Energy Efficient HPC Data Centers

Bill Tschudi and Dave Martinez

Lawrence Berkeley National Laboratory
Sandia National Laboratory

November 11, 2012

wftschudi@lbl.gov; davmart@sandia.gov

Outline

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

Resources

Benchmarking

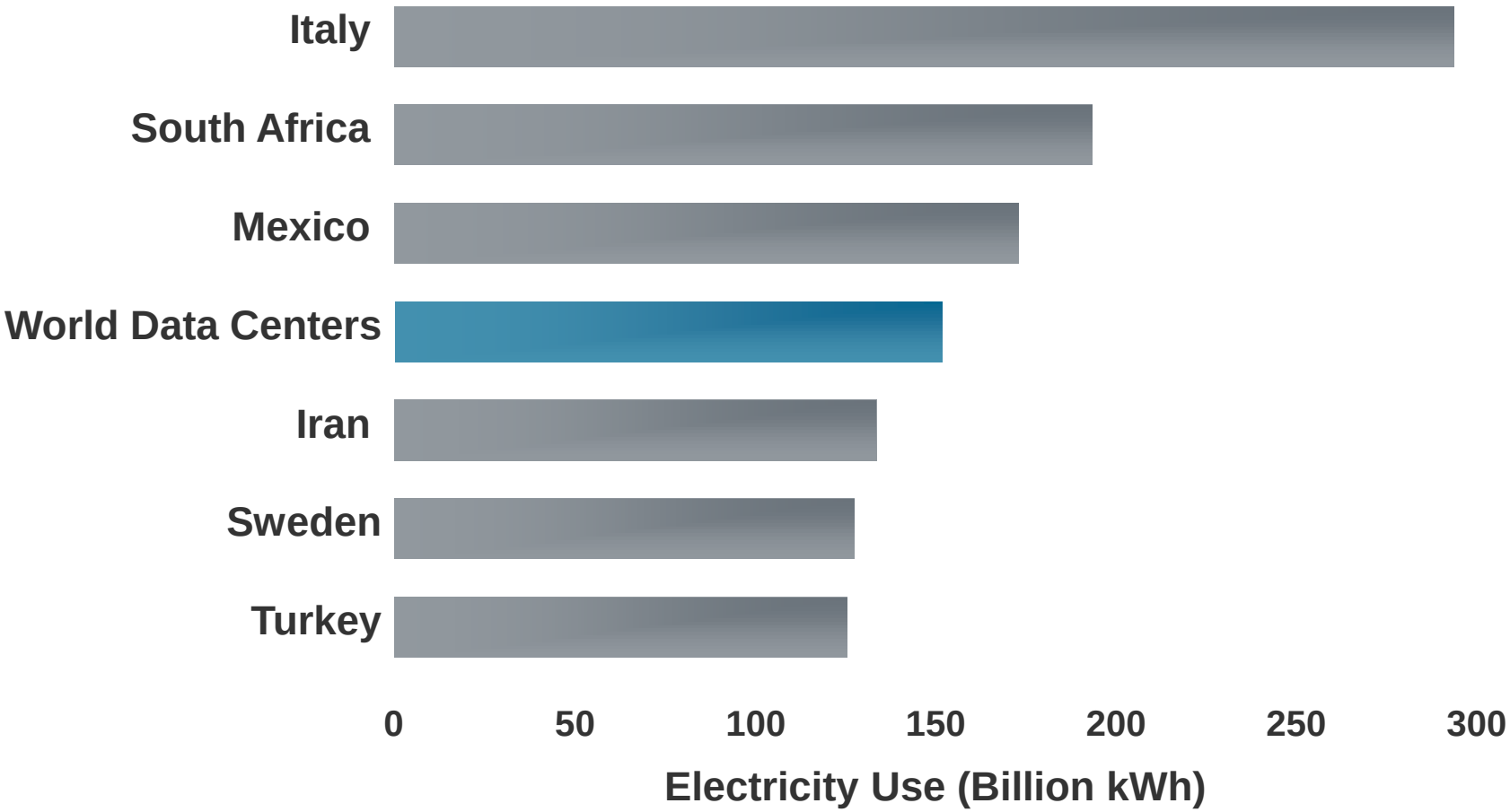
Efficiency opportunities – typical measures

- Air management
- Environmental conditions
- Power distribution
- Liquid cooling
- Free cooling

BERKELEY LAB
Lawrence Berkeley National Laboratory

Sandia National Laboratories

Data centers account for more energy than many countries



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

Many organizations involved with data center efficiency

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

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

GSA
- Workshops
- Quick Start Efficiency Guide
- Technical Assistance

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

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

Federal data center energy efficiency drivers

Federal Data Center Consolidation Initiative: The FDCCI has set aggressive goals such as decommissioning 800 Federal data centers by 2015

Executive Order 13514: E.O. 13514 directs Federal agencies to employ best practices for energy efficient data center management

Technical support is available

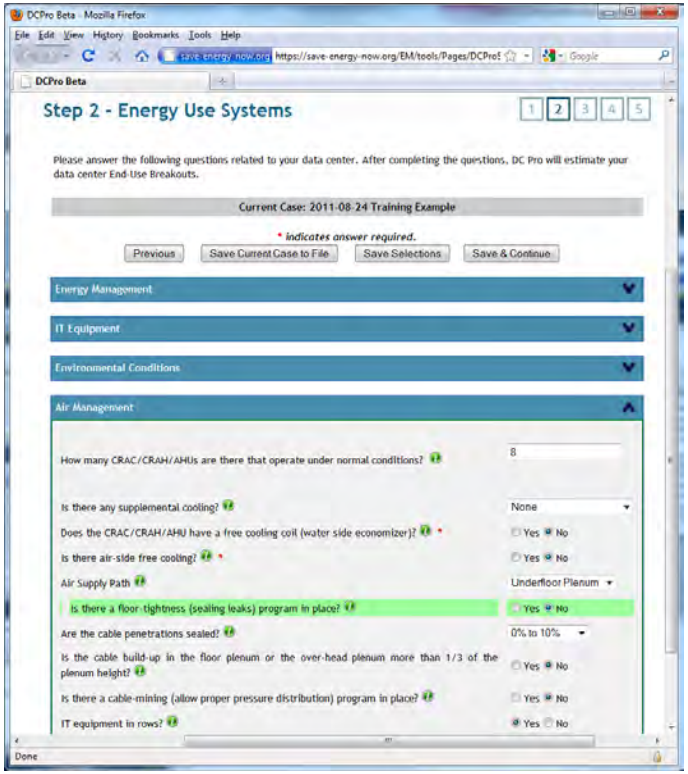
LBNL supports DOE's Data Center initiatives and the Federal Energy Management Program (FEMP)

In progress: Guideline for Energy Considerations during Consolidations

- DC Pro Tools
- Data Center Energy Practitioner
- Case studies
- Best practice guides, etc.
- Assessments

The DC Pro tool suite includes a high level profile and system level tools

- Profiling Tool: profiling and tracking
  - Establish PUE baseline and efficiency potential
    (few hours effort)
  - Document actions taken
  - Track progress in PUE over time
- Assessment tools: more in-depth site assessments
  - Suite of tools to address major sub-systems
  - Provides savings for efficiency actions
  - ~2 week effort (including site visit)



DC Pro tools point to efficiency opportunities but are not a substitute for an investment grade audit

High Level Profiling Tool

- Overall energy performance (baseline) of data center
- Performance of systems compared to benchmarks
- List of energy efficiency actions and their savings, in terms of energy cost ($), source energy (Btu), and carbon emissions (Mtons)
- Points to more detailed system tools

IT Module

- Servers
- Storage & networking
- Software

Cooling

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

Air Management

- hot cold separation
- environmental conditions

Electrical Systems

- UPS
- Transformers
- Lighting
- Standby gen.

The Data Center Energy Practitioner (DCEP) program qualifies individuals to perform data center assessments

www1.eere.energy.gov/manufacturing/datacenters/dc_cep.html

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

Advanced Manufacturing Office

About the Program | Program Areas | Information Resources | Financial Opportunities | Technologies | Deployment | Home

Saving Energy in Data Centers

- Saving Energy in Data Centers Home
- About Saving Energy in Data Centers
- Data Center Energy Practitioners
- Software
- Case Studies
- Training
- R&D Portfolio

Printable Version

Site Map

Data Center Energy Practitioner Program

DOE is partnering with industry to develop a Data Center Energy Practitioner (DCEP) program to accelerate energy savings in the dynamic and energy-intensive marketplace of data centers. Some of the following documents are available as Adobe Acrobat PDFs.

The DCEP program is being defined, designed, and implemented by working closely with industry stakeholders. DOE has set a goal to have at least 200 practitioners by 2011. Significant knowledge, training, and skills are required to perform accurate energy assessments in data centers. DCEPs will:

- Be qualified to identify and evaluate energy efficiency opportunities in data centers
- Demonstrate proficiency in the use of DOE's DC Pro software tool suite
- Address energy opportunities in electrical systems, air management, HVAC, IT equipment, and on-site generation
- Meet academic/work experience requirements (prequalifications)
- Receive training on conducting data center assessments
- Be required to pass an exam and be requalified every 3 years.

Property management companies, engineering consulting firms, service companies, data center operators, state energy agencies, and utilities will benefit from the expertise provided by DCEPs.

Read more about the Data Center Energy Practitioner program, May 2011, and download the Program Description, July 2011.

DCEPs can download the DCEP Program Energy Training-Assessment Process Manual, Oct. 2010, for administrative step-by-step instructions for conducting an energy assessment before, during, and after an on-site data center assessment. The manual also includes useful templates for assessments.

Training Calendar

Beginning in 2011, the DCEP Program will be delivered world-wide by two Professional Training Organizations (PTOs): DatacenterDynamics in the US and CNet Training outside of the US. Review current training opportunities with DatacenterDynamics and CNet Training.

Data Center Energy Practitioners

Here you will find information about Level I Practitioners (Generalists) and Level II Practitioners (Specialists). All completed training on performing energy assessments in data centers and passed an exam demonstrating their proficiency in the use of select tools in the DC Pro tool suite (Profiling Tool + System Assessments Tools).

Developers/Instructors

The following individuals are developers/instructors for the DCEP program.

Sign Up for Information

Want to learn more about the Data Center Energy Practitioner program? Sign up to be contacted.

