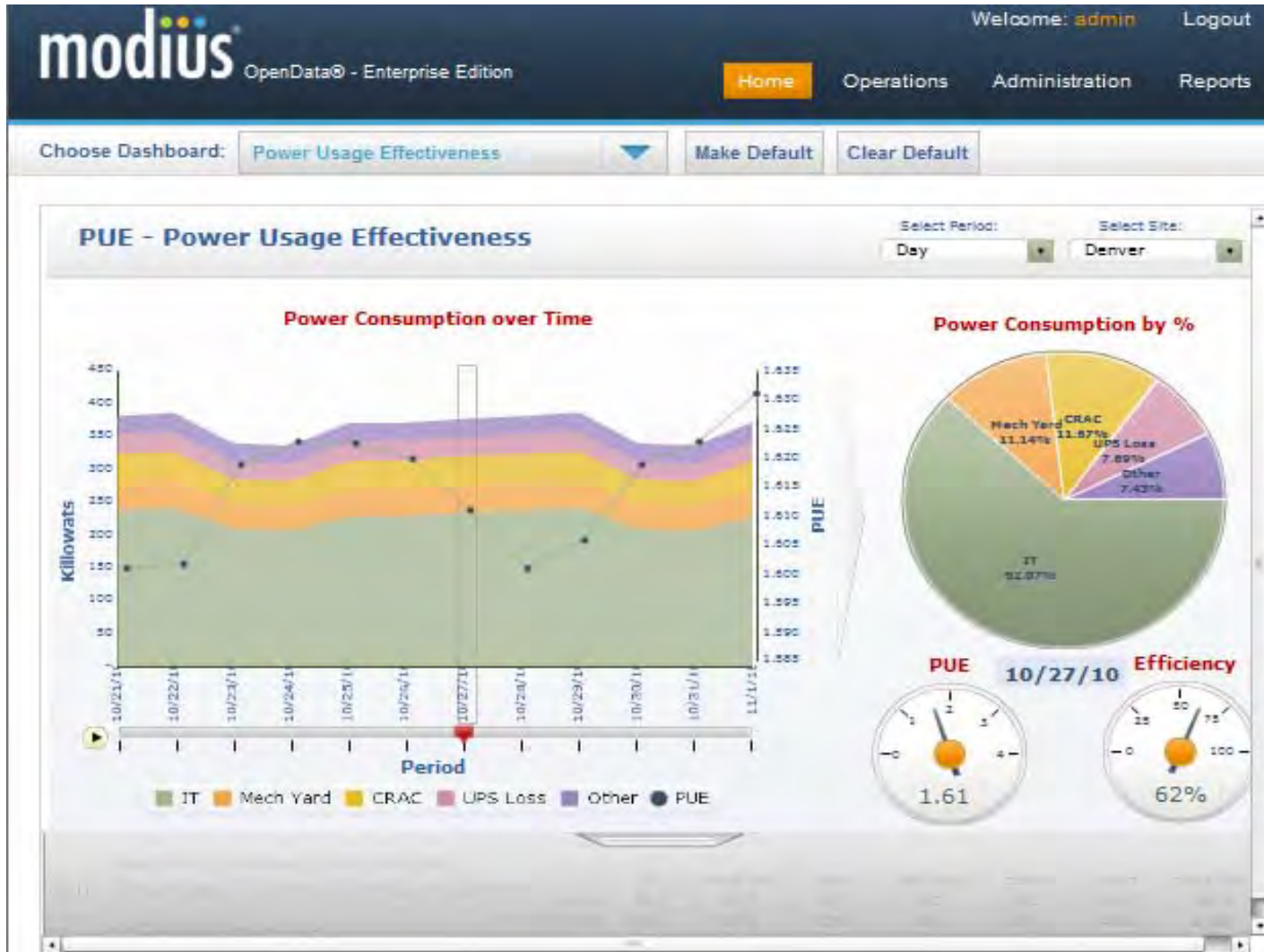


Why Dashboards?

- Provide IT and HVAC system performance at a glance
- Identify operational problems
- Baseline energy use and benchmark performance
- View effects of changes
- Share information and inform integrated decisions



Another Dashboard Example...



- **Evaluate monitoring systems to enhance operations and controls**
- **Install dashboards to manage and sustain energy efficiency.**

Questions?





Environmental Conditions



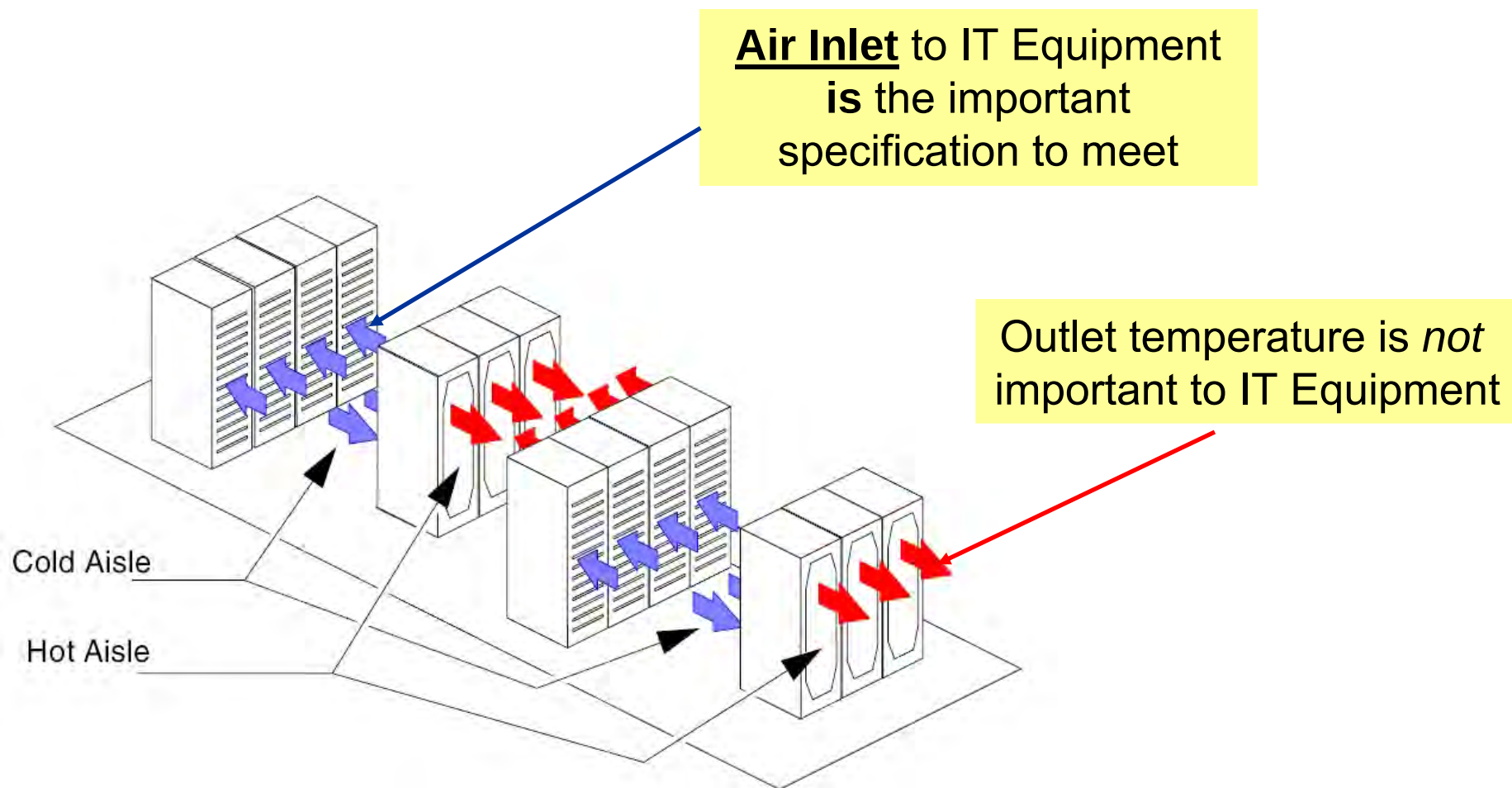
U.S. Department of Energy
Energy Efficiency and Renewable Energy



What are the main HVAC Energy Drivers?

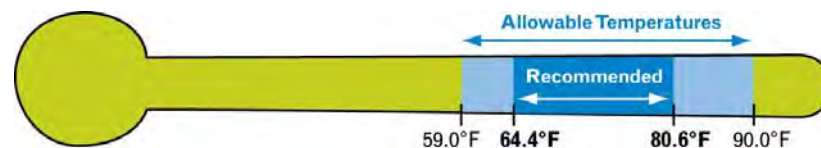
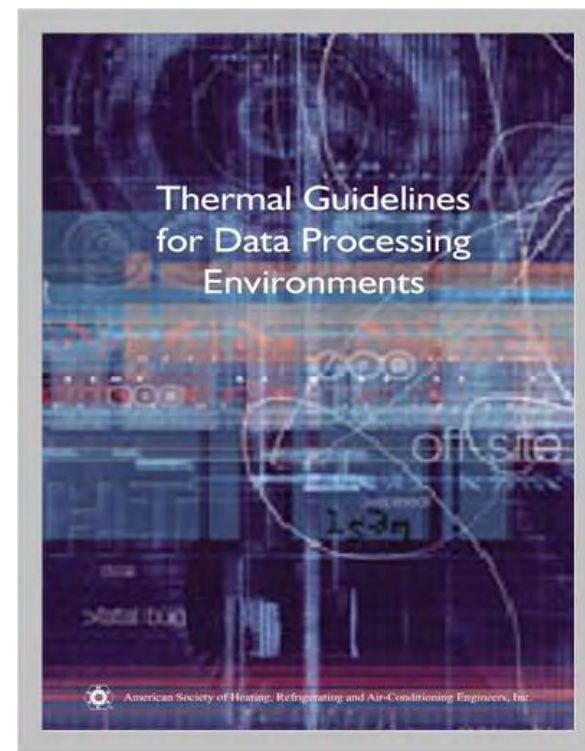
- IT Load
- Climate
- **Room temperature and humidity**
 - Most data centers are overcooled and have humidity control issues
 - Human comfort should not be a driver

Equipment Environmental Specification



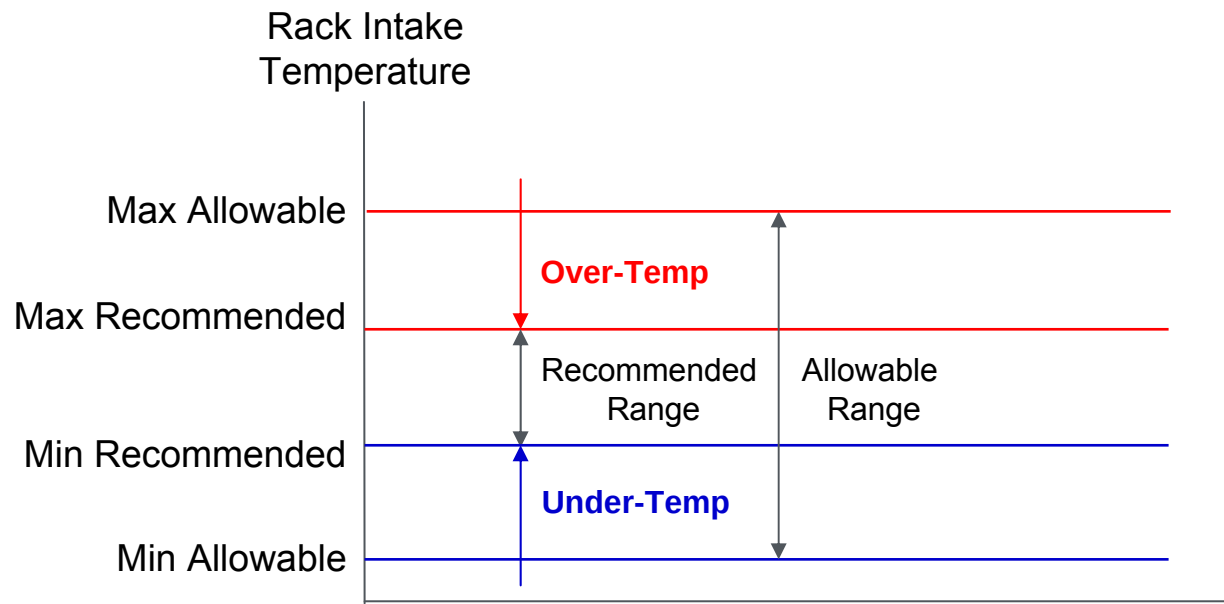
ASHRAE's Thermal Guidelines:

- Provide common understanding between IT and facility staff.
- Endorsed by IT manufacturers
- Enables large energy savings - especially when using economizers.
- Recommends temperature range of 18° C to 27° C (80.6°F) with “allowable” much higher
- New (2011) ASHRAE Guidelines
 - Six classes of equipment identified with wider allowable ranges from 32° C to 45° C (113°F).
 - Provides more justification for operating above the recommended limits (in the allowable range)
 - Provides wider humidity ranges



Key Nomenclature

- ❖ The recommended range is a statement of reliability. For extended periods of time, the IT manufacturers recommend that data centers maintain their environment within these boundaries.
- ❖ The allowable range is a statement of functionality. These are the boundaries where IT manufacturers test their equipment to verify that the equipment will function.

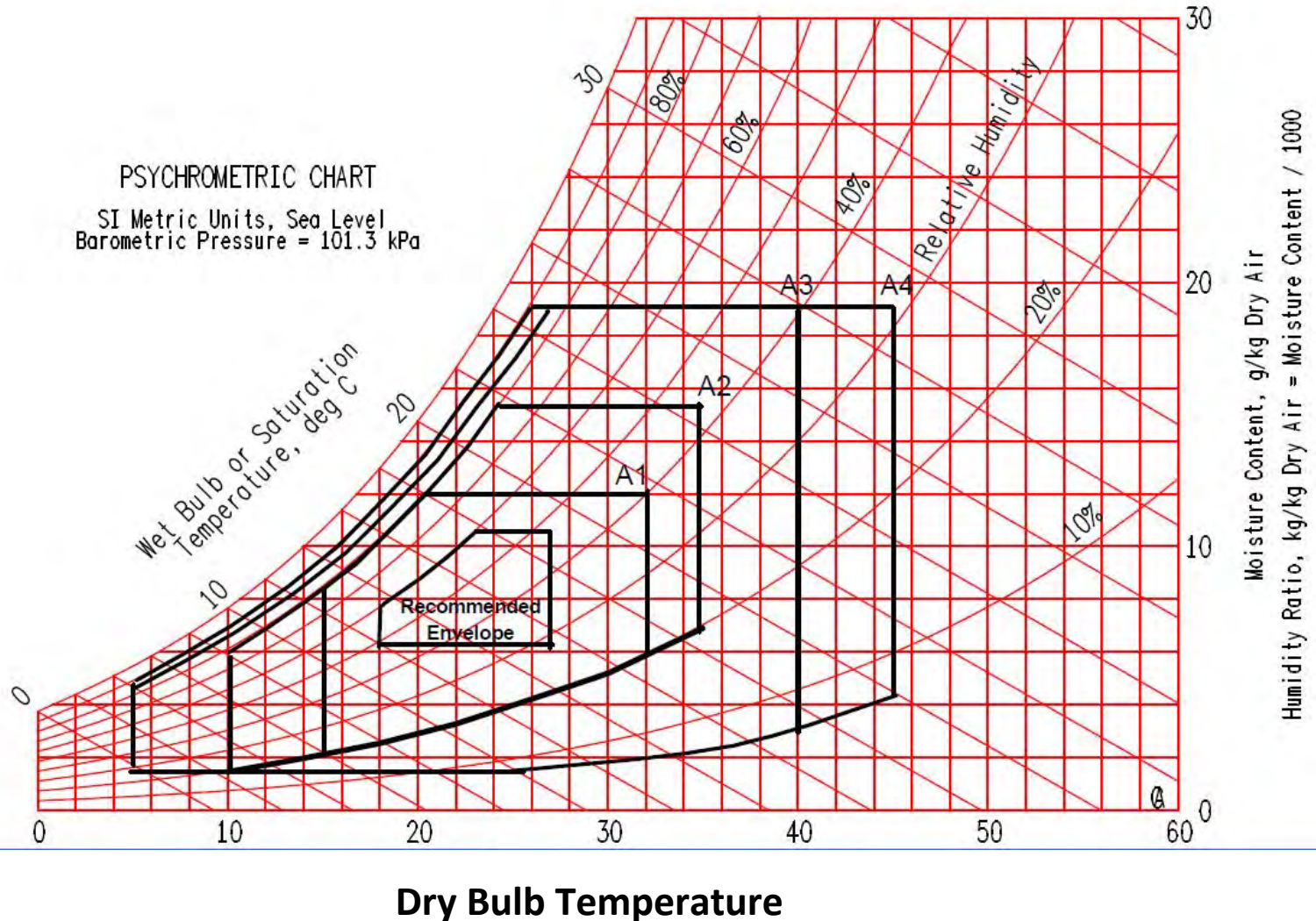


2011 ASHRAE Thermal Guidelines

Classes (a)	Equipment Environmental Specifications							
	Product Operations (b)(c)					Product Power Off (c) (d)		
	Dry-Bulb Temperature (°C) (e) (g)	Humidity Range, non-Condensing (h) (i)	Maximum Dew Point (°C) (j)	Maximum Elevation (m) (k)	Maximum Rate of Change (°C/hr) (l)	Dry-Bulb Temperature (°C) (m)	Relative Humidity (%) (n)	Maximum Dew Point (°C) (o)
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	18 to 27	5.5°C DP to 60% RH and 15°C DP						
Allowable								
A1	15 to 32	20% to 80% RH	17	3050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20% to 80% RH	21	3050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12°C DP & 8% RH to 85% RH	24	3050	5/20	5 to 45	8 to 85	27
A4	5 to 45	-12°C DP & 8% RH to 90% RH	24	3050	5/20	5 to 45	8 to 90	27
B	5 to 35	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29
C	5 to 40	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29

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



ASHRAE's key conclusion when considering potential for increased failures at higher (allowable) temperatures:

“For a majority of US and European cities, the air-side and water-side economizer projections show failure rates that are very comparable to a traditional data center run at a steady state temperature of 20°C.”

ASHRAE and a DOE High Performance Computer (HPC) user group have developing a white paper for liquid cooling

- Three temperature standards defined based on three mechanical system configurations:
 - Chilled water provided by a chiller (with or without a “tower side economizer”)
 - Cooling water provided a cooling tower with possible chiller backup
 - Cooling water provided by a dry cooler with possible backup using evaporation

Summary Recommended Limits

Liquid Cooling Class	Main Cooling Equipment	Supplemental Cooling Equipment	Building Supplied Cooling Liquid Maximum Temperature
L1	Cooling Tower and Chiller	Not Needed	17°C (63°F)
L2	Cooling Tower	Chiller	32°C (89°F)
L3	Dry Cooler	Spray Dry Cooler, or Chiller	43°C (110°F)



Environmental

Temperature:

- Operating: 10° to 35°C (50° to 95°F)
- Storage: -40° to 65°C (-40° to 149°F)

Relative humidity

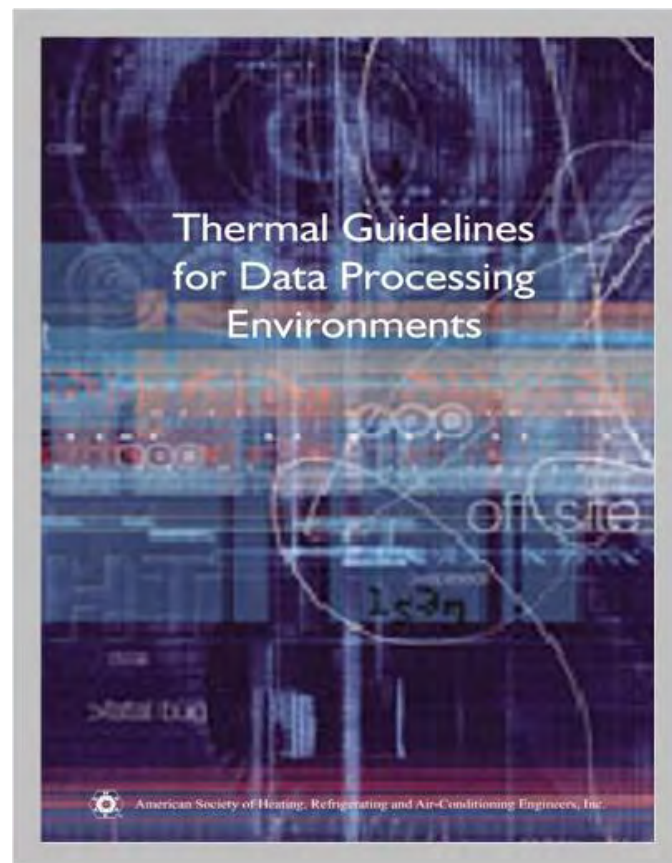
- Operating: 20% to 80% (non-condensing)
- Storage: 5% to 95% (non-condensing)

Altitude

- Operating: -15 to 3048 m (-50 to 10,000 ft)
- Storage: -15 to 10,668 m (-50 to 35,000 ft)

Environmental Conditions: Summary

- Most computer room air conditioners (CRACs) are controlled based on the return air temperature – *this needs to change*
- A cold data center = efficiency opportunity
- Perceptions, based on old technology lead to cold data centers with tight humidity ranges – *this needs to change.*
- Many IT manufacturers design for harsher conditions than ASHRAE guidelines
- Design Data Centers for IT equipment performance - *not people comfort.*
- **Address air management issues first**



Questions?





