Best Practices for Data Center Energy Efficiency Seminar

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Organized by:
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U.S. Department of Energy
Energy Efficiency and Renewable Energy

FEMP Federal Energy Management Program

Better Buildings U.S. DEPARTMENT OF ENERGY

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This Presentation is Available for download at:

http://datacenterworkshop.lbl.gov/

Agenda

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- Introduction, performance metrics and benchmarking
  - Dale Sartor, LBNL
- IT equipment and software efficiency
  - Dale Sartor, LBNL
- Break
- Data center environmental conditions
  - Magnus Hurlin, ANSIS
- Airflow management
  - Brian Donathan, Teladata
- Break
- Cooling systems
  - Dale Sartor, LBNL
- Electrical systems
  - Mukesh Khattar, EPRI
- Break
- DCIM and integrated controls (Use IT to save energy)
  - Panel
- Resources and workshop summary

Seminar Learning Objectives

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- 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

Challenging Conventional Wisdom: Game Changers

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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, Performance Metrics and Benchmarking

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Data Center Energy

- 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
  - 2% of US Electricity consumption
  - Projected to double in next 5 years
  - Power and cooling constraints in existing facilities

Global Data Center Electricity Use

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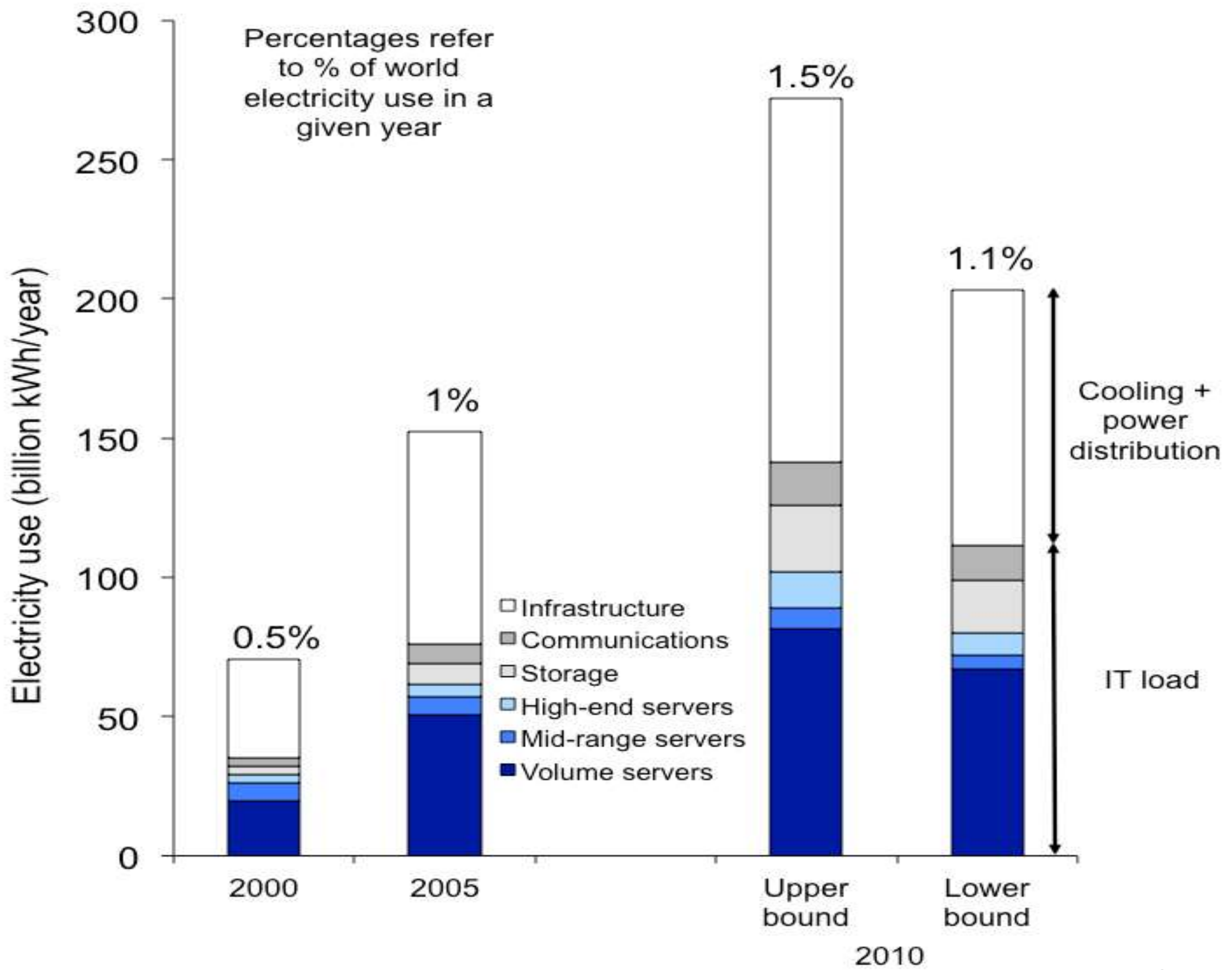

Source: Koomey 2011.

How Much is 152B kWh?

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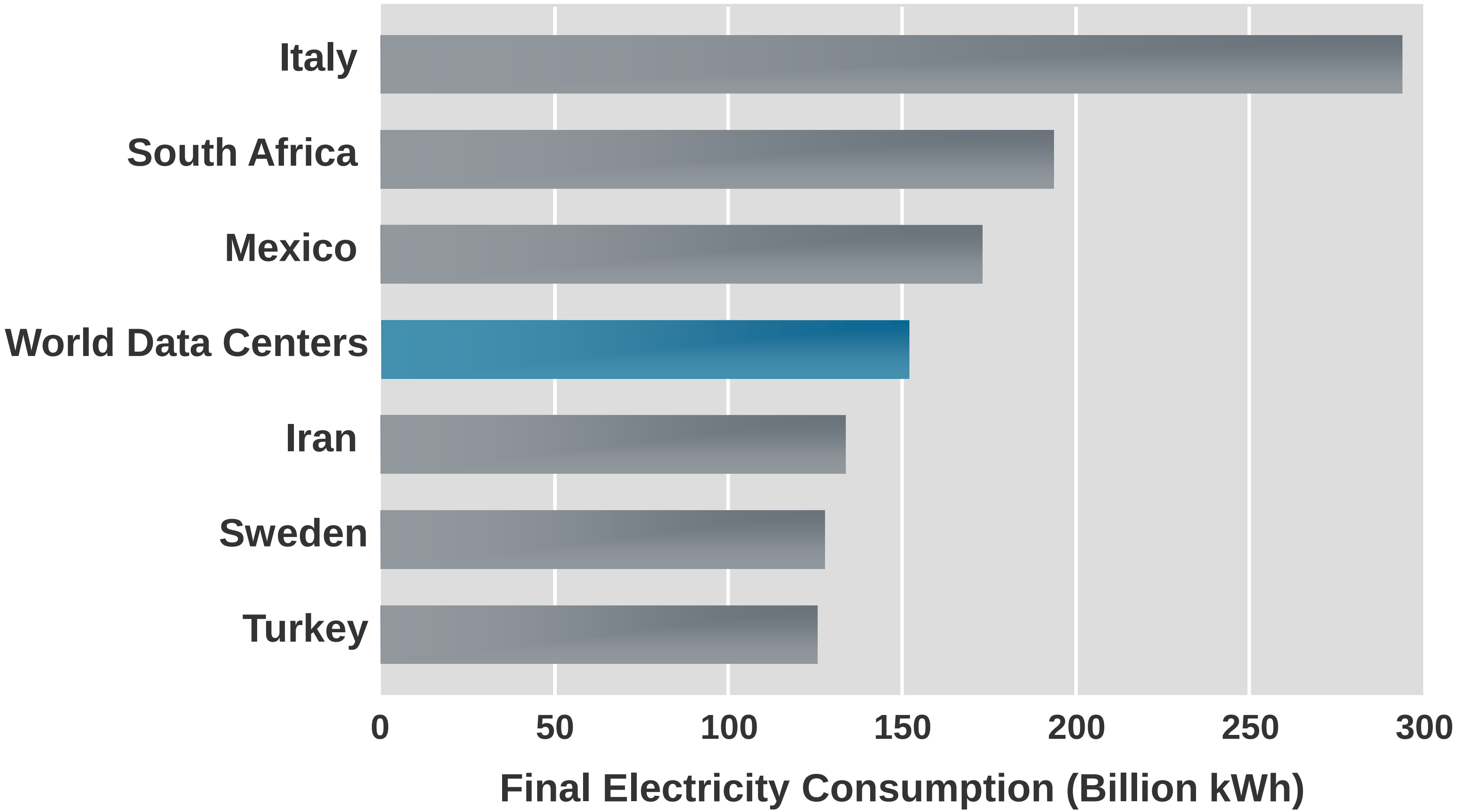

Source for country data in 2005: International Energy Agency, *World Energy Balances* (2007 edition)

Aggressive Programs Make a Difference

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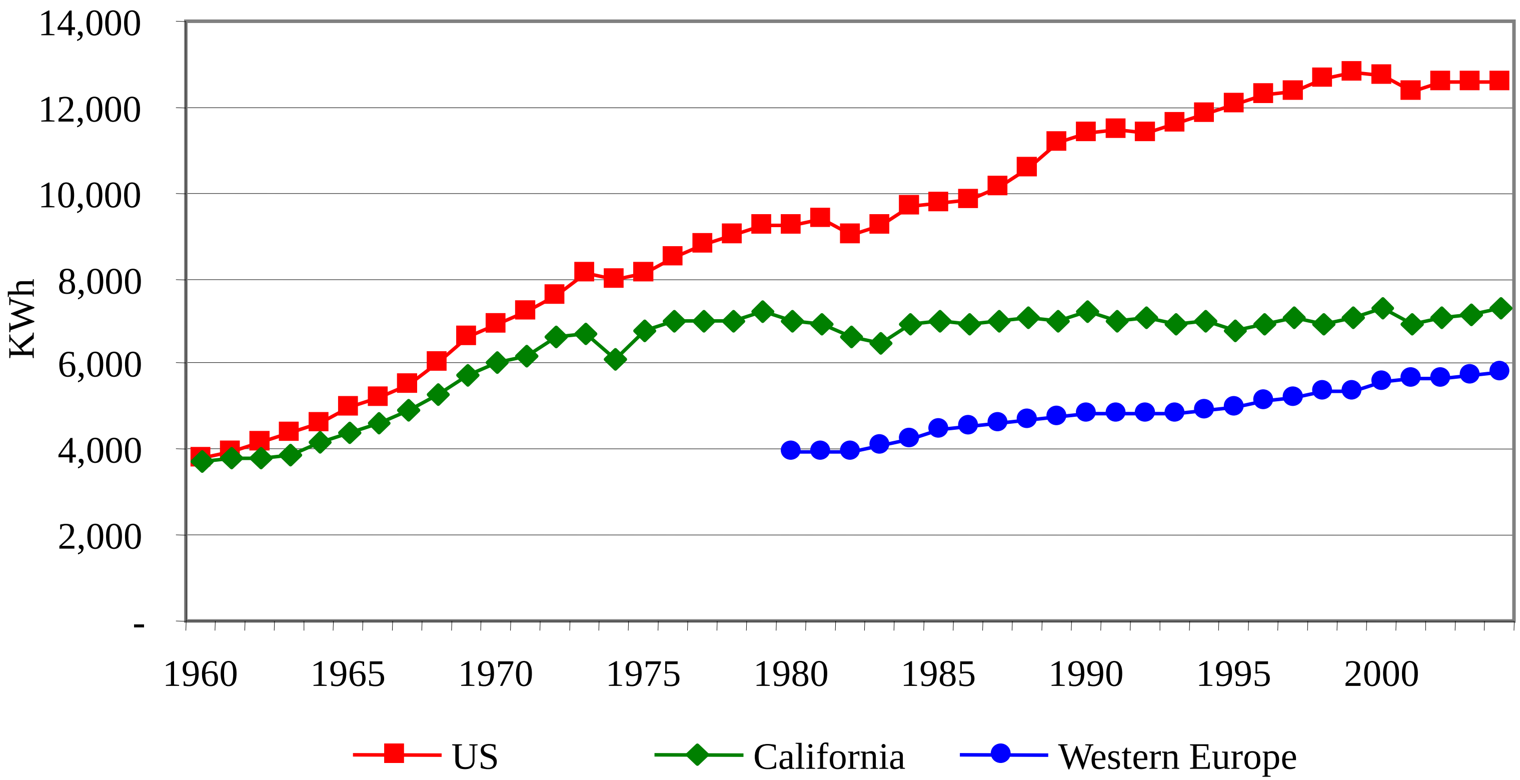
Energy efficiency programs have helped keep per capita electricity consumption in California flat over the past 30 years



Projected Data Center Energy Use

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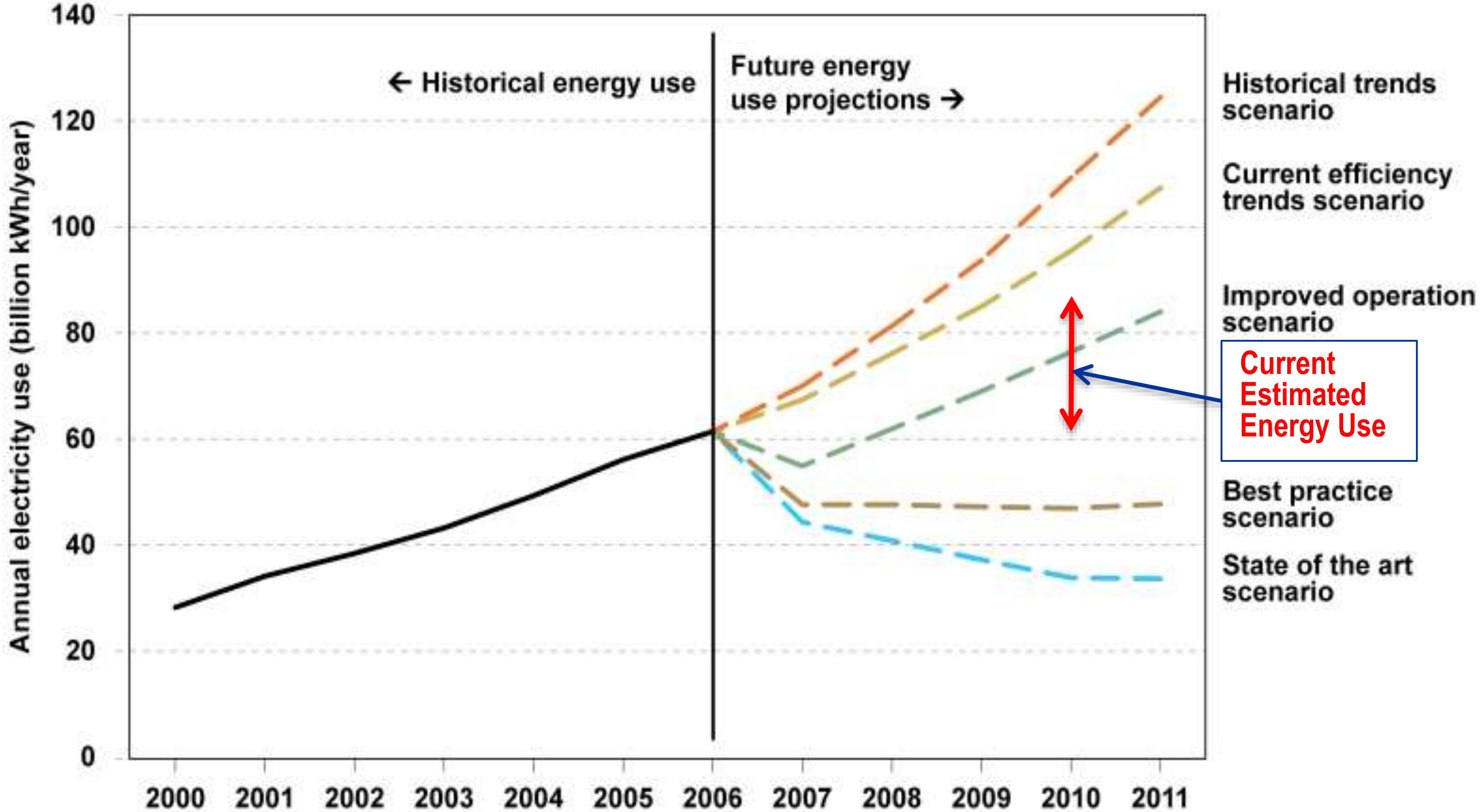

EPA Report to Congress 2008

The Rising Cost of Ownership

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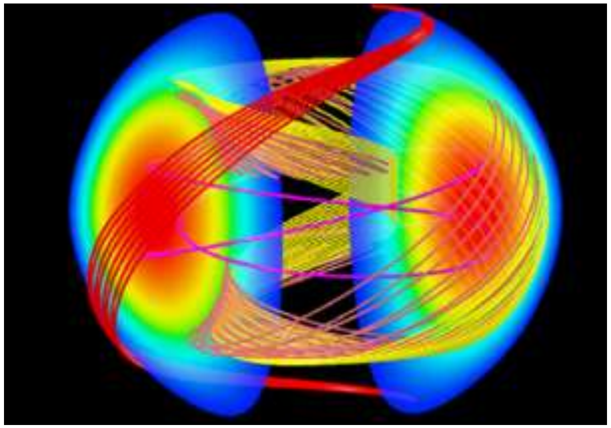
- Demand for computing is growing faster than efficiency
- Cost of electricity and supporting infrastructure now surpassing capital cost of IT equipment
- Perverse incentives -- IT and facilities costs separate

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!

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LBNL Super Computer Systems Power

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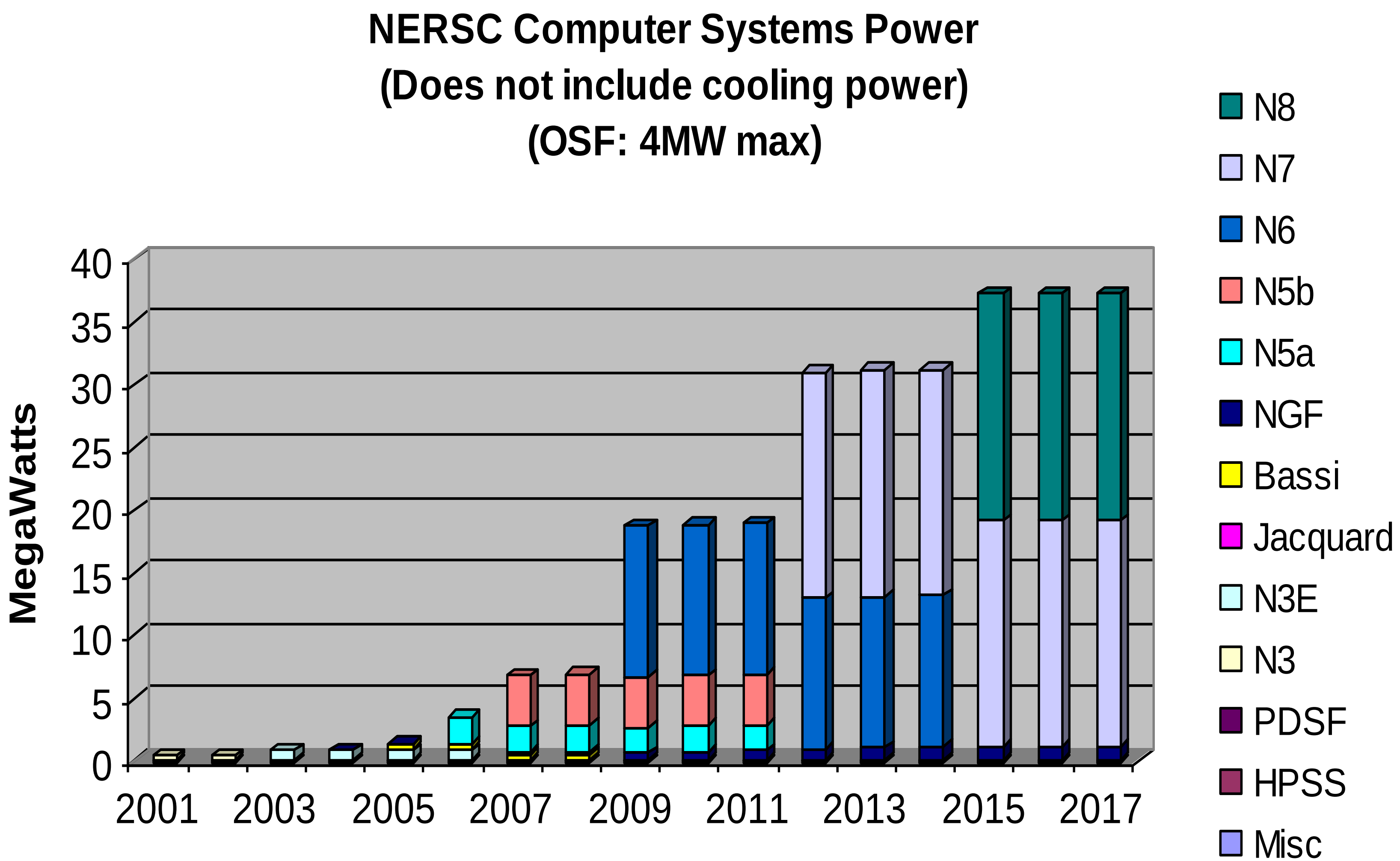
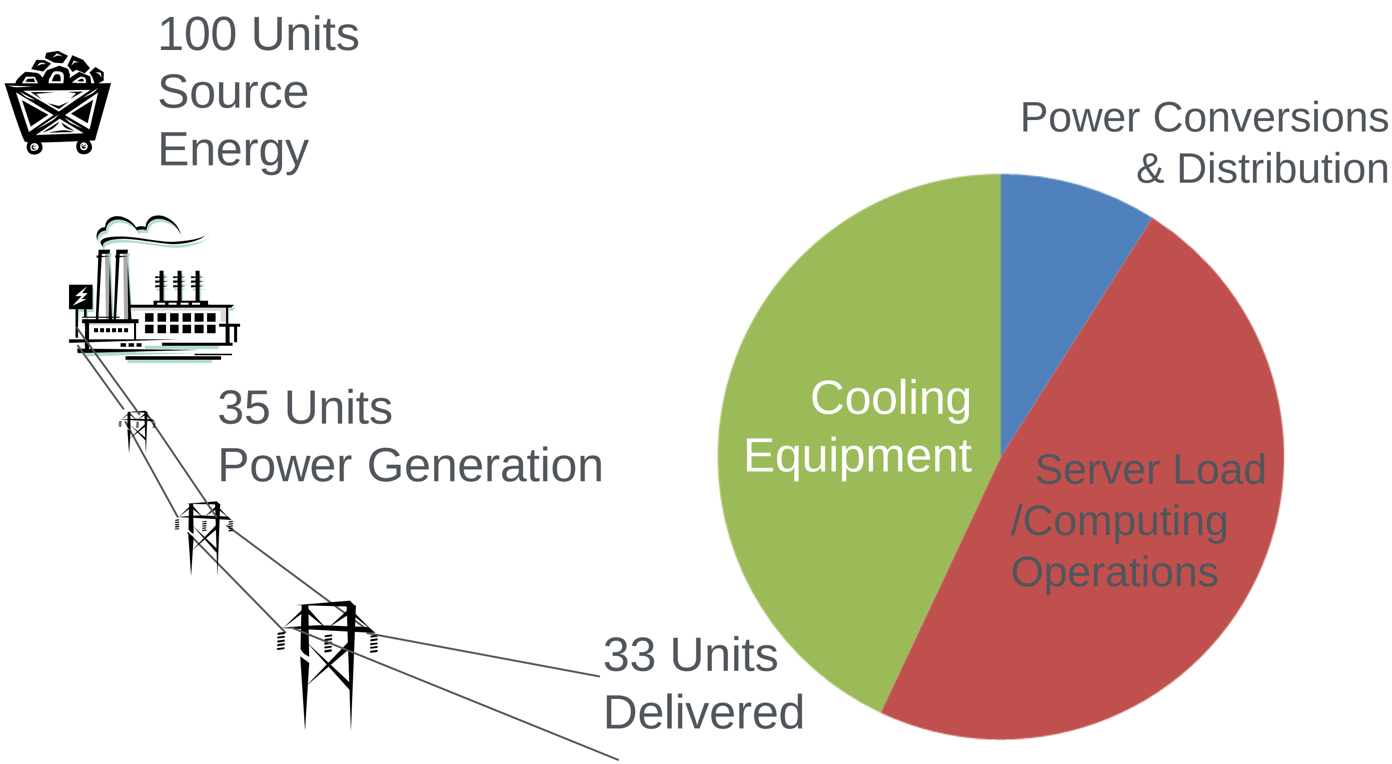


Energy Efficiency = Useful computation / Total Source Energy

Typical Data Center Energy End Use



Energy Efficiency Opportunities

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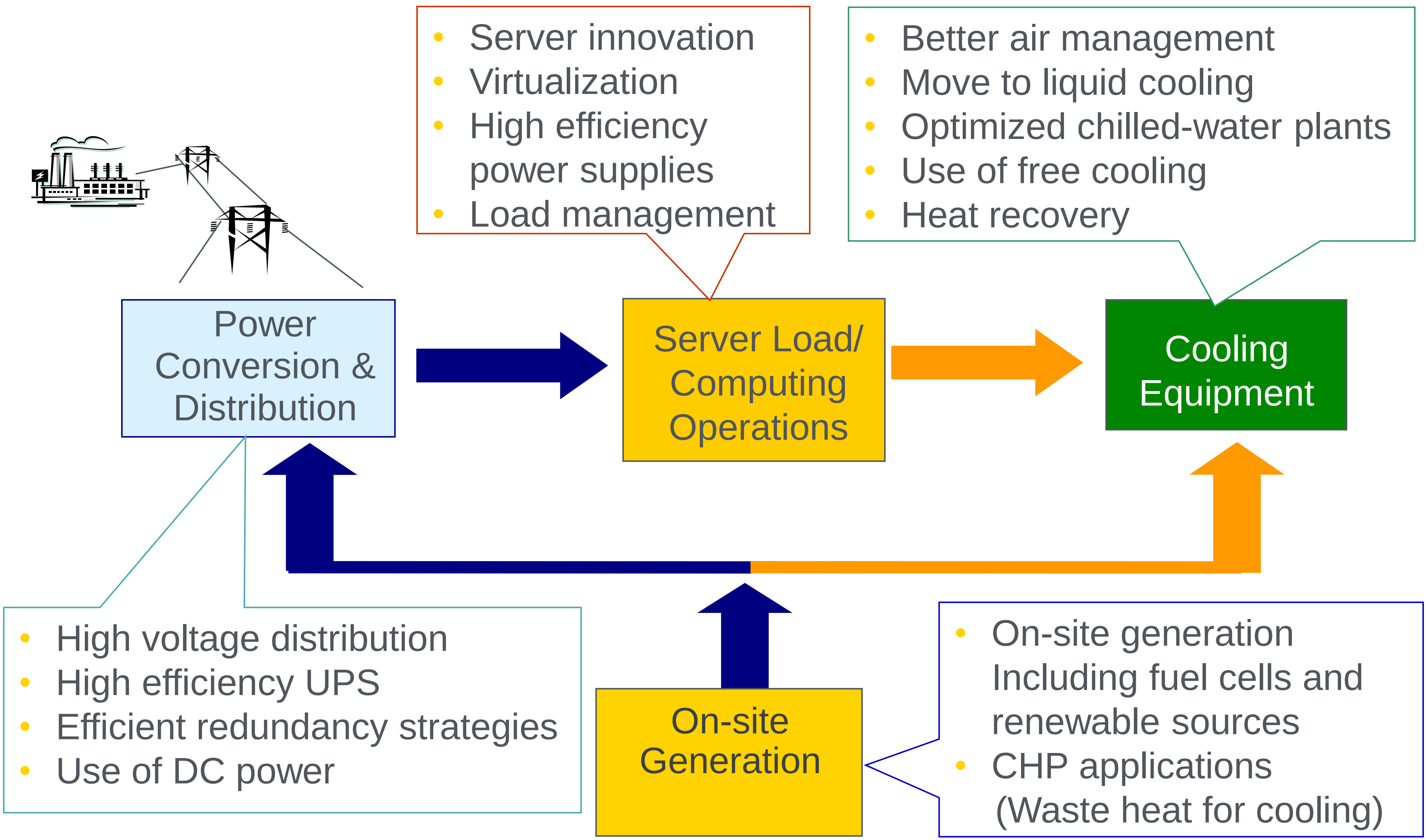
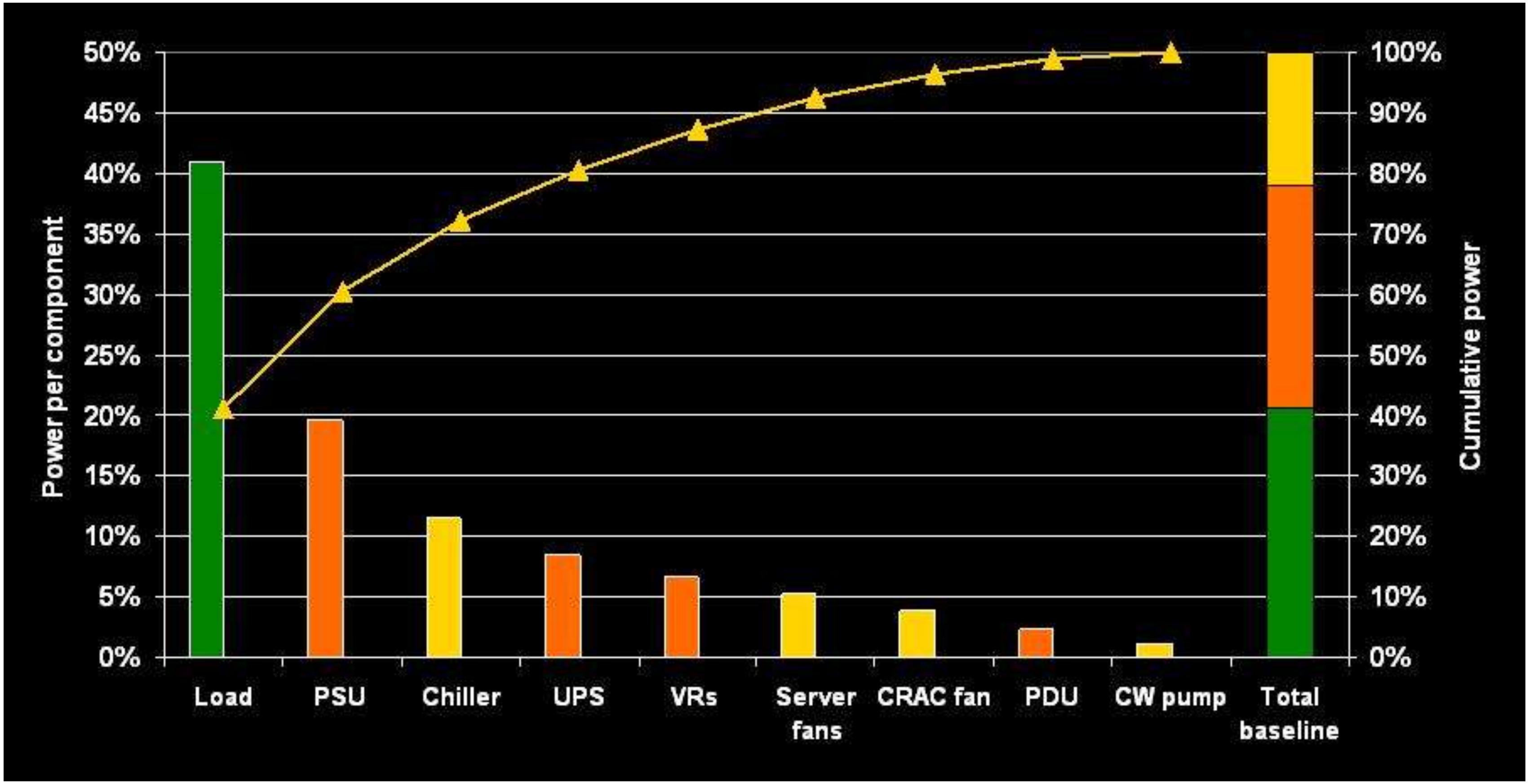


Electricity Use in Data Centers



Courtesy of Michael Patterson, Intel Corporation

Potential Benefits of Data Center Energy Efficiency

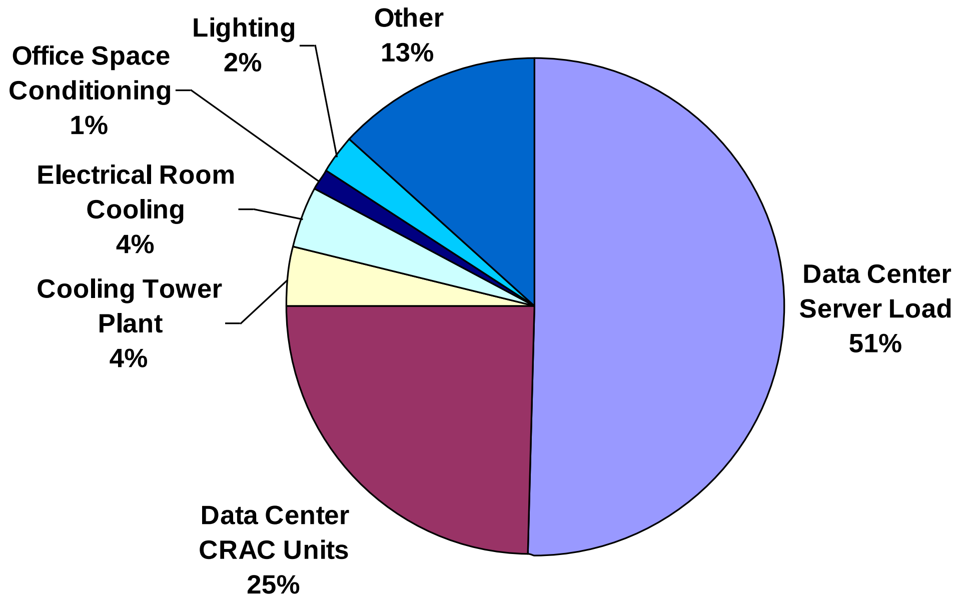
- 20-40% savings typical
- Aggressive strategies can yield 50+% savings
- Extend life and capacity of infrastructures

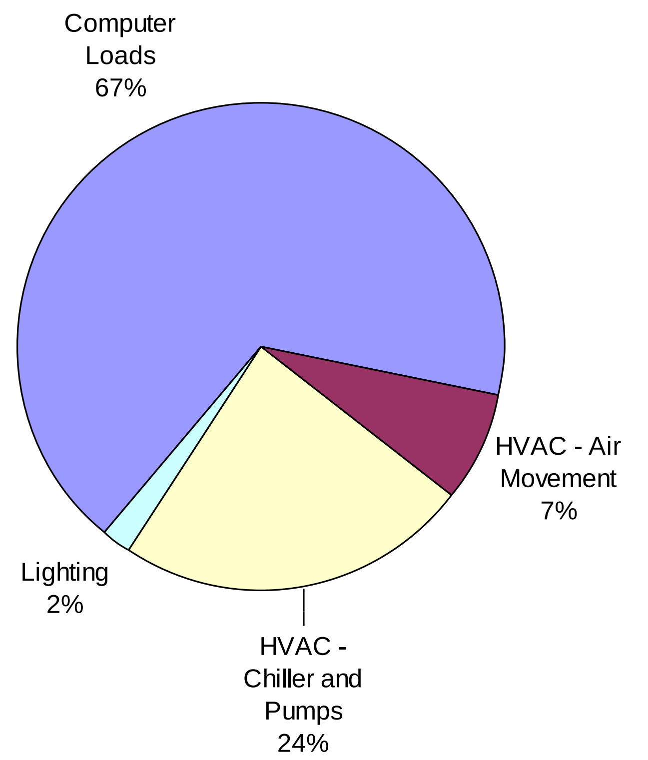
Benchmarking for Energy Performance Improvement:

- Energy benchmarking can allow performance tracking and comparison to peers
- 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

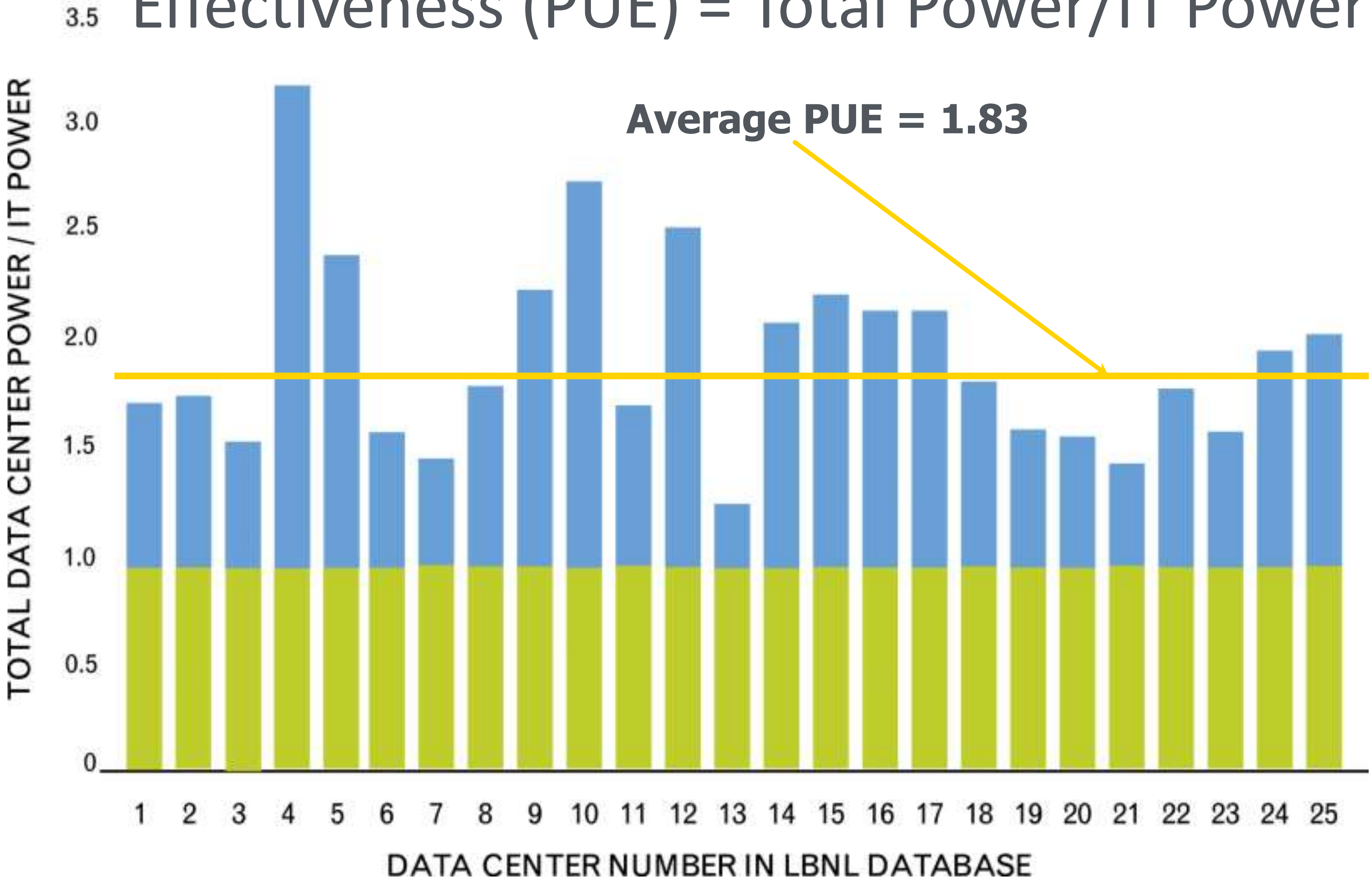
The relative percentages of the energy doing computing varies considerably.





