Saving Energy in Data Centers
Applying Best Practices

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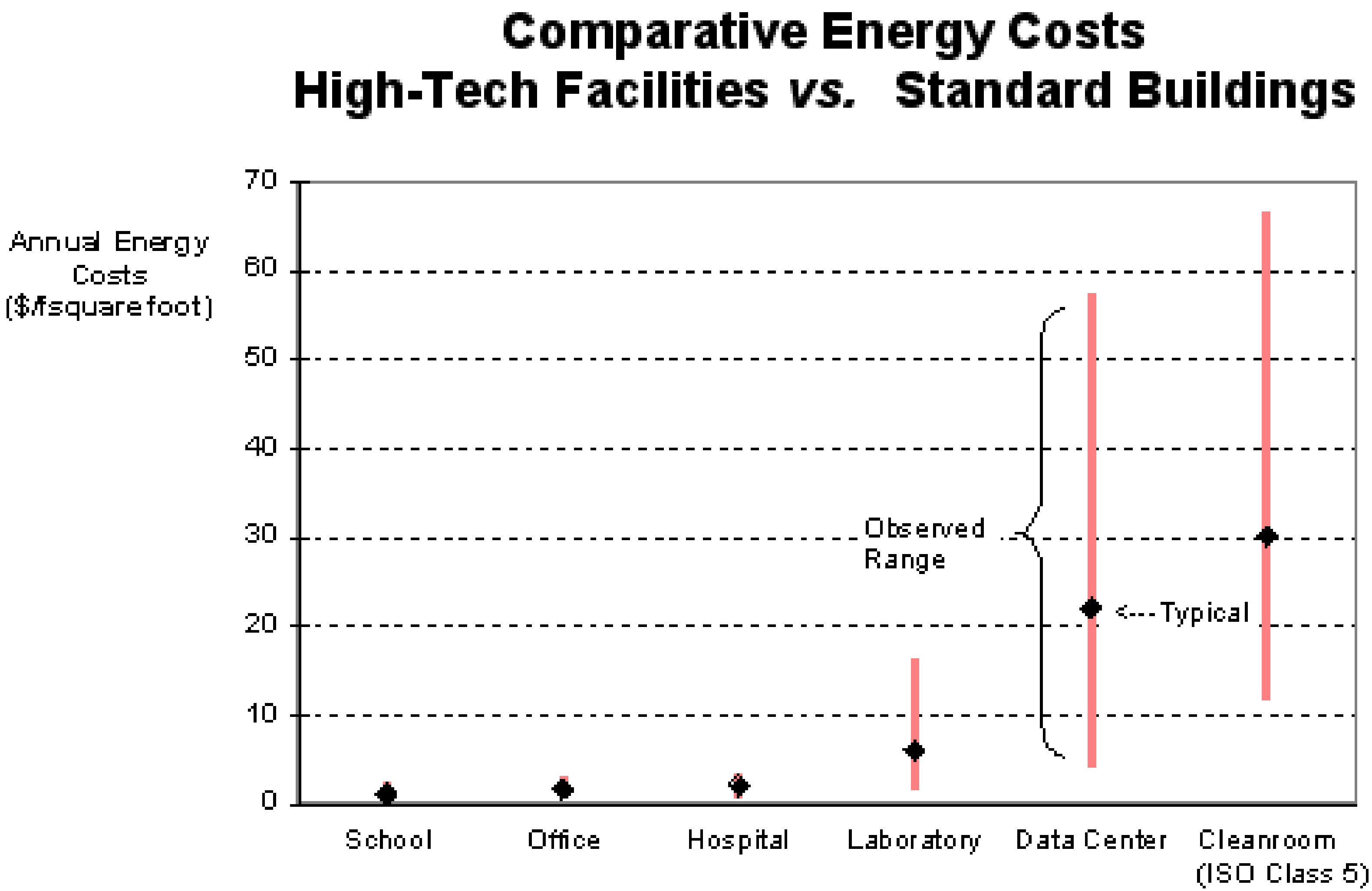
U.S. Department of Energy
Energy Efficiency and Renewable Energy

