# PG&E/FEMP Data Center Efficiency Workshop

## San Francisco

## May 2, 2012

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(Version: 4/22/12)

U.S. Department of Energy
Energy Efficiency and Renewable Energy
FEMP
Federal Energy Management Program
Berkeley Lab

# Download Presentation

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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
- 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

# Challenging Conventional Wisdom: Game Changers



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

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Energy Efficiency and Renewable Energy

FEMP Federal Energy Management Program

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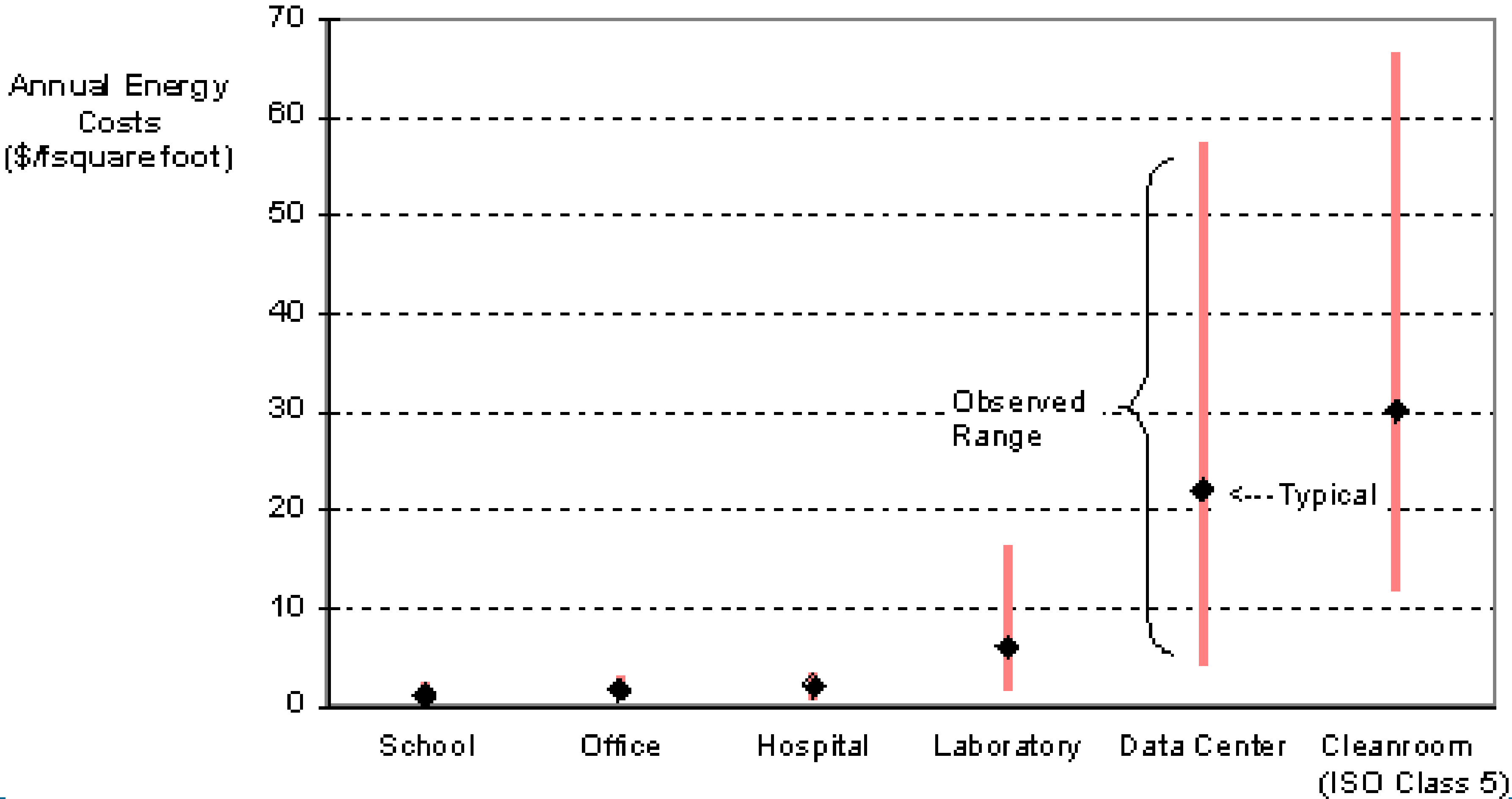
# Workshop Learning Objectives

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

## Comparative Energy Costs
## High-Tech Facilities *vs.* Standard Buildings



# 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
  - 1.5% of US Electricity consumption
  - Projected to double in next 5 years
  - Power and cooling constraints in existing facilities

# Projected Data Center Energy Use

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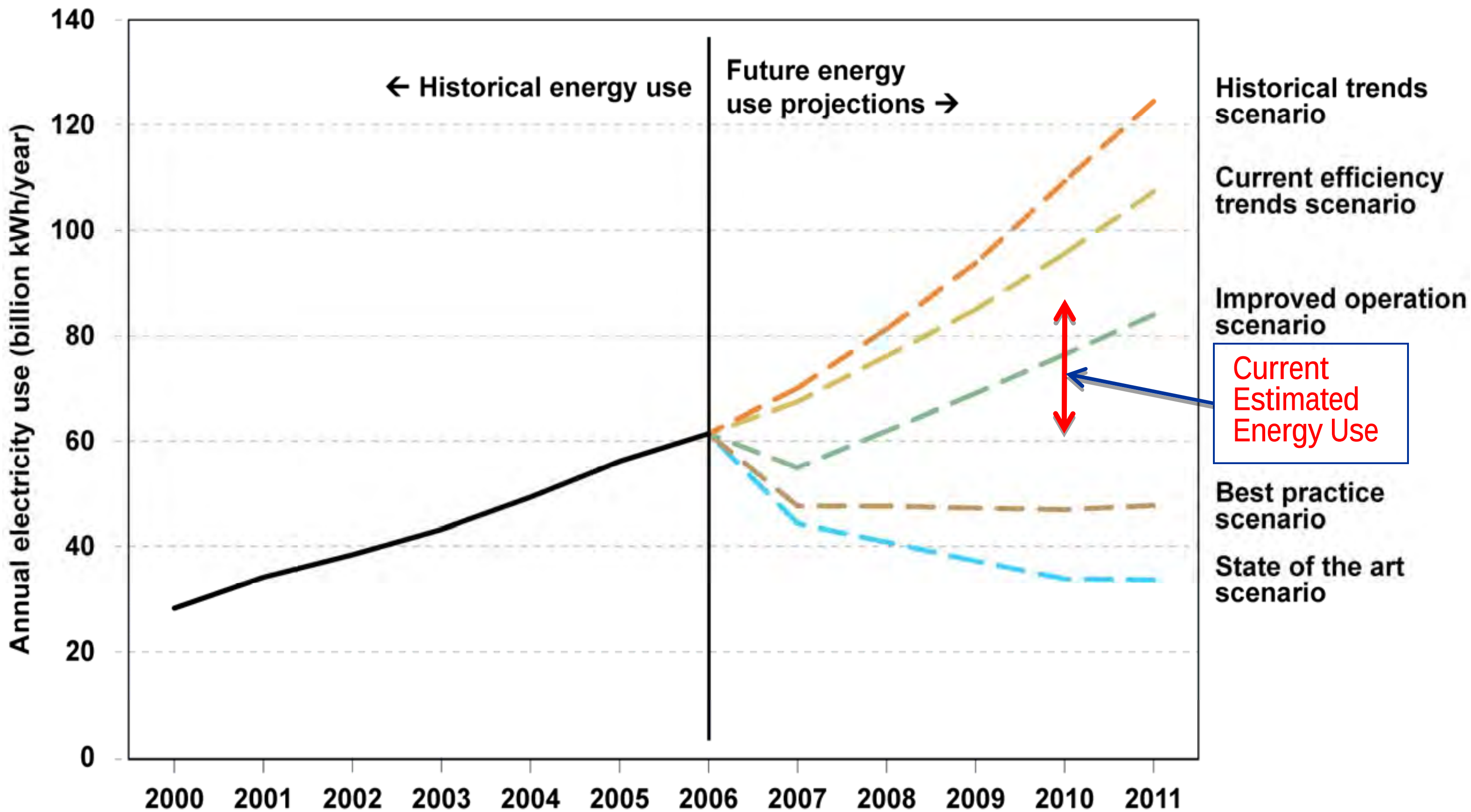


EPA Report to Congress 2008

# The Rising Cost of Ownership

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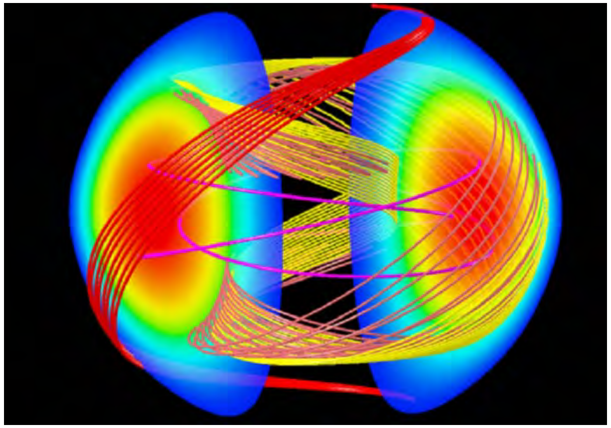
- From 2000 – 2006, computing performance increased 25x but energy efficiency only 8x
  - Amount of power consumed per $1,000 of servers purchased has increased 4x
- Cost of electricity and supporting infrastructure now surpassing capital cost of IT equipment
- Perverse incentives -- IT and facilities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

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# LBNL Super Computer Systems Power

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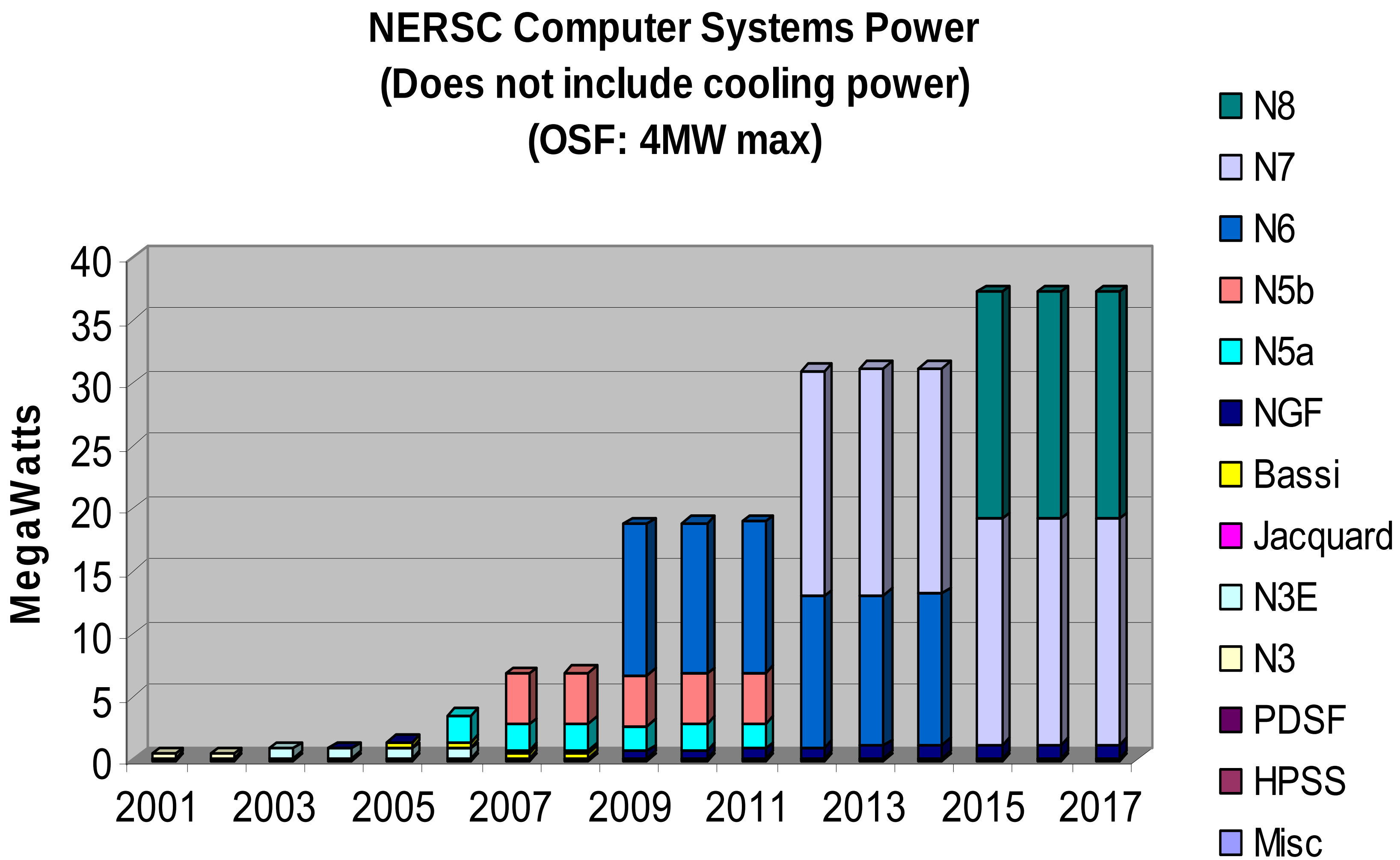
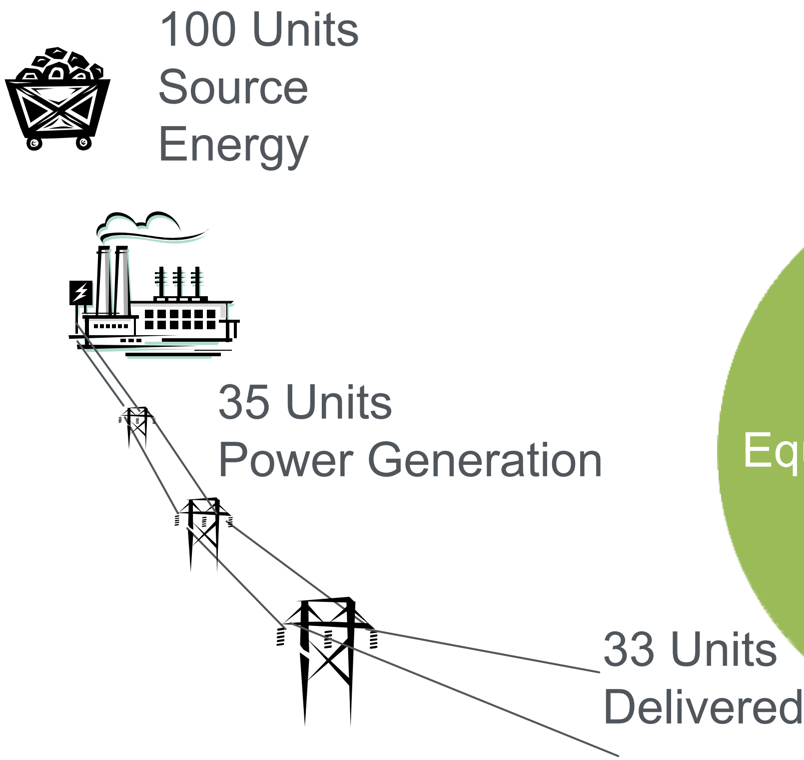
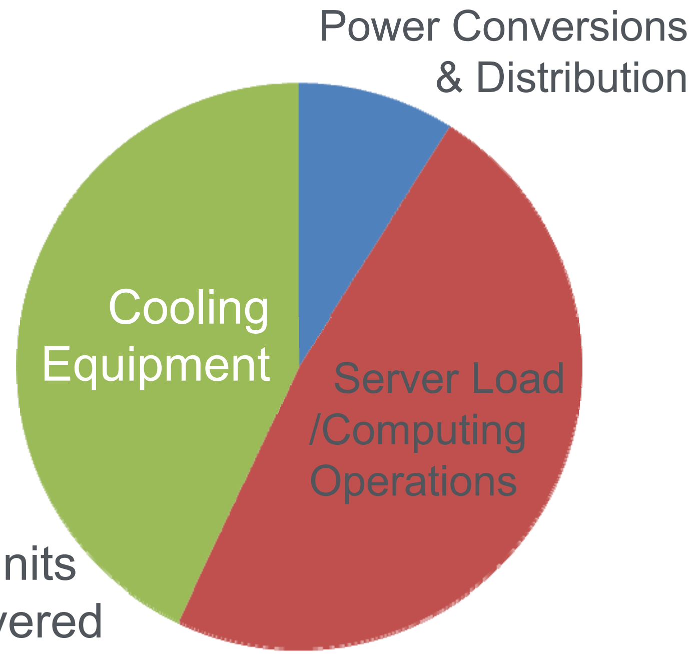


# Energy Efficiency = Useful computation / Total Source Energy

## Typical Data Center Energy End Use



# Energy Efficiency Opportunities

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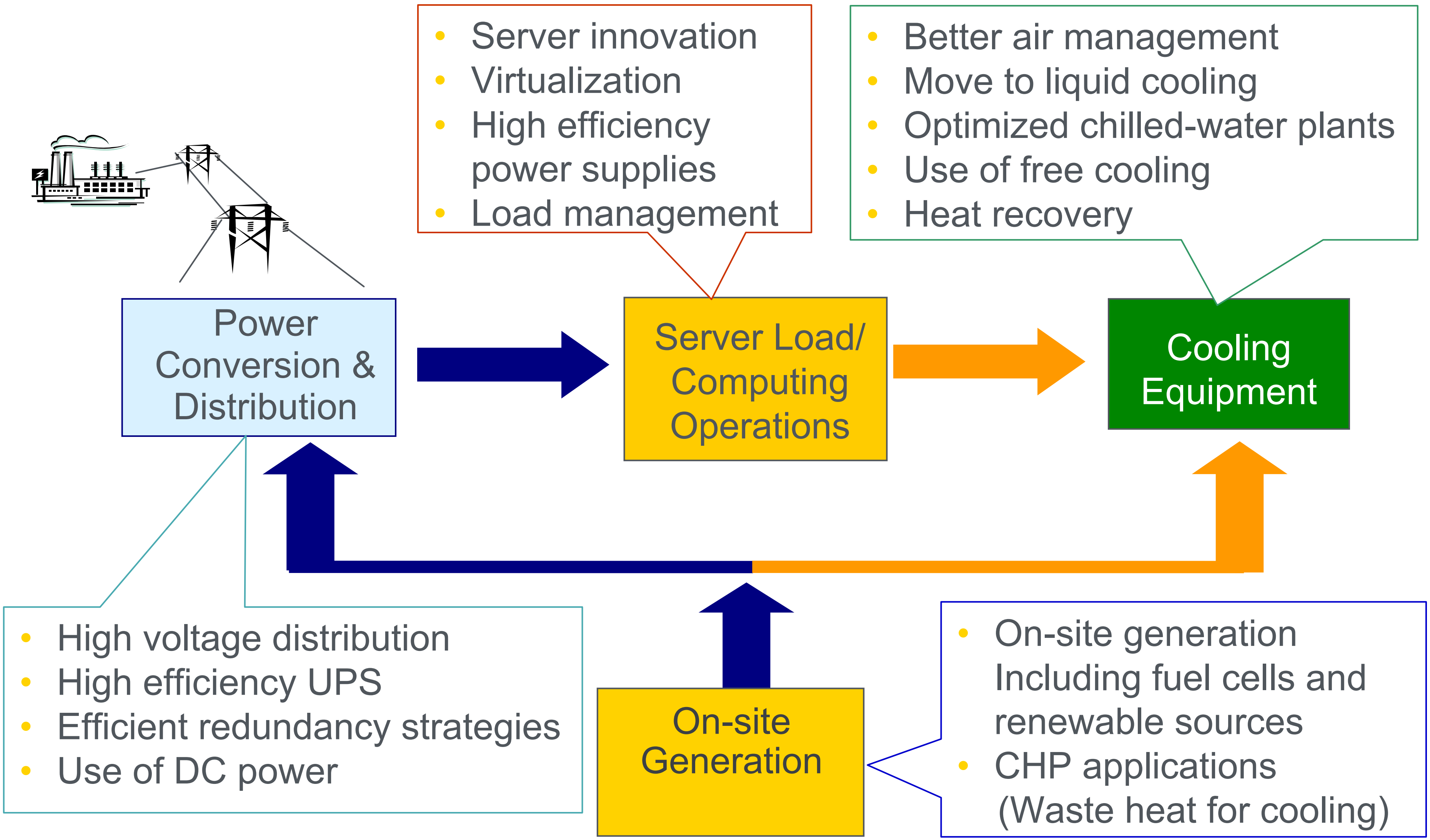
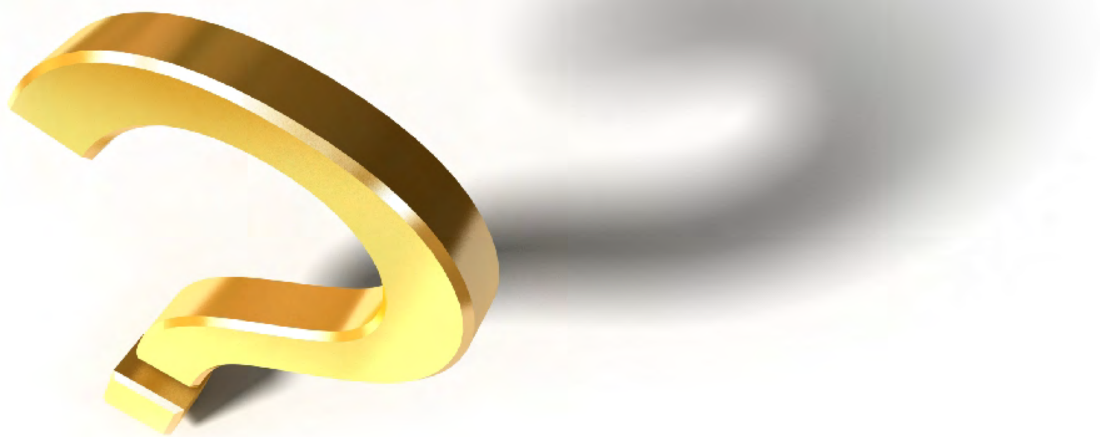


# Potential Benefits of Data Center Energy Efficiency

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

# Questions?



# Performance metrics and benchmarking

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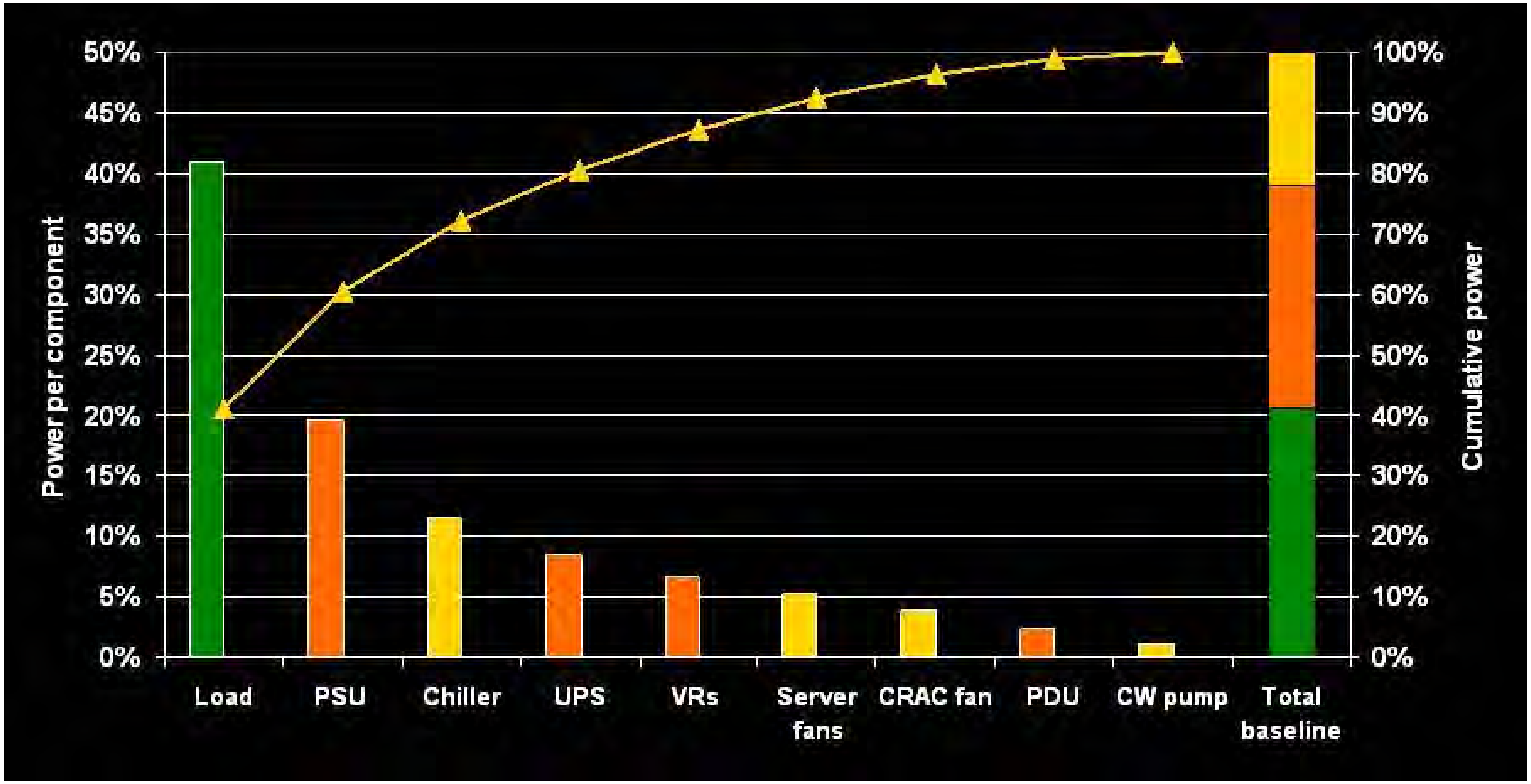
# Electricity use in data centers




Courtesy of Michael Patterson, Intel Corporation

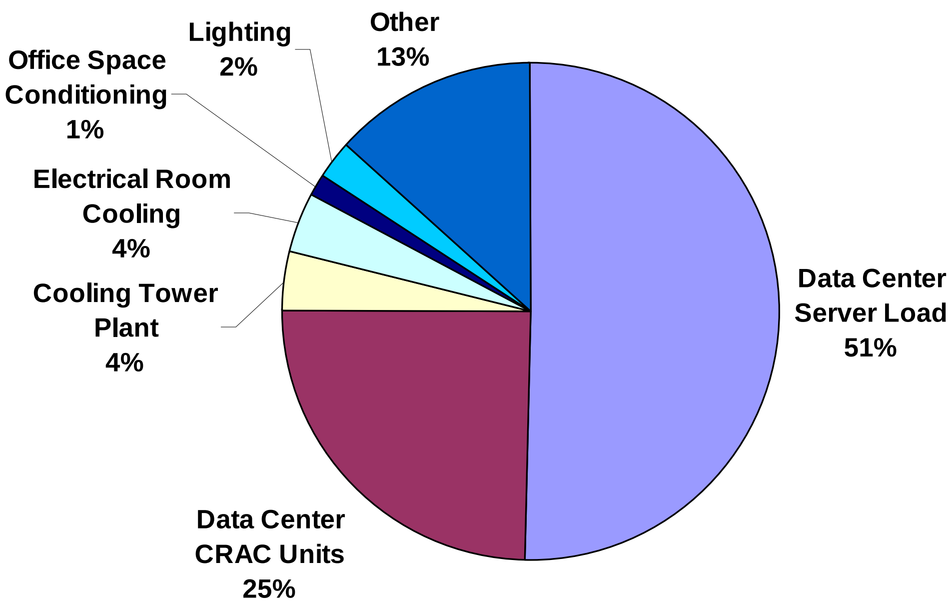
# Benchmarking for Energy Performance Improvement:

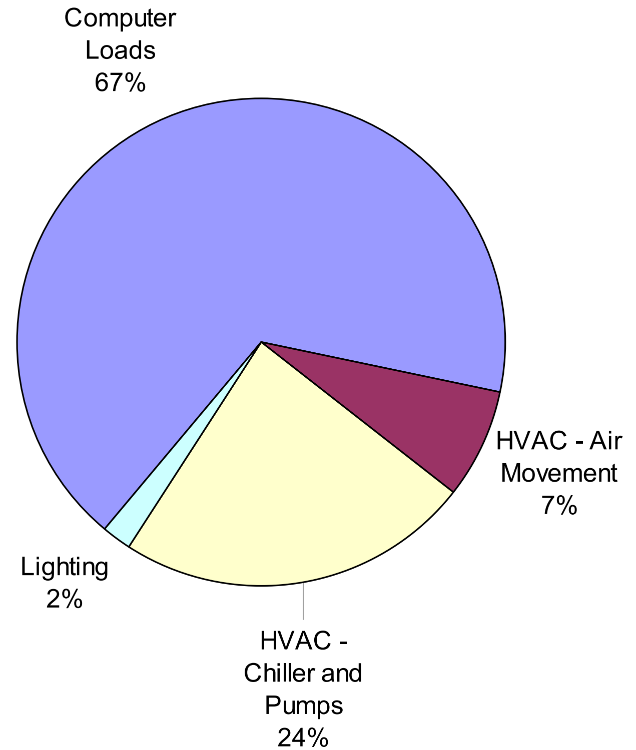


- Energy benchmarking can allow comparison to peers and help identify best practices
- LBNL conducted studies of over 30 data centers:
  - Wide variation in performance
  - Identified best practices
- Can't manage what isn't measured

# Your Mileage Will Vary

The relative percentages of the energy doing computing varies considerably.