Benchmarks Obtained by LBNL

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



PUEs: Reported & Calculated	PUE
EPA Energy Star Average	1.91
Intel Jones Farm, Hillsboro	1.41
T-Systems & Intel DC2020 Test Lab, Munich	1.24
Google	1.16
Leibniz Supercomputing Centre (LRZ)	1.15
National Center for Atmospheric Research (NCAR)	1.10
Yahoo, Lockport	1.08
Facebook, Prineville	1.07
National Renewable Energy Laboratory (NREL)	**1.06**

Slide Courtesy Mike Patterson, Intel

Energy Metrics and Benchmarking

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

Other Data Center Metrics:

- Watts per square foot, Watts per rack
- Power distribution: UPS efficiency, IT power supply efficiency
- 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)/ITΔT
- Lighting watts/square foot

Metrics & Benchmarking

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

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IT Server Performance - Saving a Watt…

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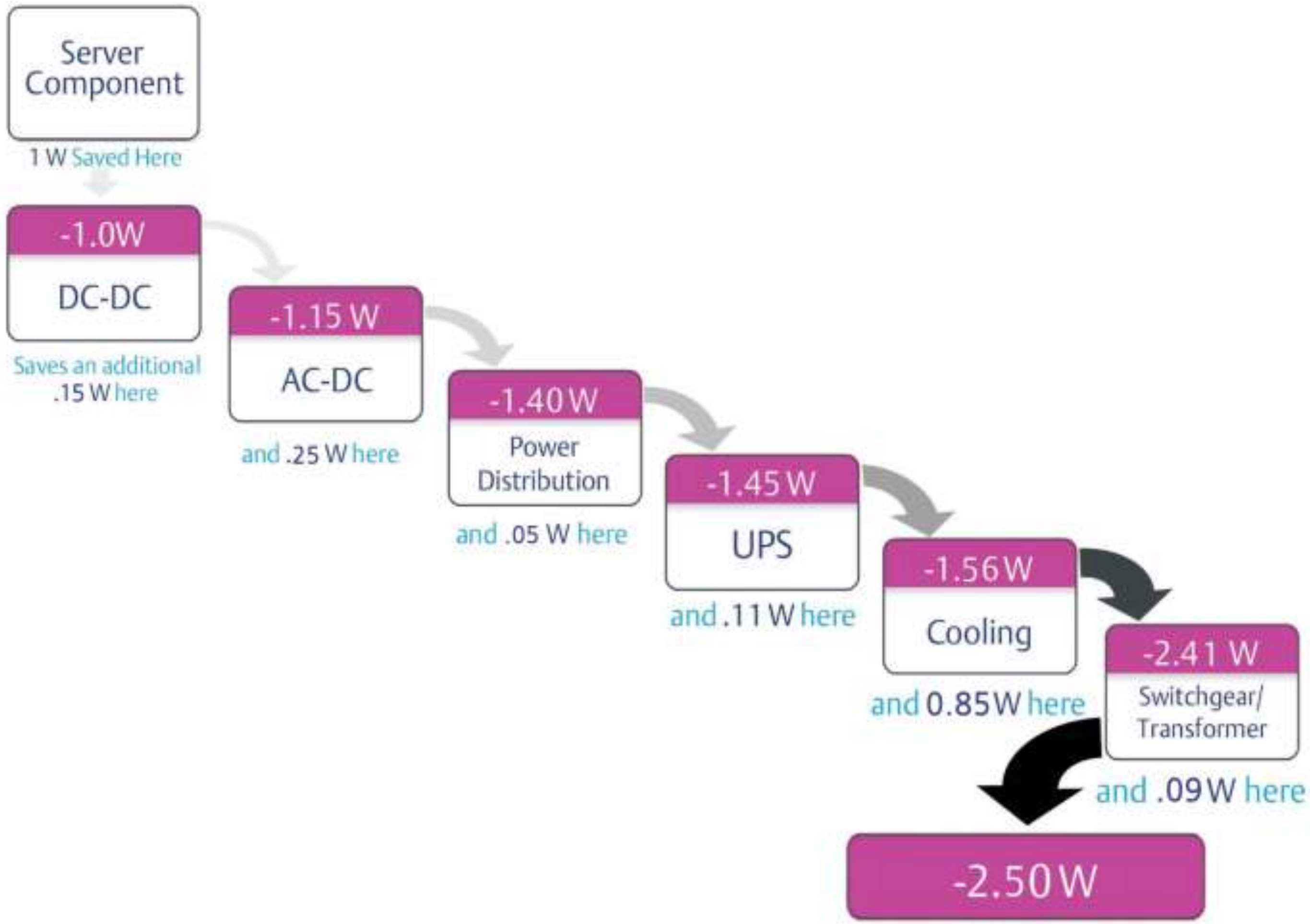
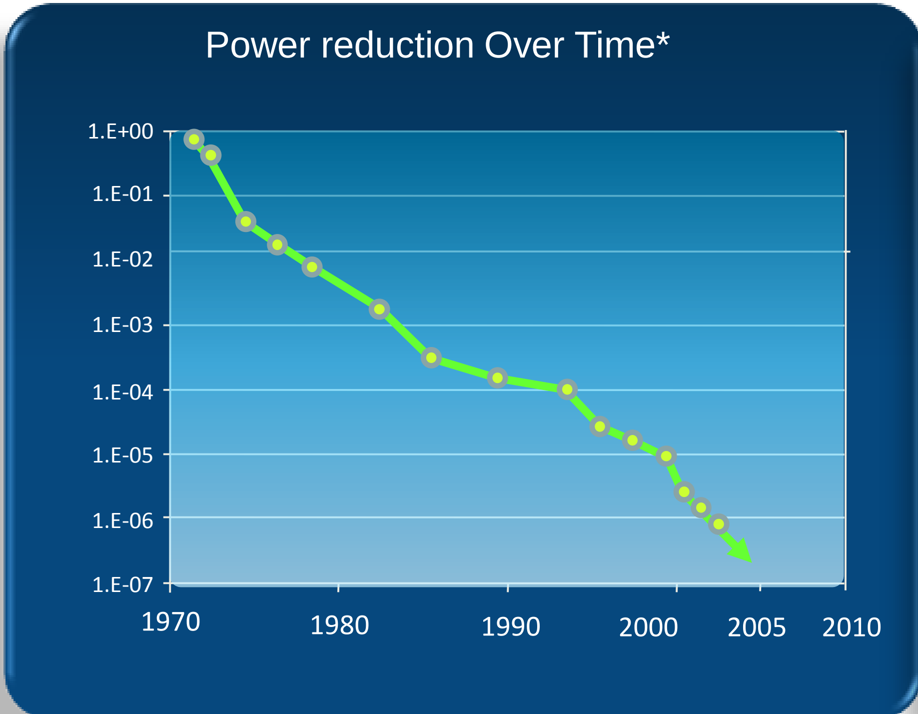
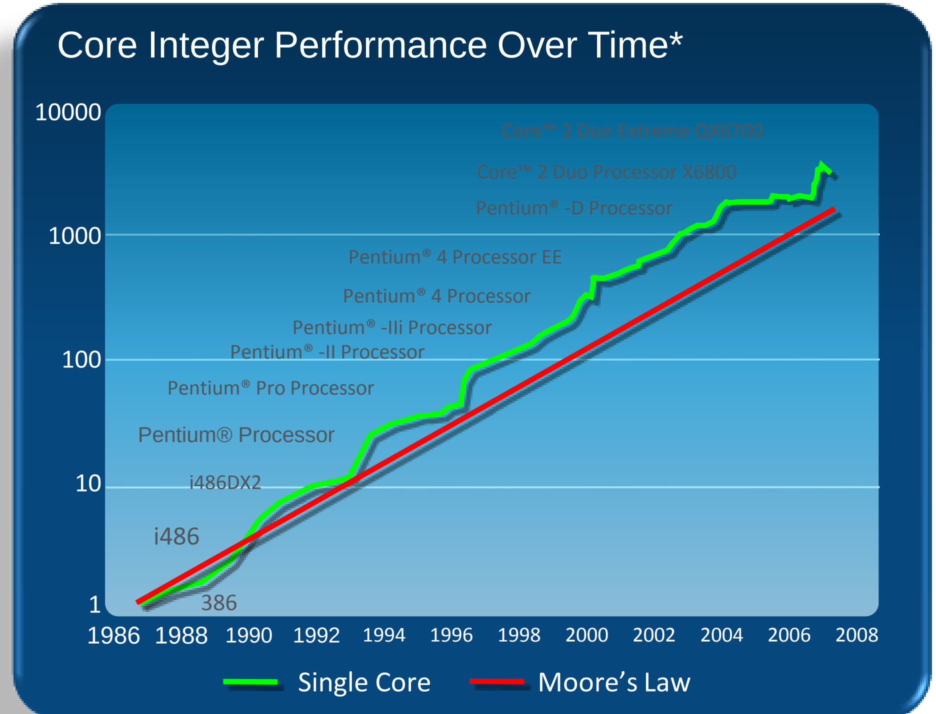
The value of one watt saved at the IT equipment



Moore's Law



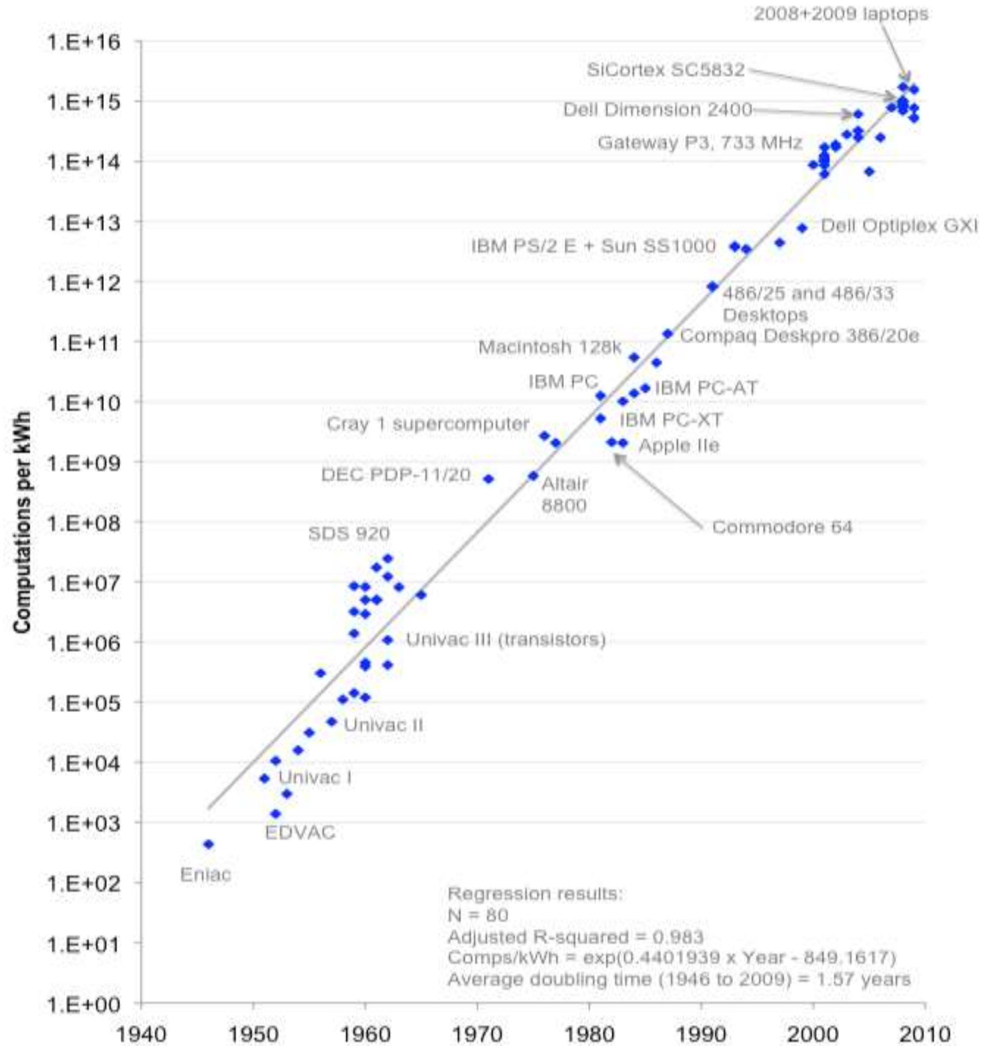


- Every year Moore's Law is followed, smaller, more energy-efficient transistors result
- Miniaturization provides 1 million times reduction in energy/transistor size over 30+ years.
- Benefits: Smaller, faster transistors => faster AND more energy-efficient chips.

Source: Intel Corp.

Source: Intel Corporate Technology Group

Computing Efficiency Increases 100x Every Decade



Source: Koomey et al. 2011

IT Equipment Age and Performance

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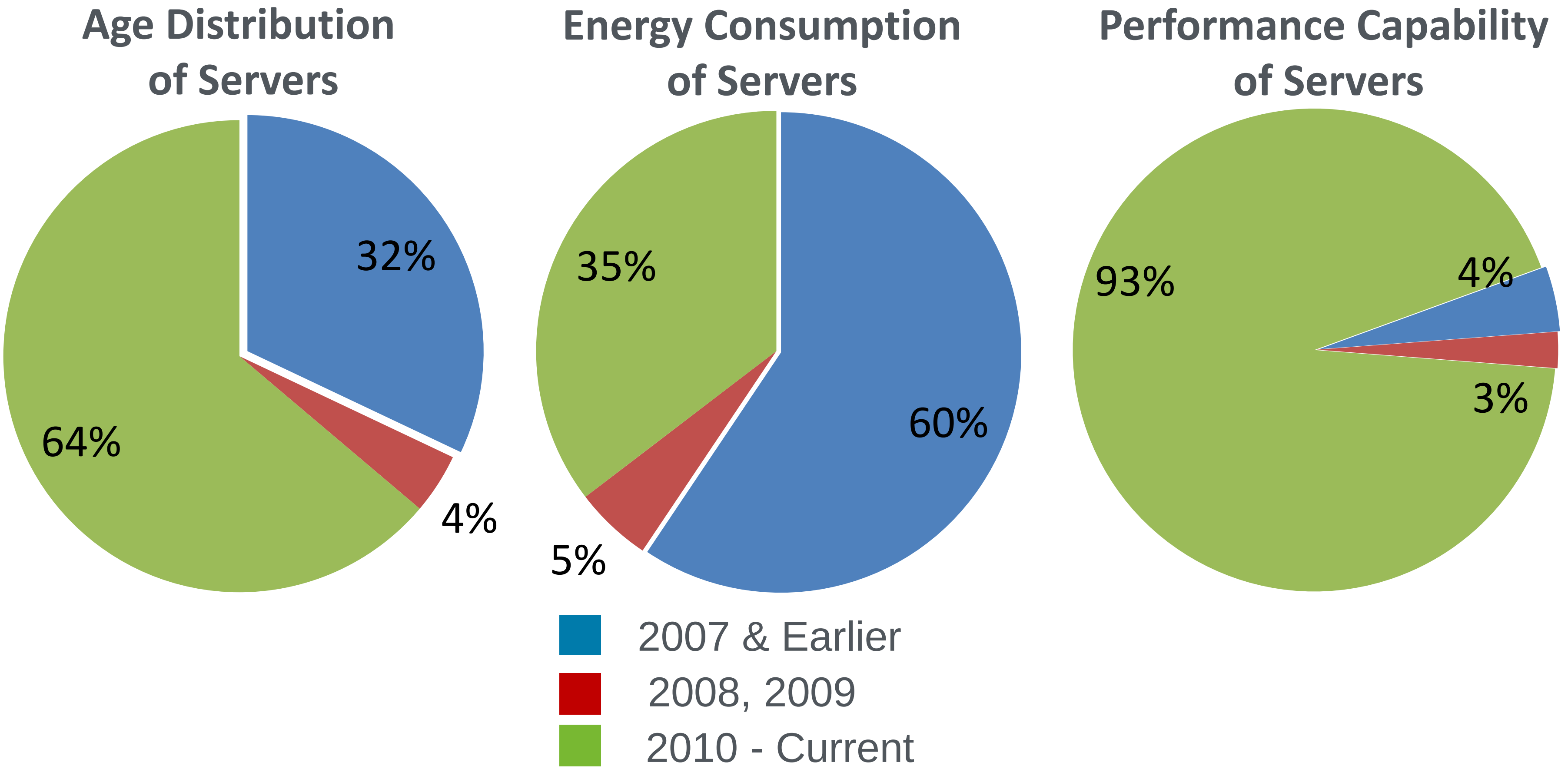


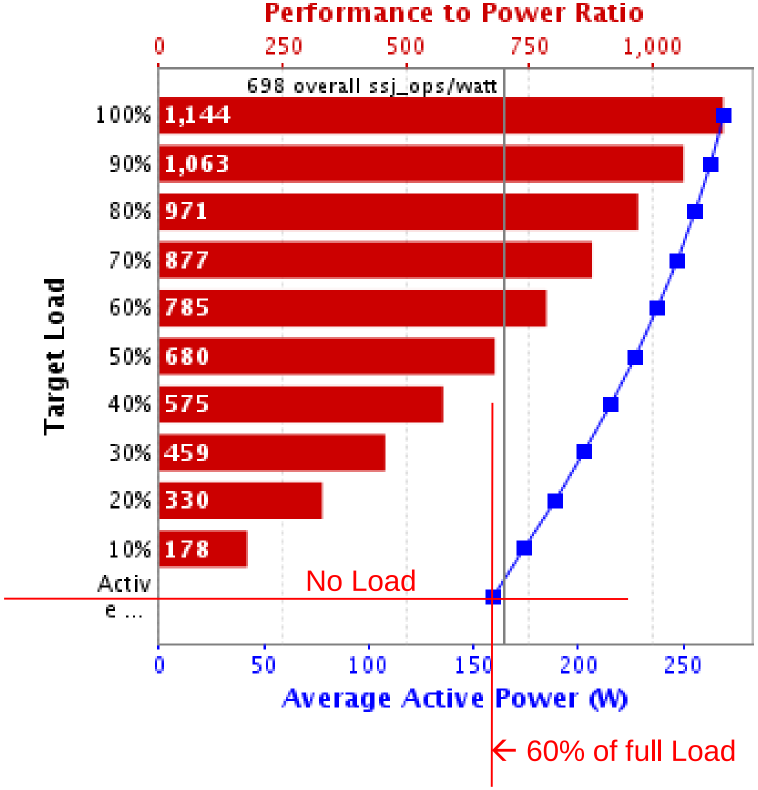
Old Servers consume 60% of Energy, but deliver only 4% of Performance Capability.

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

IT Energy Use Patterns: Servers

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

Performance			Power	
Target Load	Actual Load	ssj_ops	Average Active Power (W)	Performance to Power Ratio
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
Σ ssj_ops / Σ power =				698



Decommission Unused Servers

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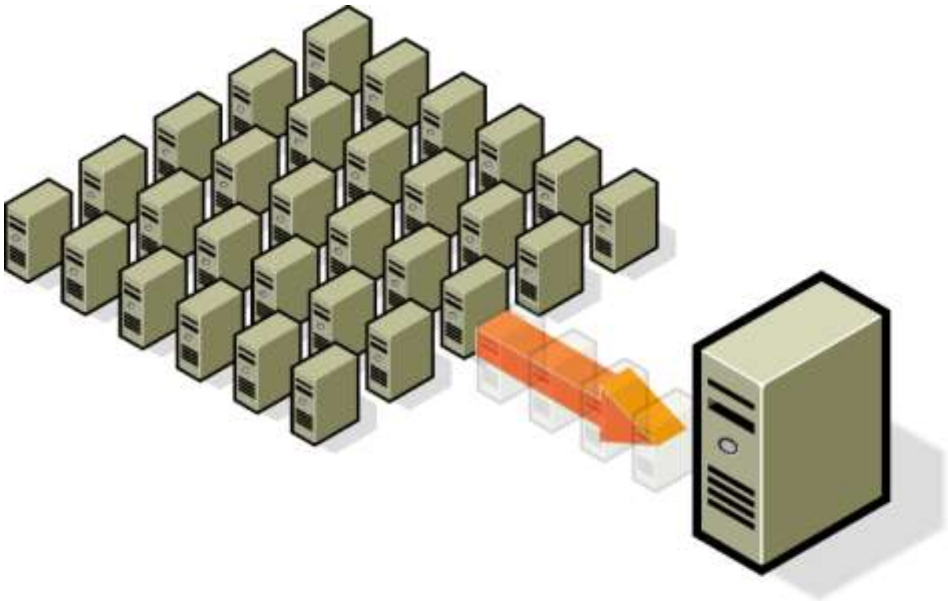
PHYSICALLY RETIRE AN INEFFICIENT OR UNUSED SYSTEM

- **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

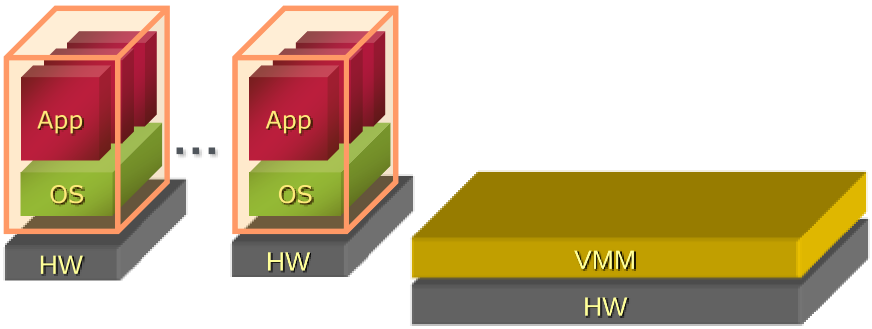
Virtualize and Consolidate Servers and Storage

- Run many "virtual" machines on a single "physical" machine
- Consolidate underutilized physical machines, increasing utilization
- Energy saved by shutting down underutilized machines

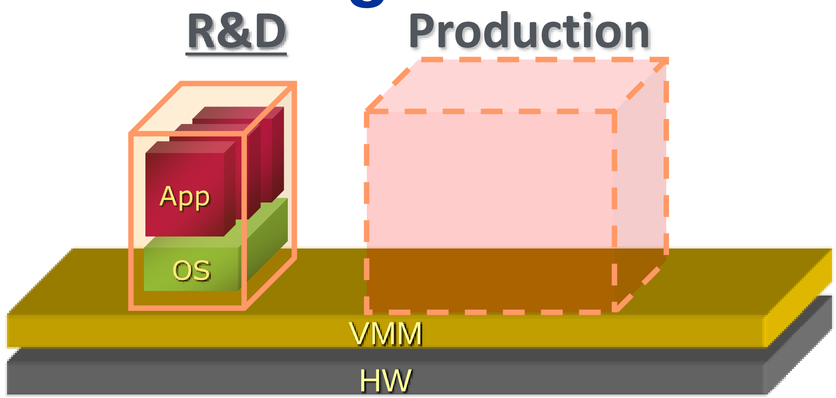


Virtualization: Workload provisioning

Server Consolidation

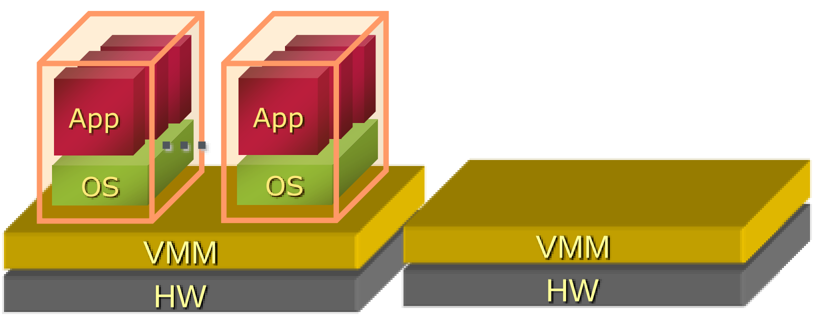


10:1 in many cases



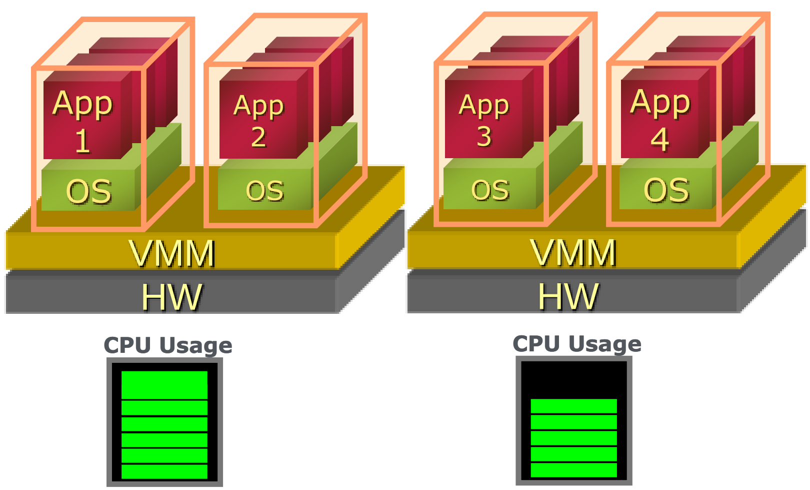
Enables rapid deployment,
reducing number of idle, staged servers

Disaster Recovery



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

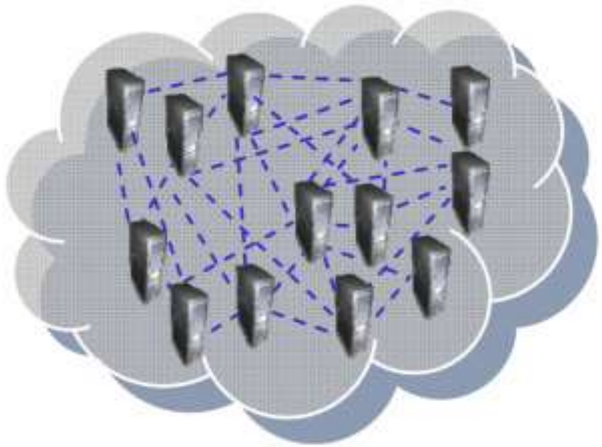
Dynamic Load Balancing



Balancing utilization with head room

Vertualized cloud computing can provide…

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



Storage Systems and Energy

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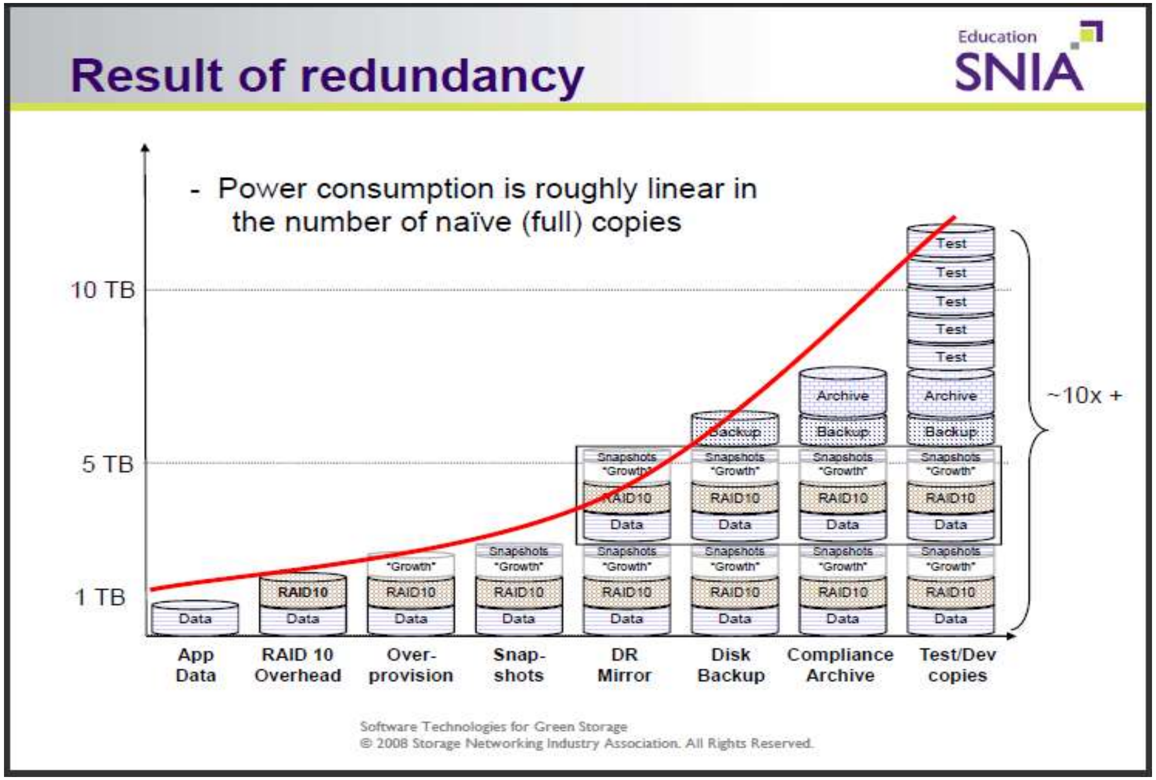
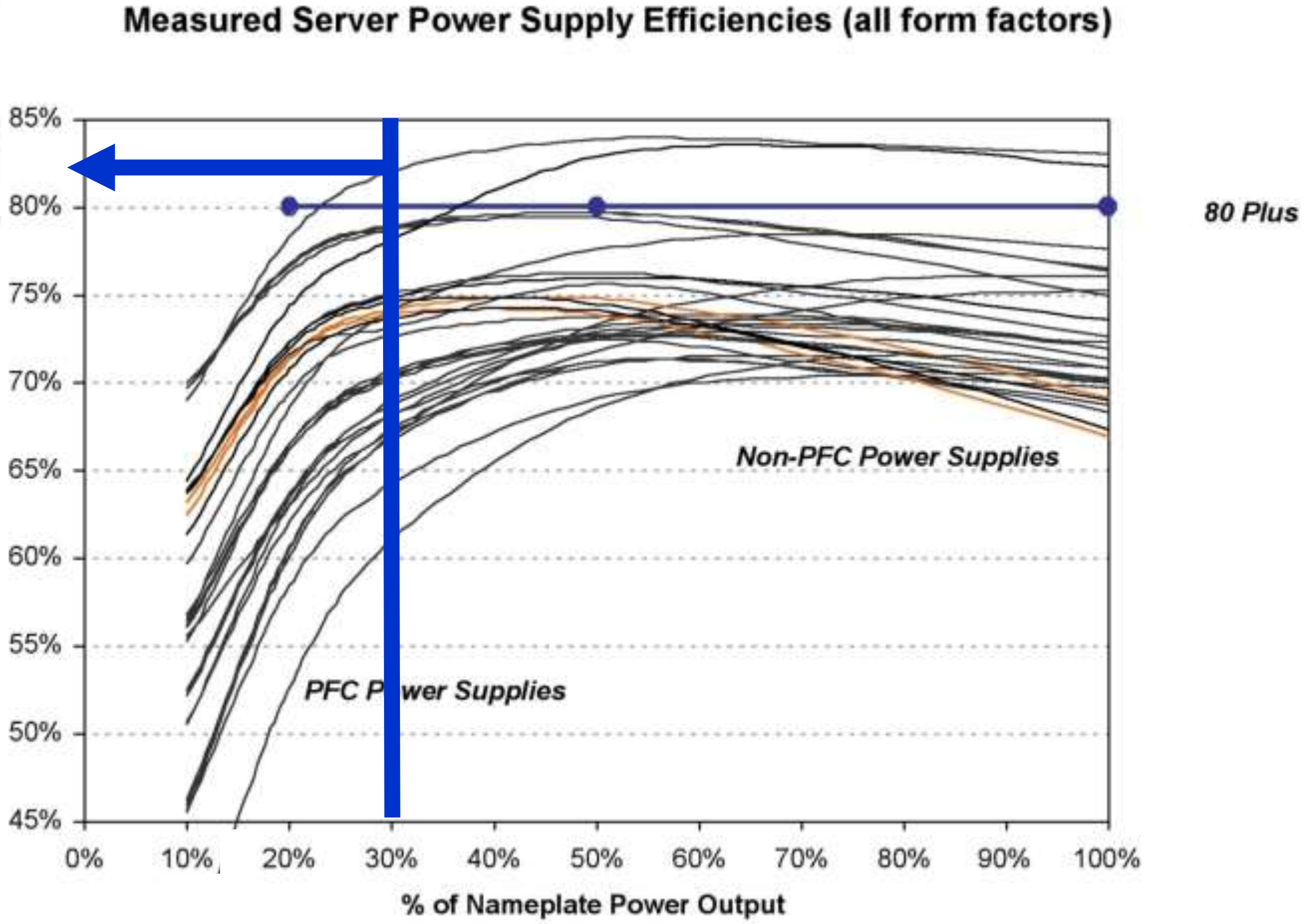
- Power roughly linear to storage modules
- Storage redundancy significantly increases energy
- Consider lower energy hierarchal storage
- Storage De-duplication - Eliminate unnecessary copies

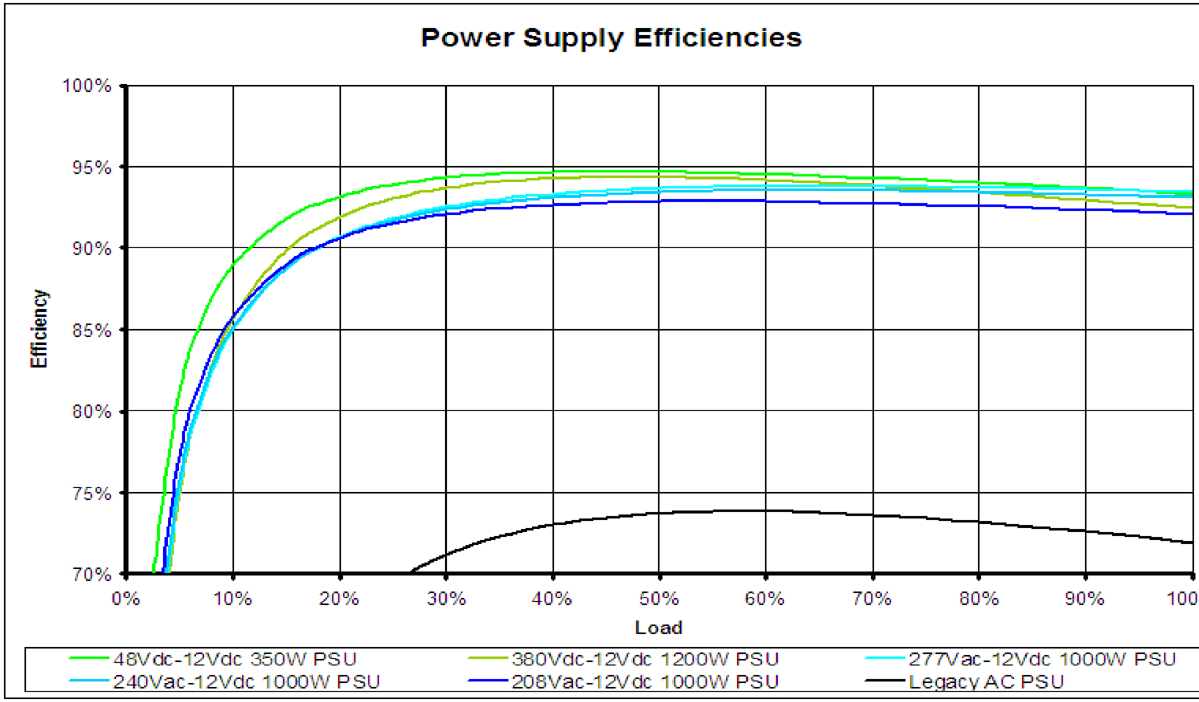


LBNL/EPRI measured power supply efficiency



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

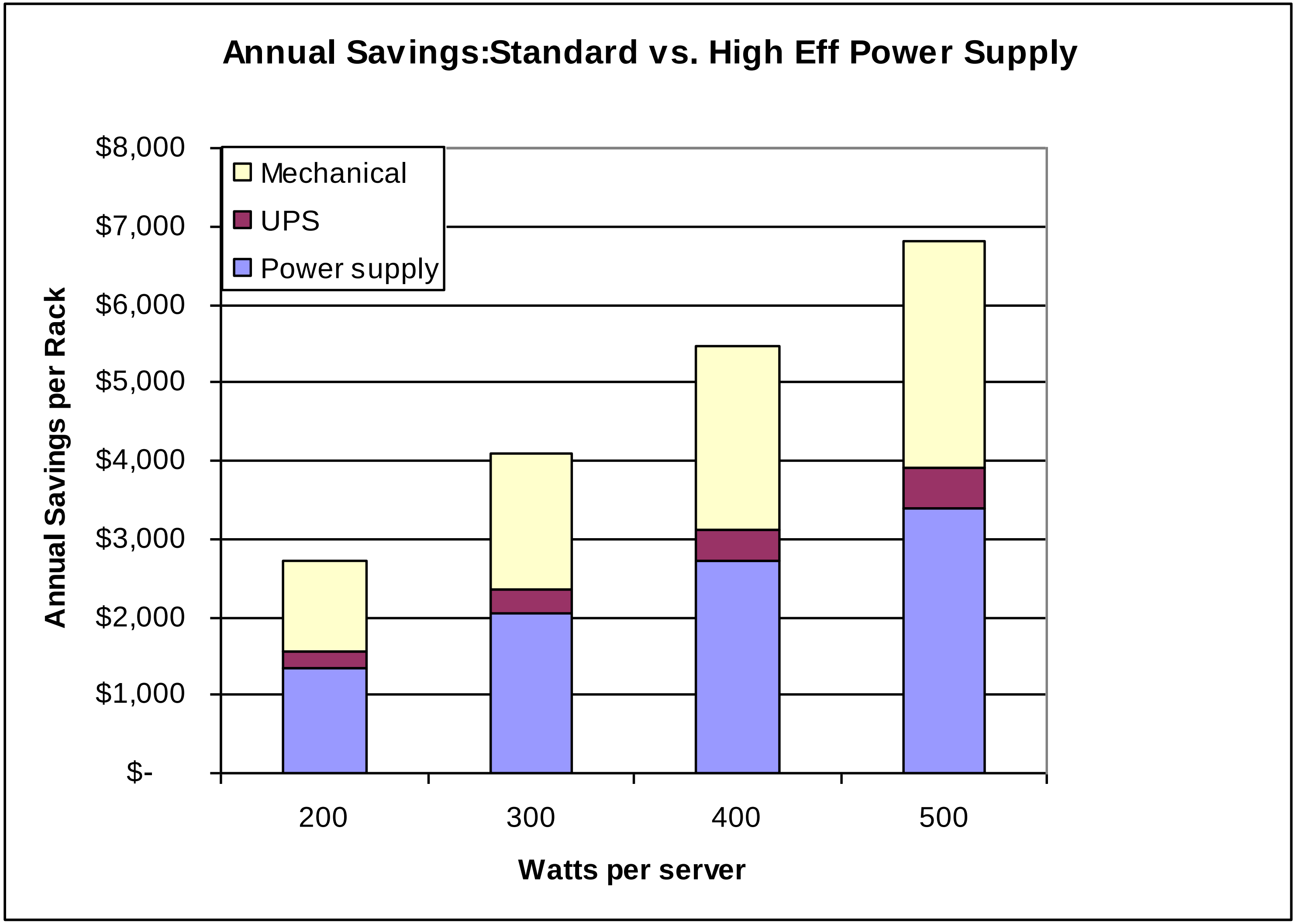


Source: The Green Grid

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…

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Servers

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

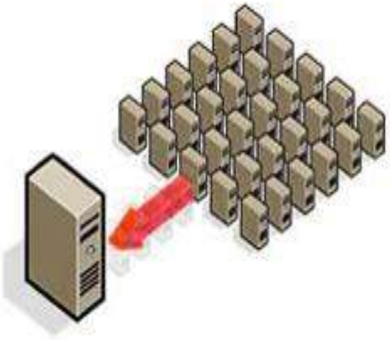
Power Supplies

- Reconsider Redundancy
- Use 80 PLUS or Climate Savers products

Storage Devices

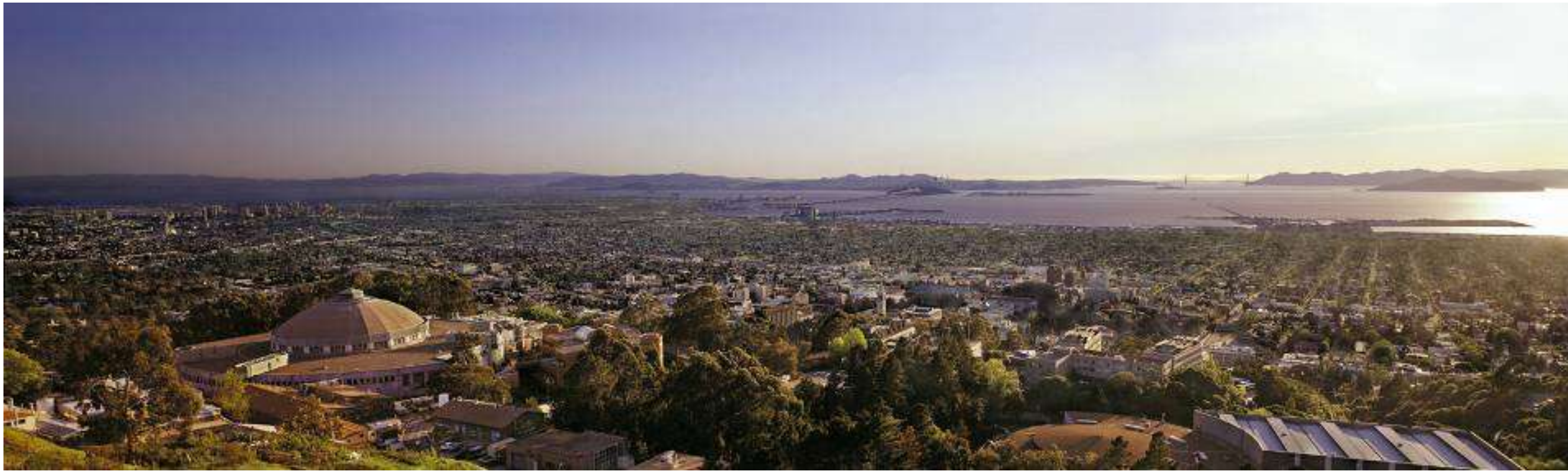
- Take superfluous data offline
- Use thin provisioning technology
- De-duplicate

Consolidation



- Use virtualization
- Consider cloud services

Questions?



Environmental Conditions

Magnus Herrlin, Principal, ANCIS Incorporated

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Main HVAC Energy Drivers

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- IT Load (up to 50,000+W per rack)
- Outdoor climate
- Air management (enables savings)
- **Environmental conditions**

  (room temperature and humidity).

Air IntakeTemperature

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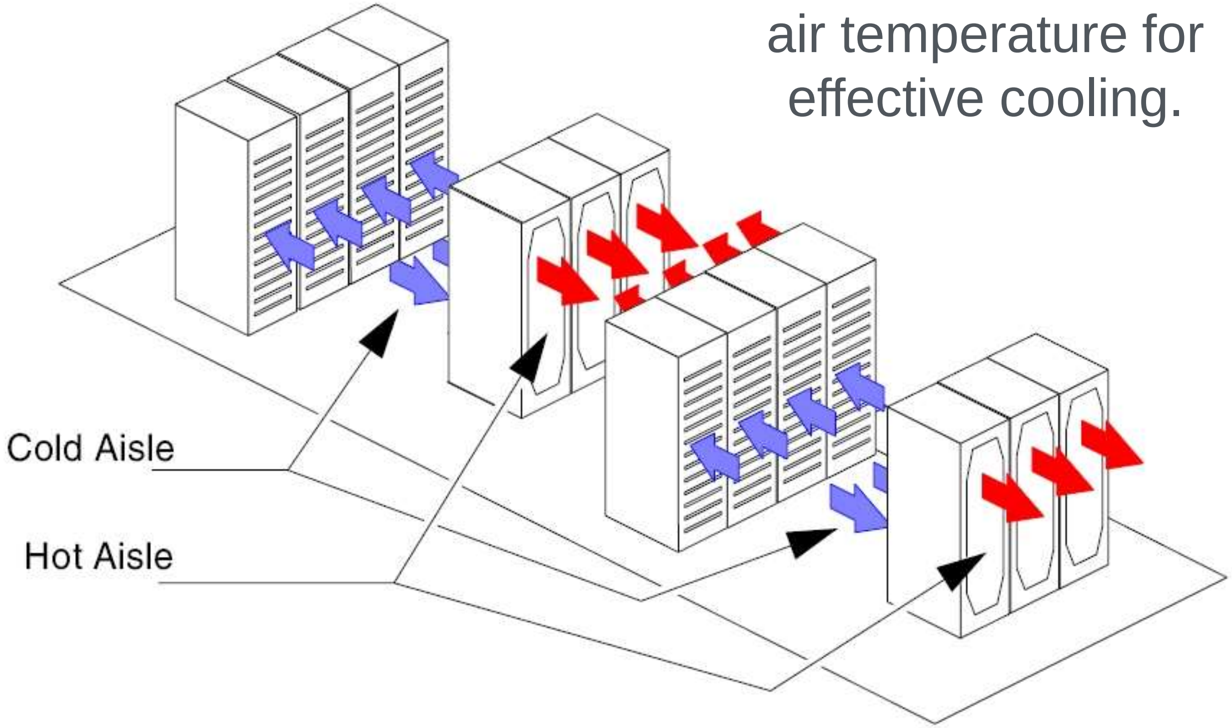

Air-cooled electronic equipment depends exclusively on the <u>intake</u> air temperature for effective cooling.