Developed by DOE in collaboration with Industry

Objective: Raise standards, repeatability, reach large numbers

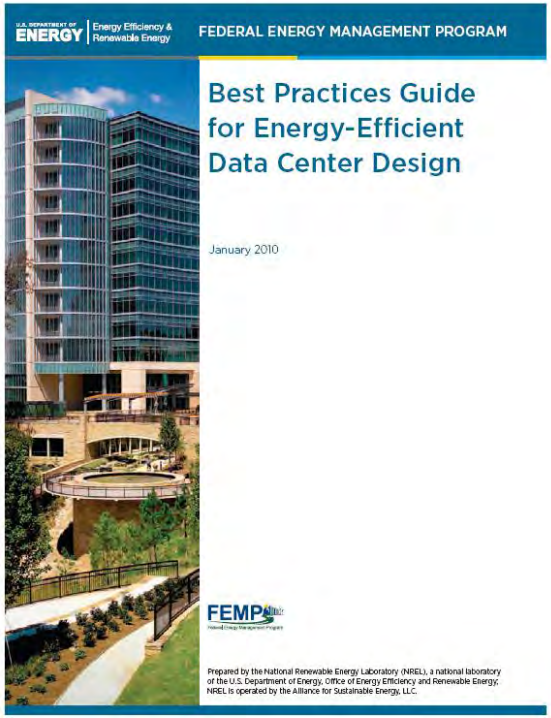
The DCEP program is administered by Professional Training Organizations – selected through a competitive process

http://www.cdcdp.com/dcep

http://www.datacenterdynamics.com/training/course-types/doe-certifed-energy-professional

PTOs license training and exam content from DOE, provide training, administer exams, and issue certificates

The Federal Energy Management Program has resources



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

LBNL's energy efficiency resources are diverse

"Hot" for Warm Water Cooling

paper presented at SC-11

PRIMARY AUTHORS:

Henry Coles
Lawrence Berkeley National Laboratory
hccoles@lbl.gov

ADDITIONAL AUTHORS

Anna-Maria Bailey, LLNL
Farhad Banisadr, LANL
Natalie Bates, EE HPC WG
Susan Coghlan, Argonne
David Cowley, PNNL
Nicolas Dube, HP
Parks Fields, LANL

EE HPC Working Group

Demonstration Projects

Influencing the Market

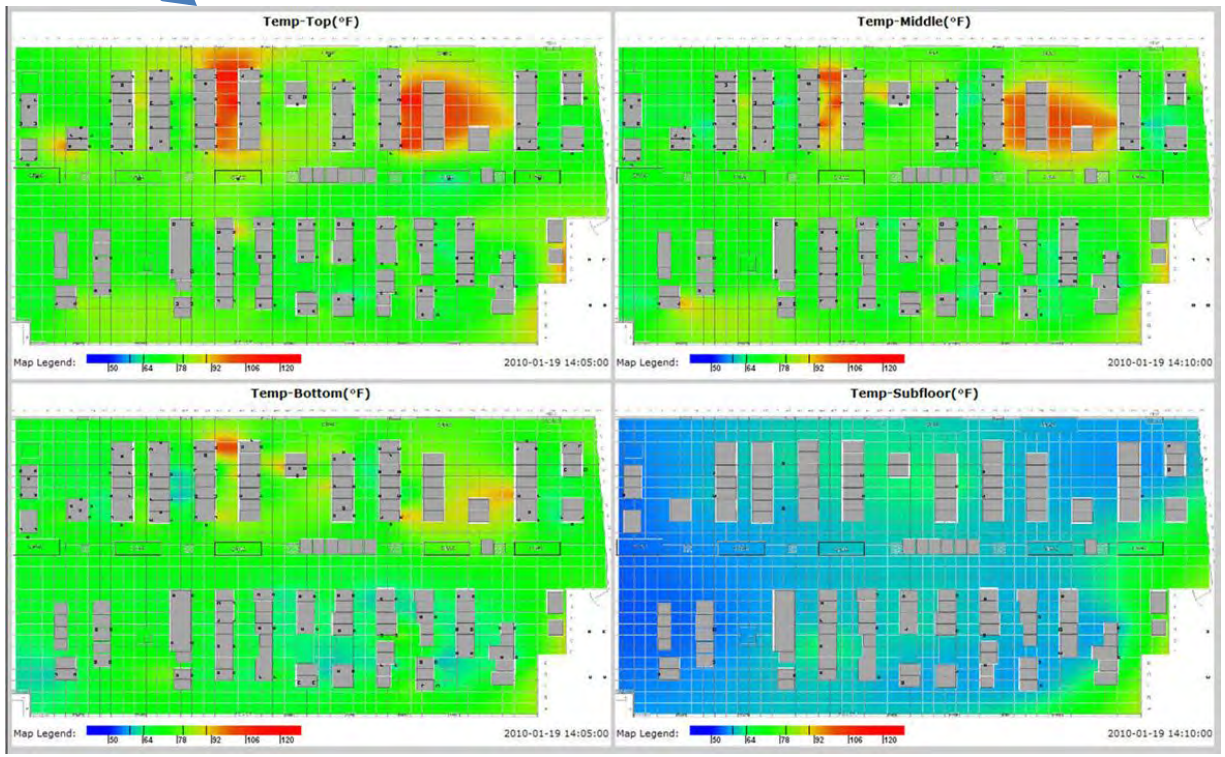
The EE HPC working group drives energy and computational performance improvement through collective actions

Members collaborate in areas such as performance metrics, thermal conditions, best practices, etc. as determined by the group. This large market influences manufacturers.

LBNL demonstrates new or under-utilized technologies that improve data center efficiency

Results of a demonstration of wireless temperature monitoring

LBNL supports the Silicon Valley Leadership Group's Data Center Summit.



Demonstrations have included DC Power, cooling options, control options, air management, etc.

LBNL develops resources for the public

DC Pro tools

Data Center Energy Practitioner program

Computing metrics development

Federal consolidation guideline

ESPC content for data centers

Wireless assessment kit

Compressor- less cooling

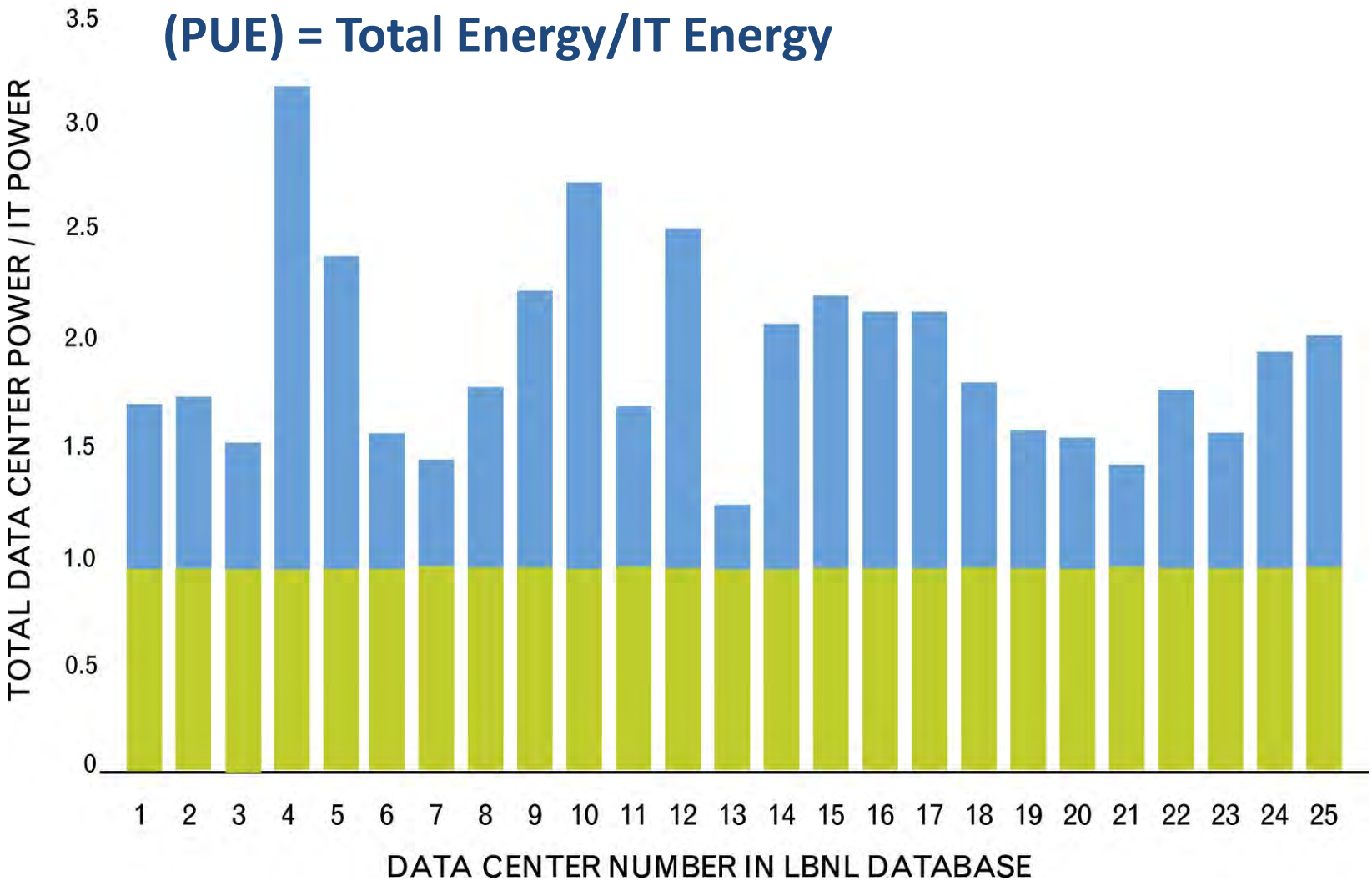
Heat re-use

Demonstration projects

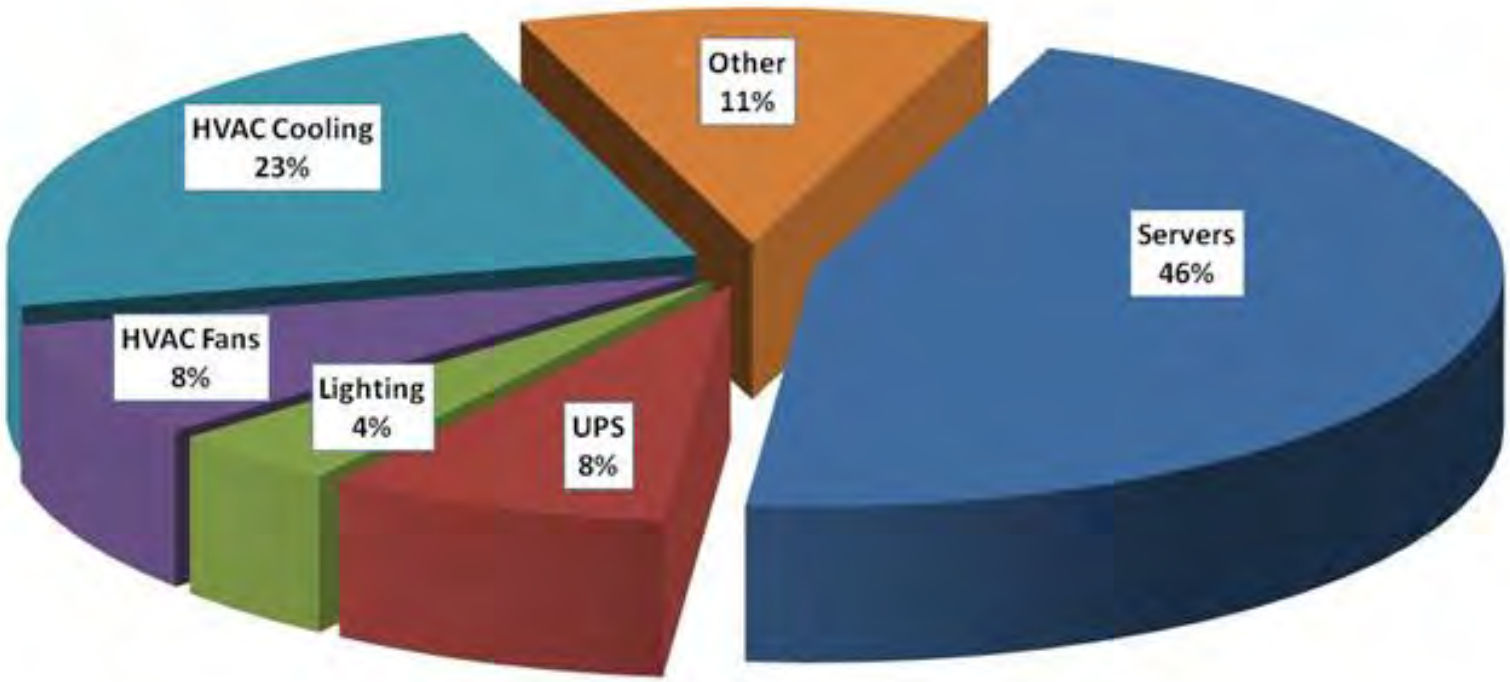
Energy benchmarking reveals wide variation