# Benchmarks obtained by LBNL

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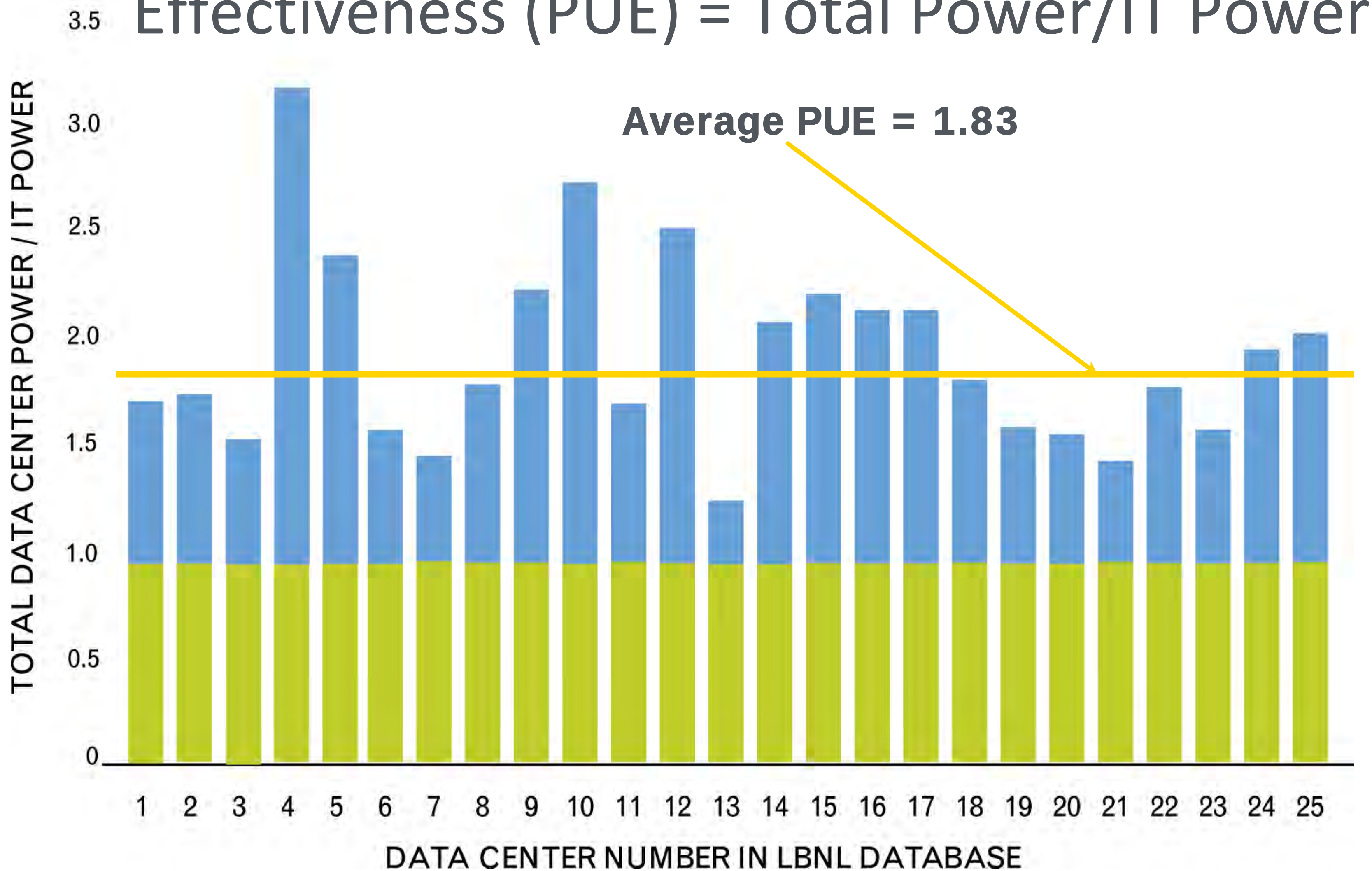
## High Level Metric: Power Utilization Effectiveness (PUE) = Total Power/IT Power



# Energy Metrics and Benchmarking

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- **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)**

# You Can't Manage What You Don't Measure

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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

# Other Data Center Metrics:

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- Watts per square foot, Watts per rack
- Power distribution: UPS efficiency, IT power supply efficiency
  - Uptime: IT Hardware Power Overhead Multiplier (ITac/ITdc)
- 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

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

| 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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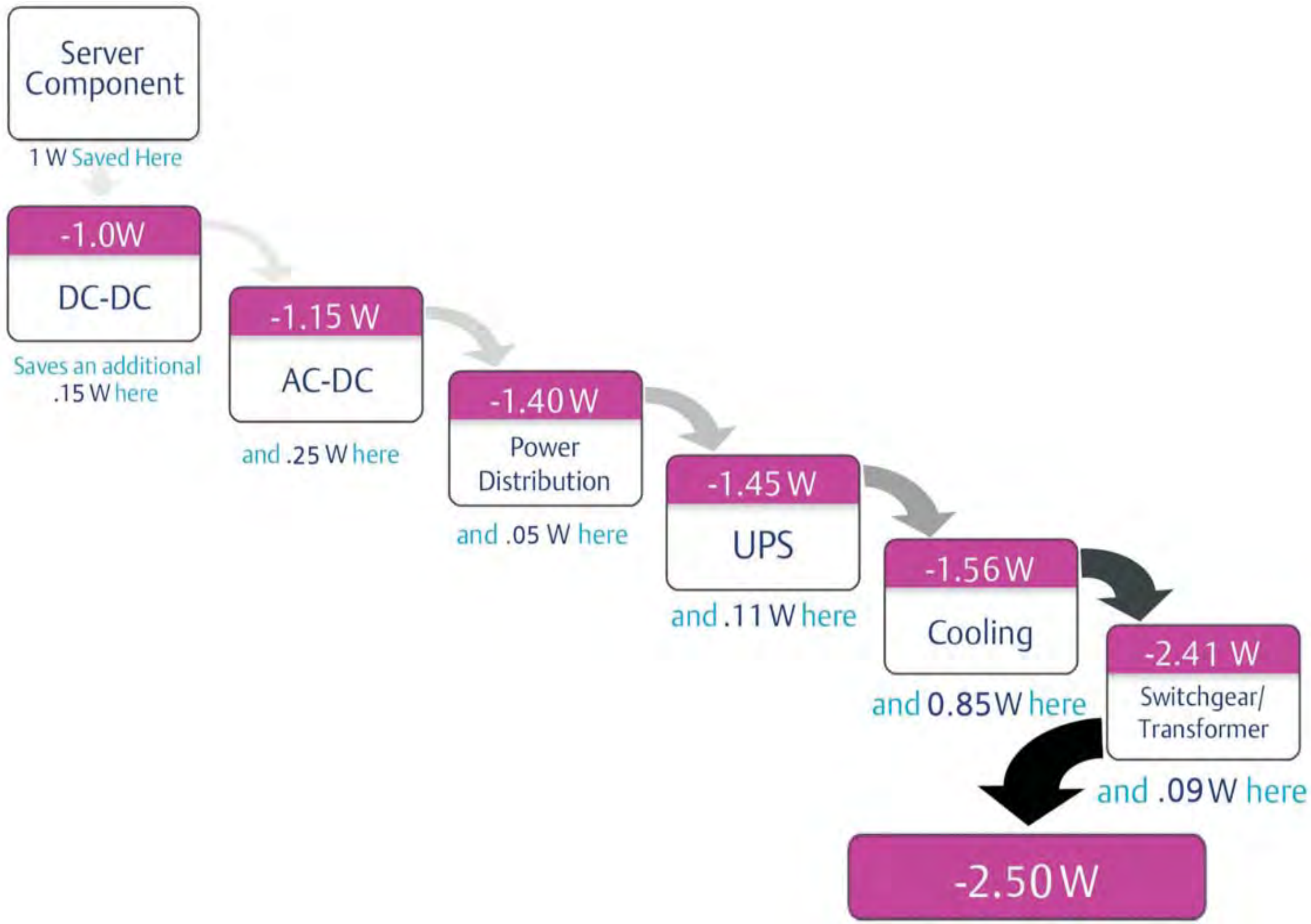
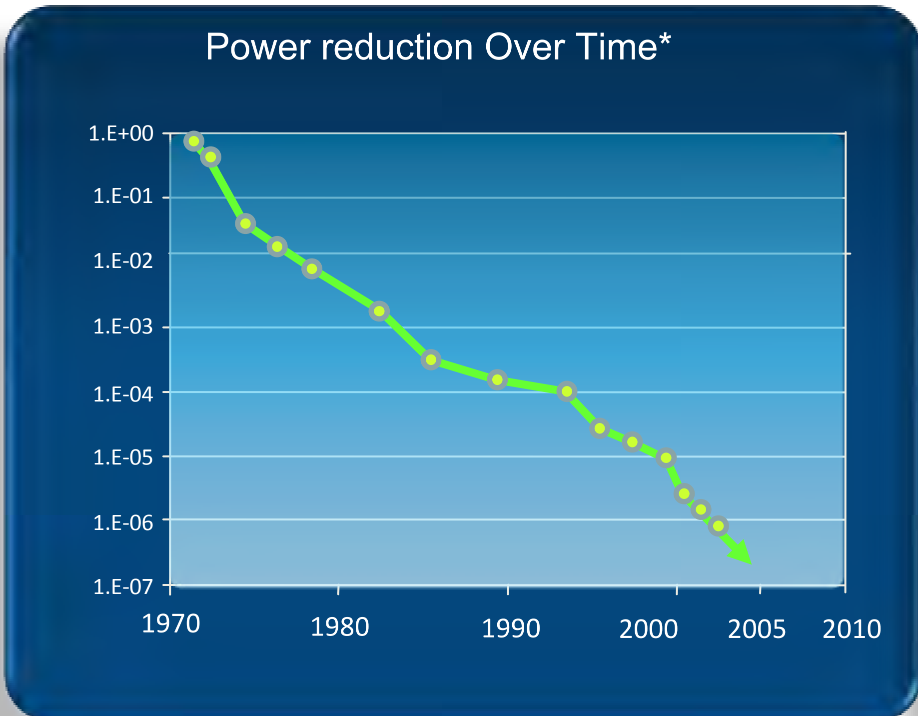
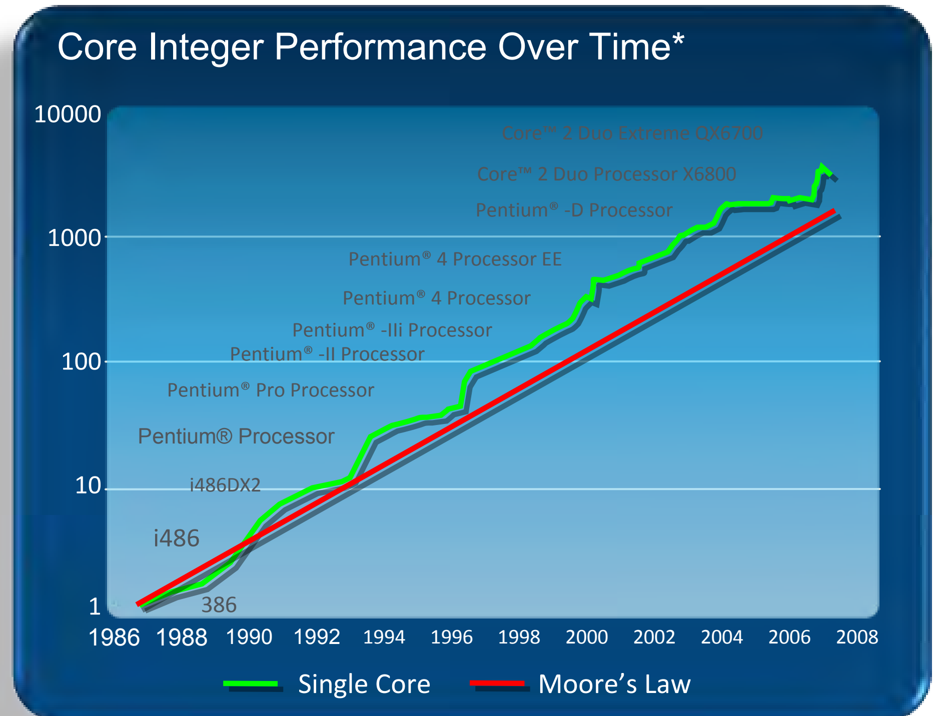
# IT server performance - saving a watt…

## 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.

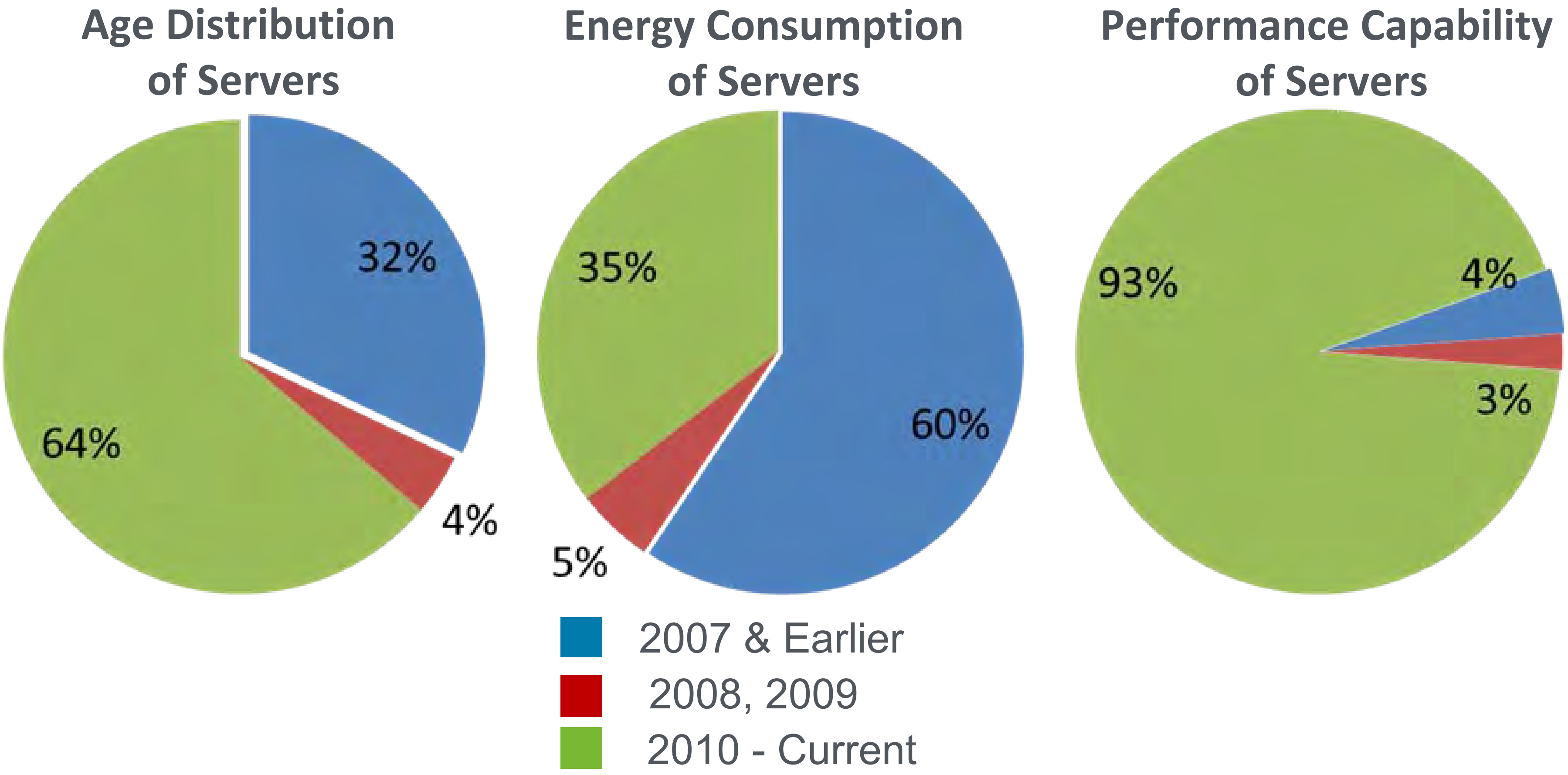
Source: Intel Corp.



Source: Intel Corporate Technology Group

# IT equipment age and performance





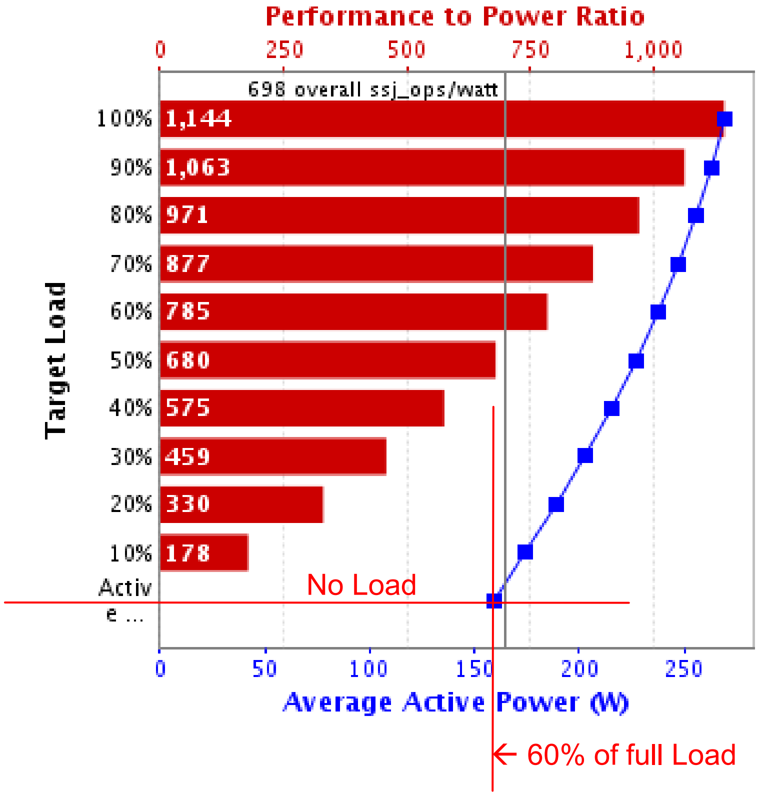

**Old Servers consume 60% of Energy, but deliver only 4% of Performance Capability.**

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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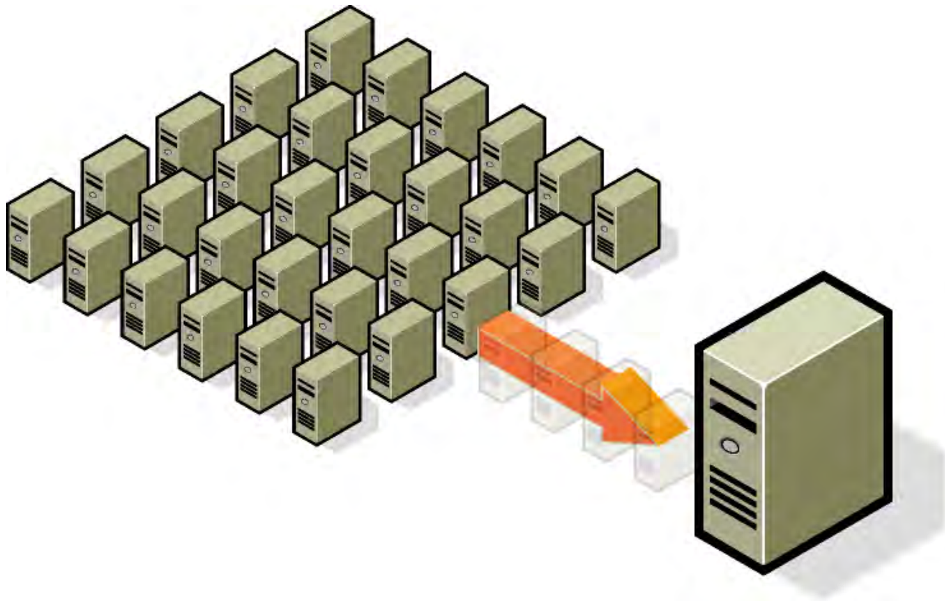
## PHYSICALLY RETIRE AN INEFFICIENT OR UNUSED SYSTEM

- **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
- Developed in the 1960s to achieve better efficiency
- Consolidate underutilized physical machines, increasing utilization
- Energy saved by shutting down underutilized machines
- .



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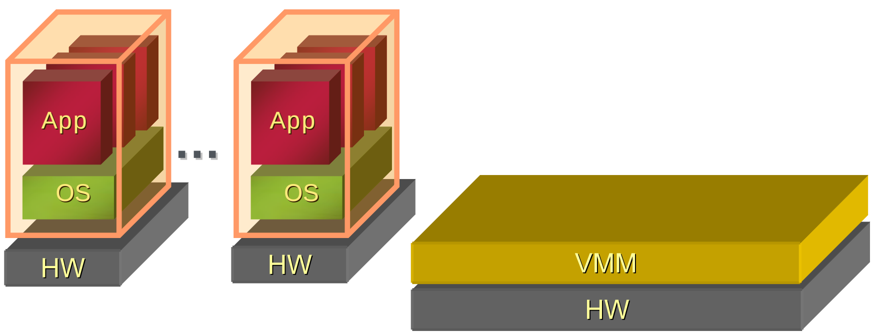
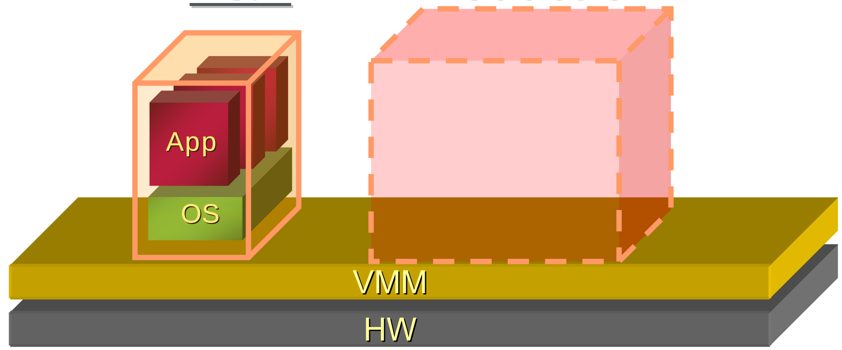
# Virtualization: Workload provisioning

## Server Consolidation



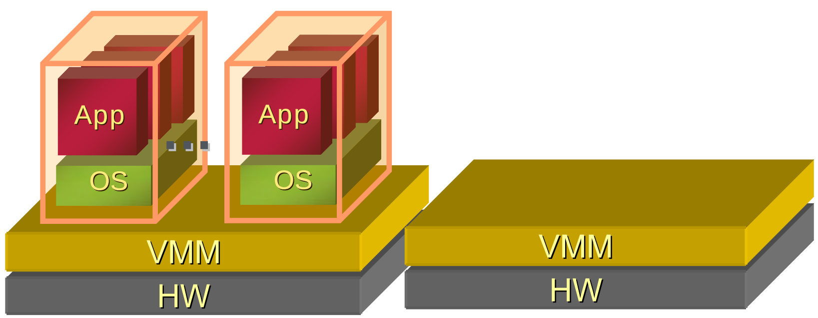

10:1 in many cases

## R&D Production



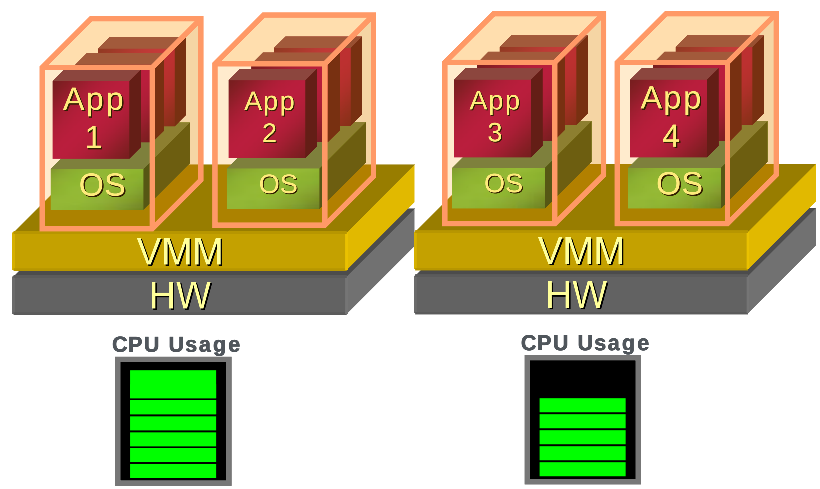

Enables rapid deployment, reducing number of idle, staged servers

## Disaster Recovery




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

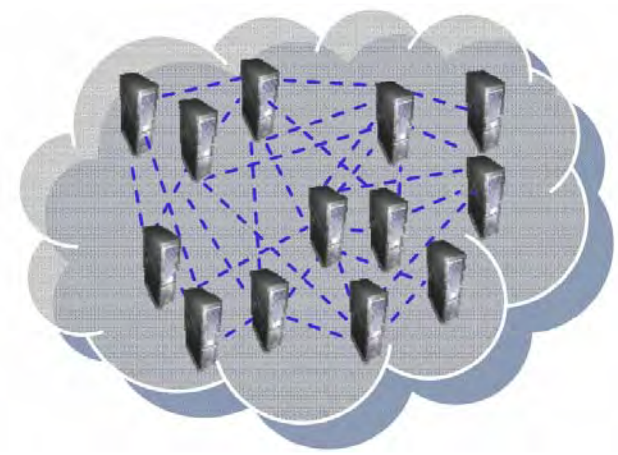
## Dynamic Load Balancing




Balancing utilization with head room

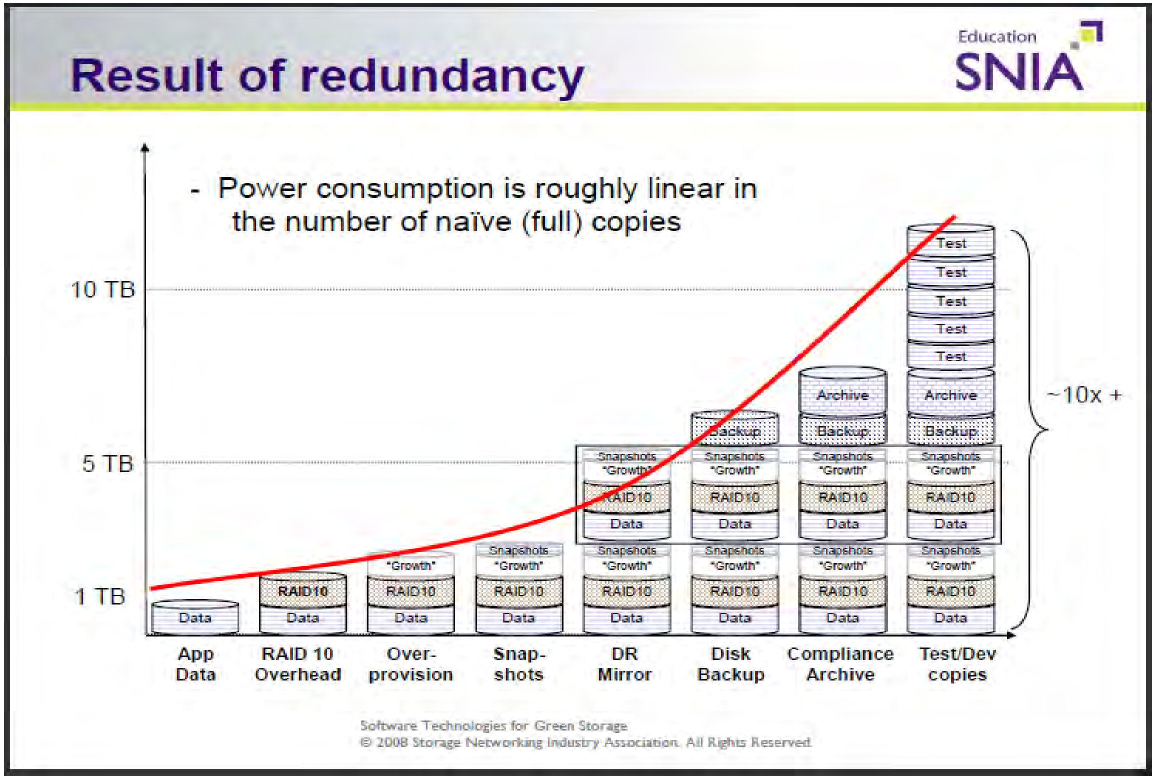
## Vertualized cloud computing can provide…

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



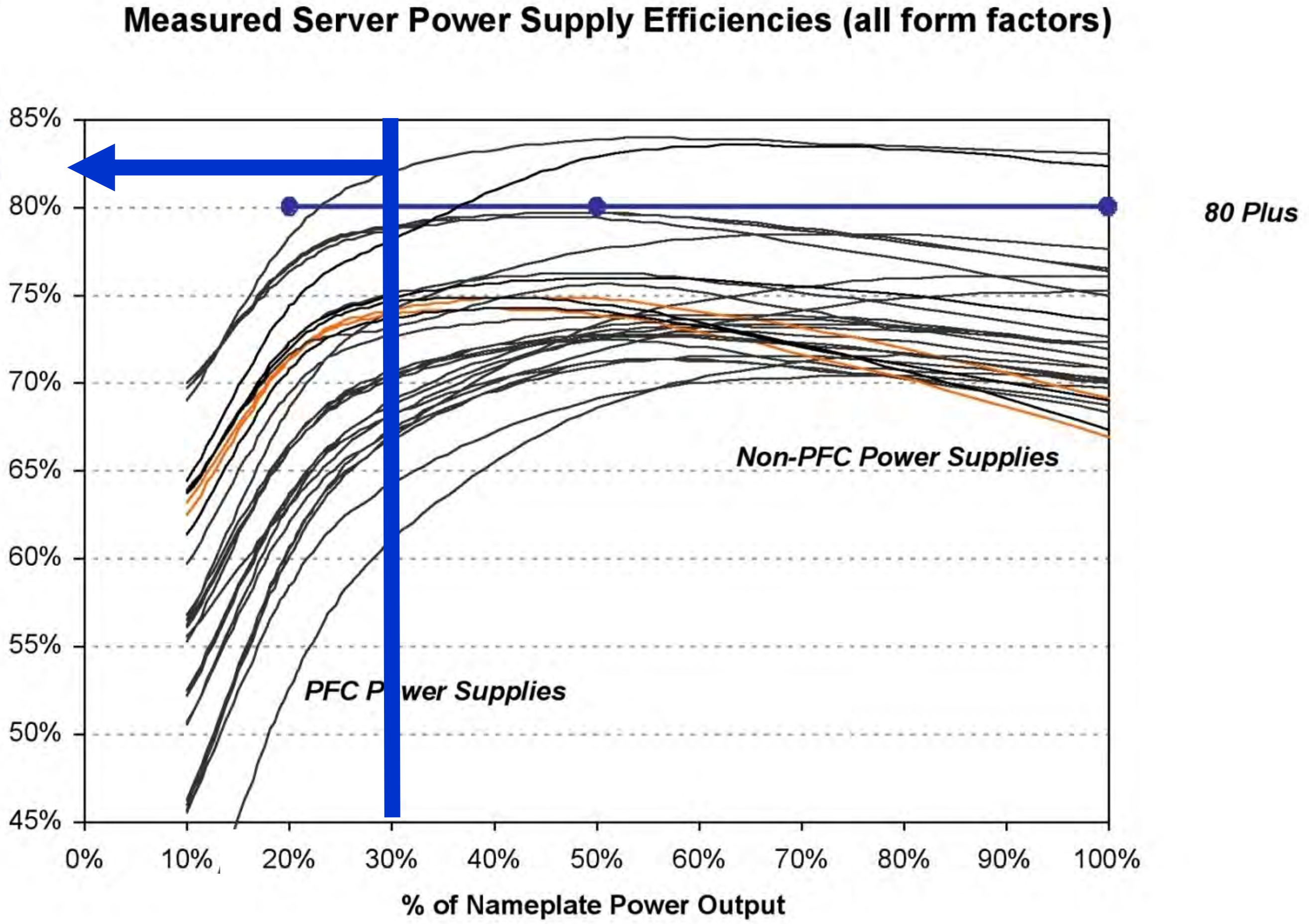
# Storage Systems and Energy

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



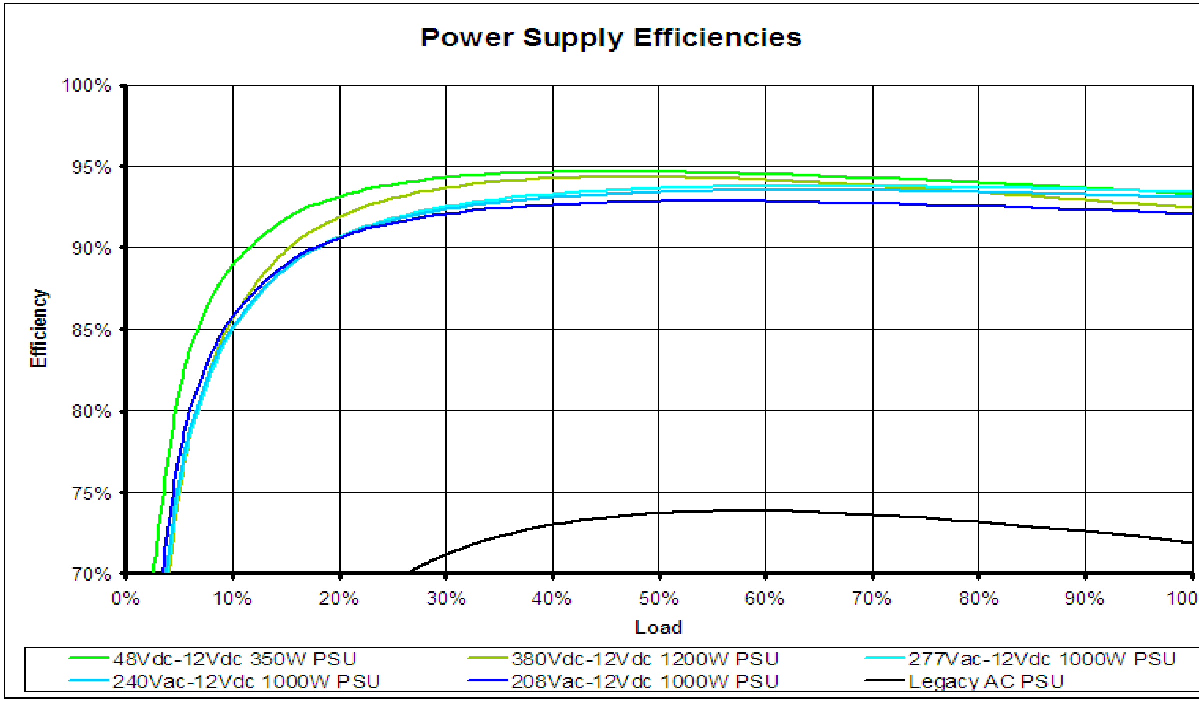
# Use Efficient Power Supplies

## 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

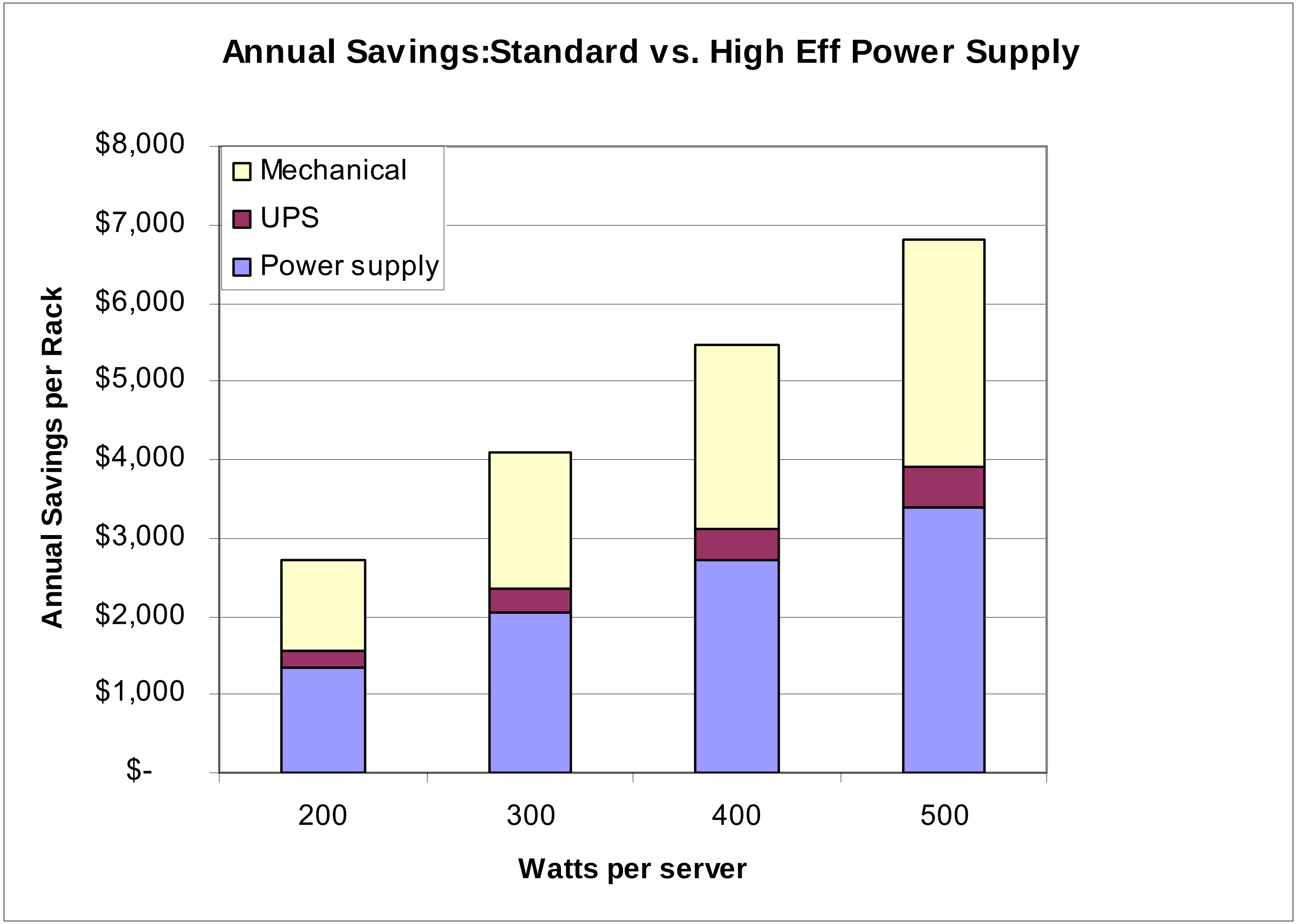



Source: The Green Grid

# 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…



## Servers

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

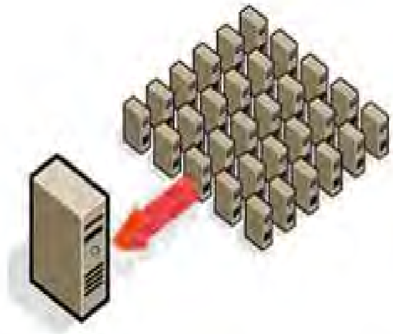
## Power Supplies

- 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

# References and Resources

Server System Infrastructure
Managing Component Interfaces

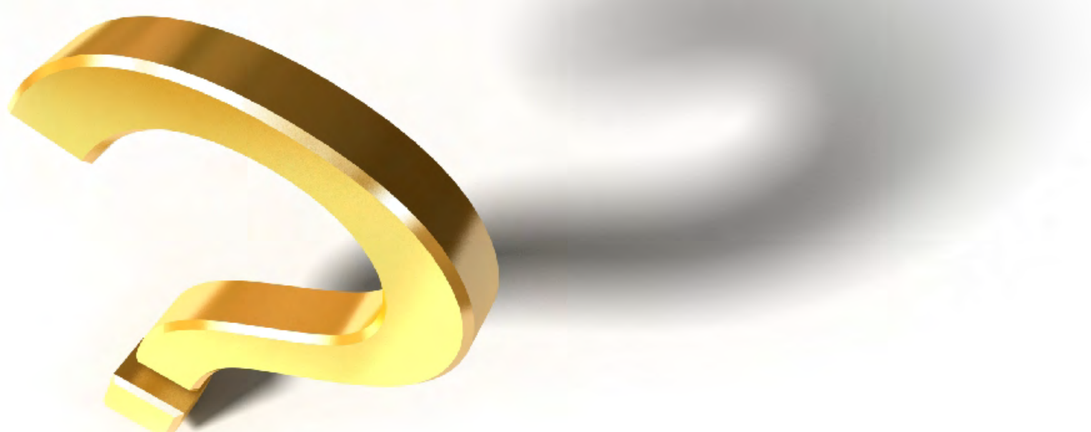
- www.ssiforums.org
- www.80plus.org
- www.climatesaverscomputing.org
- http://tc99.ashraetcs.org/