Key Nomenclature

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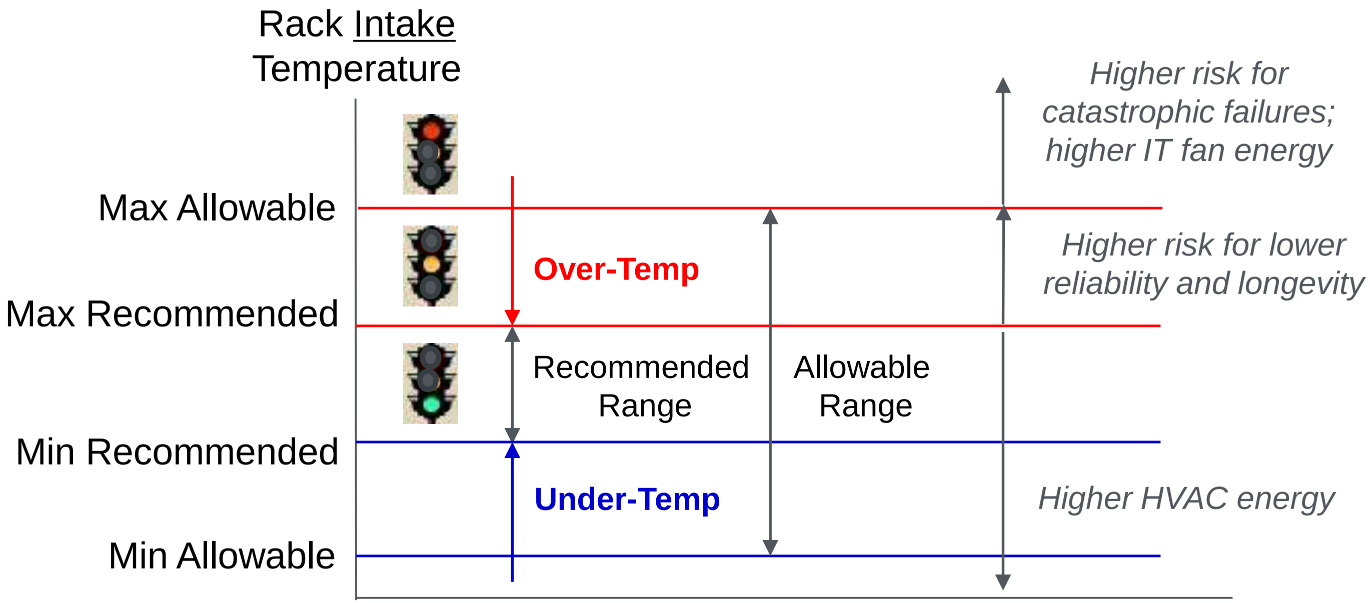
- The recommended range is a statement of reliability. For extended periods of time, the IT manufacturers recommend that data centers maintain their environment within these boundaries.

- 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.



Energy vs. IT-Reliability

- The purpose of the allowable and recommended ranges is to give guidance to data center operators on maintaining high reliability but yet operate their data centers in an energy efficient manner.

- Ultimately, energy vs. IT-reliability in data centers is an optimization problem.

NEBS (telecom)

Facility Operation

Equipment Design

NEBS is the de-facto standard for telecom equipment and facilities

ASHRAE Thermal Guidelines

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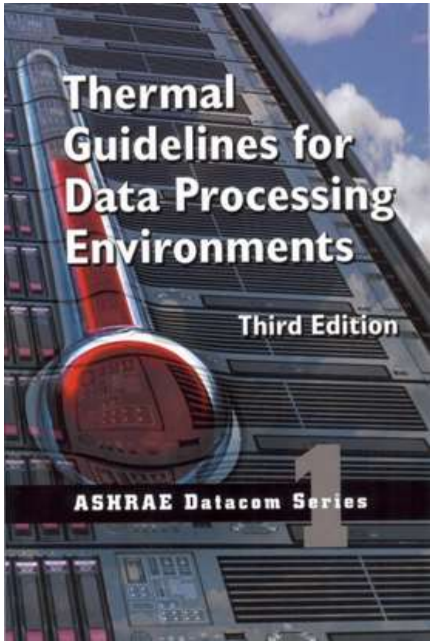
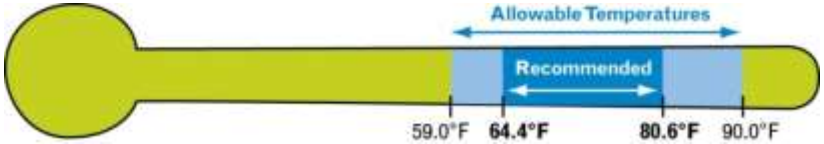
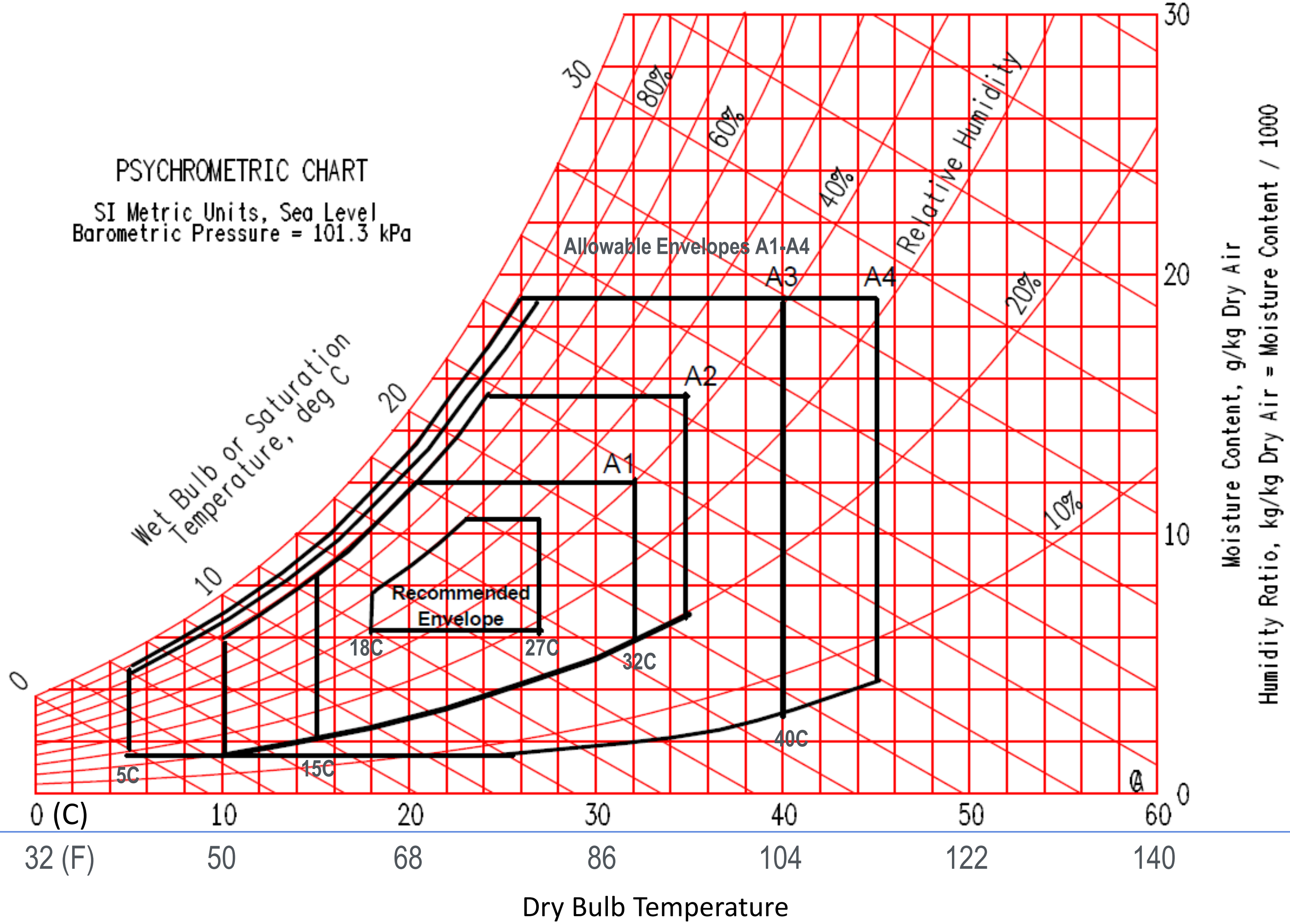


- Default recommended range = 64.4 - 80.6F
- Provides guidance for operating above the default upper limit

- Default allowable range = 59.0 – 89.6F (Class A1)
- Six classes with allowable ranges up to 113.0F



ASHRAE "Envelopes"



ASHRAE Failure Rates (not incl. Delta-T, RH, particles)

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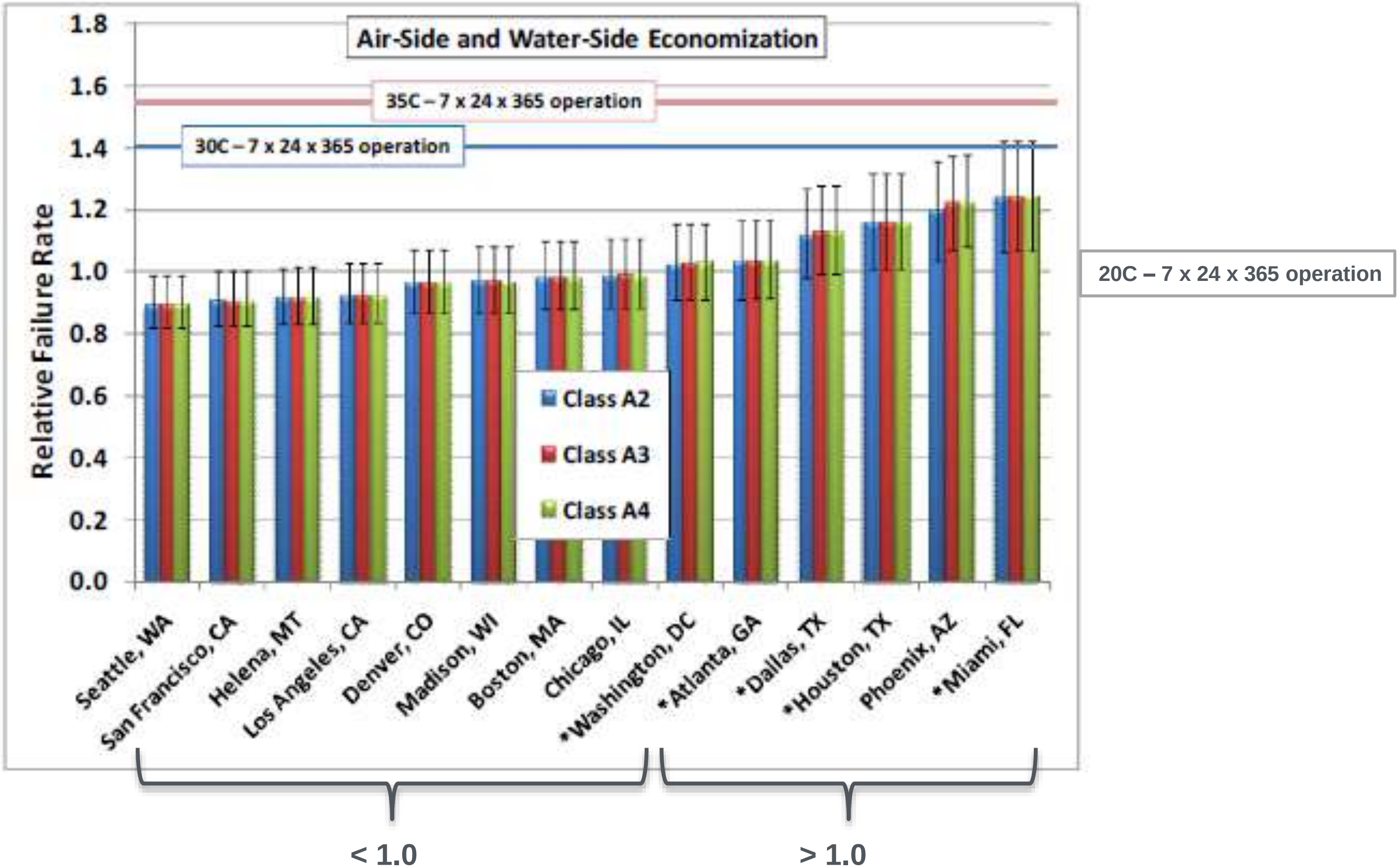

1. Data center temperature tracks with the outdoor temperature
2. A minimum of 15C – 20C can be maintained (heat from equipment)
3. A maximum below the maximum of the environmental class (mechanical cooling).

ASHRAE Failure Rates (not incl. Delta-T, RH, particles)

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"For the majority of U.S. 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 20ºC (68ºF)."

ASHRAE

ASHRAE Liquid-Cooled IT-Equipment Classes

Liquid Cooling Class	Main Cooling Equipment	Supplemental Cooling Equipment	Facility Supply-Water Max Temperature
W1	Chiller/ Cooling Tower	Water-Side Economizer	17C (63F)
W3	Cooling Tower	Chiller	32C (90F)
W4	Water-Side Economizer	N/A	45C (113F)

These Maximum Temperatures are requirements to be met by the liquid-cooled IT equipment.

Summary

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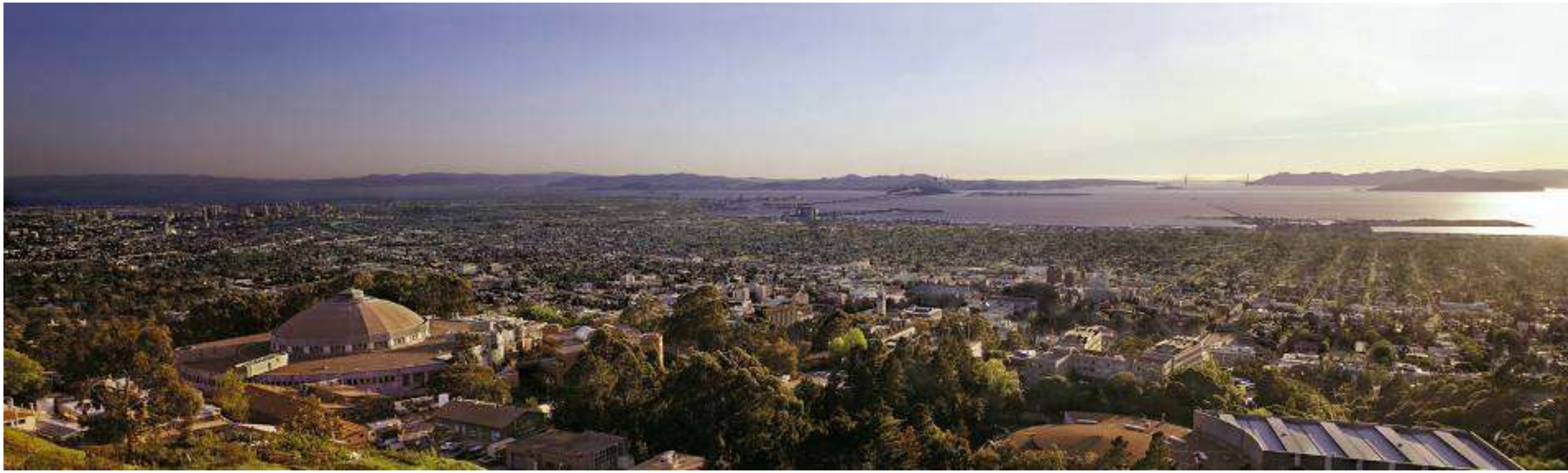
- ASHRAE and NEBS provide guidance on temperature and humidity. Legacy gear may require more benign conditions
- For each update, ASHRAE provides more flexibility and more aggressive guidance and is now closing in on NEBS
- Many IT manufacturers design for harsher conditions than ASHRAE “default” Class A1. There is already A3 and A4 rated equipment
- Economizer projections show failure rates that are very comparable to traditional data centers with a constant temperature of 68ºF
- A cold data center = efficiency opportunity! However, address inadequate air management before increasing the temperature
- Energy vs. IT-reliability in data centers is an optimization problem.

Questions?



Airflow Management

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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

Air Management

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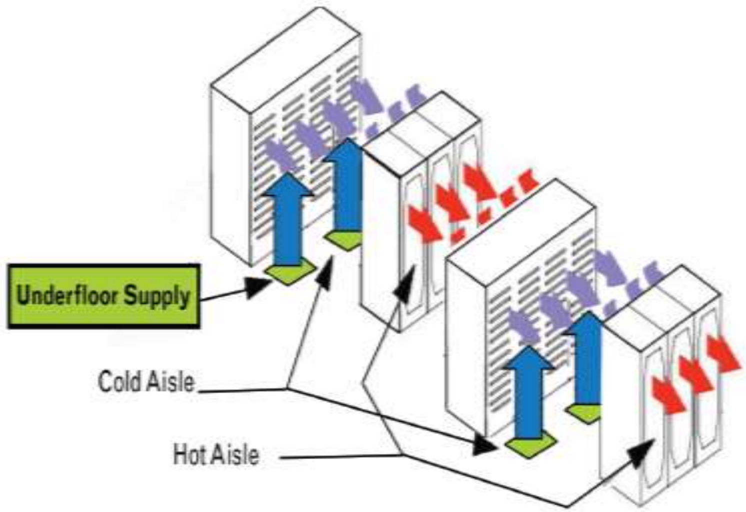
- Typically, more air circulated than required
- Air mixing and short circuiting leads to:
  - Low supply temperature
  - Low Delta T
- Use hot and cold aisles
- Improve isolation of hot and cold aisles
  - Reduce fan energy
  - Improve air-conditioning efficiency
  - Increase cooling capacity



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

Benefits of Hot- and Cold-aisles

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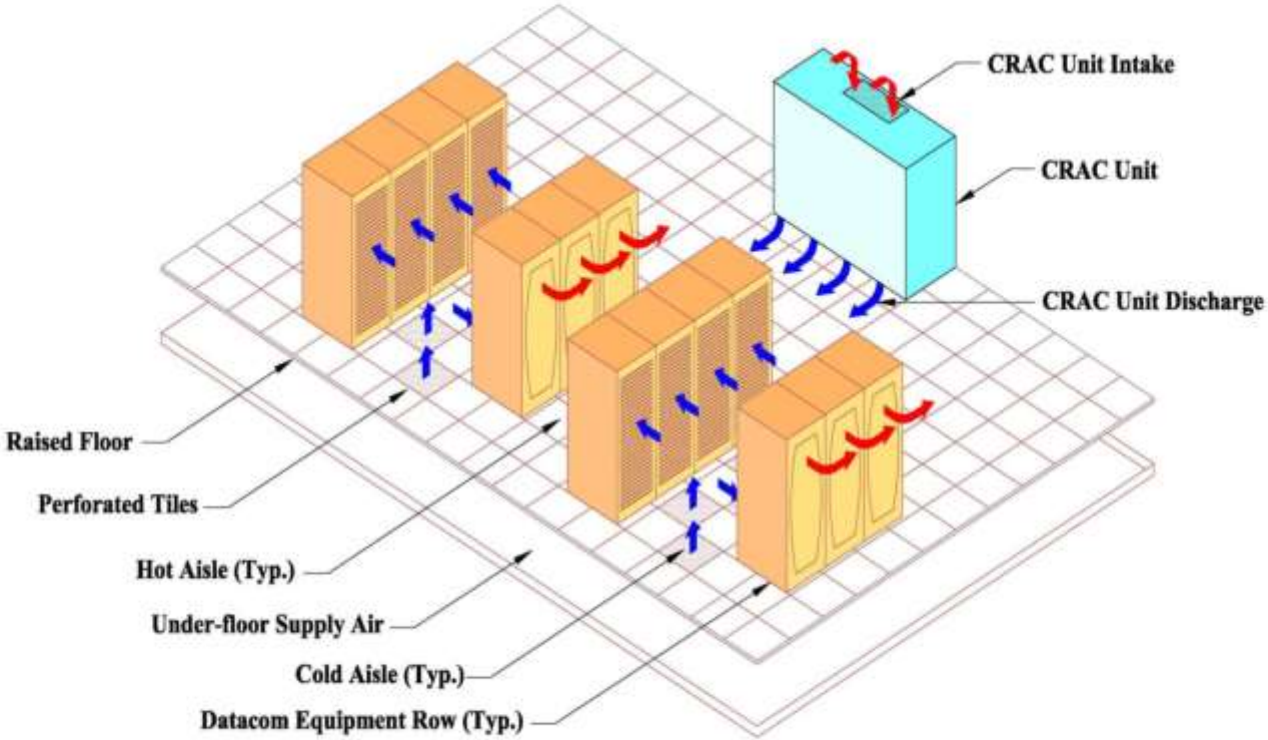
➢ **Improves equipment intake air conditions by separating cold from hot airflow.**

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…

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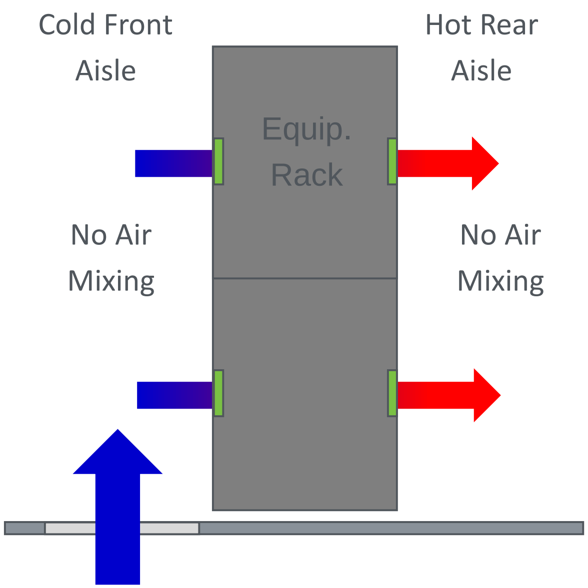
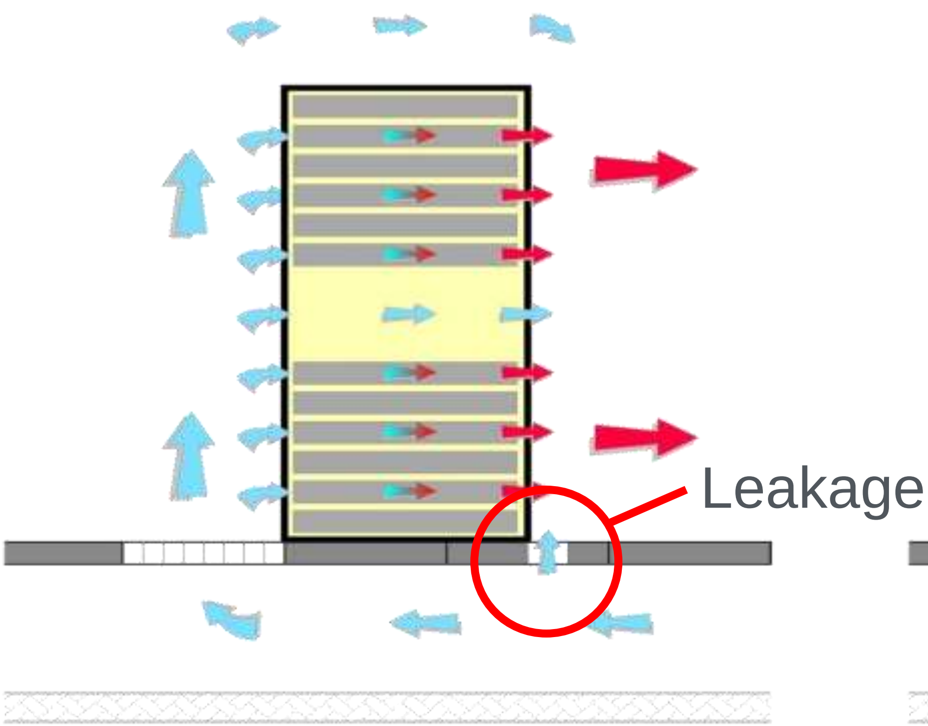
- Supply cold air as close to rack inlet as possible.
- Reduce mixing with ambient air and hot rack exhaust
- Flow air from the cold front aisle to the rear hot aisle



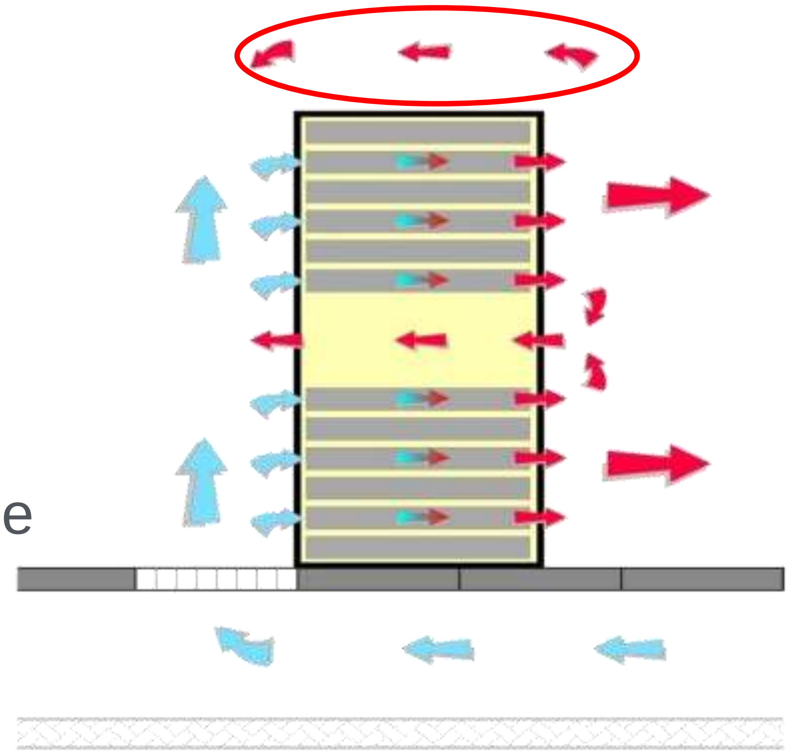
Reduce Bypass and Recirculation

Bypass Air / Short-Circuiting…



Wastes cooling capacity.

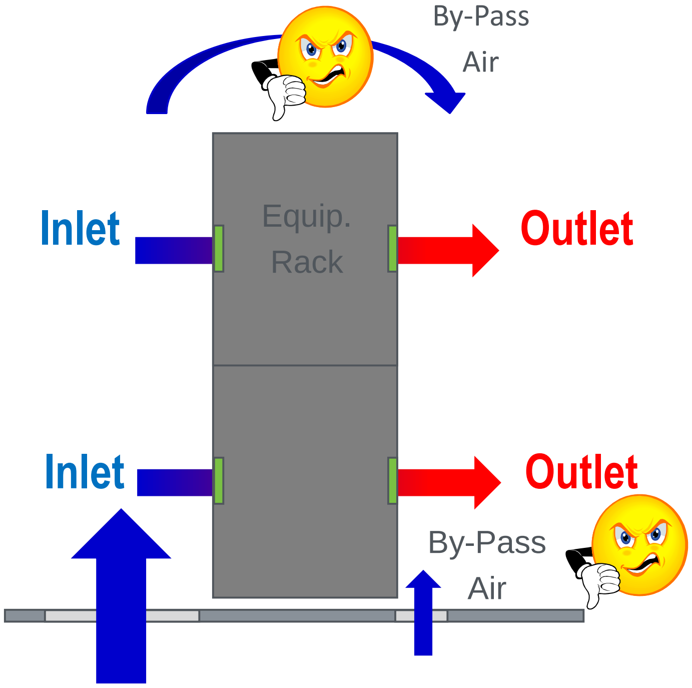
Recirculation…



Increases inlet temperature to servers.

Some common causes:

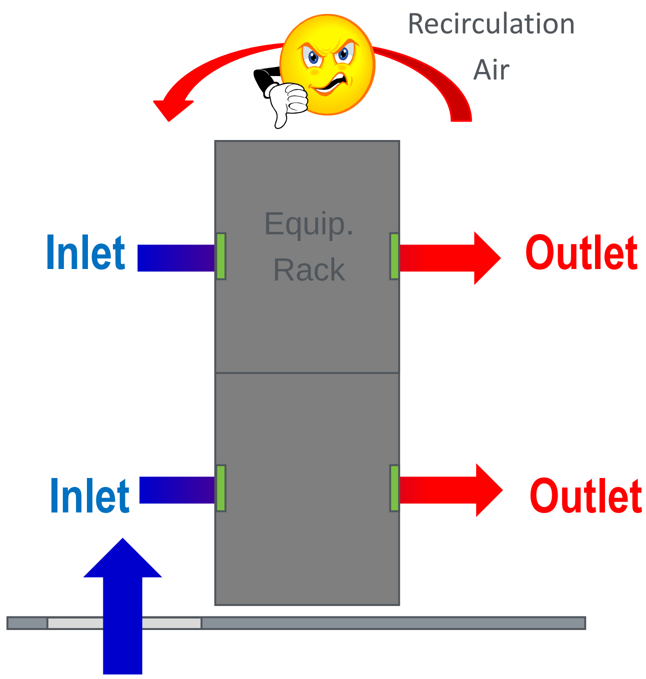
- Too much supply airflow
- Misplaced perforated tiles
- Leaky cable penetrations
- Too high tile exit velocity



Recirculation Air

Some common causes:

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



Maintain Raised-Floor Seals

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

Unsealed cable penetration

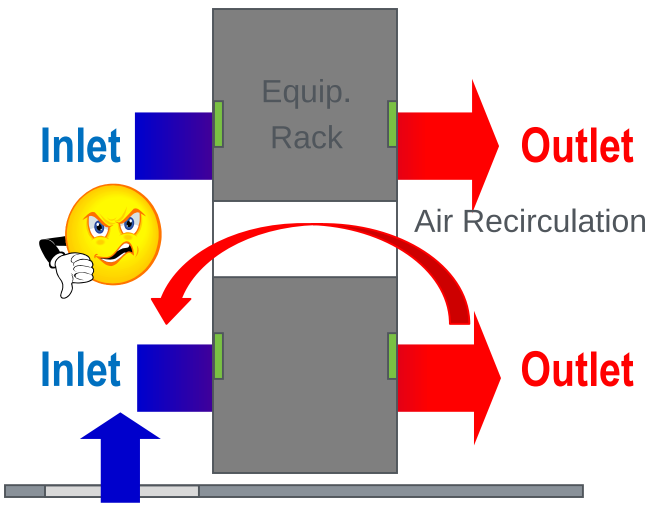
Sealed cable penetration

Manage Blanking Panels

Any opening will degrade the separation of hot and cold air

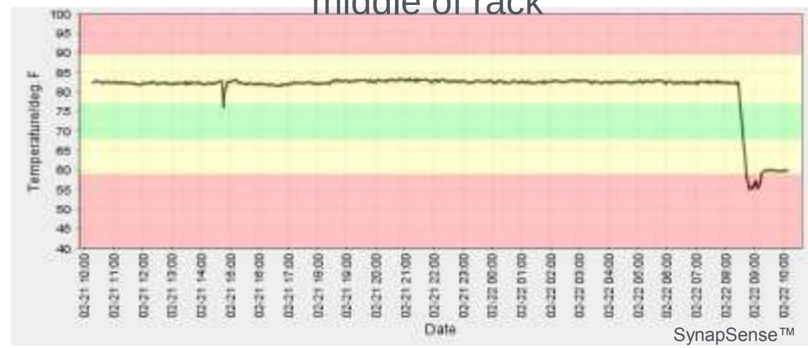
- ➢ maintain server blanking and side panels.

One 12” blanking panel added
Temperature dropped ~20°



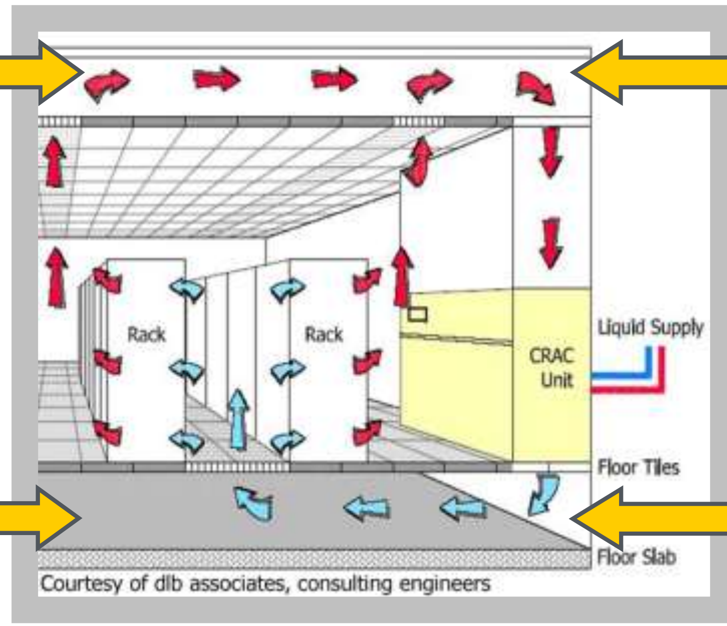
top of rack

middle of rack



Reduce Airflow Restrictions & Congestion

Congested Floor & Ceiling Cavities



Consider The Impact That Congestion Has On The Airflow Patterns

Empty Floor & Ceiling Cavities

Reduce Cable Congestion

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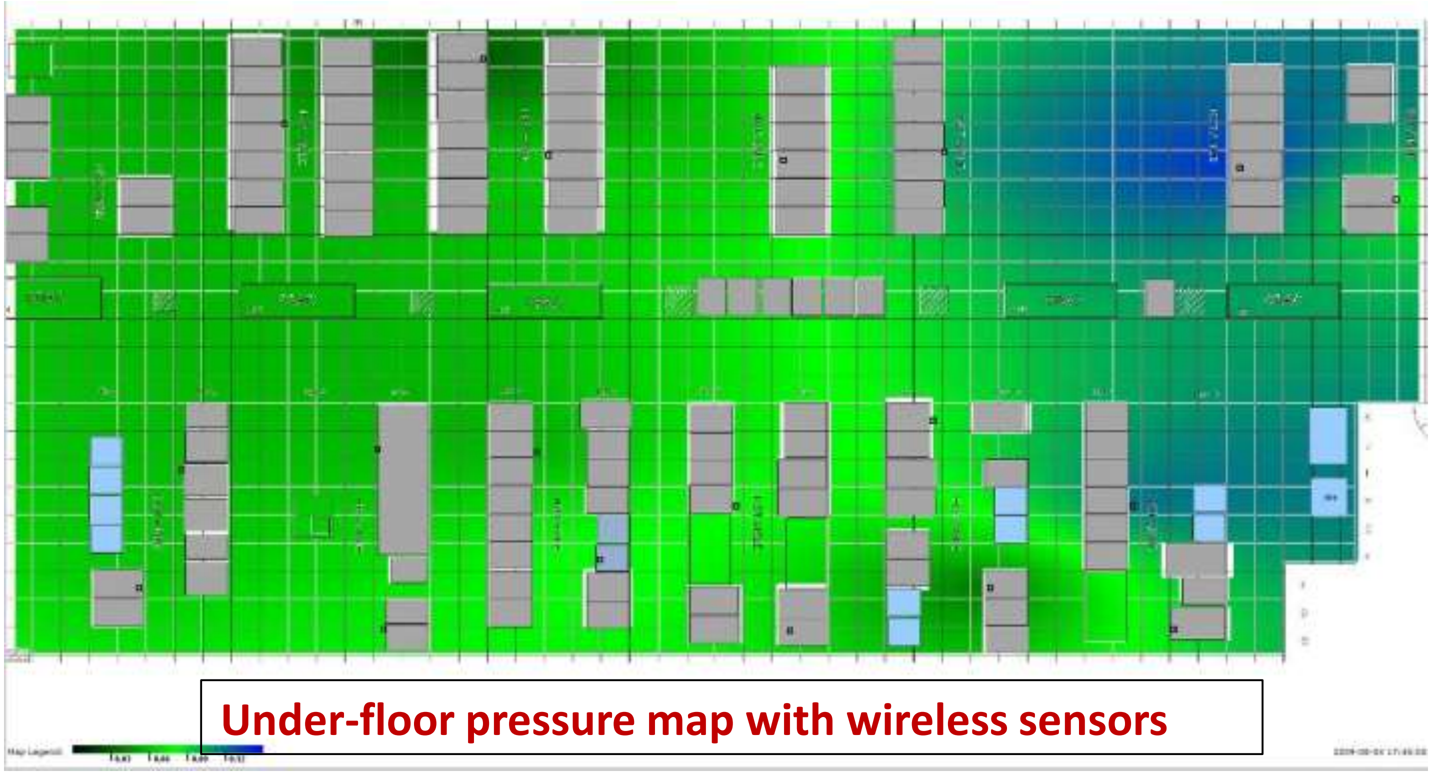
- Cable congestion sharply reduces airflow and degrades airflow distribution.
- No cable trays should be placed below perforated tiles.