Airflow Management



U.S. Department of Energy
Energy Efficiency and Renewable Energy



Air Management: The Early Days at LBNL

It was cold but hot spots were everywhere

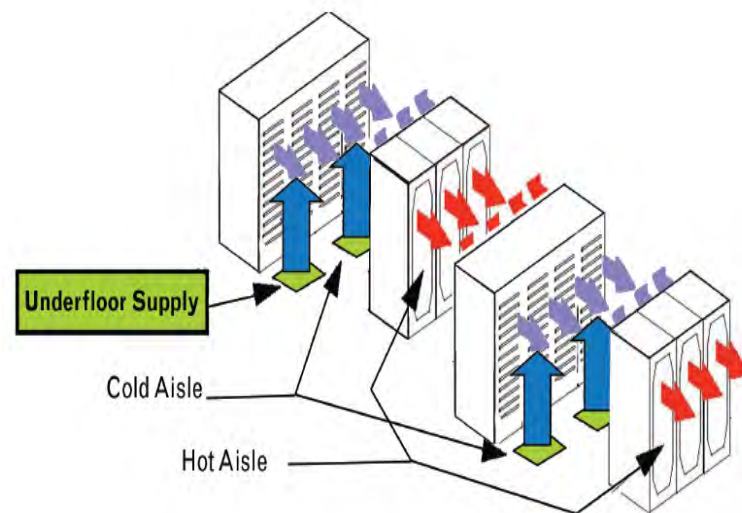


Fans were used to redirect air

High flow tiles reduced air pressure



- 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



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

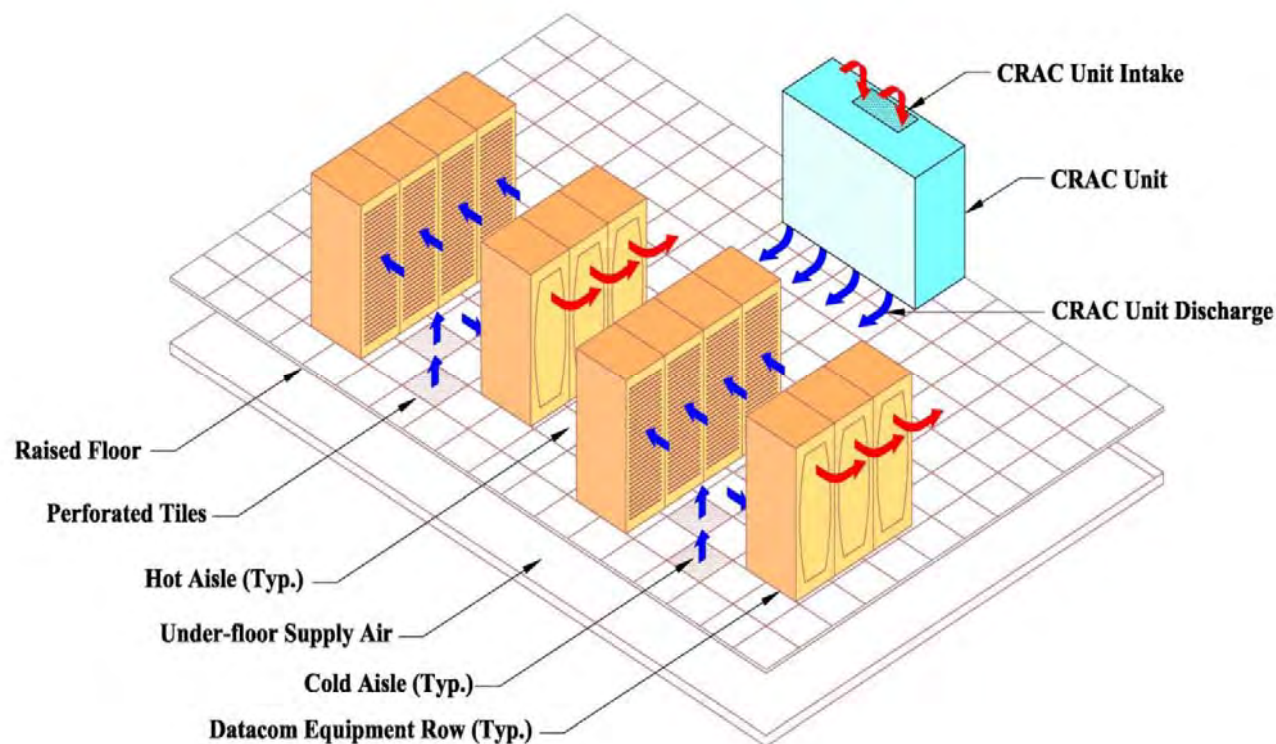
➤ Improves equipment intake air conditions by separating cold from hot airflow.

Preparation:

- ✓ Arranging racks with alternating hot and cold aisles.

- ✓ Supply cold air to front of facing servers.

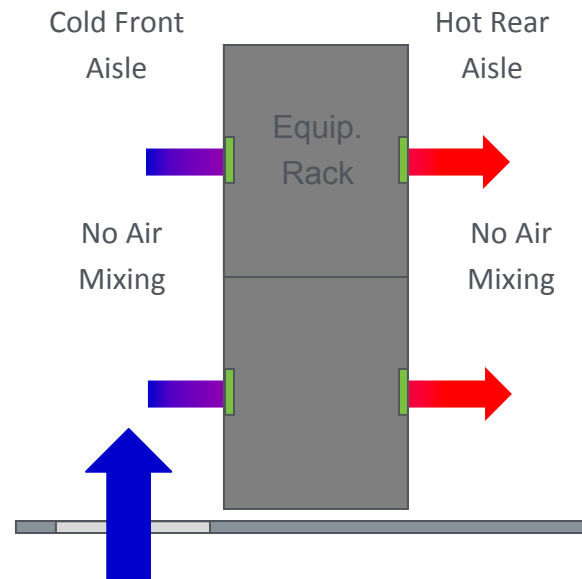
- ✓ Hot exhaust air exits into rear aisles.



Graphics courtesy of DLB Associates

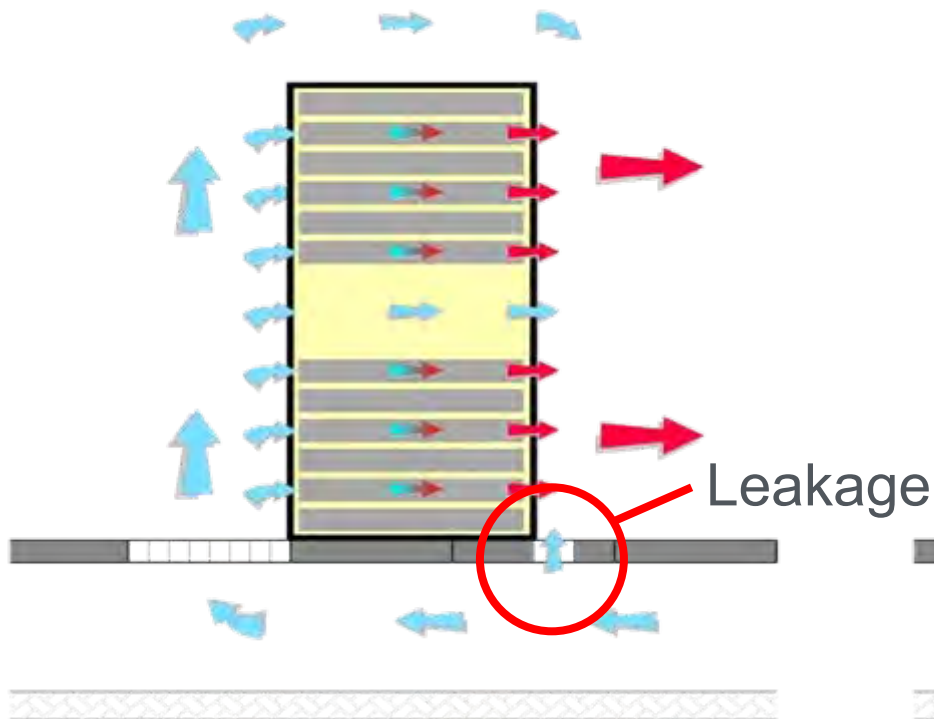
Separating Cold from Hot Airflow...

- Supply cold air as close to rack inlet as possible.
- Reduce mixing with ambient air and hot rack exhaust
- Flow air from the cold front aisle to the rear hot aisle



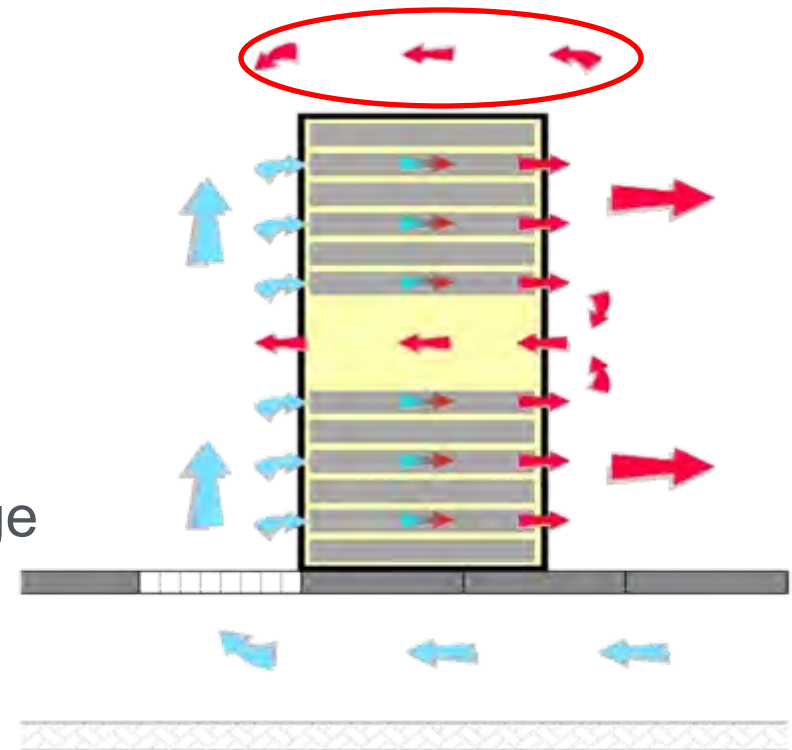
Reduce Bypass and Recirculation

Bypass Air / Short-Circuiting...



Wastes cooling capacity.

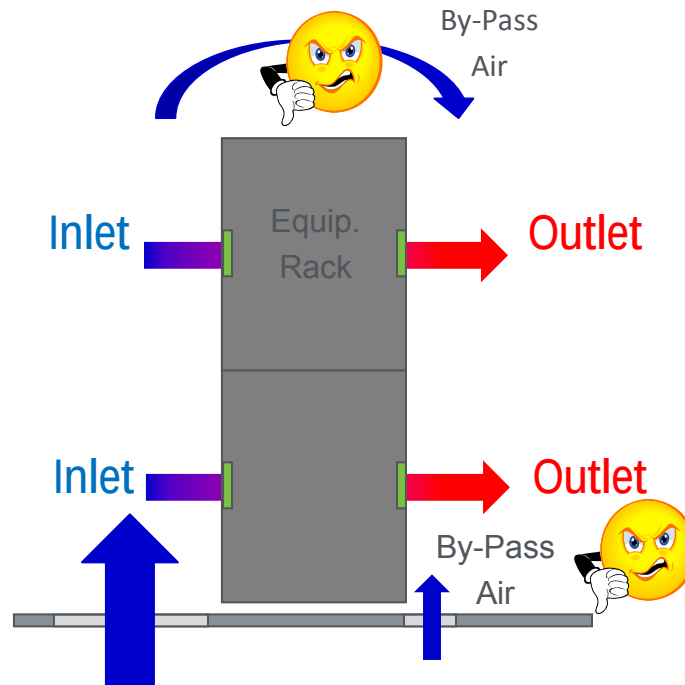
Recirculation...



Increases inlet temperature to servers.

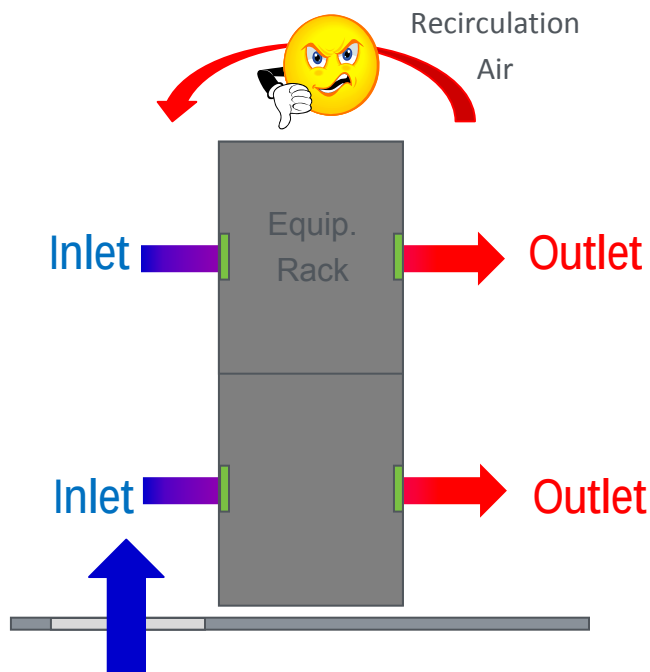
Some common causes:

- Too much supply airflow
- Misplaced perforated tiles
- Leaky cable penetrations
- Too high tile exit velocity

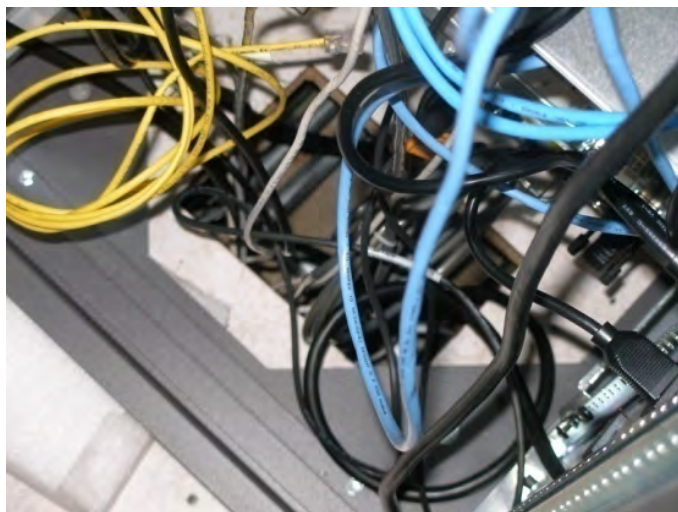


Some common causes:

- Too little supply airflow
- Lack of blanking panels
- Gaps between racks
- Short equipment rows



Maintain sealing of all potential leaks in the raised floor plenum.



Unsealed cable penetration



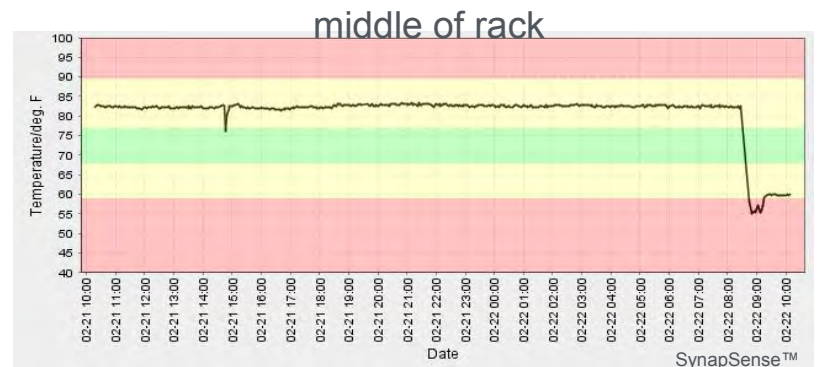
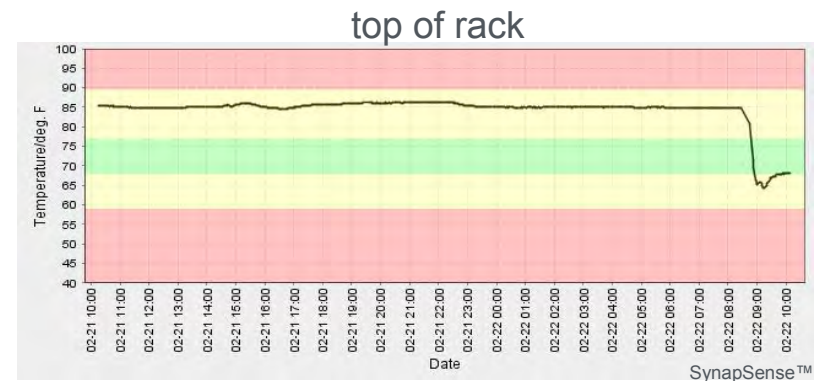
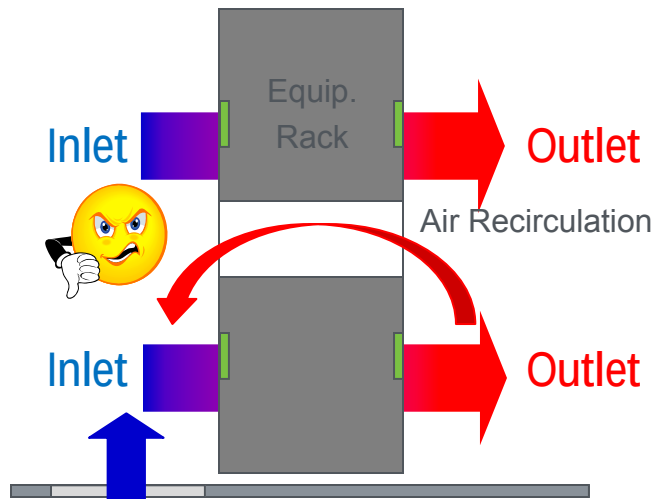
Sealed cable penetration

Manage Blanking Panels

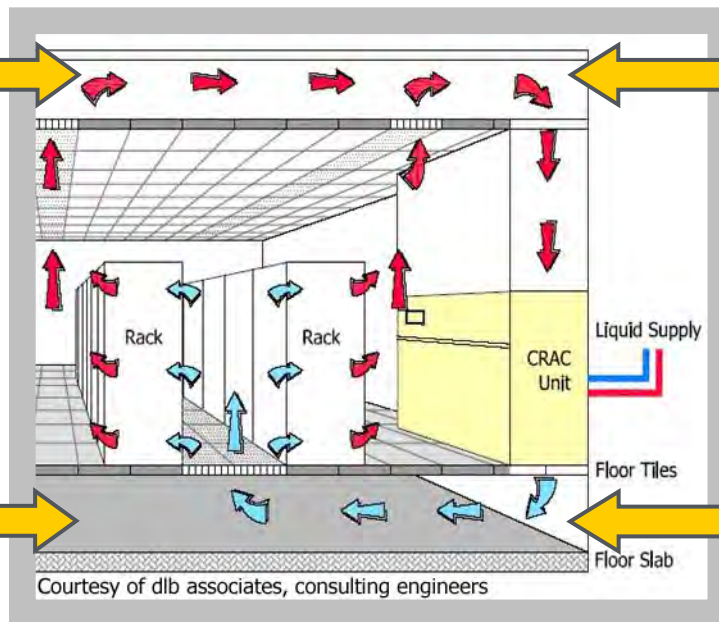
Any opening will degrade the separation of hot and cold air

- maintain server blanking and side panels.

One 12" blanking panel added
Temperature dropped ~20°



Reduce Airflow Restrictions & Congestion



Consider The Impact That Congestion
Has On The Airflow Patterns

**Congested Floor &
Ceiling Cavities**

**Empty Floor &
Ceiling Cavities**

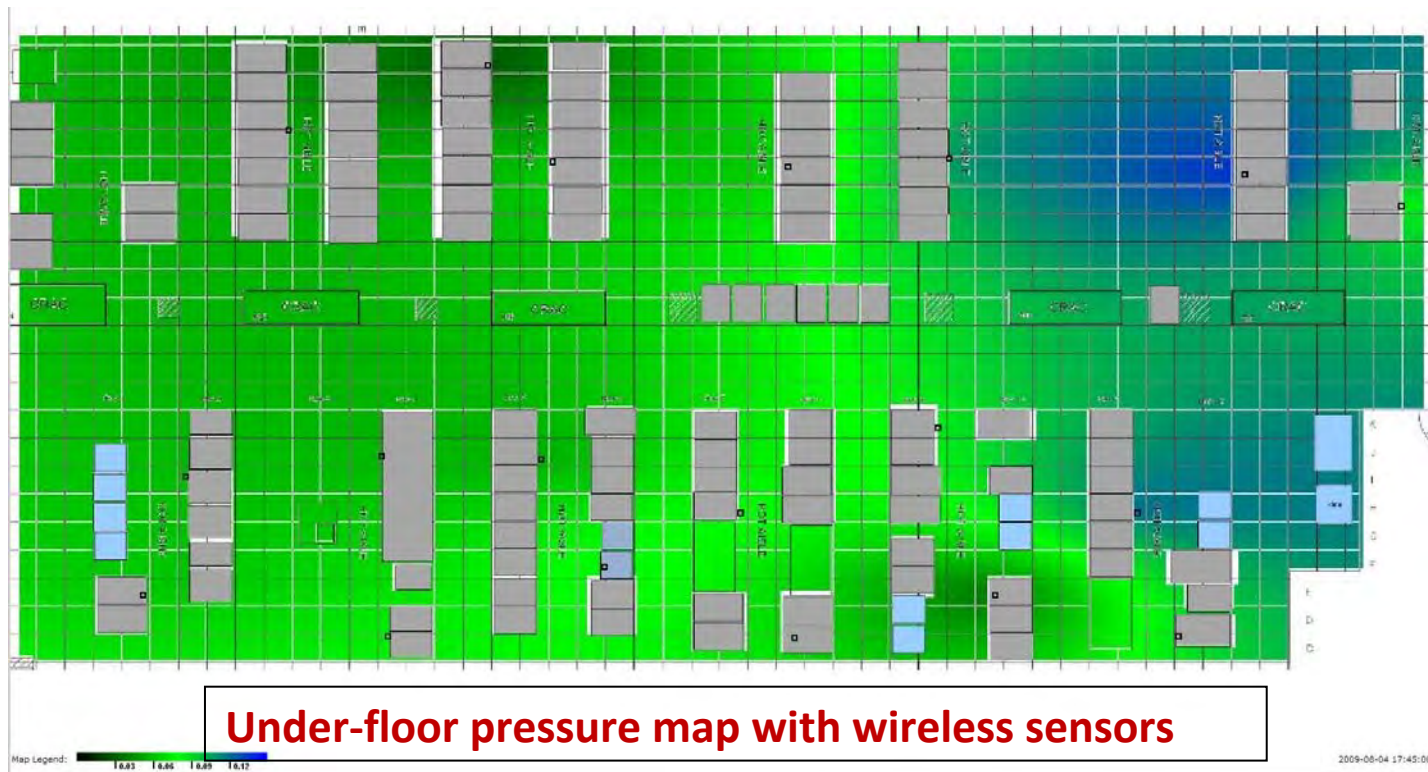
Reduce Cable Congestion

- Cable congestion sharply reduces airflow and degrades airflow distribution.
- No cable trays should be placed below perforated tiles.
- Generally, it is obvious when there is too much “*stuff*.”