80 PLUS

climate savers computing

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

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# Use IT to Manage IT Energy

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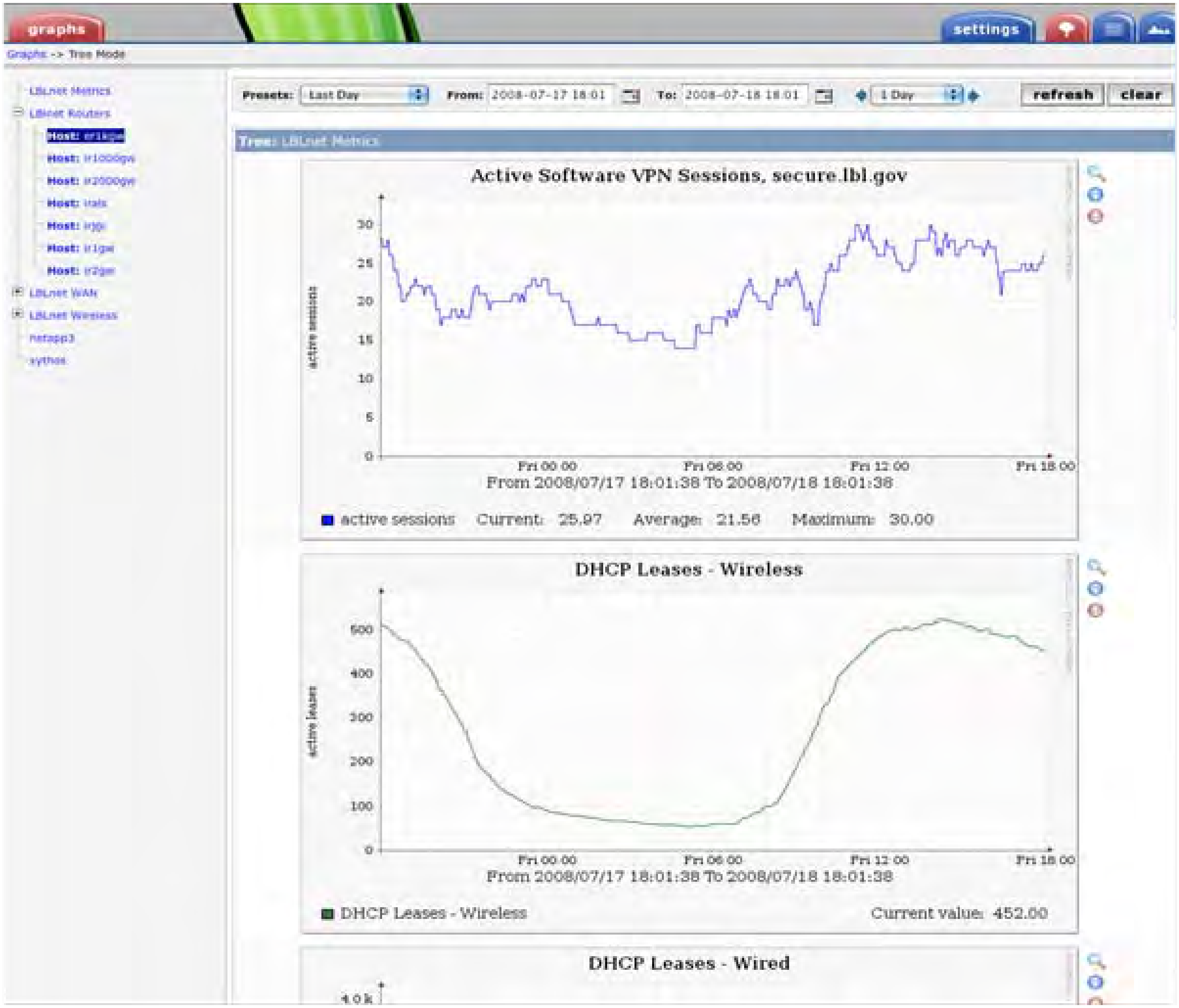
## Using IT to Save Energy in IT:

- 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.

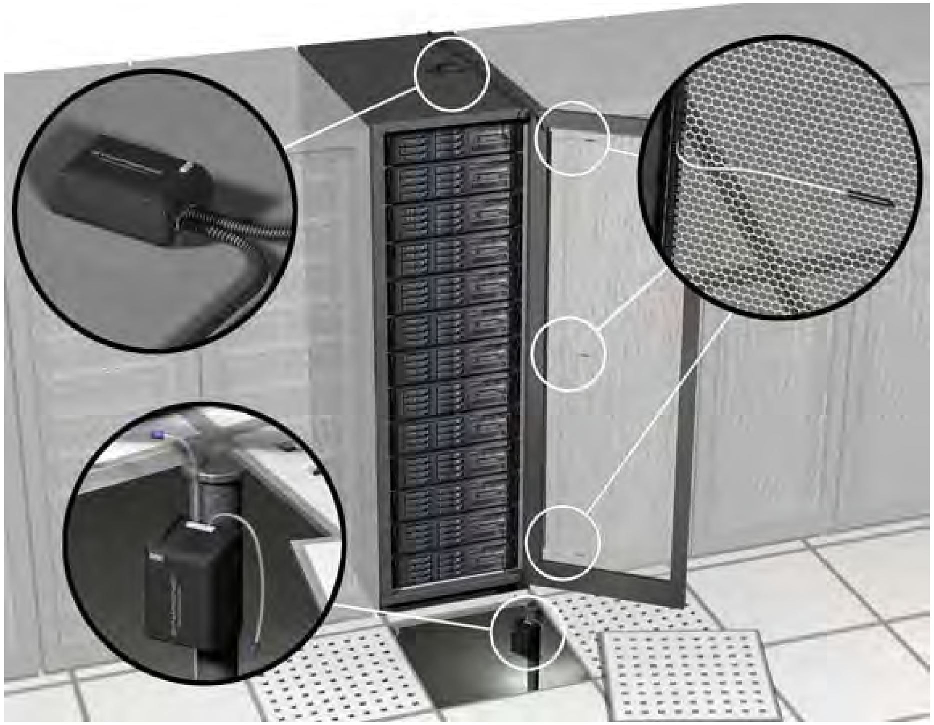
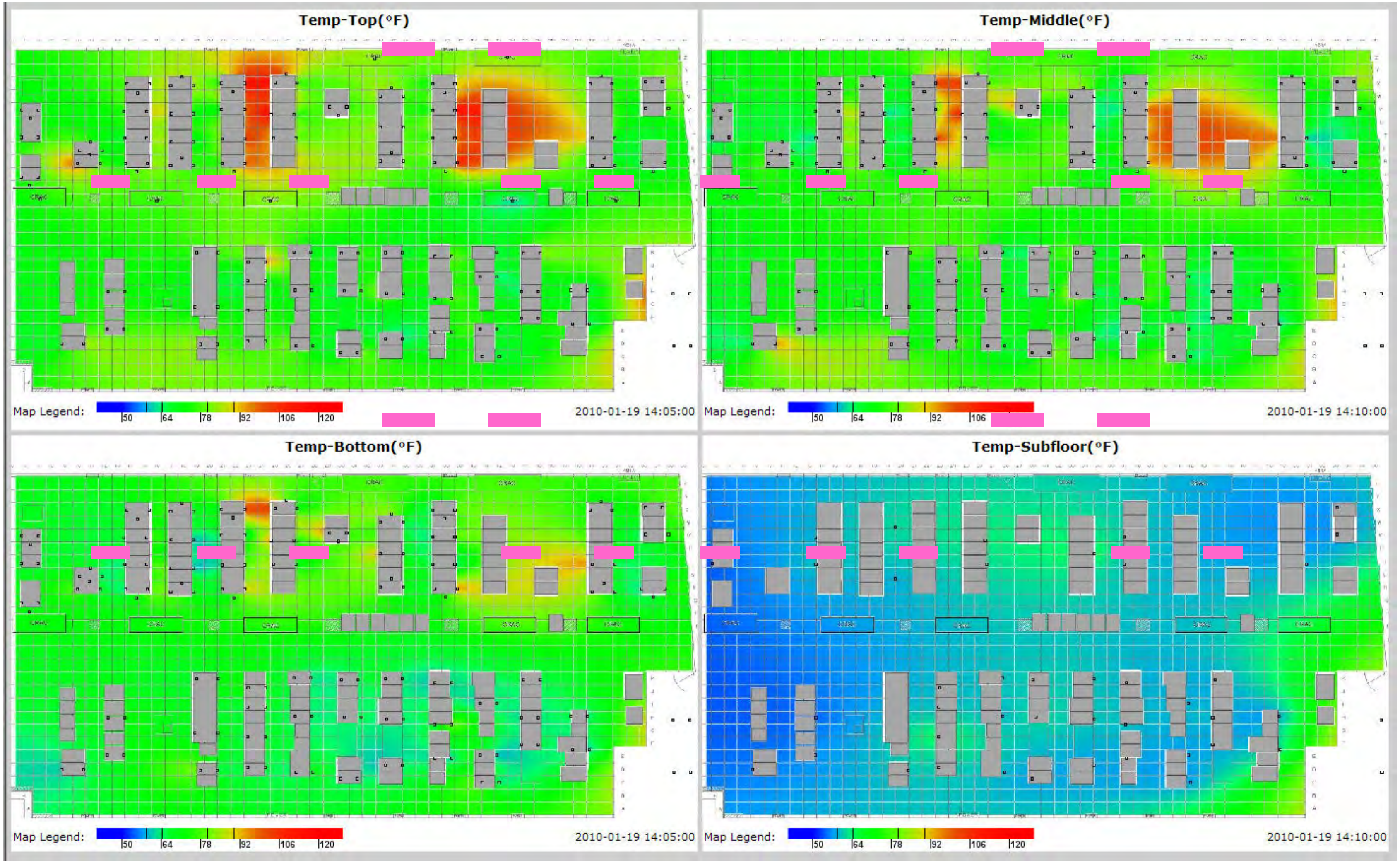


Image: SynapSense

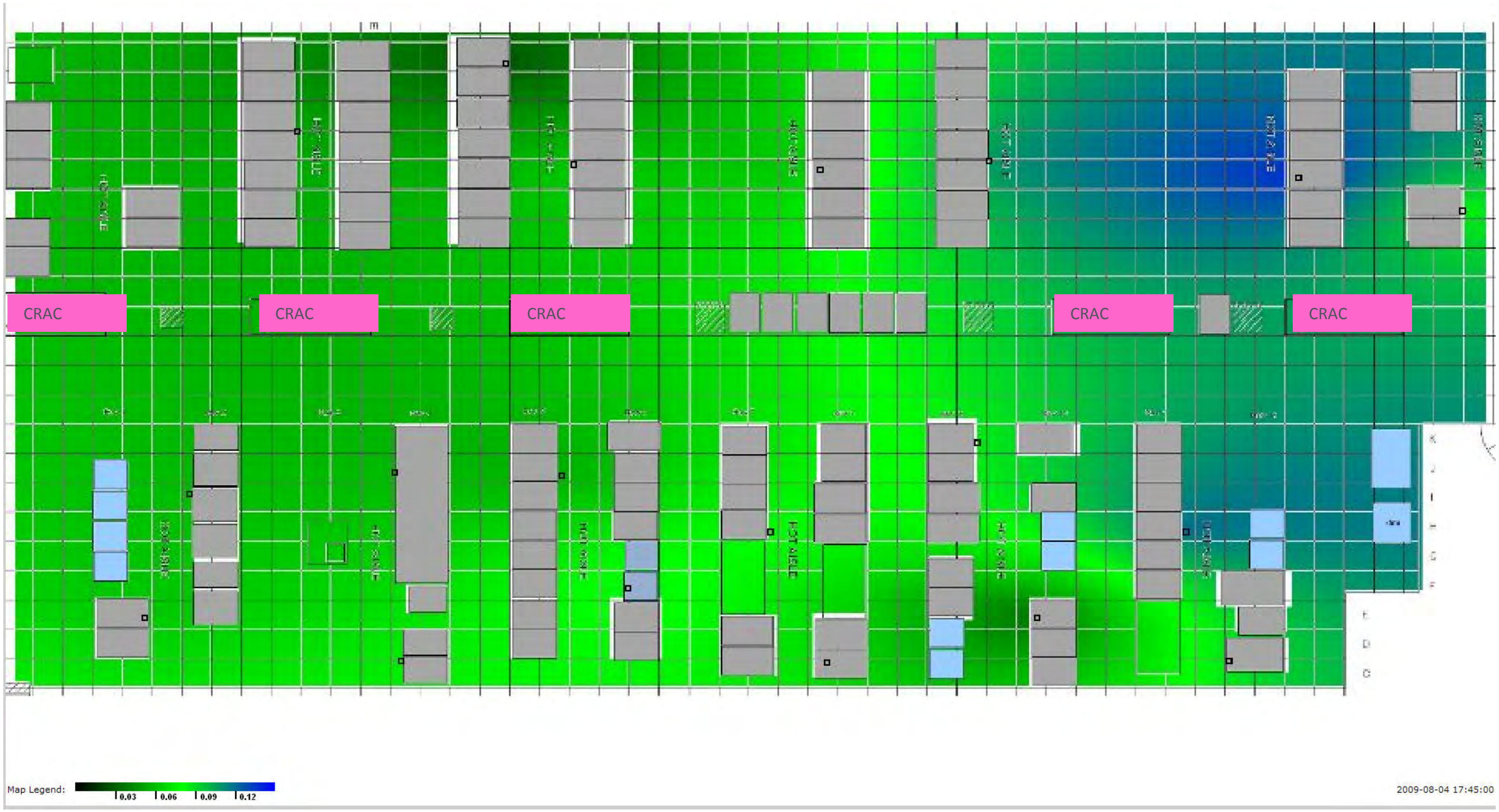
# Real-time temperature visualization by level





# Displayed Under-floor pressure map…



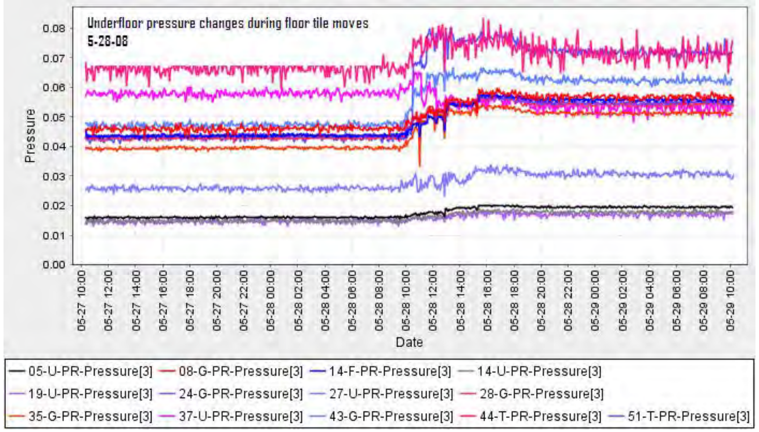


# Provided real-time feedback during floor-tile tuning

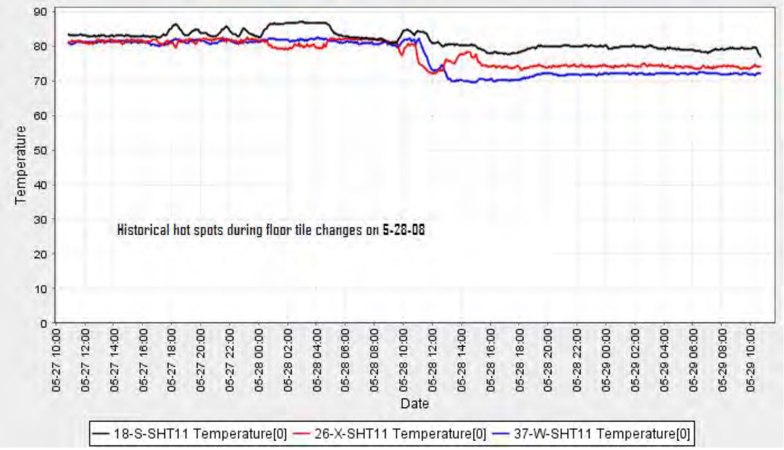


- ✓ Removed guesswork by monitoring and using visualization tool.

## Under-Floor Pressure



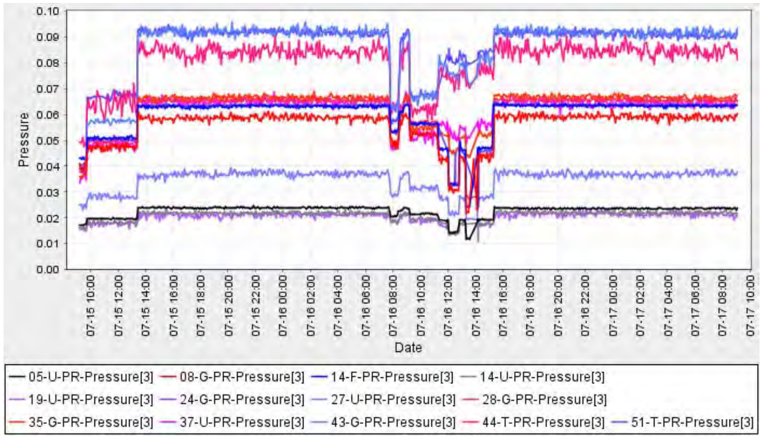

## Rack-Top Temperatures



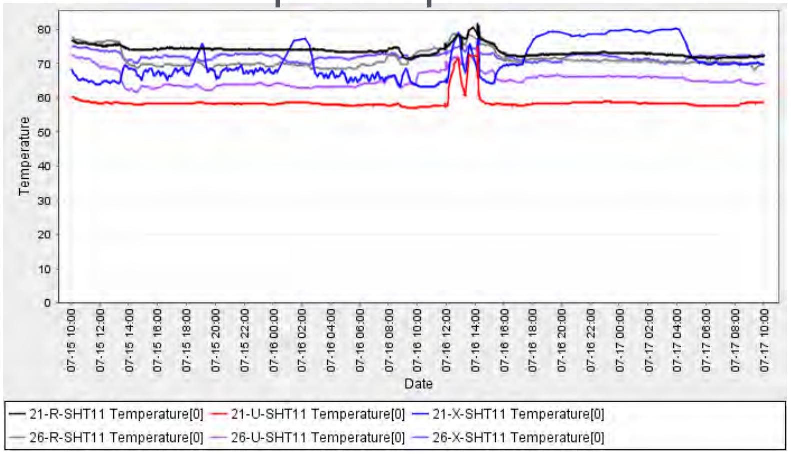
# Determined relative CRAC cooling energy impact

- 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!

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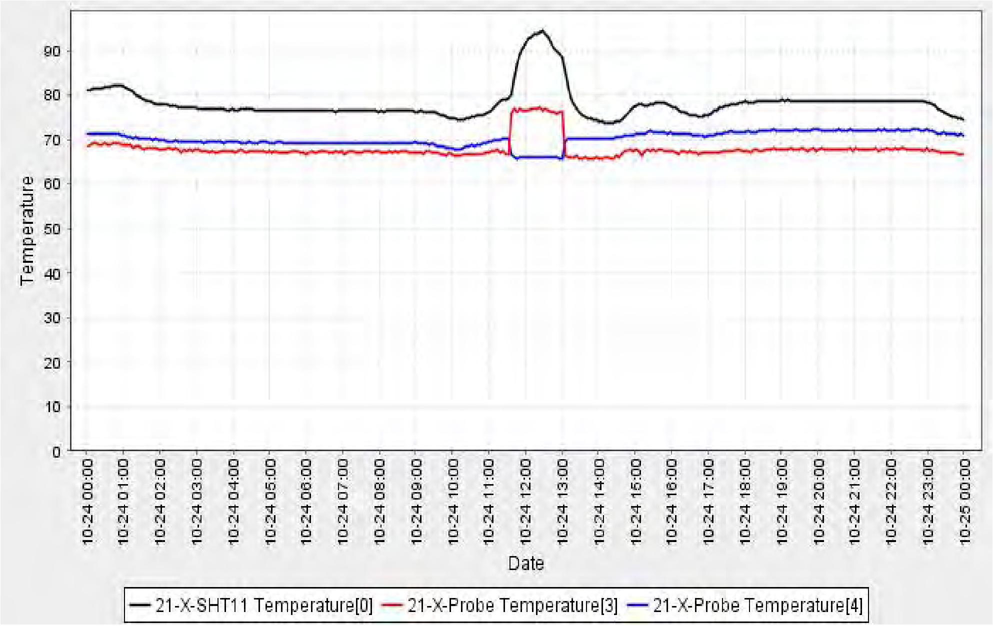
## Real-time feedback identified cold aisle air flow obstruction!




# Real-time PUE Display

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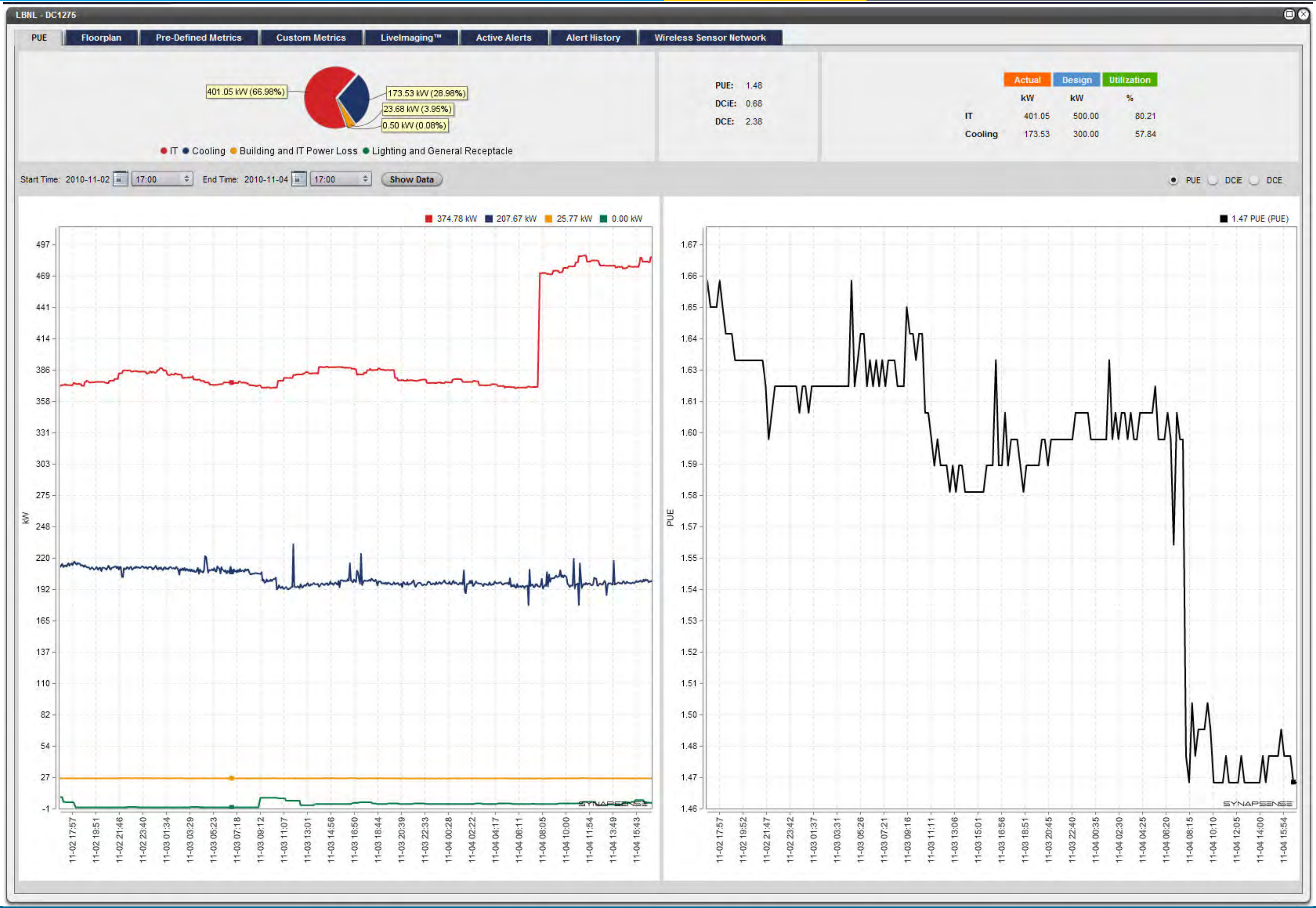


# PUE Calculation Diagram



# Franchise Tax Board (FTB) Case Study



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

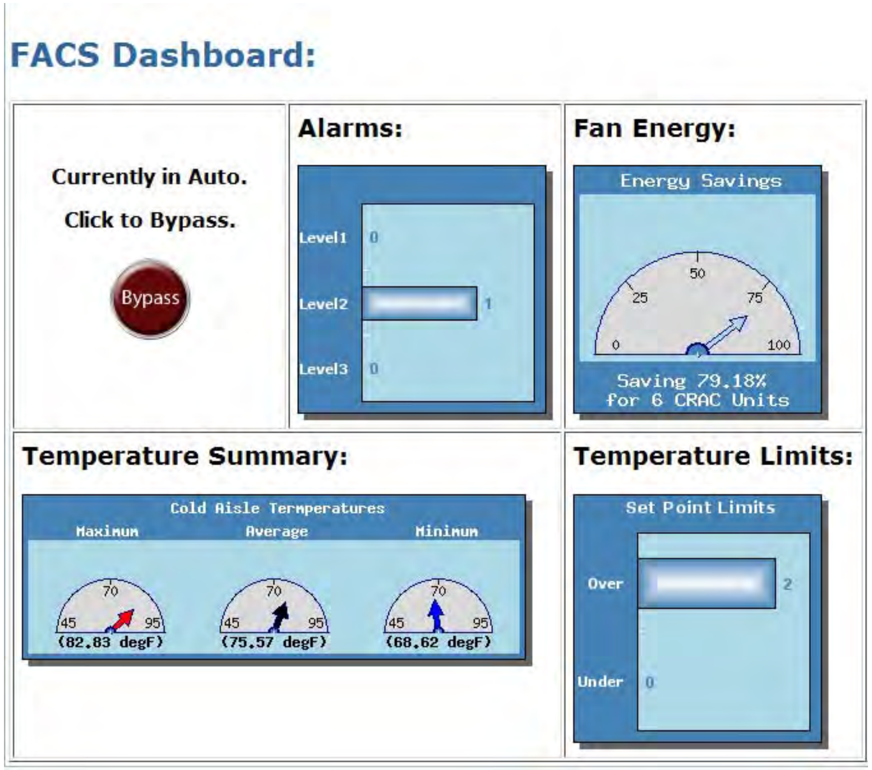
**Challenges:**
- Over-provisioned
- History of fighting
- Manual shutoff not successful

**Solution:**
- Intelligent supervisory control software with inlet air sensing

# 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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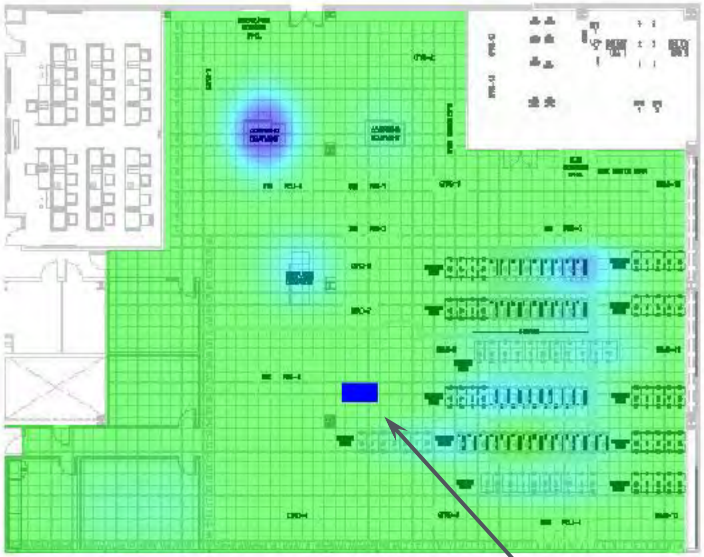
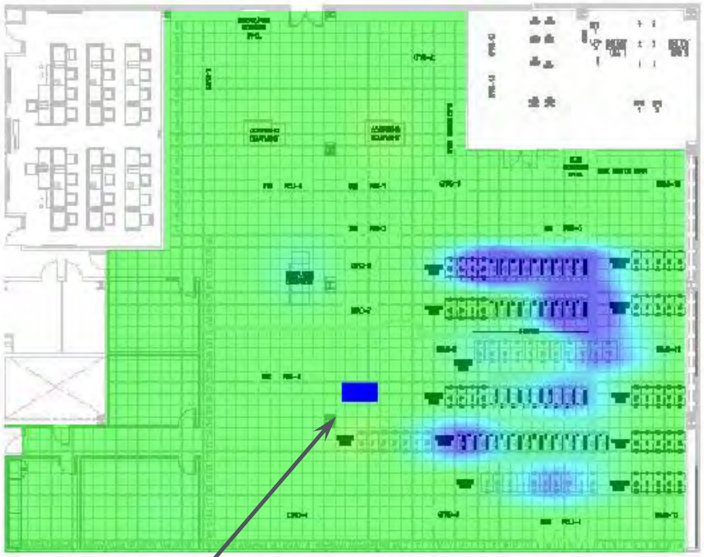
CRAH 3 influence at start