Berkeley Lab

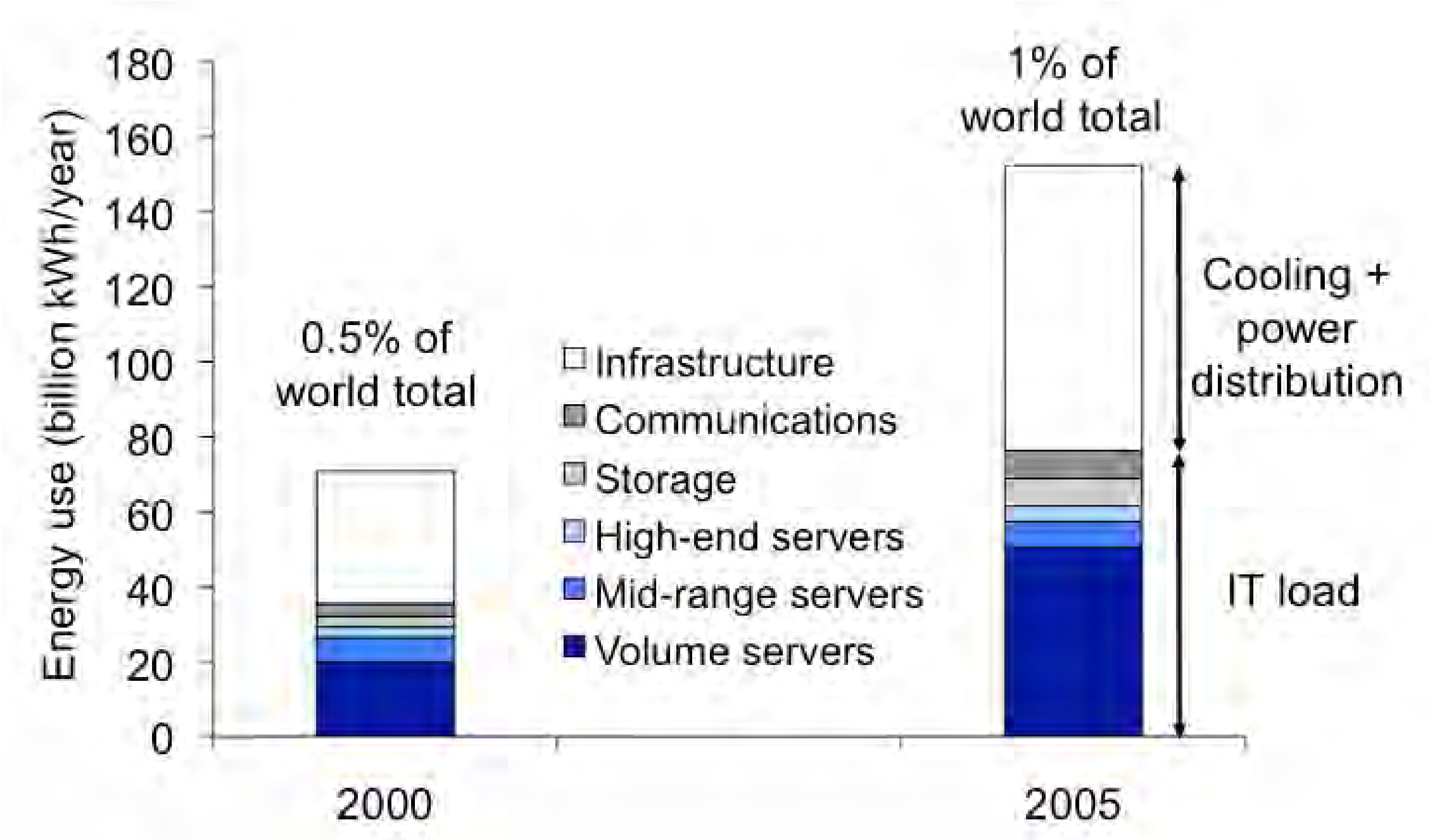
High Tech Buildings are Energy Hogs:



Data Center Energy

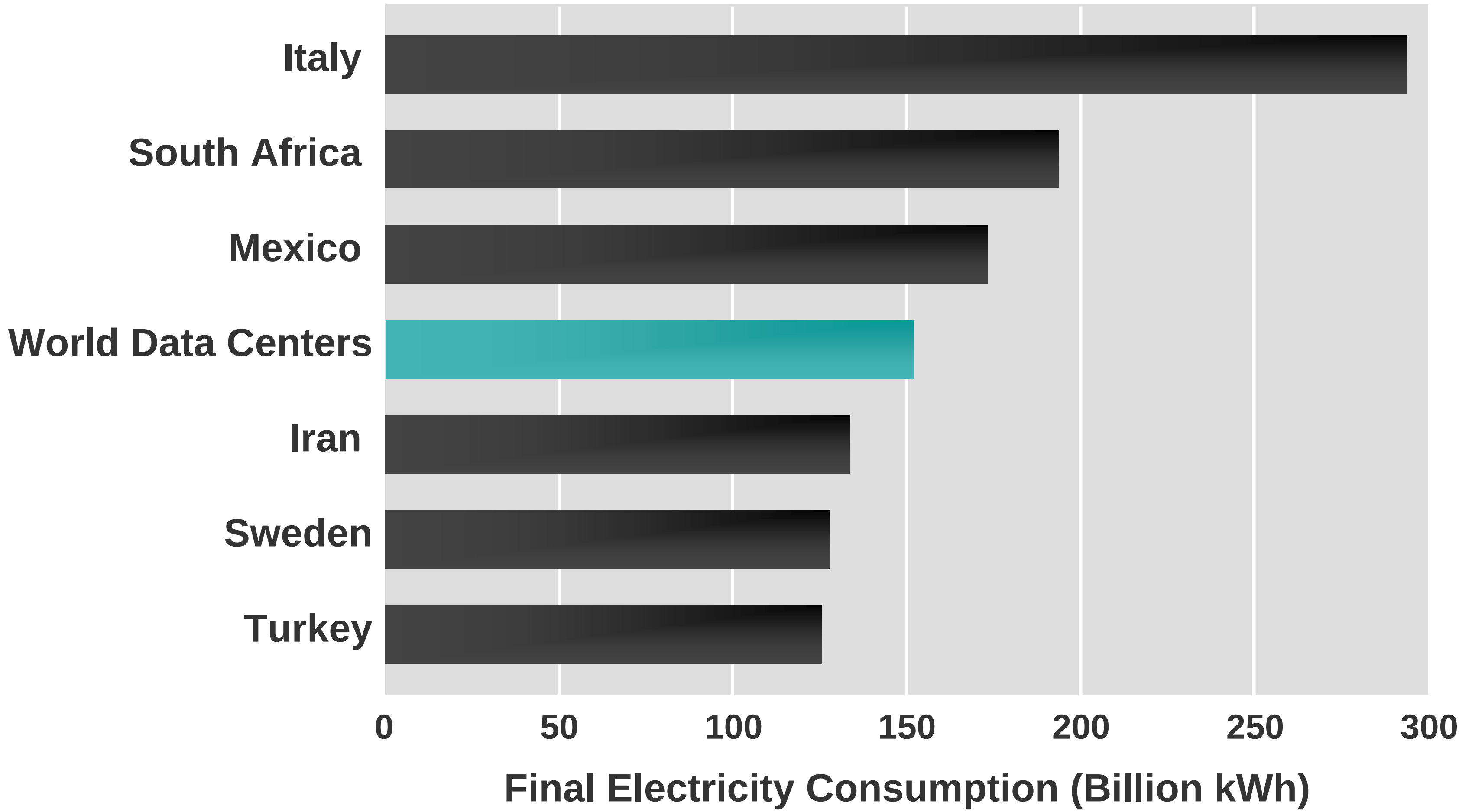
- Data centers are energy intensive facilities
  - 10 to 100 times more energy intensive than an office
  - Server racks now designed for more than 25+ kW
  - Surging demand for data storage
  - 2% of US Electricity consumption
  - Projected to double in next 5 years
  - Power and cooling constraints in existing facilities

World Data Center Electricity Use - 2000 and 2005



Source: Koomey 2008

How much is 152B kWh?