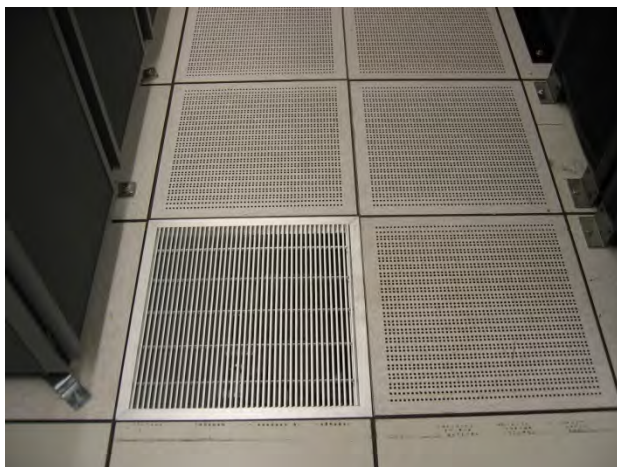


Resolve Airflow Balancing

- BALANCING is required to optimize airflow.
- Rebalance with new IT or HVAC equipment
- Locate perforated floor tiles *only* in cold aisles

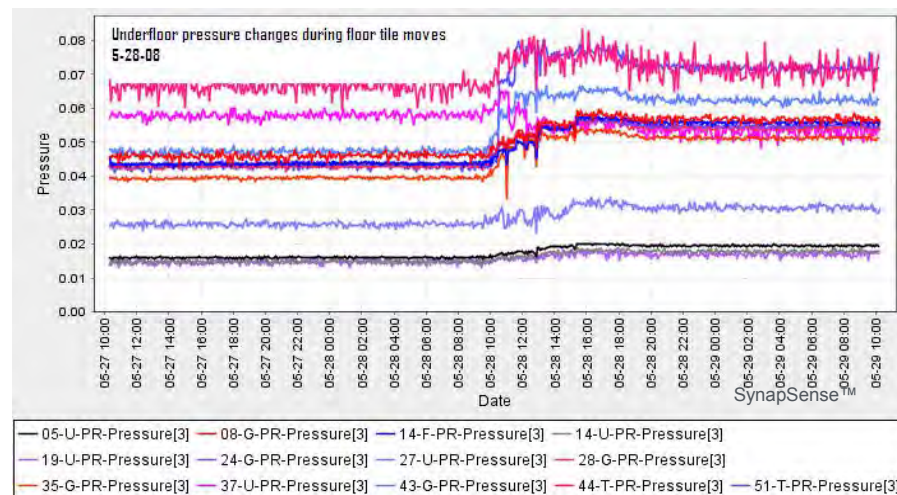


Results: Tune Floor Tiles

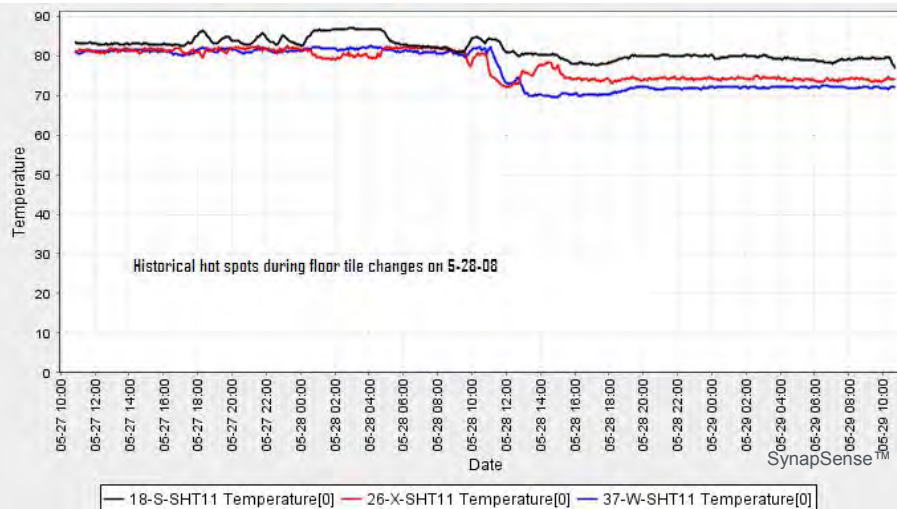


- Too many permeable floor tiles
- if airflow is optimized
 - under-floor pressure up ☐
 - rack-top temperatures down ☐
 - data center capacity increases
- Measurement and visualization assisted tuning process

under-floor pressures

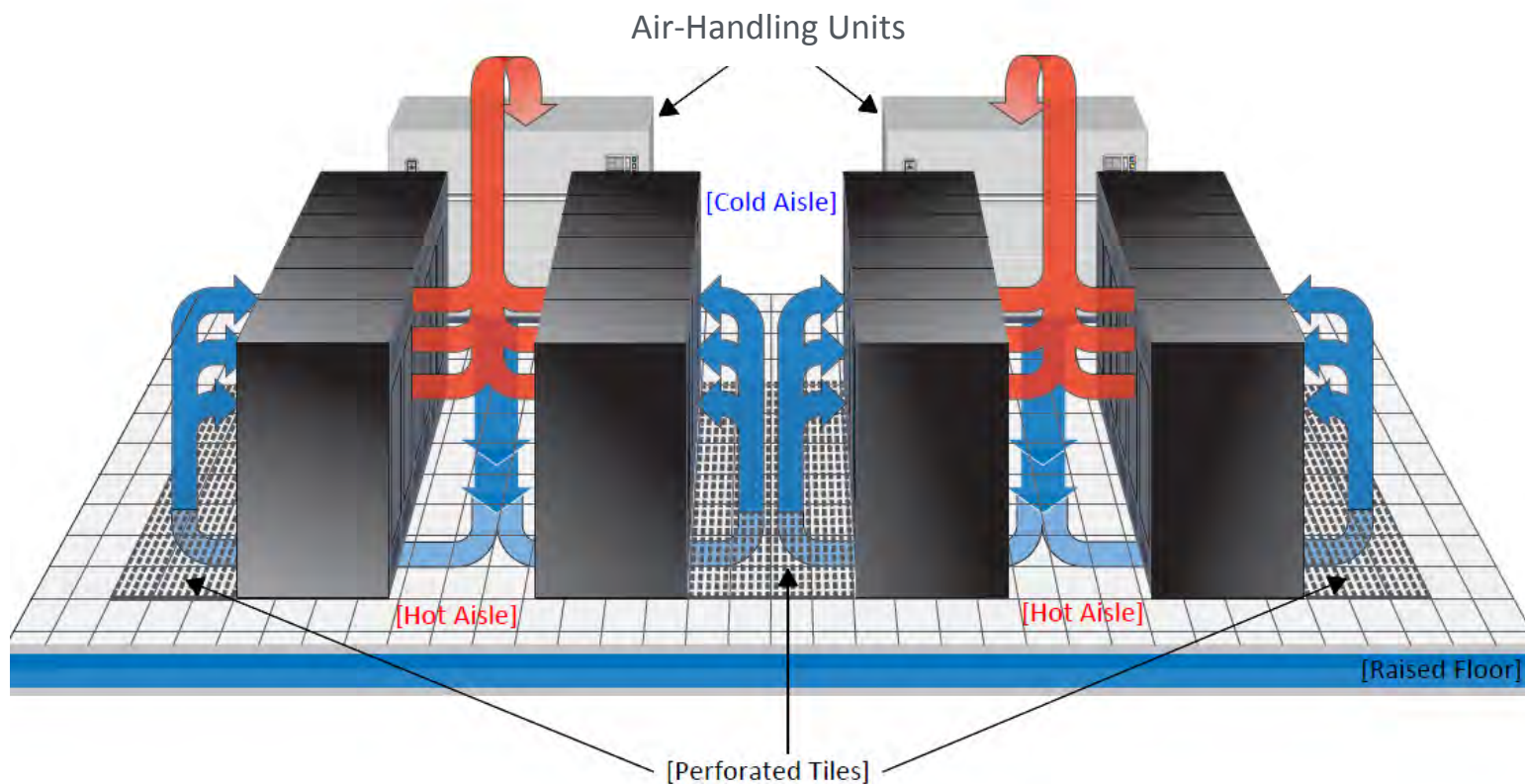


rack-top temperatures

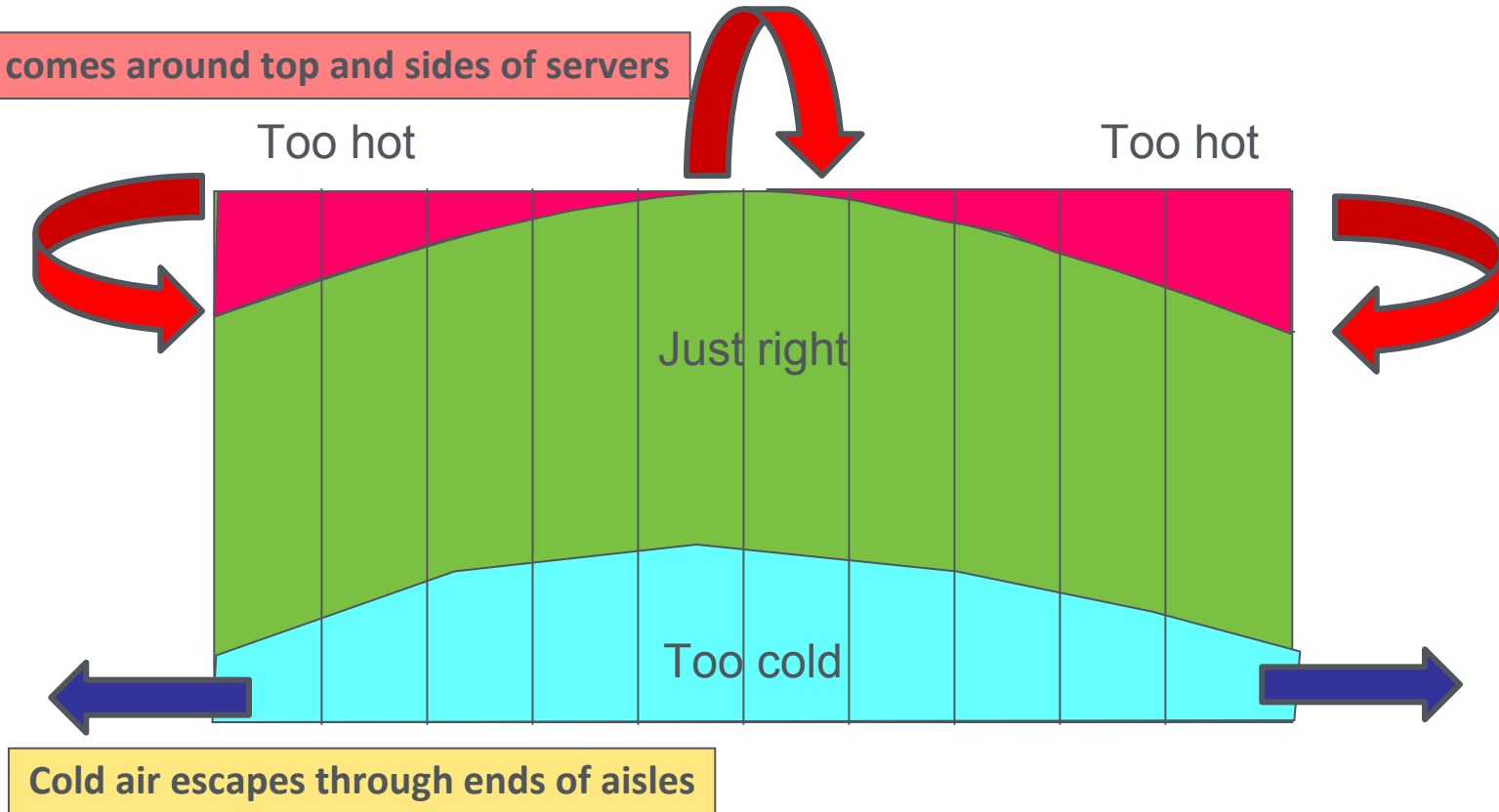


Locate CRAC/CRAH units at ends of Hot Aisles

HOT AISLE/COLD AISLE APPROACH



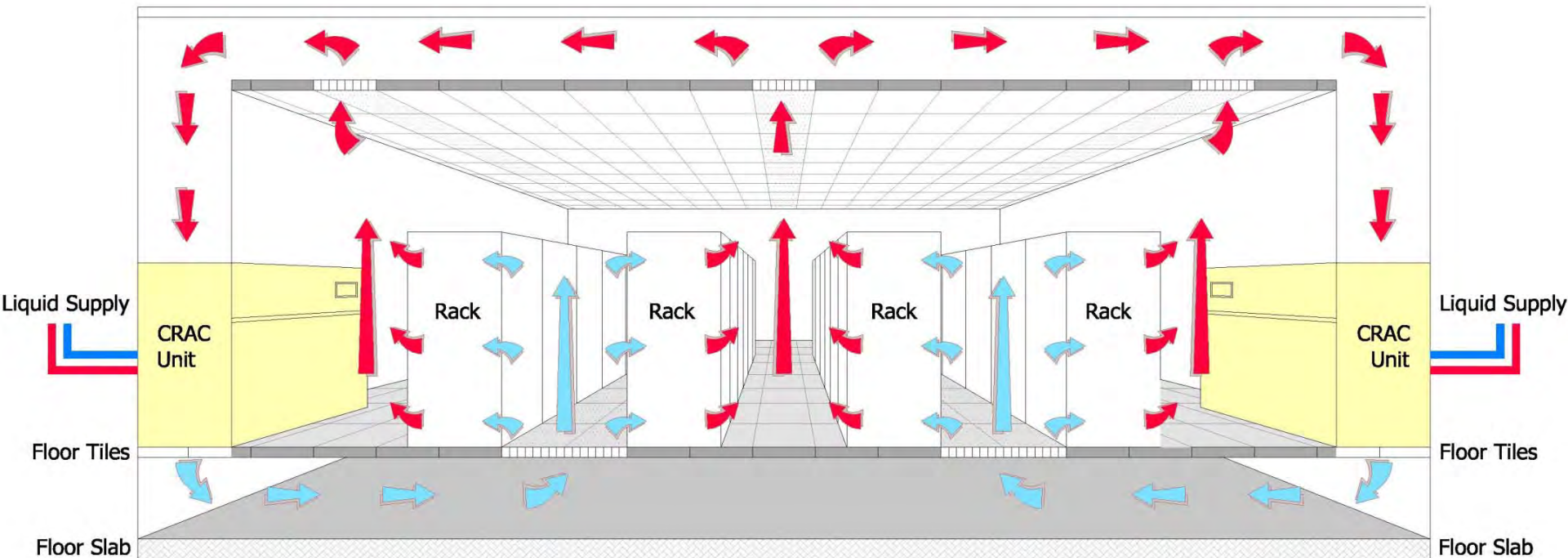
Typical Temperature Profile with Under-floor Supply



Elevation at a cold aisle looking at racks

There are numerous references in ASHRAE. See for example V. Sorell et al; "Comparison of Overhead and Underfloor Air Delivery Systems in a Data Center Environment Using CFD Modeling"; ASHRAE Symposium Paper DE-05-11-5; 2005

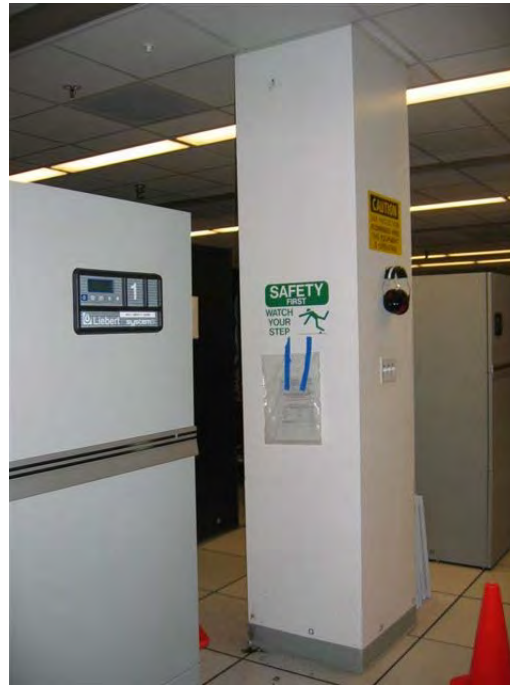
Next step: Air Distribution Return-Air Plenum



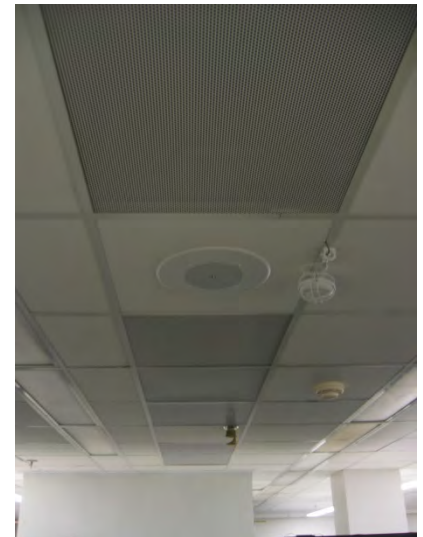
Return Air Plenum

- Overhead plenum converted to hot-air return
- Return registers placed over hot aisle
- CRAC intakes extended to overhead

Before



After





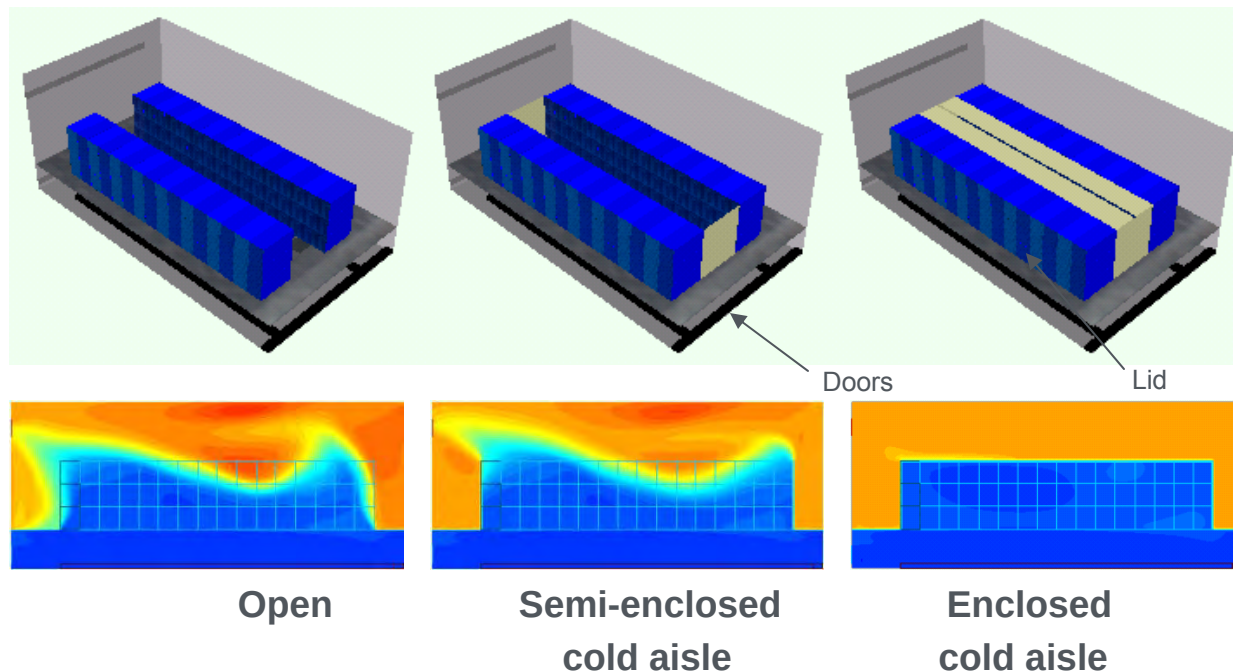
Return air duct on top of CRAC unit connects to the return air plenum.

Isolate Hot Return



Duct on top of each rack connects to the return air plenum.

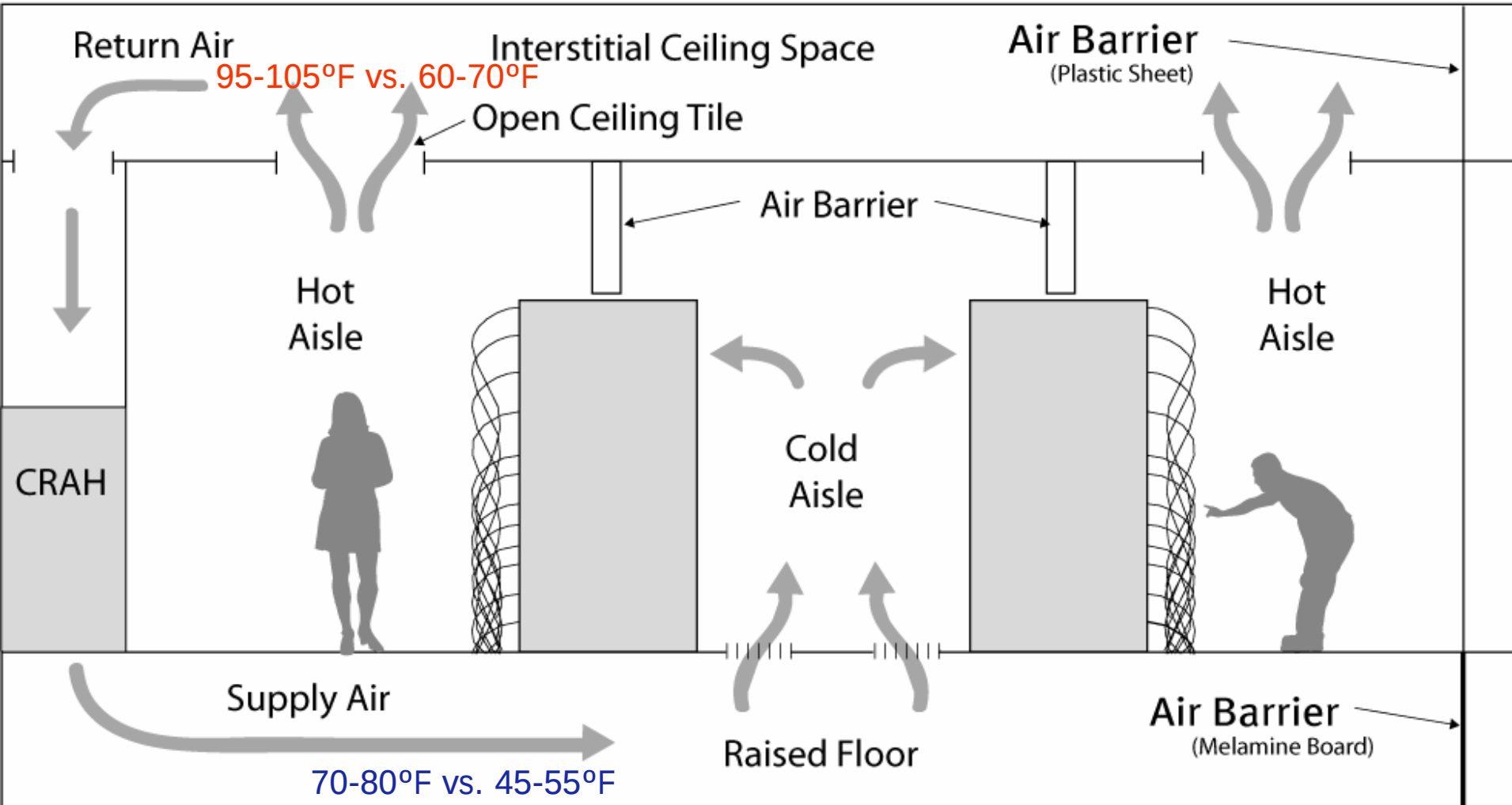
- ✓ Physical barriers enhance separate hot and cold airflow.
- ✓ Barriers placement must comply with fire codes.
- ✓ Curtains, doors, or lids have been used successfully.