➢ 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

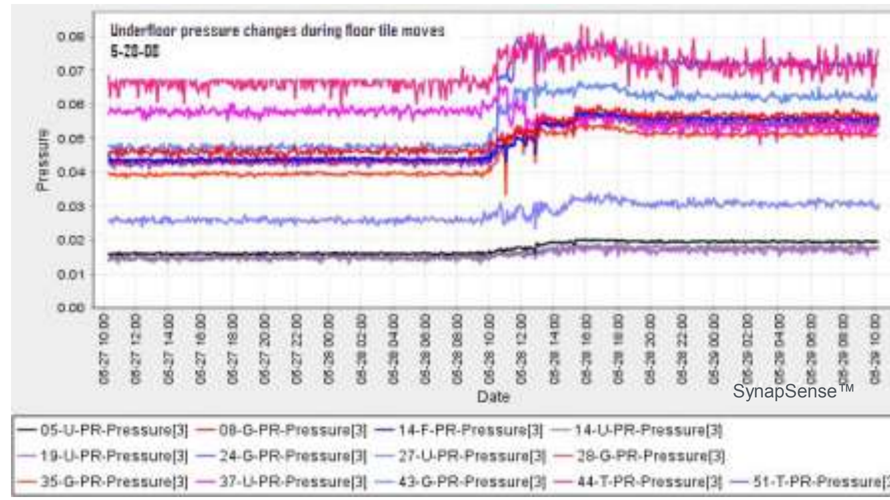


Under-floor pressure map with wireless sensors

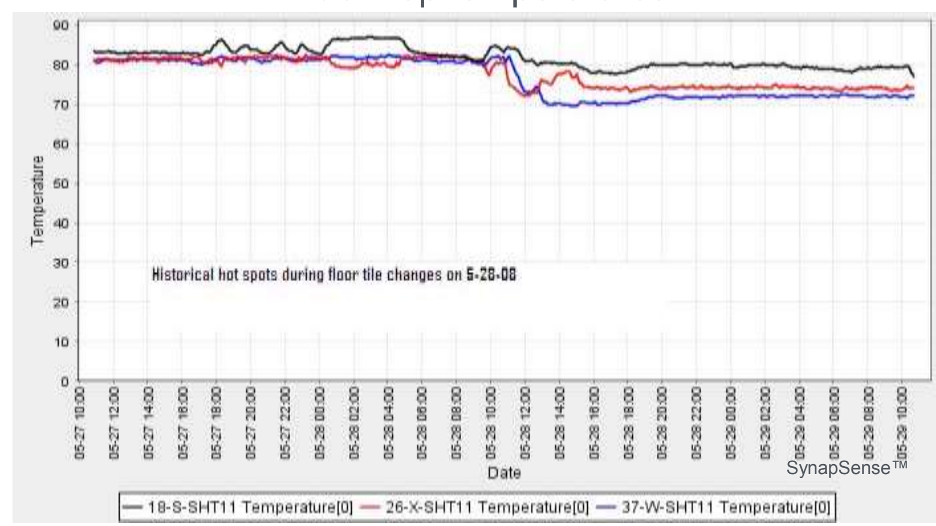
Results: Tune Floor Tiles

- 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



Optimally Locate CRAC/CRAHs

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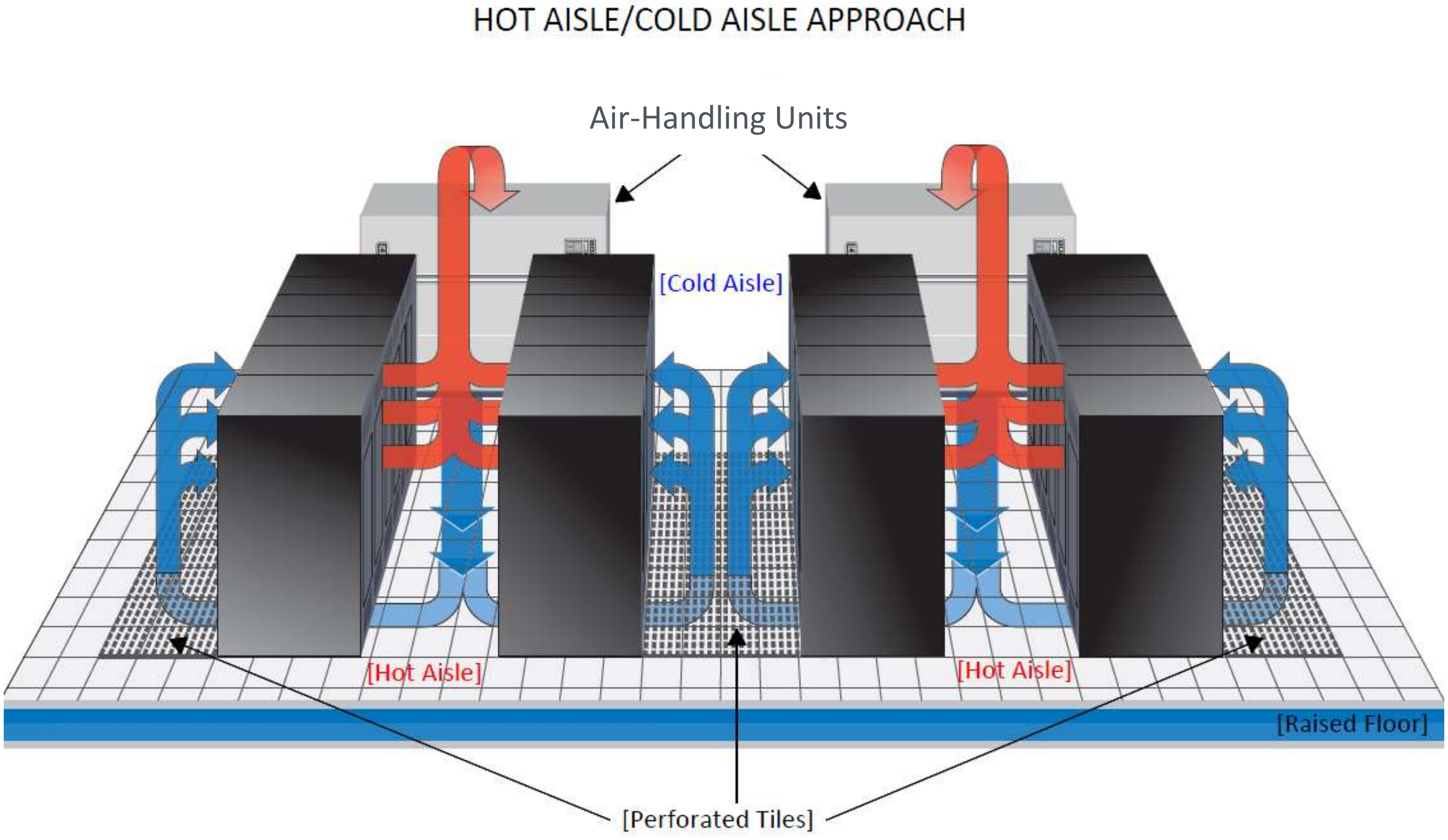
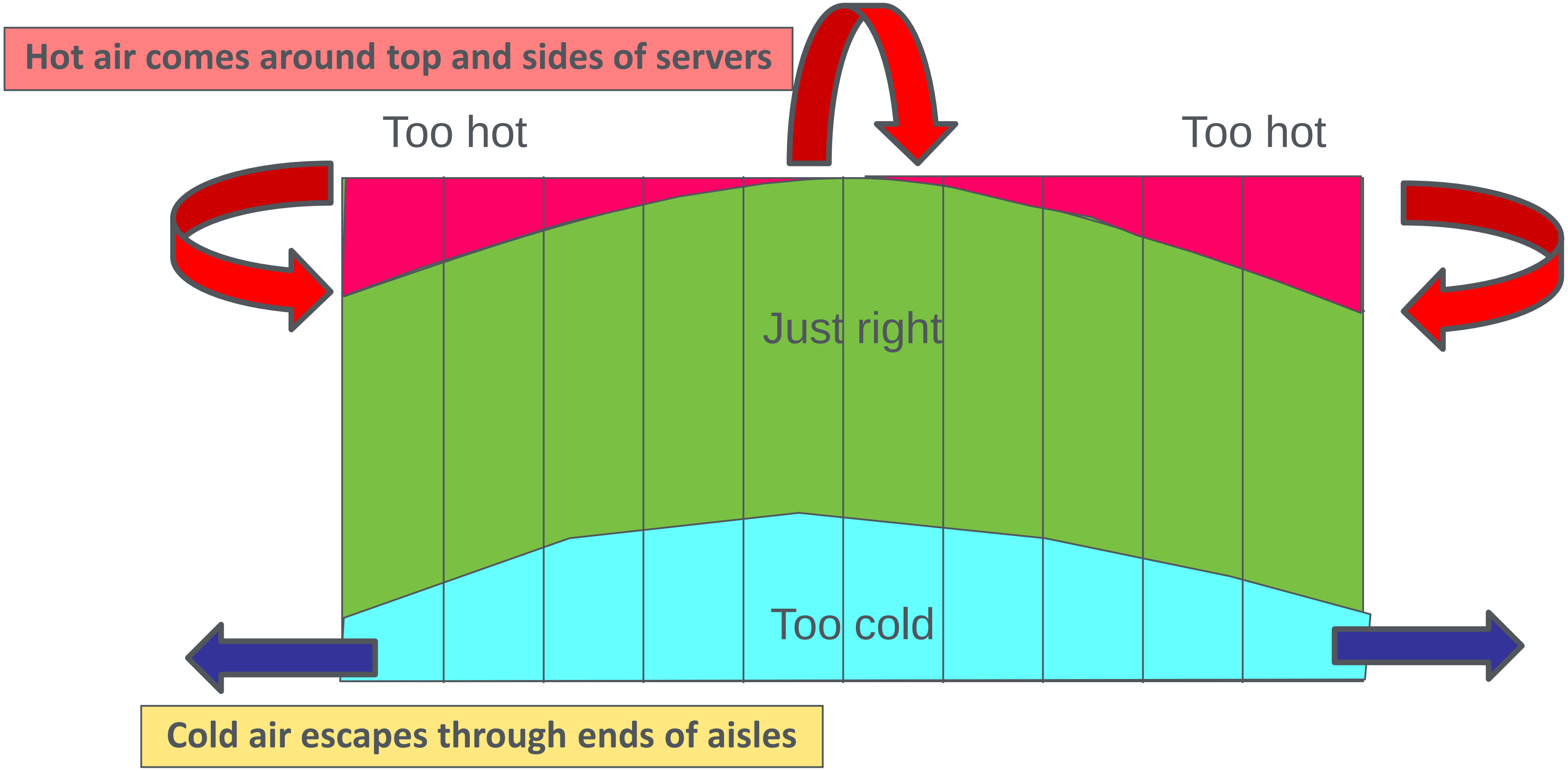
Locate CRAC/CRAH units at ends of Hot Aisles



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

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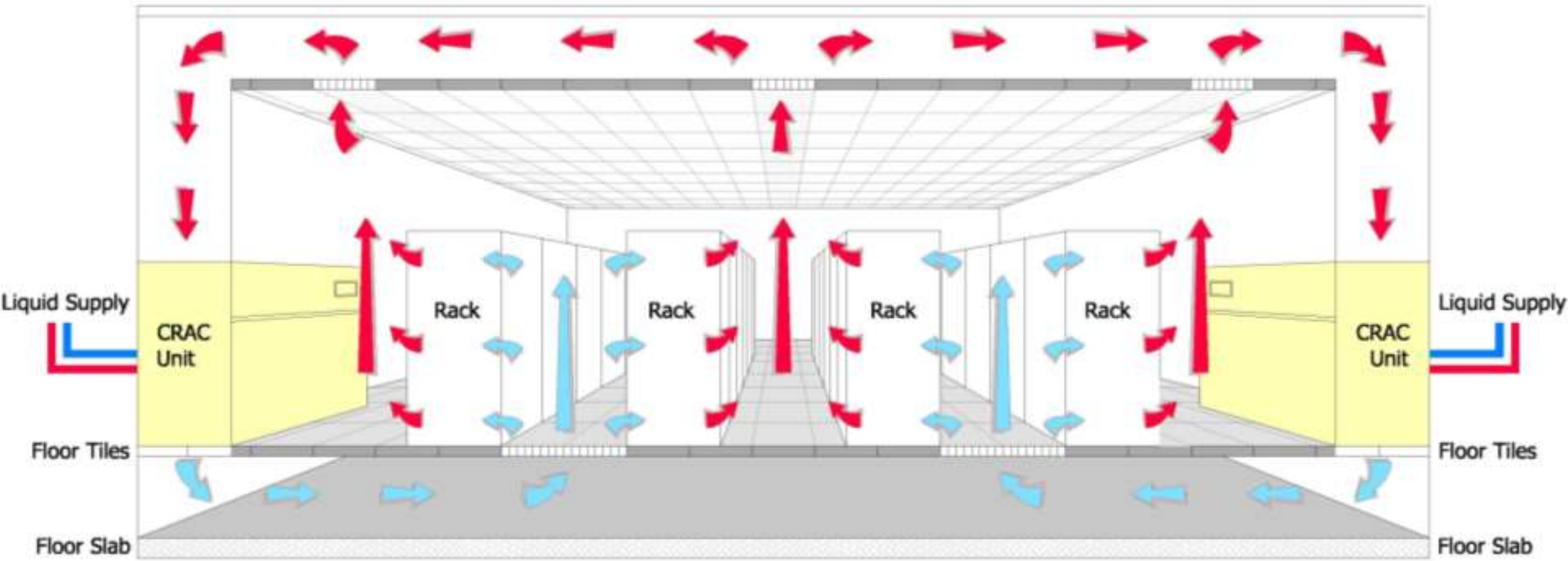

Return Air Plenum

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

Before

After

Return-Air Plenum Connections

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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.

Cabinet/row containment

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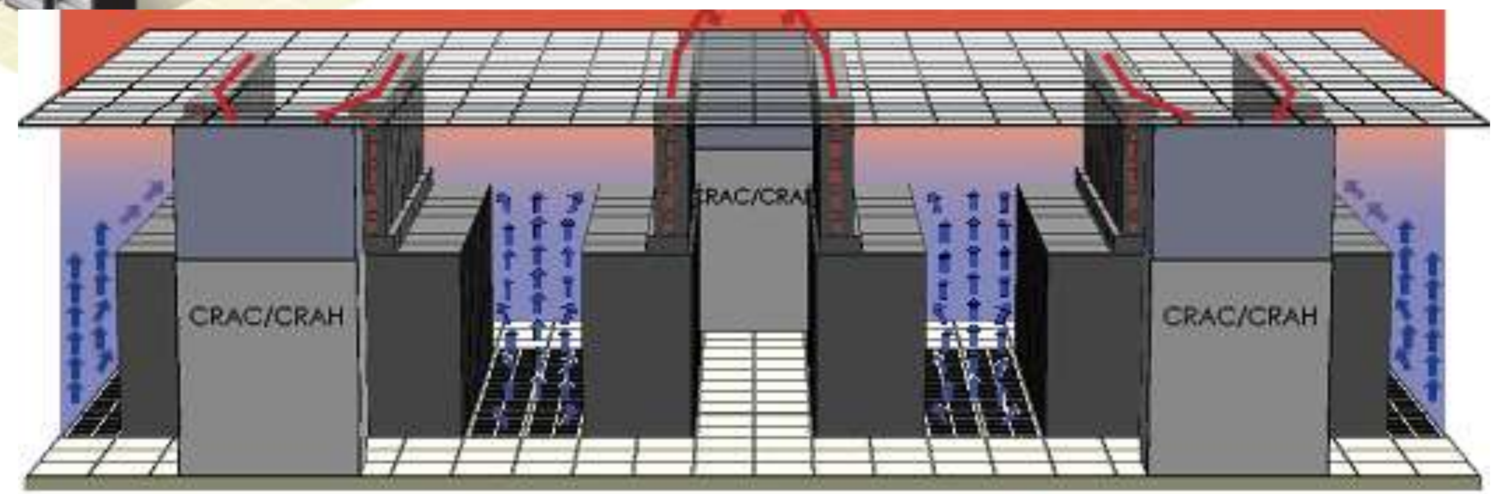
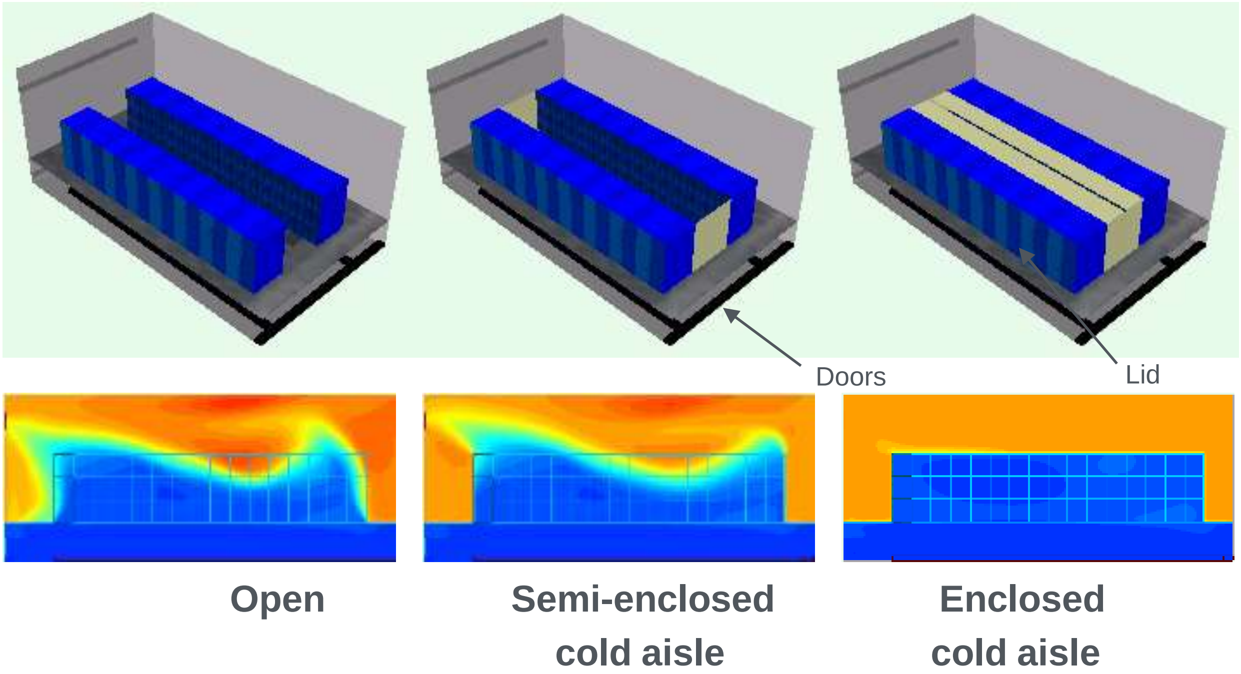


geist's **ACTIVE CABINET or ROW BASED** containment method

+ No hot air mixing, no wrap around heating, NO HOT SPOTS
+ Actively balances return airflow to server usage
+ Complete hot air separation enabling highest CRAC/CRAH return air temperatures
+ Eliminates raised floor pressure balancing issues making it suitable for slab environments
+ Data center floor becomes a cold aisle providing comfortable working conditions
+ 1:1 airflow balance makes cooling over-provision unnecessary

Other Isolation Options

- ✓ 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

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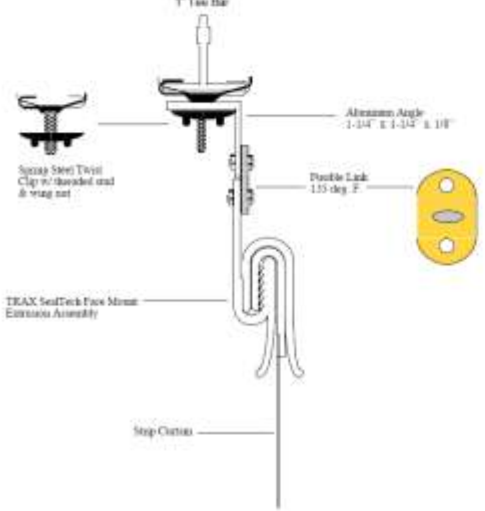
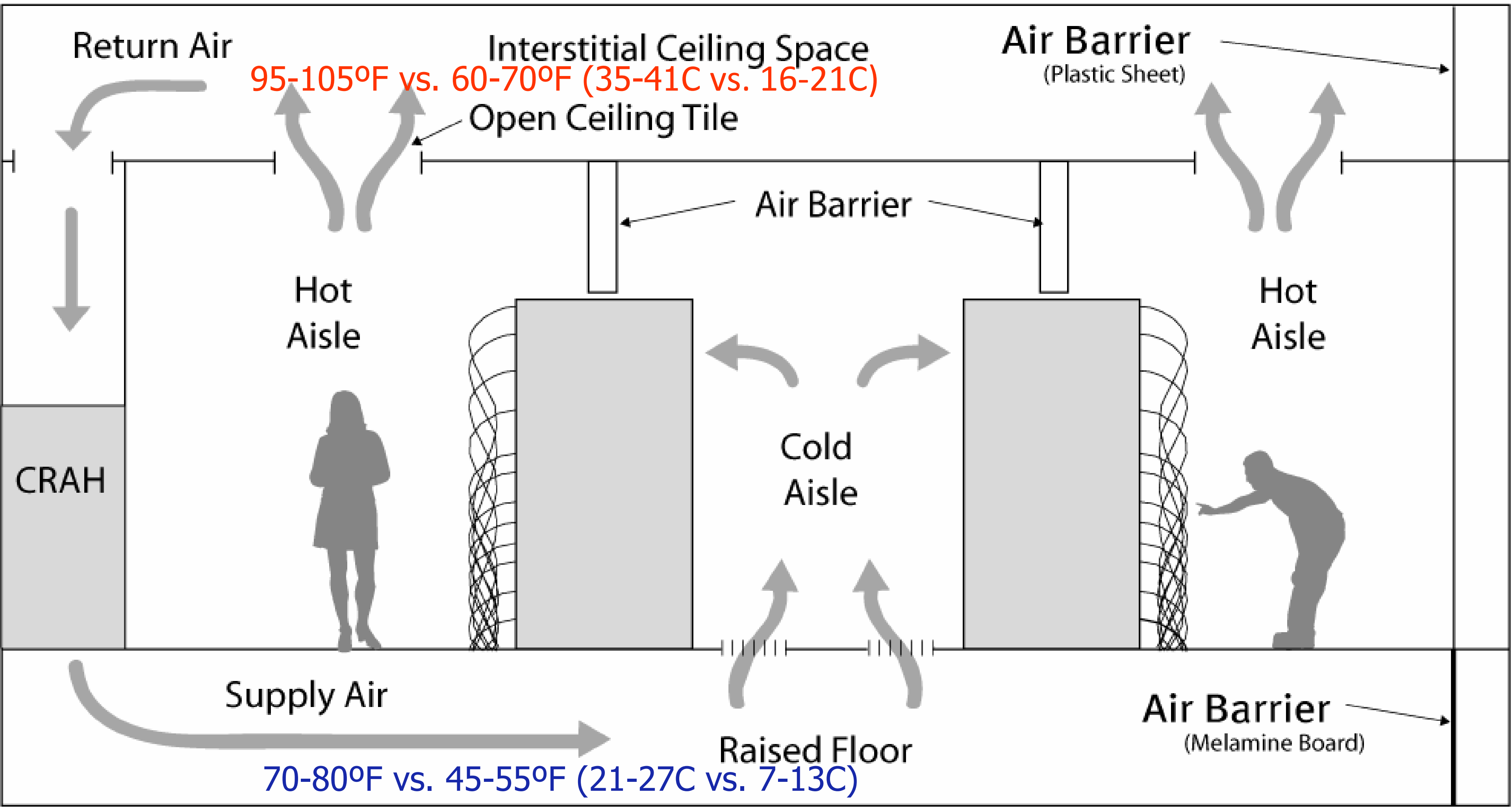
CoolShield or Trax SealTech



Isolate Cold and Hot Aisles



Cold Aisle Airflow Containment Example

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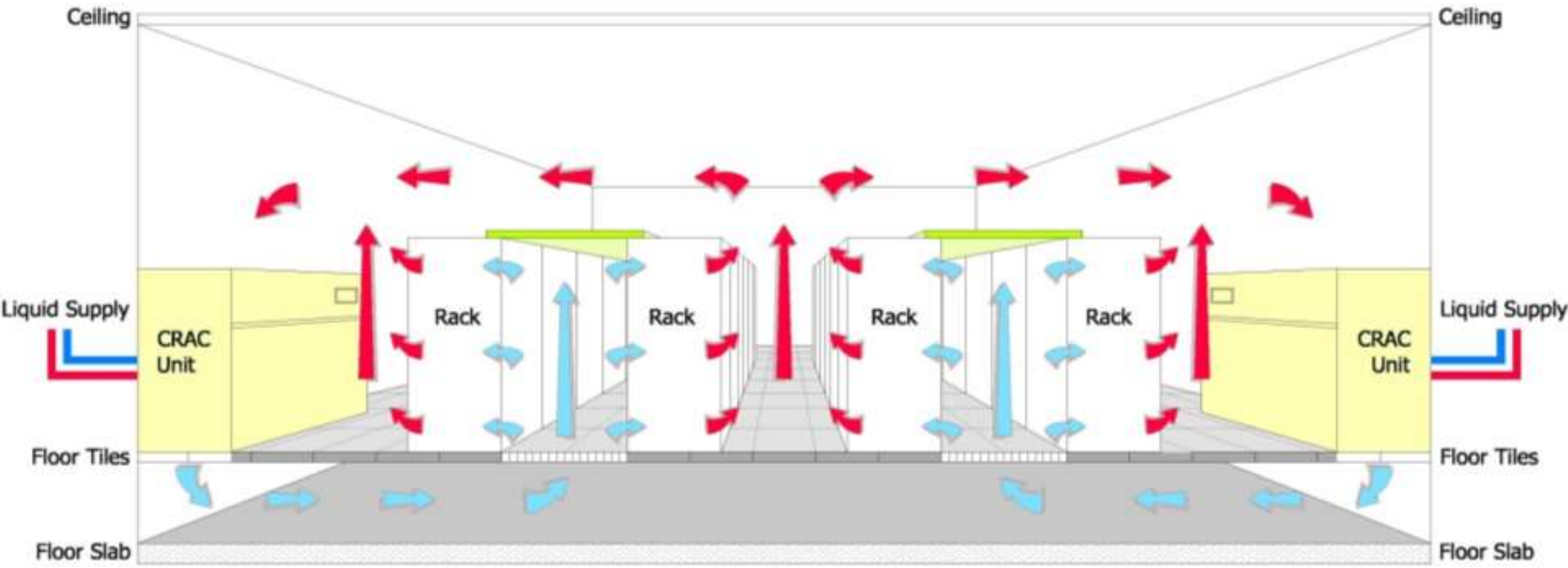
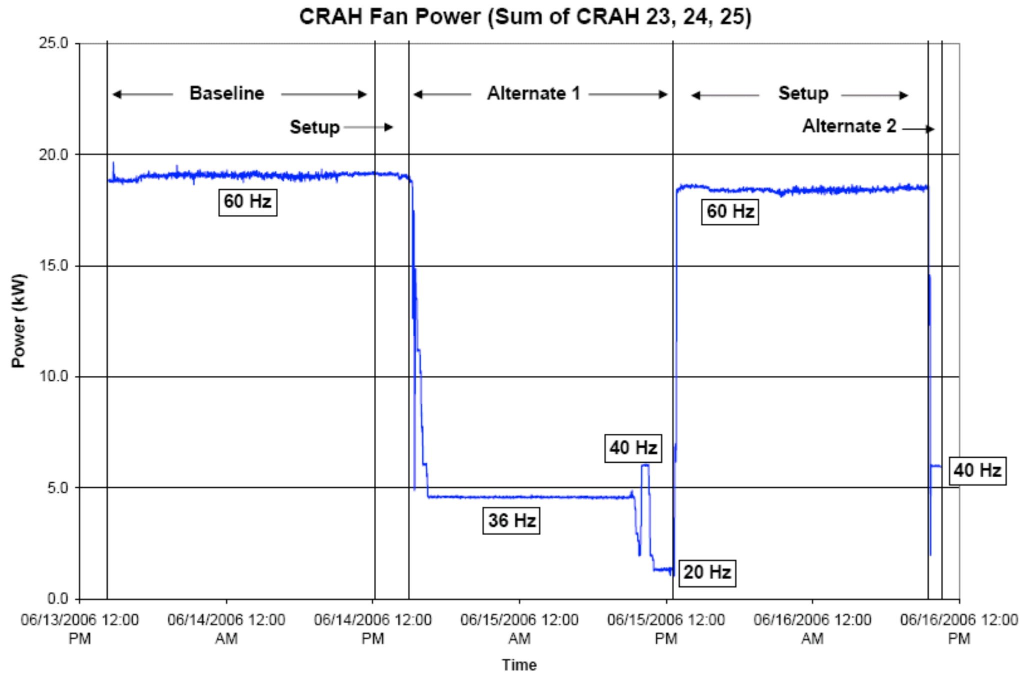


LBNL Cold Aisle Containment study achieved fan energy savings of ~ 75%

Fan Energy Savings

- Isolation can significantly reduce air bypass 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)

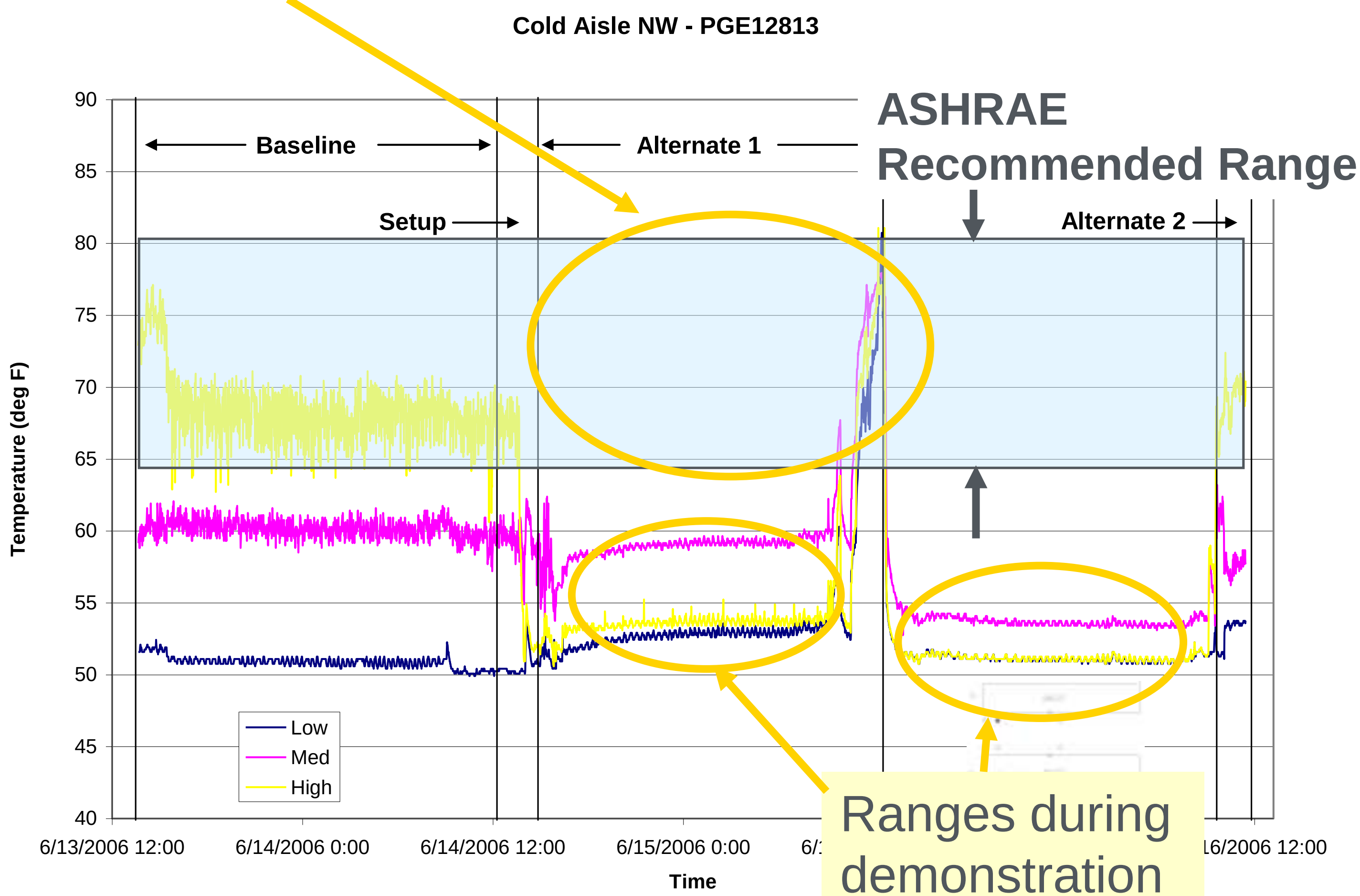


Without Enclosure With Enclosure Without Enclosure

LBNL Air Management Demonstration

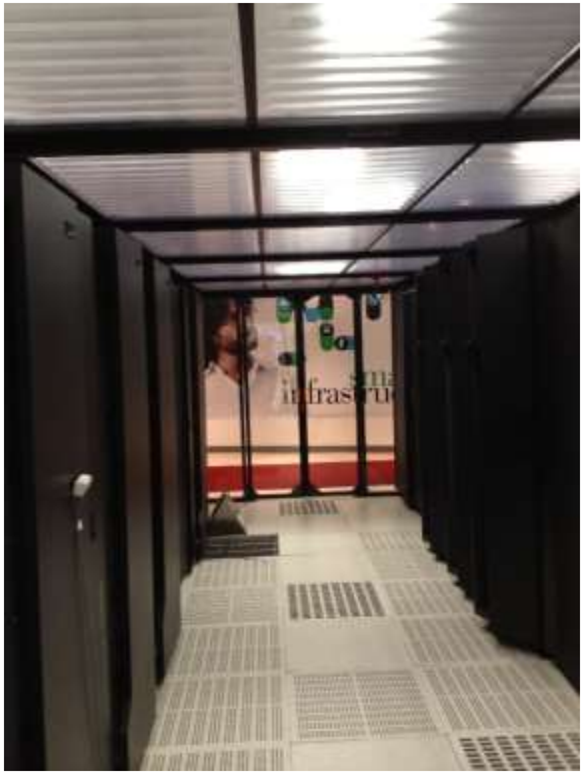
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Better airflow management permits warmer supply temperatures!

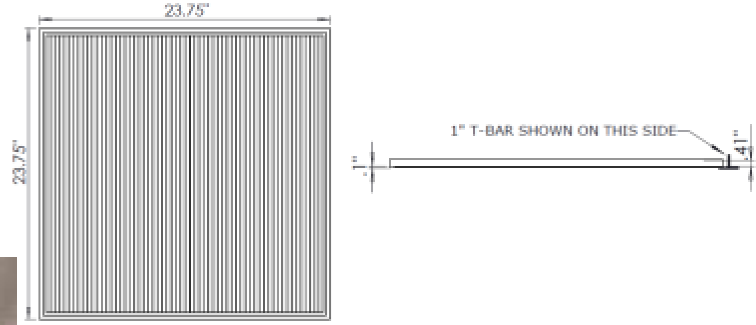


Hot and Cold Aisle Containment

Subzero Cold Aisle Containment



APC Hot Aisle Containment
(with in-row cooling)



Ceilume Heat Shrink Tiles

Isolating Hot and Cold Aisles Summary

- Energy intensive IT equipment needs good isolation of “cold” inlet and “hot” discharge.
- Supply airflow can be reduced if no bypass 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.

Efficient Alternatives to Under-floor Air Distribution

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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

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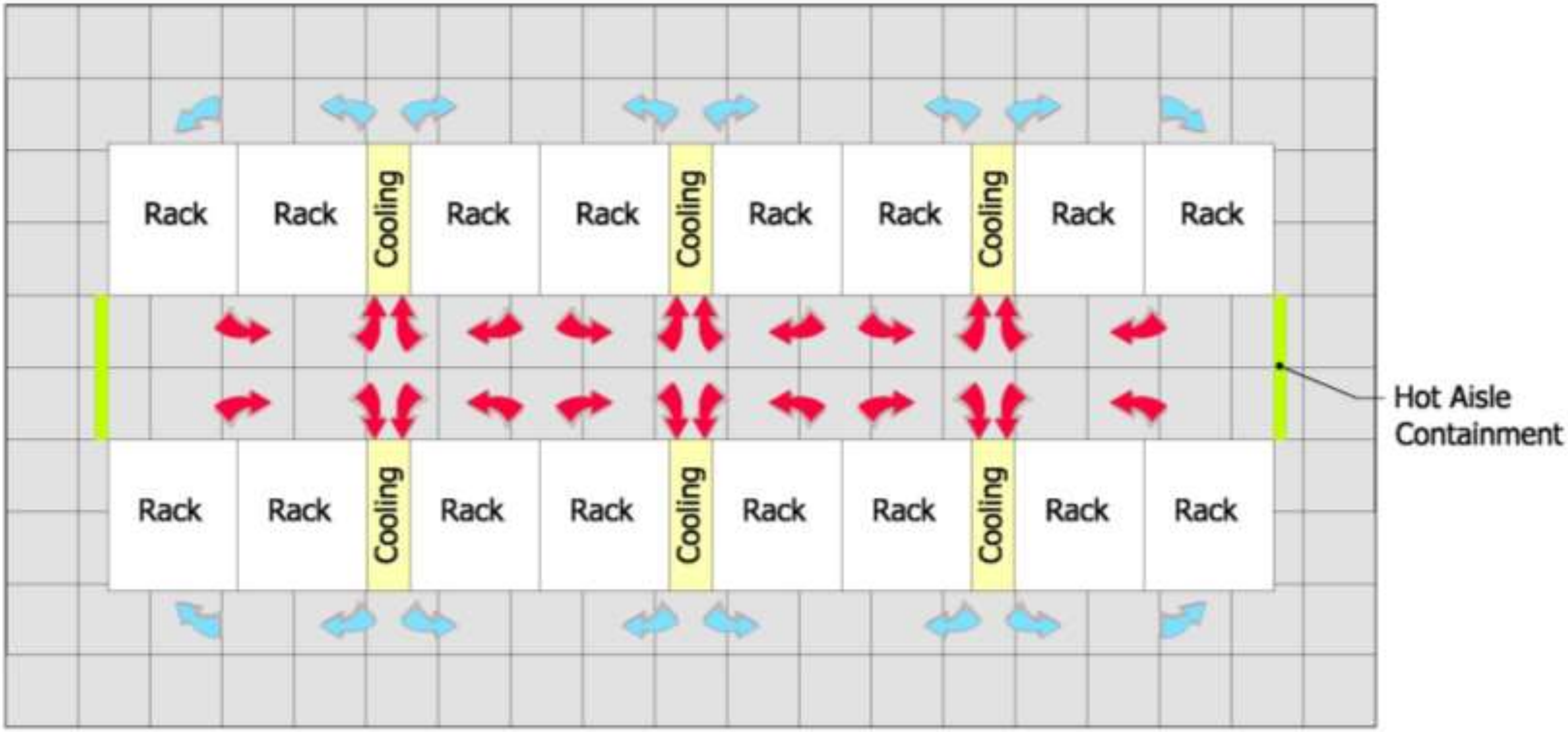

In-row cooling system

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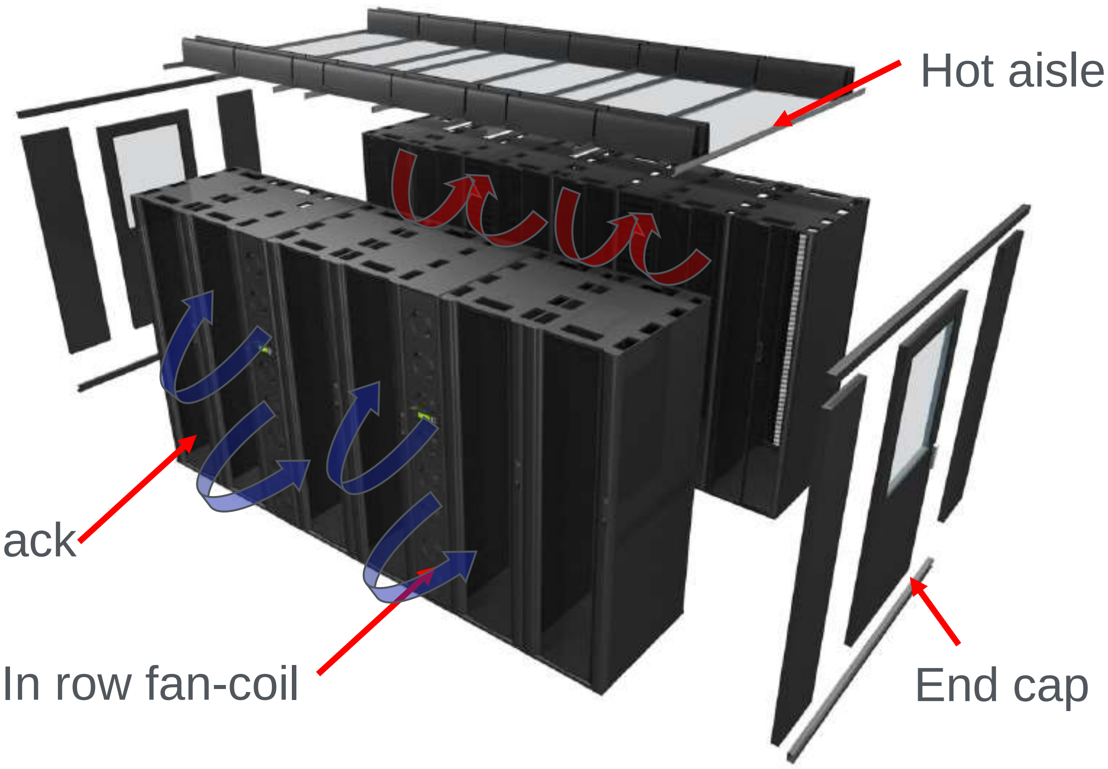
With hot aisle containment, the general data center is neutral (75-80F)



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Air Distribution – Rack-Mounted Heat Exchangers

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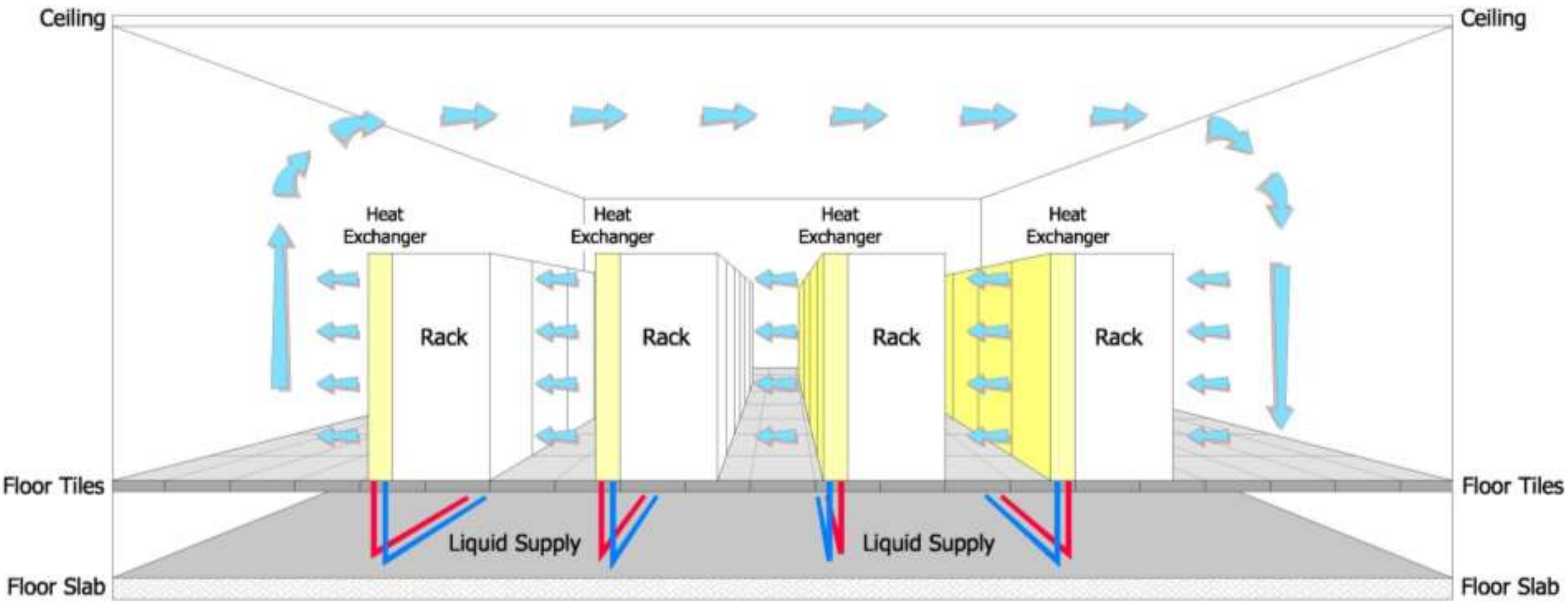

Review: Airflow Management Basics

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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