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

The Rising Cost of Ownership

- 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

Challenging Conventional Wisdom: Game Changers

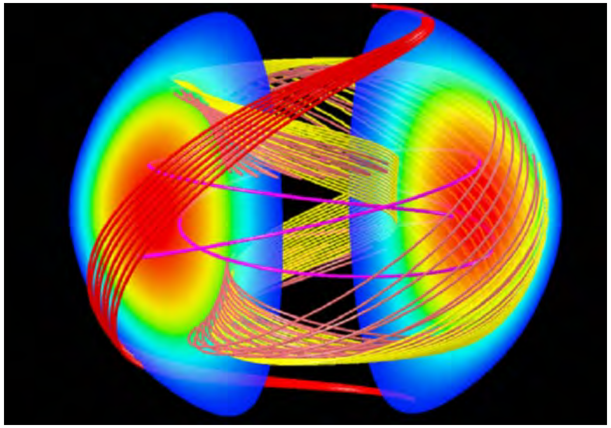
Conventional Approach

- 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

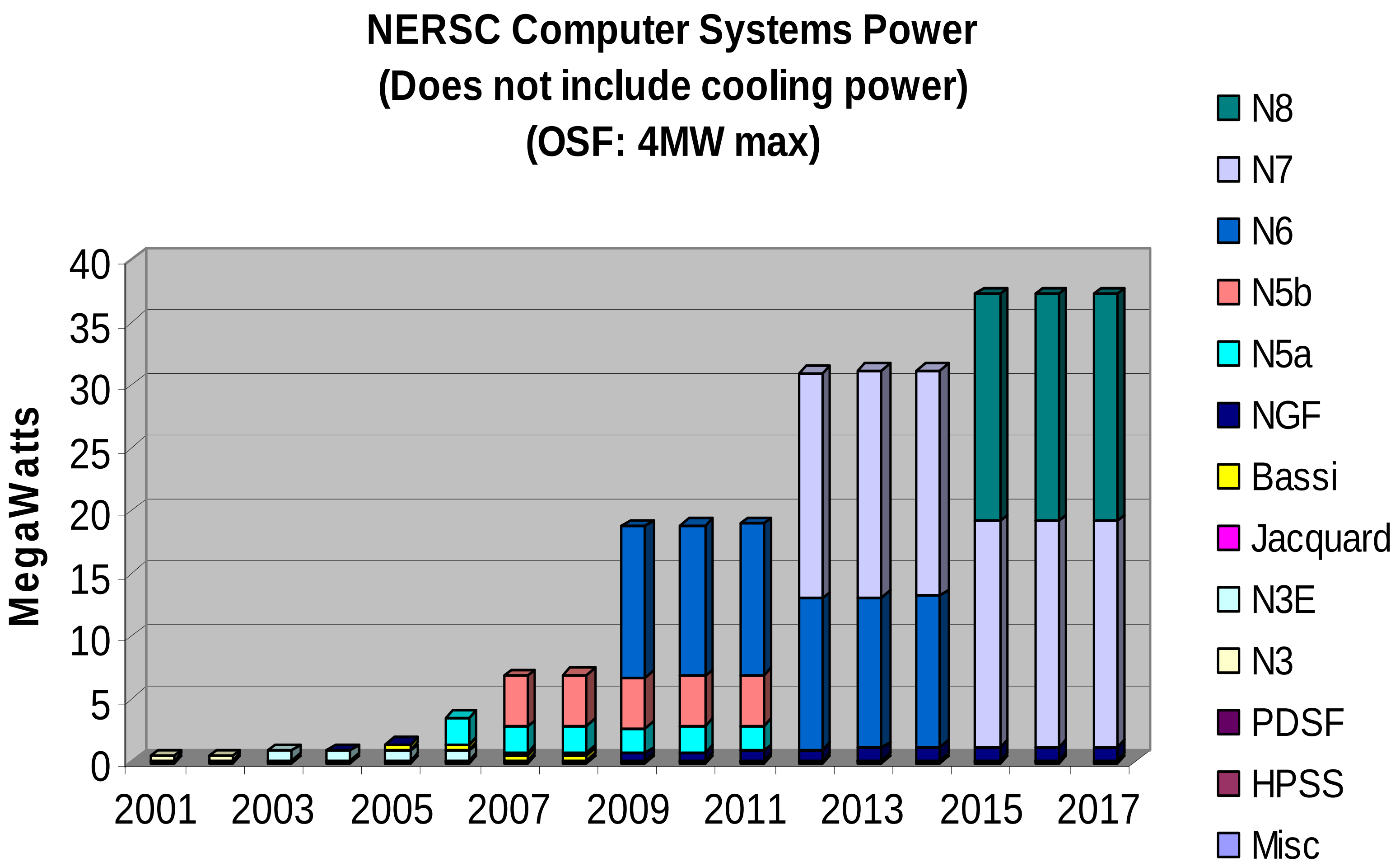
LBNL operates large systems along with legacy systems