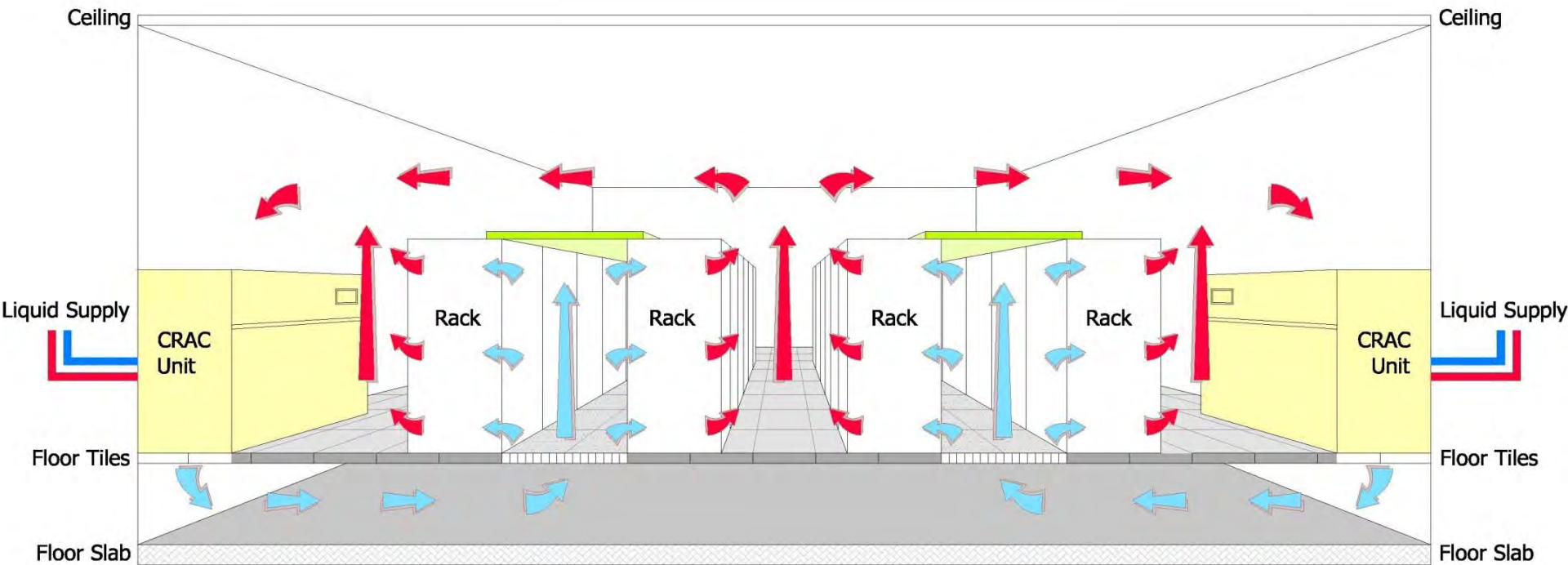
Adding Air Curtains for Hot/Cold Isolation



Isolate Cold and Hot Aisles



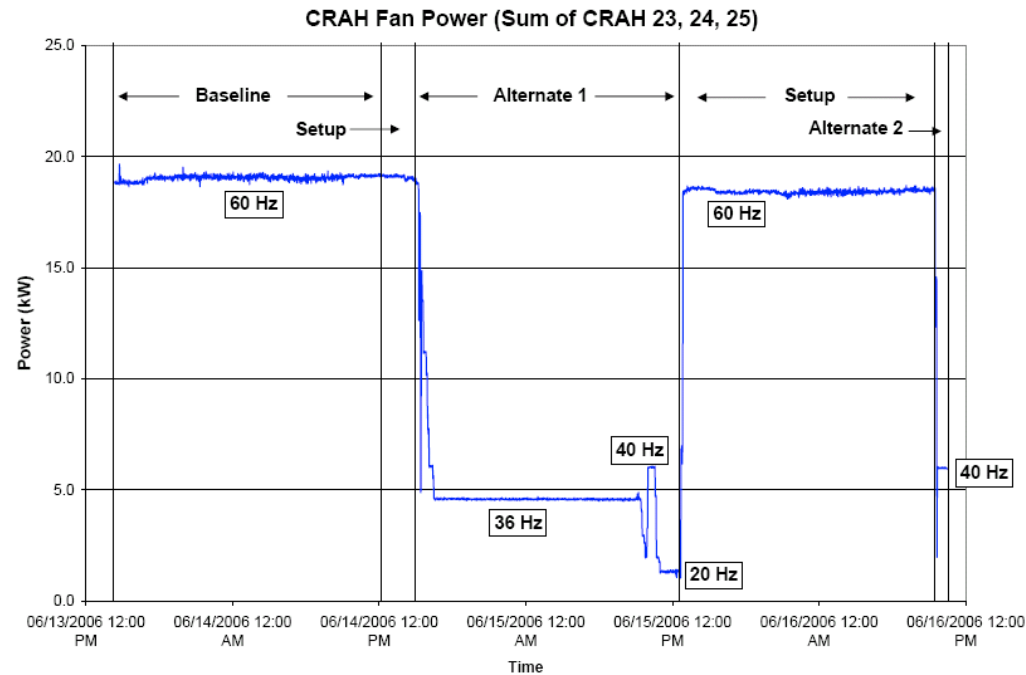
Cold Aisle Airflow Containment Example



LBLN Cold Aisle Containment study achieved fan energy savings of ~ 75%

Fan Energy Savings

- Isolation can significantly reduce air mixing and hence flow
- Fan speed can be reduced and fan power is proportional to the cube of the flow.
- Fan energy savings of 70-80% is possible with variable air volume (VAV) fans in CRAH/CRAC units (or central AHUs)

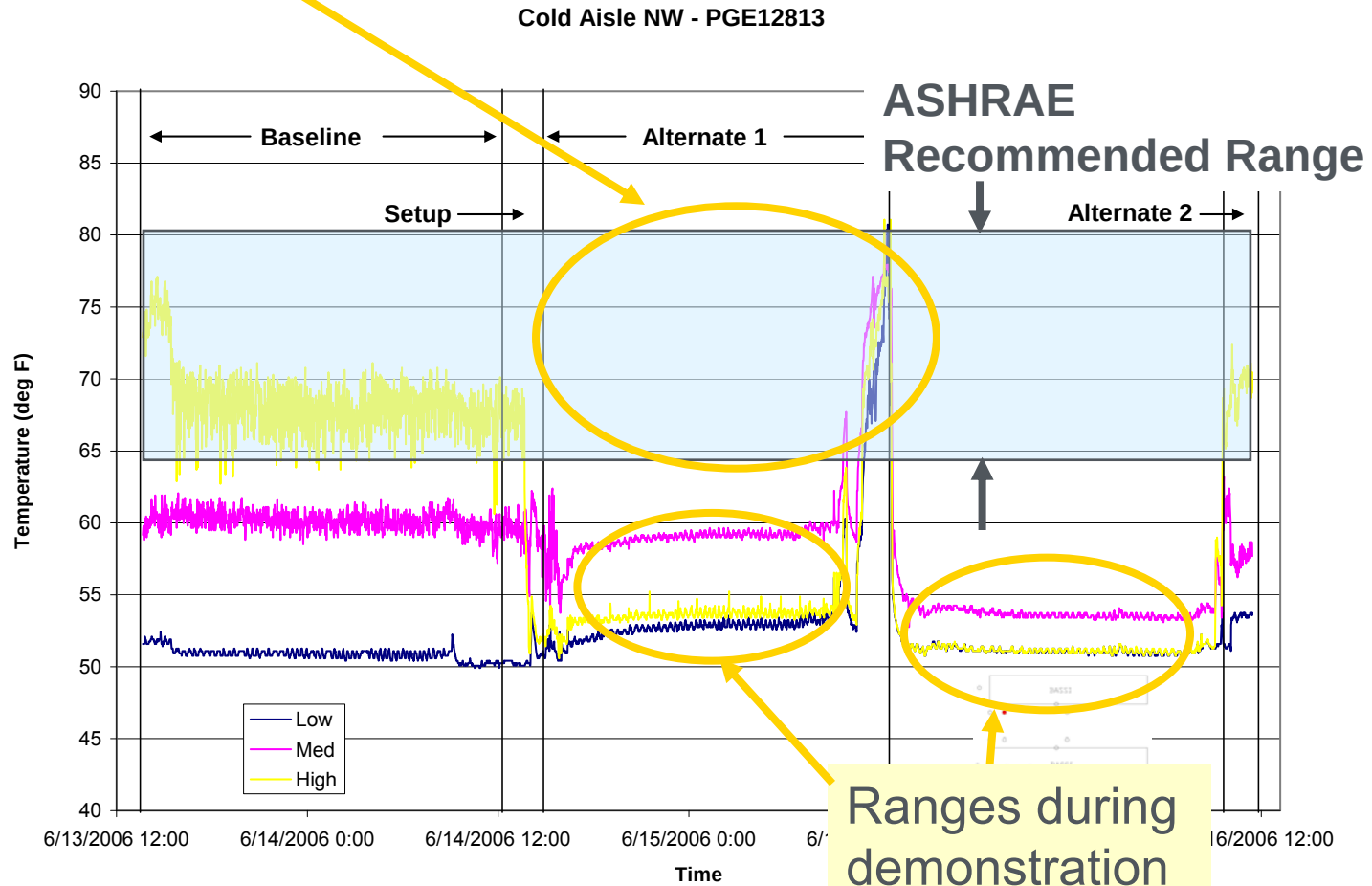


Without Enclosure

With Enclosure

Without Enclosure

Better airflow management permits warmer supply temperatures!



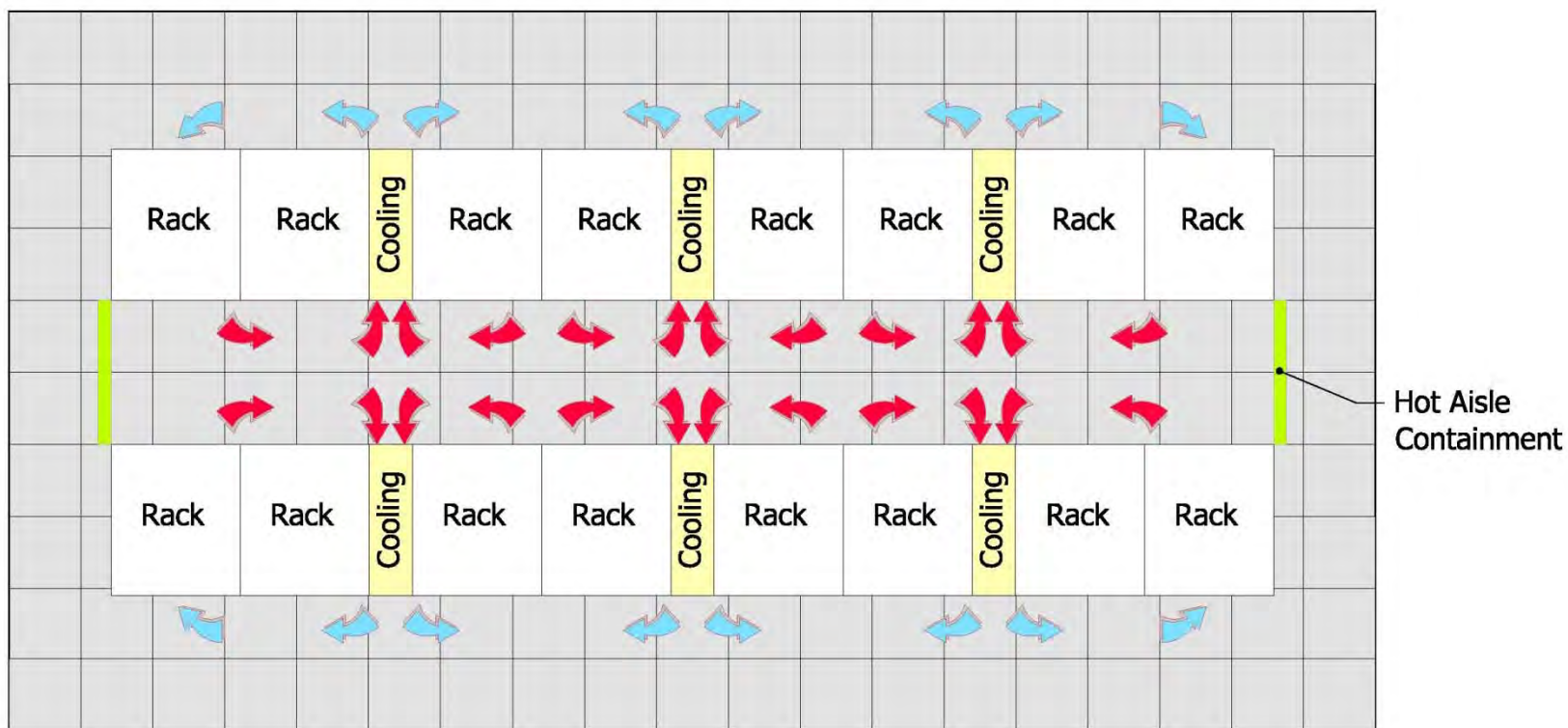
- Energy intensive IT equipment needs good isolation of “cold” inlet and “hot” discharge.
- Supply airflow can be reduced if no mixing occurs.
- Overall temperature can be raised if air is delivered without mixing.
- Cooling systems and economizers use less energy with warmer return air temperatures.
- Cooling capacity increases with warmer air temperatures.

Localized air cooling systems with hot and cold isolation can supplement or replace under-floor systems (raised floor not required!)

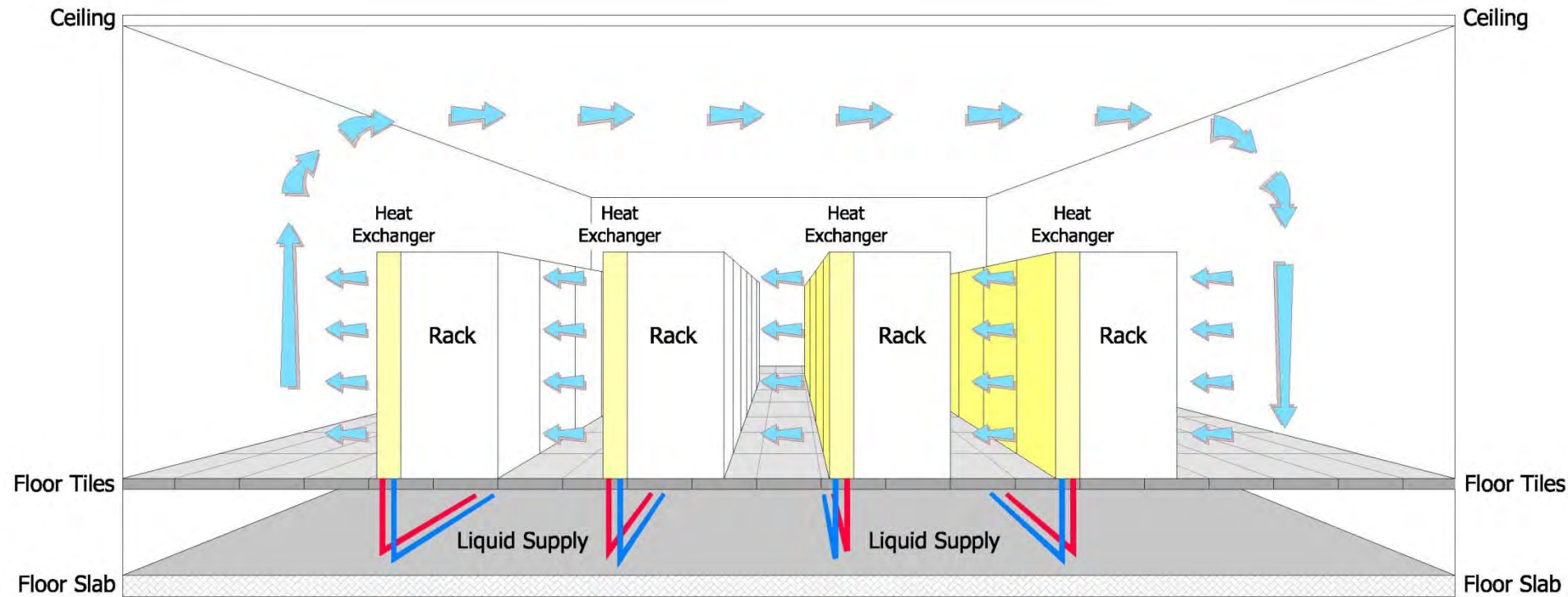
Examples include:

- **Row-based cooling units**
- **Rack-mounted heat exchangers**
- **Both options “Pre-engineer” hot and cold isolation**

Example – Local Row-Based Cooling Units



Air Distribution – Rack-Mounted Heat Exchangers



Air management techniques:

- Seal air leaks in floor (e.g. cable penetrations)
- Prevent recirculation with blanking panels in racks
- Manage floor tiles (e.g. no perforated tiles in hot aisle)
- Improve isolation of hot and cold air (e.g. return air plenum, curtains, or complete isolation)

Impact of good isolation:

- Supply airflow reduced
 - Fan savings up to 75%+
- Overall temperature can be raised
 - Cooling systems efficiency improves
 - Greater opportunity for economizer (“free” cooling)
- Cooling capacity increases

Questions?





Cooling systems



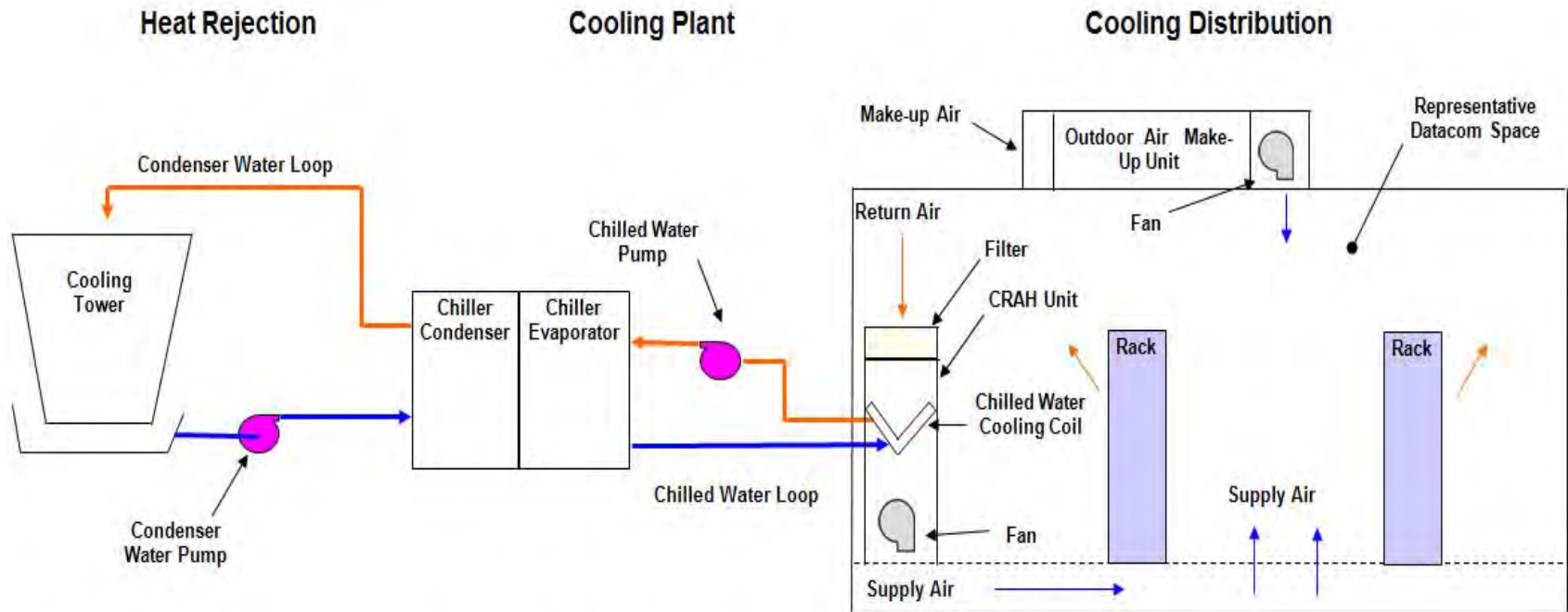
U.S. Department of Energy
Energy Efficiency and Renewable Energy



Linking good air management and an optimized cooling system:

- ✓ Improved efficiencies
- ✓ Increased cooling capacity
- ✓ More hours for air-side and water-side free cooling
- ✓ Lower humidification/dehumidification energy
- ✓ Reduced fan energy

HVAC Systems Overview



Heat Rejection Alternatives:



- Water Cooled Direct (shown)
- Water Cooled Indirect (with HX)
- Evaporatively Cooled
- Air Cooled
- Dry Cooler (Air Cooled with Glycol)

Cooling Plant Alternatives:

- Water-Side Economizer (HX)
- Chiller (shown)
- Direct Expansion (DX)

Terminal Unit Alternatives

- Liquid Cooling
- Central AHU
- CRAH Unit (shown)
- CRAC Unit (DX)

Distribution Alternatives

- On Board
- In Rack
- In Row
- Overhead Air
- Underfloor Air (Shown)

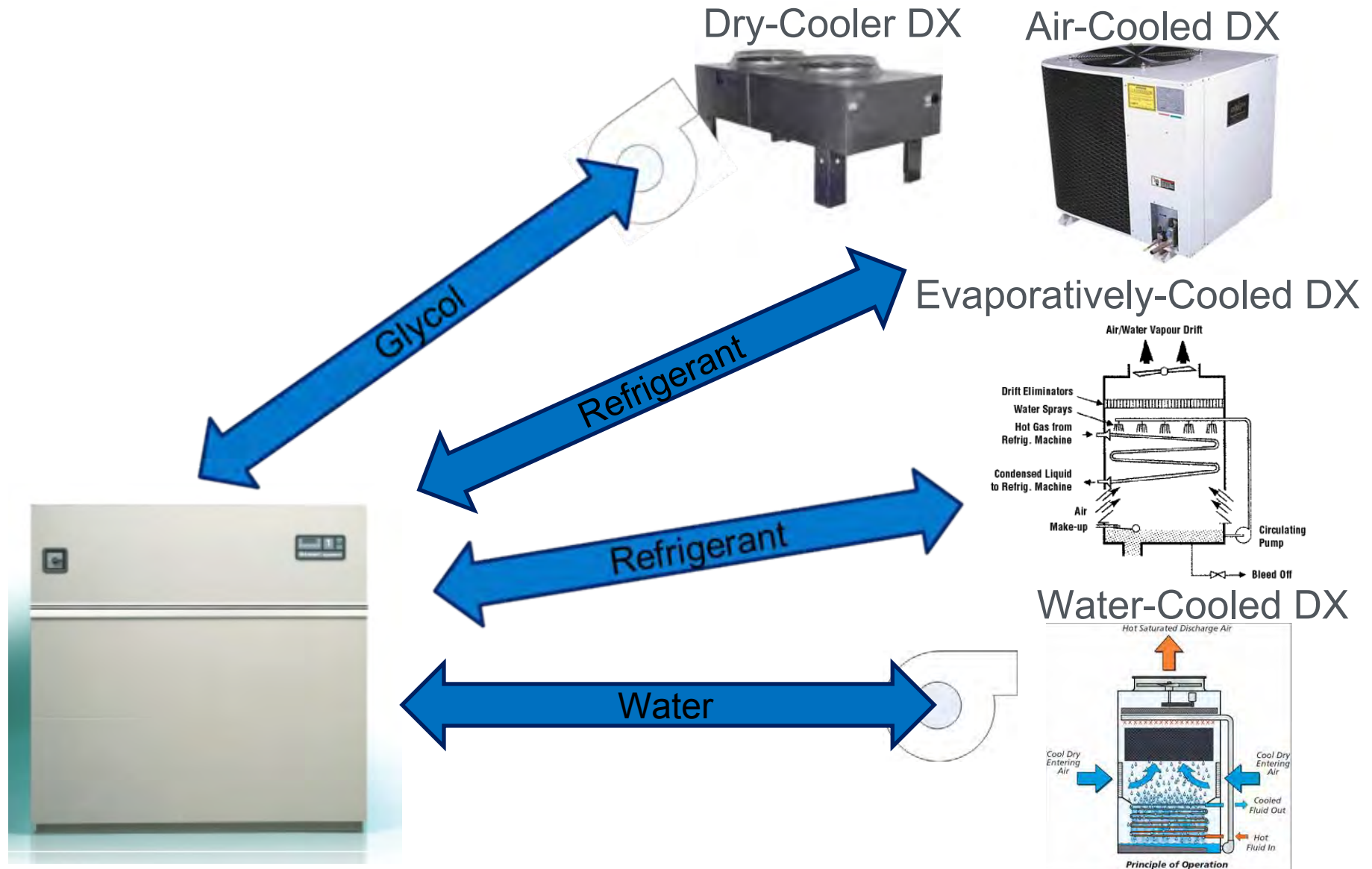


Computer Room Air Conditioners (CRACs) and Air Handlers (CRAHs)