High Level Metric: Power Utilization Effectiveness

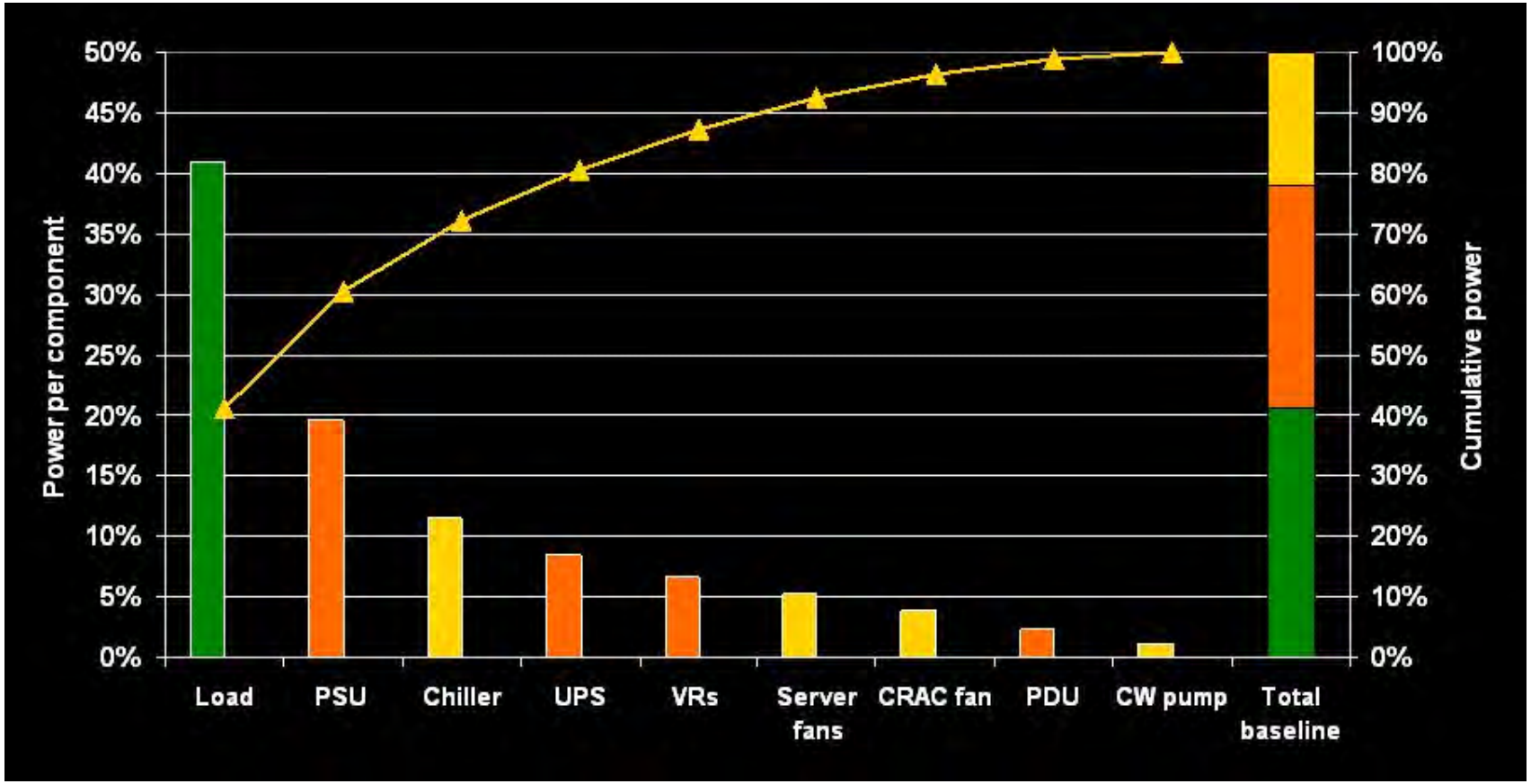
(PUE) = Total Energy/IT Energy



End use breakdowns can be instructional



Intel measured energy end use in one of their data centers



Courtesy of Michael Patterson, Intel Corporation

We found many areas for improvement…

Cooling

- Air Management
- Free Cooling – air or water
- Environmental conditions
- Centralized Air Handlers
- Low Pressure Drop Systems
- Fan Efficiency
- Cooling Plant Optimization
- Direct Liquid Cooling
- Right sizing/redundancy
- Heat recovery
- Building envelope

Electrical

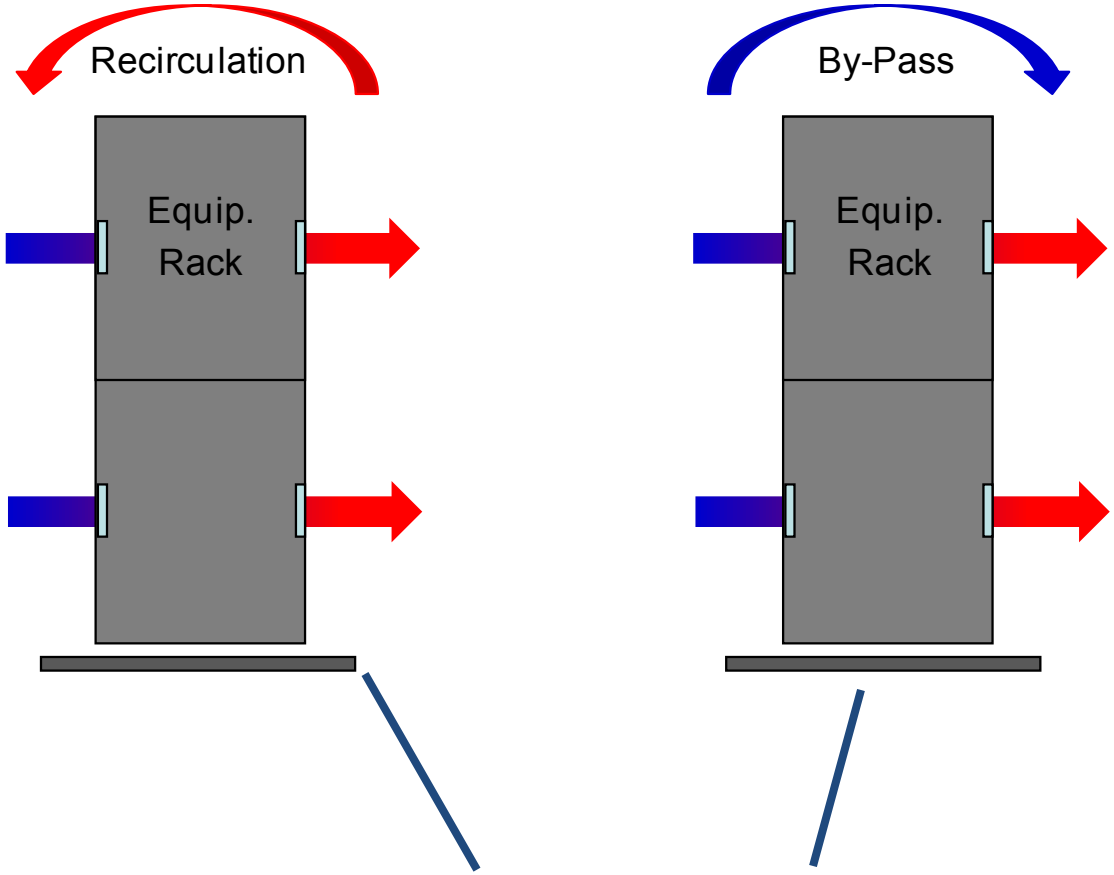
- UPS and transformer efficiency
- High voltage distribution
- Premium efficiency motors
- Use of DC power
- Standby generation
- Right sizing/redundancy
- Lighting – efficiency and controls
- On-site generation

IT

- Power supply efficiency
- Standby/sleep power modes
- IT equipment fans
- Virtualization
- Load shifting
- Storage de-duplication