FEMP
Federal Energy Management Program

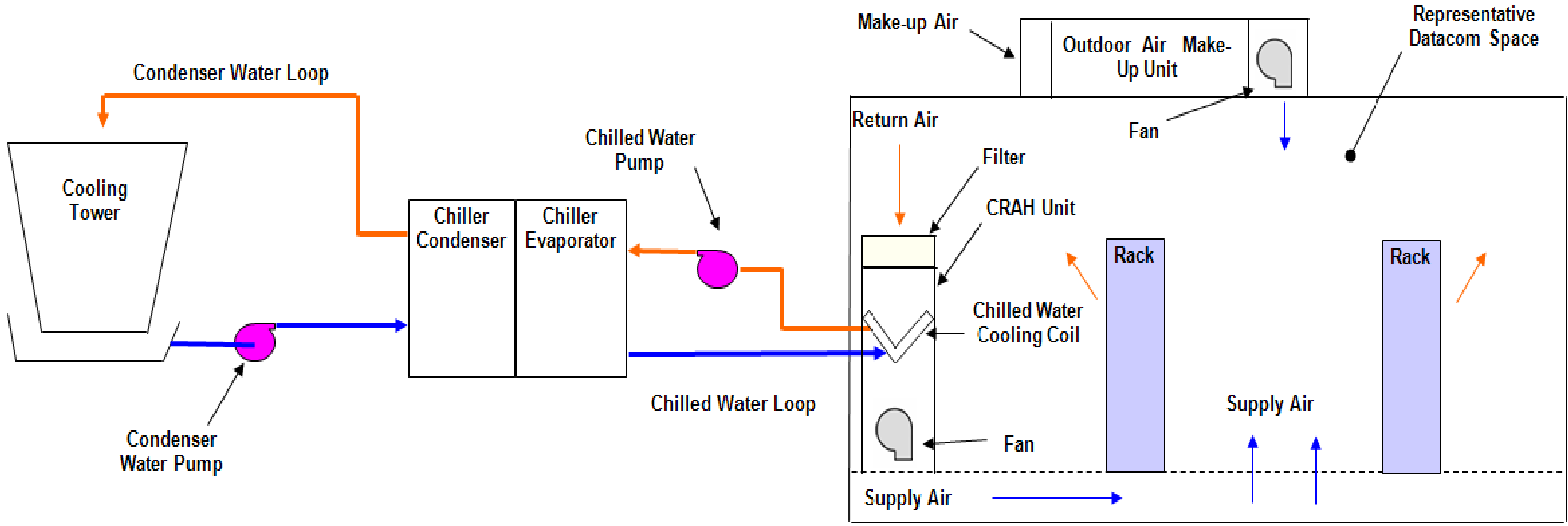
BERKELEY LAB

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 | **Cooling Plant** | **Cooling Distribution**



High Eff / Low Eff (η)

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)

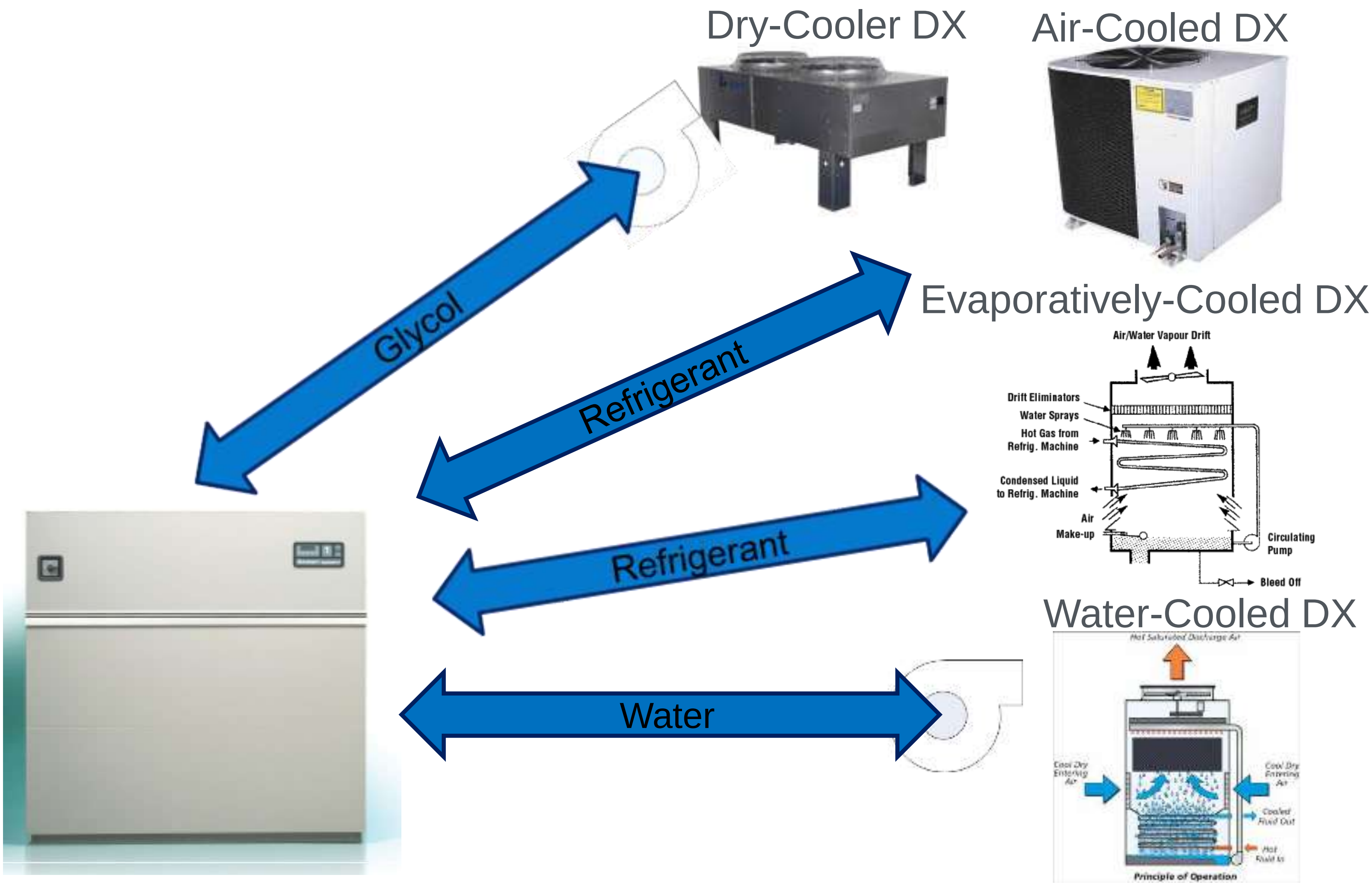
Distribution Alternatives
- On Board
- In Rack
- In Row
- Overhead Air
- Underfloor Air (Shown)

Adapted from ASHRAE

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

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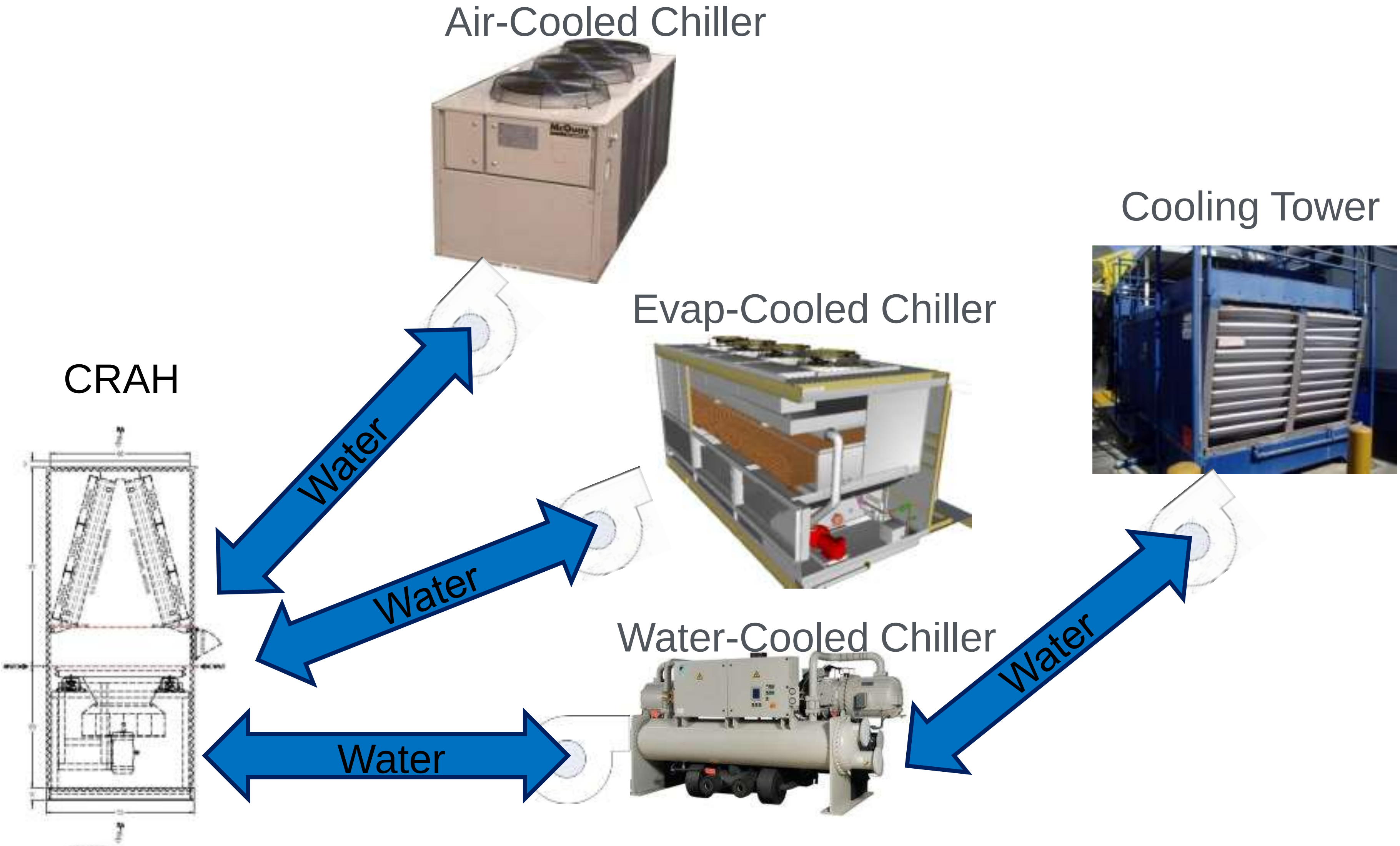

98

Optimize the Chiller Plant

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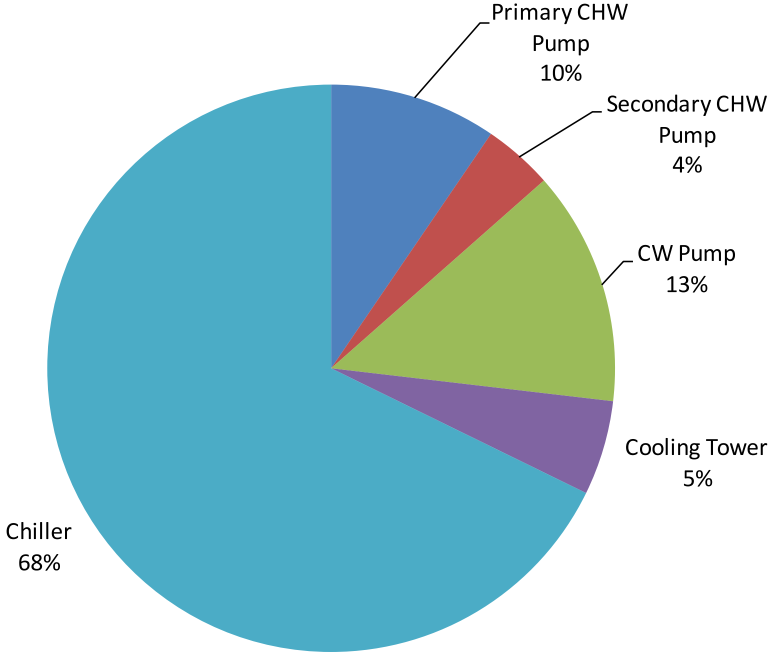
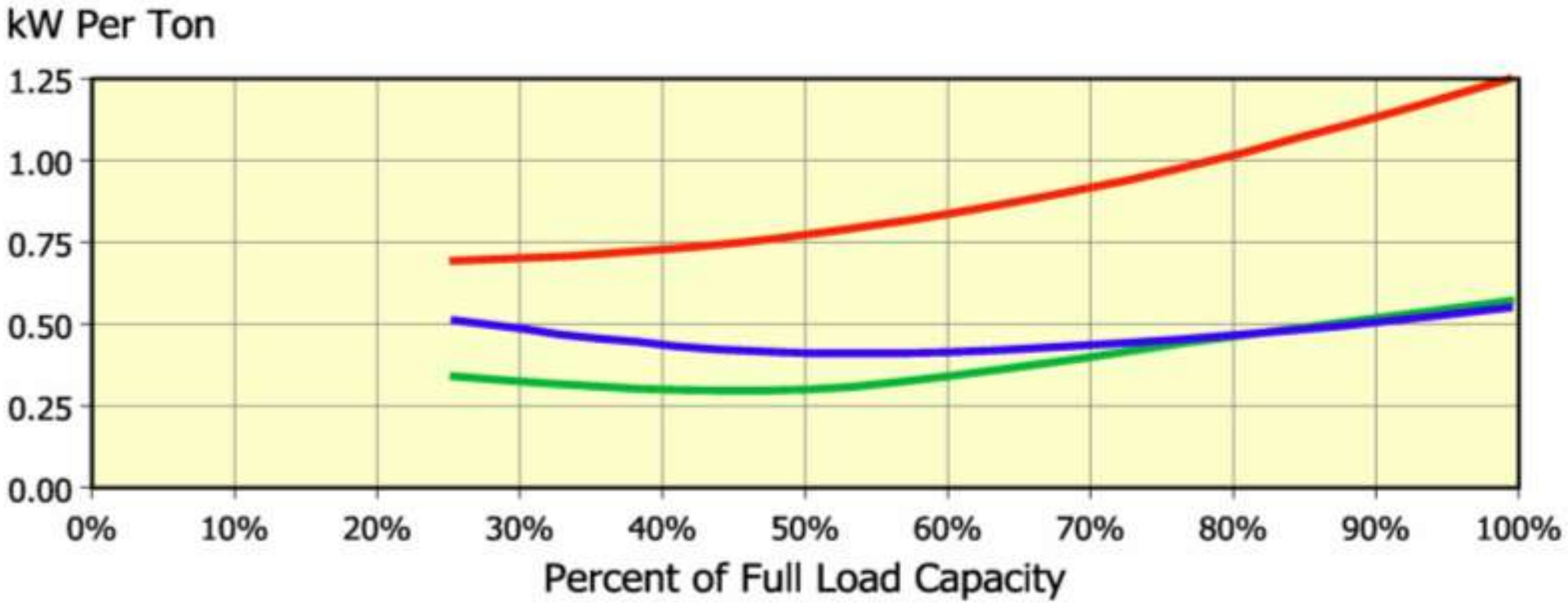
- Have a plant (vs. distributed cooling)
- Use “warm” water cooling (multi-loop)
- Size cooling towers for “free” cooling
- Integrate controls and monitor efficiency of all primary components
- Thermal storage
- Utilize variable speed drives on:
  - Fans
  - Pumps
  - Towers
  - Chillers



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



Increase Temperature of Chiller Plant

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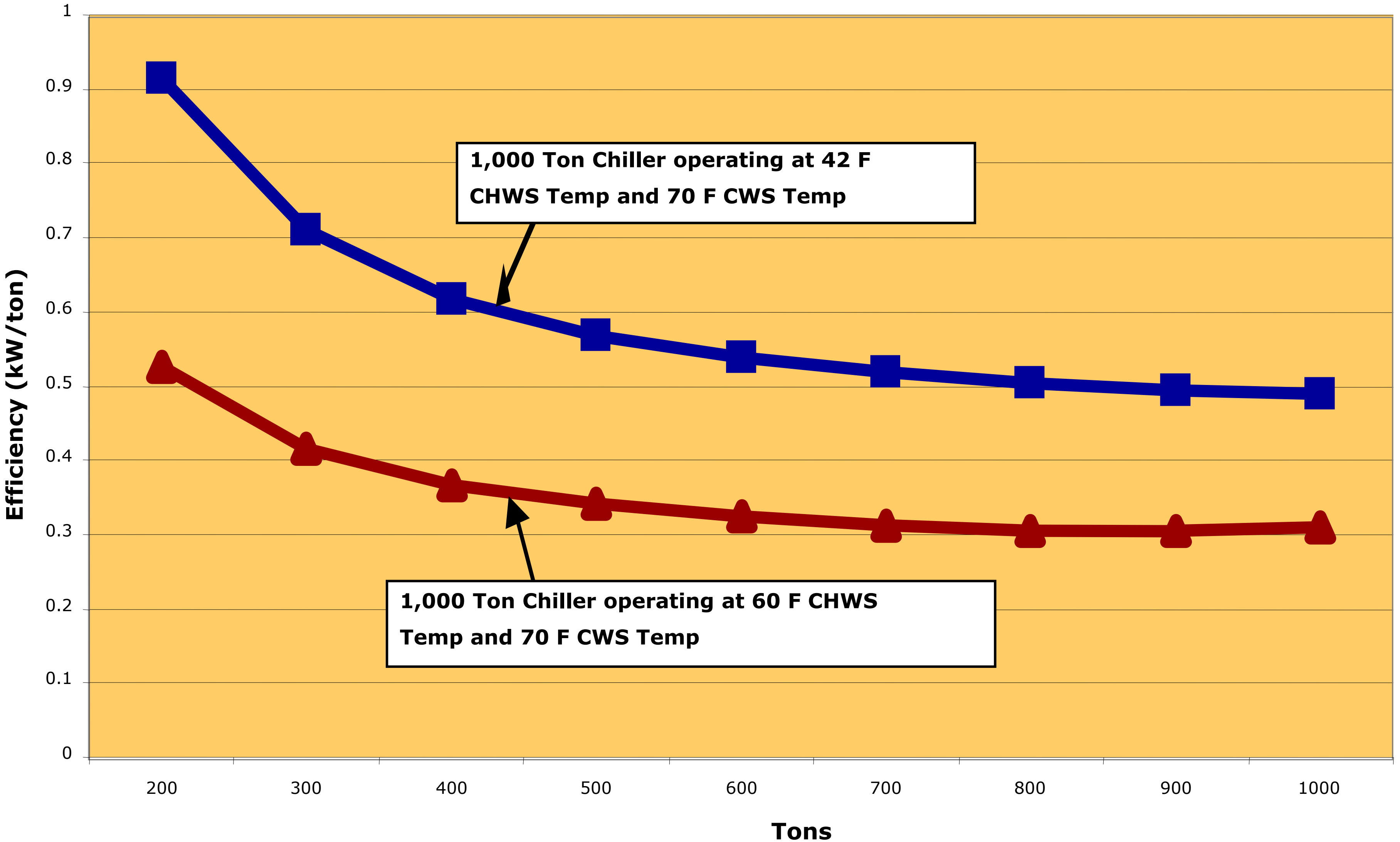

Data provided by York International Corporation.

As heat densities rise, liquid solutions become more attractive:

Volumetric heat capacity comparison

Water

=

Air

Why Liquid Cooling?

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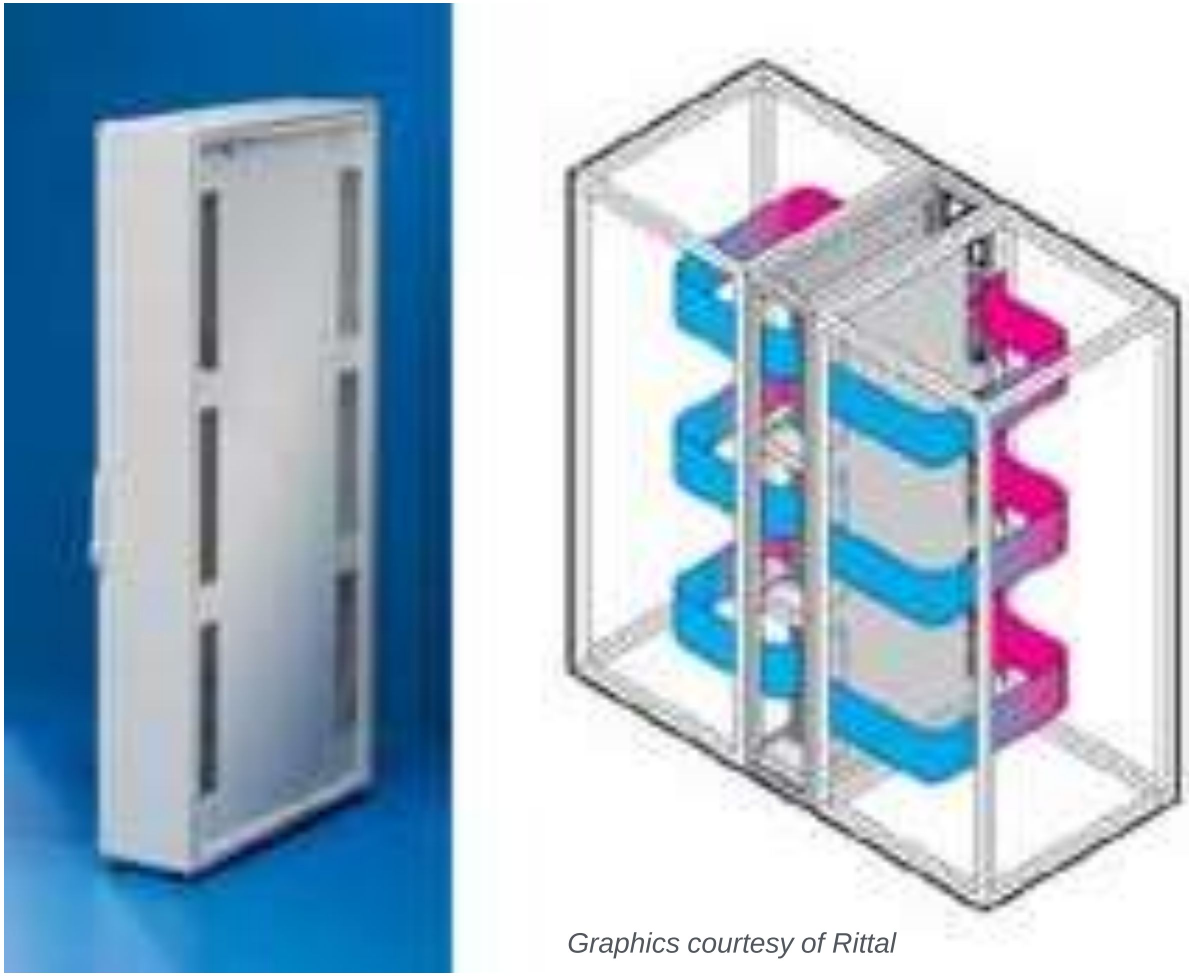
- Heat removal efficiency increases as liquid gets closer to the heat source
- Liquids can provide cooling with higher temperature coolant
  - Improved cooling efficiency
  - Increased economizer hours
  - Greater potential use of waste heat
- Reduced transport energy:

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

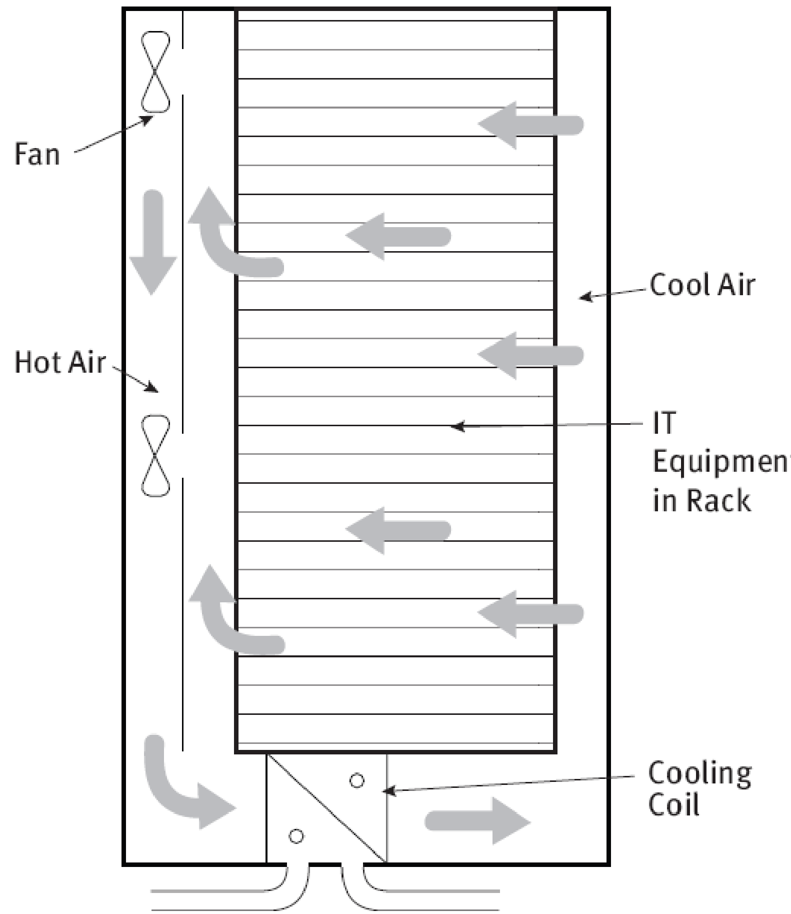
In-Row Liquid Cooling



Graphics courtesy of Rittal

In Rack Liquid Cooling

Racks with integral coils and full containment



Rear Door Heat Exchanger

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- Passive technology: relies on server fans for airflow
- Can use chilled or higher temperature water for cooling

Photo courtesy of Vette

Rear-Door Liquid Cooling

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Rear Door (open)

Inside rack RDHx, open 90°

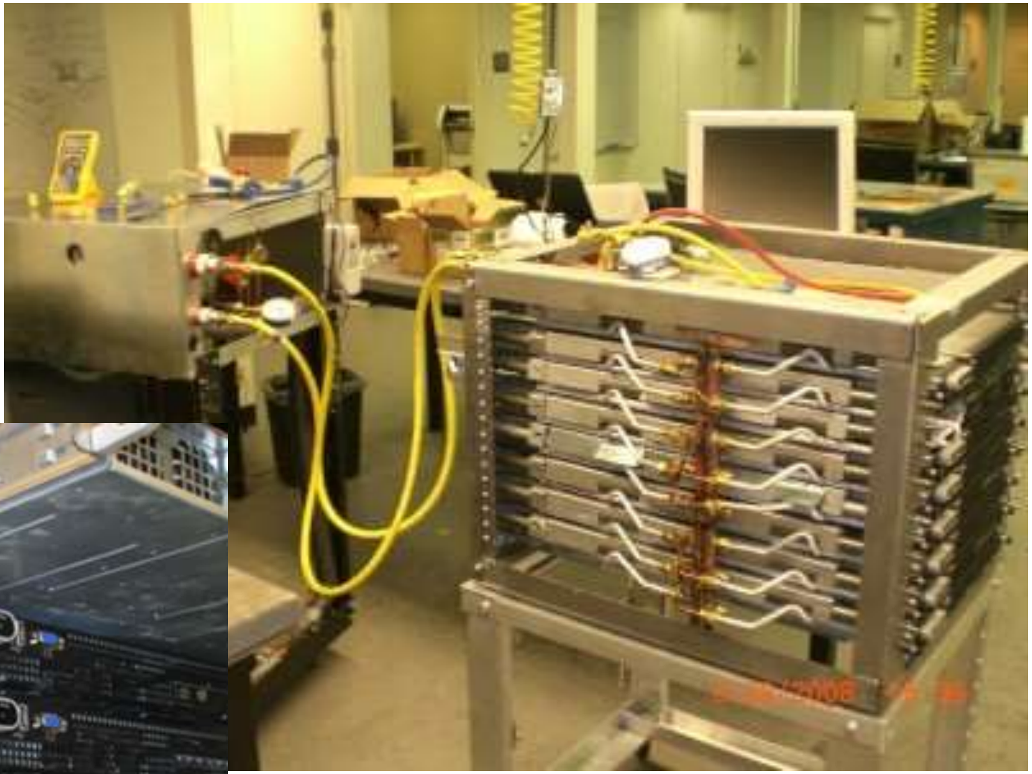
Rear Doors (closed)

Liquid Cooling Connections

Direct touch cooling

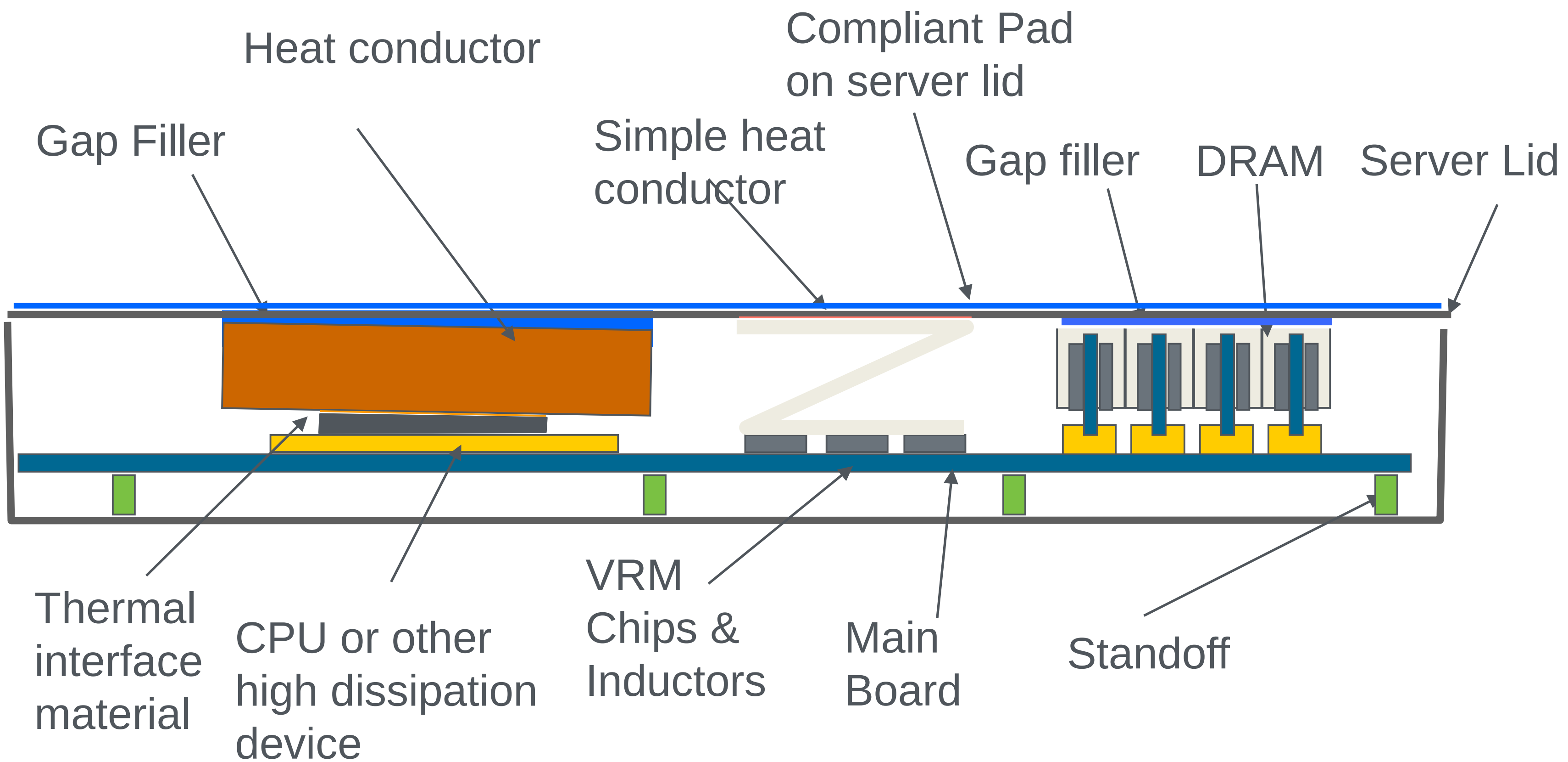
Clustered Systems design

Conducting heat to a cold plate containing refrigerant



Schematic

- Server fans are removed
- Heat risers connect to top plate which has a micro channel heat exchanger



On Board Cooling

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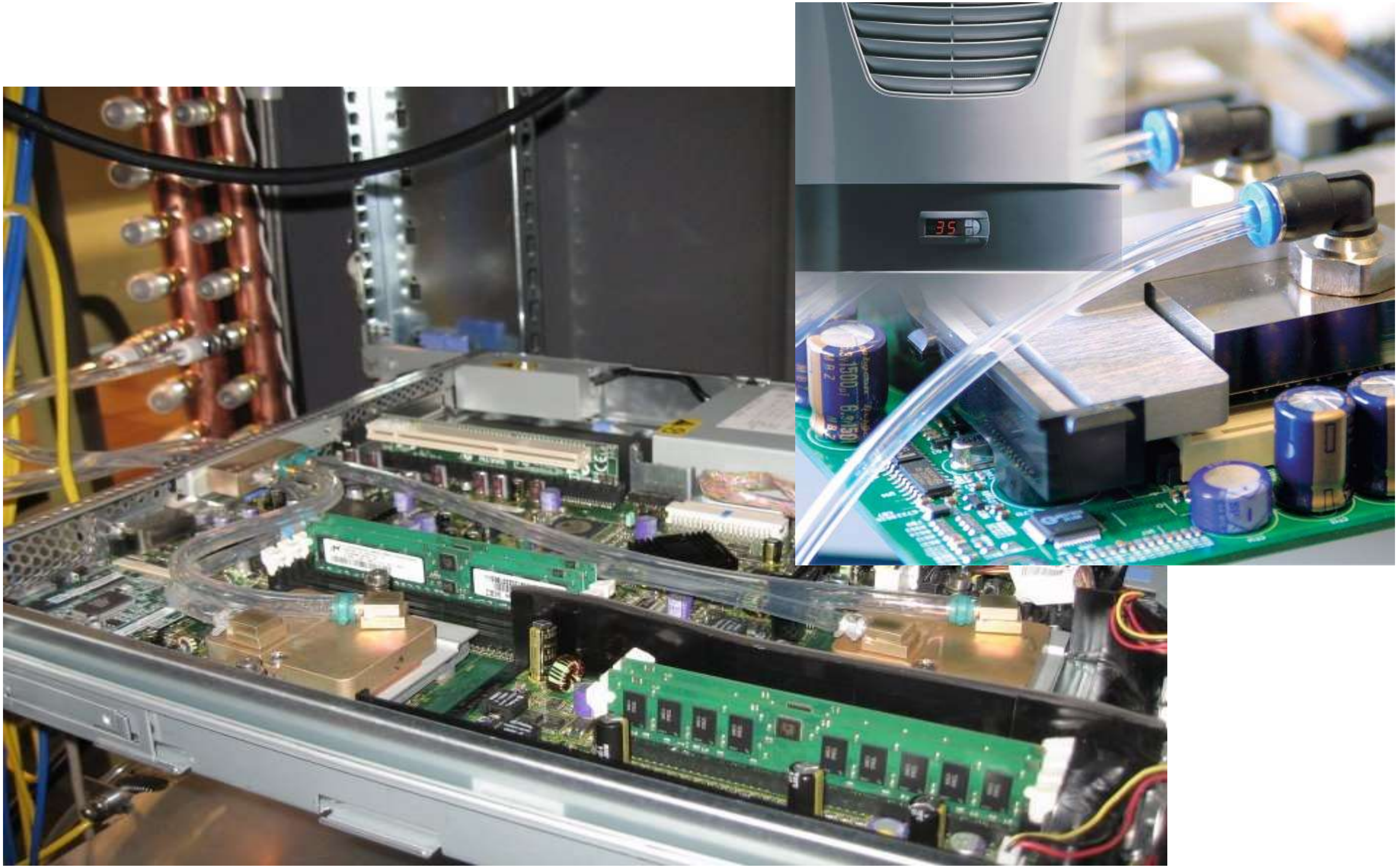
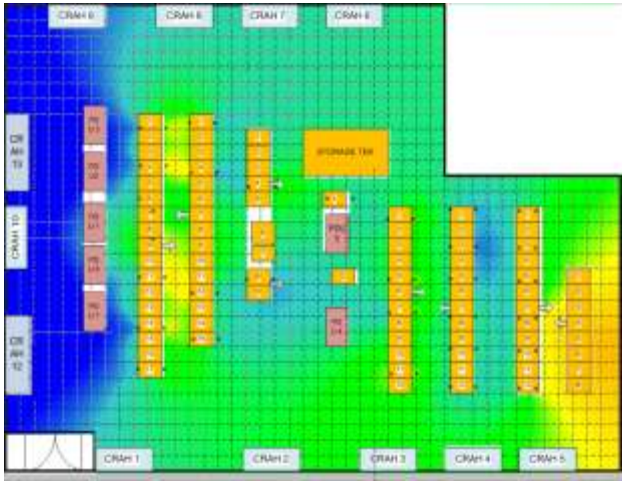


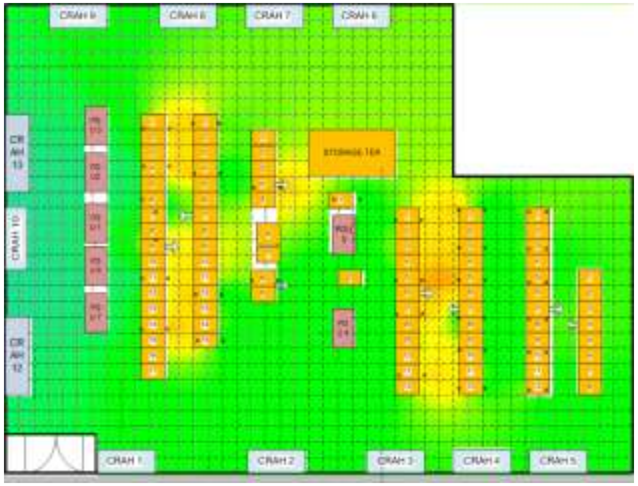
Maui High Performance Computing Center

- Increased air intake temperature
- Turned off 3 CRAHs
- Saved almost $300,000 annually

Then:

- Installed dry coolers for water cooled system
- Will save additional $200,000 annually
- 6 times more compute





Maui HPC Center
Warm Water Cooling

IBM Riptide

- 91% water cooled, 9% air cooled

Water inside

MHPCC Water Cooling, continued

Water Piping Behind the servers

- Cooling water temperature as high as 44° C

Dry Coolers, 10kW each compared to 100kW Chillers

Liquid immersion cooling demonstration

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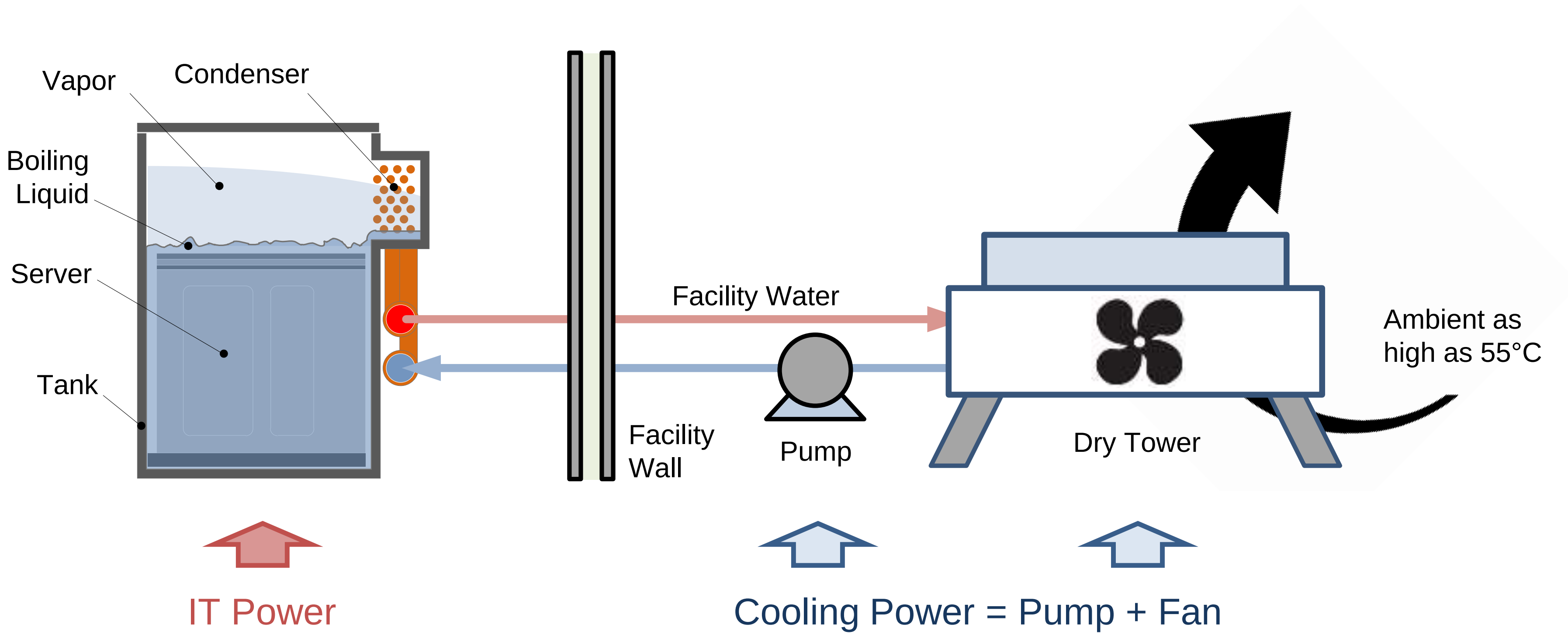
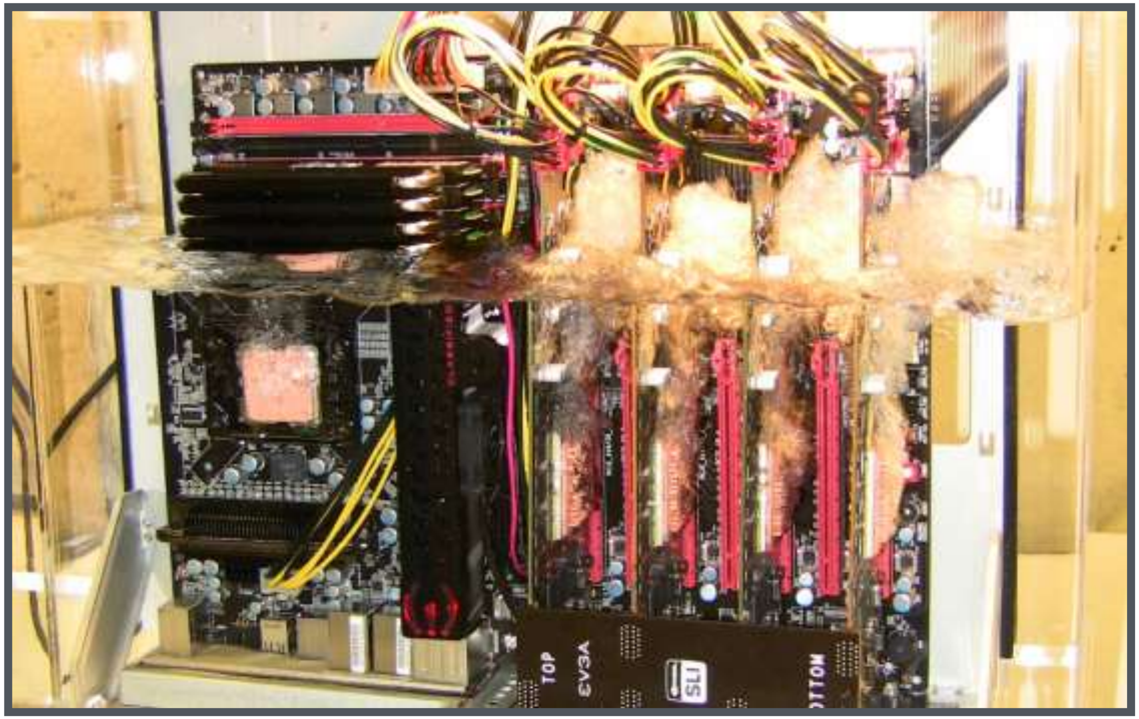


No longer requires:

- chillers
- cooling towers
- water use
- raised floors
- computer room air conditioners
- earplugs!