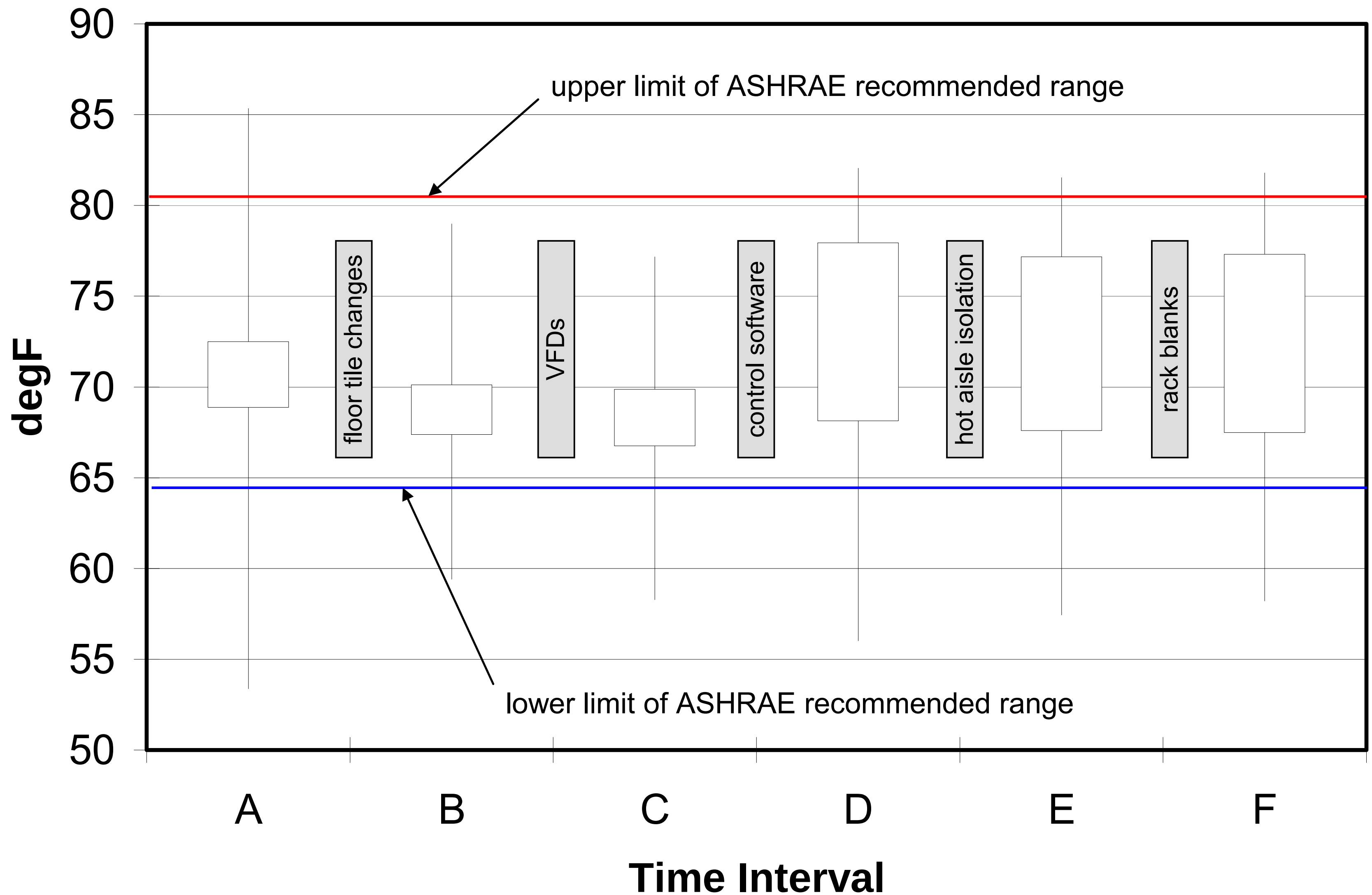
CRAH 3 influence after curtains





CRAH-03

# WSN provided effect on cold-aisle temperatures:



# WSN software = Dramatic Energy Reduction…

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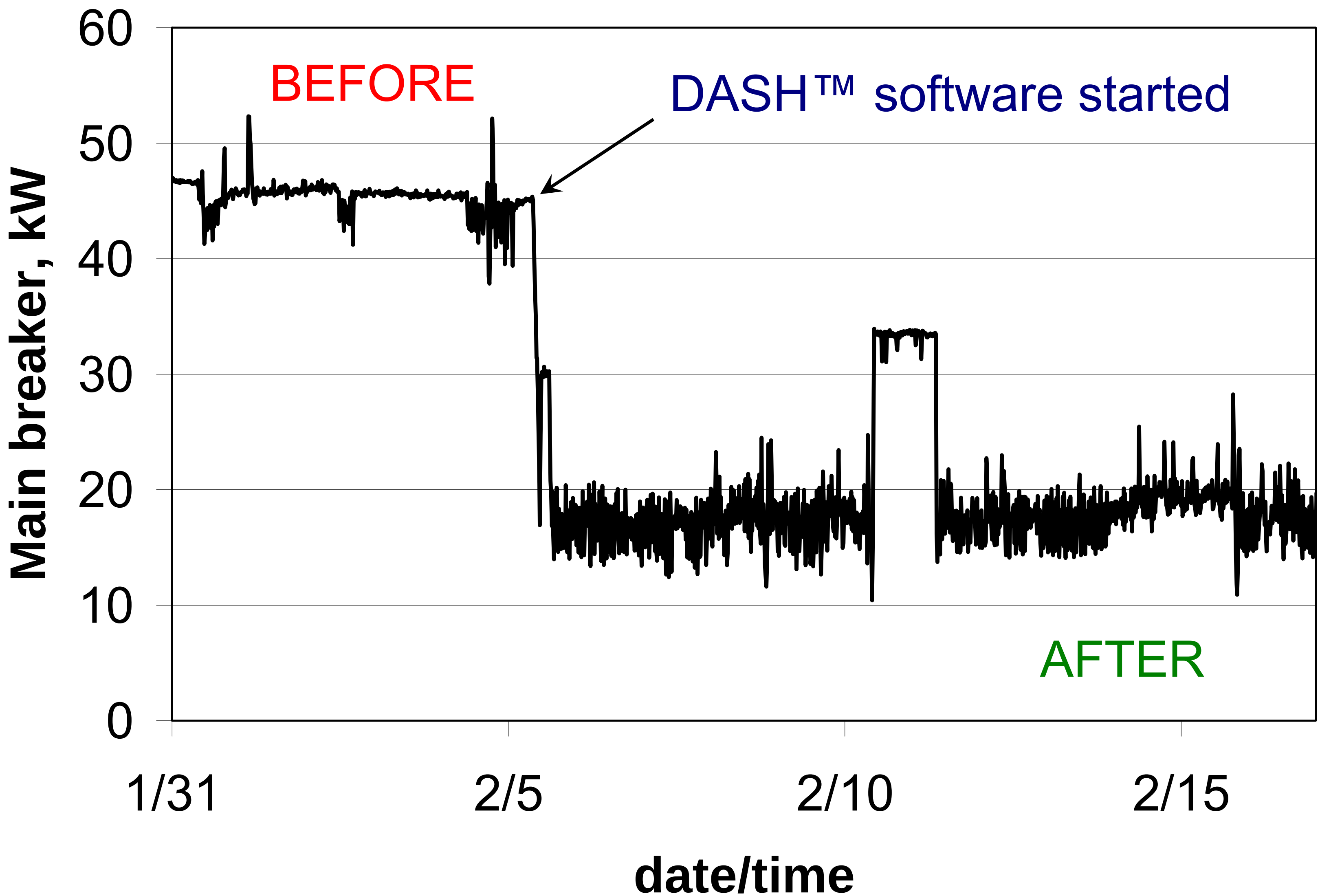

# Cost-Benefit analysis:



- 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

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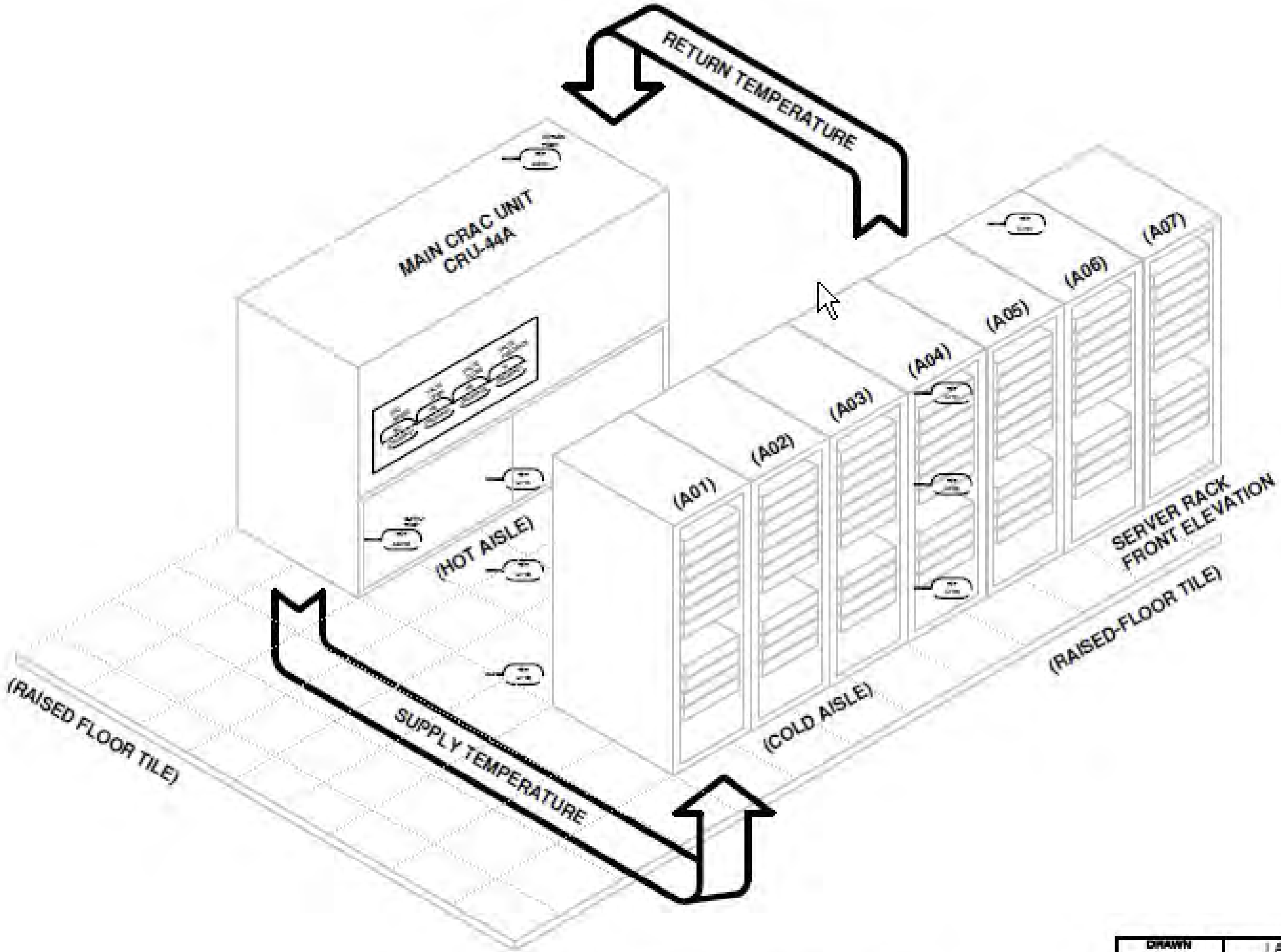
# Control data center air conditioning using the *built-in* IT server-equipment temperature sensors

# Intel Demonstration

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

- **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

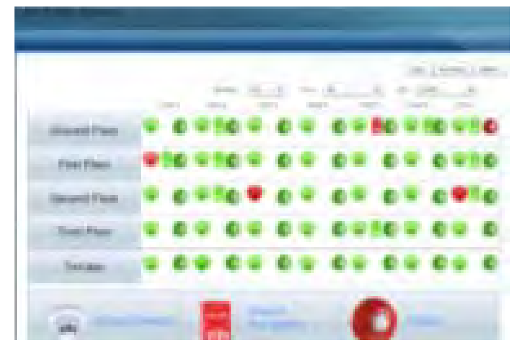
| DRAWN | LAWRENCE BERKELEY NATIONAL LABORATORY<br>INTEL CORPORATION |
|---|---|
| CHECKED | |
| DATE | HVAC CONTROLS<br>DEMONSTRATION PROJECT |
| DWG. NO. | |

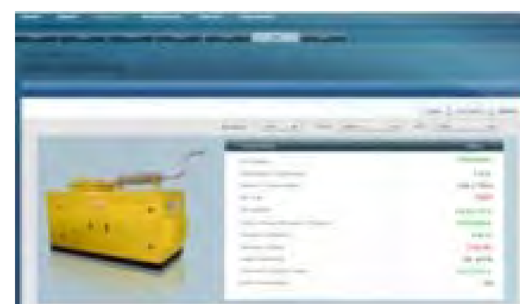
# Intel Demonstration

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

- 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

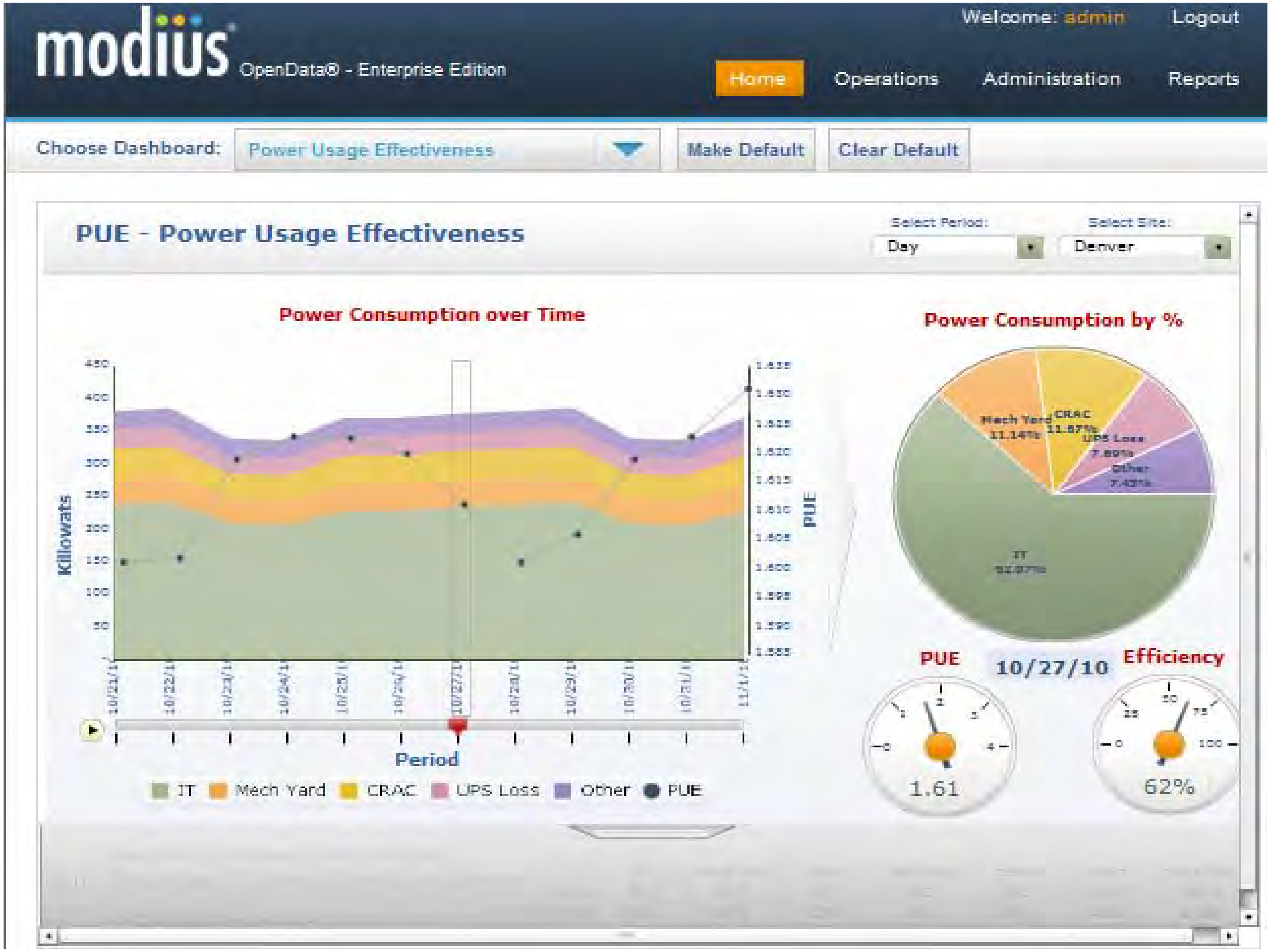




# Why Dashboards?

- 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…



# Use IT to Manage IT: Summary



- **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

FEMP
Federal Energy Management Program

Berkeley Lab

# What are the main HVAC Energy Drivers?

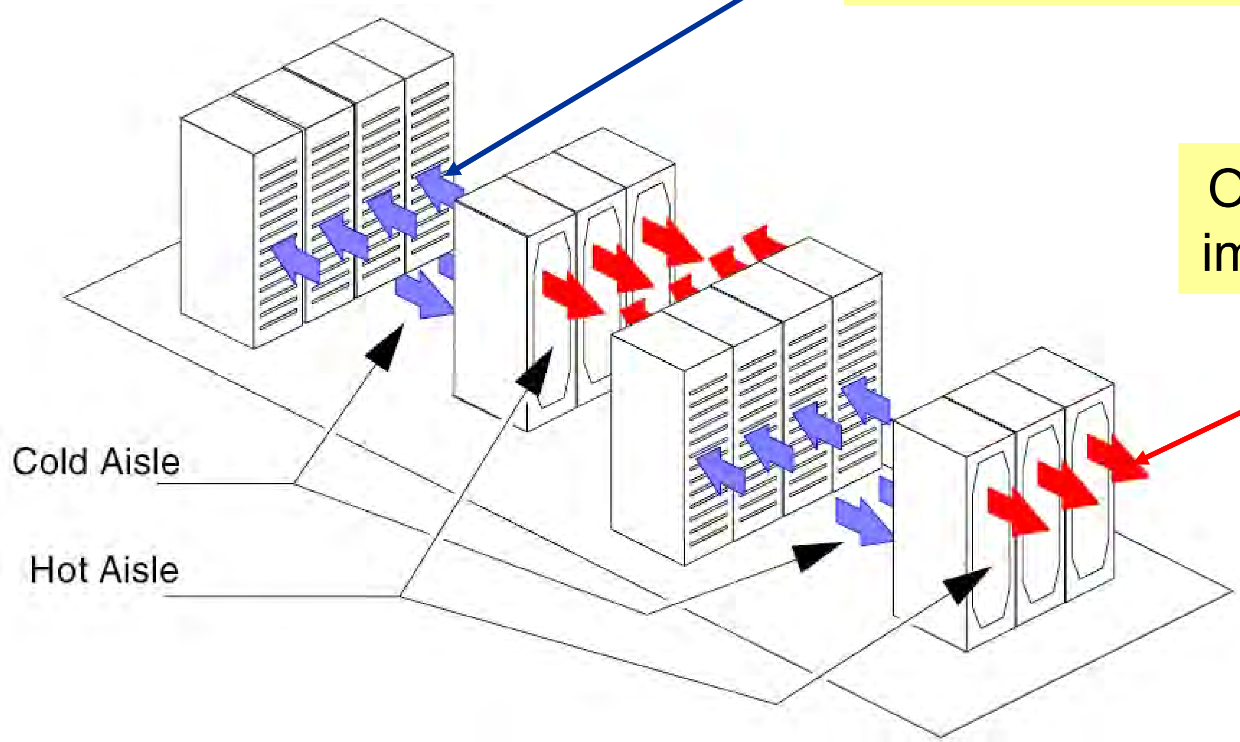
- IT Load
- Climate
- **Room temperature and humidity**
  - **Most data centers are overcooled and have humidity control issues**
  - **Human comfort should not be a driver**

# Equipment environmental specification



**<u>Air Inlet</u>** to IT Equipment **is** the important specification to meet

Outlet temperature is *not* important to IT Equipment

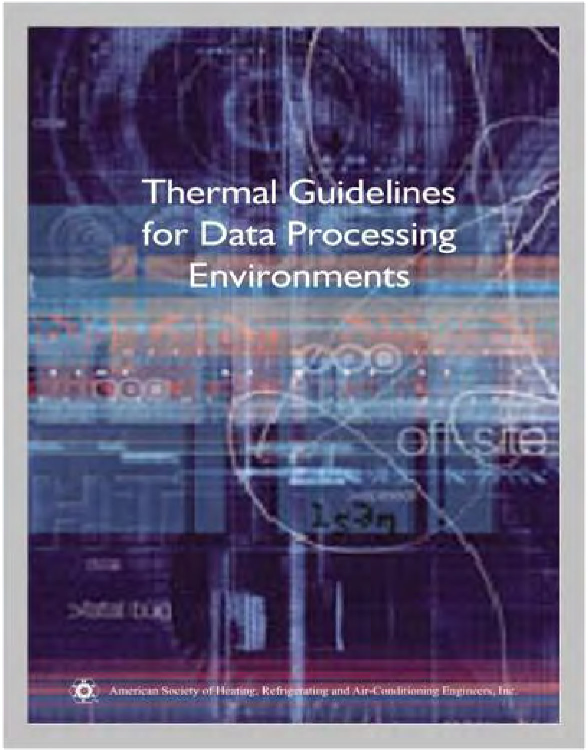


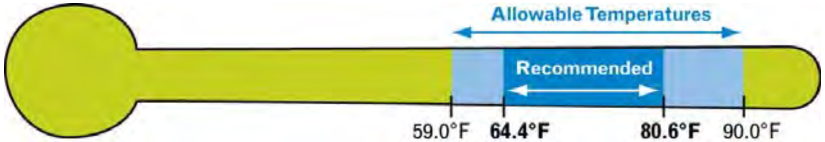
# Environmental conditions

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

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



# Purpose of the Ranges

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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.

# 2011 ASHRAE Thermal Guidelines

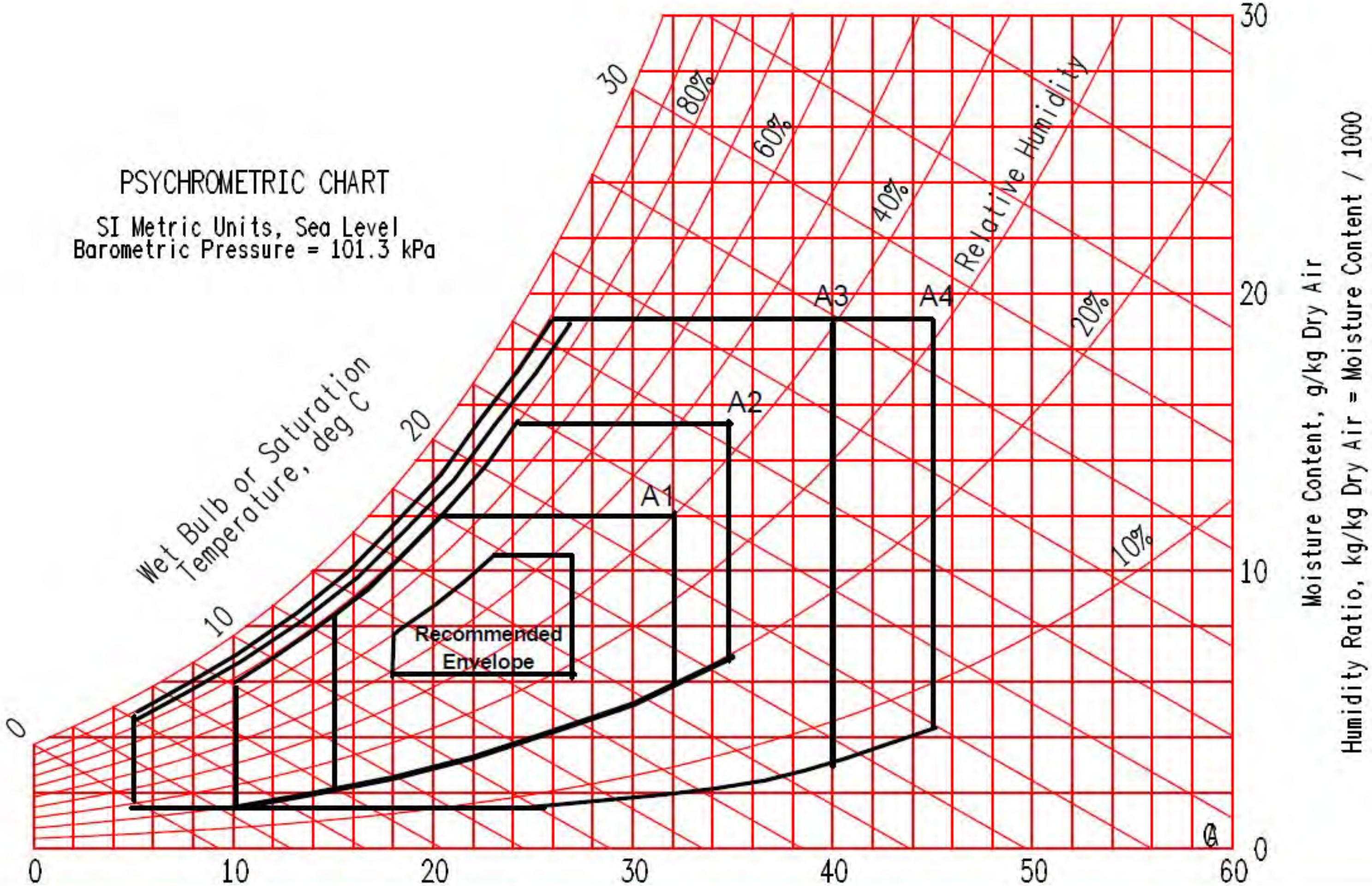
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

| 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) | Maximum Elevation (m) | Maximum Rate of Change(˚C/hr) (f) | Dry-Bulb Temperature (˚C) | Relative Humidity (%) | Maximum Dew Point (˚C) |
| **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 | 5.5ºC DP to 60% RH and 15ºC 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






**Dry Bulb Temperature**

**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 Liquid Cooling Guidelines

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) |

# Example server specification

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## Environmental

Temperature:

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

Relative humidity

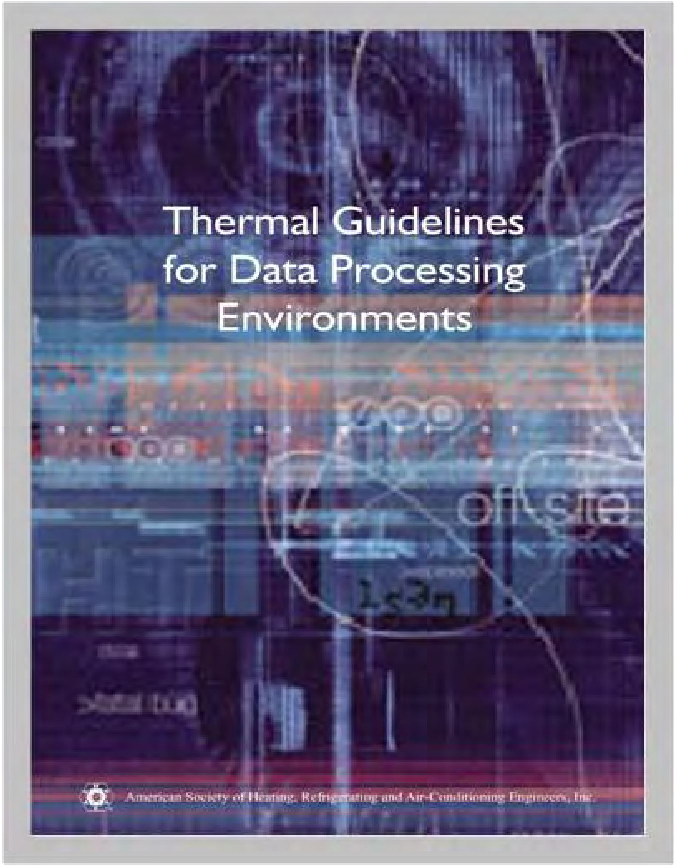
- Operating: 20% to 80% (non-condensing)
- Storage: 5% to 95% (non-condensing)

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

FEMP Federal Energy Management Program

Berkeley Lab

# Air Management: The Early Days at LBNL

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**It was cold but hot spots were everywhere**

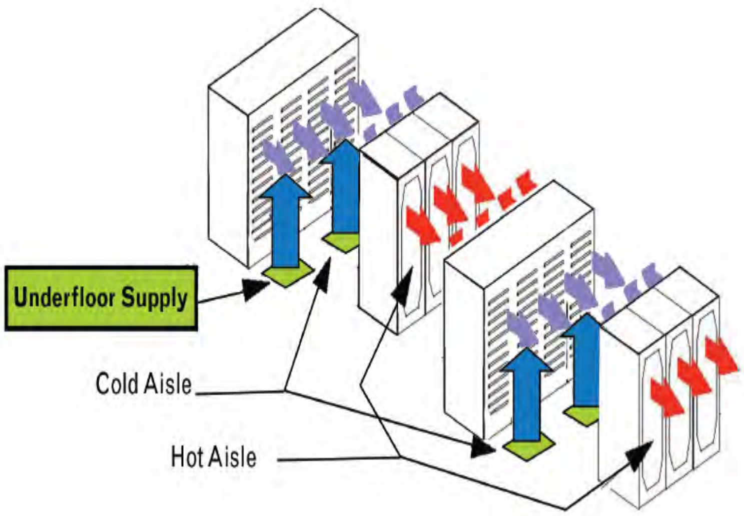
Fans were used to redirect air

High flow tiles reduced air pressure

# Air Management



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




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

# What are the benefits of hot- and cold-aisles?

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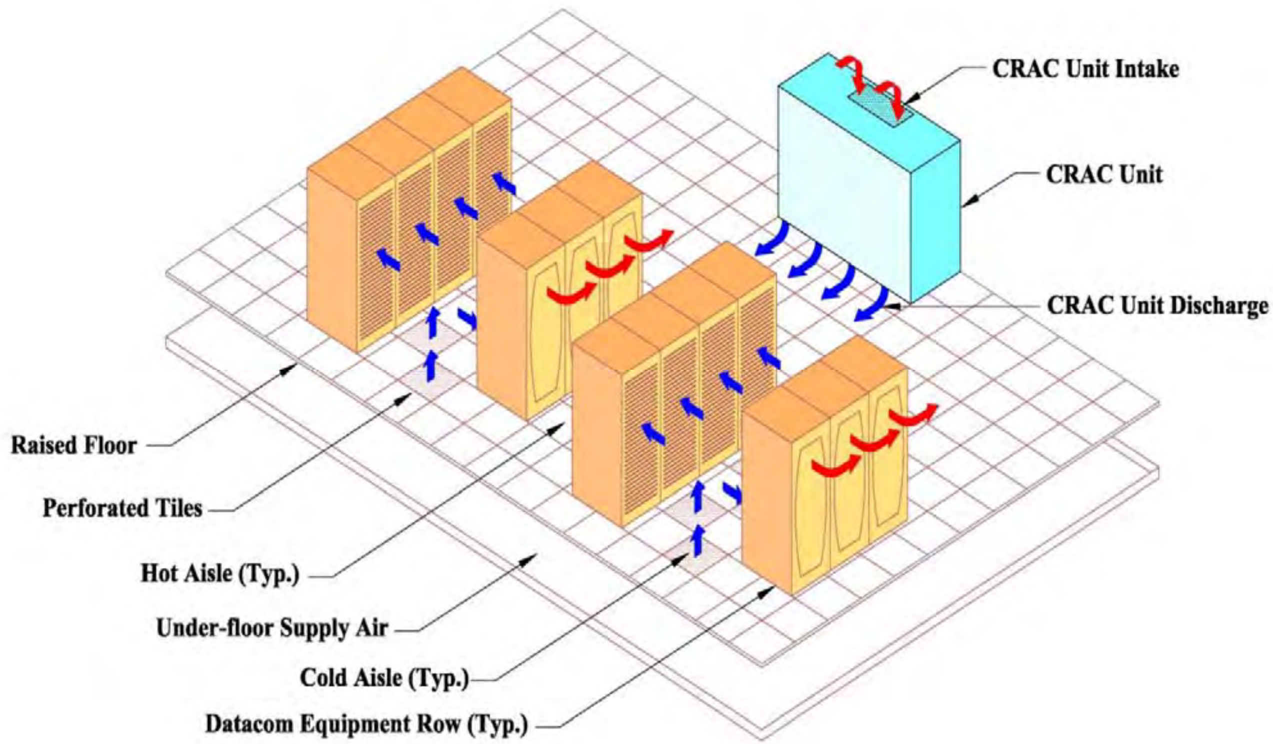
- **Improves equipment intake air conditions by separating cold from hot airflow.**

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

# Reduce Bypass and Recirculation

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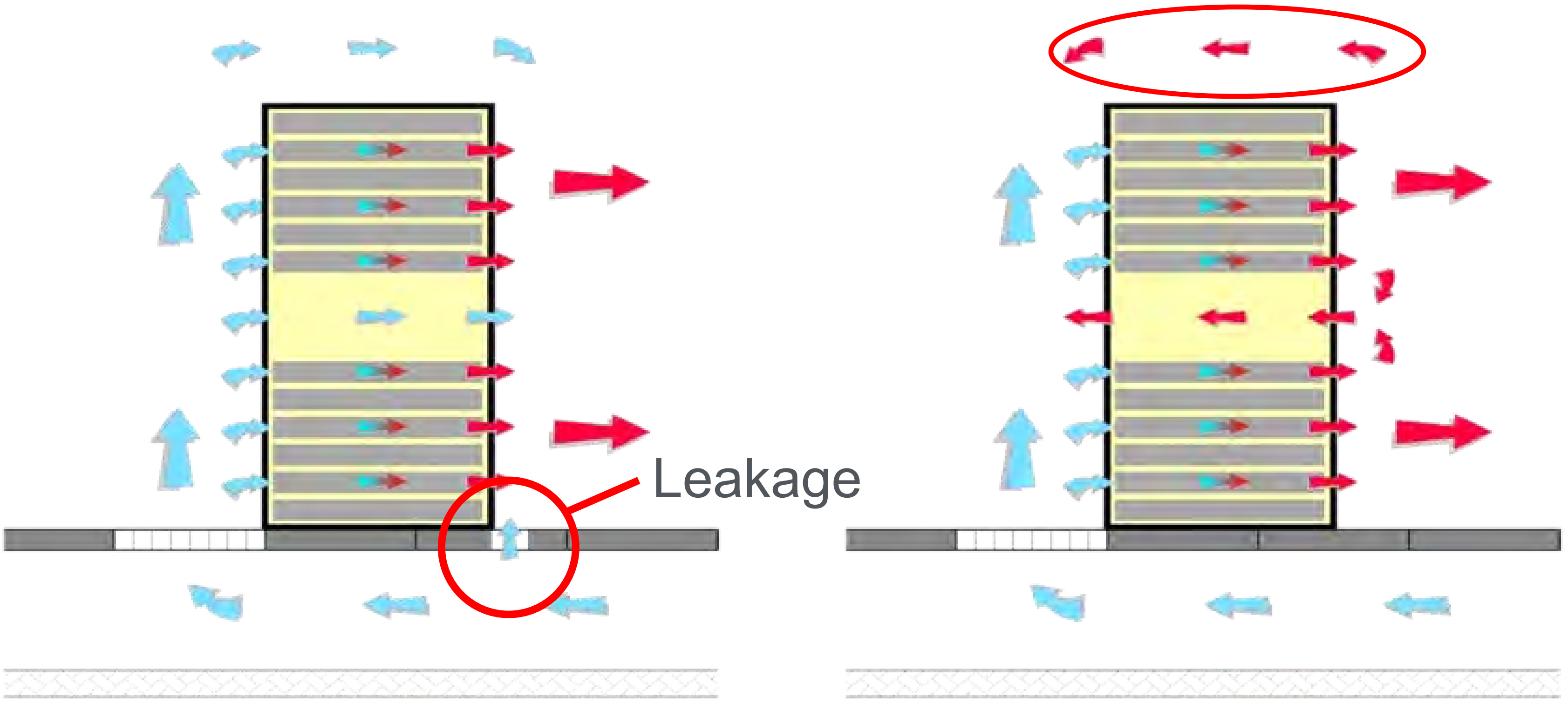
Bypass Air / Short-Circuiting…

Recirculation…




Wastes cooling capacity.

Increases inlet temperature to servers.