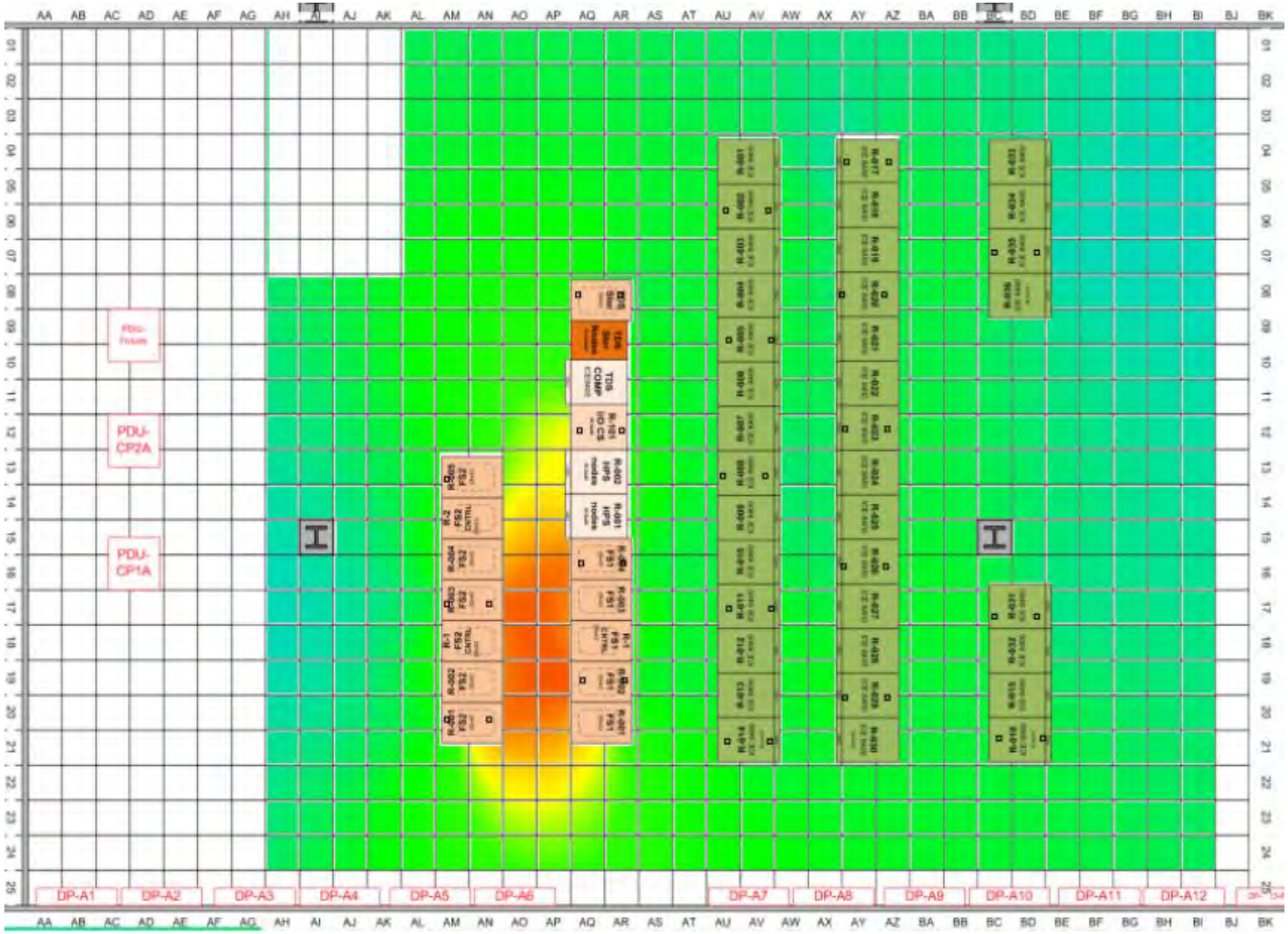
Some strategies could be demand response strategies

What is Air Management?

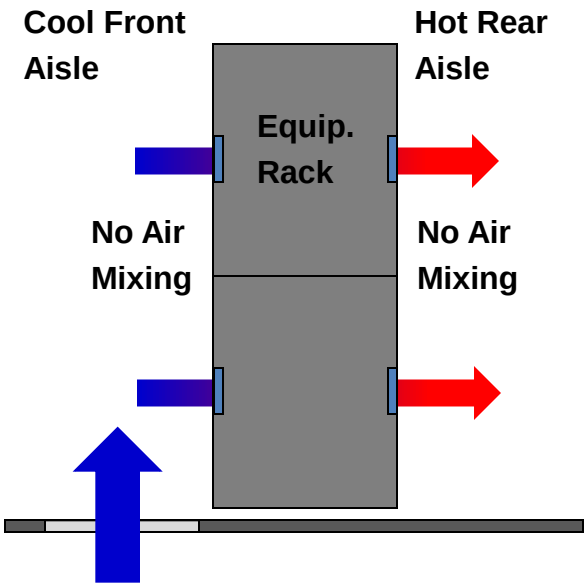


Minimize mixing of air – both recirculated and bypassed

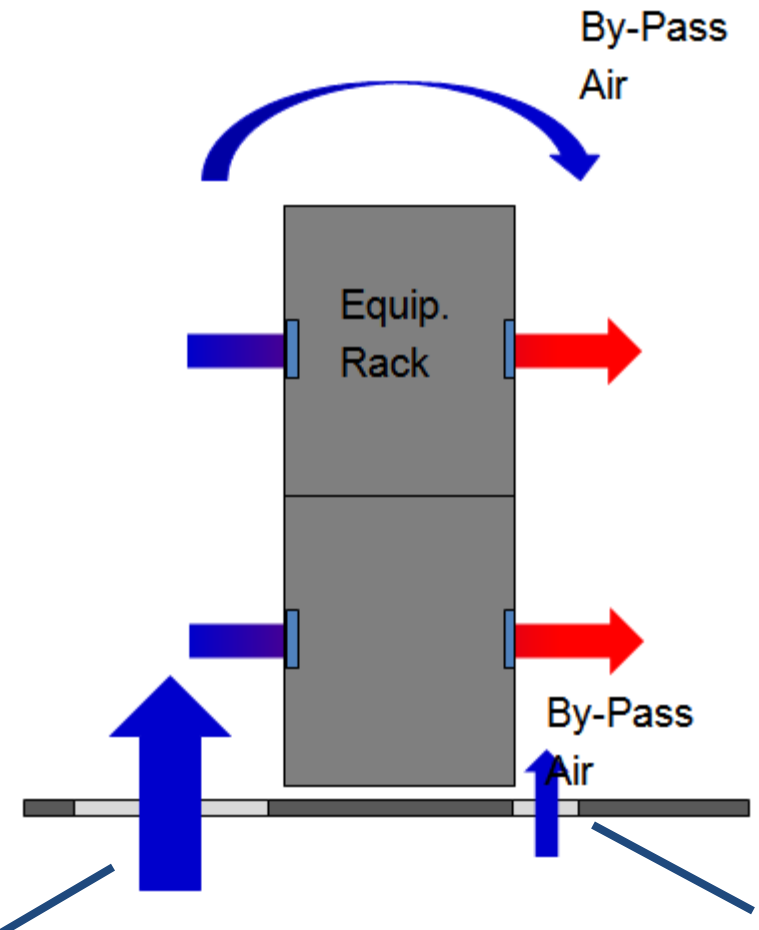
Thermal monitoring confirms separation of hot and cold air streams



Goal: Supply air directly to IT equipment intakes without mixing



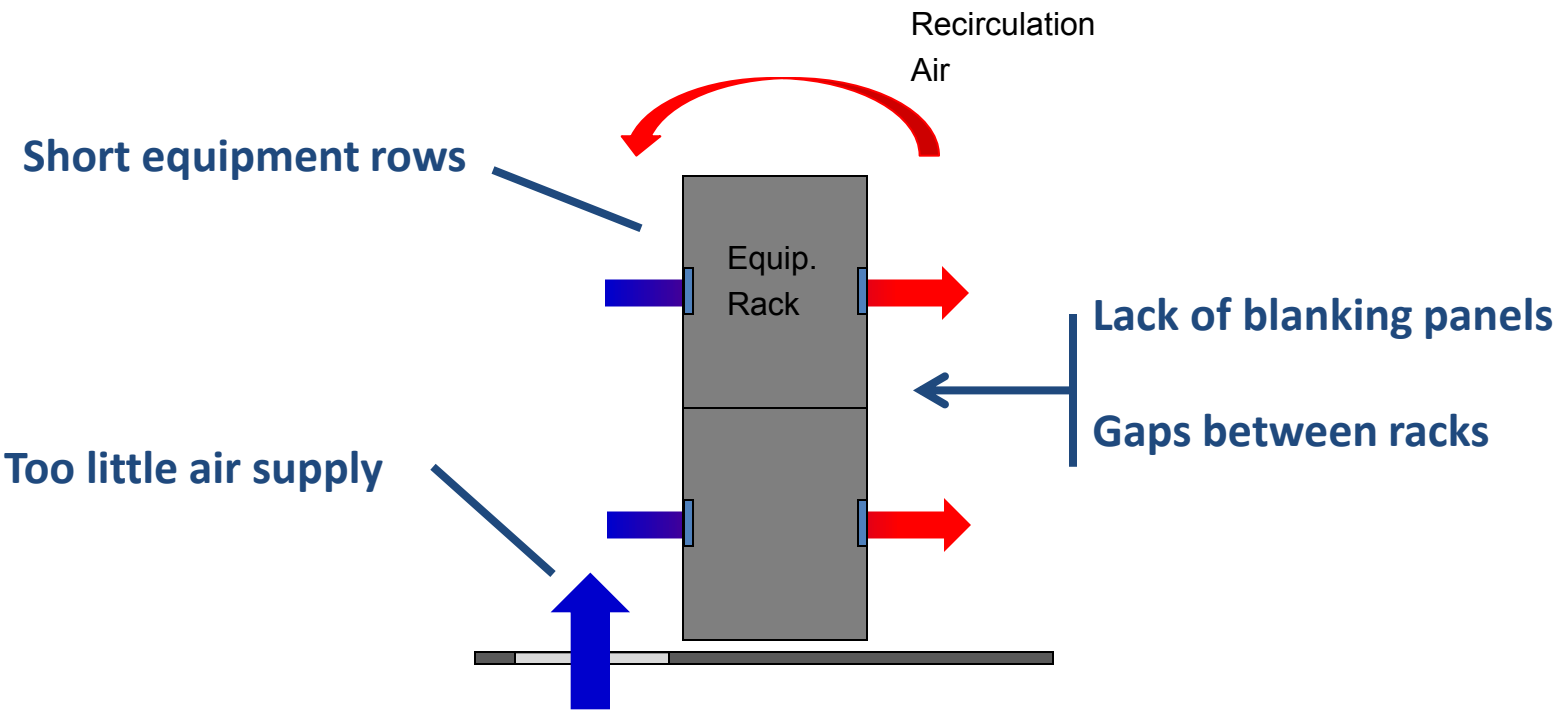
By-pass air does no cooling



Too much supply airflow
Too high tile exit velocity

Misplaced perforated tiles
Leaky cable penetrations

Recirculated air causes localized cooling problems

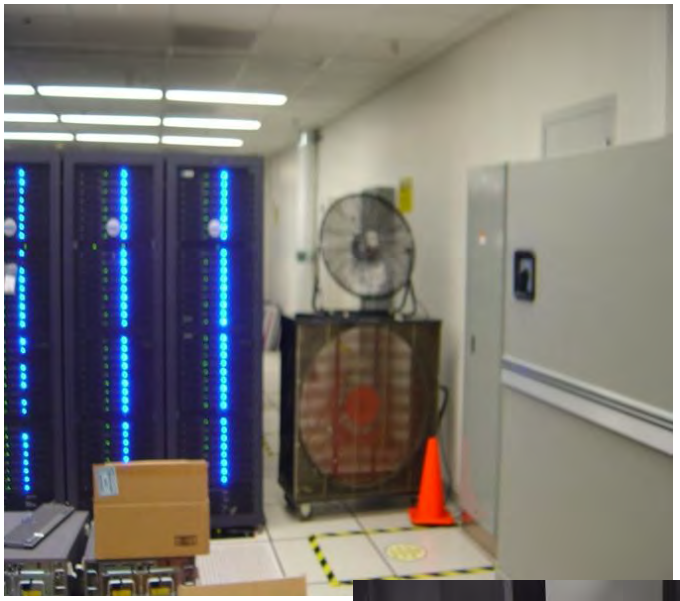


Containment can be achieved in various ways

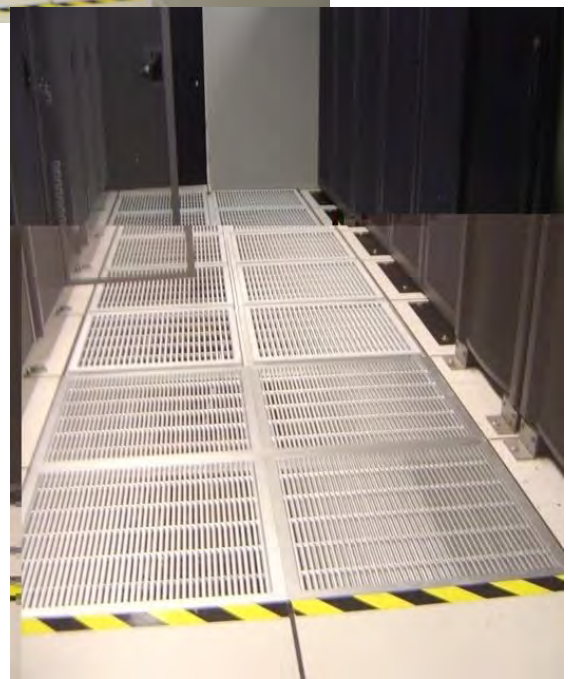
Air curtains from the cleanroom industry