Phase change of dielectric fluid removes heat efficiently



Computer in glass tank

3M Corp.
4 server system

"Chill-off 2" Evaluation of Liquid Cooling Solutions

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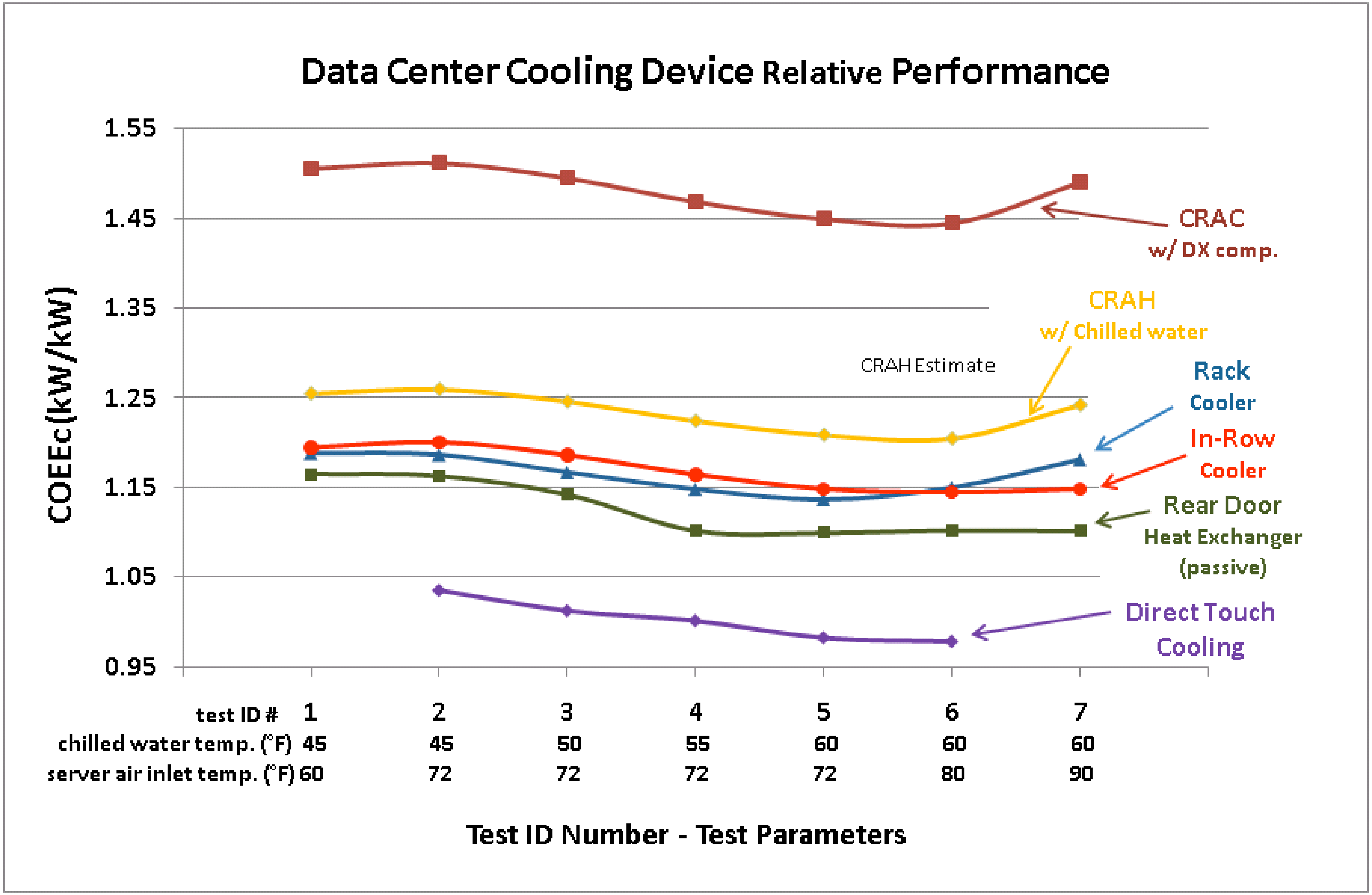

Use Free Cooling:

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Cooling without Compressors:

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

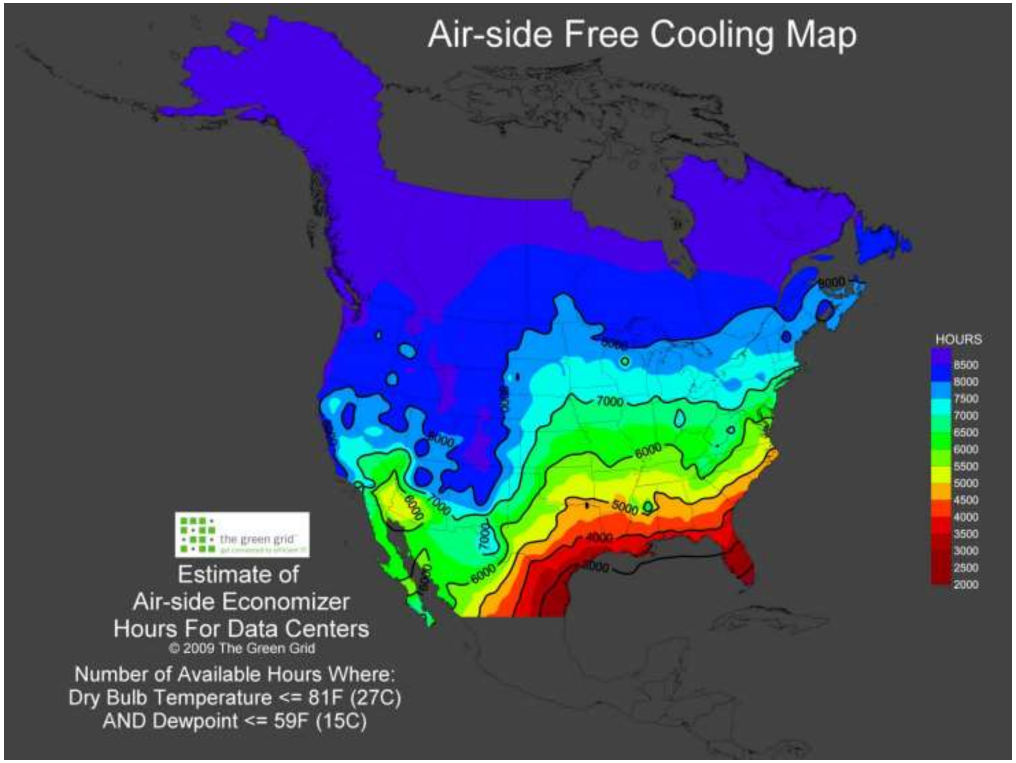
Outside-Air Economizers

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.



http://cooling.thegreengrid.org/namerica/WEB_APP/calc_index.html

Green Grid Tool

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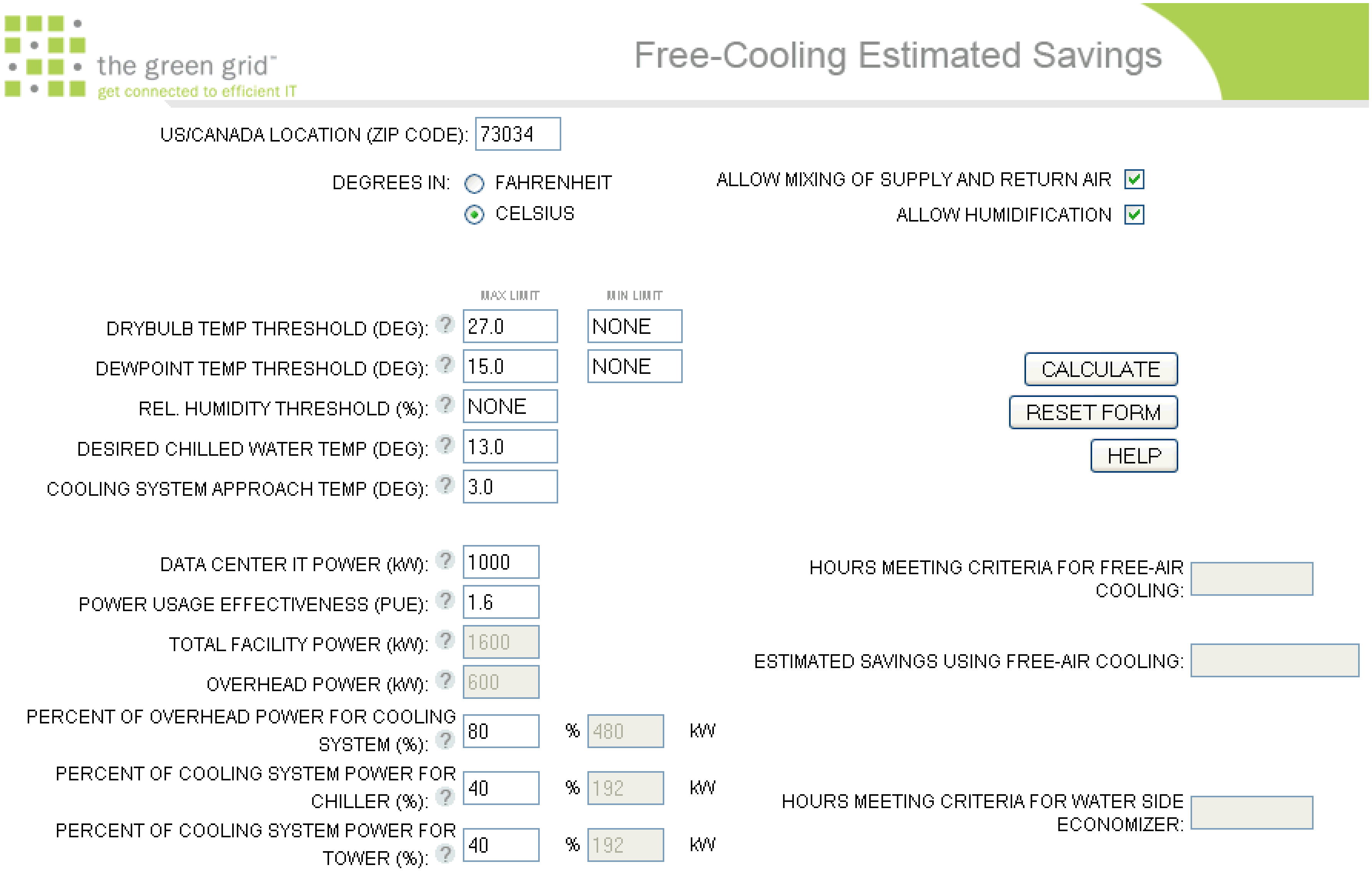
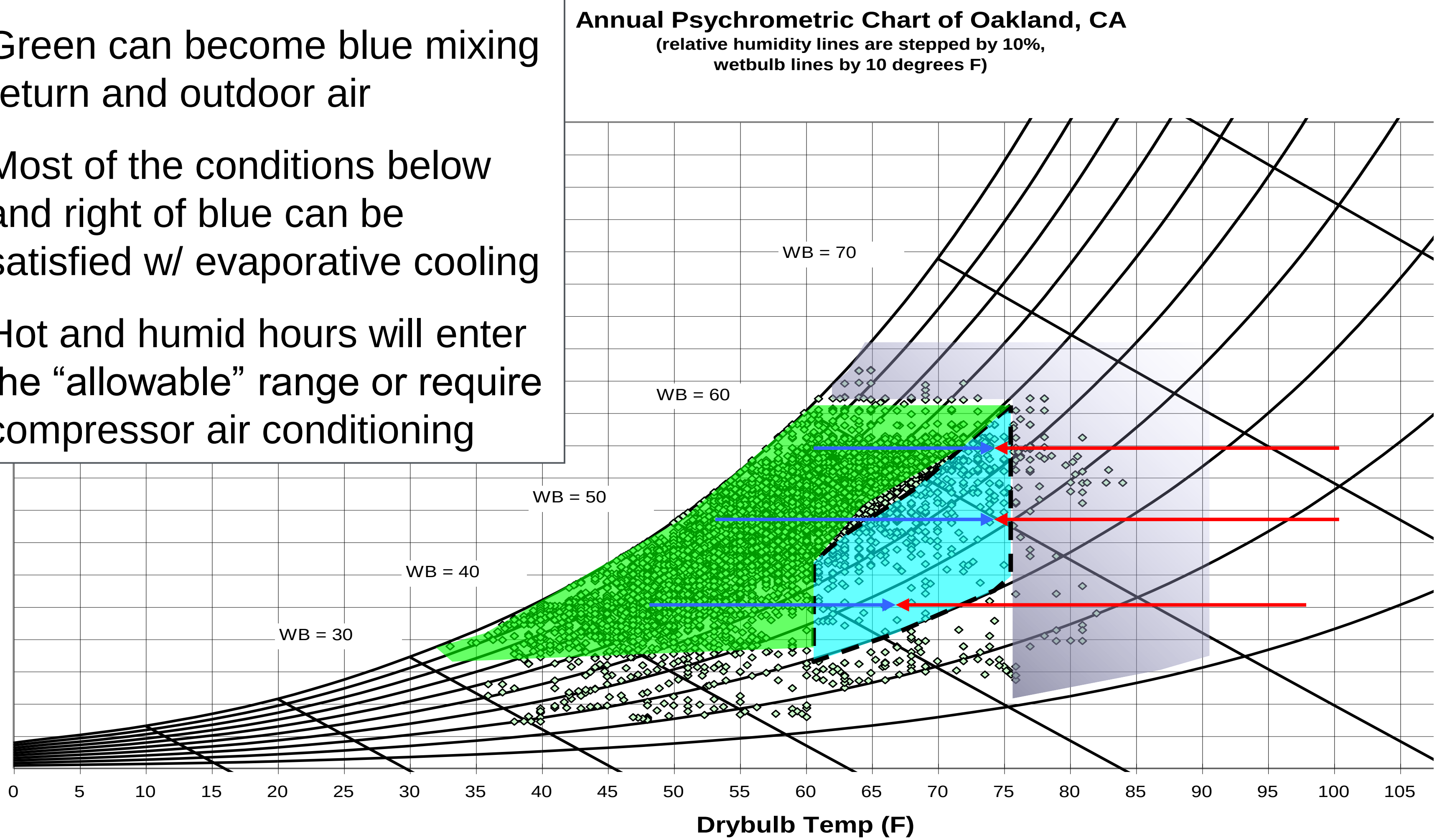


UC's Computational Research and Theory (CRT) Facility

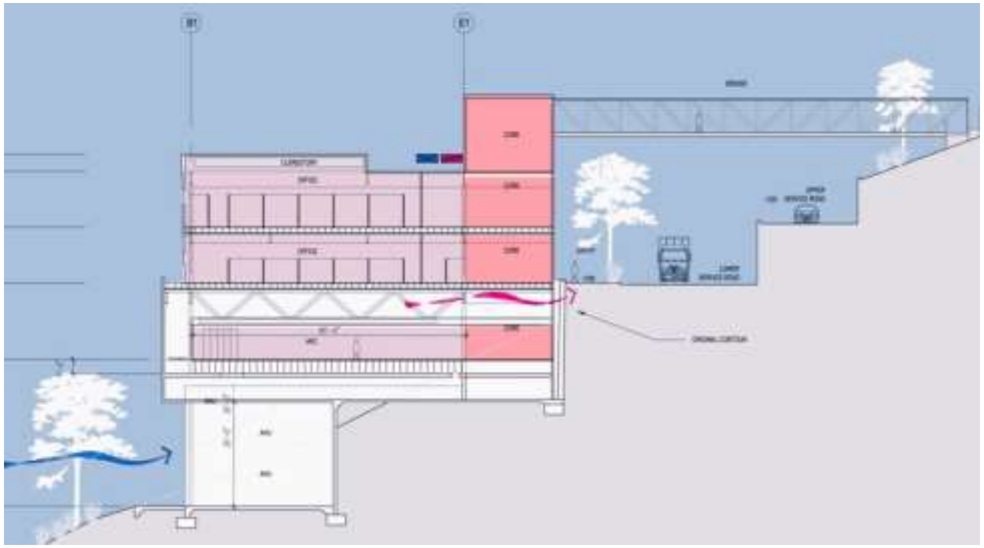
Free Cooling – Outside Air Based

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



System Design Approach:

- 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

Water Coolir:

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

Predicted CRT Performance:

- Annual PUE = 1.1

Water-Side Economizers

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

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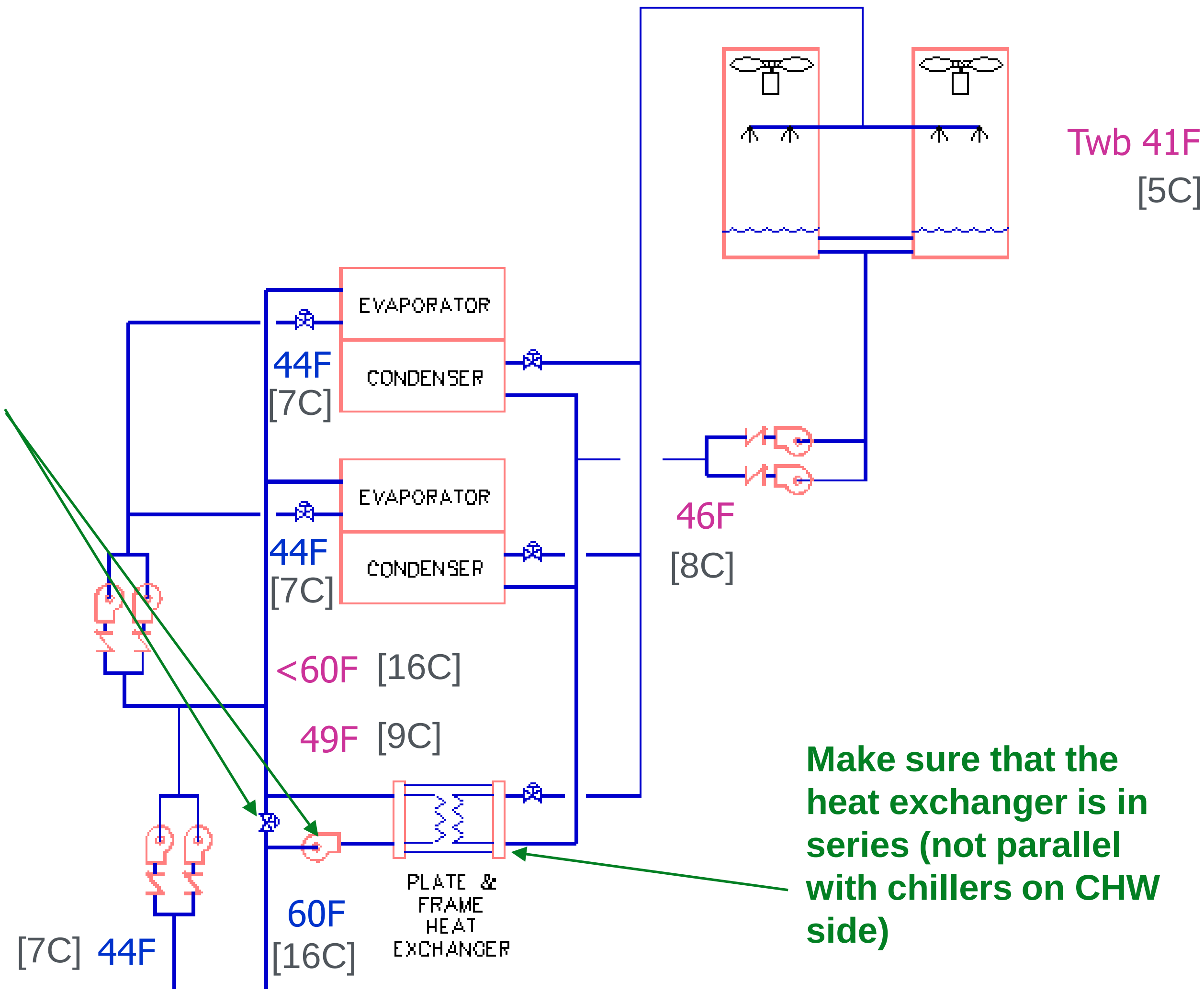
You can use either a control valve or pump



Make sure that the heat exchanger is in series (not parallel with chillers on CHW side)

Potential for Tower Cooling

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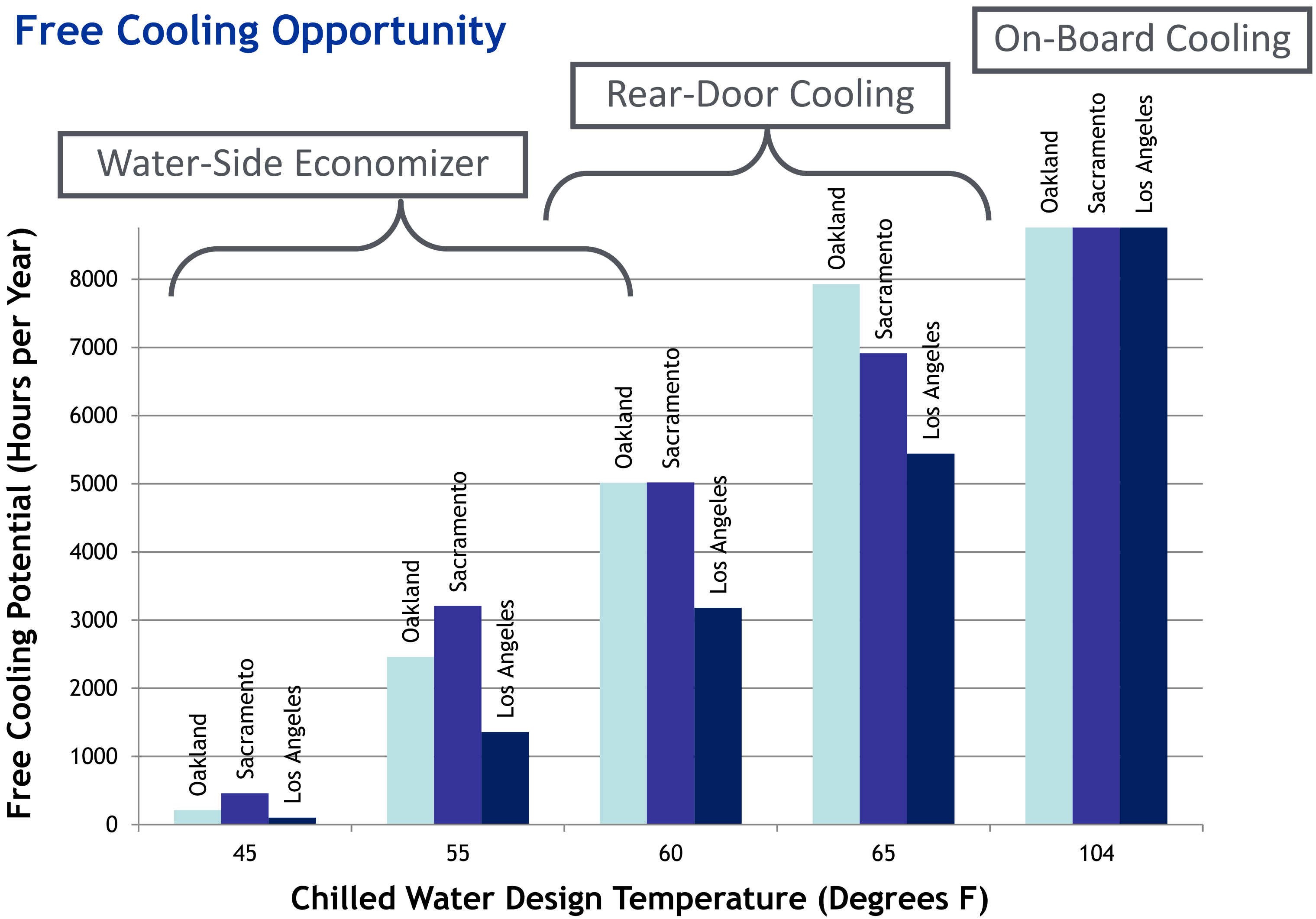

LBNL Example: Rear Door Cooling

- 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.

Improve Humidity Control:

- 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!)

High Humidity Limit Issues

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- Some contaminants (hydroscopic 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.

Low Humidity Limit Issues

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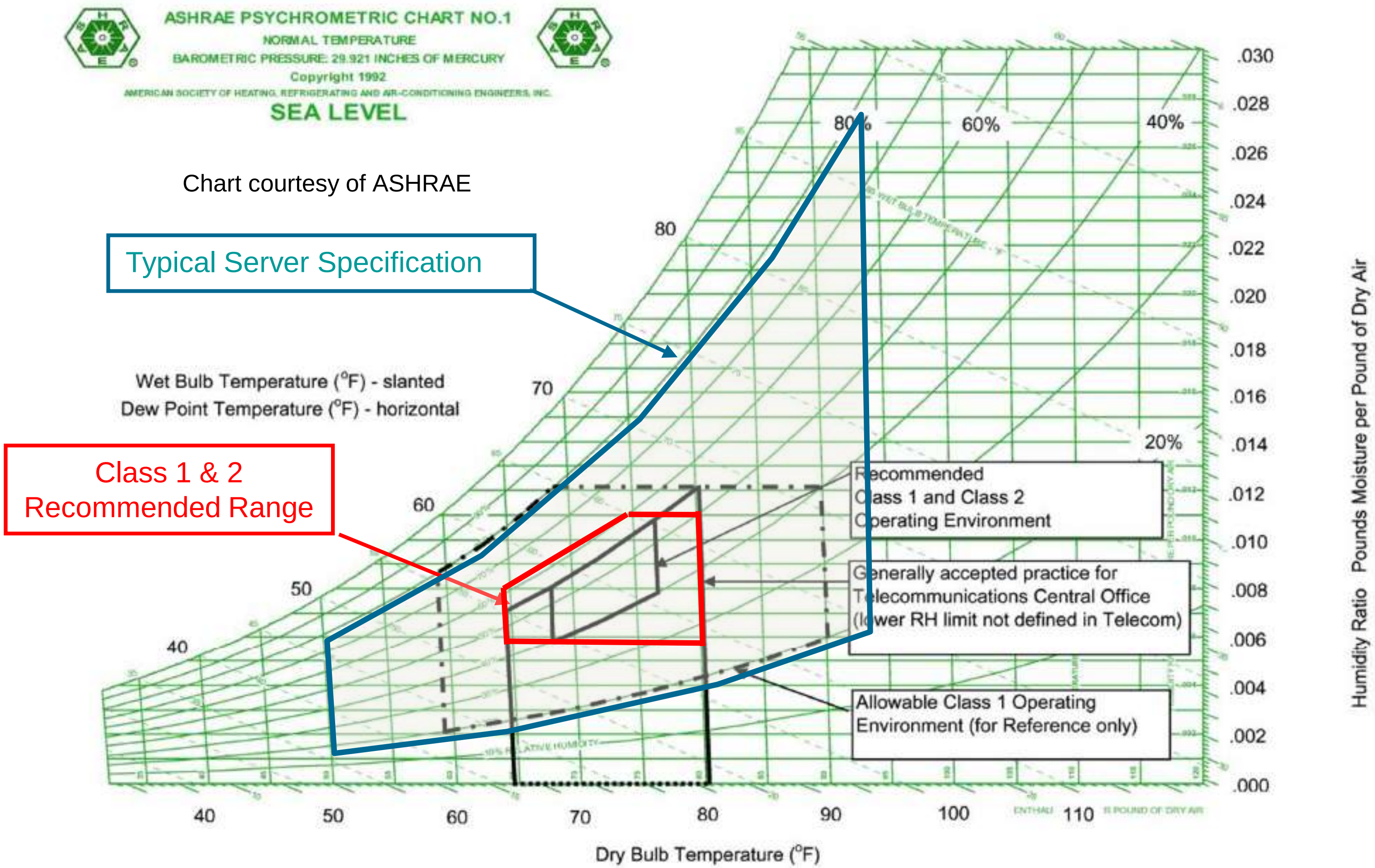
Electrostatic discharge

- 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

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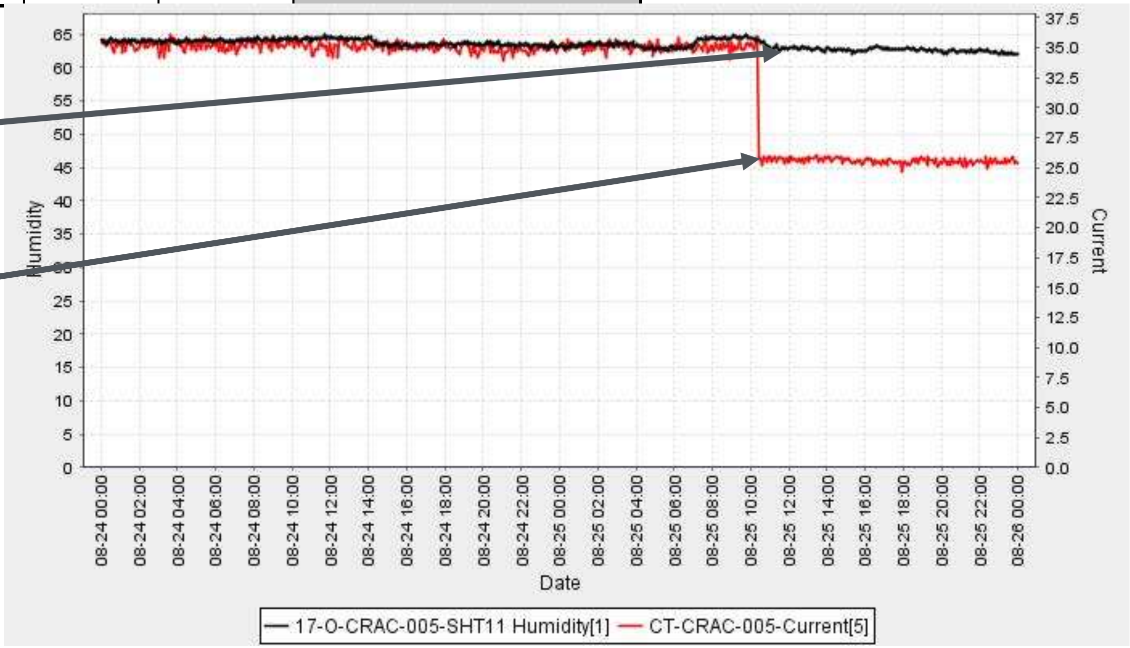
	Visalia Probe			CRAC Unit Panel			
	Temp	RH	Tdp	Temp	RH	Tdp	Mode
AC 005	84.0	27.5	47.0	76	32.0	44.1	Cooling
AC 006	81.8	28.5	46.1	55	51.0	37.2	Cooling & Dehumidification
AC 007	72.8	38.5	46.1	70	47.0	48.9	Cooling
AC 008	80.0	31.5	47.2	74	43.0	50.2	Cooling & Humidification
AC 010	77.5	32.8	46.1	68	45.0	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%



Cooling Takeaways…

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- 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

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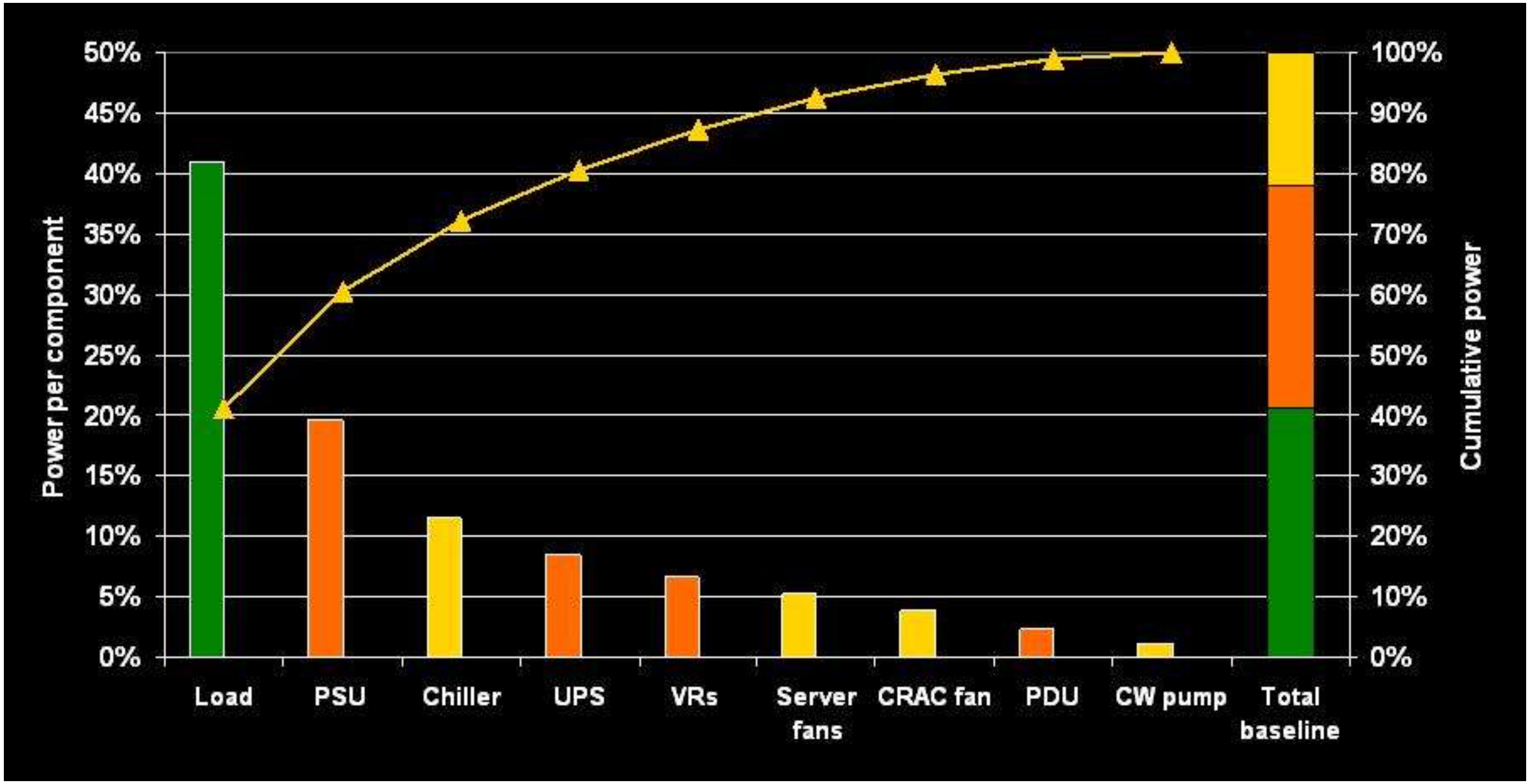
Energy Efficiency and Renewable Energy

FEMP
Federal Energy Management Program

BERKELEY LAB

Electrical system end use – Orange bars

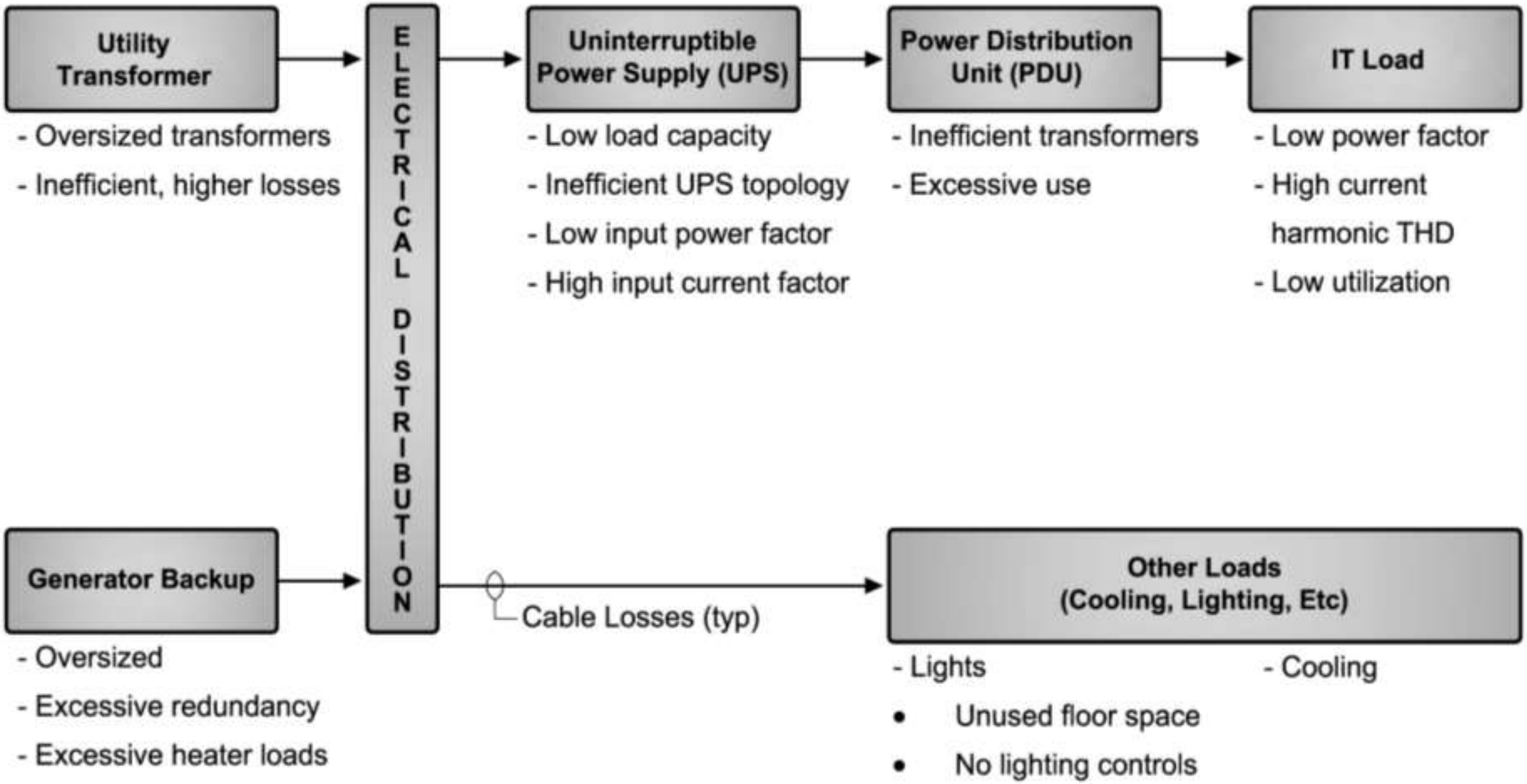


Courtesy of Michael Patterson, Intel Corporation

Electrical Distribution

- 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

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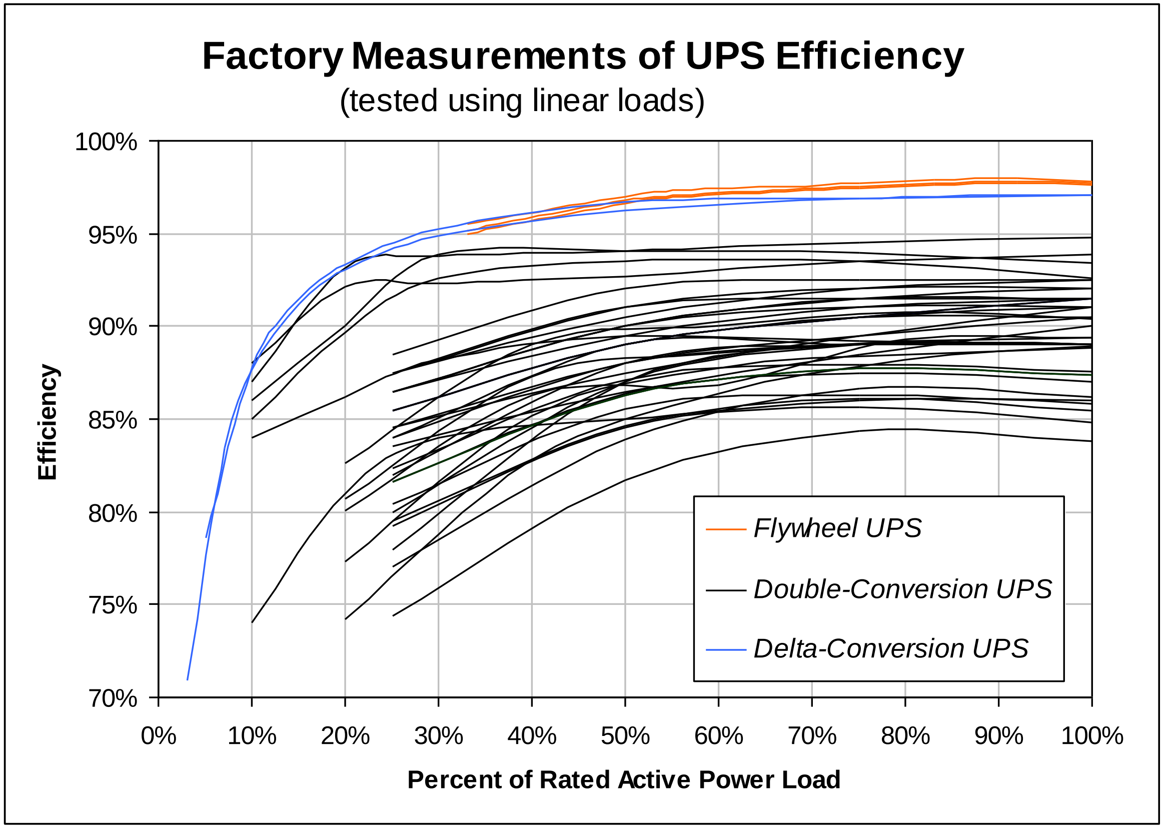
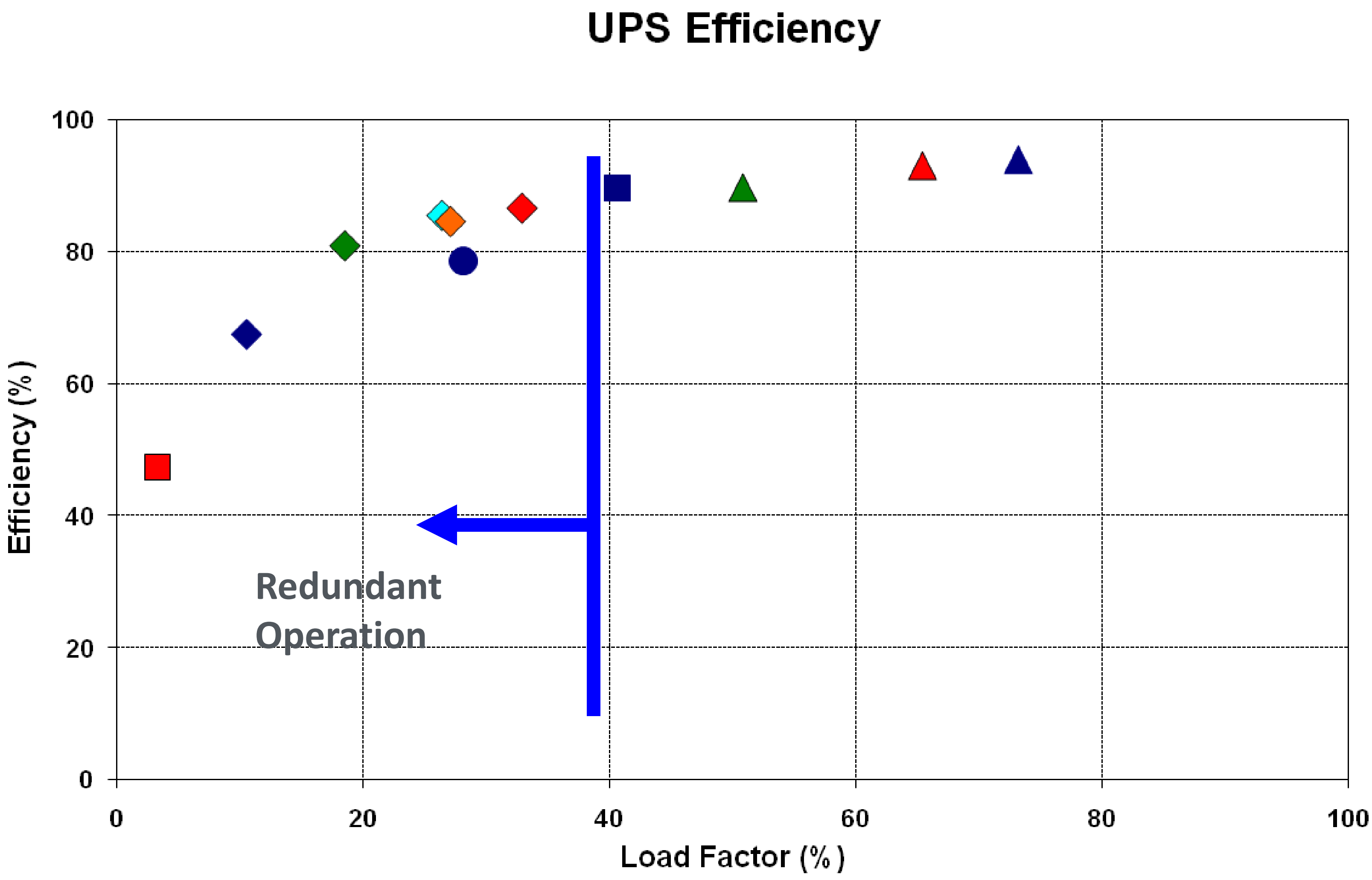
- Efficiencies vary with system design, equipment, and load
- Redundancies impact efficiency