# Maintain Raised-Floor Seals

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

**Unsealed cable penetration**

**Sealed cable penetration**

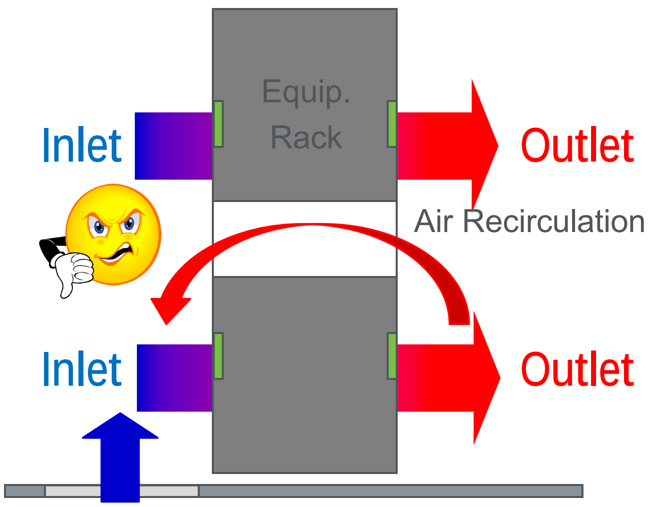
# Manage Blanking Panels

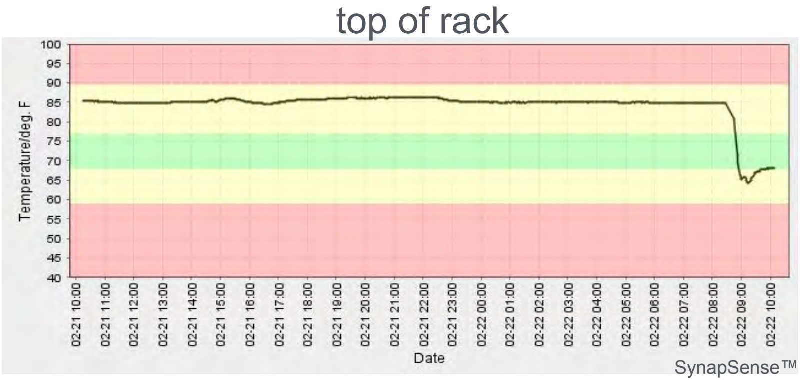


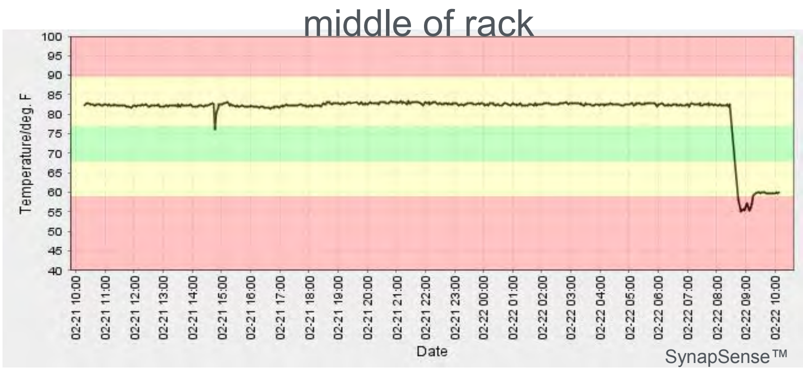
*Any* opening will degrade the separation of hot and cold air

- ➢ maintain server blanking and side panels.

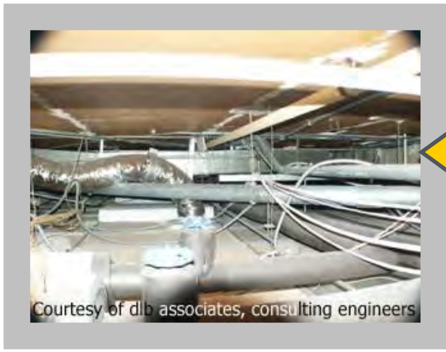
One 12” blanking panel added
Temperature dropped ~20°

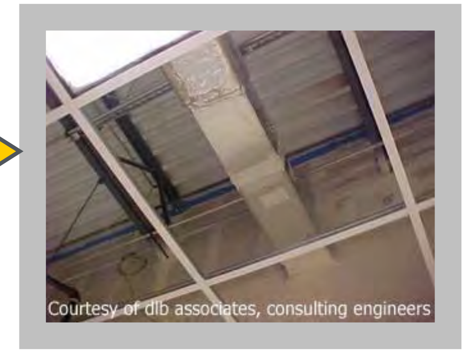


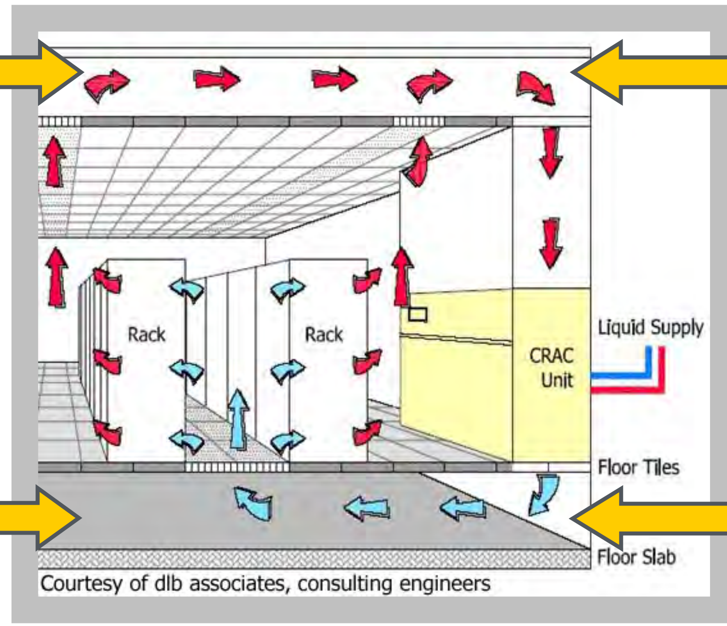



# Reduce Airflow Restrictions & Congestion






Congested Floor & Ceiling Cavities

Consider The Impact That Congestion Has On The Airflow Patterns

Empty Floor & Ceiling Cavities

# Resolve Airflow Balancing

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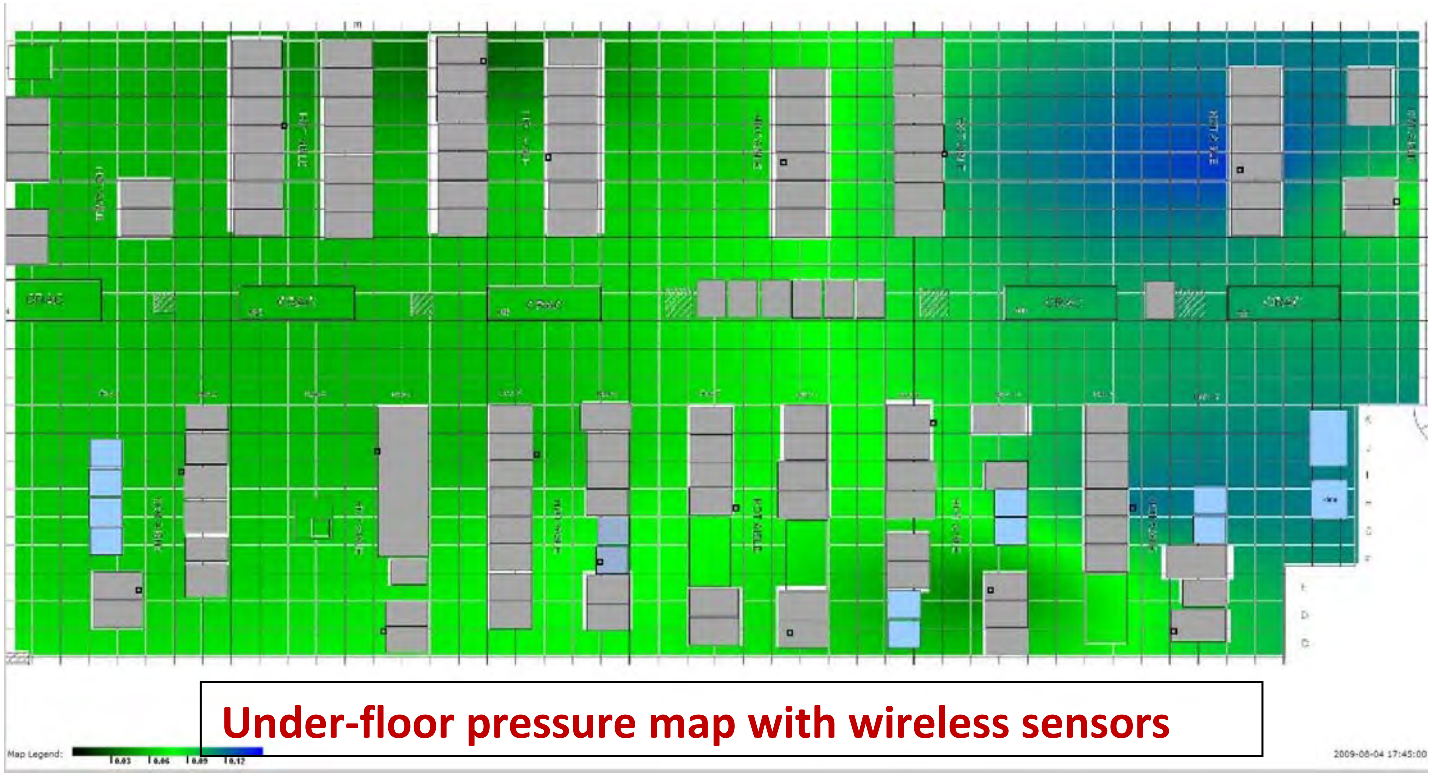
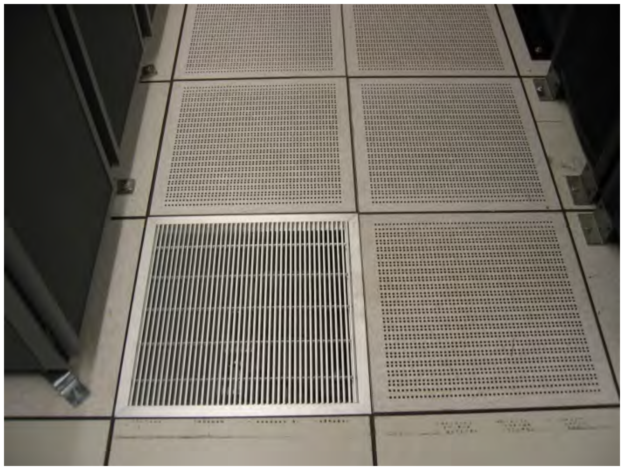
- BALANCING is required to optimize airflow.
- Rebalancing needed with new IT or HVAC equipment
- Locate perforated floor tiles *only* in cold aisles



Under-floor pressure map with wireless sensors

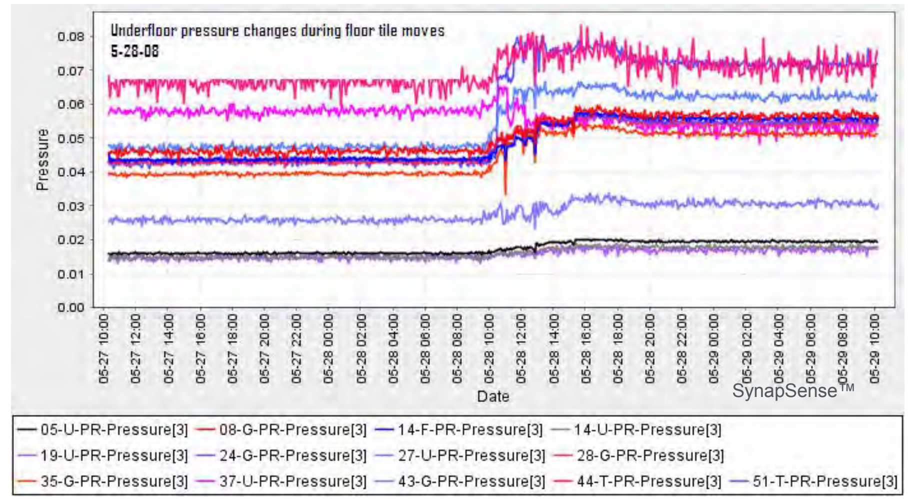
# Results: Tune Floor Tiles



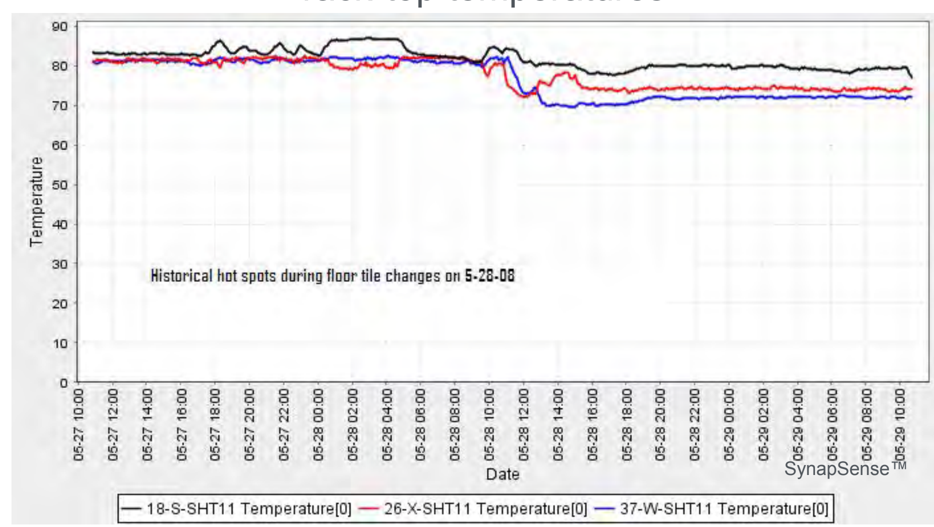


- Too many permeable floor tiles
- if airflow is optimized
  - under-floor pressure up □
  - rack-top temperatures down □
  - data center capacity increases
- Measurement and visualization assisted tuning process

under-floor pressures




rack-top temperatures



# Optimally Locate CRAC/CRAHs

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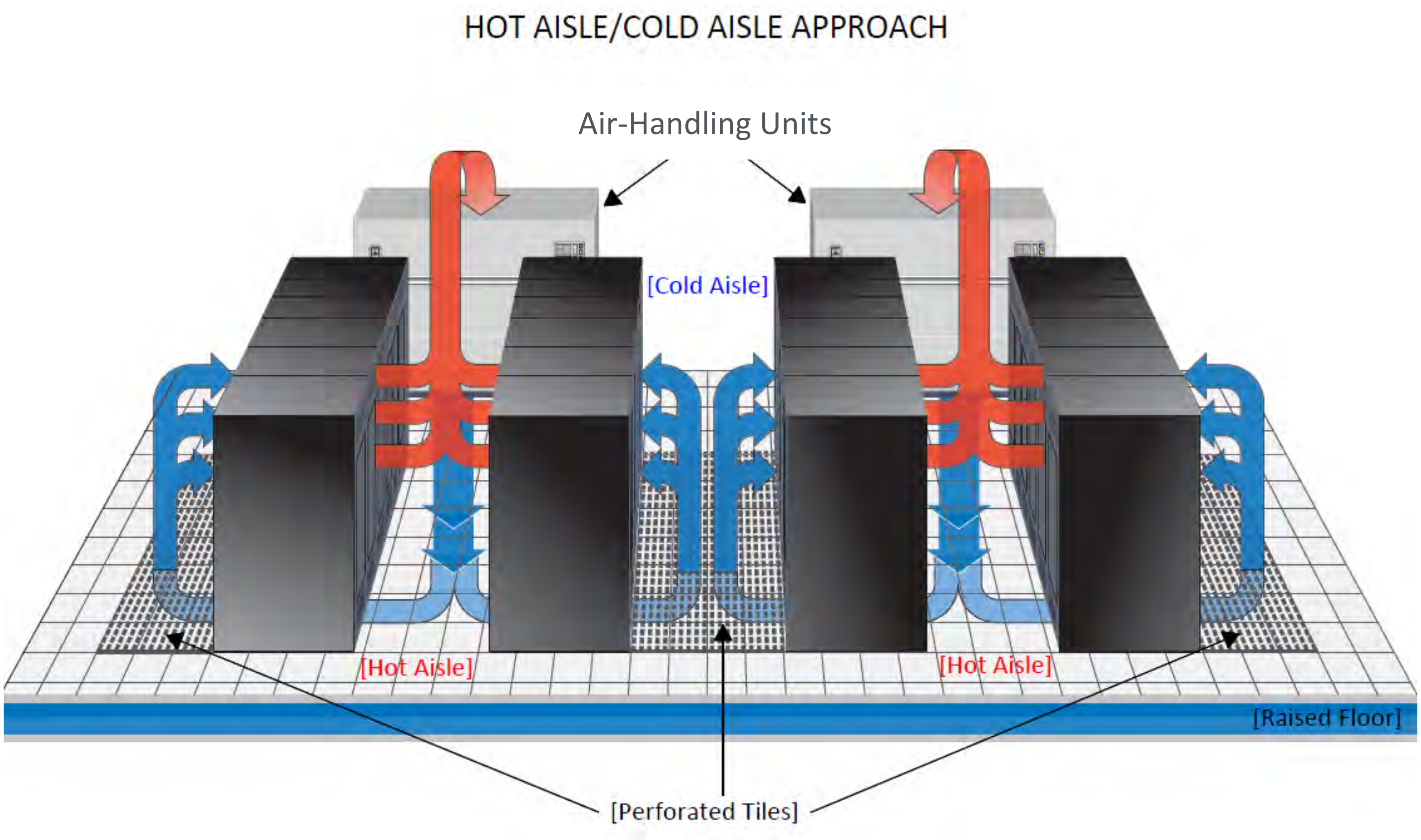
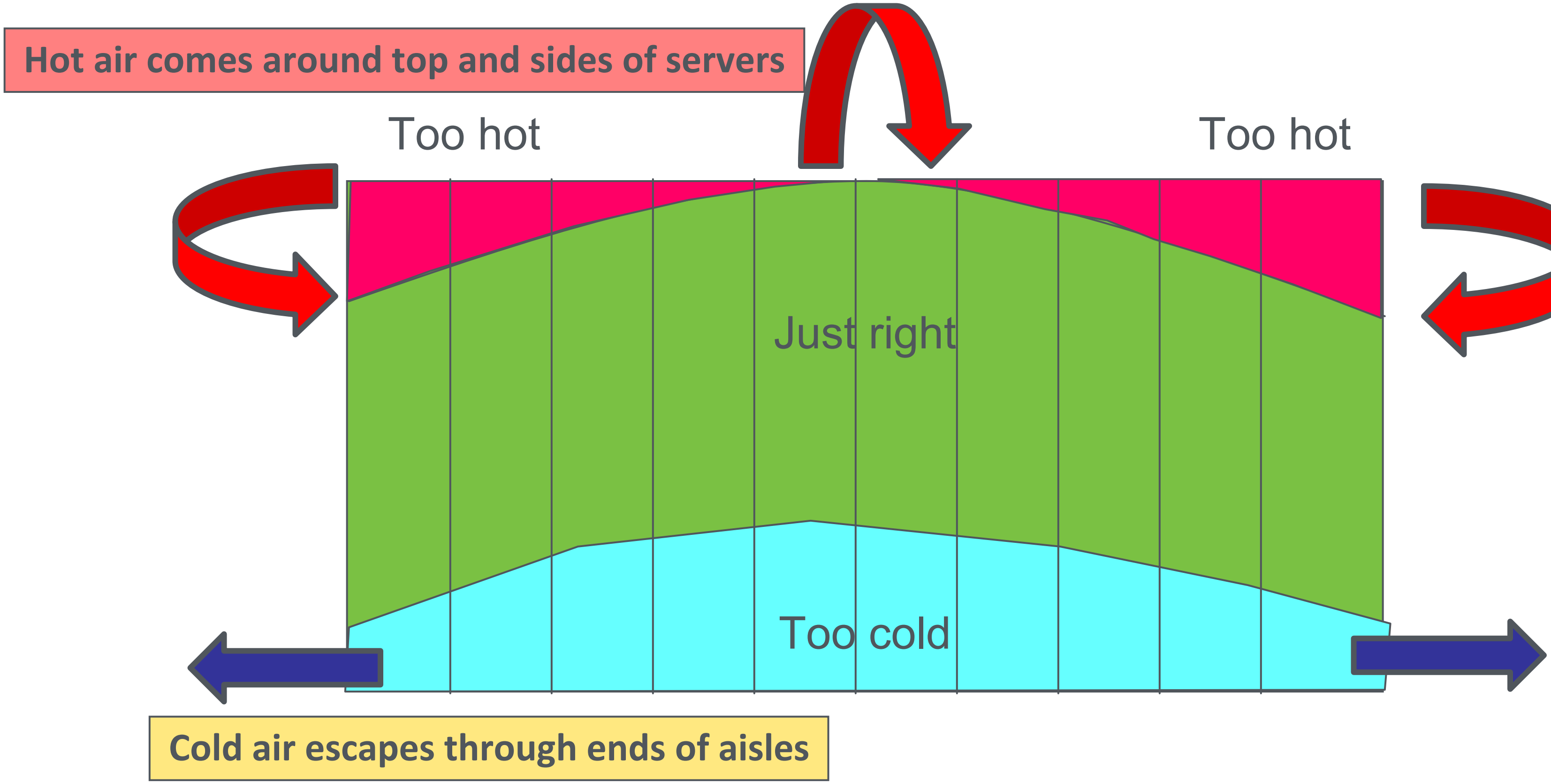
Locate CRAC/CRAH units at ends of Hot Aisles



# 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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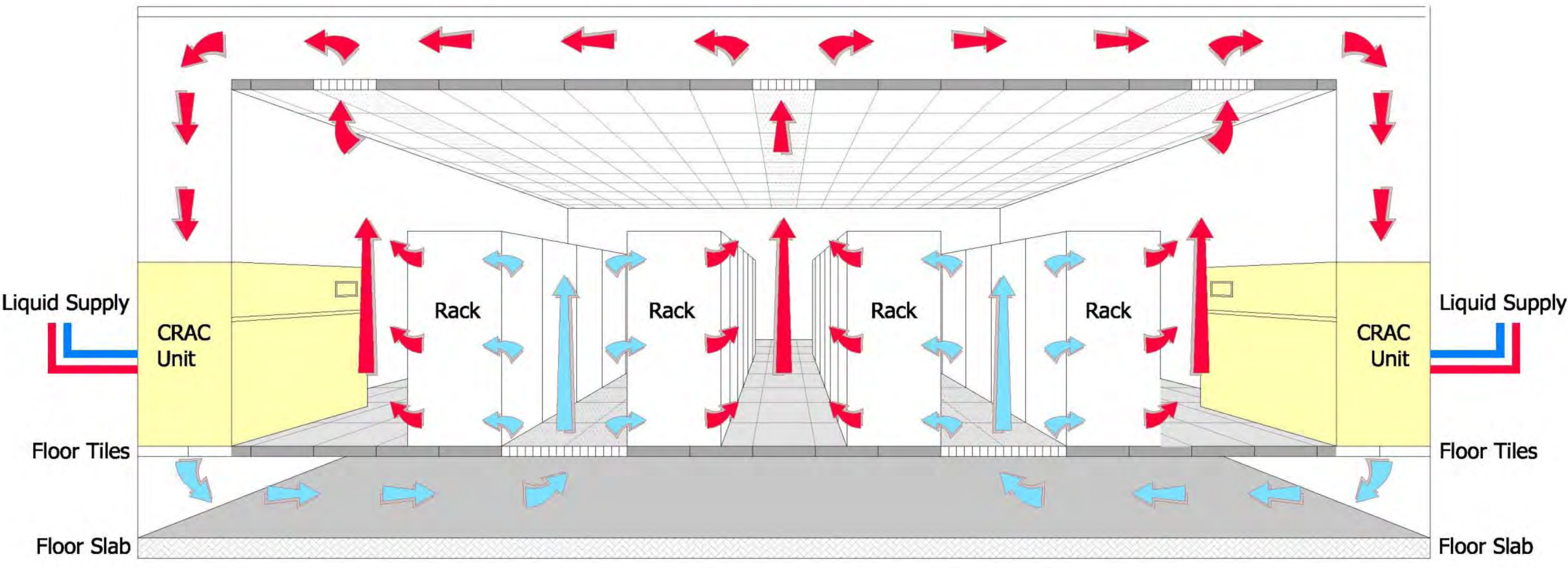
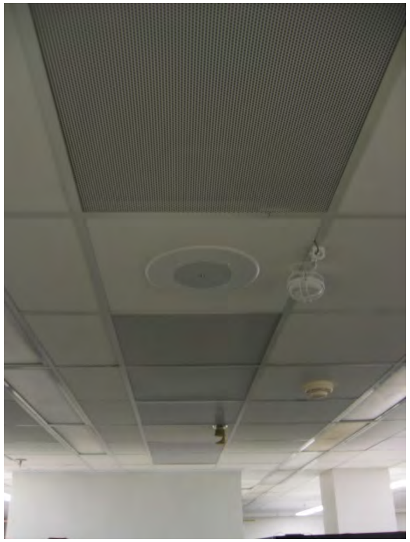


# Return air plenum

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

Before


After



# Return-Air Plenum Connections



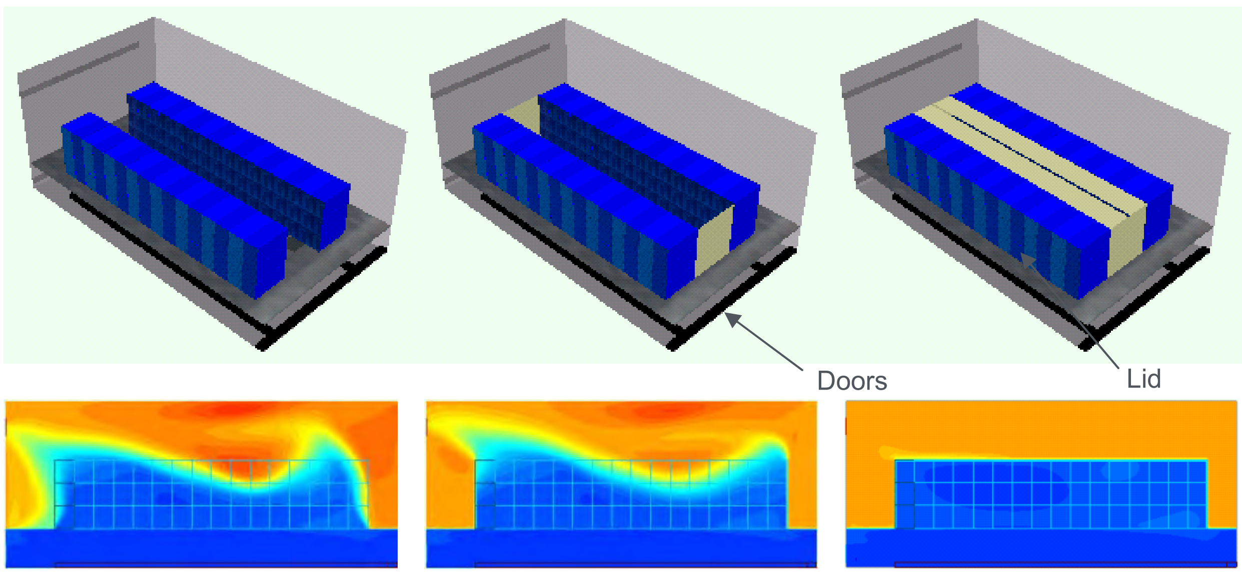
**Return air duct on top of CRAC unit connects to the return air plenum.**

# Isolate Hot Return

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

# 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.




**Open** | **Semi-enclosed cold aisle** | **Enclosed cold aisle**

# Adding Air Curtains for Hot/Cold Isolation

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# Isolate Cold and Hot Aisles

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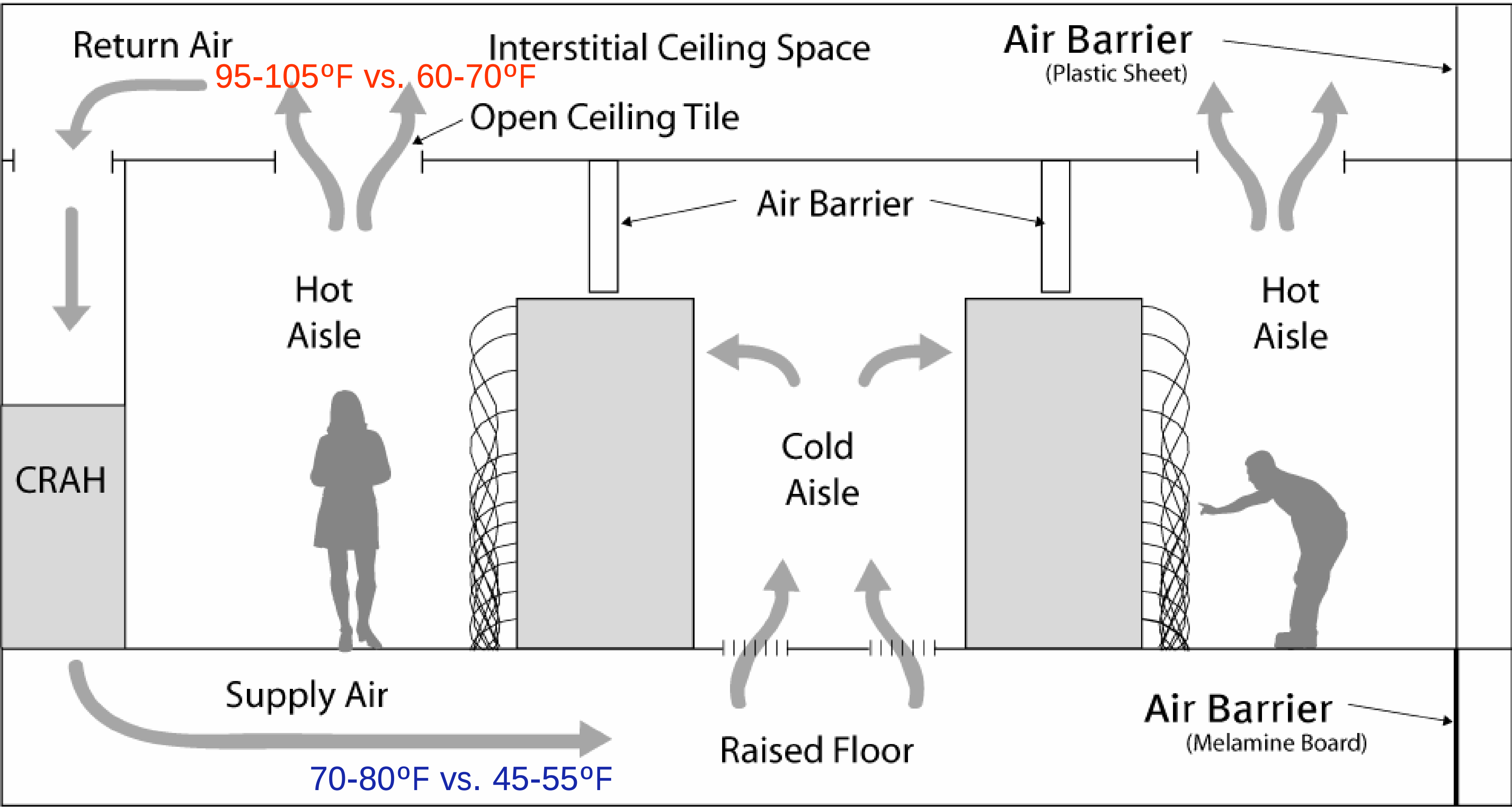
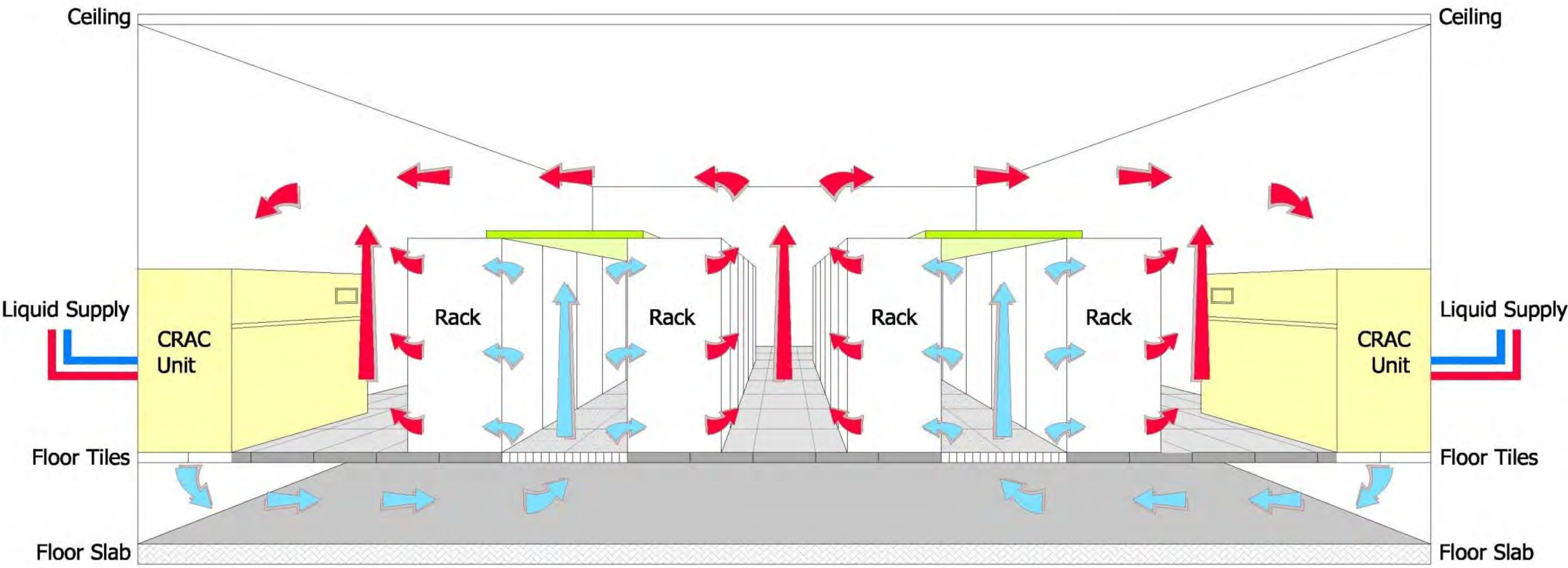