Fire marshal needs to be consulted

Don’t do stupid things

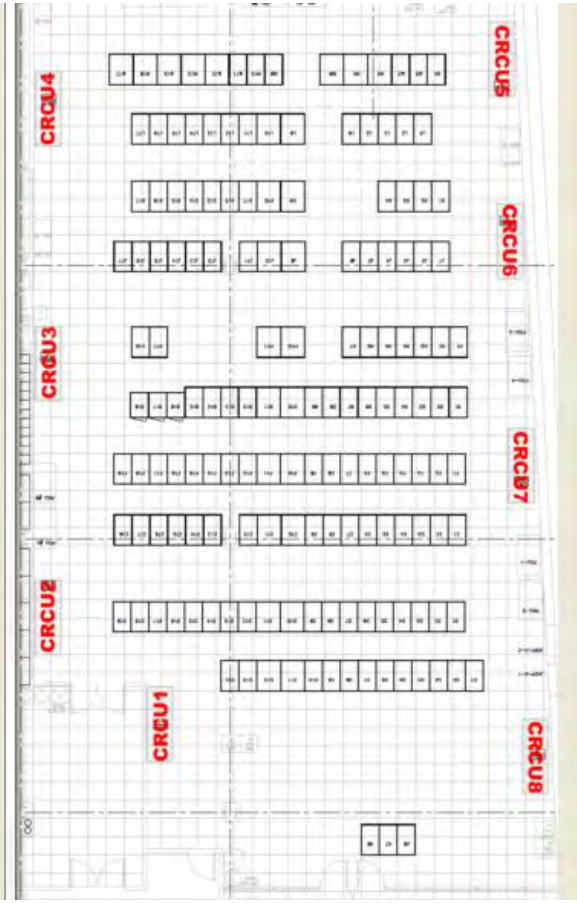


Air management does not include adding more fan heat to the room



Open grate floor tiles reduce underfloor air pressure so air cannot flow to the top of racks

If you walk into an HPC center and it is cold… there is an energy efficiency opportunity



These displays show two issues – low return air temperatures and simultaneous heating and cooling.

There is a lot of misunderstanding of environmental conditions needed for IT equipment

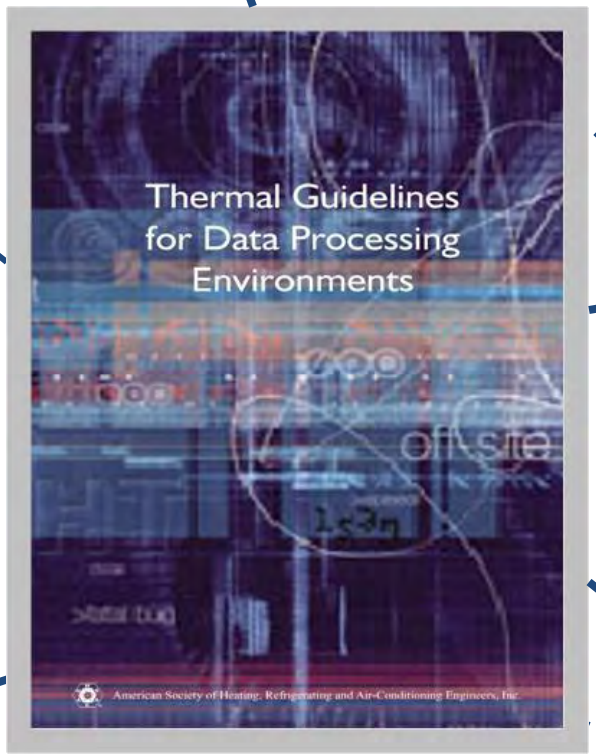
Microsoft operated computers in a tent for 8 months with no failures

ASHRAE Thermal Guidelines apply to HPC systems

Provides common understanding between IT and facility staff.

Recommends temperature range up to 80.6°F with "allowable" much higher.

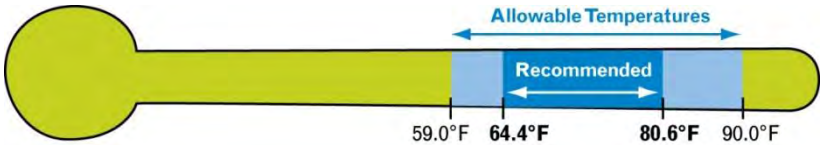
Developed with IT manufacturers



Six classes of equipment identified with wider allowable ranges to 45° C (113°F).

Provides more justification for operating above the recommended limits

Provides wider humidity ranges



ASHRAE Thermal Guidelines

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

Note that recommended range goes to 80F and allowable is much higher

Computing equipment is designed to meet ASHRAE Guidelines

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)

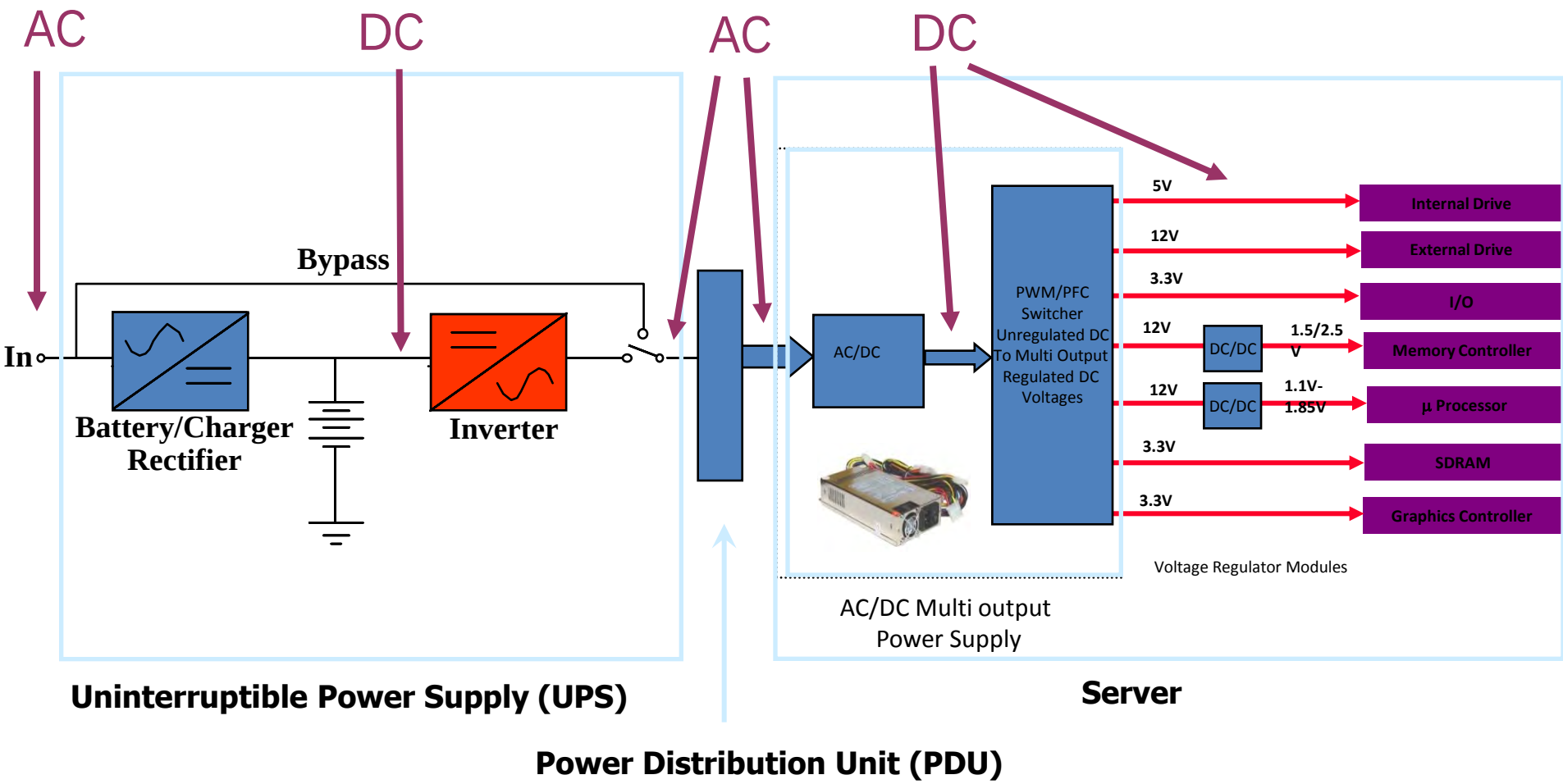
The industry has moved on - IT equipment operates reliably at higher temperatures.