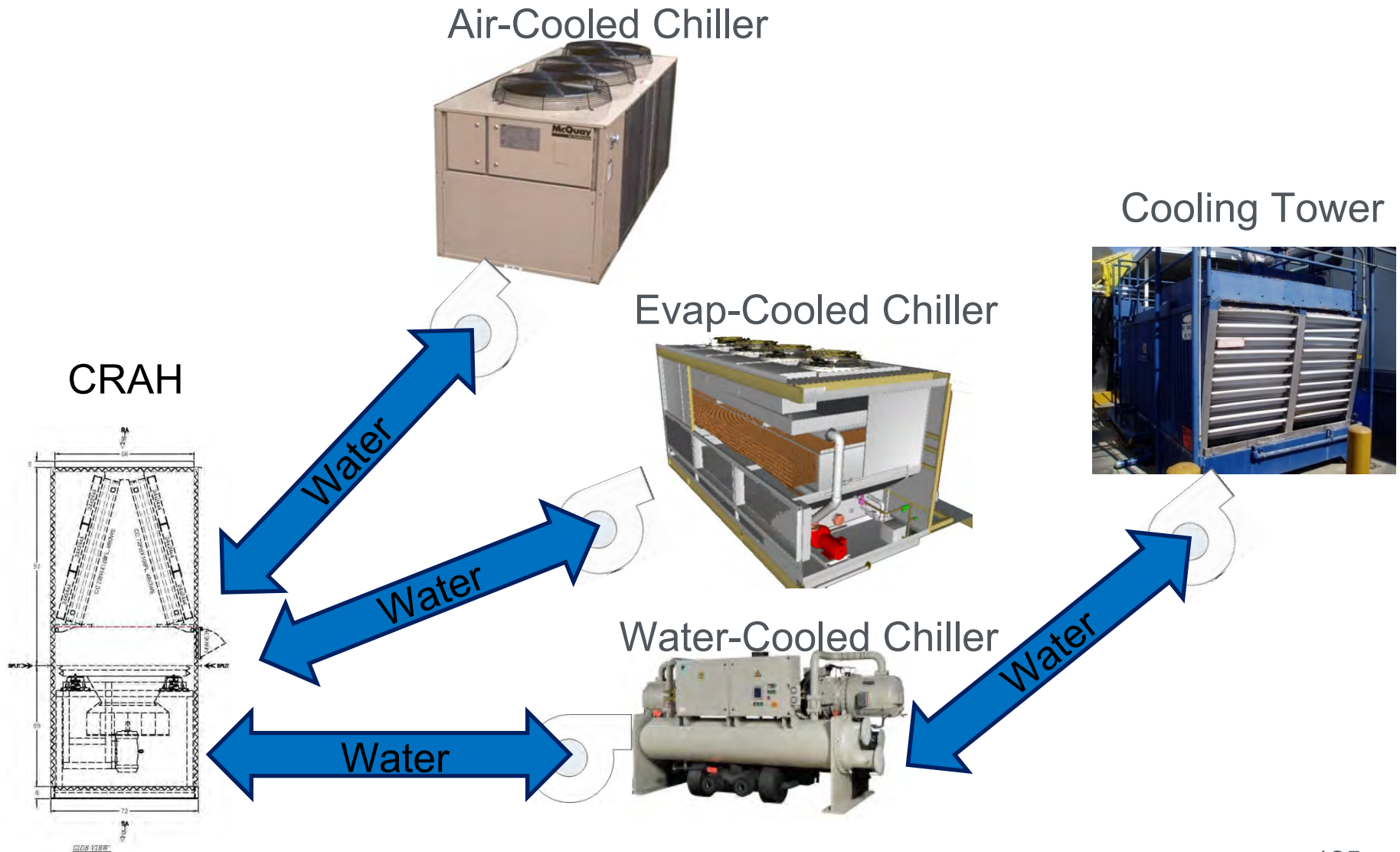
- **CRAC units**
 - Fan, direct expansion (DX) coil, and refrigerant compressor.
- **CRAH units**
 - Fan and chilled water coil
 - Typically in larger facilities with a chiller plant
- **Both often equipped with humidifiers and reheat for dehumidification**
- **Often independently controlled**
 - Tight ranges and poor calibration lead to fighting



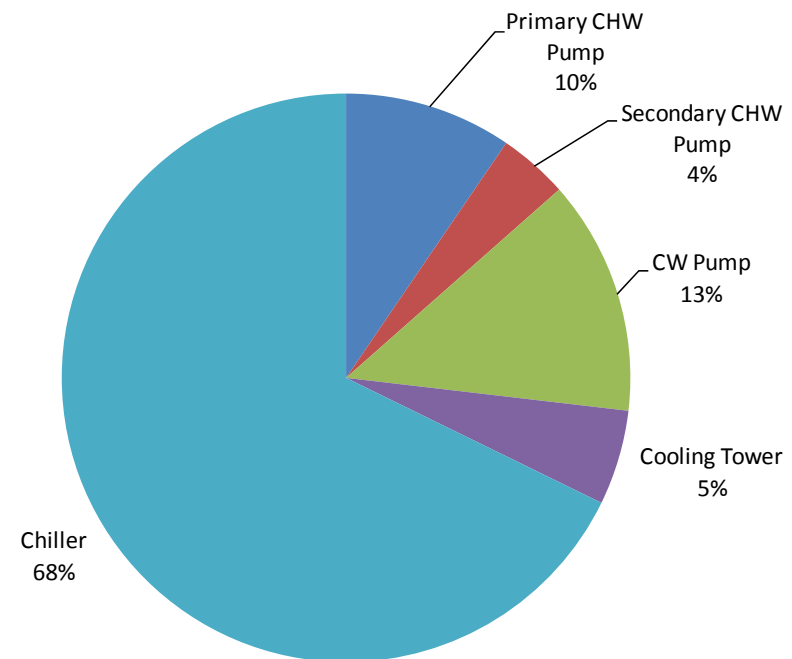
DX (or AC) units reject heat outside...



Computer Room Air Handling (CRAH) units using Chilled-Water



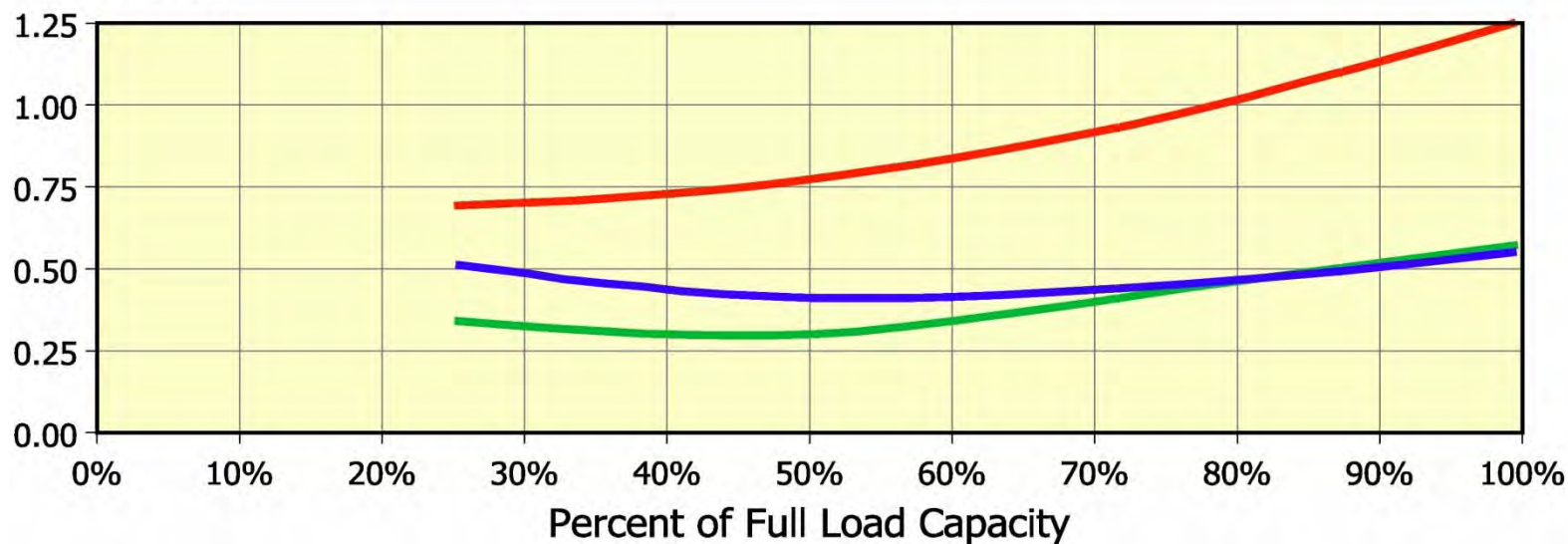
- **Have a plant (vs. distributed cooling)**
- **Use “warm” water cooling (multi-loop)**
- **Size cooling towers for “free” cooling**
- **Integrate controls and monitor efficiency of all primary components**
- **Thermal storage**
- **Utilize variable speed drives on:**
 - **Fans**
 - **Pumps**
 - **Towers**
 - **Chillers**



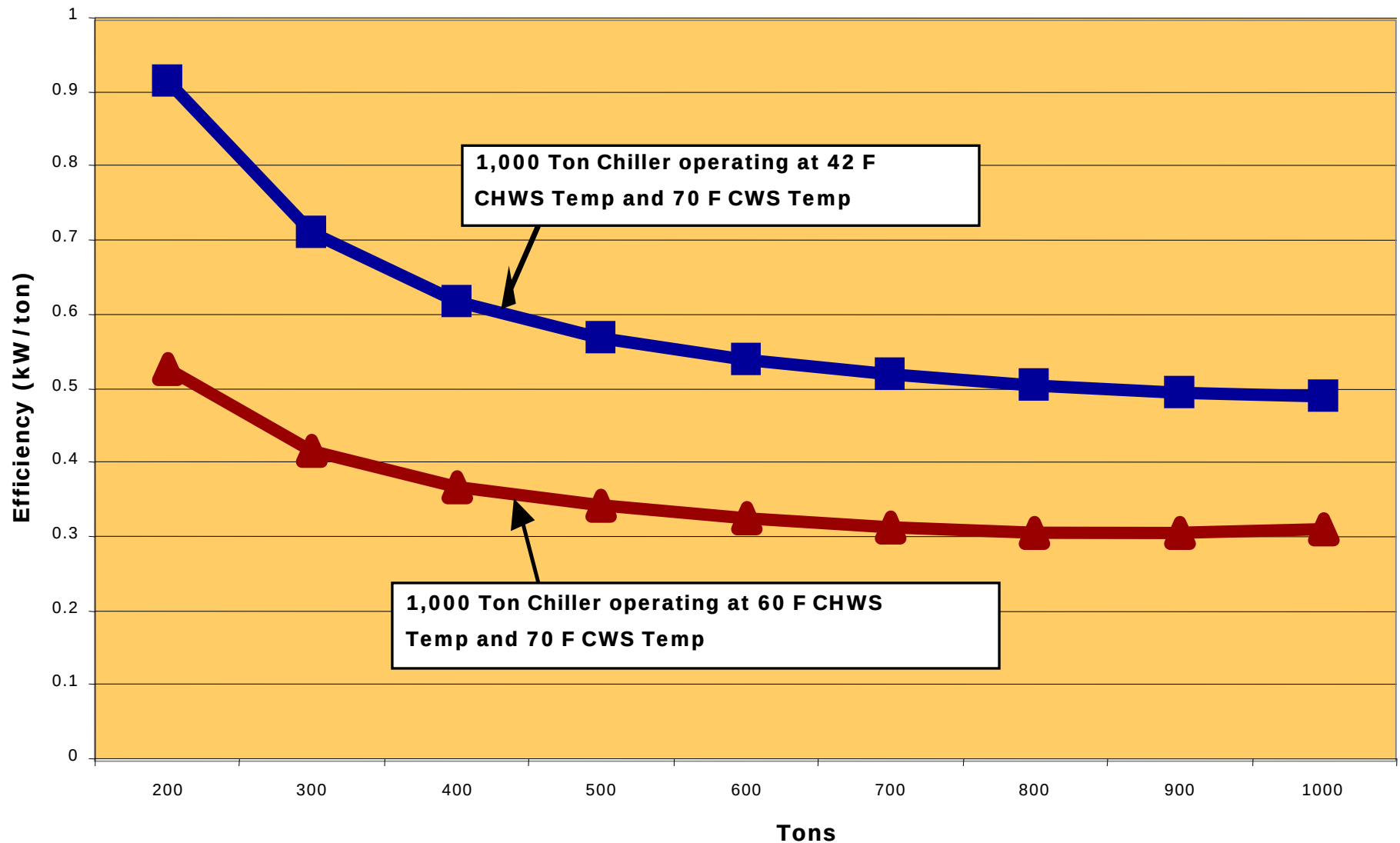
Select Efficient Chillers

Chiller	Compressor kW / ton			
	25%	50%	75%	100%
400 Ton Air Cooled	0.69	0.77	0.96	1.25
1200 Ton Water Cooled w/o VFD	0.51	0.41	0.45	0.55
1200 Ton Water Cooled with a VFD	0.34	0.30	0.43	0.57

kW Per Ton



Increase Temperature of Chiller Plant



Data provided by York International Corporation.

As heat densities rise, liquid solutions become more attractive:

Volumetric heat capacity comparison



400 Gallon pool
[1.5 m³]

Water

=



[5380 m³]

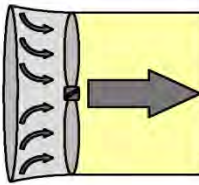
~ 190,000 cubic foot blimp

GOODYEAR

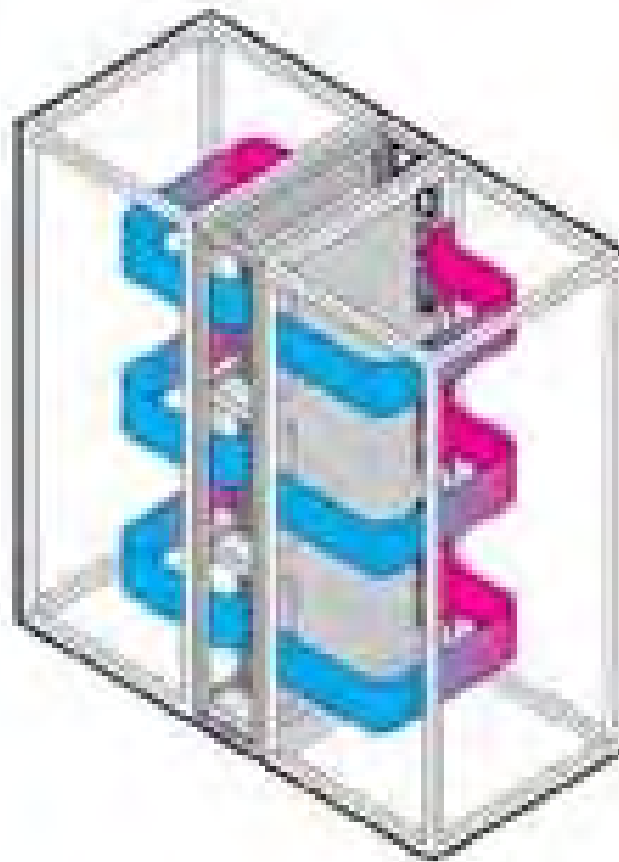
Air

Why Liquid Cooling?

- Heat removal efficiency increases as liquid gets closer to the heat source
- Liquids can provide cooling with higher temperature coolant
 - Improved cooling efficiency
 - Increased economizer hours
 - Greater potential use of waste heat
- Reduced transport energy:

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

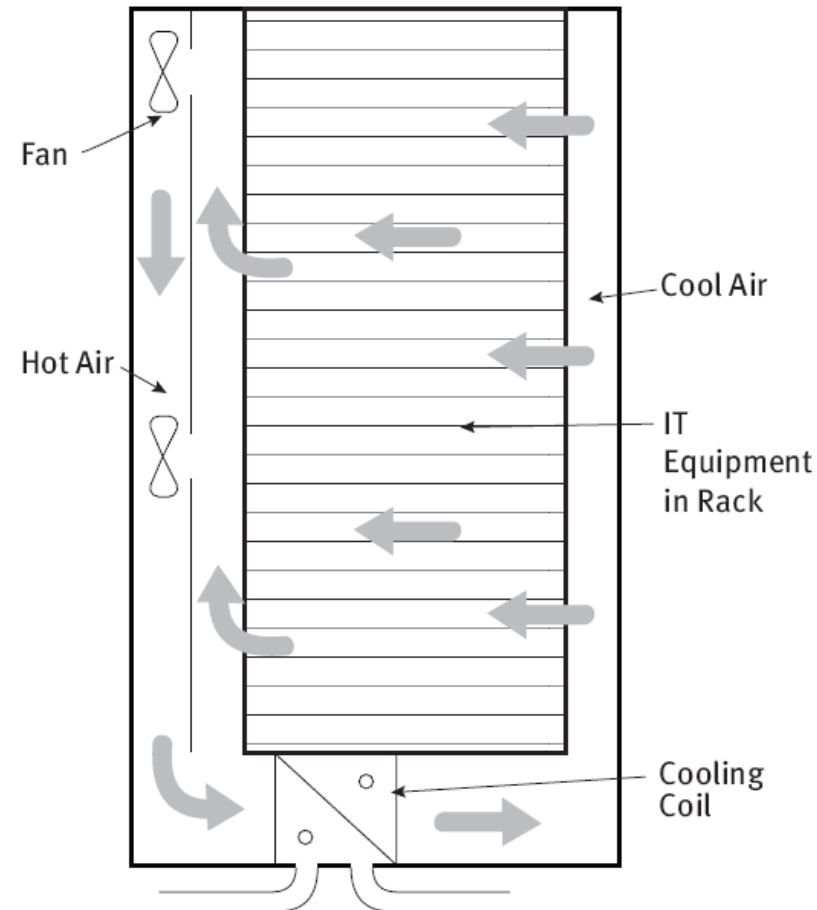
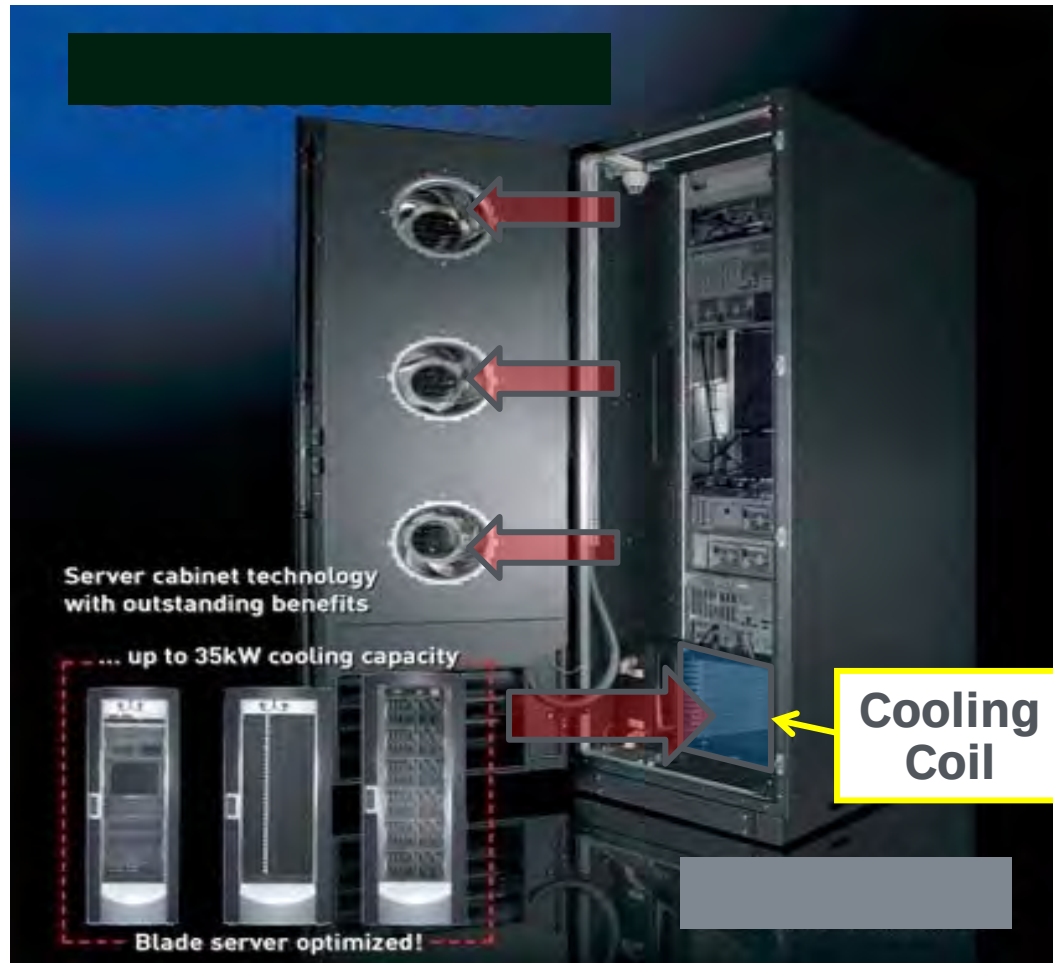
In-Row Liquid Cooling



Graphics courtesy of Rittal

In Rack Liquid Cooling

Racks with integral coils and full containment



Rear-Door Liquid Cooling

Rear Door (open)

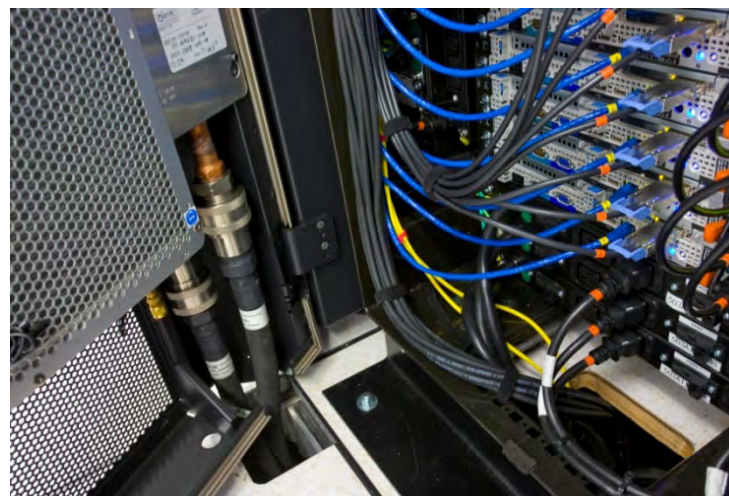


Inside rack RDHx, open 90°

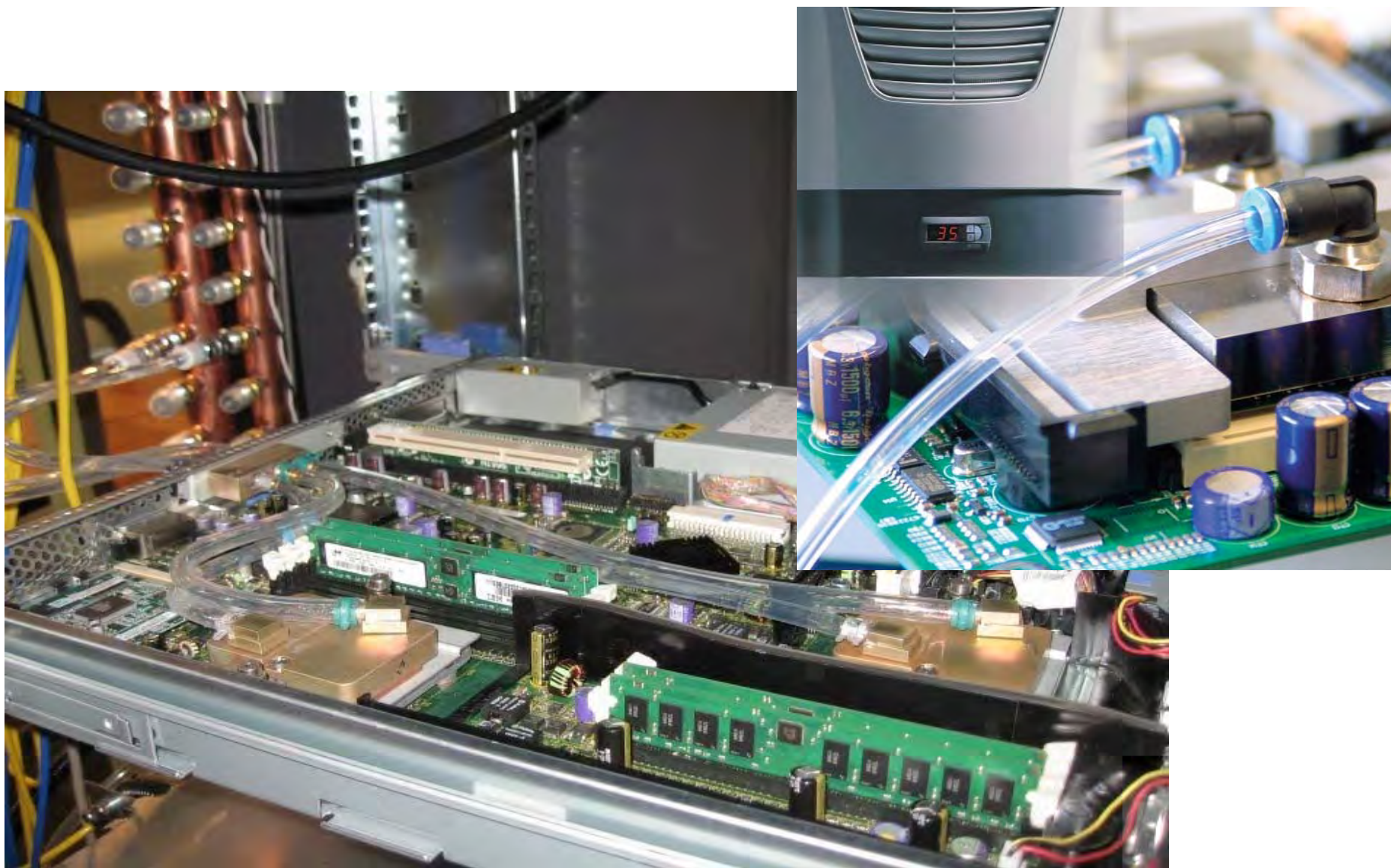
Rear Doors (closed)