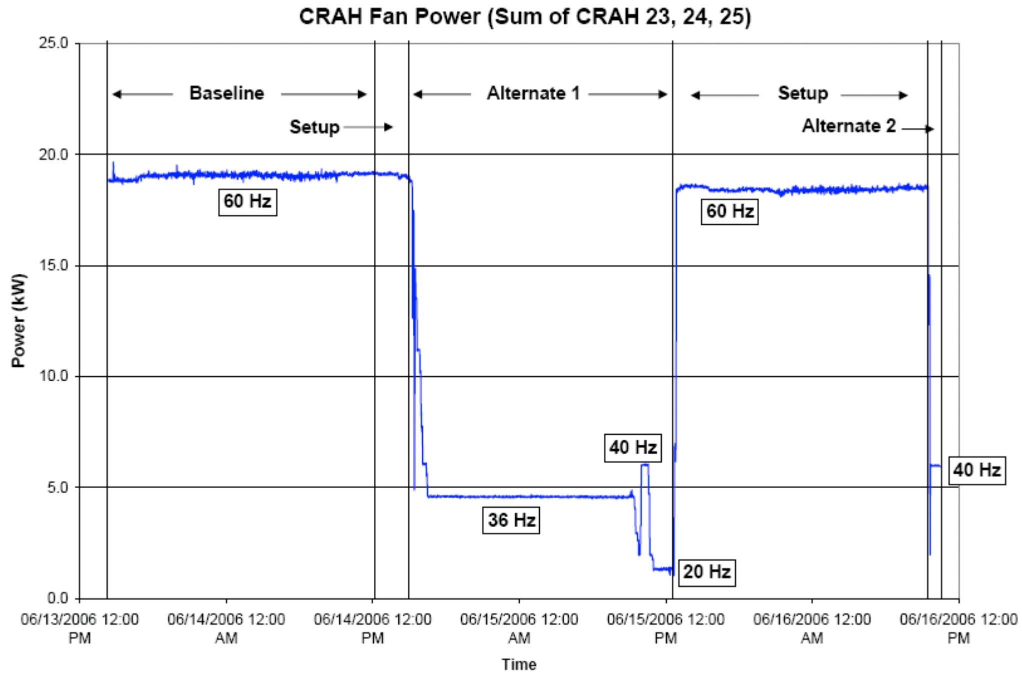
# Cold Aisle Airflow Containment Example




**LBNL 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)

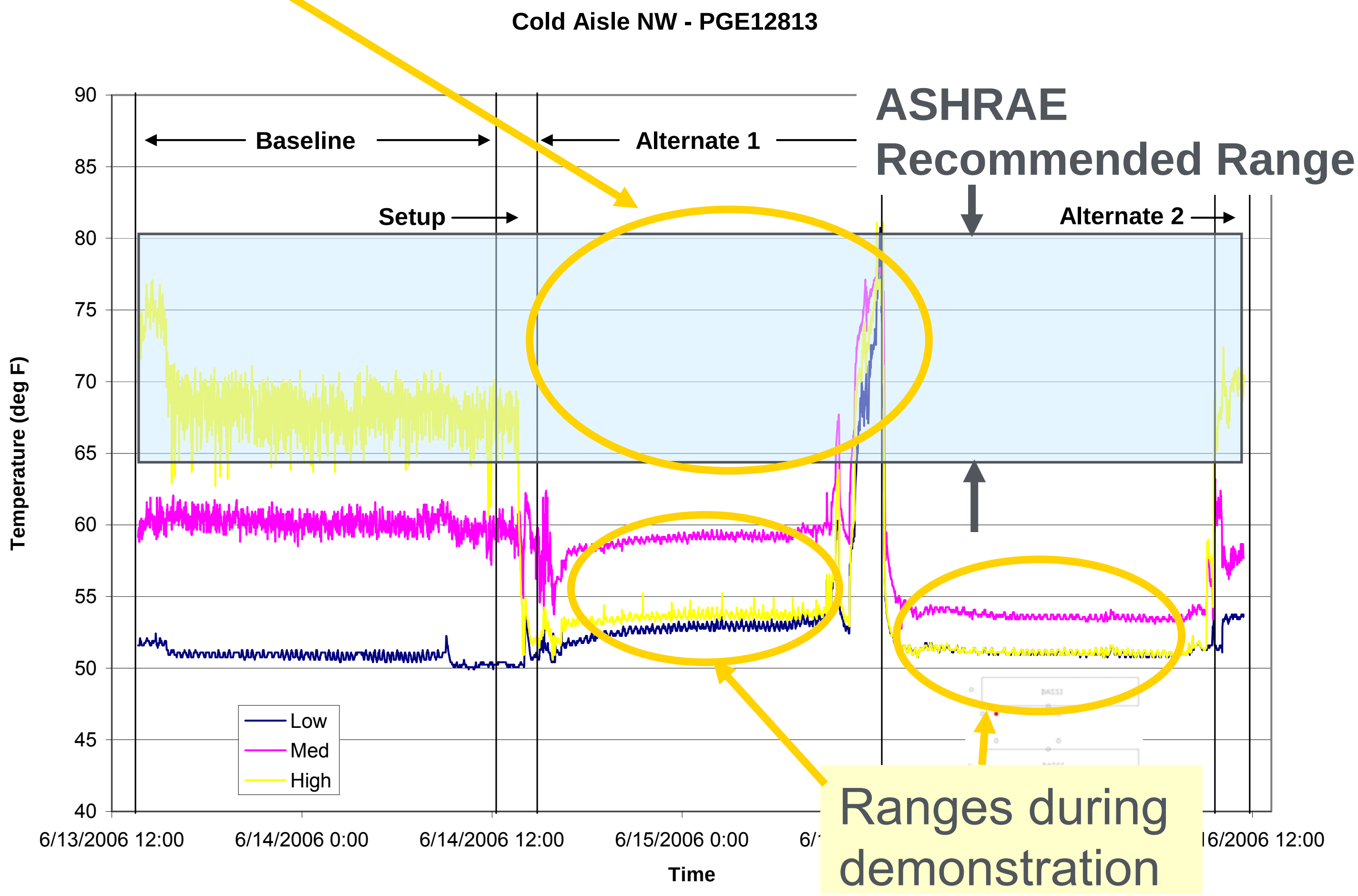



Without Enclosure With Enclosure Without Enclosure

# LBNL Air Management Demonstration



Better airflow management permits warmer supply temperatures!



# Isolating hot or cold aisles



- 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.

# 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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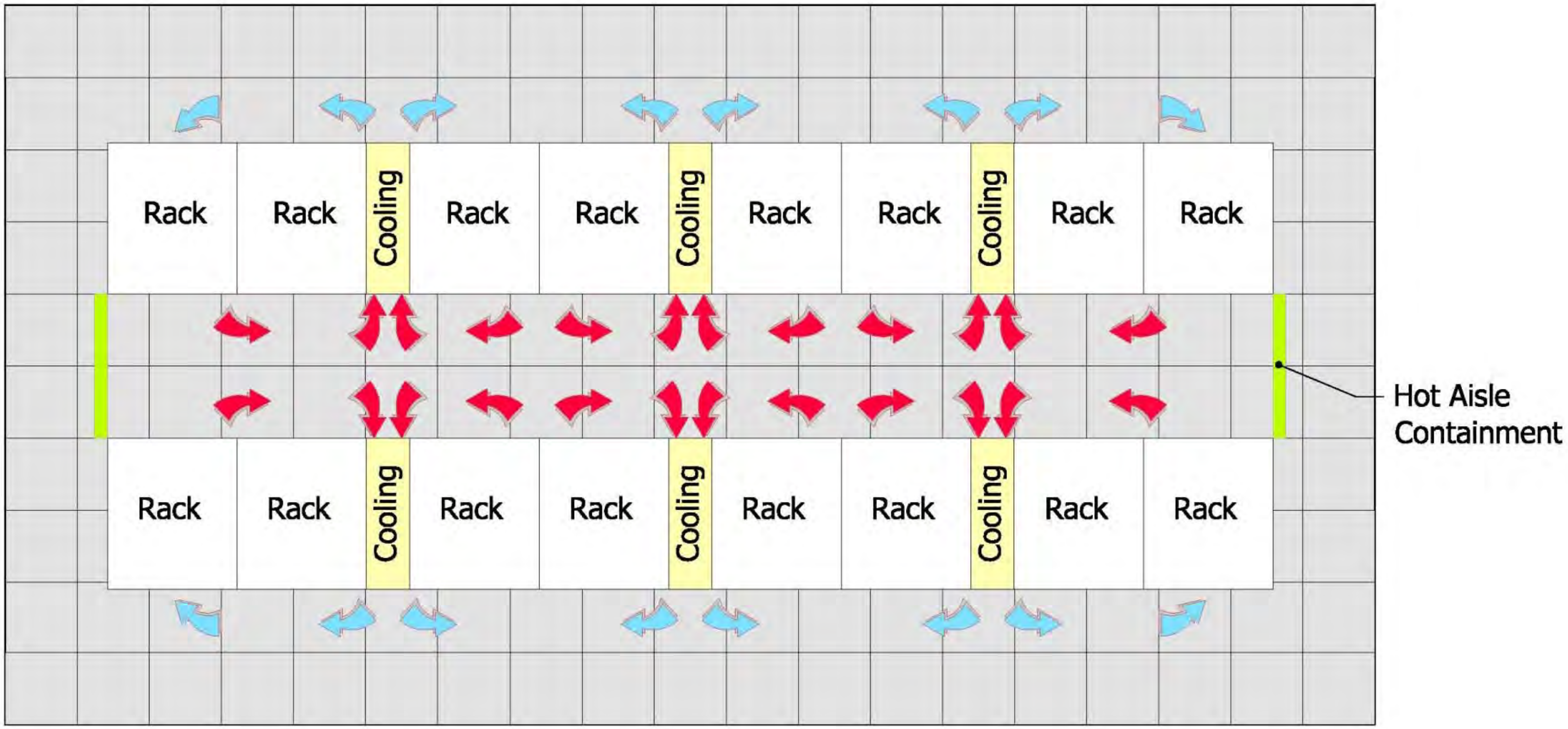
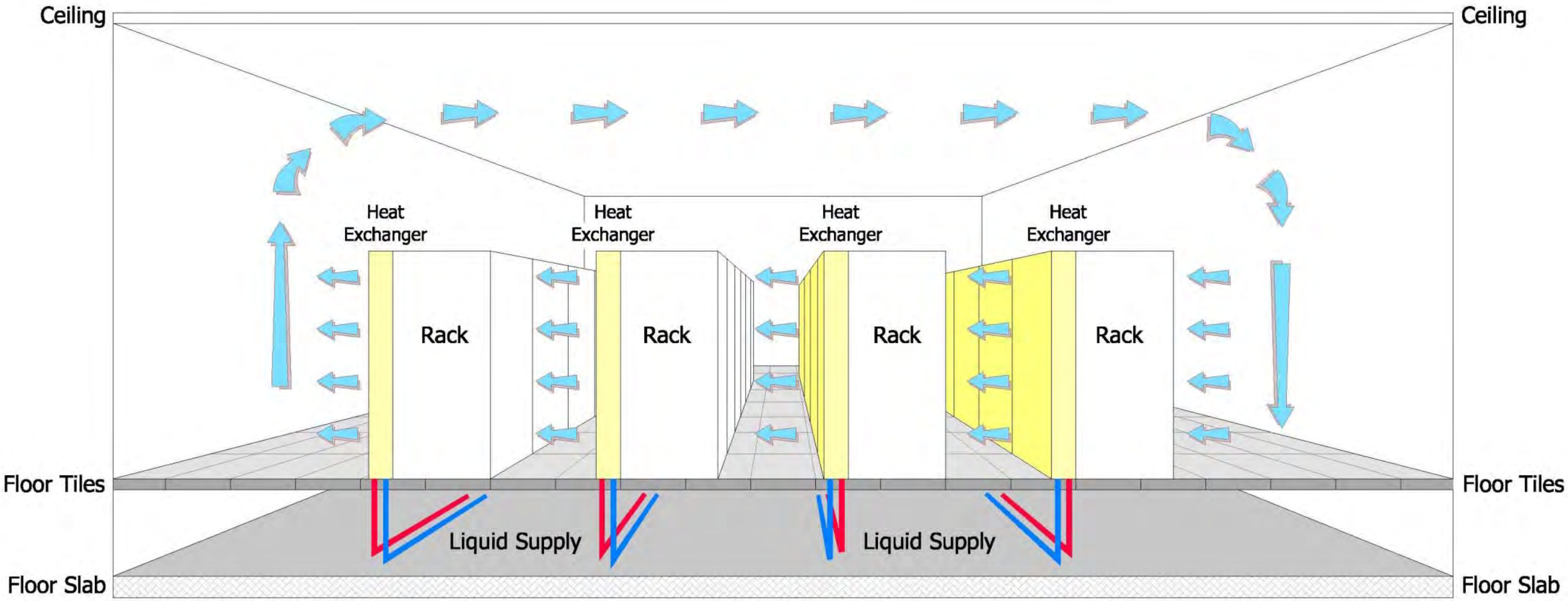


# Air Distribution – Rack-Mounted Heat Exchangers



# 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?

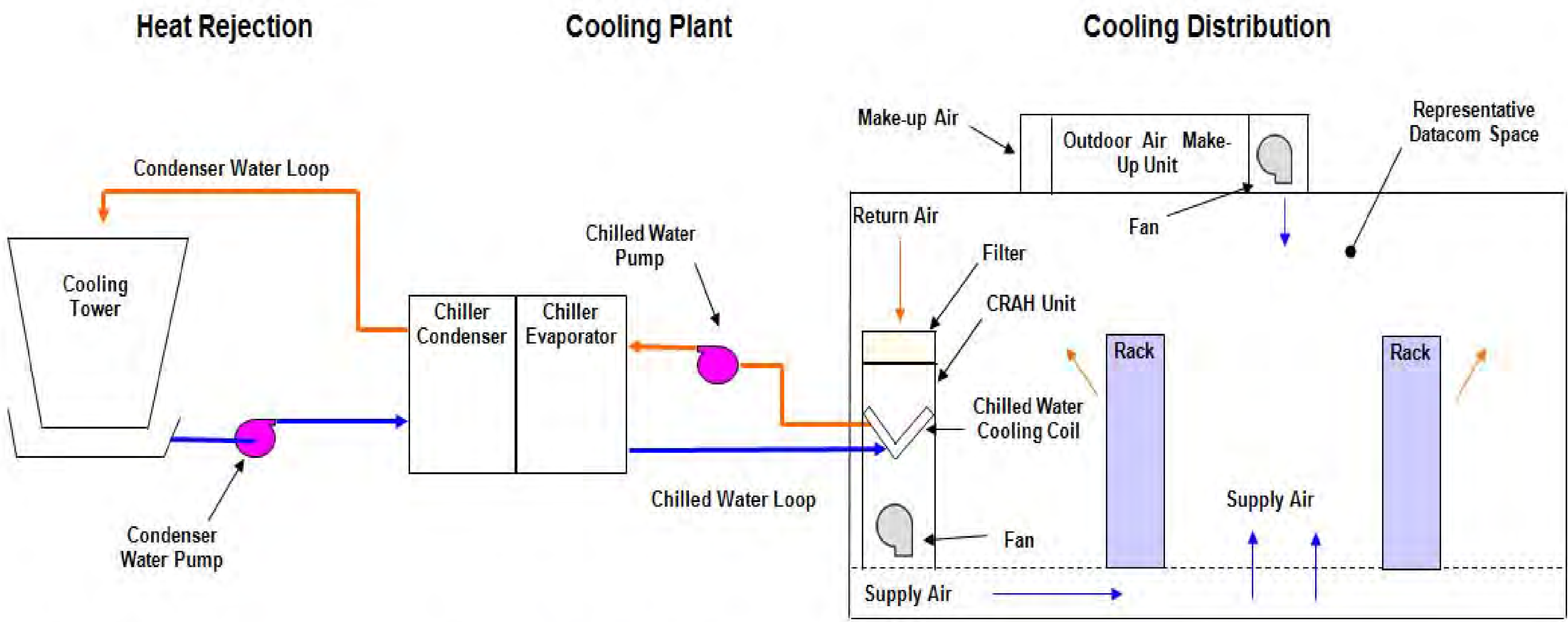
# Cooling systems

## 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:**

High Eff

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

Low Eff

**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**

High Eff

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

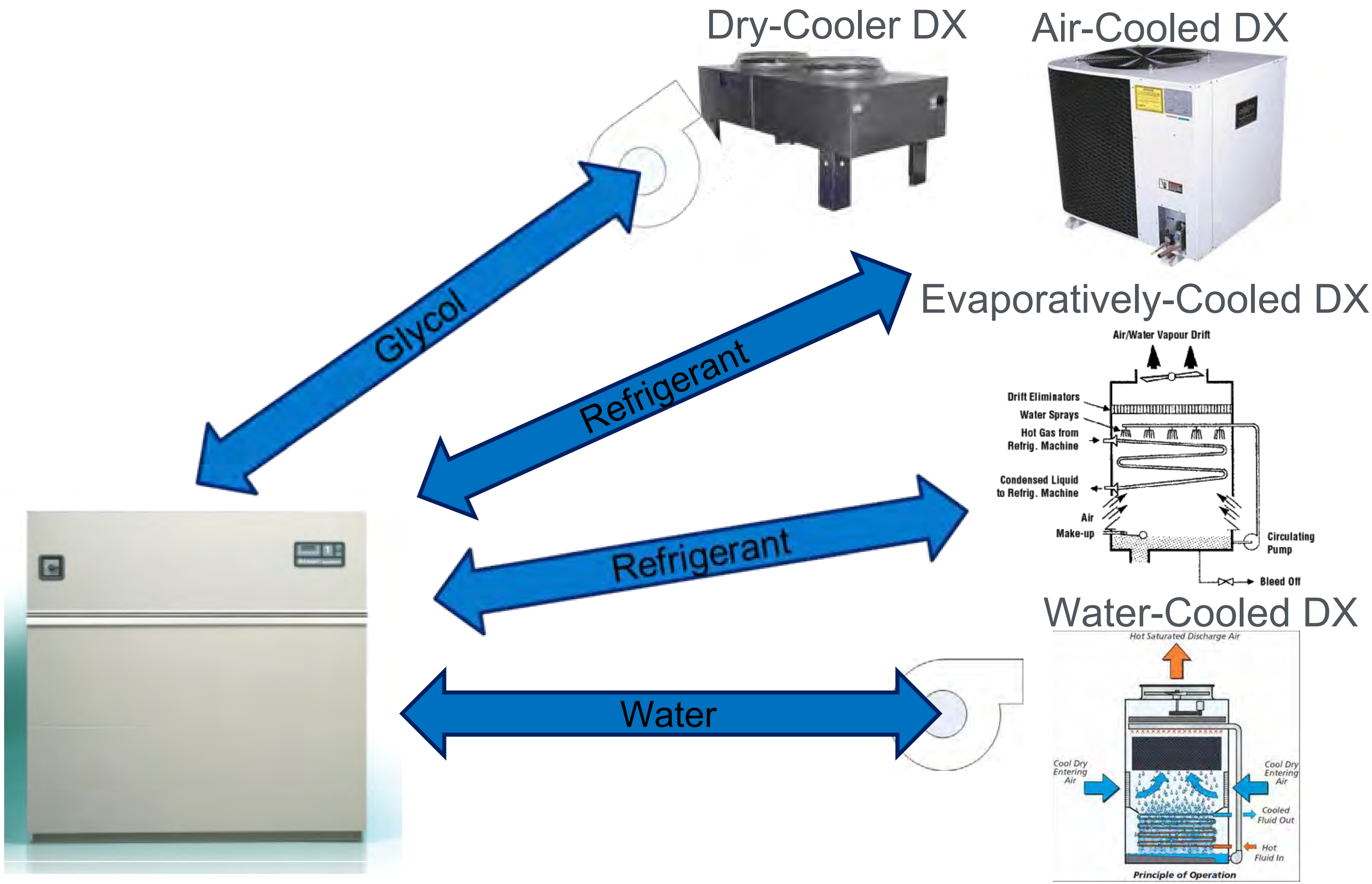
Low Eff

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



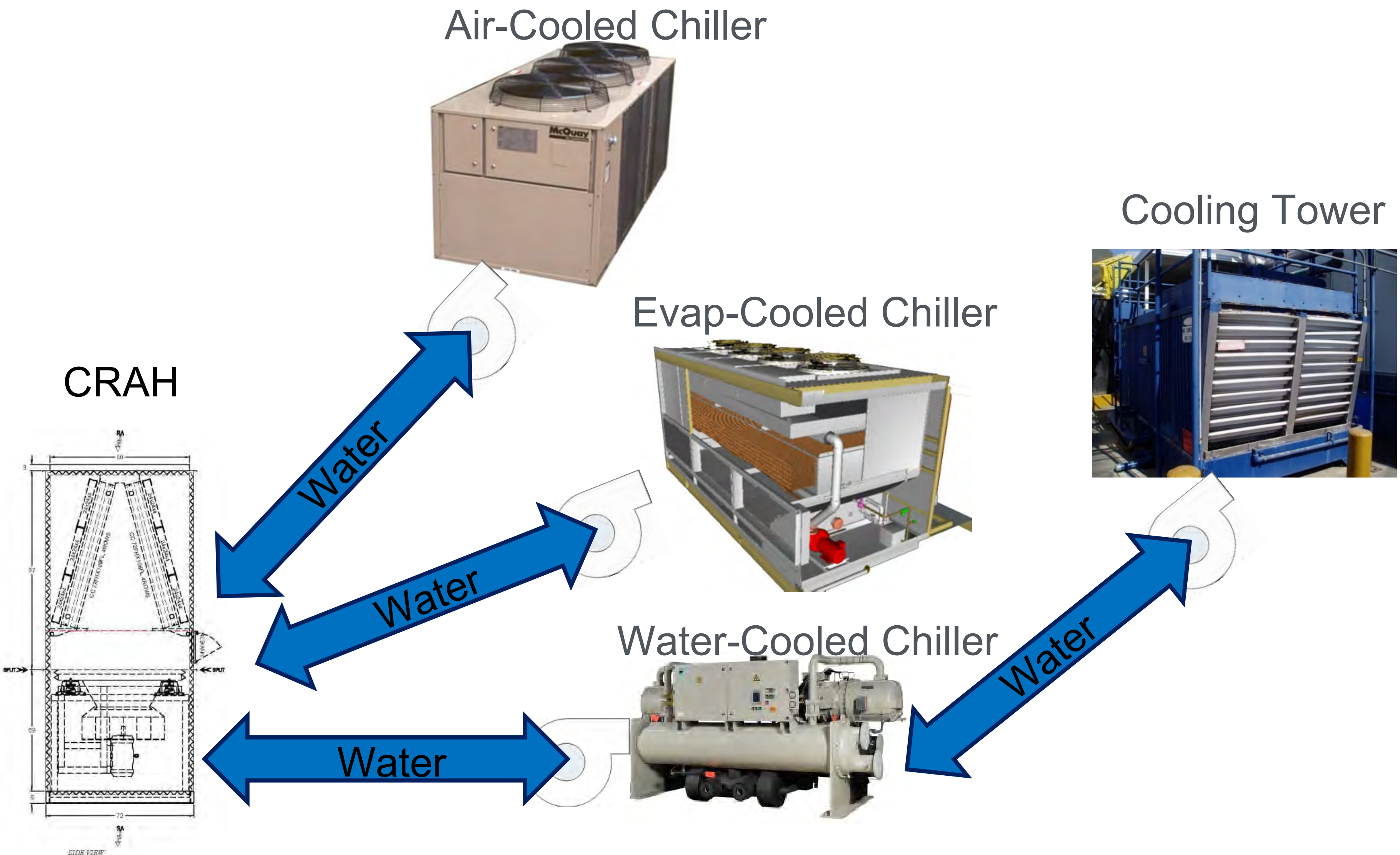
- **CRAC units**
  - Fan, direct expansion (DX) coil, and refrigerant compressor.
- **CRAH units**
  - Fan and chilled water coil
  - Typically in larger facilities with a chiller plant
- **Both often equipped with humidifiers and reheat for dehumidification**
- **Often independently controlled**
  -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

# DX (or AC) units reject heat outside…



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

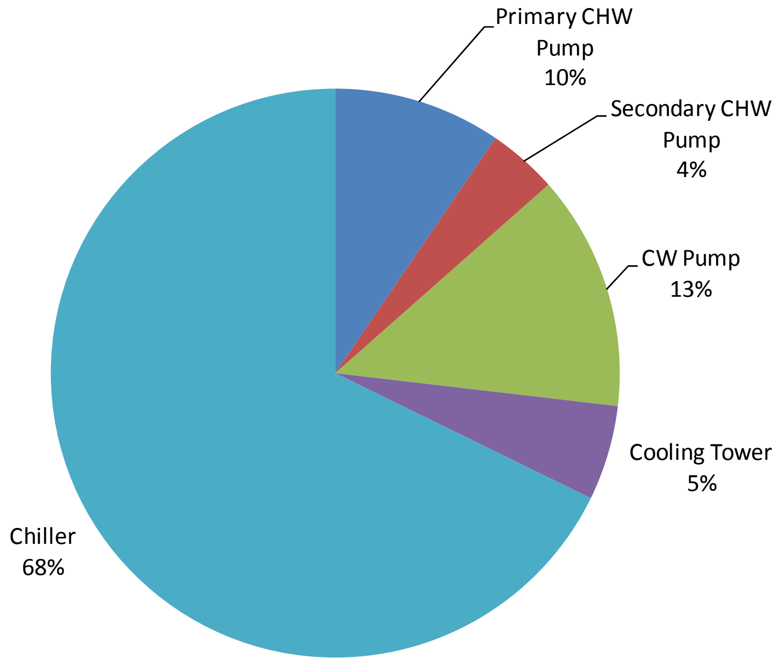




# Optimize the Chiller Plant



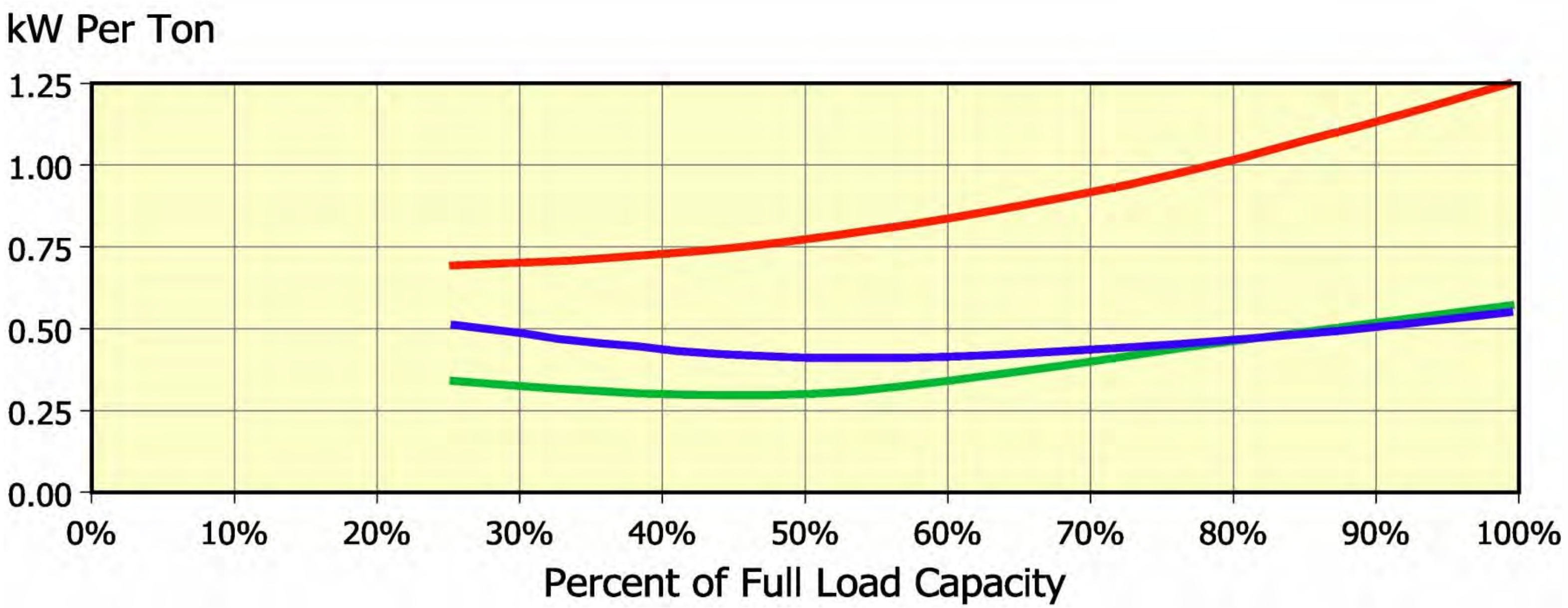
- Have a plant (vs. distributed cooling)
- Use “warm” water cooling (multi-loop)
- Size cooling towers for “free” cooling
- Integrate controls and monitor efficiency of all primary components
- Thermal storage
- Utilize variable speed drives on:
  - Fans
  - Pumps
  - Towers
  - Chillers



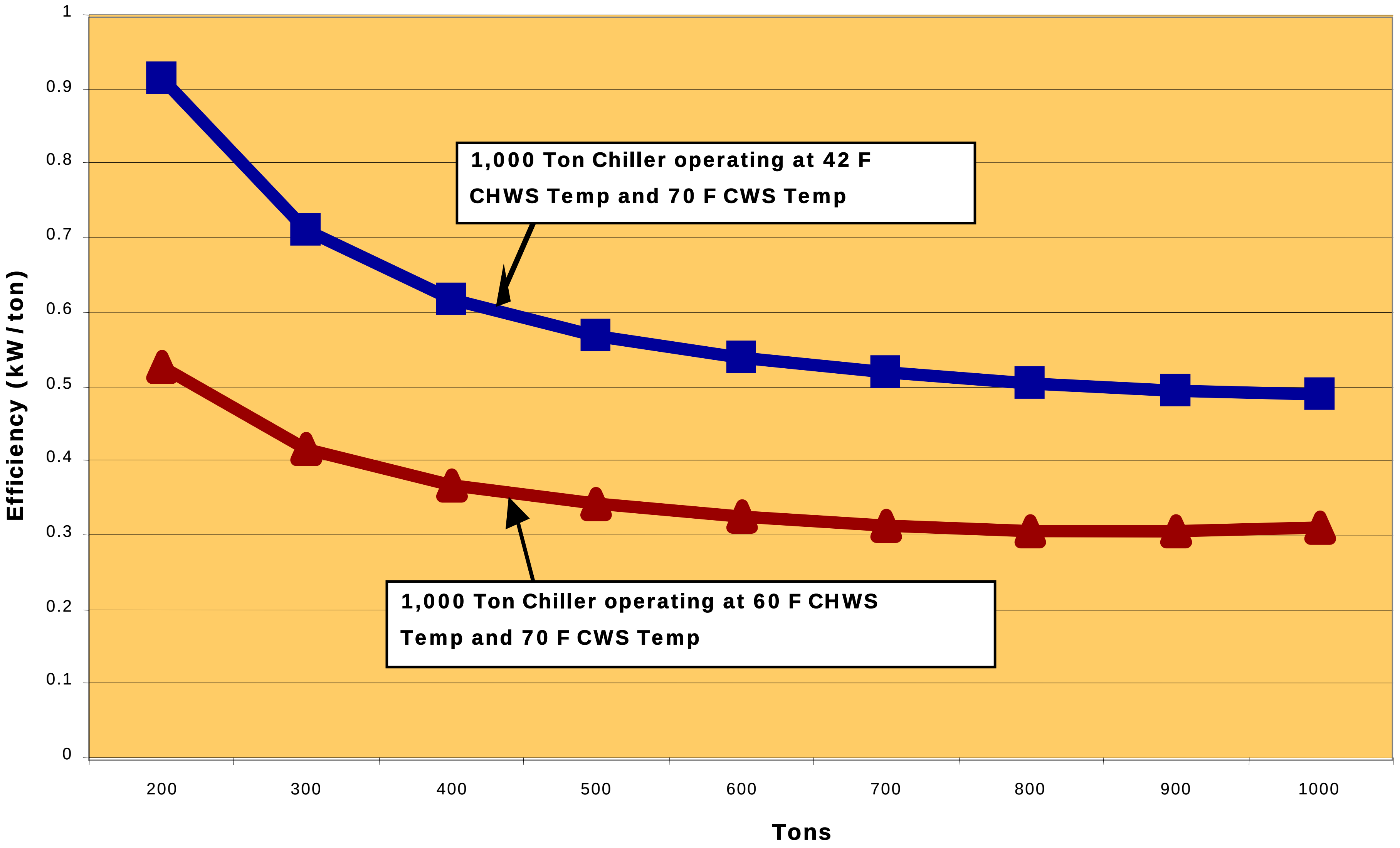
# Select Efficient Chillers



| 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




Data provided by York International Corporation.

# Moving (Back) to Liquid Cooling

As heat densities rise, liquid solutions become more attractive:

## Volumetric heat capacity comparison


Water

=


Air

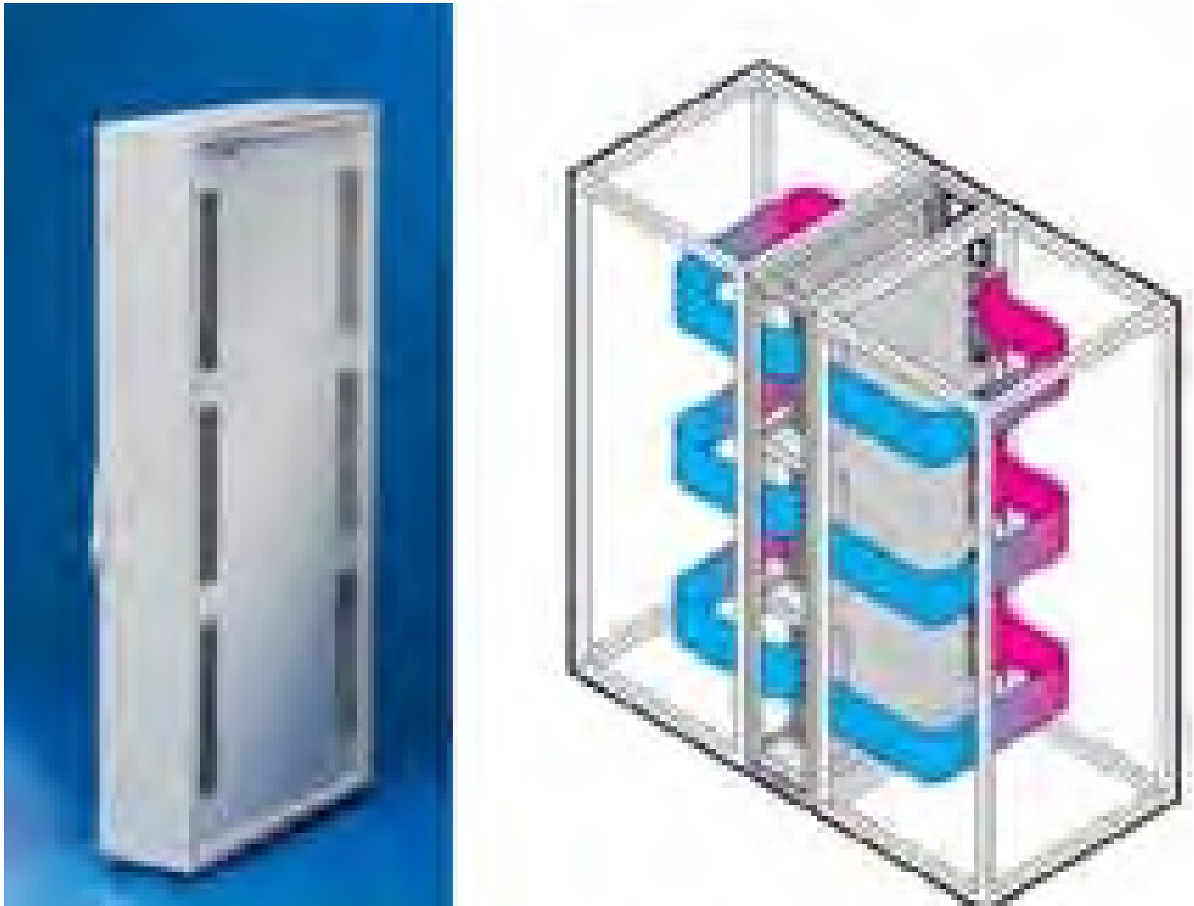
# Why Liquid Cooling?