Focusing on environmental conditions can lead to large energy savings

Perceptions that data centers need to be cold should change

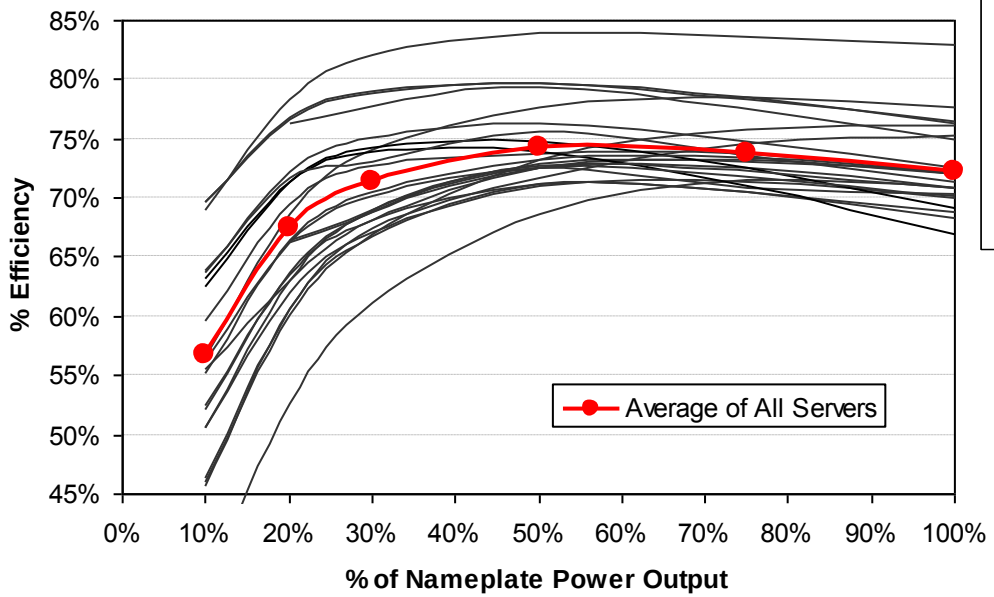
Data centers should be designed for computer comfort, not people comfort

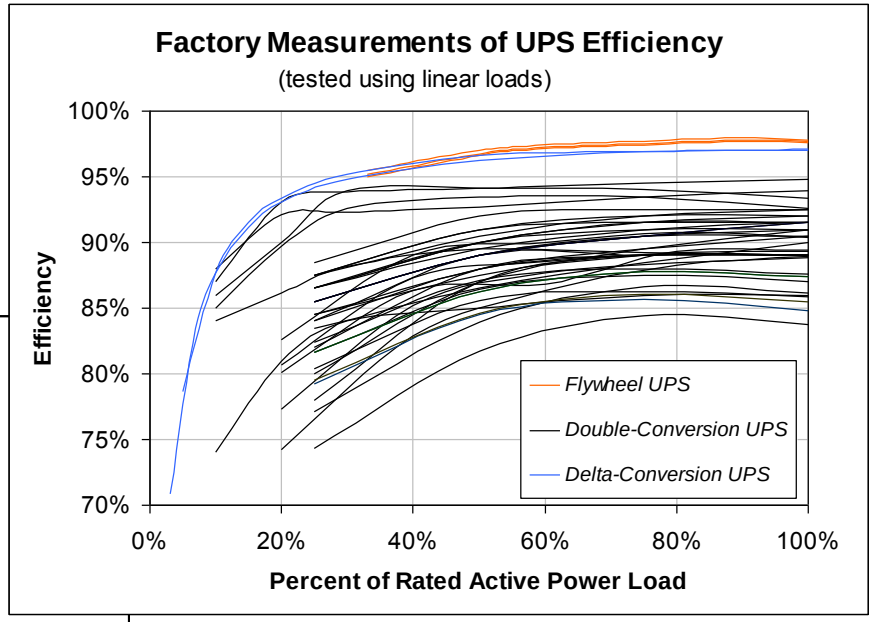
Many power conversions occur before any computing is done. Each power conversion loses some energy and creates heat in the process.



Research illustrated that power conversion losses can be significant

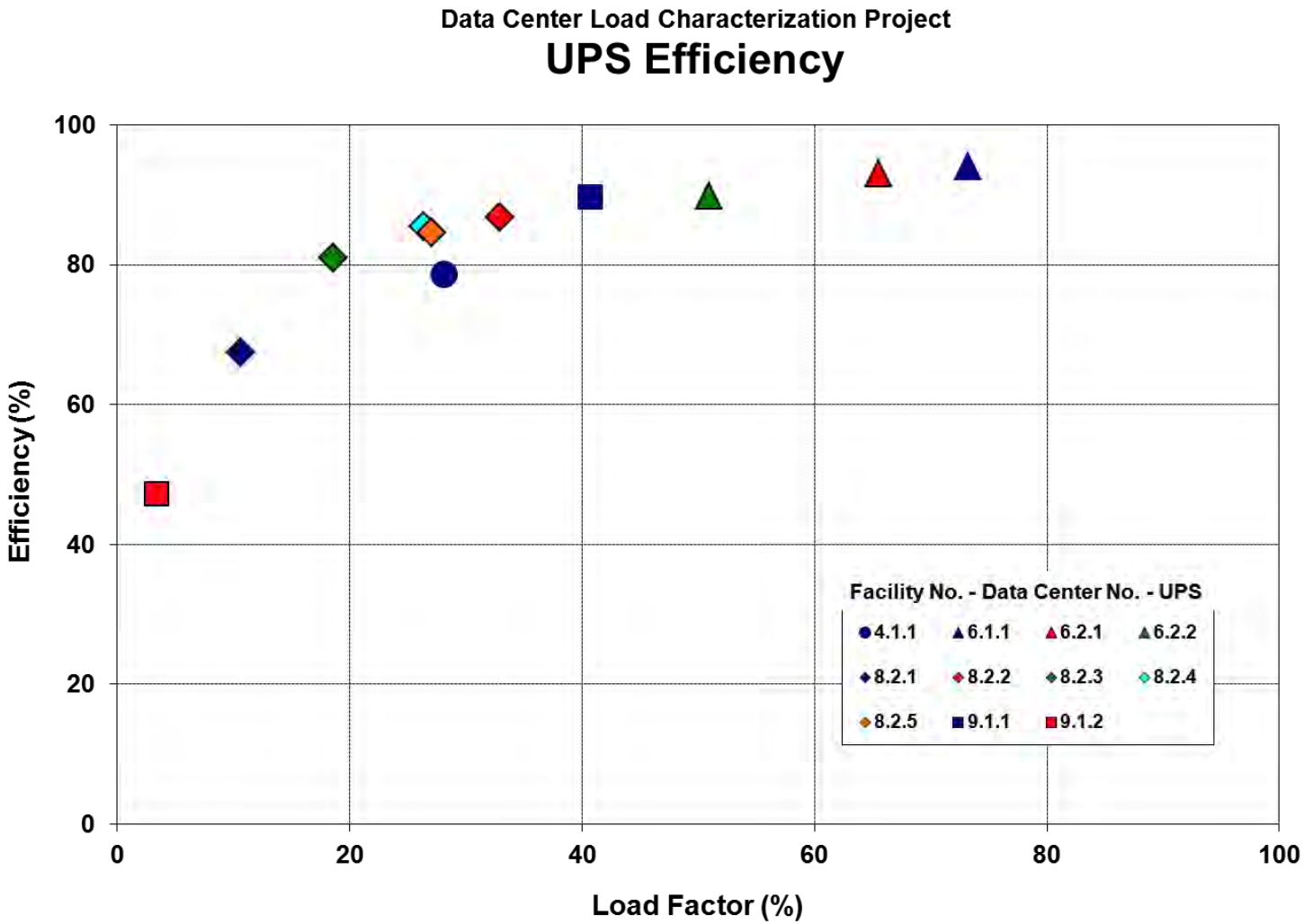
Power supplies in IT equipment





Uninterruptible Power Supplies (UPS)

Measured UPS efficiency confirms the curve



Sandia - Thermal management case study

- **Past**
  - Supply 48-52°F
  - Centrifugal fans
  - No automation
  - No integrated controls
  - Little concern for efficiency
  - Moved from water cooled to air cooled computers
- **Today**
  - Supply at 58-70°F
  - Plug fans
  - Automation
  - Integrated controls
  - Efficiency drives CRAC selection decisions
  - Mixed environment of water/refrigerant cooled computers and indirect (air) cooled
  - Hot/cold aisles

Unclassified

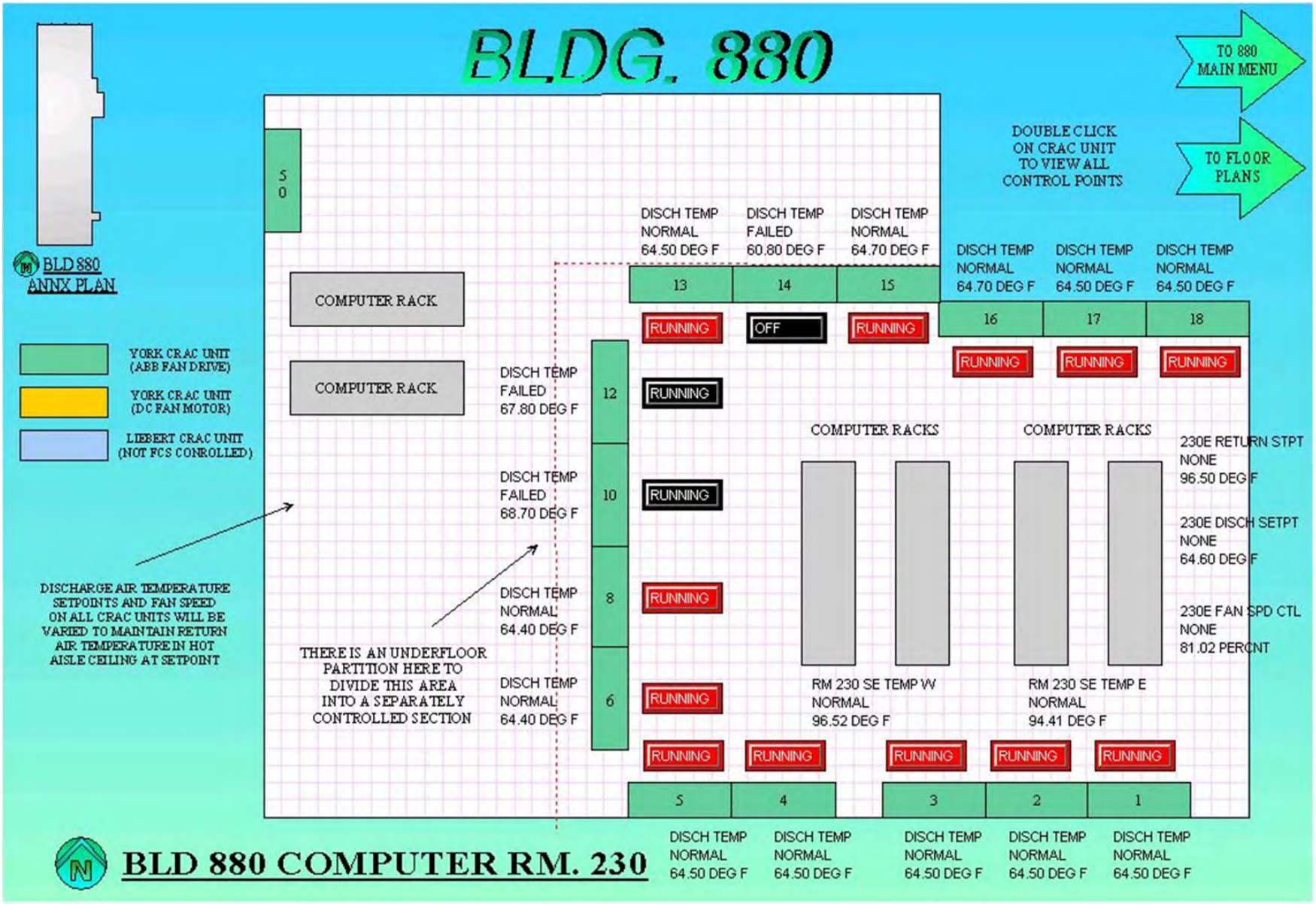
Thermal management

In order to achieve these goals we have taken the following approach :