Liquid Cooling Connections

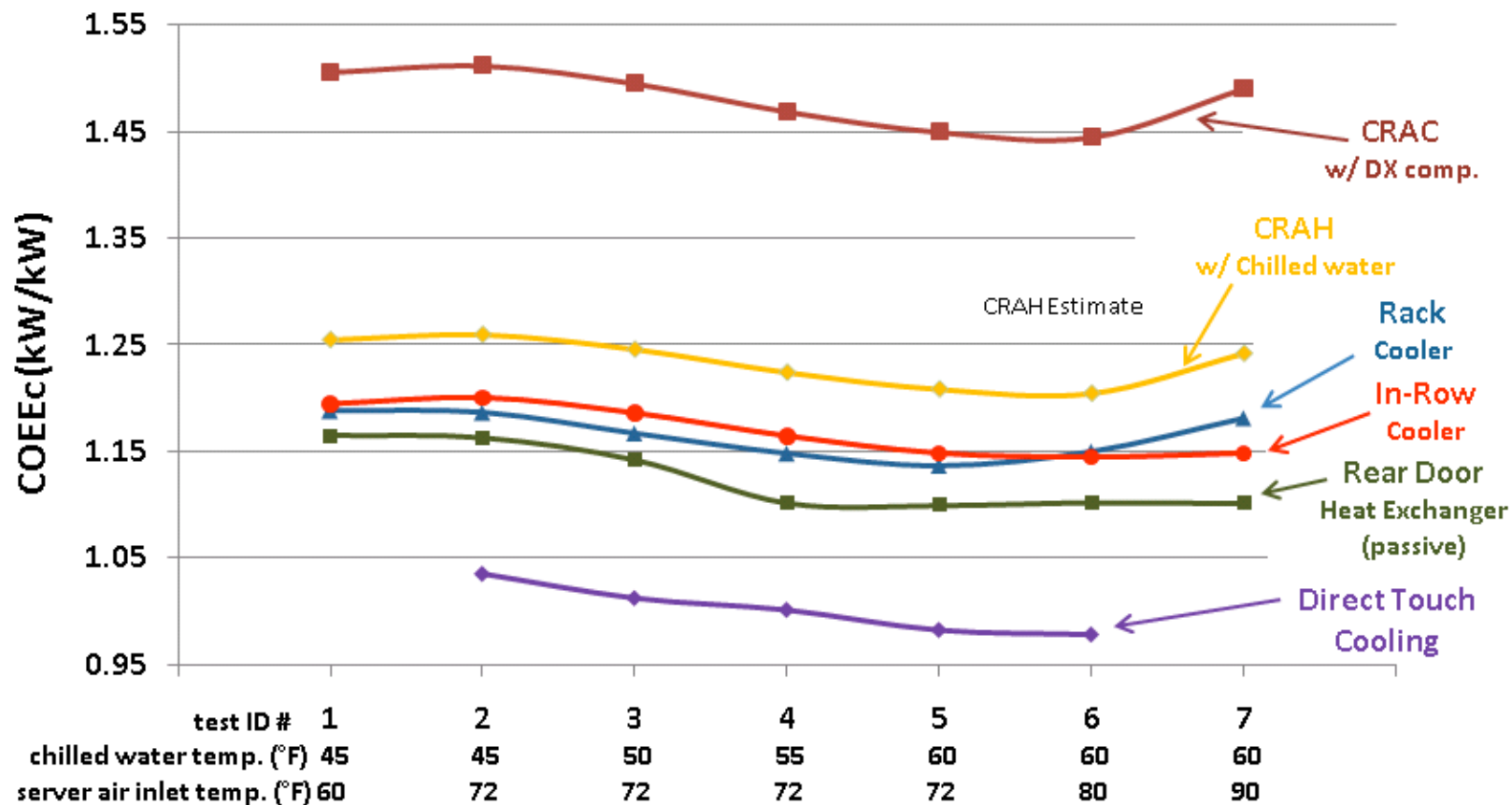


On Board Cooling



“Chill-off 2” Evaluation of Liquid Cooling Solutions

Data Center Cooling Device Relative Performance



Use Free Cooling:

Cooling without Compressors:

- Outside-Air Economizers
- Water-side Economizers
- Let's get rid of chillers in data centers

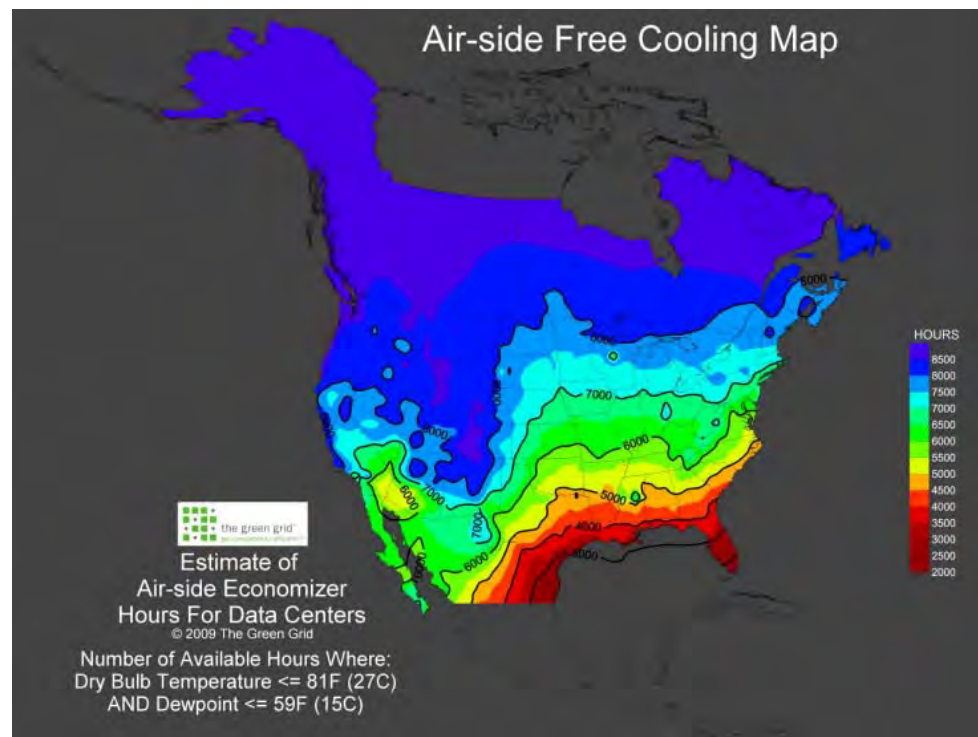


Advantages

- Lower energy use
- Added reliability (backup for cooling system)

Potential Issues

- Space.
- Dust
 - Not a concern with Merv 13 filters
- Gaseous contaminants
 - Not widespread
 - Impacts normally cooled data centers as well
- Shutdown or bypass if smoke is outside data center.



UC's Computational Research and Theory (CRT) Facility

U.S. DEPARTMENT OF
ENERGY

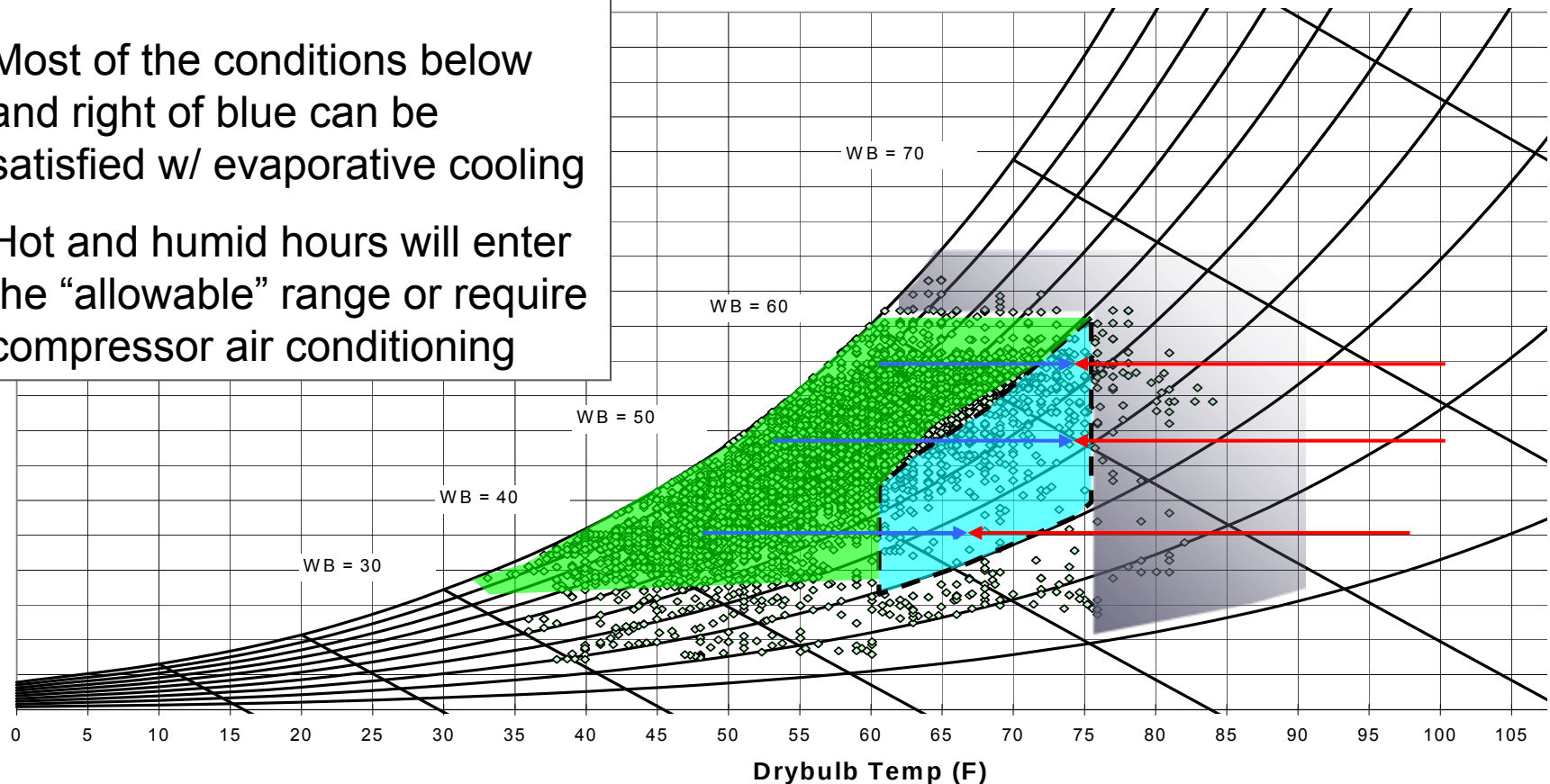
Energy Efficiency &
Renewable Energy



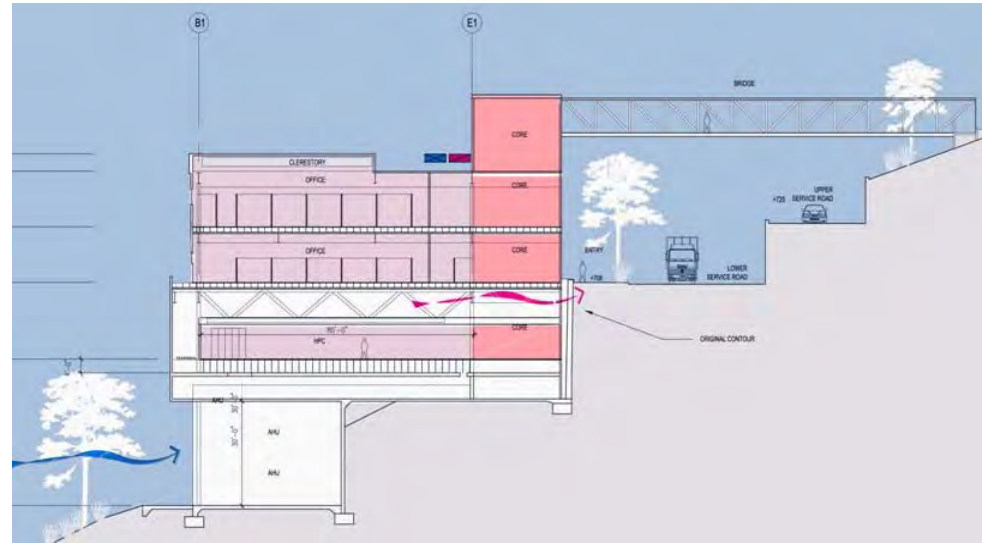
Free Cooling – Outside Air Based

1. Blue = recommended supply
2. Green can become blue mixing return and outdoor air
3. Most of the conditions below and right of blue can be satisfied w/ evaporative cooling
4. Hot and humid hours will enter the “allowable” range or require compressor air conditioning

Annual Psychrometric Chart of Oakland, CA
(relative humidity lines are stepped by 10%,
wetbulb lines by 10 degrees F)



- Air-Side Economizer (93% of hours)
- Direct Evaporative Cooling for Humidification/ pre-cooling
- Low Pressure-Drop Design (1.5" total static peak)



Hours of Operation

Mode 1	100% Economiser	2207	hrs
Mode 2	OA + RA	5957	hrs
Mode 3	Humidification	45	hrs
Mode 4	Humid + CH cooling	38	hrs
Mode 5	CH only	513	hrs
total		8760	hrs

- Tower side economizer
- Four pipe system
- Waste heat reuse
- Headers, valves and caps for modularity and flexibility

Predicted CRT Performance:

- Annual PUE = 1.1

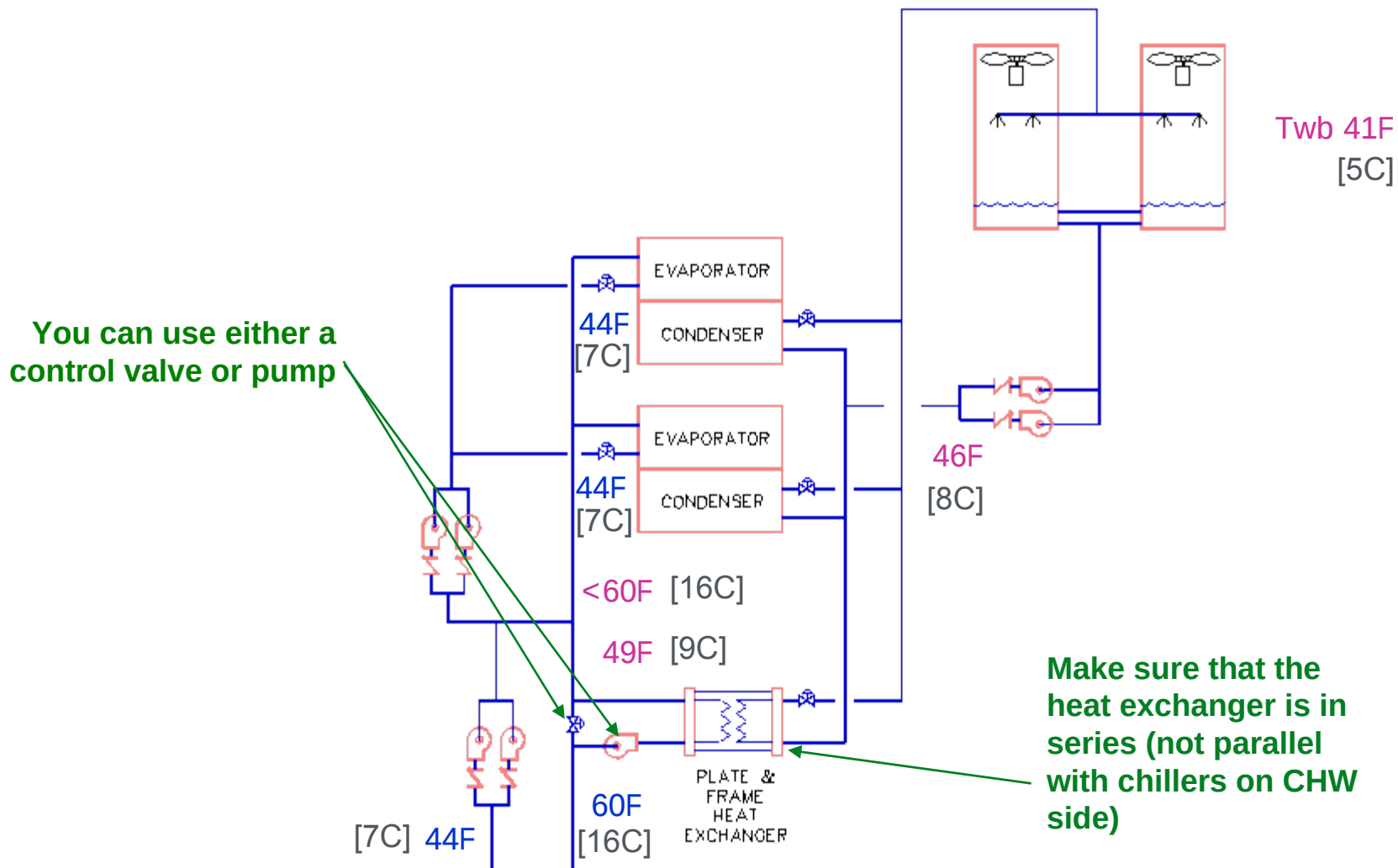


Advantages

- Cost effective in cool and dry climates
- Often easier retrofit
- Added reliability (backup in the event of chiller failure).
- No contamination questions

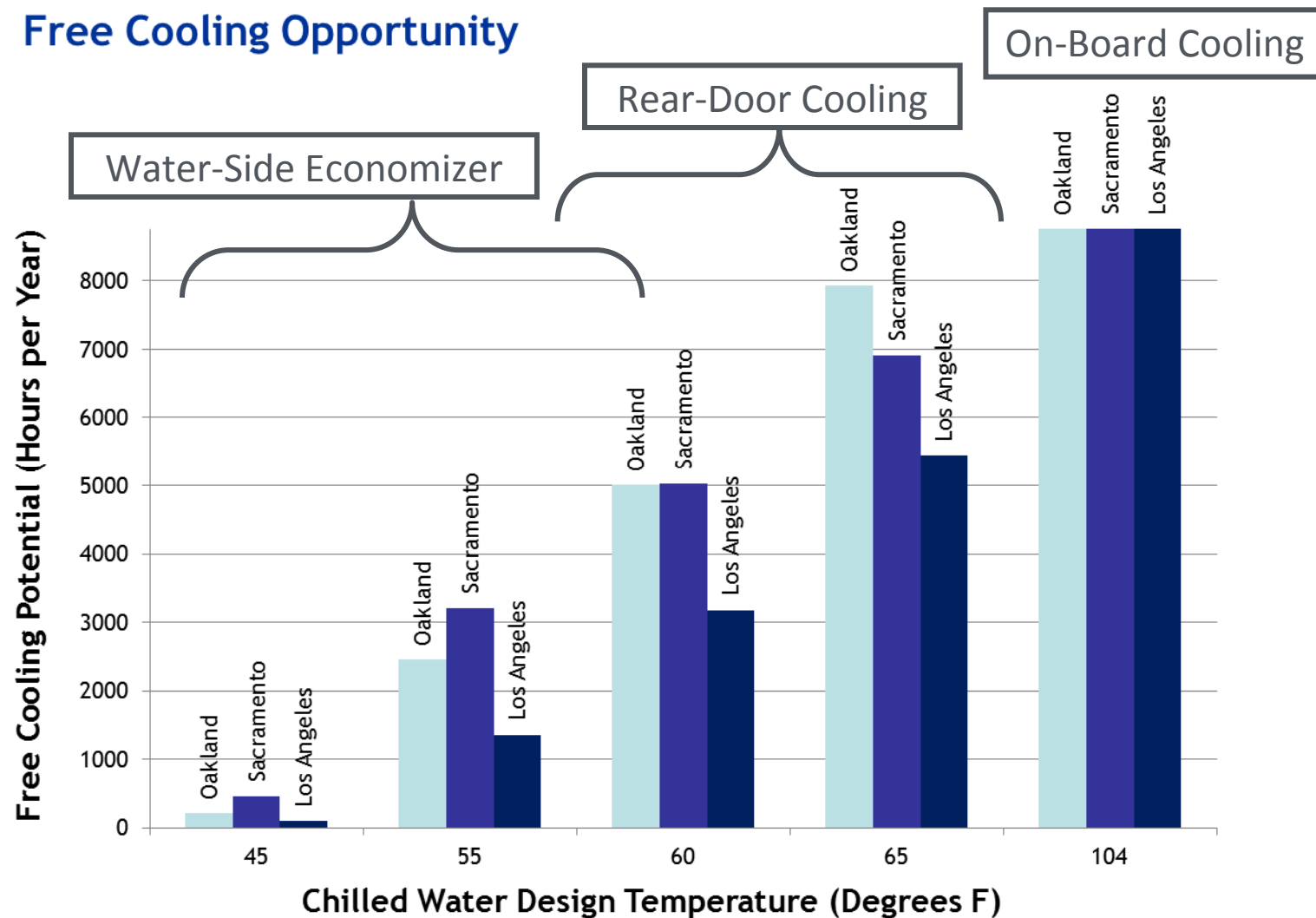


Integrated Water-Side Economizer



Potential for Tower Cooling

Free Cooling Opportunity



LBL Example: Rear Door Cooling

- Used instead of adding CRAC units
- Rear door water cooling with tower-only (or central chiller plant in series).
 - Both options significantly more efficient than existing direct expansion (DX) CRAC units.