Measured UPS efficiency



LBNL/EPRI Measured Power Supply Efficiency

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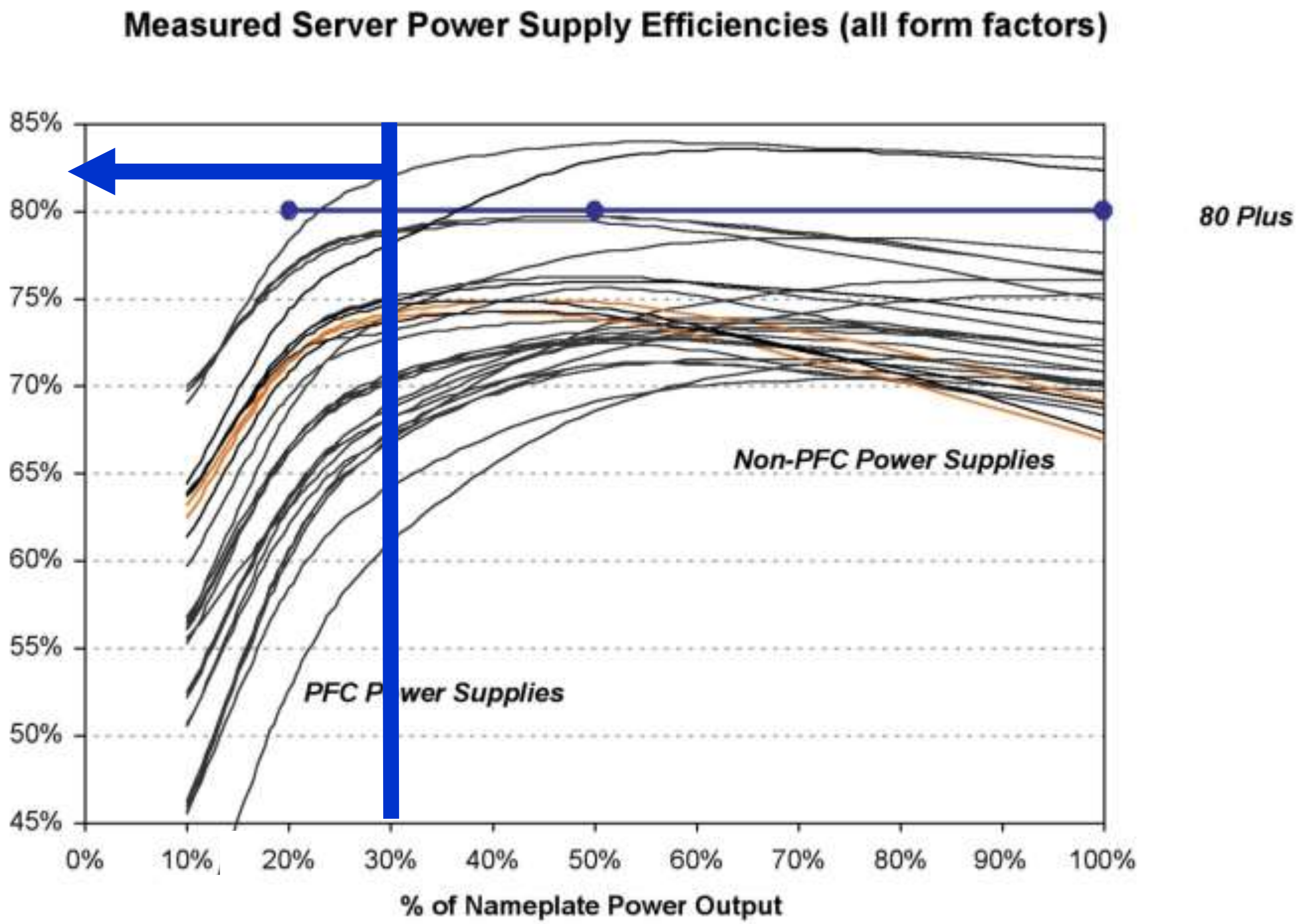
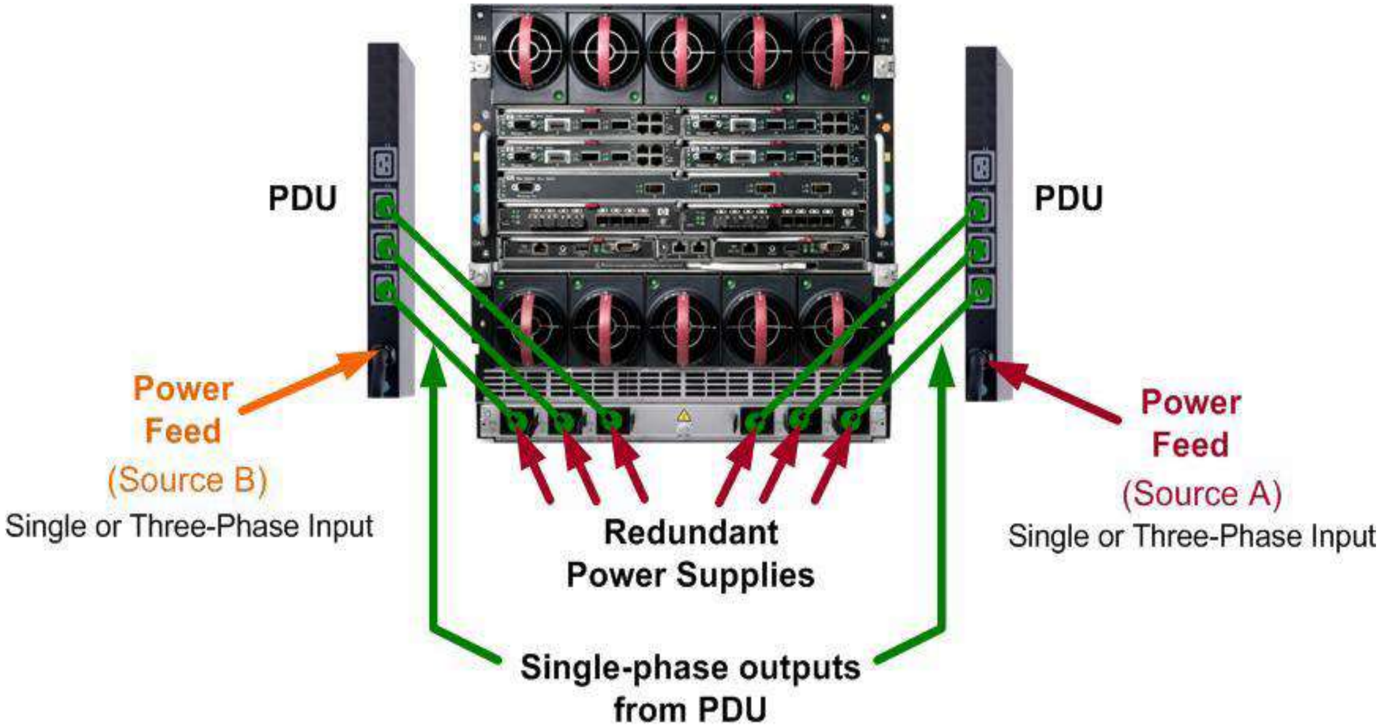


The 80 Plus program drives efficiency improvement



An Electric Power Research Institute case study illustrated the savings

Upgraded power supplies

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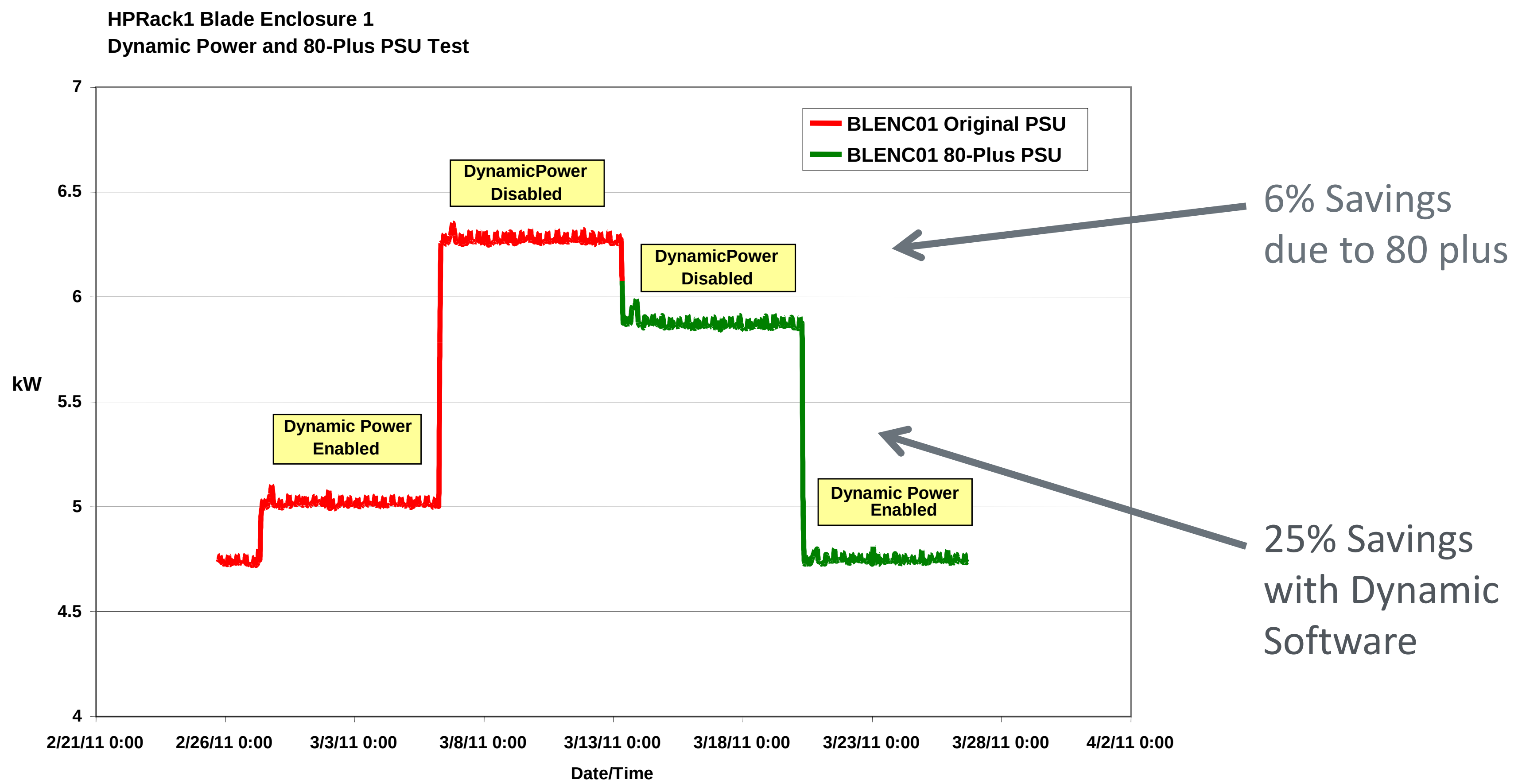

Dynamic power software turns off redundant power supplies when not needed

Redundancy

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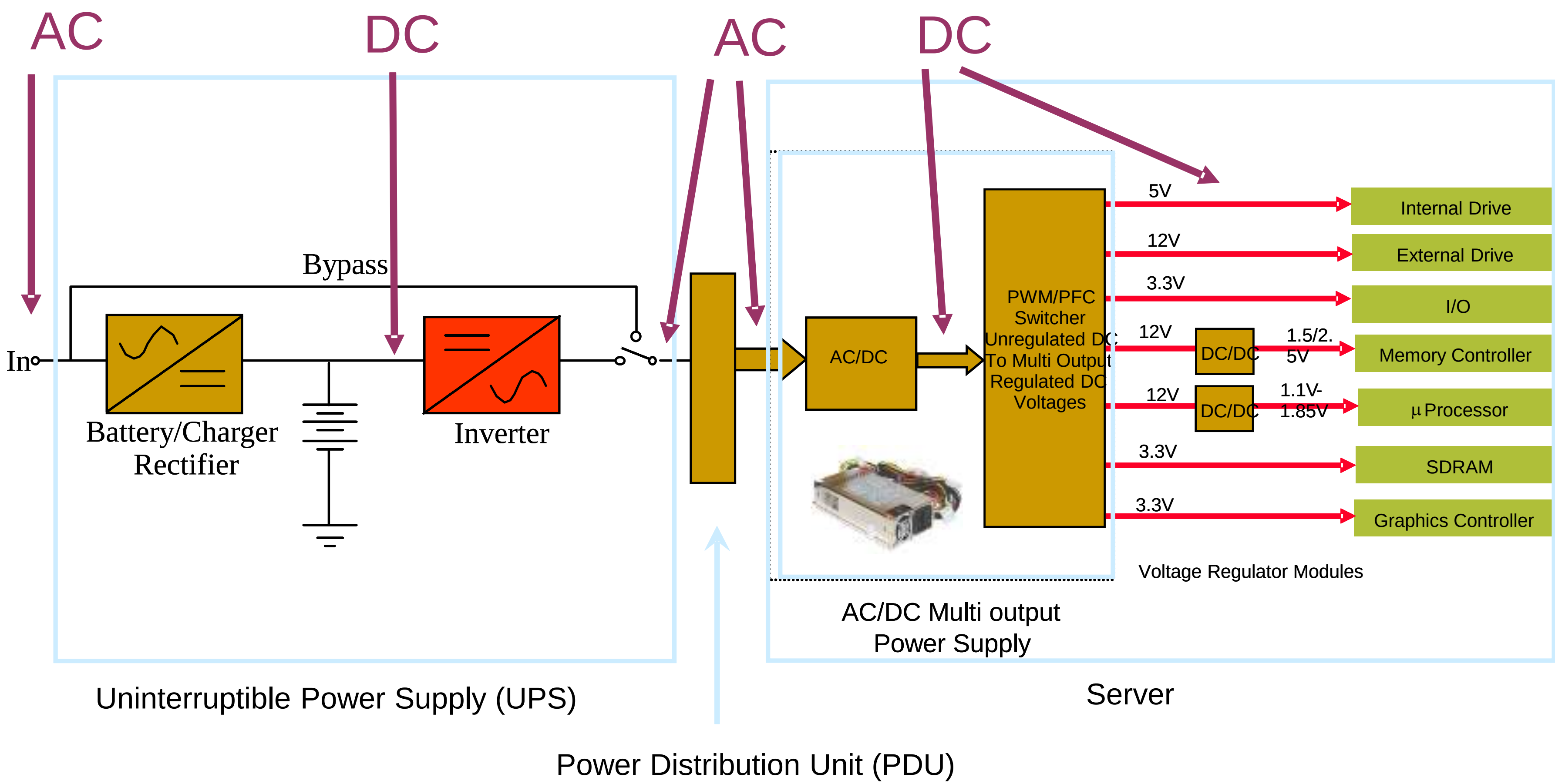
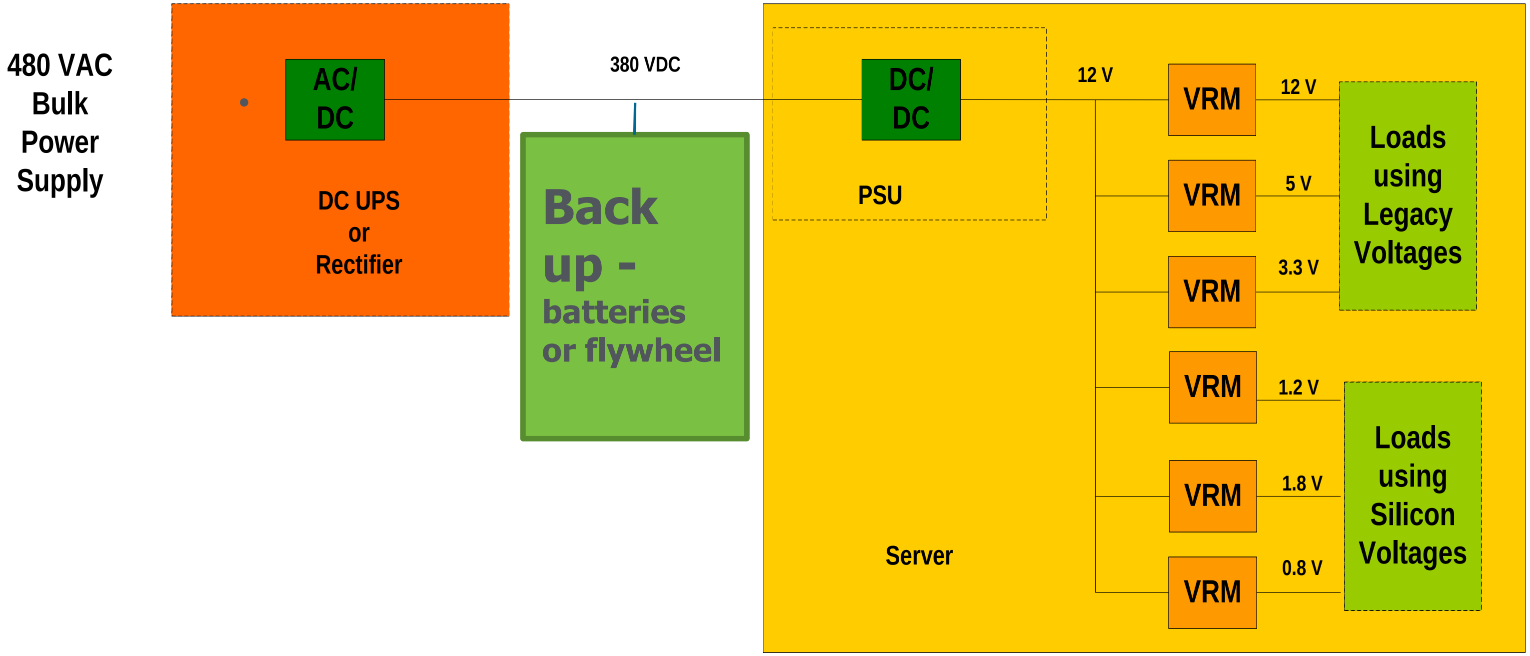
- Understand what redundancy costs and what it gets you – is it worth it?
- Does everything need the same level?
- Different strategies have different energy penalties (e.g. 2N vs. N+1)
- It's possible to more fully load UPS systems and achieve desired redundancy
- Redundancy in electrical distribution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

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



Standby generation loss

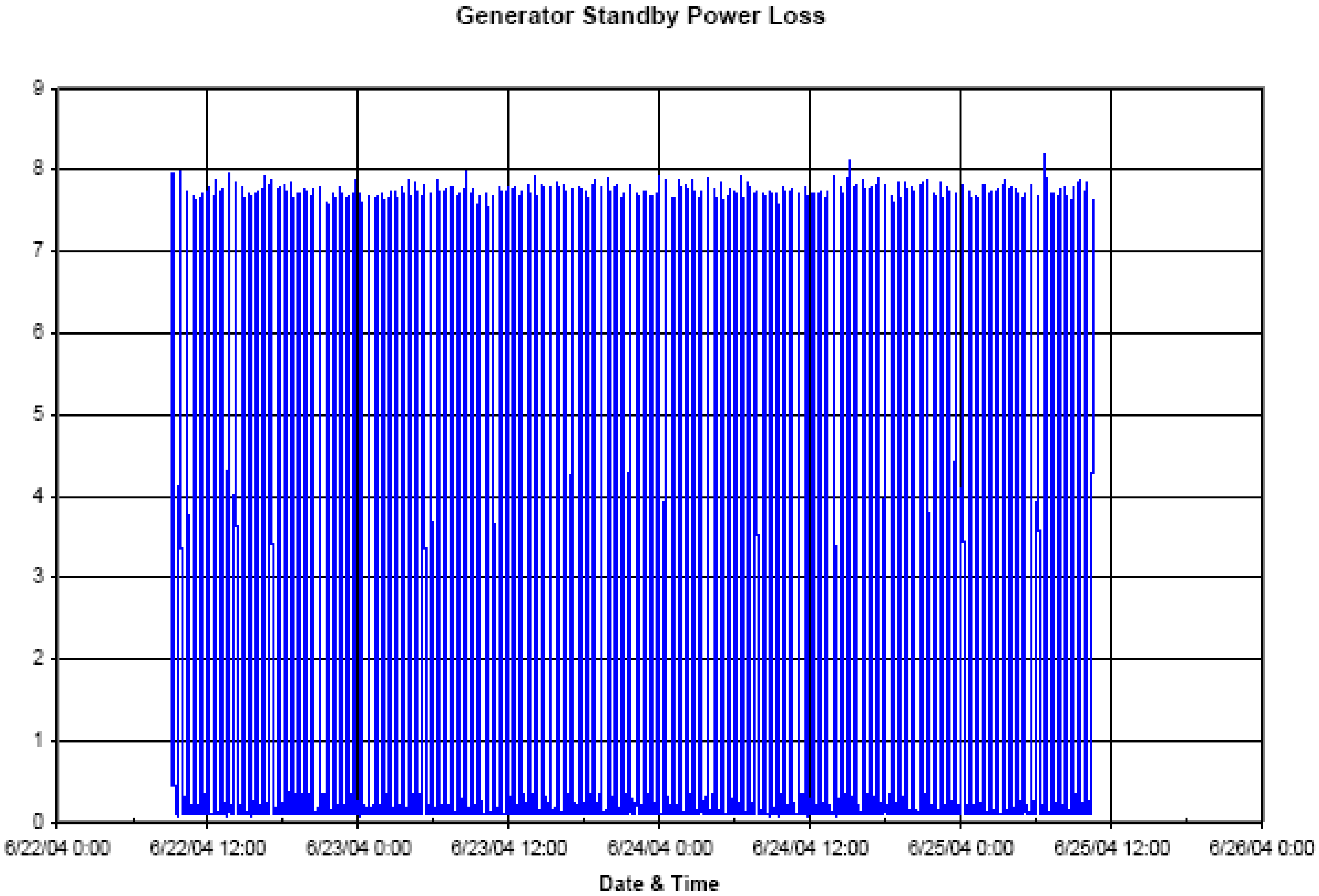
Standby generators typically use more energy than they will ever generate

Several load sources
- Heaters
- Battery chargers
- Transfer switches
- Fuel management systems

Reduce or eliminate heating, batteries, and chargers – check with manufacturer for temperature and control

Other options:
- **Right-sizing of stand-by generation**
- **Consider redundancy options**

Standby generator heater



Data center lighting

- 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

Motors and Drives

- 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

Key Electrical Takeaways

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- **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?

DCIM and Integrated Controls (Using IT to Manage IT) A Panel Discussion

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

FEMP
Federal Energy Management Program

BERKELEY LAB

DCIM Panel

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Bruce Myatt, Critical Facilities Roundtable (Moderator)

Dale Sartor, LBNL

Craig Compiano, Modius

Use IT to Manage IT Energy

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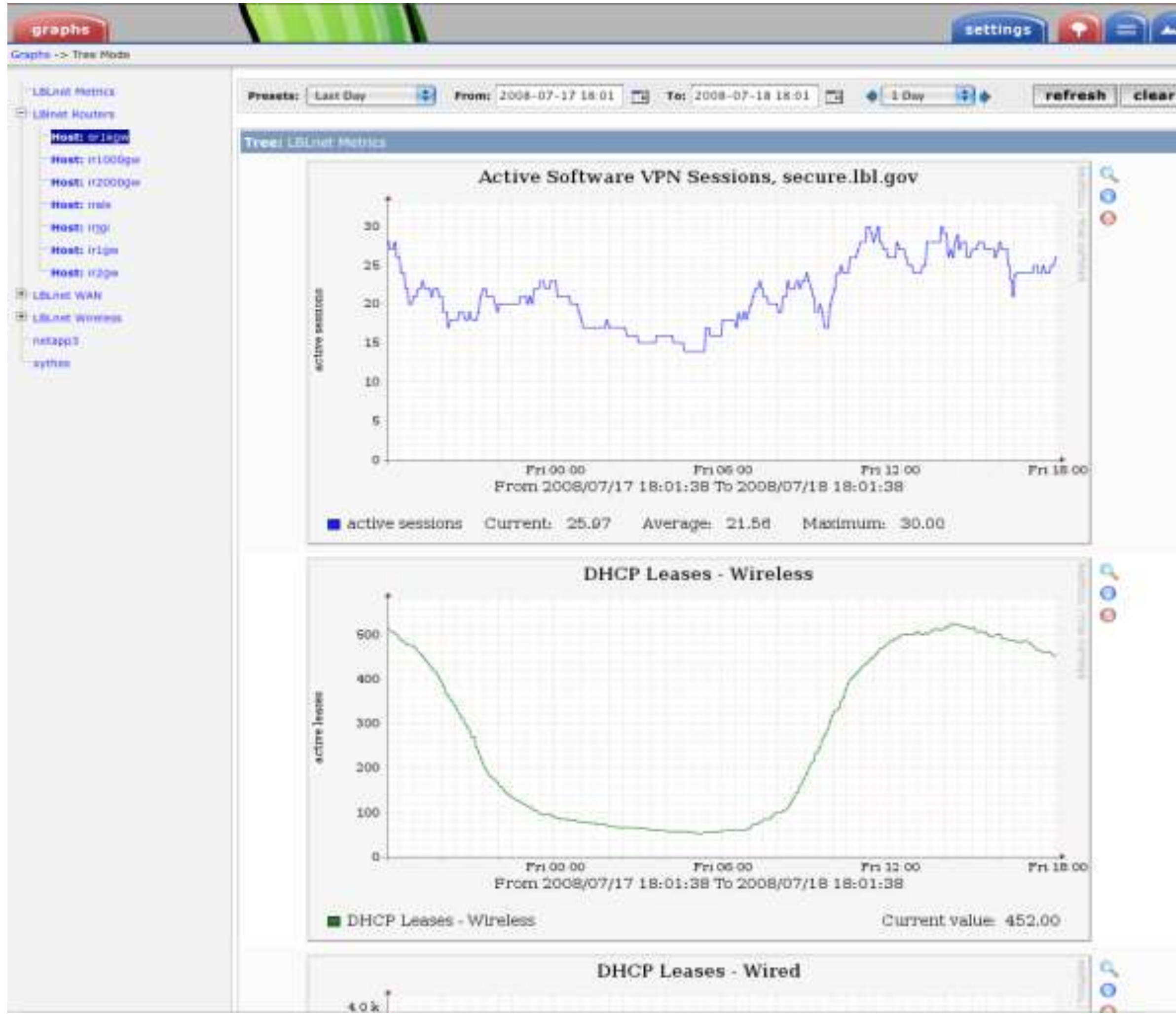
Using IT to Save Energy in IT:

- 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 Wireless Sensor Installation

- ✓ 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.

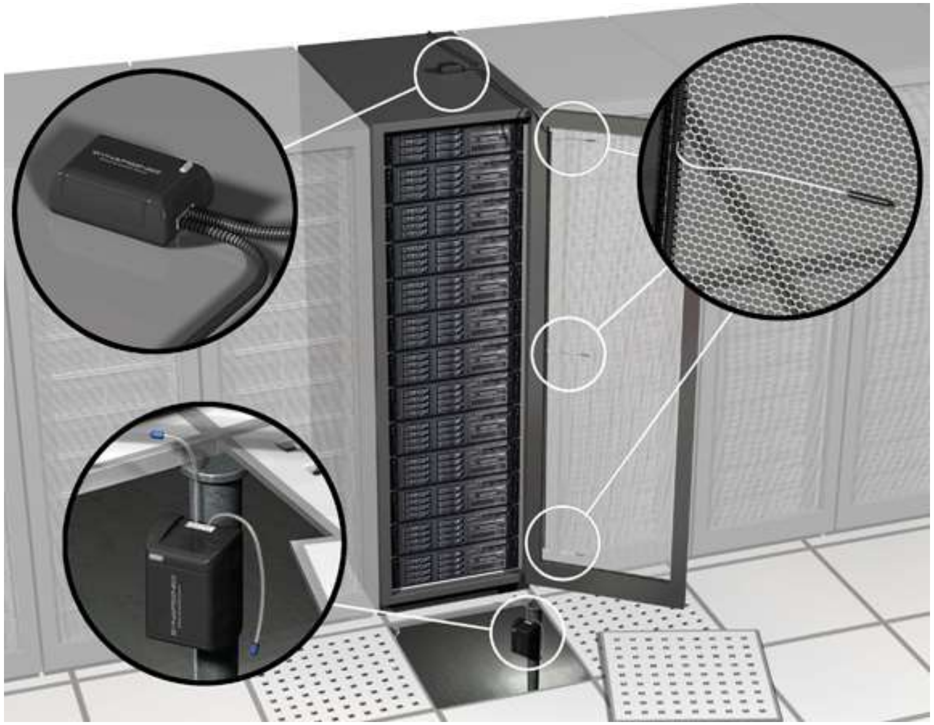


Image: SynapSense

Real-time Temperature Visualization by Level

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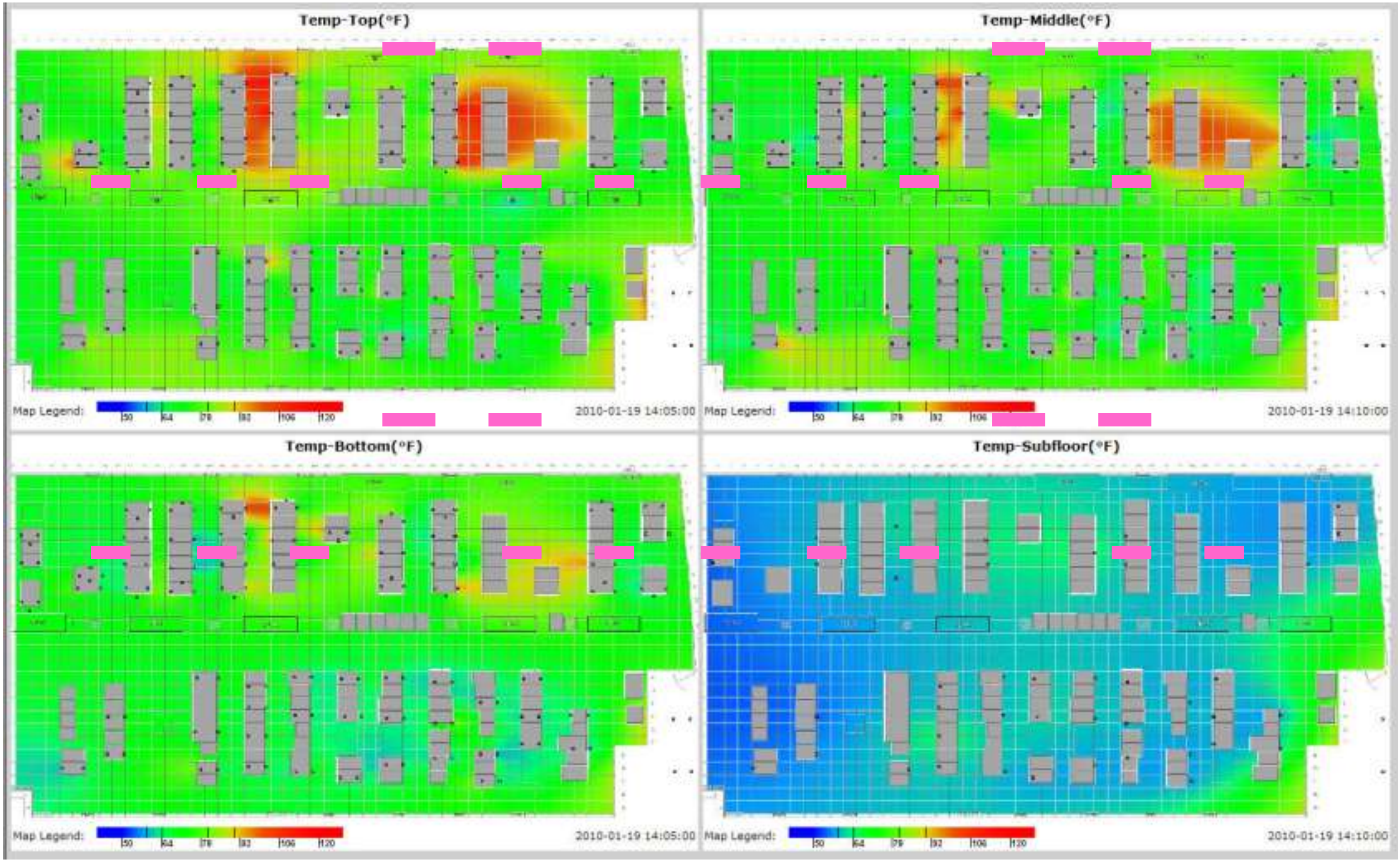

Displayed Under-floor Pressure Map…

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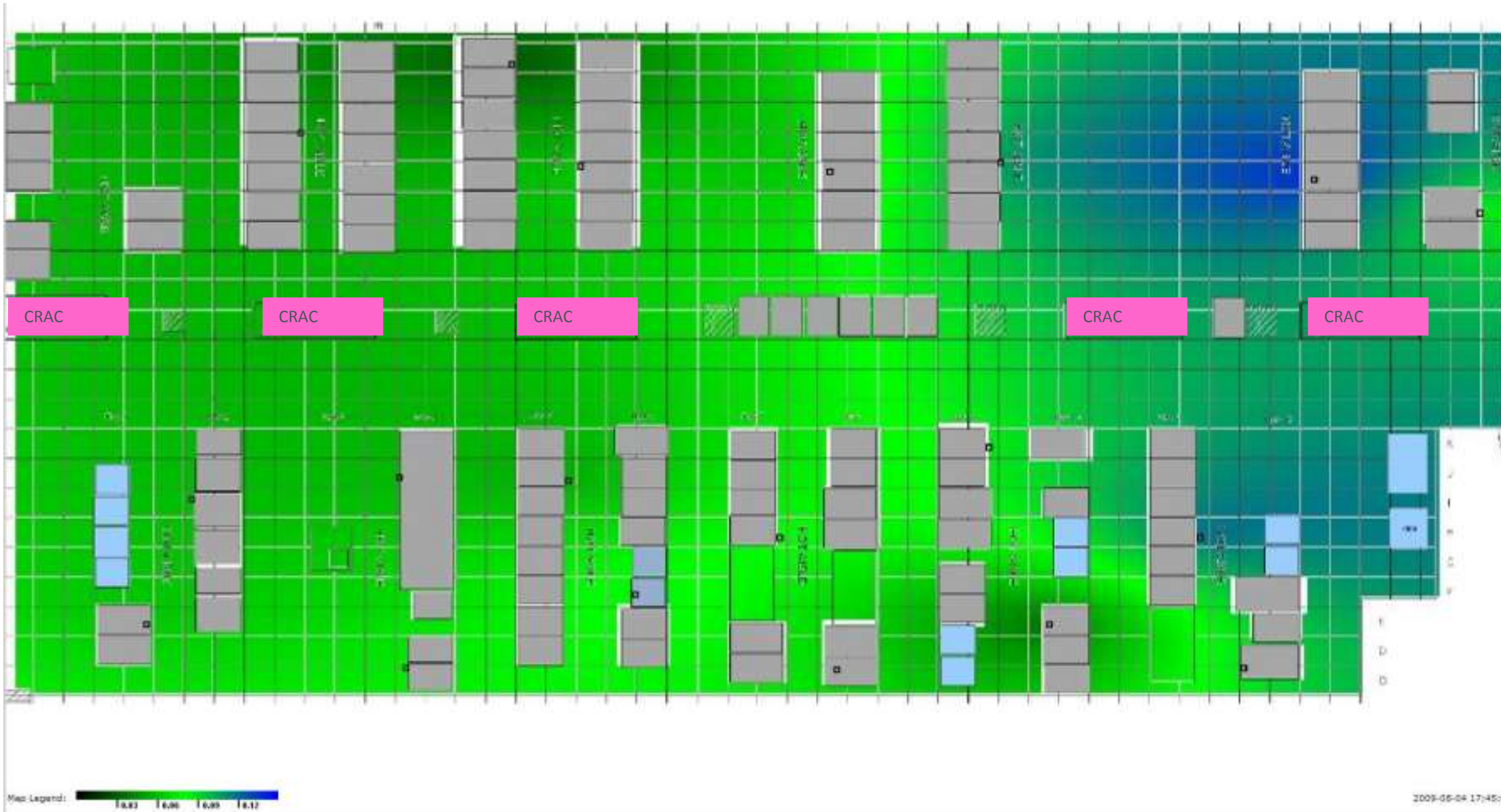

Provided Real-time Feedback During Floor-tile Tuning

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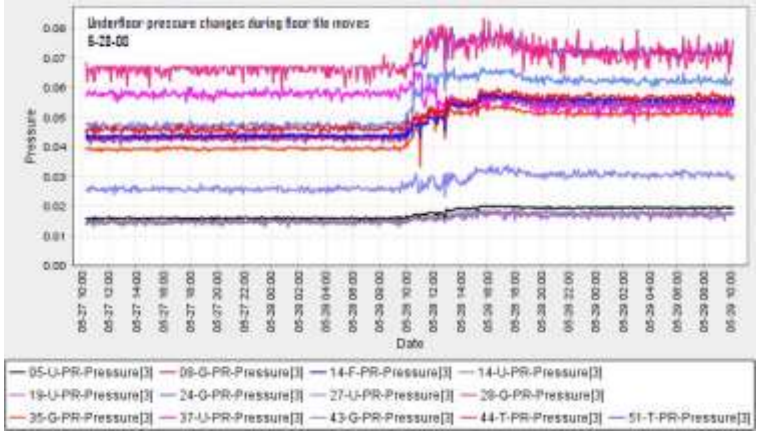
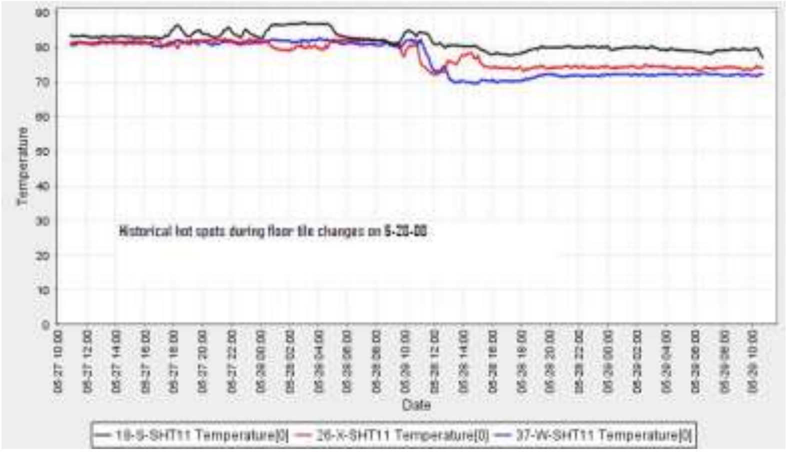
- ✓ Removed guesswork by monitoring and using visualization tool.