- Build a written program that would automate and tie all the CRAC units together and interface with our existing Facilities Control System.
- Standardize our equipment (CRAC units). Equipment criteria included:
  - CRAC units that could deliver an even air flow under the floor
    - Plug fan technology to modulate based on air temperature of the fan motors (VFD's)
  - Improved water-side technologies (e.g. coil surface area, slant fin coils)
  - Vendors with demonstrated commitment:
    - Improving energy efficiencies
    - Vision of the future

Unclassified

Automated controls



Unclassified

Thermal management

Red Sky's Glacier Doors and XDPs 2009

Structured CRAC Plenums 2008

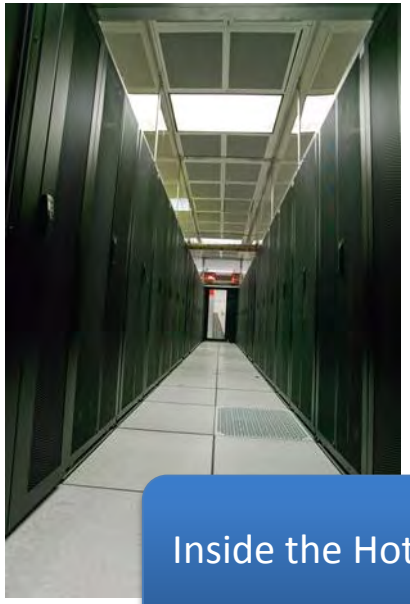
Hot Air Balloon Material for Cold Aisle Containment 2006

Air Flow Dams Removed from Under Floor 2010

Welding Curtain CRAC Plenum early 1980's

Unclassified

Thermal management - 2012



Inside the Hot Aisle

Hot Aisle Containment and Controls

- Set point 95°F return air temperature
  - Controls water valve & speed of fans
- 24kW per rack
- Water temperature 50°F (can raise to 60°F)
- 12 CRAC units controlled by VFD
  - 30 ton units at 15,000 cfm

TLCC's Chama

Top View of Containment

TLCC's Pecos

Unclassified

HPC centers are moving to liquid cooling. Liquid has much more heat capacity than air

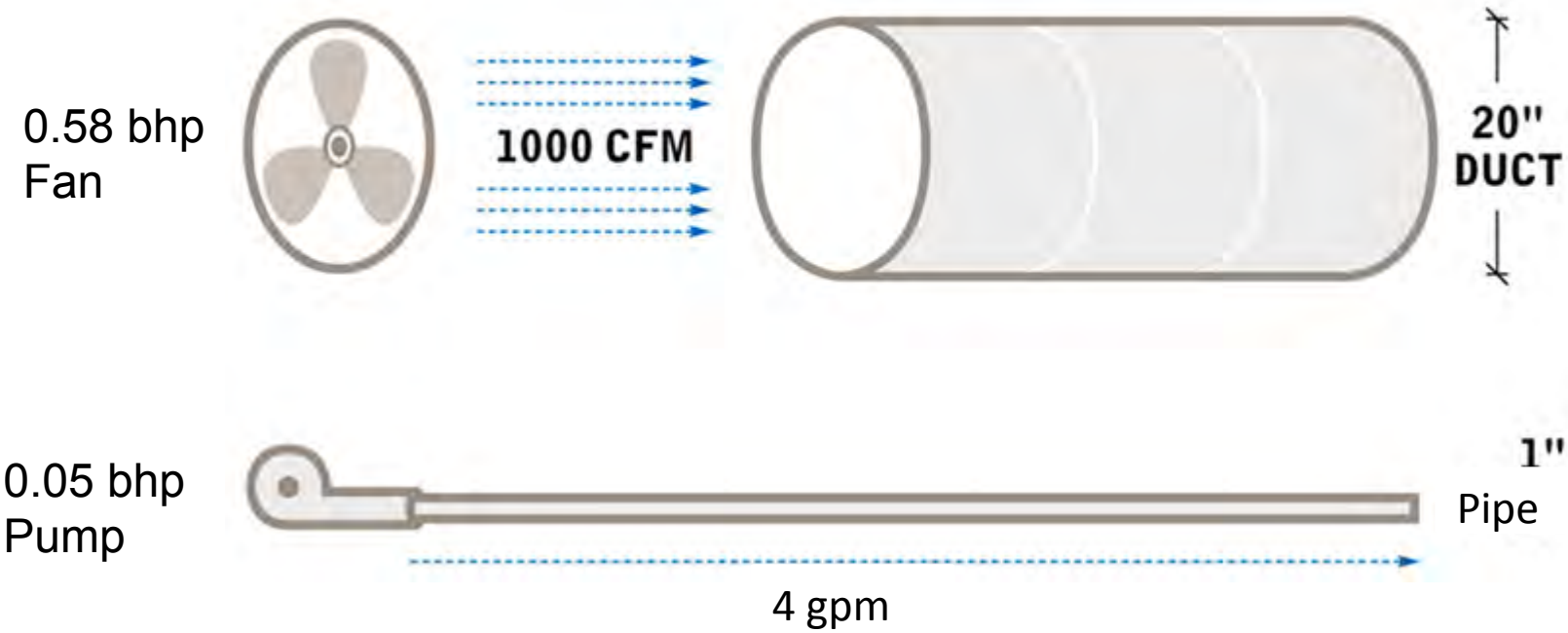
Volumetric heat capacity comparison

=

Water

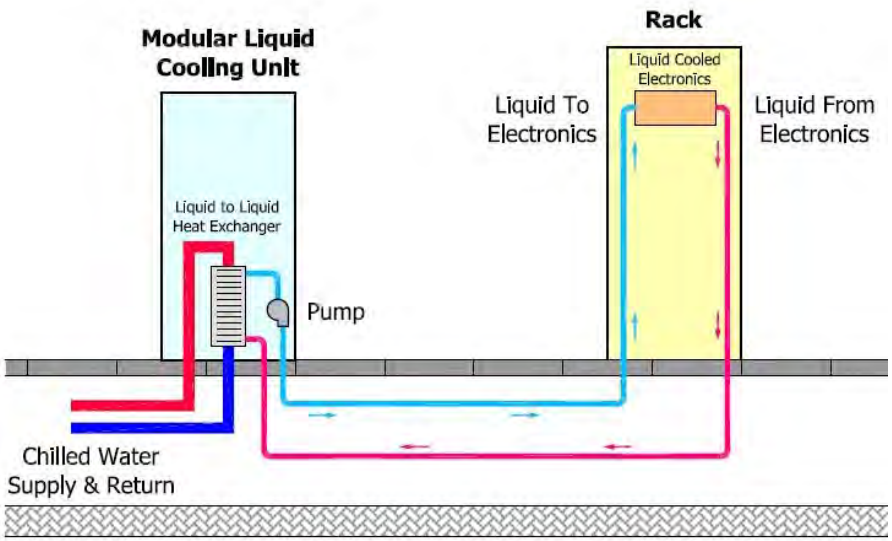
Air

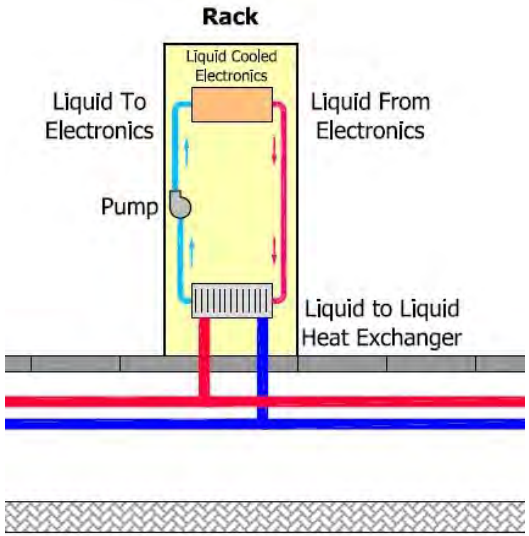
Pumps move energy more efficiently

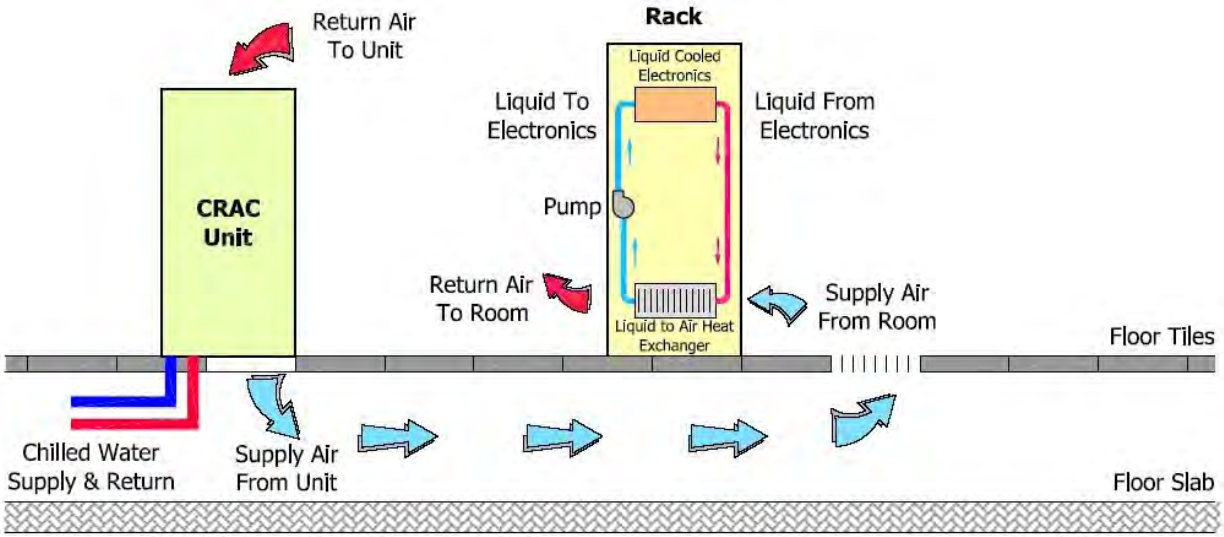


Flow		Formula	DT		BTUH	Eff	DP		Formula	BHP
1,000	cfm	BTUH=1.1*cfm*DT	21.8	°F	24,000	54%	2	in w.c.	bhp=cfm*DP/(6350*eff)	0.58
4	gpm	BTUH=500*gpm*DT	12.0	°F	24,000	80%	40	ft w.c.	bhp=gpm*DP/(3960*eff)	0.05

Liquid cooling takes on different forms







Liquid cooling guidelines enable standardization while achieving energy efficient liquid cooling

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

High temperature chilled water

Higher temperature produced with a cooling tower alone

Highest temperature produced with dry cooler (no water use)