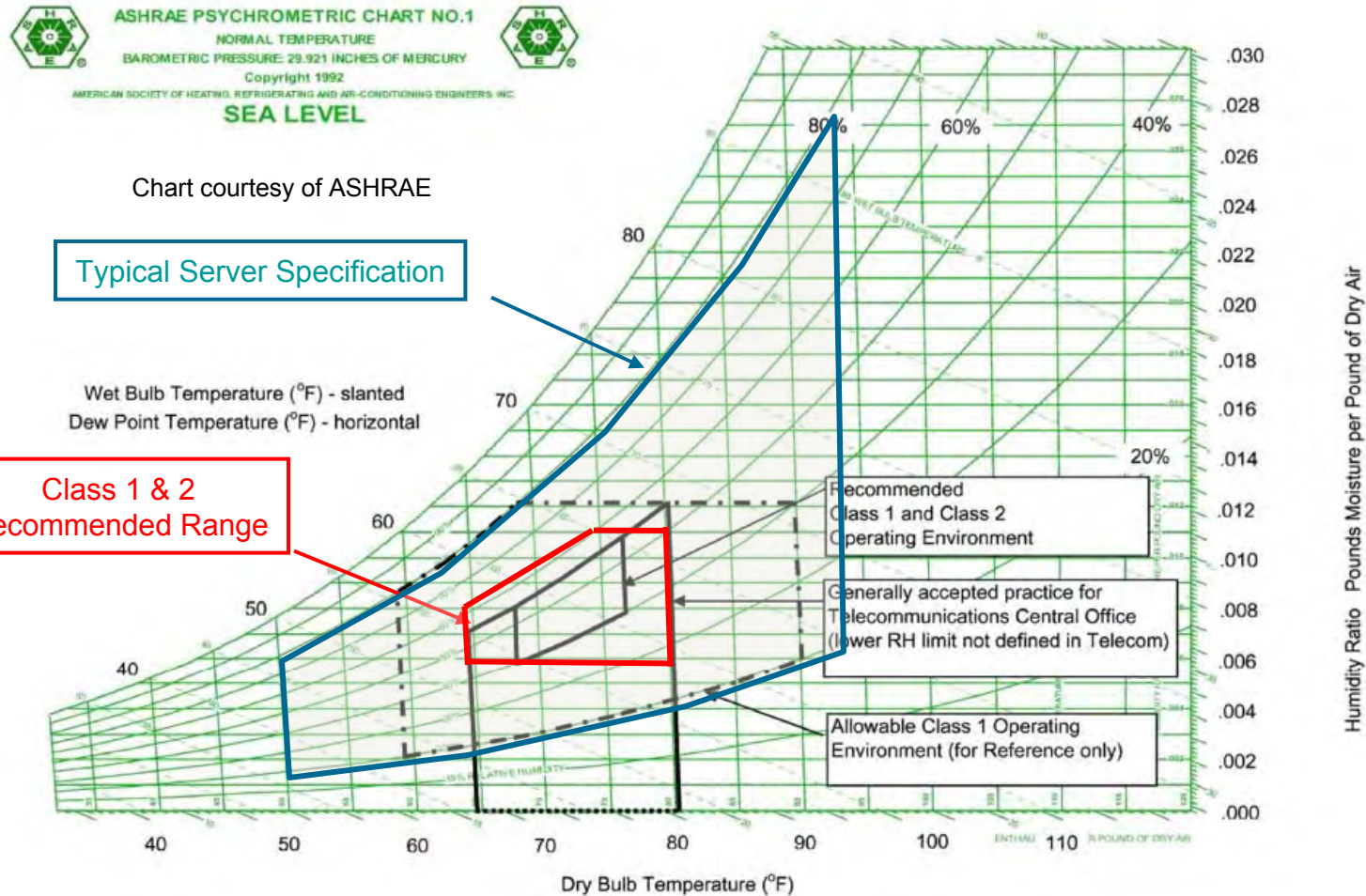
- Eliminate inadvertent dehumidification
 - Computer load is sensible only
- Use ASHRAE allowable humidity ranges
 - Maintain inlet conditions between 41.9° F dew-point and 59° F dew-point and 60% RH or manufacturer's requirements (many manufacturers allow even wider humidity range).
 - Use dew-point control, NOT %RH.
- Defeat equipment fighting
 - Coordinate controls
- Disconnect and only control humidity of makeup air or one CRAC/CRAH unit
- Entirely disconnect (many have!)

- Some contaminants (hygroscopic salts) with high humidity can deposit and bridge across circuits
- Operating with high humidity (>60%) in an environment with high concentrations of particulates could be a problem.
- **Normal building filtration is effective in removing particulates**
- Operating with high humidity (>60%) in areas with gaseous contamination could cause problems. More study is needed in this area, however few locations have such conditions.

Electrostatic discharge

- Industry practices
 - Telecom has no lower limit (personnel grounding expected)
 - Electrostatic Discharge Association removed humidity control as a primary ESD control measure in ESD/ANSI S20.20
 - IT equipment is qualified to withstand ESD and it is grounded
 - Many centers eliminate humidification with no adverse effects
- Recommended procedures
 - Personnel grounding
 - Cable and floor grounding

Server Performance Specifications Generally Exceed ASHRAE Ranges

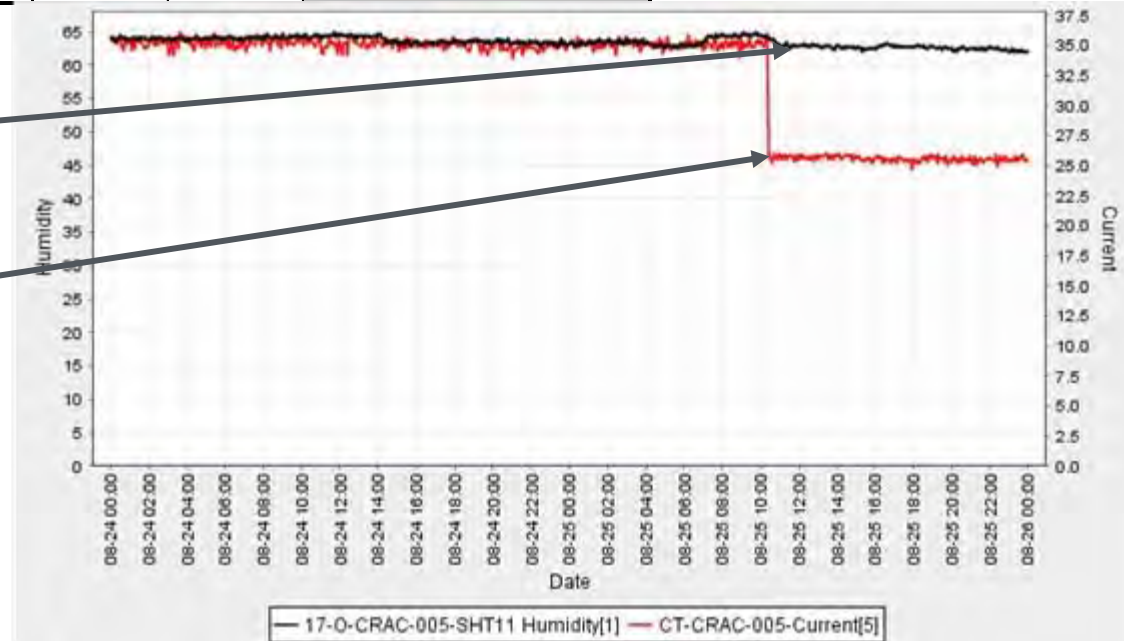


Cost of Unnecessary Humidity Control

	Visalia Probe			CRAC Unit Panel			
	Temp	RH	Tdp	Temp	RH	Tdp	Mode
AC 005	84.0	27.5	47.0	76	32.0	44.1	Cooling
AC 006	81.8	28.5	46.1	55	51.0	37.2	Cooling & Dehumidification
AC 007	72.8	38.5	46.1	70	47.0	48.9	Cooling
AC 008	80.0	31.5	47.2	74	43.0	50.2	Cooling & Humidification
AC 010	77.5	32.8	46.1	68	45.0	45.9	Cooling
AC 011	78.9	31.4	46.1	70	43.0	46.6	Cooling & Humidification
Min	72.8	27.5	46.1	55.0	32.0	37.2	
Max	84.0	38.5	47.2	76.0	51.0	50.2	
Avg	79.2	31.7	46.4	68.8	43.5	45.5	

Humidity down ~2%

CRAC power down 28%



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

Questions?





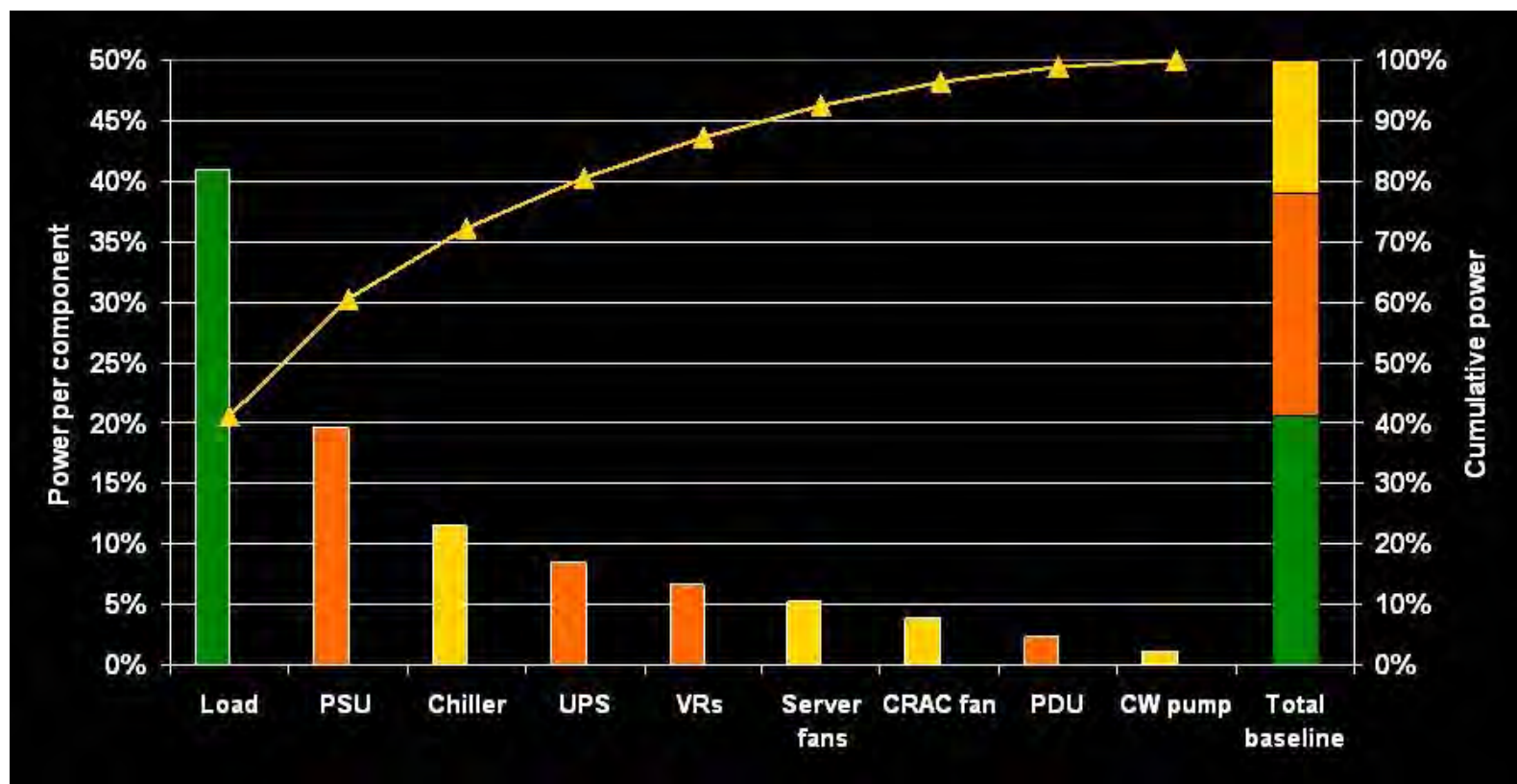
Electrical Systems



U.S. Department of Energy
Energy Efficiency and Renewable Energy



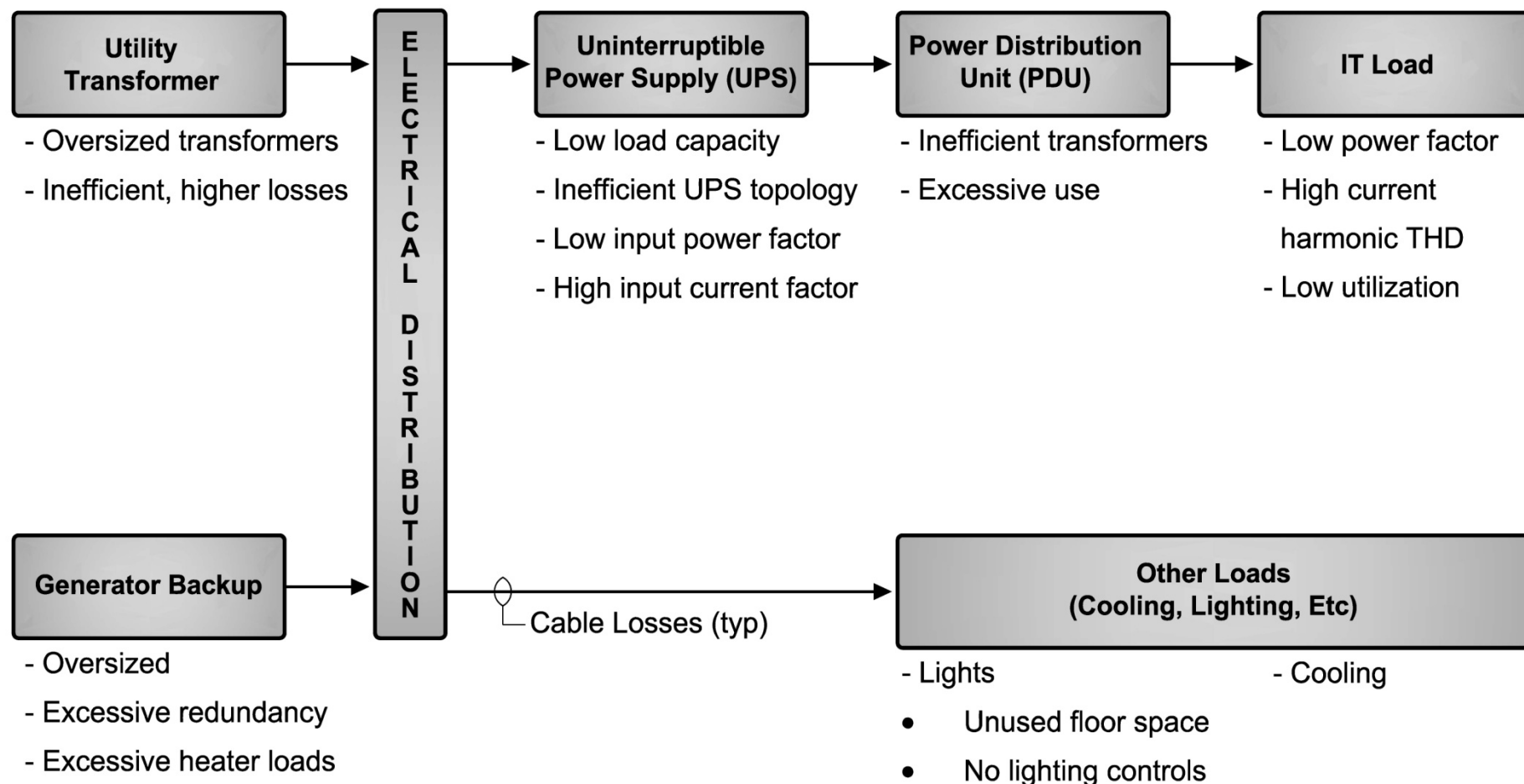
Electrical system end use – Orange bars



Courtesy of Michael Patterson, Intel Corporation

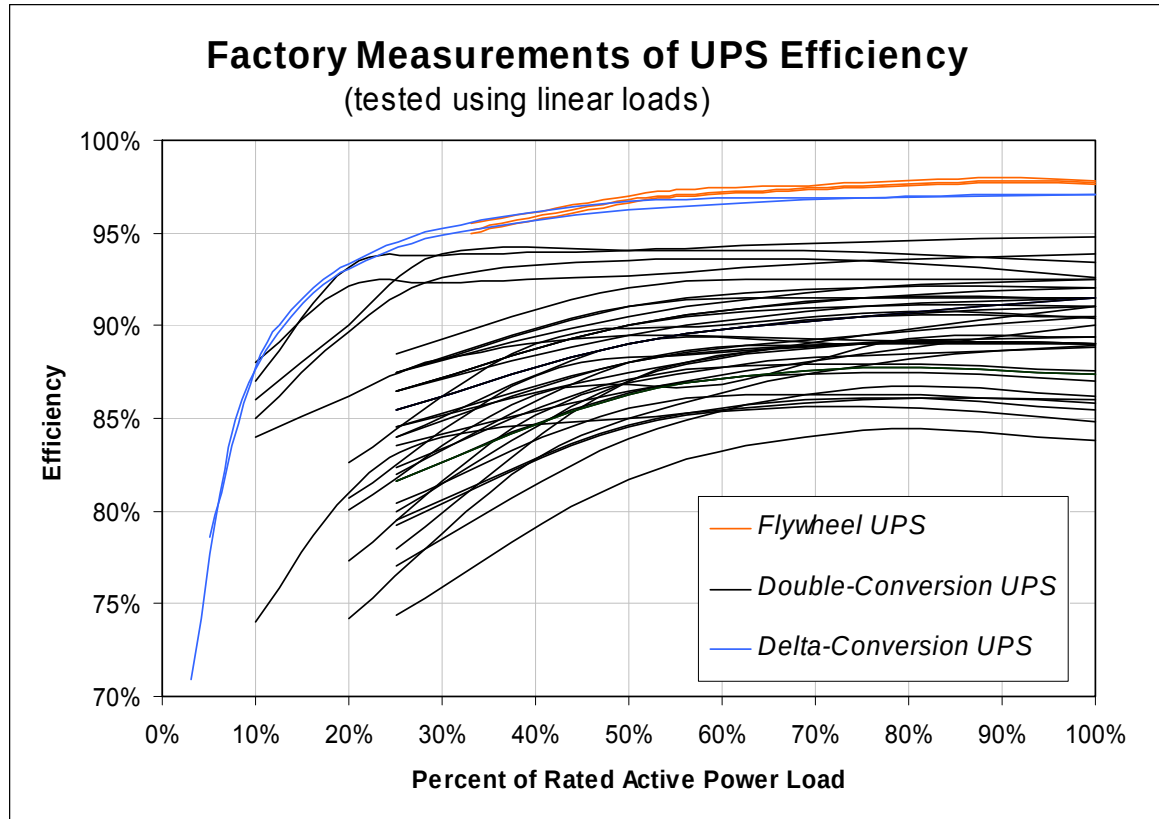
- Every power conversion (AC-DC, DC-AC, AC-AC) loses some energy and creates heat
- Efficiency decreases when systems are lightly loaded
- Distributing higher voltage is more efficient and can save capital cost (conductor size is smaller)
- Power supply, uninterruptible power supply (UPS), transformer, and PDU efficiency varies – carefully select
- Lowering distribution losses also lowers cooling loads

Electrical Systems – Points of Energy Inefficiency

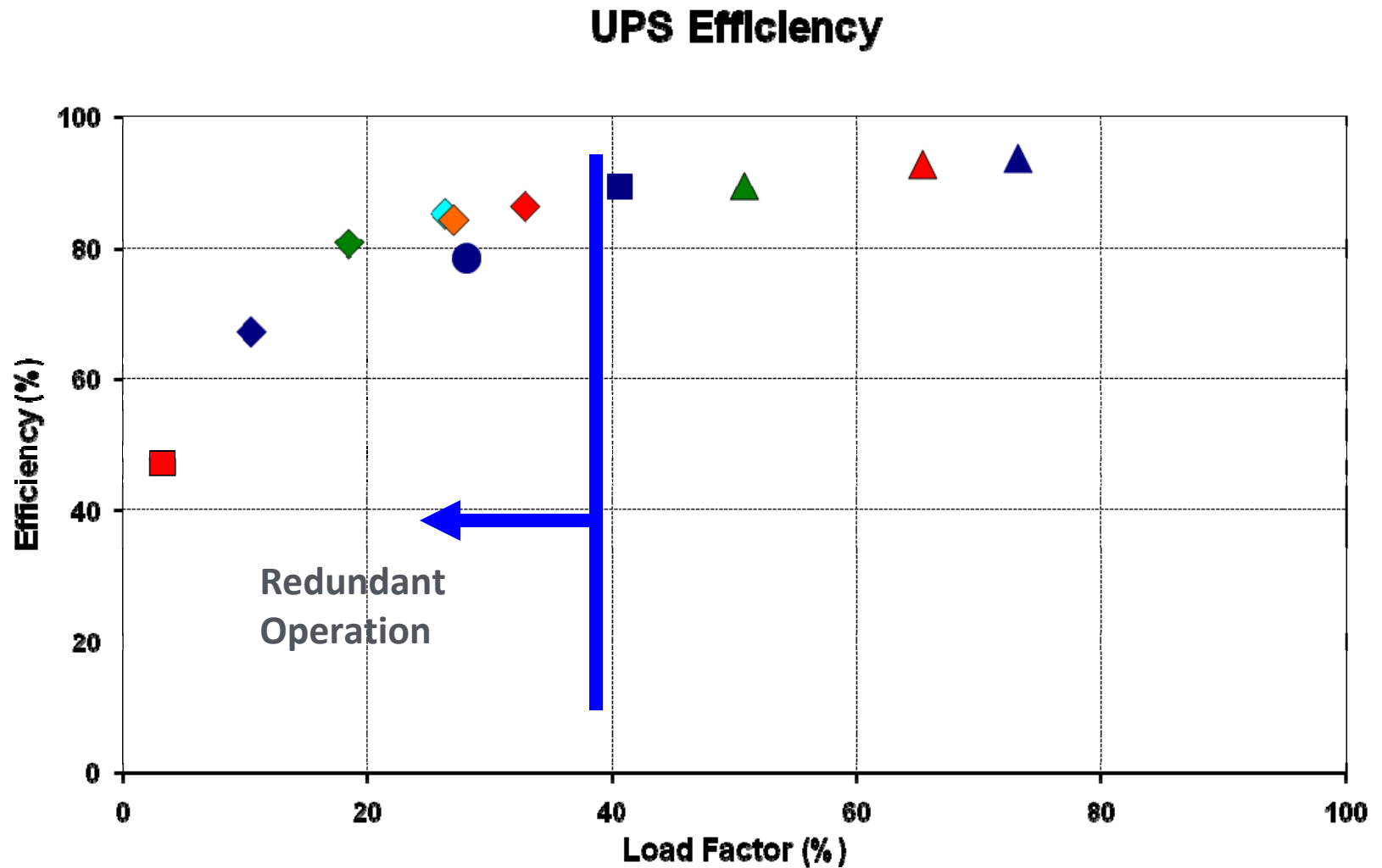


UPS, Transformer, & PDU Efficiency

- Efficiencies vary with system design, equipment, and load
- Redundancies impact efficiency