Under-Floor Pressure



Rack-Top Temperatures



Determined Relative CRAC Cooling Energy Impact

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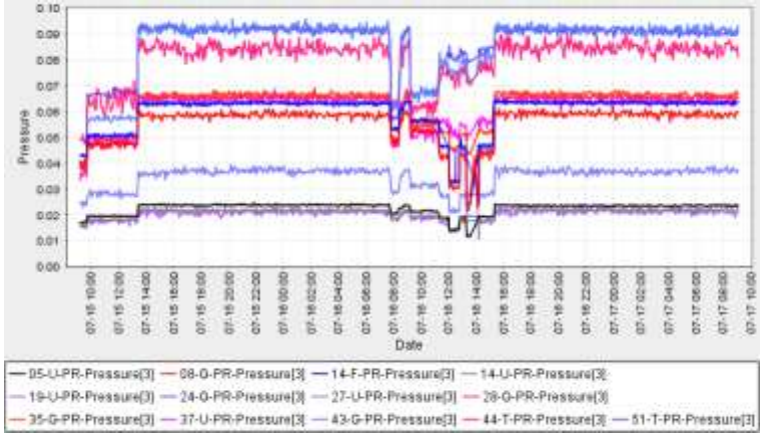
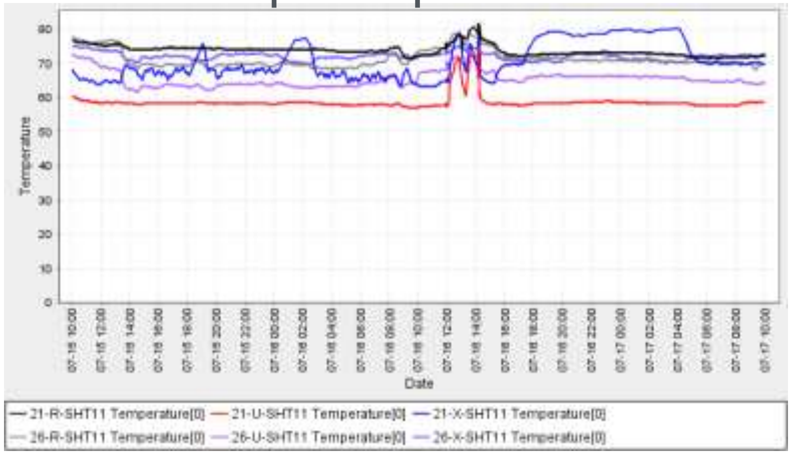
- Enhanced knowledge of data center redundancy.
- Turned off unnecessary CRAC units to save energy.

Under-Floor Pressure



Rack-Top Temperatures



Feedback Continues to Help: Note impact of IT cart!

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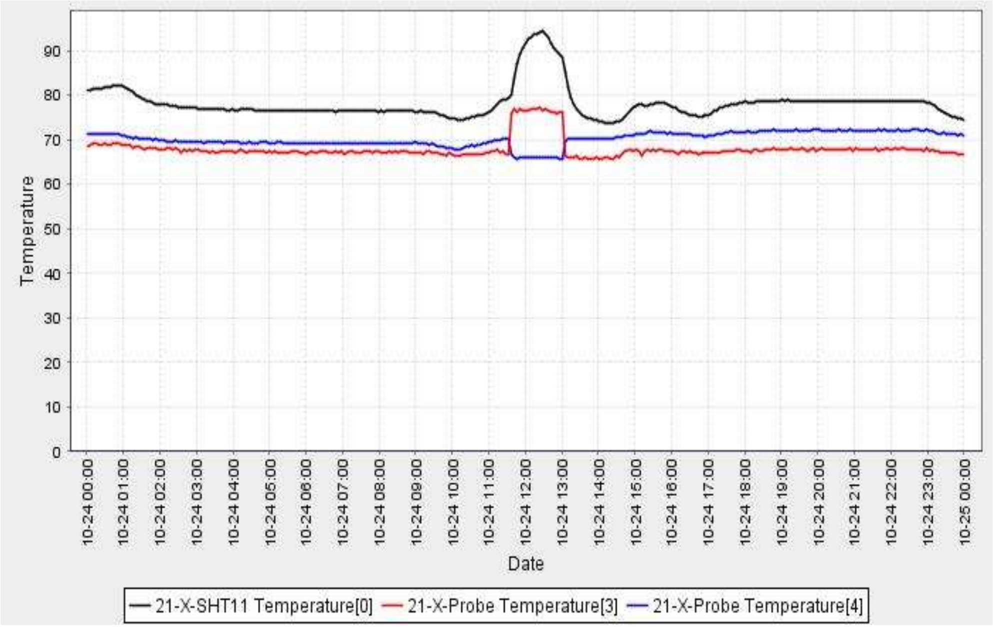
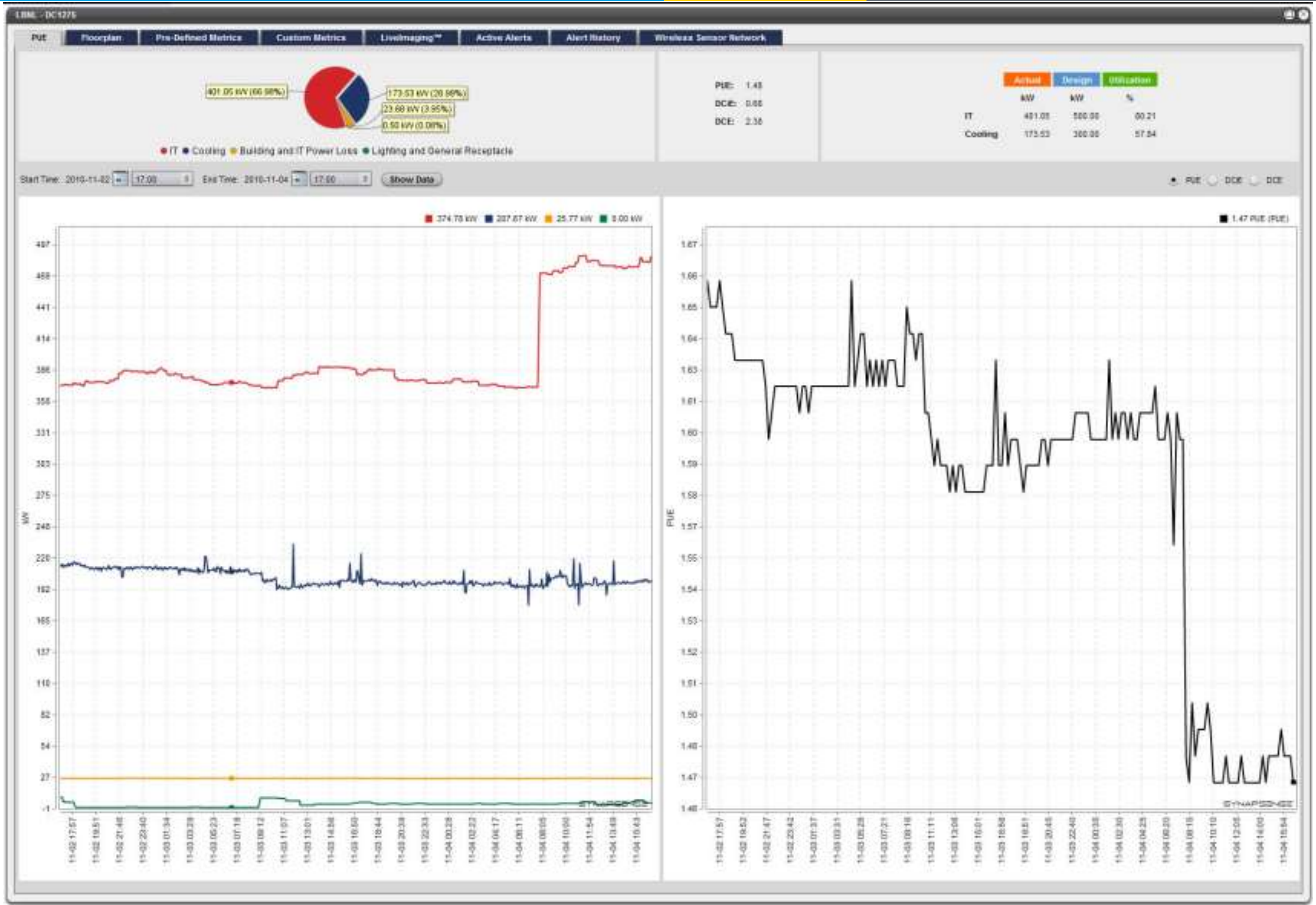
Real-time feedback identified cold aisle air flow obstruction!



Real-time PUE Display



PUE Calculation Diagram

Franchise Tax Board (FTB) Case Study

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Description:

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

Challenges:

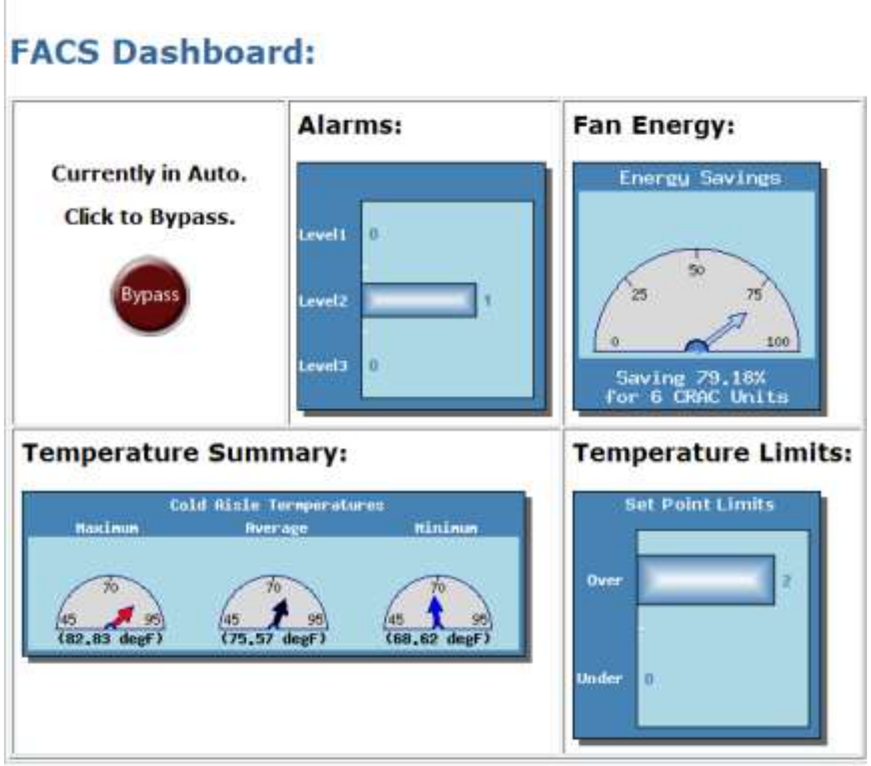
- Over-provisioned
- History of fighting
- Manual shutoff not successful

Solution:

- Intelligent supervisory control software with inlet air sensing

FTB Wireless Sensor Network

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



WSN Smart Software: learns about curtains

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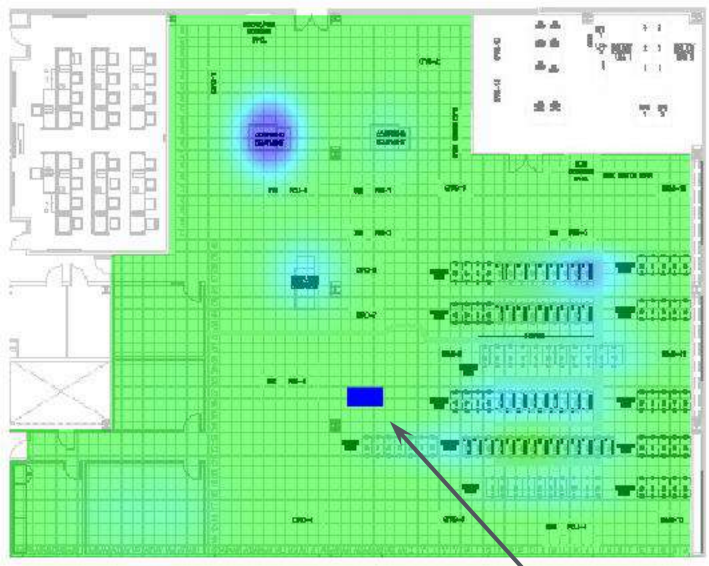
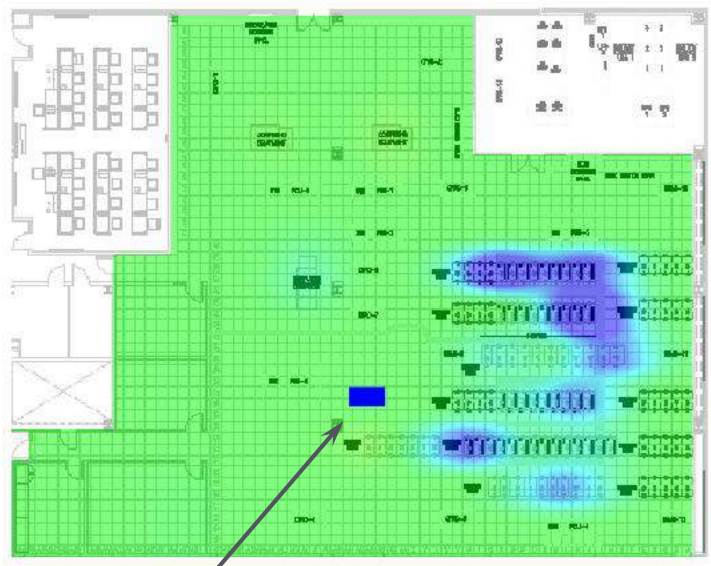
CRAH 3 influence at start

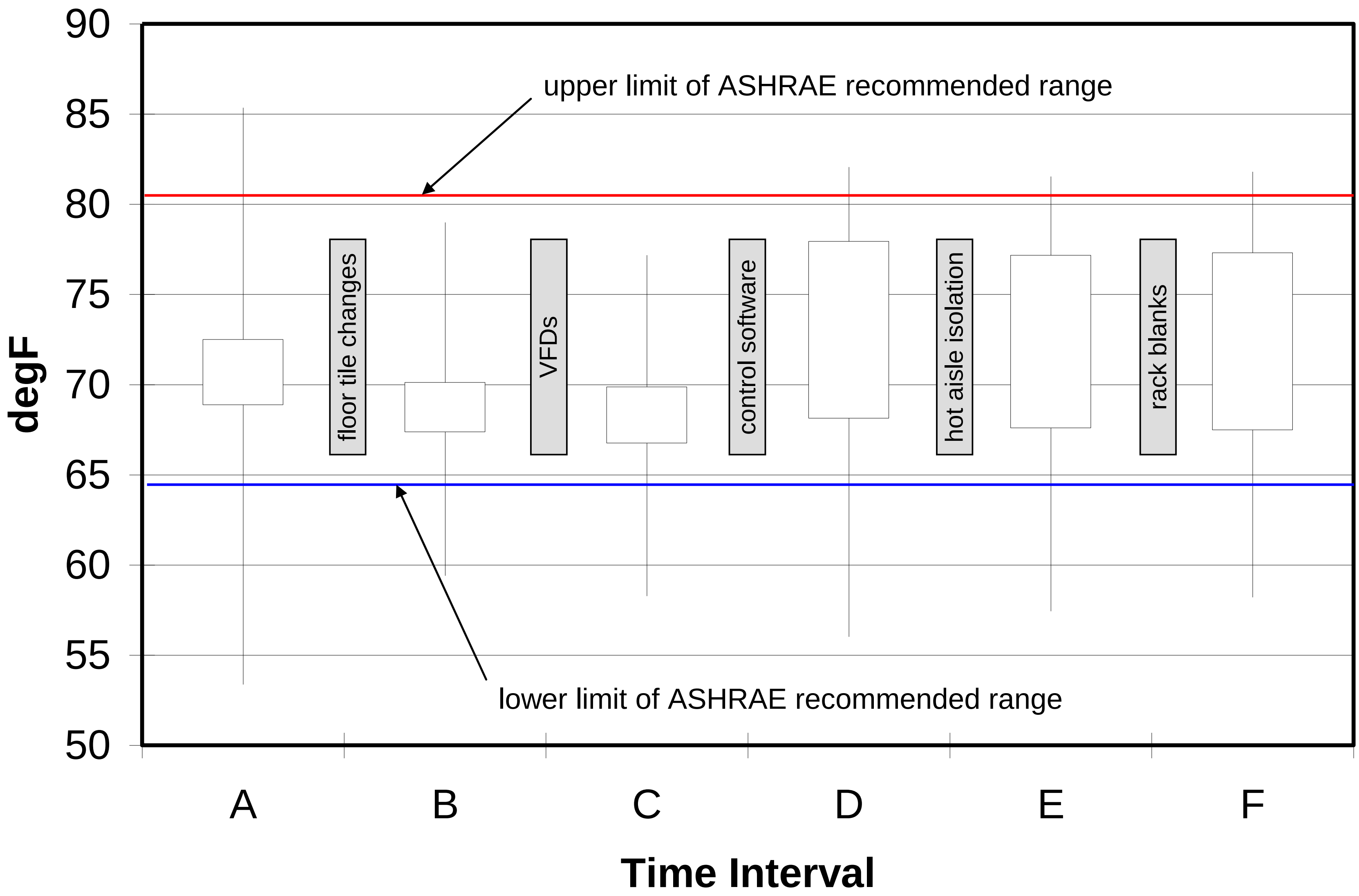


CRAH 3 influence after curtains



CRAH-03

WSN Provided Effect on Cold-aisle Temperatures:



WSN Software = Dramatic Energy Reduction…

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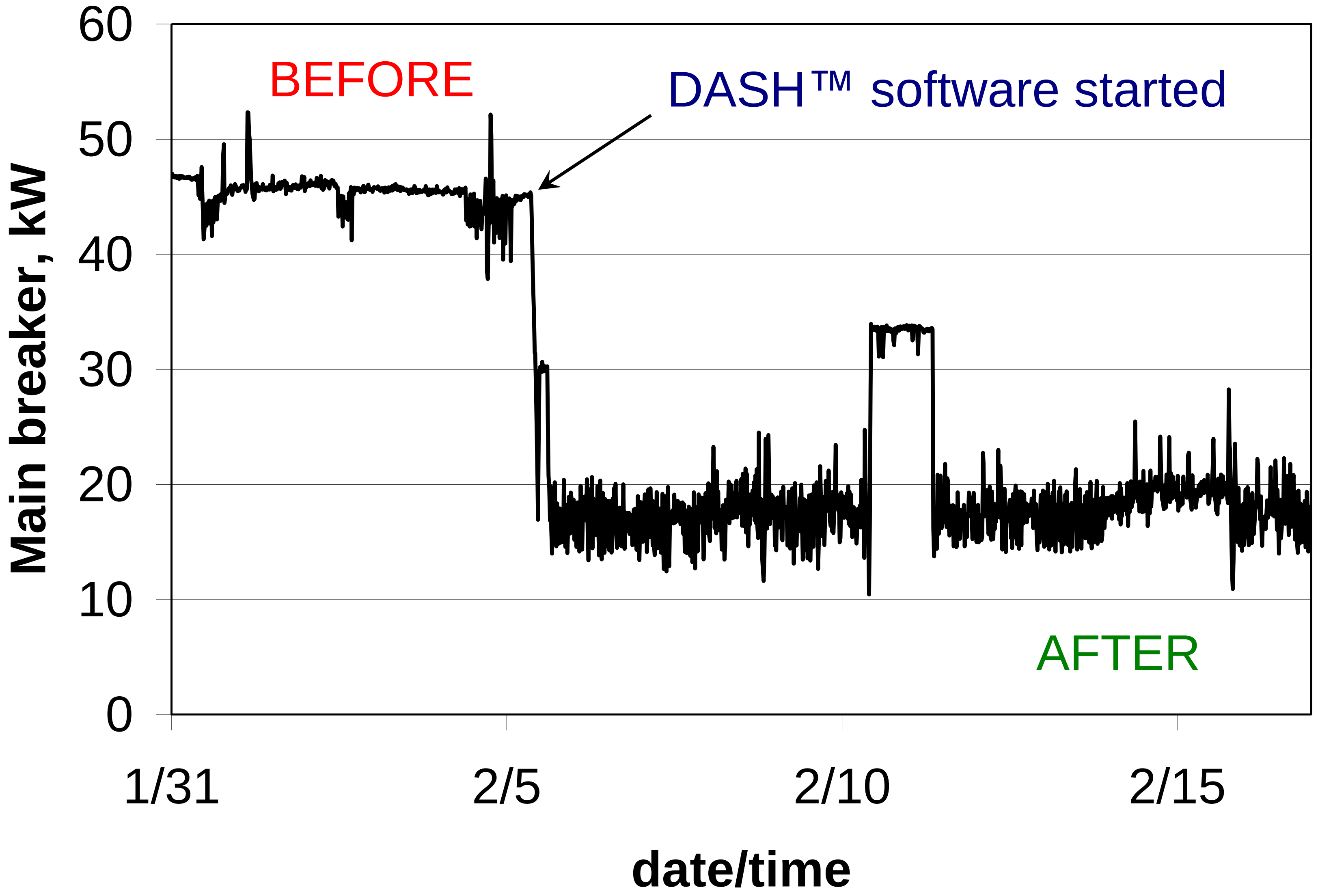

Cost-Benefit Analysis:

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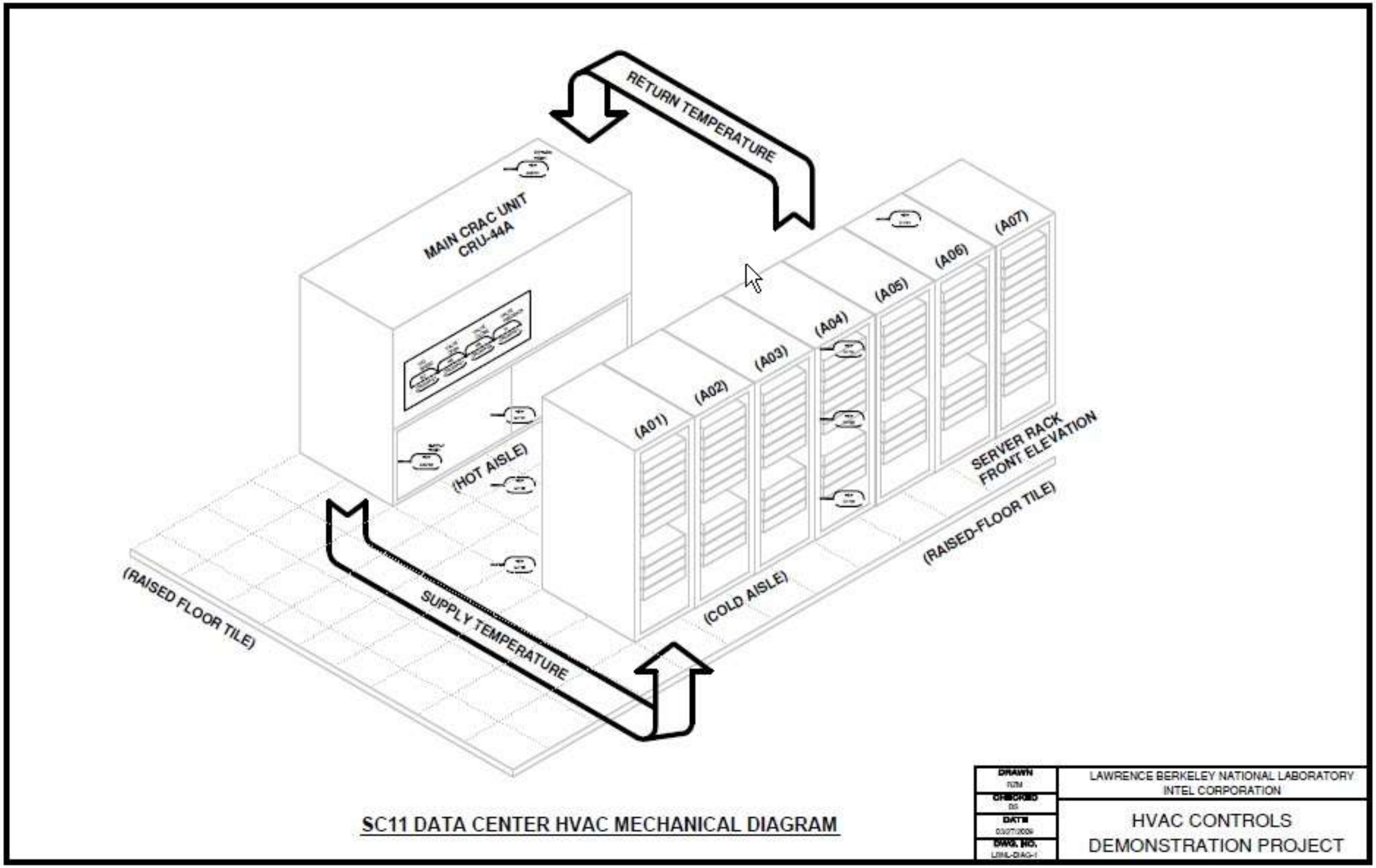
- DASH cost-benefit (sensors and software)
  - Cost: $56,824
  - Savings: $30,564
  - Payback: 1.9 years

- 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 uses *return air temperature* as the primary control-variable
  - ASHRAE and IT manufacturers agree IT equipment inlet air temperature is the key parameter
  - Optimum control difficult
- IT equipment has multiple sensors used to protect itself by adjusting internal fans, clock speeds, etc.
- One such sensor is typically located at the air inlet to the IT equipment - monitoring intake conditions
- Information from these sensors is available on the IT network

Intel Demonstration



Intel Demonstration

- 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

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

Why Dashboards?

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- 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…

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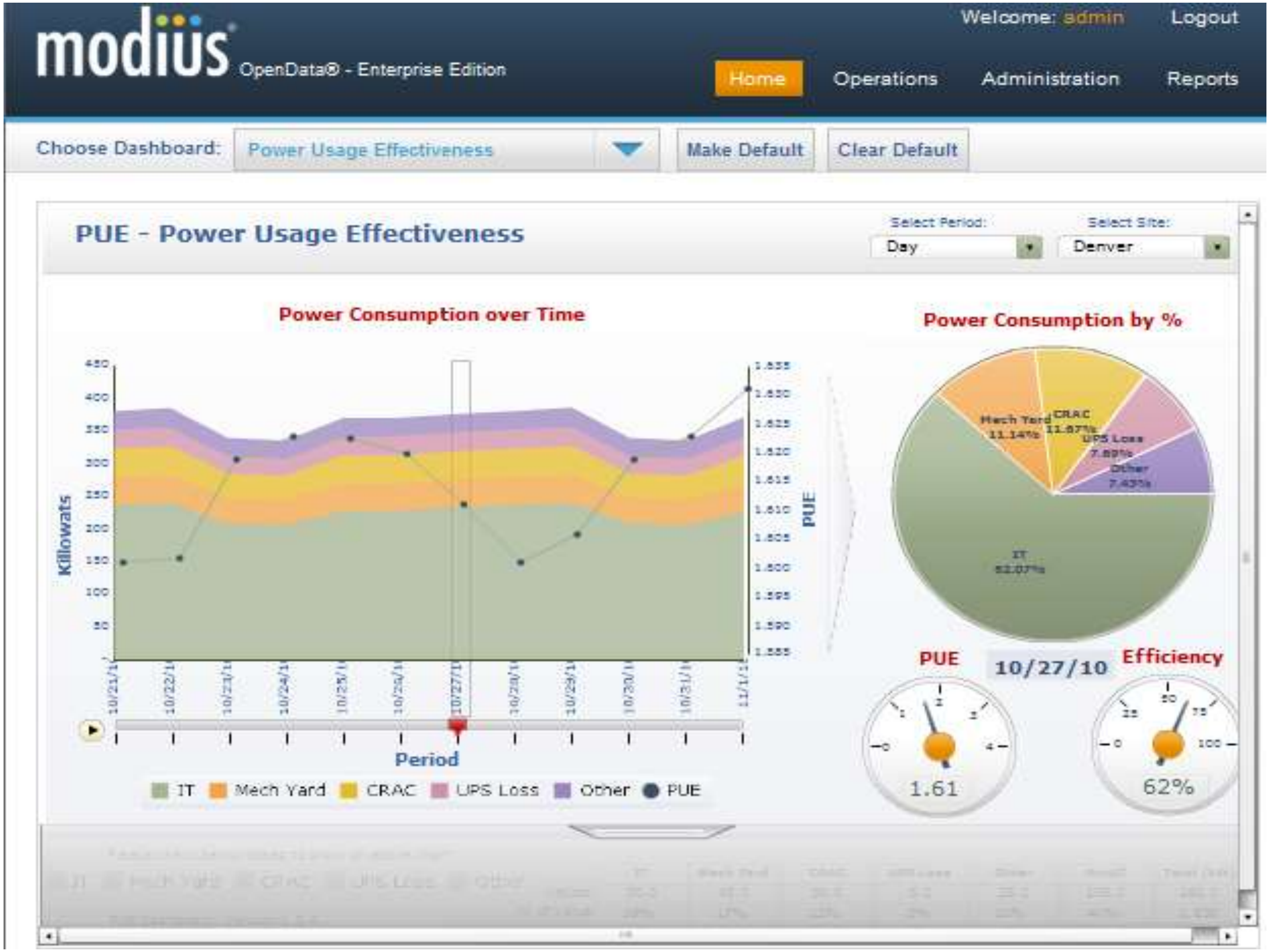
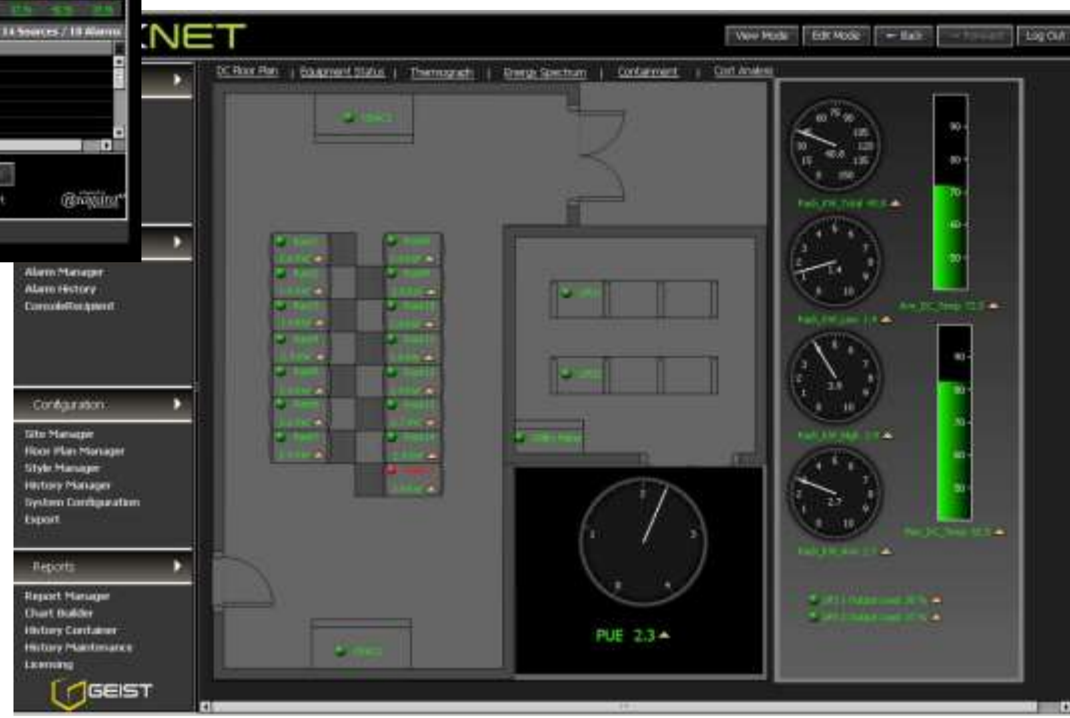


Dashboard Examples



Use IT to Manage IT: Summary

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

Questions?

Resources

Resources

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DOE Better Buildings
- Tool suite & metrics for baselining
- Training
- Qualified specialists
- Showcase Case studies
- Recognition of high energy savers

Federal Energy Management Program
- Workshops
- Federal case studies
- Federal policy guidance
- Information exchange & outreach
- Qualified specialists
- Technical assistance

GSA
- Workshops
- Quick Start Efficiency Guide
- Technical Assistance

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

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

Resources from DOE Federal Energy Management Program (FEMP)

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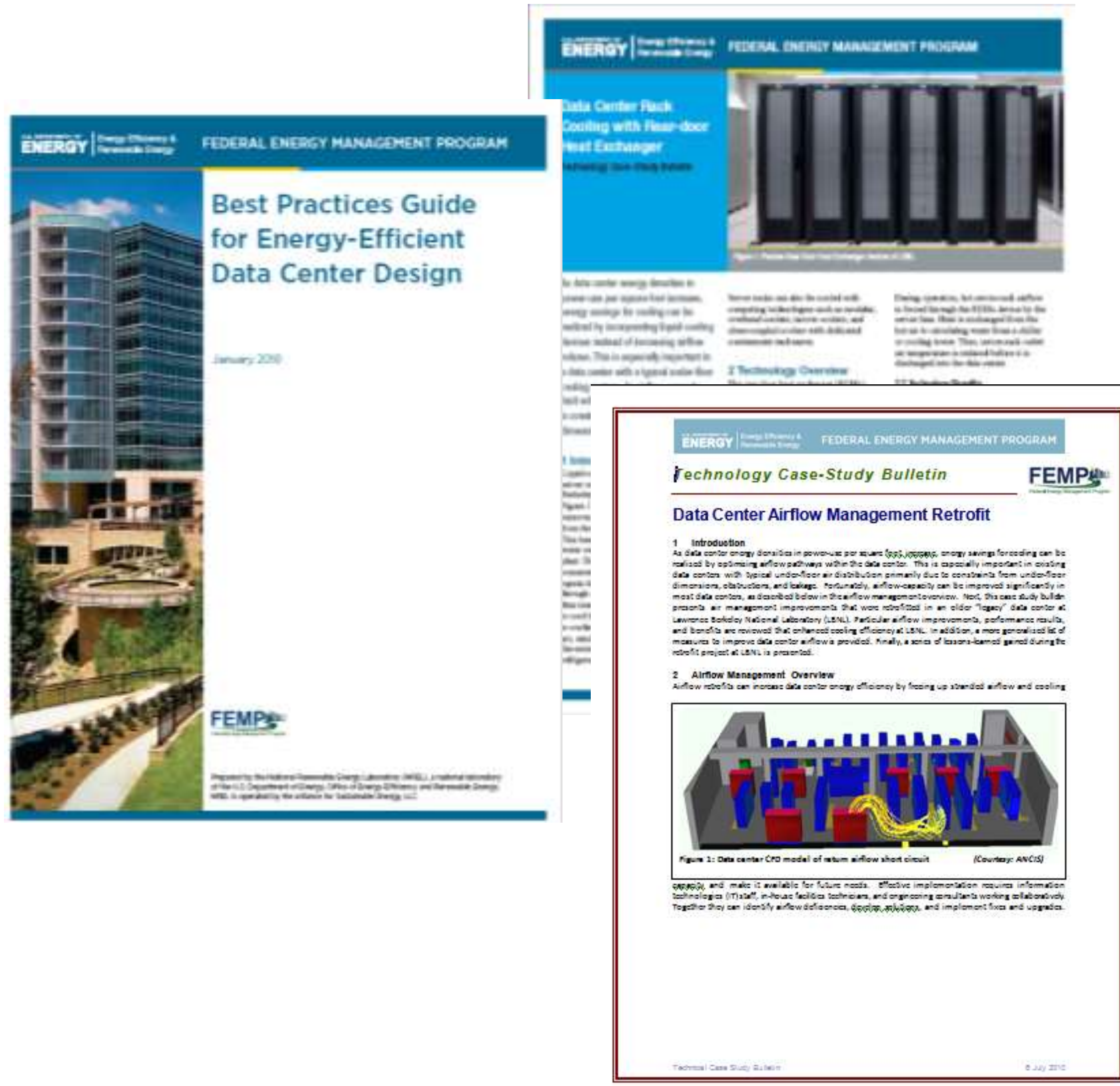
- Best Practices Guide
- Benchmarking Guide
- Data Center Programming Guide
- Technology Case Study Bulletins
- Procurement Specifications
- Report Templates
- Process Manuals
- Quick-Start Guide



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

- **DC Pro Software and Assessment 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**
- **Data Center Energy Practitioner (DCEP) certificate program**
  - Qualification of professionals to evaluate energy efficiency opportunities

DOE DC Pro Tool Suite

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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

Data Center Energy Practitioner (DCEP) Program

U.S. DOE certificate process for energy practitioners qualified to assess energy consumption and energy efficiency opportunities in Data Centers.

Key objective:

- Raise the standard of energy assessors
- Greater repeatability/credibility of recommendations.

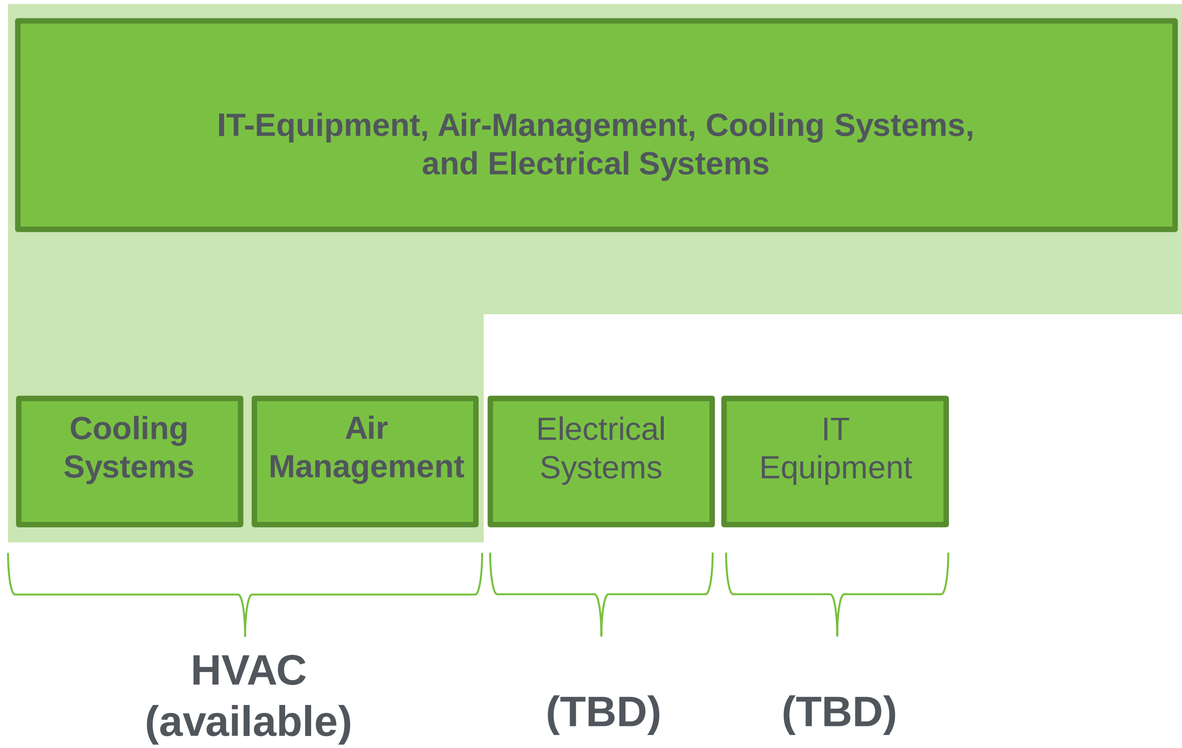
Target groups include:

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

Training & Certificate Disciplines, Levels, and Tracks

Level 1 "Generalist" (1-day):
Pre-qualifications, Training/Exam on All Disciplines
+ Assessment Process
+ DC Pro Profiling Tool

Level 2 "Specialist" (2-day):
Pre-qualifications, Training/Exam on Select Disciplines
+ Assessment Process
+ System Assessment Tool



There is also a "Training Track": Training only (no pre-qualifications and no exam)

DCEP Training Organizations

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DCEP training is delivered by two training organizations that were selected through a competitive process. The DCEP Program Manager is also providing training.

The training organizations:

- license training and exam content from U.S. DOE
- provide training/exams
- issue certificates.

Access up-to-date program information and complete training schedule at U.S. DOE Center of Expertise for Energy Efficiency in Data Centers:

http://datacenters.lbl.gov/dcep

Energy Star

A voluntary public-private partnership program

- Buildings
- Products

Energy Star Data Center Activities

- 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, UPSs, storage, and networking equipment

Resources

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

http://datacenters.lbl.gov/

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

https://www4.eere.energy.gov/challenge/partners/data-centers

Questions?

Workshop Summary

Best Practices

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

FEMP
Federal Energy Management Program

BERKELEY LAB

Data Center Best Practices Summary

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

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

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7. Improve Electrical Efficiency

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

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.

Most importantly…

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

Questions?

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