Heat reuse

Source: ASHRAE whitepaper, 2011

Liquid cooling can reduce or eliminate compressor based cooling

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

High capital and operating cost for chillers

Chillers can be eliminated or downsized

Dry coolers alone can produce these temperatures

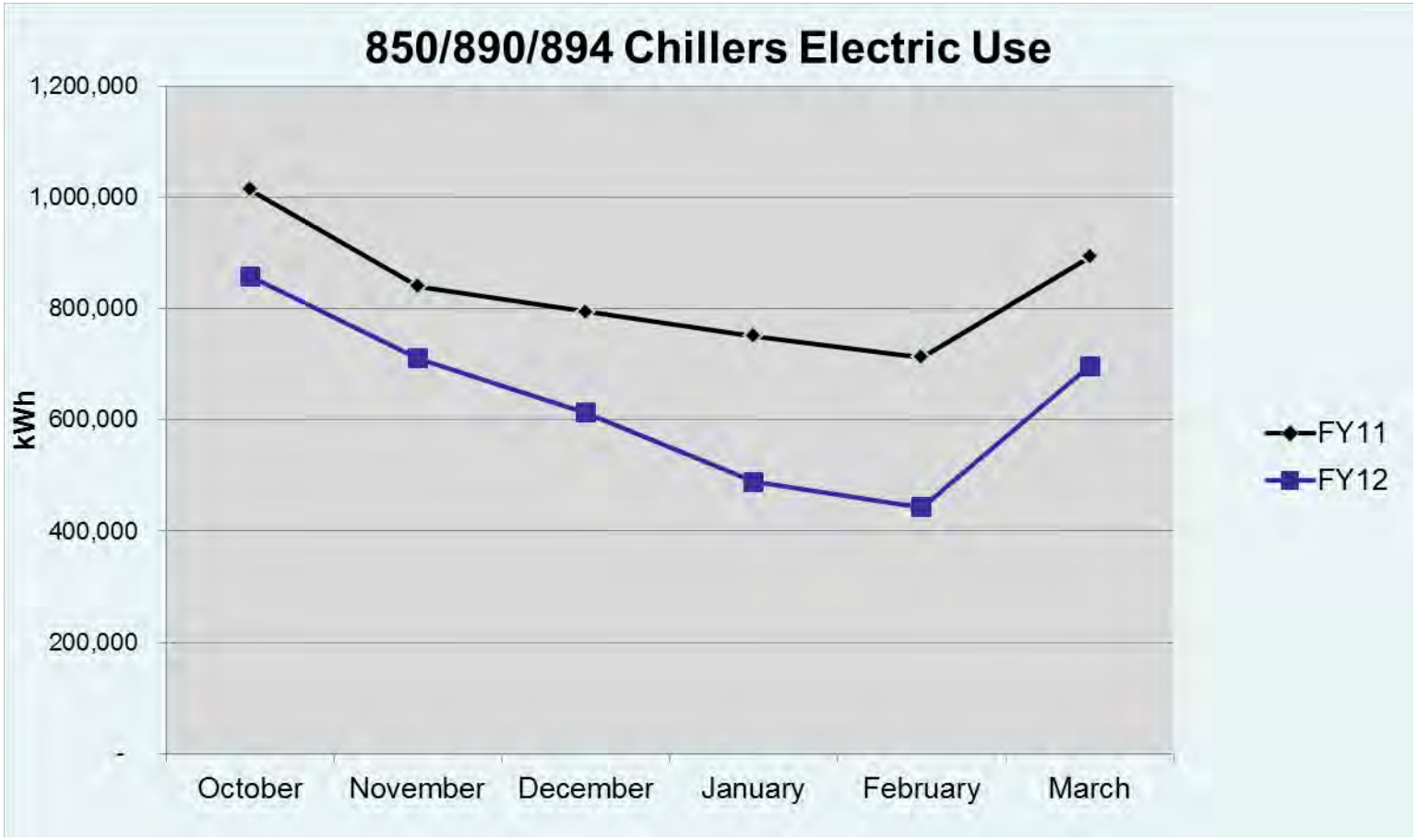
“Free cooling” isn’t entirely free but can save considerable energy in data centers

Translation –

- Air economizer – open the window
- Water economizer - use cooling towers with a heat exchanger
- Reduce or eliminate need for chillers

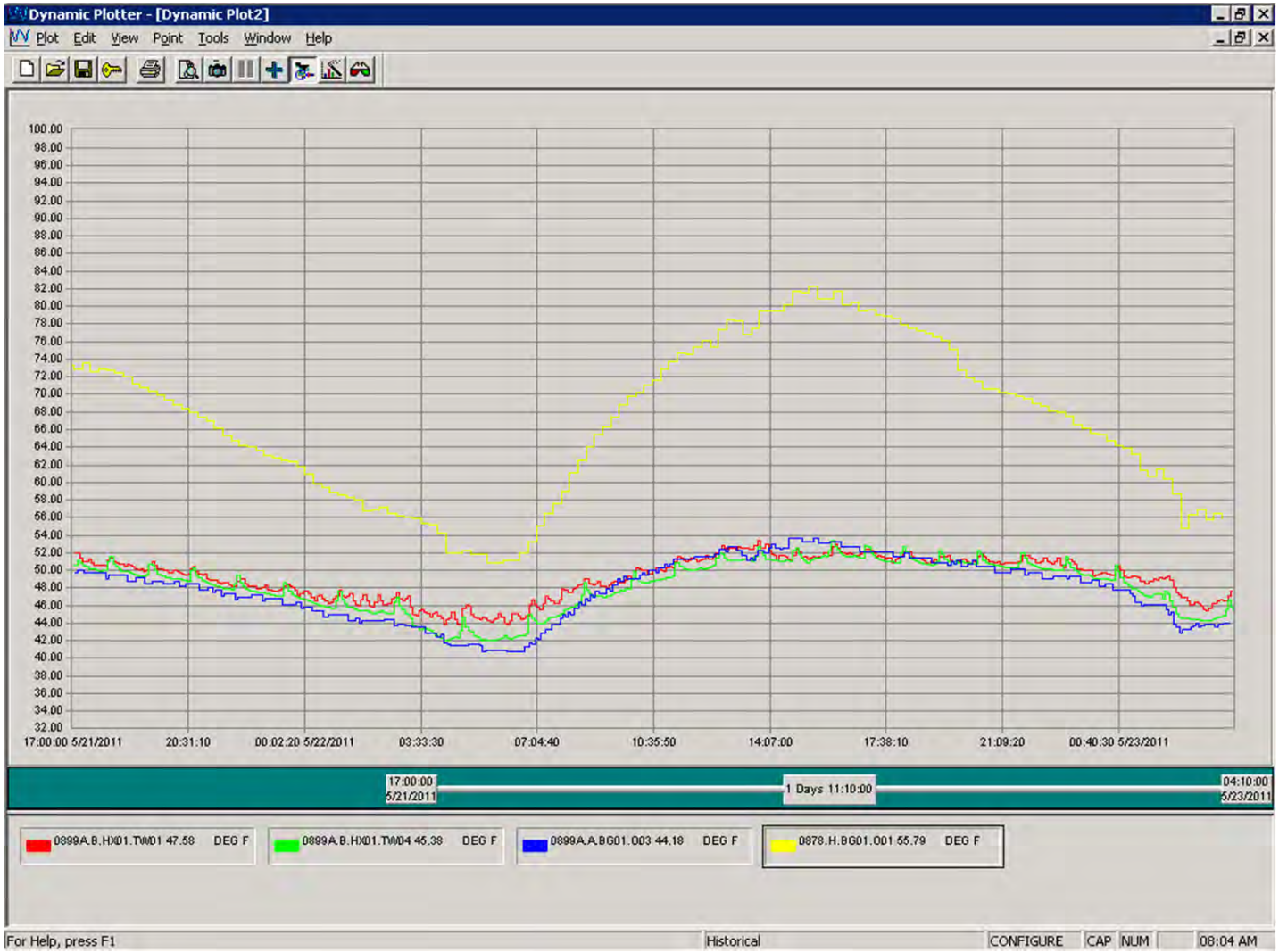
The results so far……

850/890/894 Chillers - Electric Use (kWh)						
	October	November	December	January	February	March
FY11	1,013,662	839,853	794,412	750,219	711,943	892,594
FY12	857,433	710,621	612,255	488,537	442,201	696,893
% Change	-15.41%	-15.39%	-22.93%	-34.88%	-37.89%	-21.92%



Unclassified

Cold plate data



	Chilled water supply temperature from heat exchanger
	Tower water supply temperature to heat exchanger
	Outside air wetbulb temperature
	Outside air drybulb temperature

Unclassified

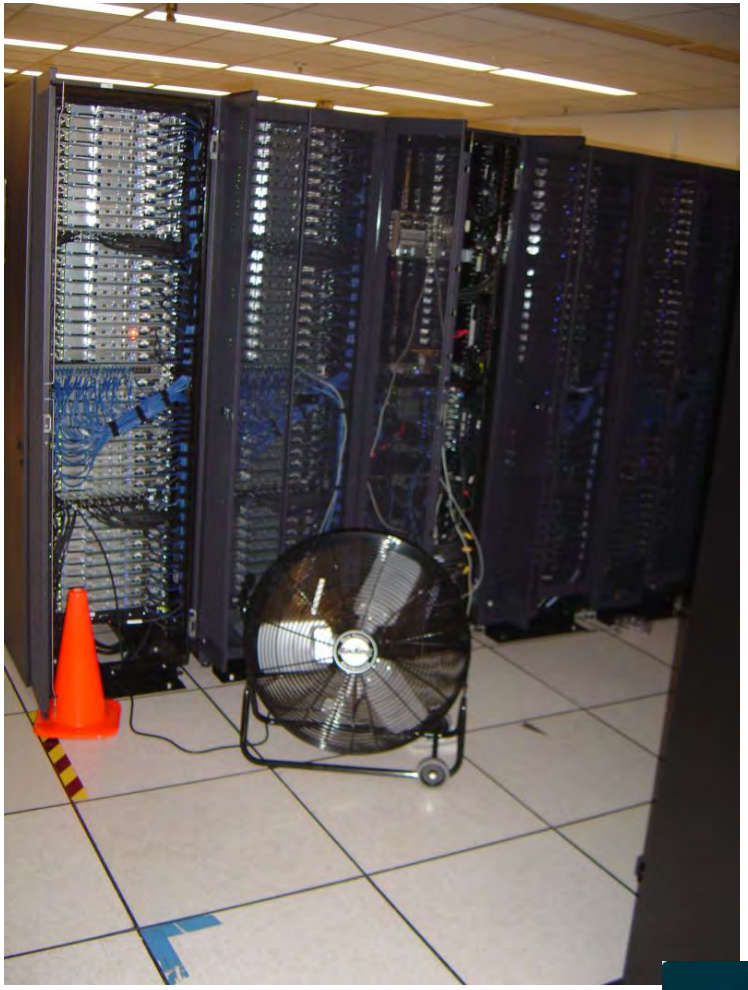
In summary, there are many opportunities for energy efficiency in HPC centers.

Knowledge and Adoption of Best Practices

Influencing suppliers:
- Thermal conditions
- Liquid cooling

Training

There is always more that can be done



Sandia National Laboratories

Questions?

BERKELEY LAB
Lawrence Berkeley National Laboratory

Resources - websites

http://hightech.lbl.gov/datacenters.html
http://hightech.lbl.gov/serverclosets.htm

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

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

U.S. Department of
ENERGY

http://www1.eere.energy.gov/manufacturing/datacenters/