- 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

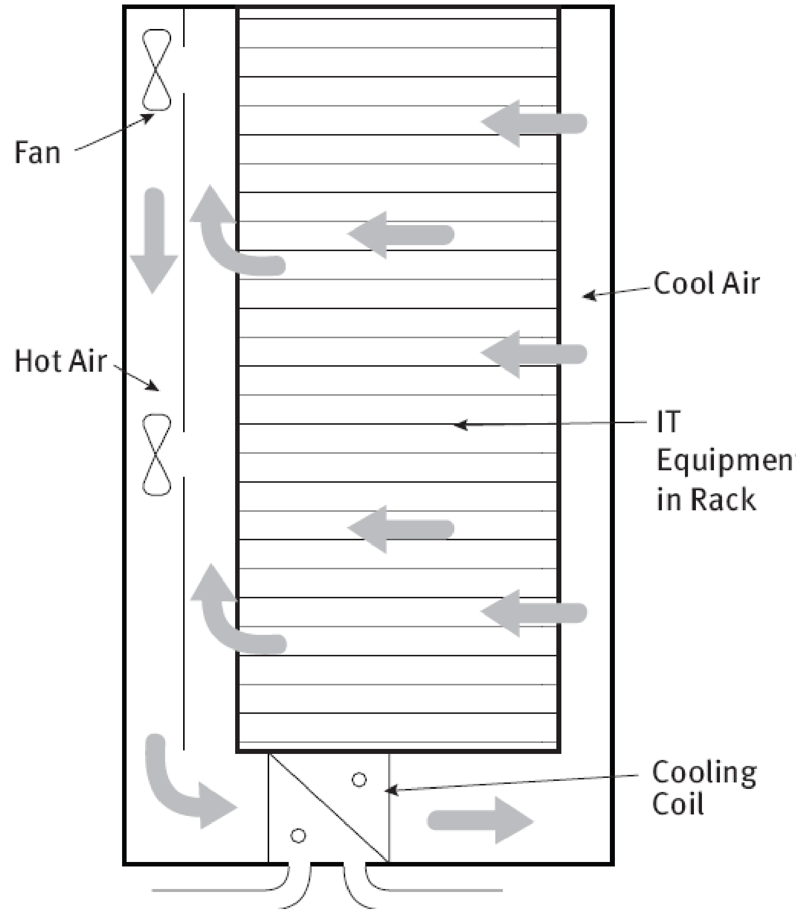


*Graphics courtesy of Rittal*

# In Rack Liquid Cooling

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

## Racks with integral coils and full containment

# Rear-Door Liquid Cooling

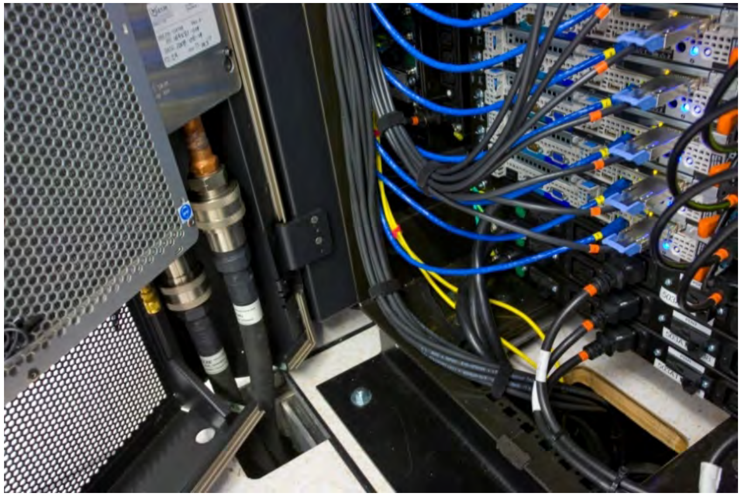
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Rear Door (open)

Inside rack RDHx, open 90°

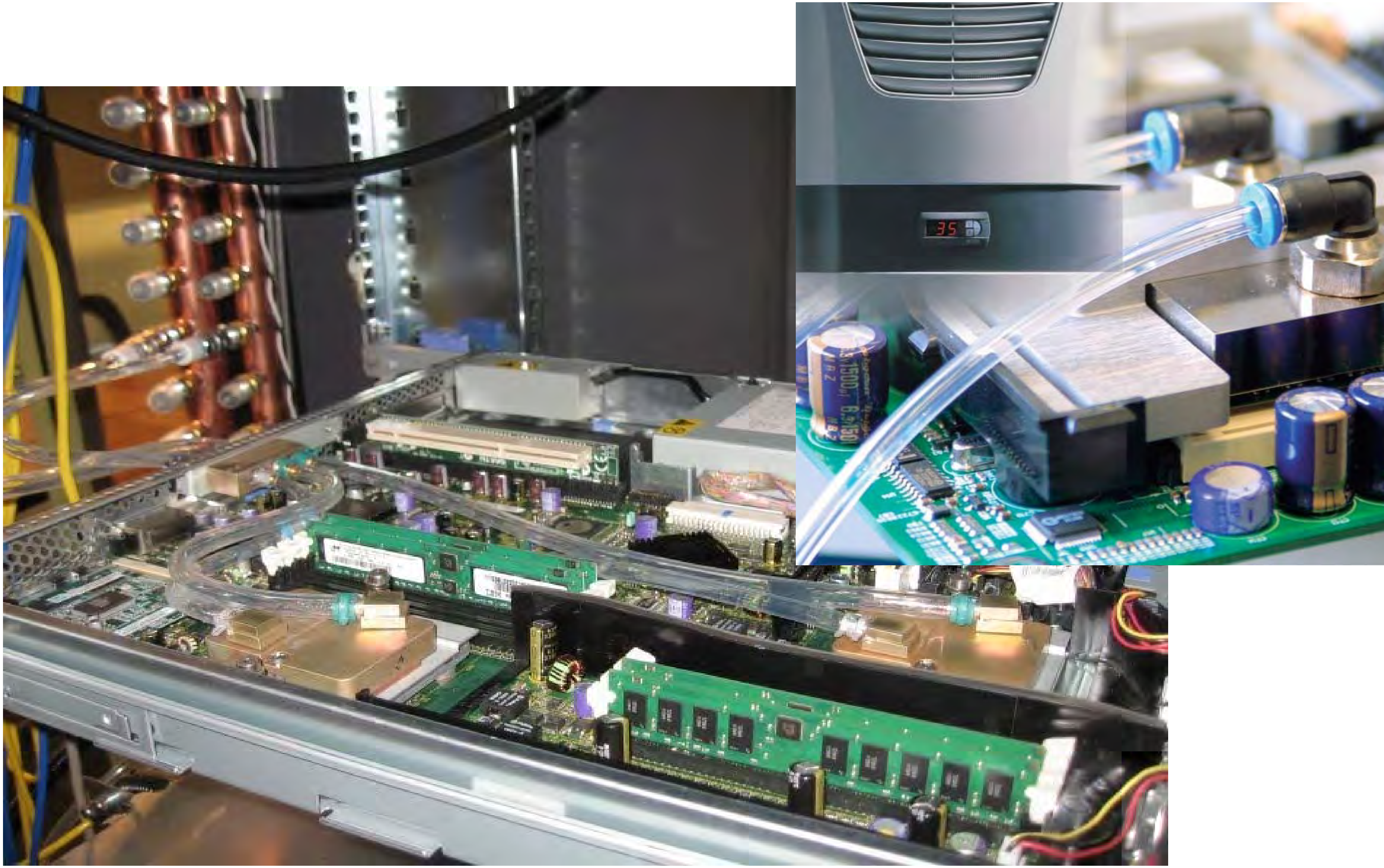
Rear Doors (closed)

Liquid Cooling Connections



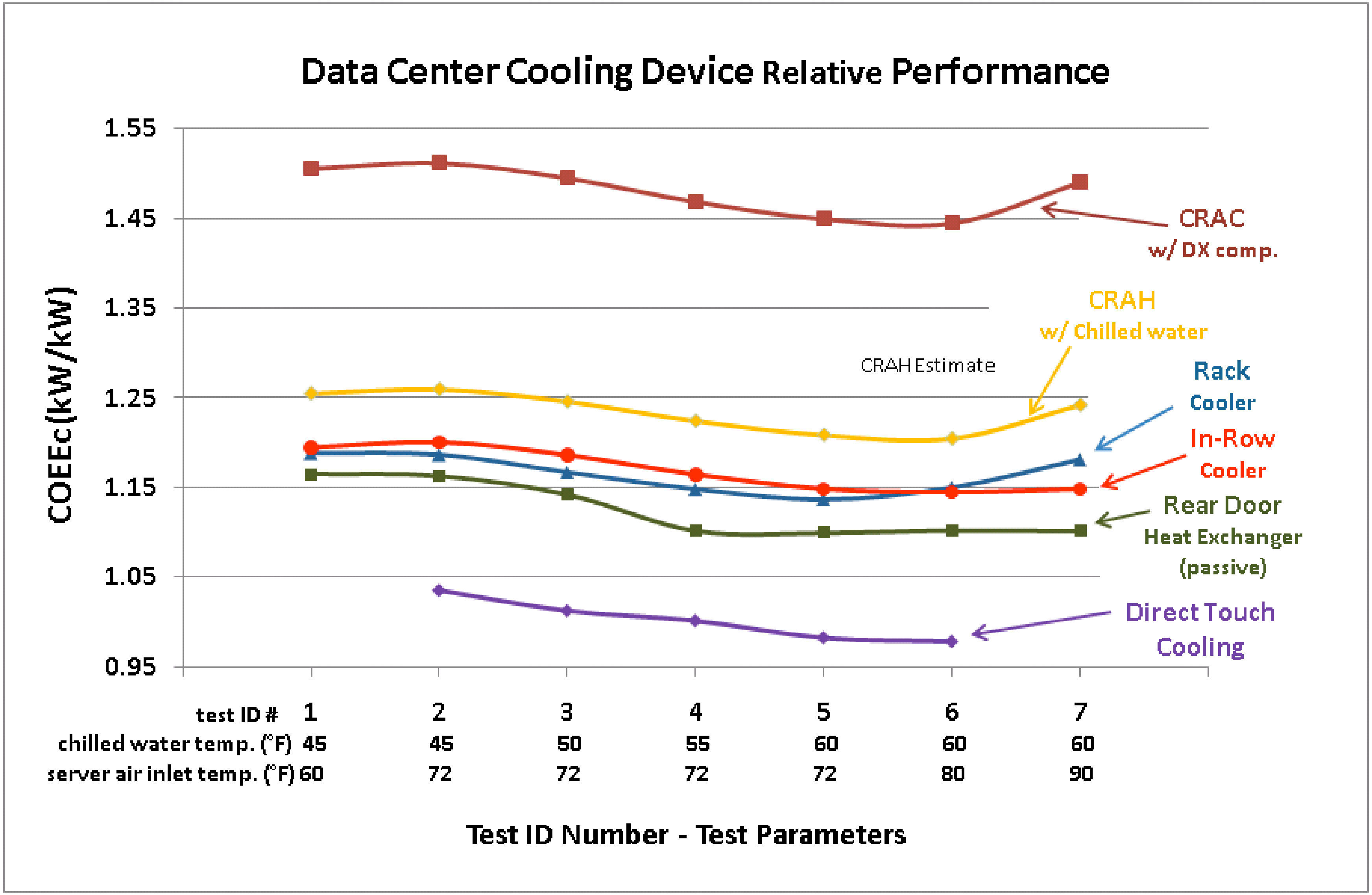
# On Board Cooling





# "Chill-off 2" evaluation of liquid cooling solutions

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



## Cooling without Compressors:

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

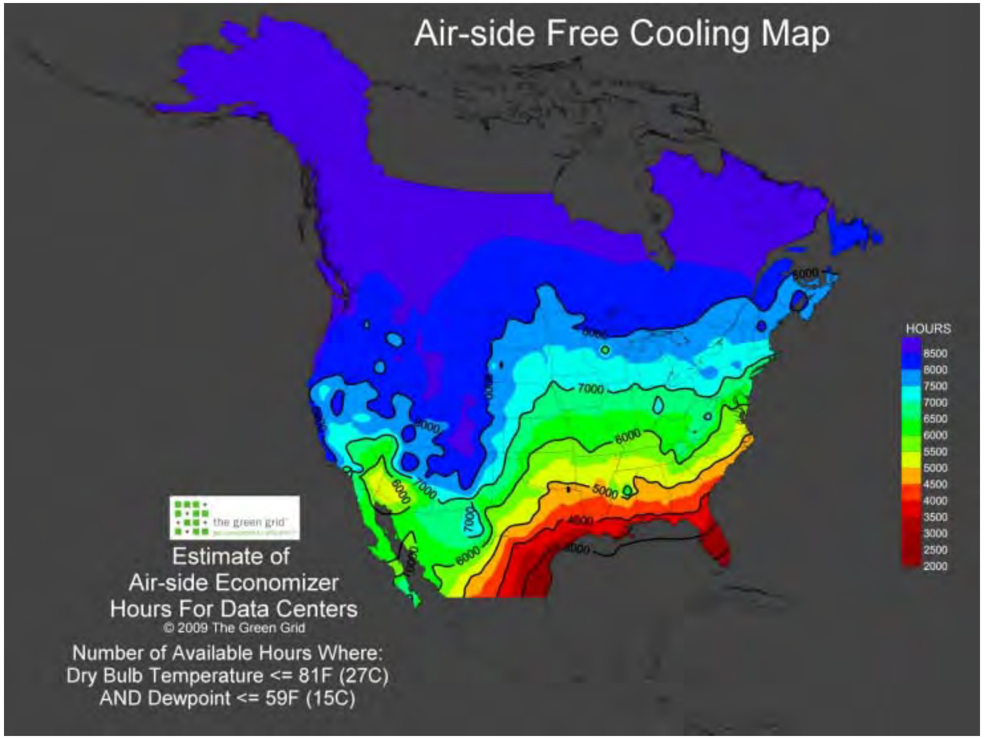
# Outside-Air Economizers

## 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

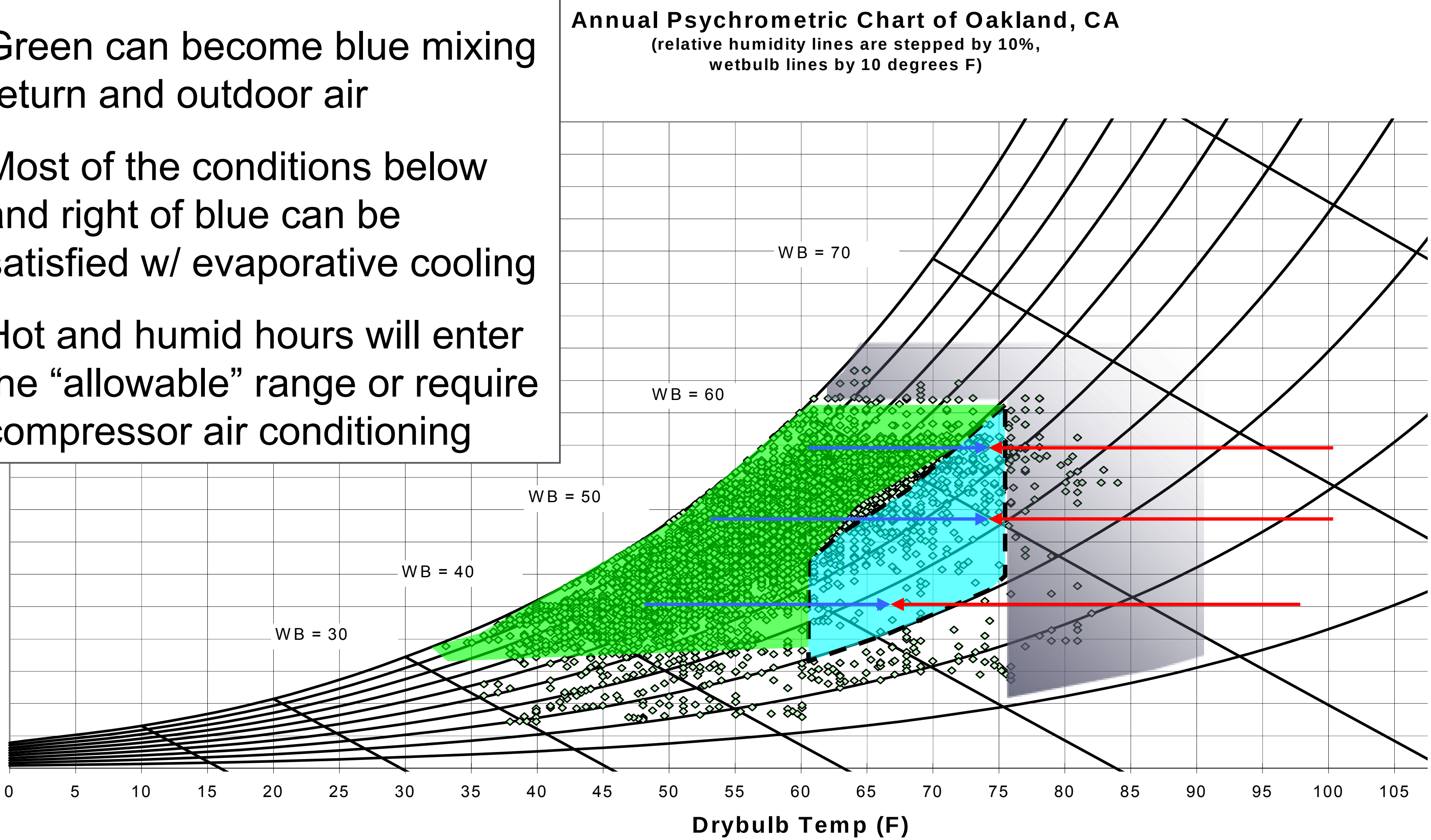
# UC's Computational Research and Theory (CRT) Facility



# Free Cooling – Outside Air Based

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

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

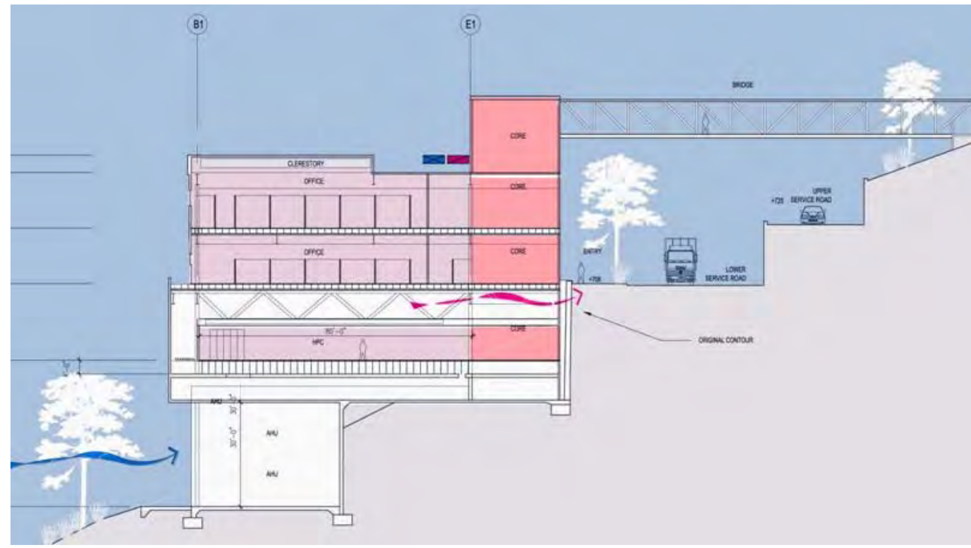


# System Design Approach:



- 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 Cooling:

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

## Predicted CRT Performance:

- Annual PUE = 1.1

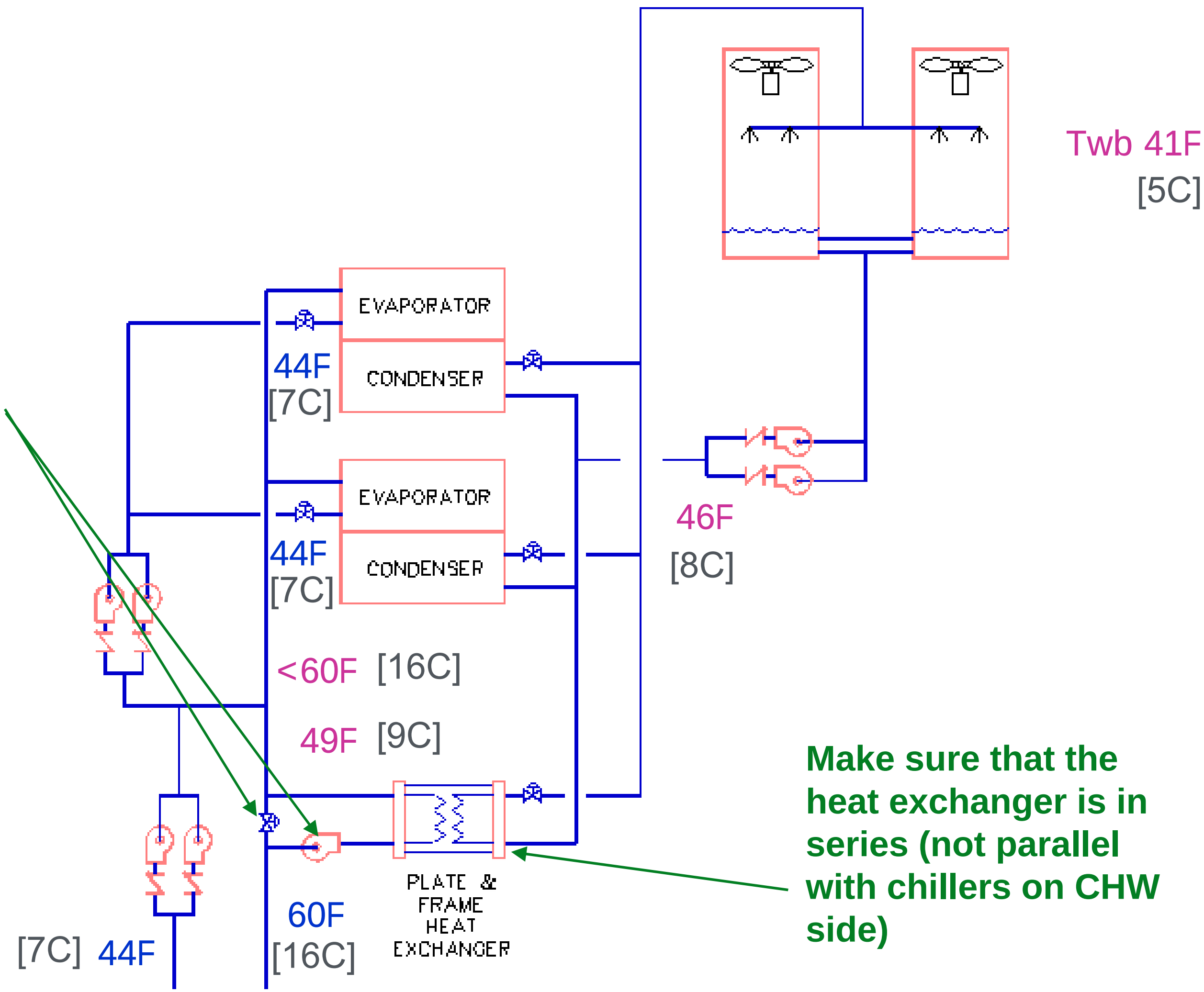
# Water-Side Economizers

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

## Advantages

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

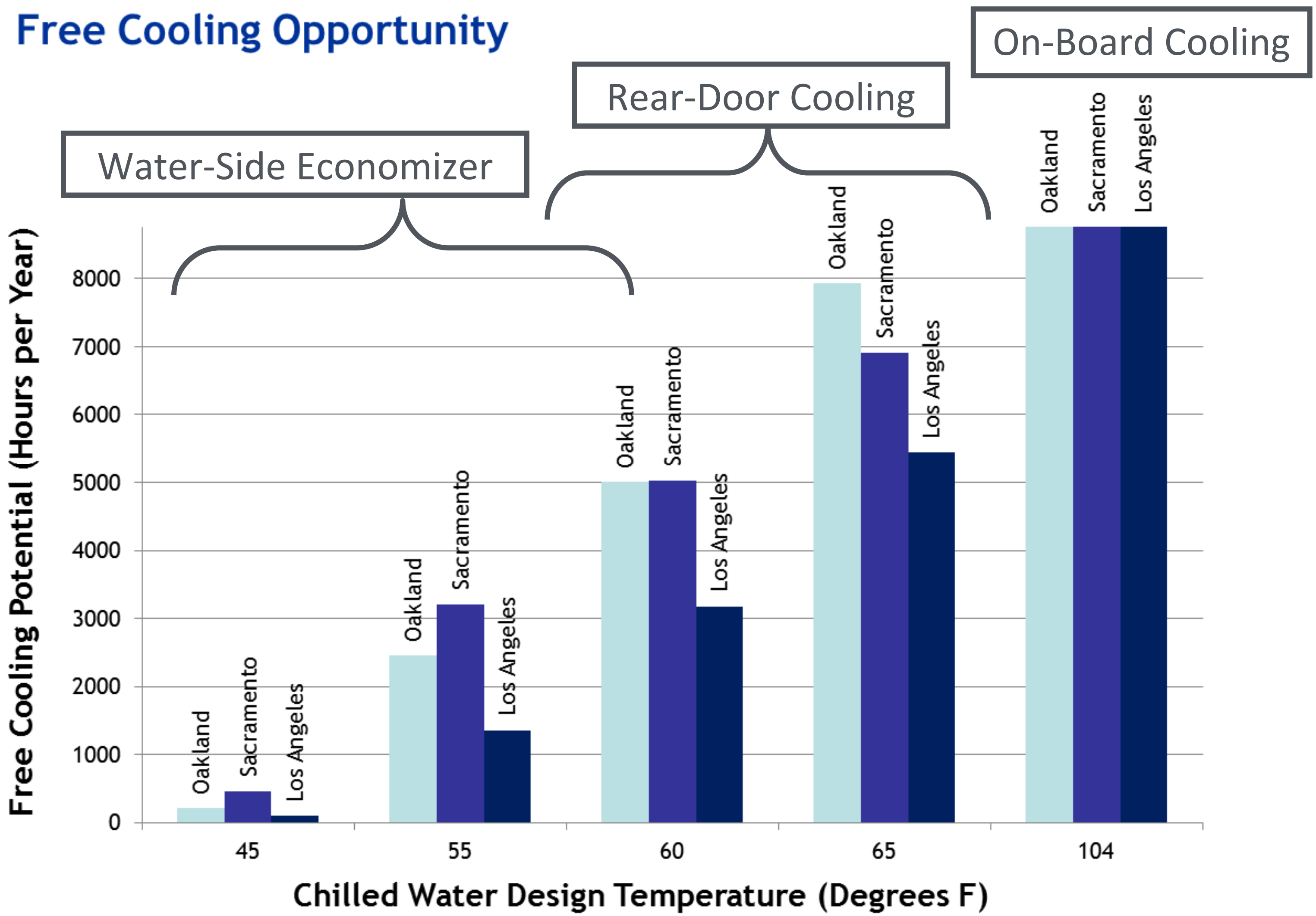
# Integrated Water-Side Economizer




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



# 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
  - Many manufacturers allow even wider humidity range
- Defeat equipment fighting
  - Coordinate controls
- Disconnect and only control humidity of makeup air or one CRAC/CRAH unit
- Entirely disconnect (many have!)

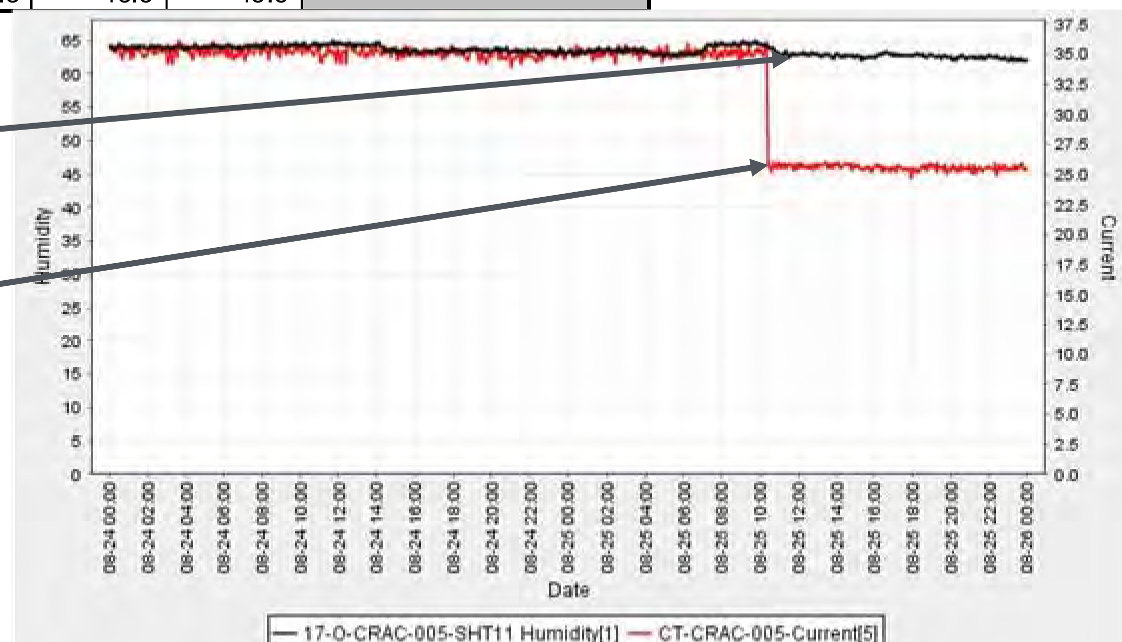
# Cost of Unnecessary Humidification

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

| | 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…

- 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?