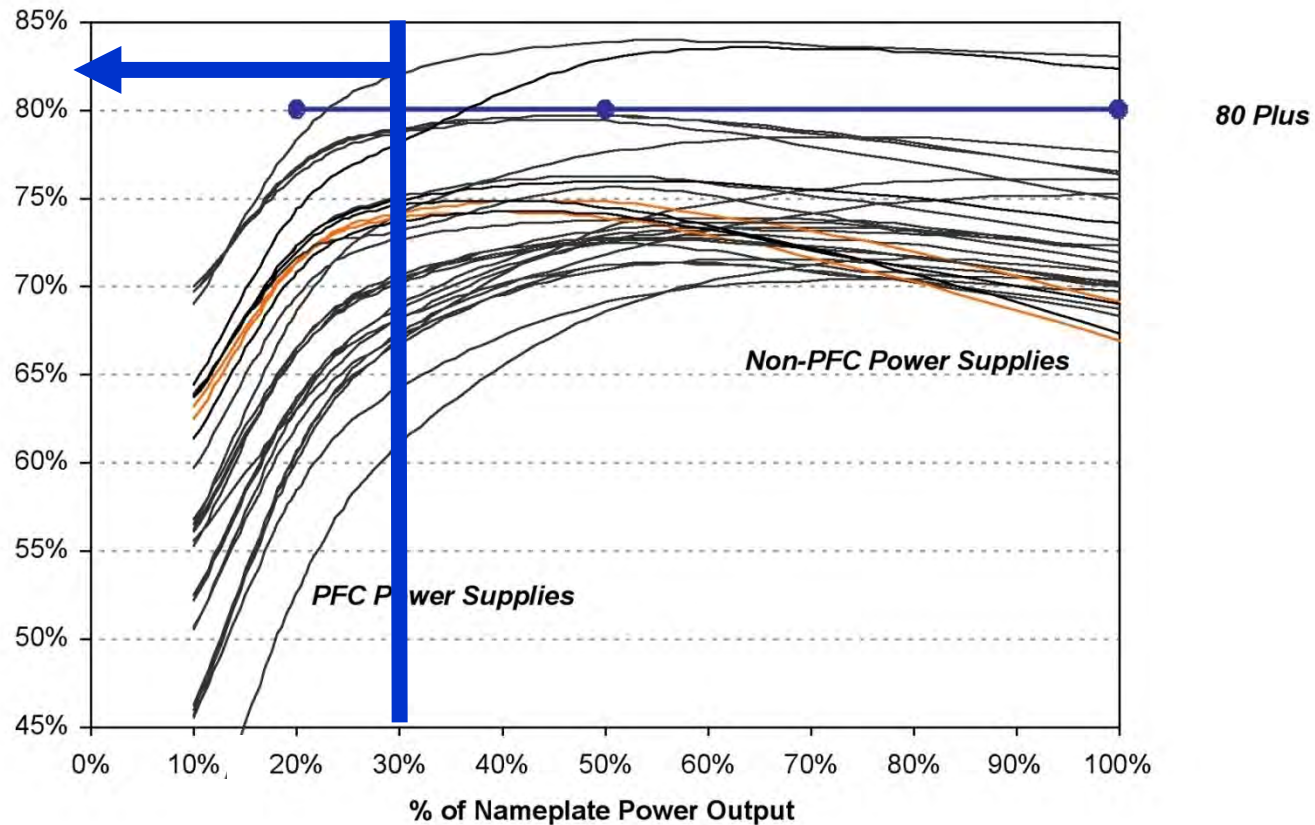


Measured UPS efficiency



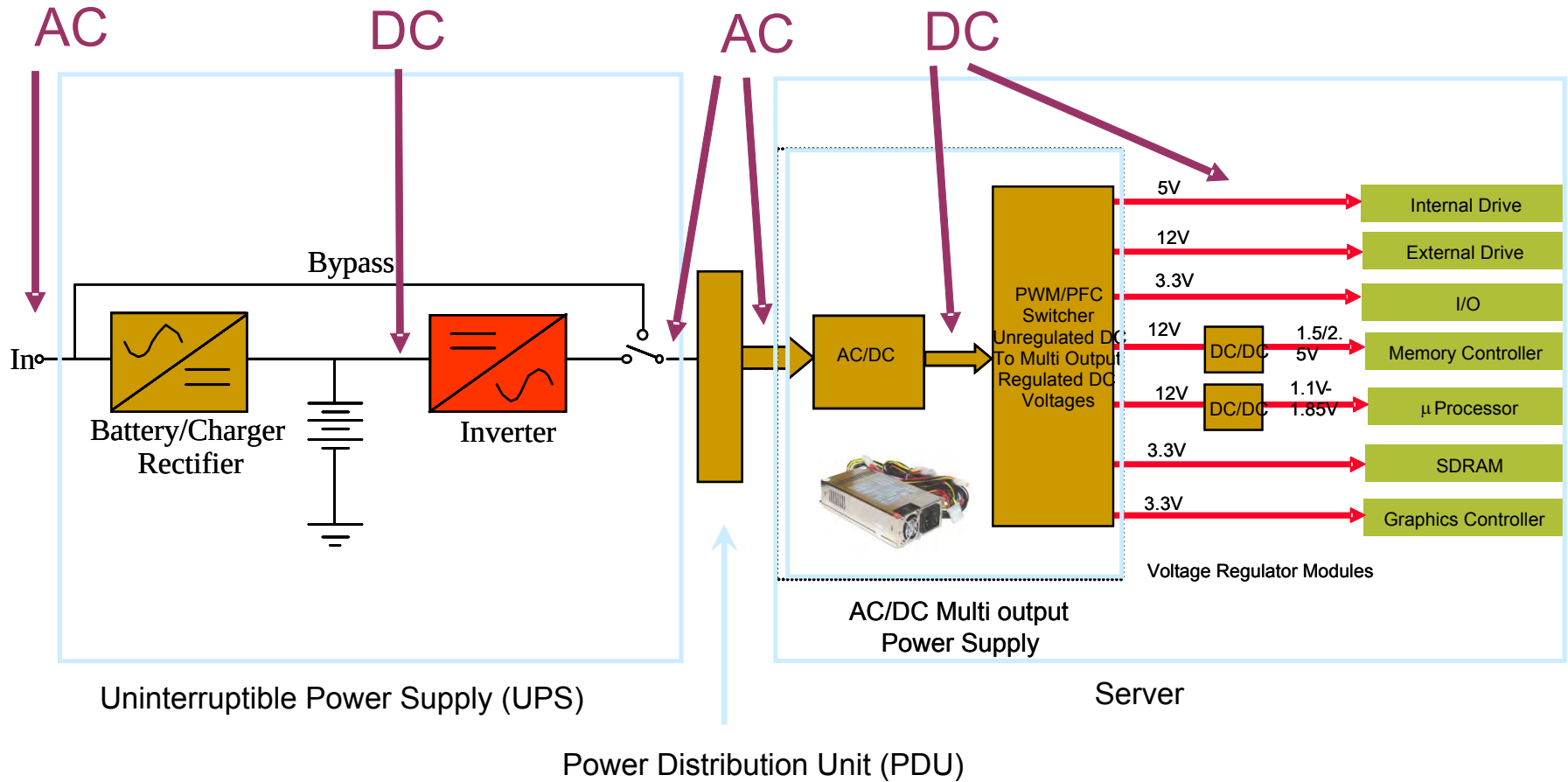
LBNL/EPRI Measured Power Supply Efficiency

Measured Server Power Supply Efficiencies (all form factors)



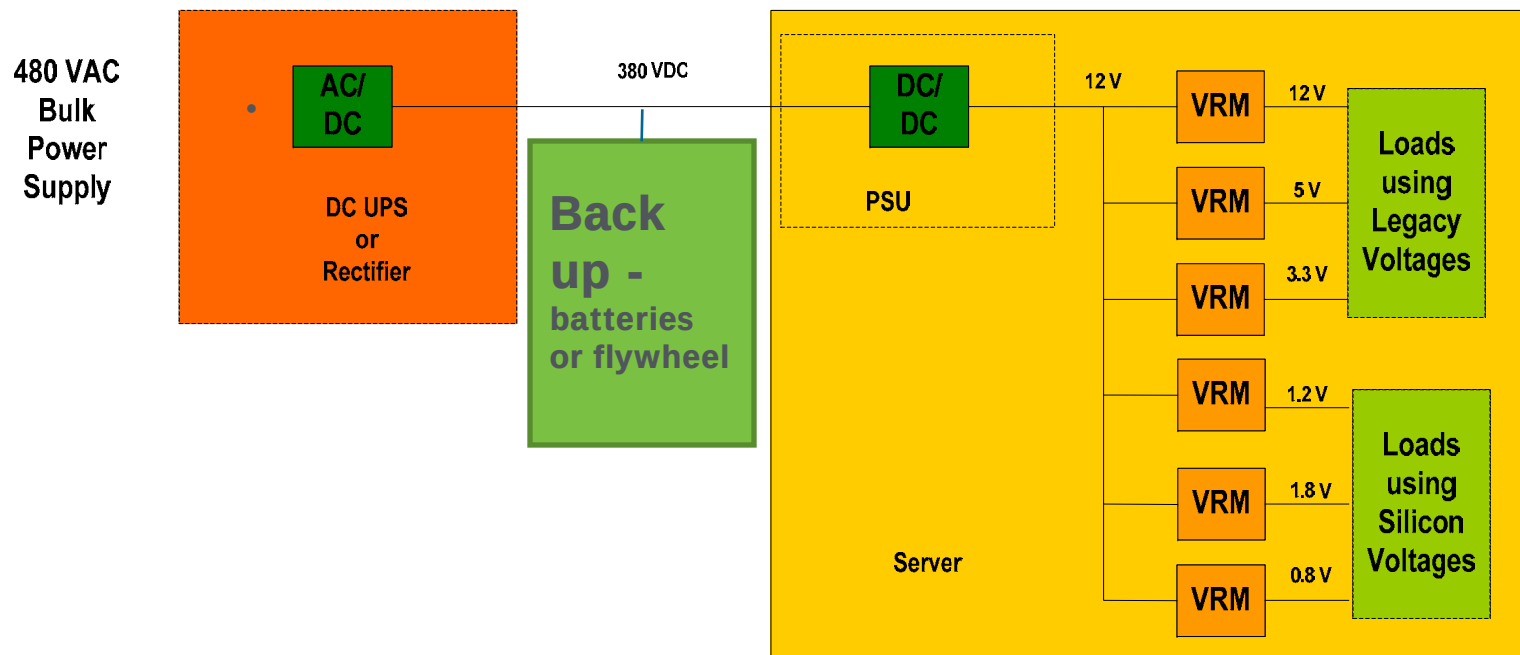
- Understand what redundancy costs and what it gets you – is it worth it?
- Does everything need the same level?
- Different strategies have different energy penalties (e.g. $2N$ vs. $N+1$)
- It's possible to more fully load UPS systems and achieve desired redundancy
- Redundancy in electrical distribution puts you down the efficiency curve

From Utility Power to the Chip – Multiple Electrical Power Conversions



380V. DC power distribution

- Eliminate several conversions
- Also use for lighting, and variable speed drives
- Use with on-site generation including renewable energy sources

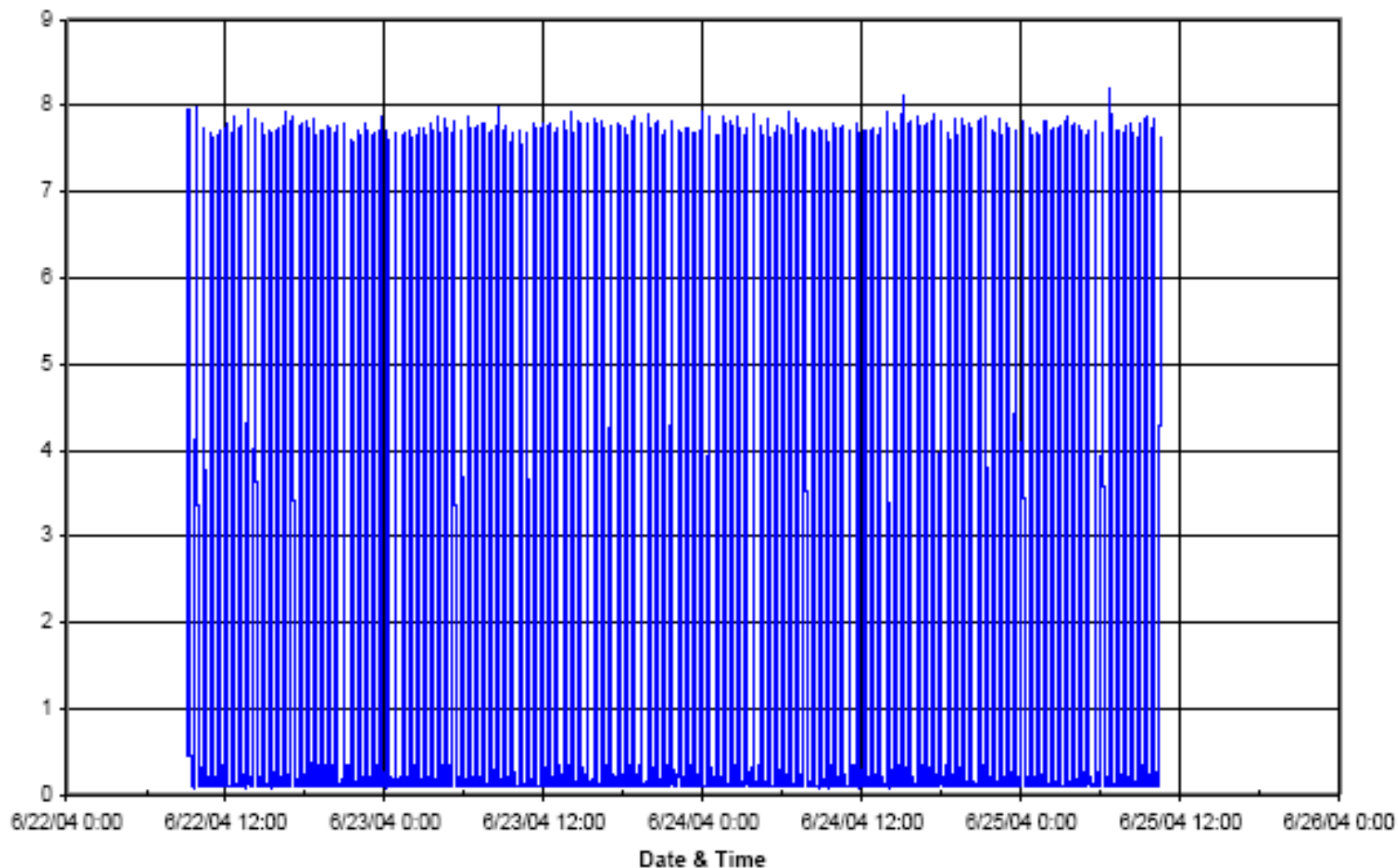


- Losses
 - Heaters
 - Battery chargers
 - Transfer switches
 - Fuel management systems
- Opportunities to reduce or eliminate losses
- Heaters (many operating hours) use more electricity than the generator produces (few operating hours)
 - Check with generator manufacturer on how to reduce the energy consumption of block heaters (e.g. temperature settings and control)



Standby generator heater

Generator Standby Power Loss



- Lights are on and nobody's home
 - Switch off lights in unused/unoccupied areas or rooms (UPS, Battery, S/Gear, etc)
 - Lighting controls such as occupancy sensors are well proven
- Small relative benefit but easy to accomplish – also saves HVAC energy
- Use energy efficient lighting
- Lights should be located over the aisles

- Since most cooling system equipment operates continuously, premium efficiency motors should be specified everywhere
- Variable speed drives should be used
 - Chillers
 - Pumps
 - Air handler fans
 - Cooling tower fans

- Choose highly efficient components and configurations
- Reduce power conversion (AC-DC, DC-AC, AC-AC, DC-DC)
- Consider the minimum redundancy required as efficiency decreases when systems are lightly loaded
- Use higher voltage

Questions?





Resources



U.S. Department of Energy
Energy Efficiency and Renewable Energy



Advanced Manufacturing Office

- Tool suite & metrics for baselining
- Training
- Qualified specialists
- Case studies
- Recognition of high energy savers
- R&D - technology development



Federal Energy Management Program

- Workshops
- Federal case studies
- Federal policy guidance
- Information exchange & outreach
- Access to financing opportunities
- Technical assistance



GSA

- Workshops
- Quick Start Efficiency Guide
- Technical Assistance



EPA

- Metrics
- Server performance rating & ENERGY STAR label
- Data center benchmarking



Industry

- Tools
- Metrics
- Training
- Best practice information
- Best-in-Class guidelines
- IT work productivity standard

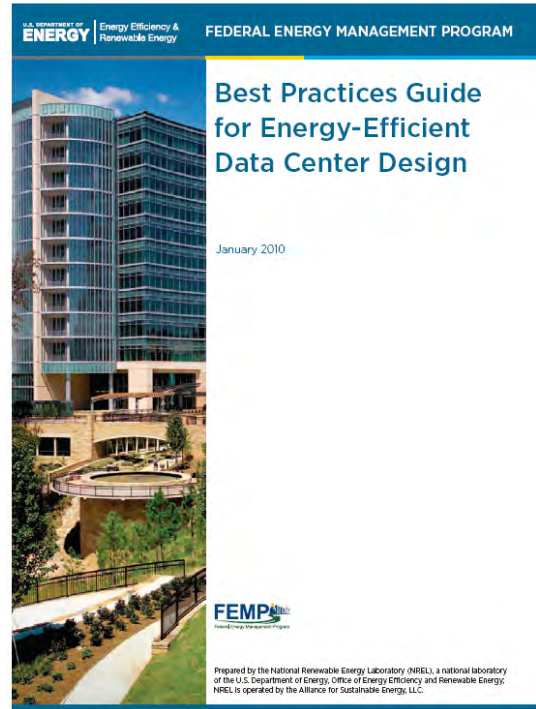


Resources from DOE Federal Energy Management Program (FEMP)

U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

- Best Practices Guide
- Benchmarking Guide
- Data Center Programming Guide
- Technology Case Study Bulletins
- Procurement Specifications
- Report Templates
- Process Manuals
- Quick-Start Guide



As data center energy densities in power-use per square foot increase, energy savings for cooling can be realized by incorporating liquid-cooling devices instead of increasing airflow volume. This is especially important in a data center with a typical under-floor cooling system.

Server racks can also be cooled with competing technologies such as modular, overhead coolers, server coolers, and chassis-cooled coolers with dedicated containment enclosures.

During operation, hot server-rack airflow is forced through the RDHs device by the server fans. Hot air is exchanged from the hot air to circulating water from a chiller or cooling tower. Then, server-rack outlet air temperature is reduced before it is discharged into the data center.

2 Technology Overview
The covered data center is located at LBNL.



supply, and make it available for future needs. Effective implementation requires information technologies (IT) staff, in-house facilities technicians, and engineering consultants working collaboratively. Together they can identify airflow deficiencies, develop solutions, and implement fixes and upgrades.

DOE's AMO data center program provides tools and resources to help owners and operators:

- **DC Pro Software Tool Suite**
 - Tools to define baseline energy use and identify energy-saving opportunities
- **Information products**
 - Manuals, case studies, and other resources
- **End-user awareness training**
 - Workshops in conjunction with ASHRAE
- **Data Center Energy Practitioner (DCEP) certificate program**
 - Qualification of professionals to evaluate energy efficiency opportunities
- **Research, development, and demonstration of advanced technologies**

High-Level On-Line Profiling and Tracking Tool

- Overall efficiency (Power Usage Effectiveness [PUE])
- End-use breakout
- Potential areas for energy efficiency improvement
- Overall energy use reduction potential

In-Depth Assessment Tools → Savings

Air Management

- Hot/cold separation
- Environmental conditions
- RCI and RTI

Electrical Systems

- UPS
- PDU
- Transformers
- Lighting
- Standby gen.

IT-Equipment

- Servers
- Storage & networking
- Software

Cooling

- Air handlers/conditioners
- Chillers, pumps, fans
- Free cooling

A certificate process for energy practitioners qualified to evaluate energy consumption and efficiency opportunities in Data Centers.

Key objective:

- Raise the standards of assessors
- Provide greater repeatability and credibility of recommendations.

Target groups include:

- Data Center personnel (in-house experts)
- Consulting professionals (for-fee consultants)

Training & Certificate Disciplines/Levels/Tracks

Level 1 Generalist:

Prequalification,
Training and Exam on
All Disciplines
+ Assessment Process
+ DC Pro Profiling Tool

IT-Equipment, Air-Management, Cooling Systems,
and Electrical Systems

Level 2 Specialist:

Prequalification,
Training and Exam on
Select Disciplines
+ Assessment Process
+ DC Pro System
Assessment Tools

Cooling
Systems

Air
Management

Electrical
Systems

IT
Equipment

HVAC
(available)

IT
(2012)

Two Tracks:

- Certificate track (training + exam)
- Training track (training only)

A voluntary public-private partnership program

- Buildings
- Products



- ENERGY STAR Datacenter Rating Tool
 - Build on existing ENERGY STAR platform with similar methodology (1-100 scale)
 - Usable for both stand-alone and data centers housed within another buildings
 - Assess performance at building level to explain how a building performs, not why it performs a certain way
 - ENERGY STAR label to data centers with a rating of 75+
 - Rating based on data center infrastructure efficiency
 - Ideal metric would be measure of useful work/energy use.
 - Industry still discussing how to define useful work.
- Energy STAR specification for servers and UPSs
- Evaluating enterprise data storage, and networking equipment for Energy STAR product specs





http://www1.eere.energy.gov/femp/program/data_center.html



<http://hightech.lbl.gov/datacenters.html>



http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency



<http://www1.eere.energy.gov/industry/datacenters/>

Questions?





Workshop Summary

Best Practices



U.S. Department of Energy
Energy Efficiency and Renewable Energy



LBNL's Legacy Data Center:

- Increased IT load
 - >50% (~180kW) increase with virtually no increase in infrastructure energy use
- Raised room temperature 8+ degrees
- AC unit turned off
 - (1) 15 ton now used as backup
- Decreased PUE from 1.65 to 1.45
 - 30% reduction in infrastructure energy
- More to come!

Next Steps for LBNL's Legacy Data Center

- Integrate CRAC controls with wireless monitoring system
- Retrofit CRACs w/ VSD
 - Small VAV turndown, yields big energy savings
- Improve containment (overcome curtain problems)
- Increase liquid cooling (HP in-rack, and APC in-row)
- Increase free cooling (incl. tower upgrade)

1. Measure and Benchmark Energy Use
2. Identify IT Opportunities
3. Use IT to Control IT
4. Manage Airflow
5. Optimize Environmental Conditions
6. Evaluate Cooling Options
7. Improve Electrical Efficiency
8. Implement Energy Efficiency Measures

1. Measure and Benchmark Energy Use

- Use metrics to measure efficiency
- Benchmark performance
- Establish continual improvement goals

2. Identify IT Opportunities

- Specify efficient servers (incl. power supplies)
- Virtualize
- Refresh IT equipment
- Turn off unused equipment.

3. Use IT to Control IT Energy

- Evaluate monitoring systems to enhance real-time management and efficiency.
- Use visualization tools (e.g. thermal maps).
- Install dashboards to manage and sustain energy efficiency.

4. Manage Airflow

- Implement hot and cold aisles
- Fix leaks
- Manage floor tiles
- Isolate hot and cold airstreams.

5. Optimize Environmental Conditions

- Follow ASHRAE guidelines or manufacturer specifications
- Operate to maximum ASHRAE recommended range.
- Anticipate servers will occasionally operate in allowable range.
- Minimize or eliminate humidity control

6. Evaluate Cooling Options

- Use centralized cooling system
- Maximize central cooling plant efficiency
- Provide liquid-based heat removal
- Compressorless cooling

7. Improve Electrical Efficiency

- Select efficient UPS systems and topography
- Examine redundancy levels
- Increase voltage distribution and reduce conversions

8. Implement Standard Energy Efficiency Measures

- Install premium efficiency motors
- Upgrade building automation control system
 - Integrate CRAC controls
- Variable speed everywhere
- Optimize cooling tower efficiency

Most importantly...

Get IT and Facilities People
Talking and working
together as a team!!!

Questions?



Contact Information:

Dale Sartor, P.E.
Lawrence Berkeley National Laboratory
Applications Team
MS 90-3111
University of California
Berkeley, CA 94720

DSartor@LBL.gov
(510) 486-5988
<http://Ateam.LBL.gov>