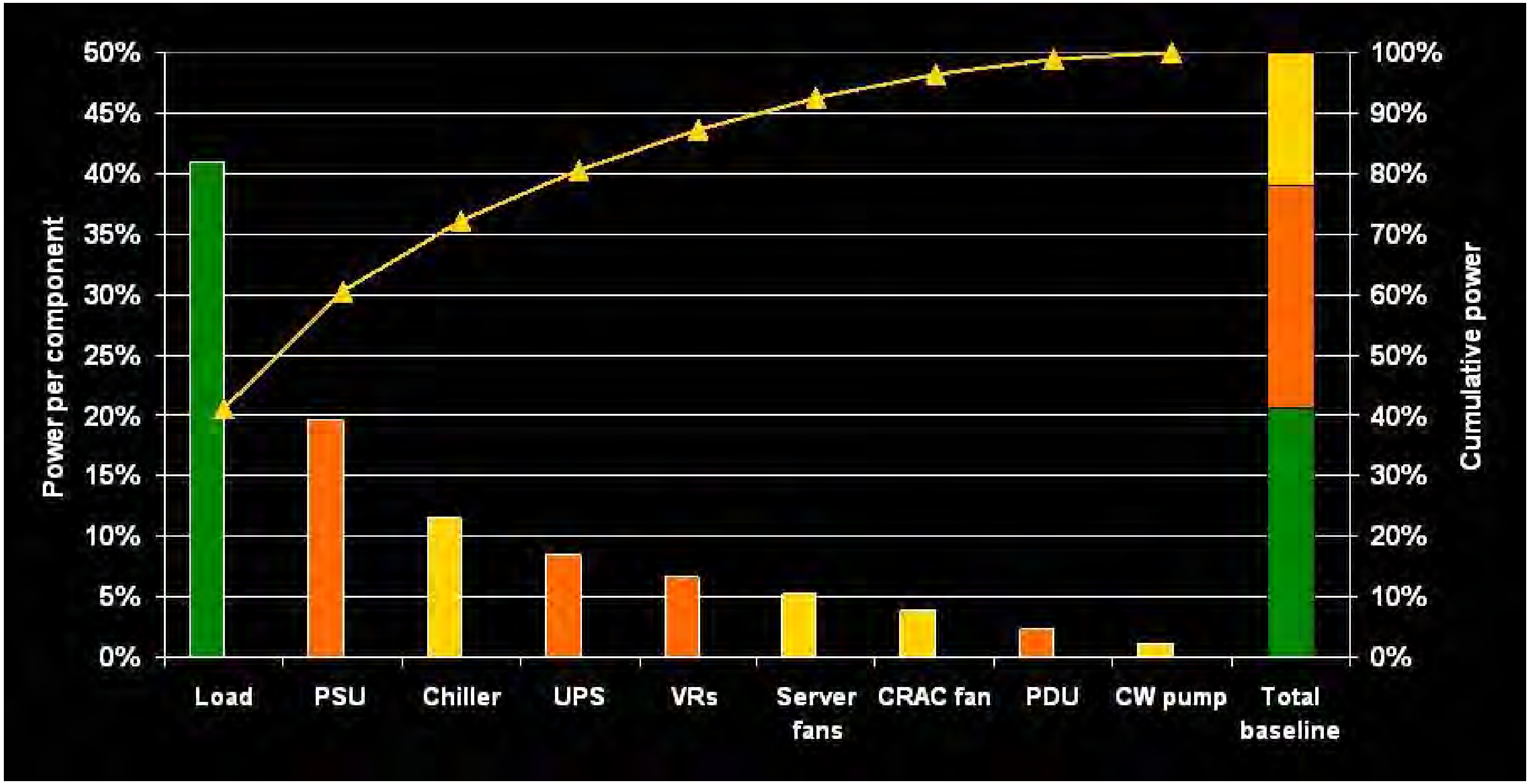
# Electrical Systems

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

FEMP
Federal Energy Management Program

BERKELEY LAB

# Electrical system end use – Orange bars




Courtesy of Michael Patterson, Intel Corporation

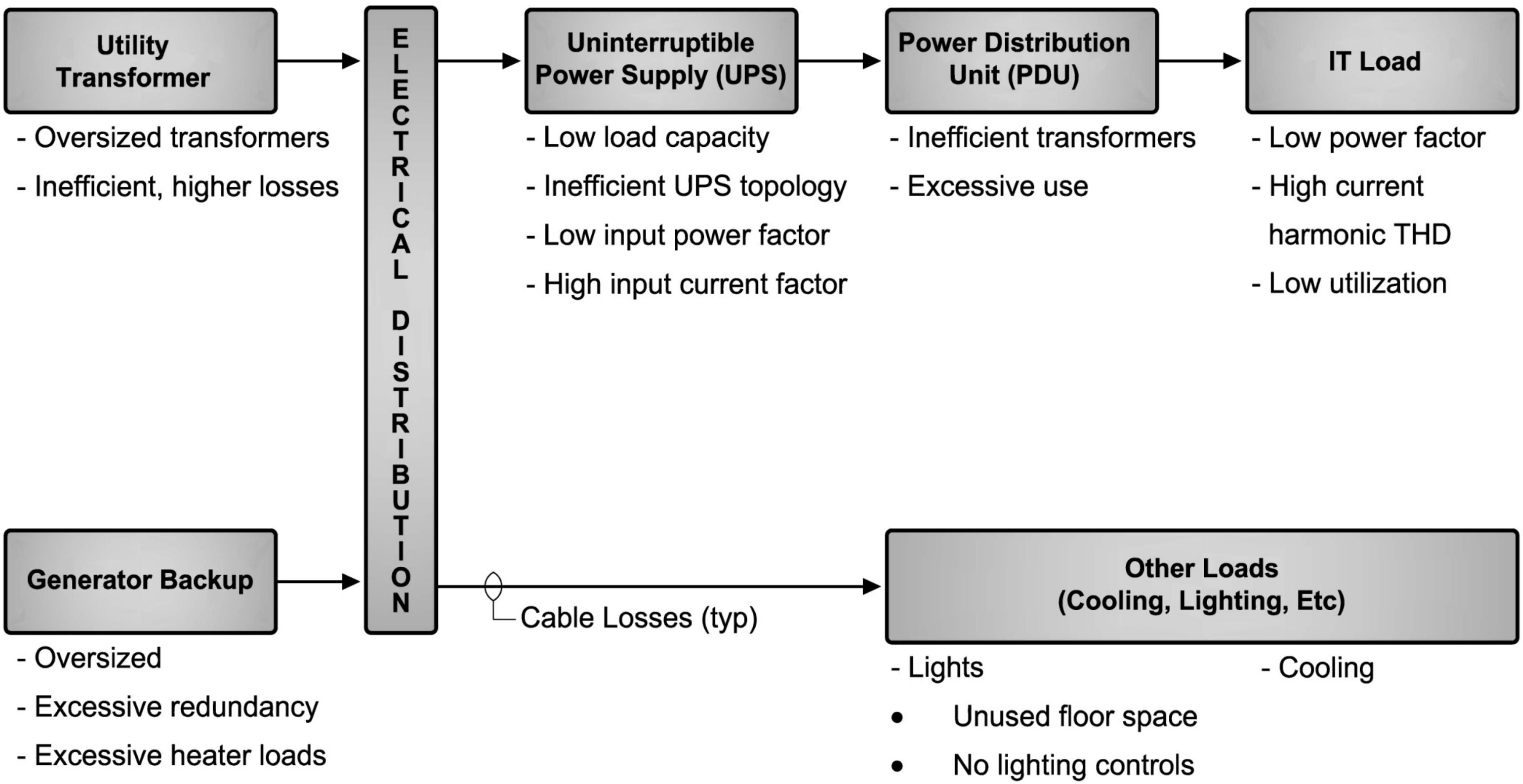
# Electrical Distribution



- 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

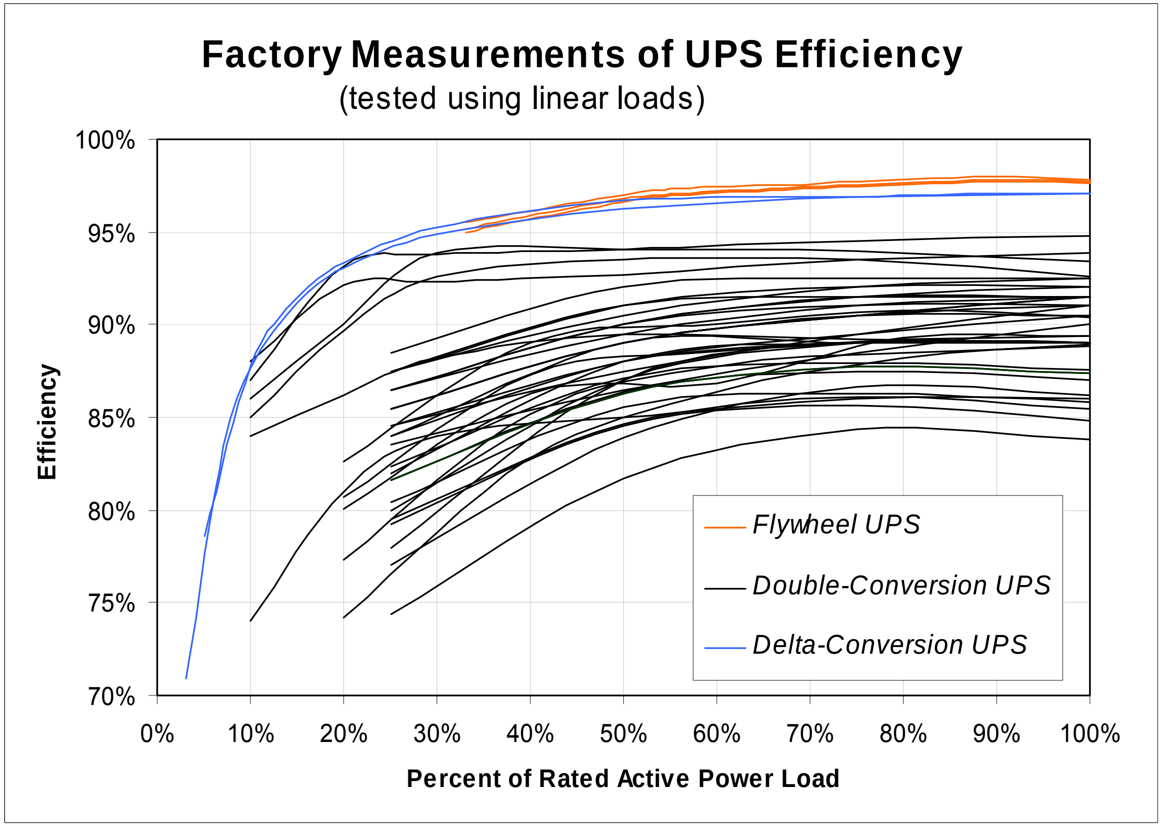
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



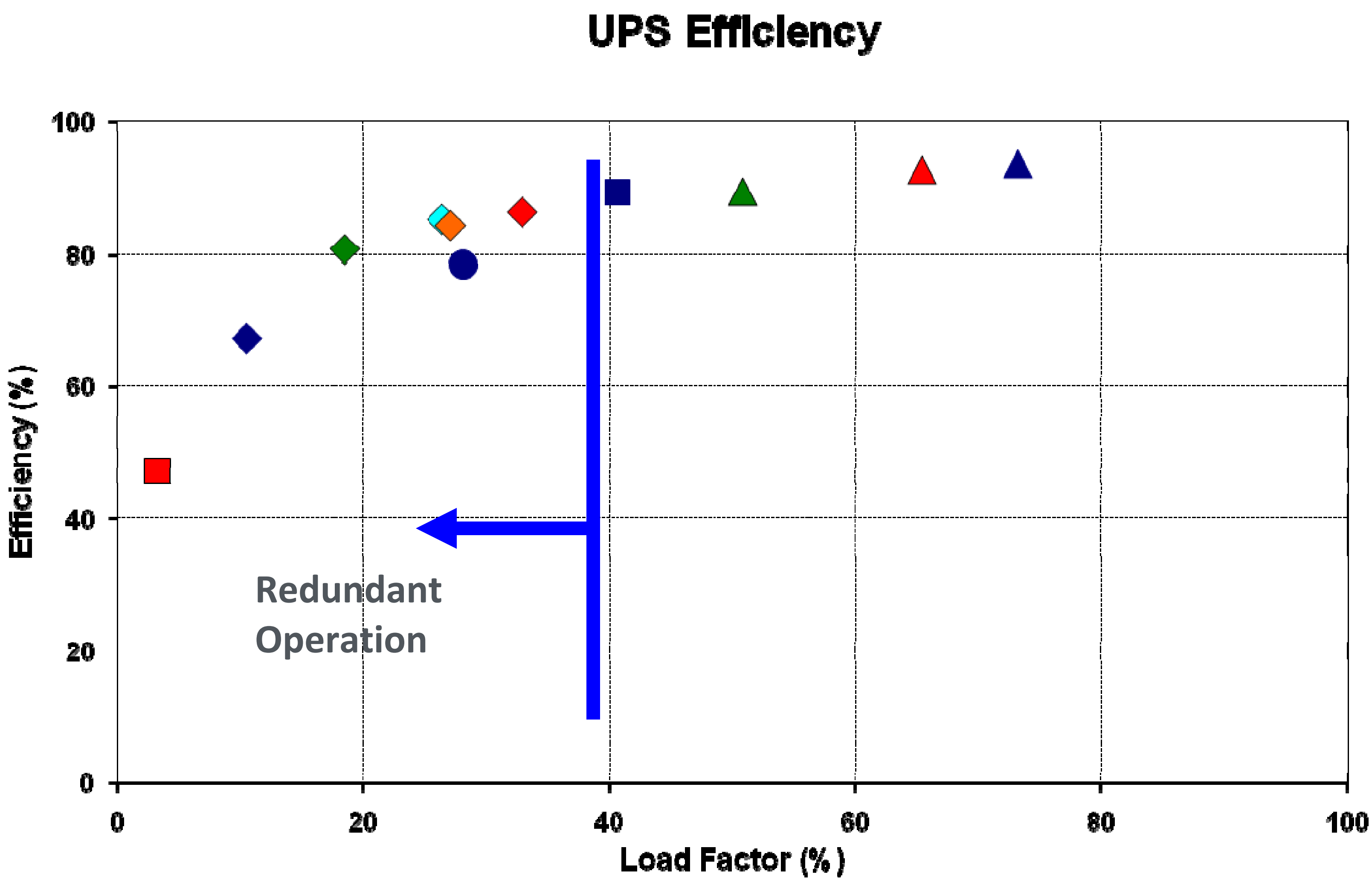
# UPS, transformer, & PDU efficiency

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

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

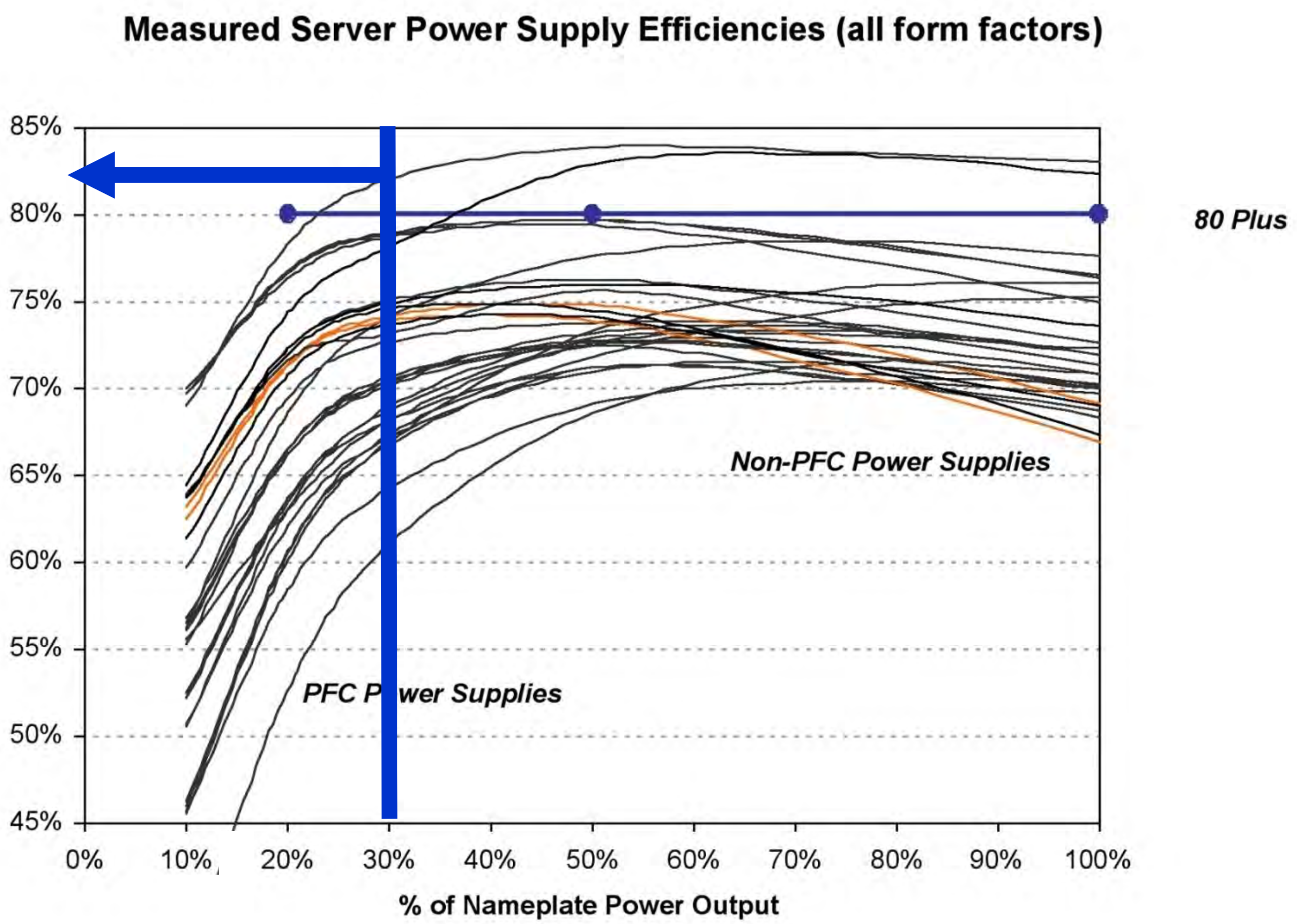


# Measured UPS efficiency



# LBNL/EPRI measured power supply efficiency





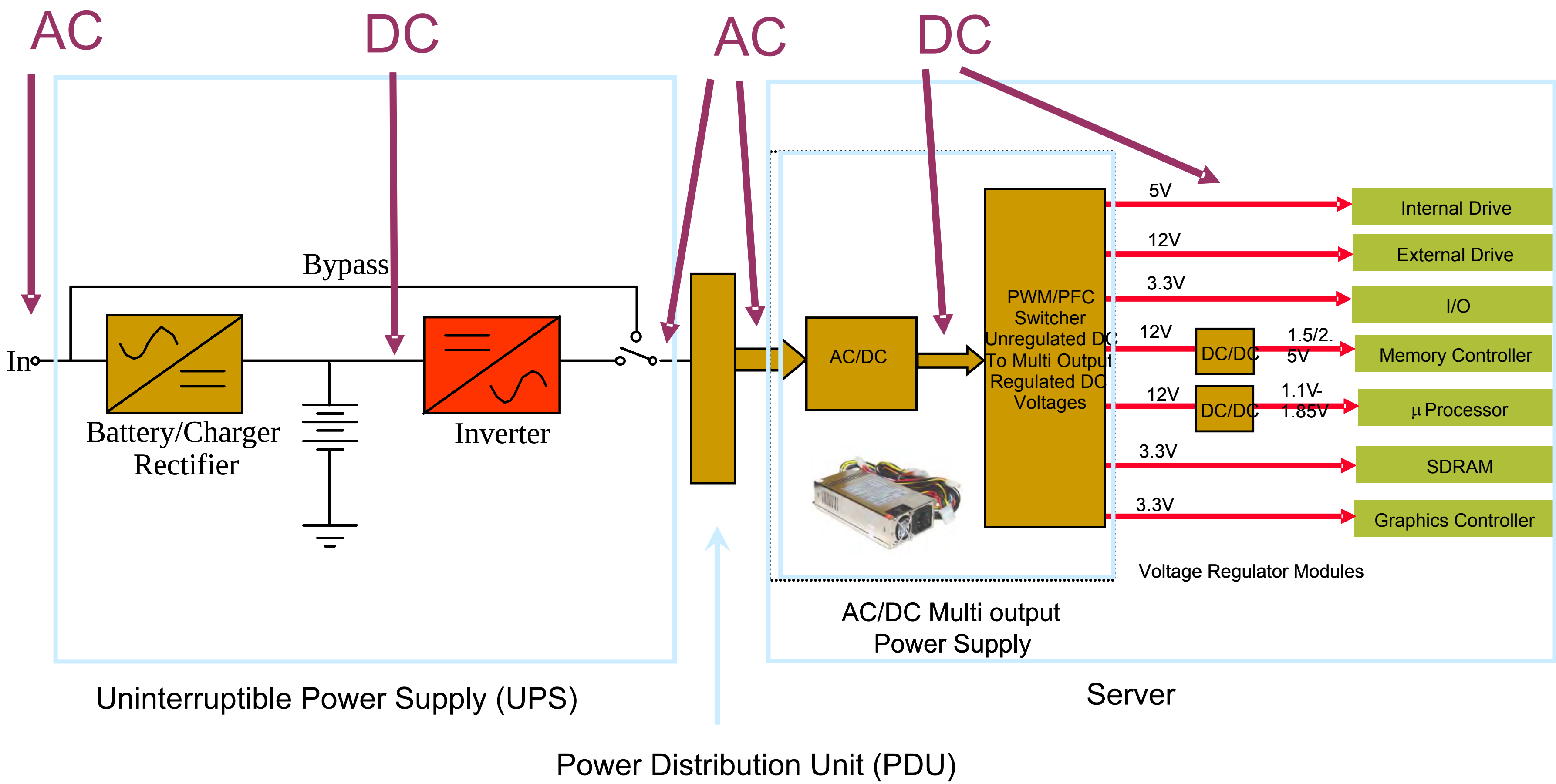
# Redundancy

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

- 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

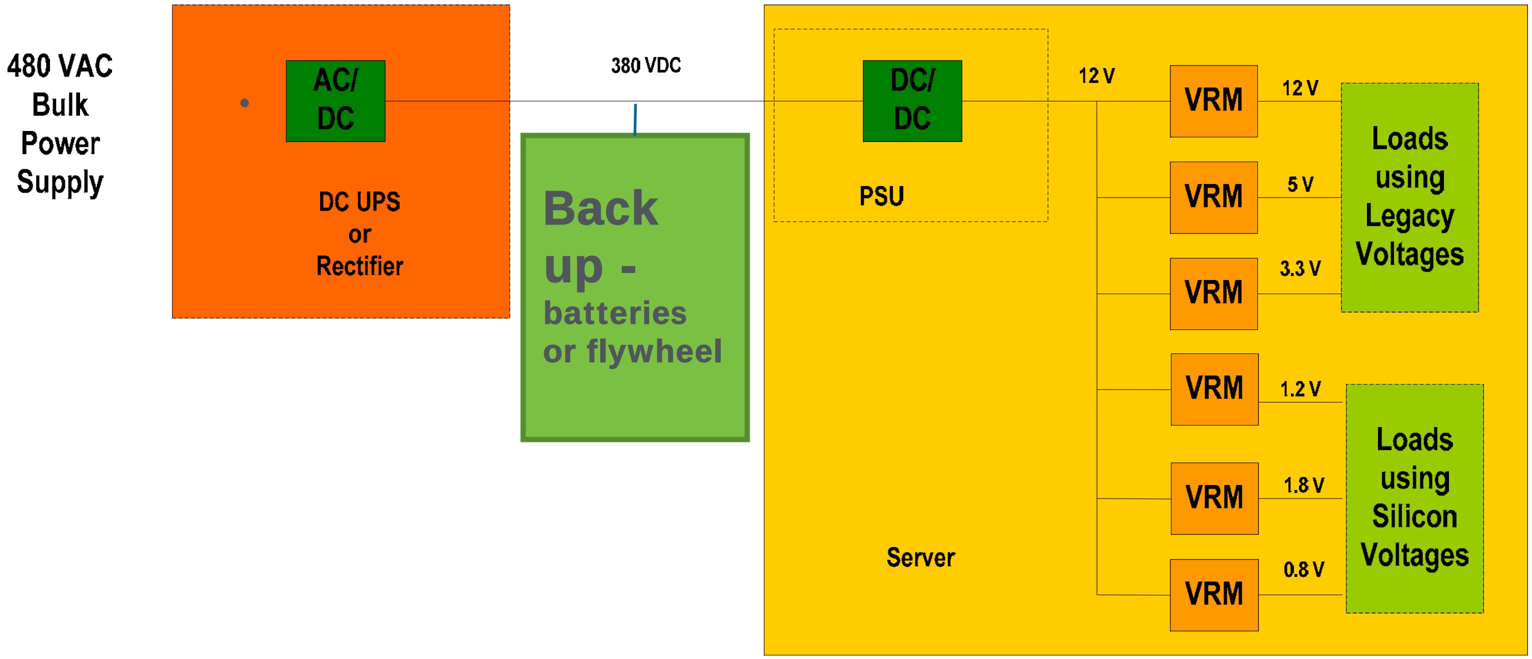
# From utility power to the chip – multiple electrical power conversions





## 380V. DC power distribution

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



# Standby generation loss

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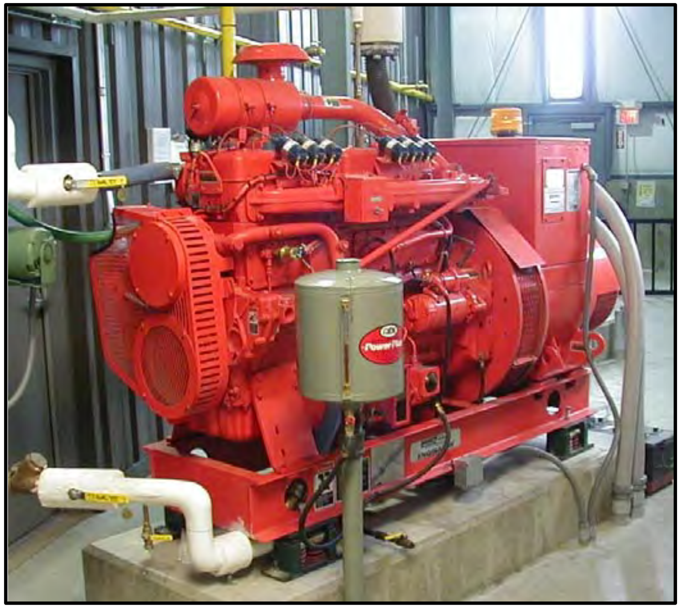


- Losses
  - Heaters
  - Battery chargers
  - Transfer switches
  - Fuel management systems
- Opportunities to reduce or eliminate losses
- Heaters (many operating hours) use more electricity than the generator produces (few operating hours)
  - Check with generator manufacturer on how to reduce the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

# Standby generator heater

# 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



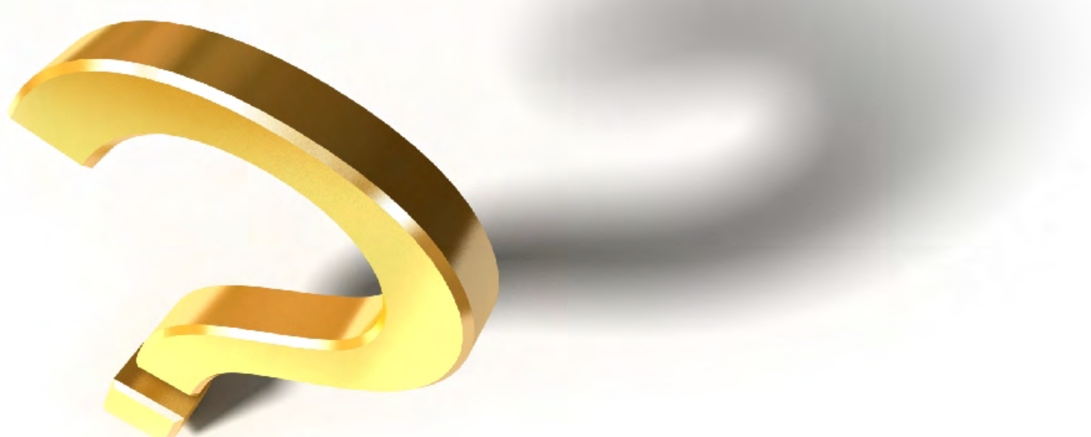
- Since most cooling system equipment operates continuously, premium efficiency motors should be specified everywhere
- Variable speed drives should be used
  - Chillers
  - Pumps
  - Air handler fans
  - Cooling tower fans

# Key Electrical Takeaways



- **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

FEMP
Federal Energy Management Program

BERKELEY LAB

# Federal Programs/Resources

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

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

Save ENERGY Now

**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

**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

## Federal agencies have been instructed to…


- Reduce facility energy intensity
- Increase renewable energy use
- Reduce water consumption intensity
- Purchase EPEAT and FEMP-designated products
- Meter and benchmark facilities
- Consolidate data center facilities wherever possible

# FEMP Support for Data Center Energy Efficiency



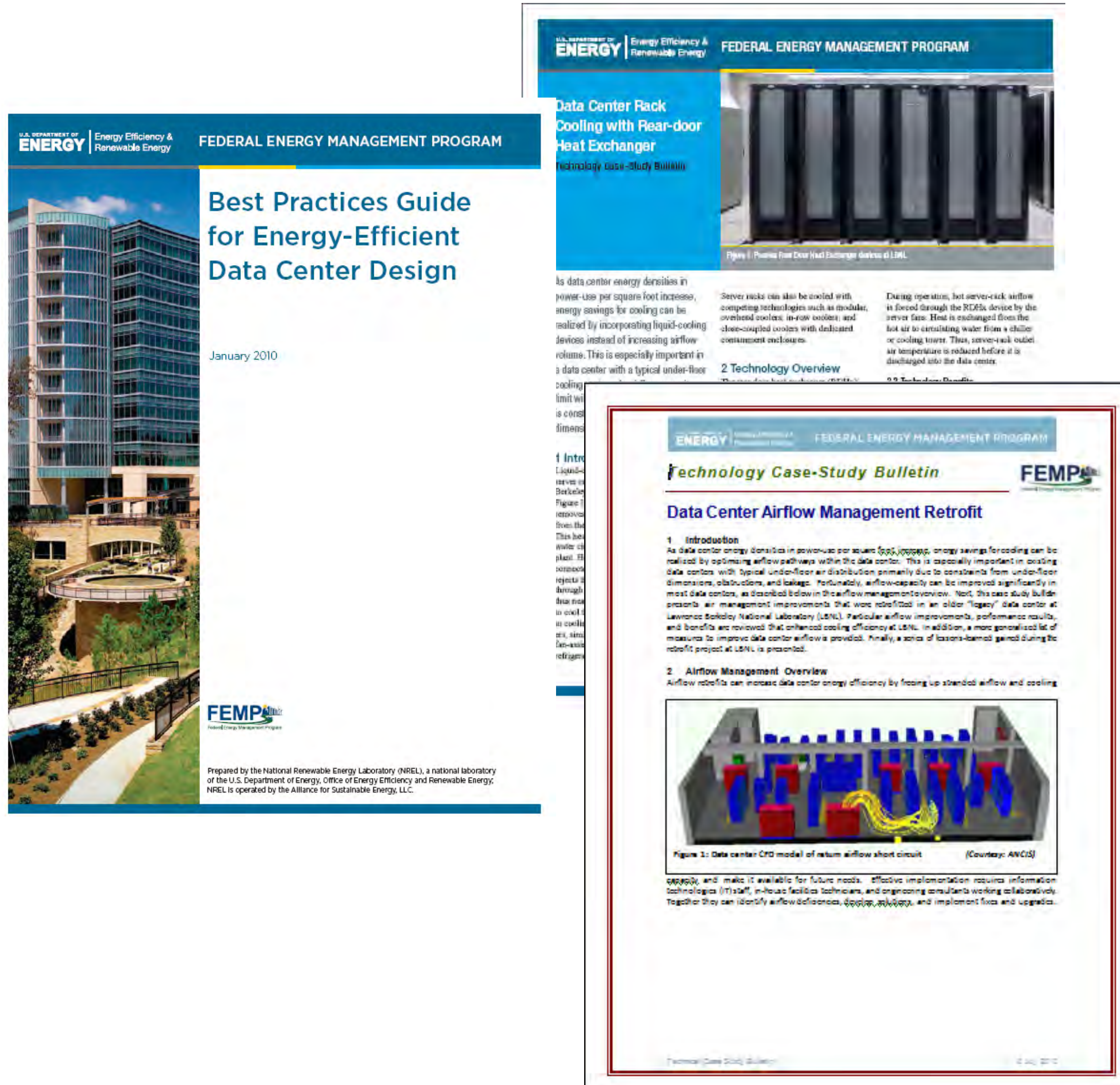
## FEMP in partnership with GSA and other agencies supports data center efficiency in the Federal sector:

- Technical Assistance
  - Implementation of DC Pro Tool Suite for benchmarking and assessments
  - Project planning and early design
  - Technology demonstration projects
- Training
  - Webinars
  - Workshops
- Development of tools and resources
- Access to funding sources
  - Energy savings performance contracts
  - Utility energy savings contracts
- Federal Energy Management Program awards

# Federal Data Center Resources

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



# Data Center Working Groups

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

## The Federal Partnership for Green Data Centers

- **An Inter-Agency forum to exchange ideas, develop policy guidance & tools to improve data center performance**

## High Performance Computing Working Group

- **A forum for sharing information on best practices in scientific computing**
- **Includes members from the public and private sectors**

## 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**

# DOE DC Pro Tool Suite



**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



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

**Key objective:**

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

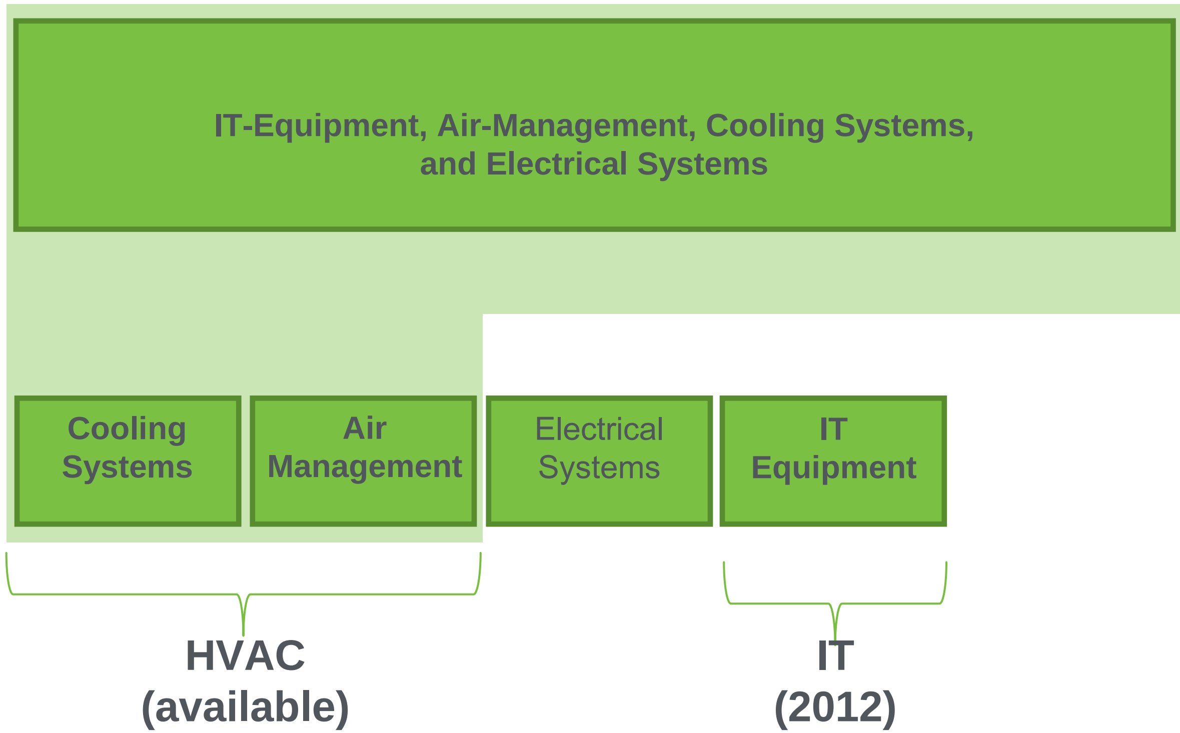
**Target groups** include:

- 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**

**Level 2 Specialist:**
**Prequalification, Training and Exam on Select Disciplines**
**+ Assessment Process**
**+ DC Pro System Assessment Tools**




Two Tracks:

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

# What is 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
- Evaluating enterprise data storage, UPS, and networking equipment for Energy STAR product specs

# Resources



Federal Energy Management Program

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 and Trends

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

FEMP
Federal Energy Management Program

BERKELEY LAB

# Results

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

# 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)

# Data Center Best Practices Summary



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.

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

## 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: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