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

LBNL Feels the Pain!

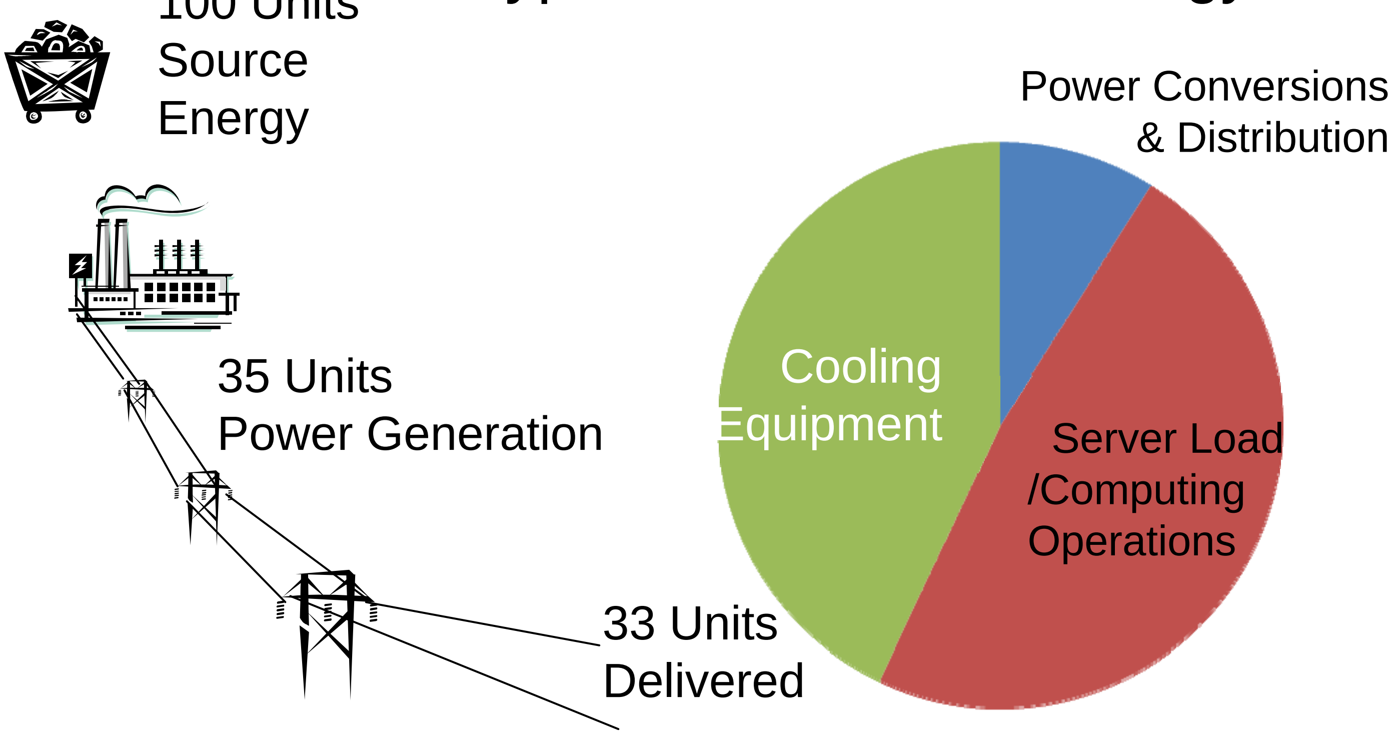
LBNL Super Computer Systems Power:



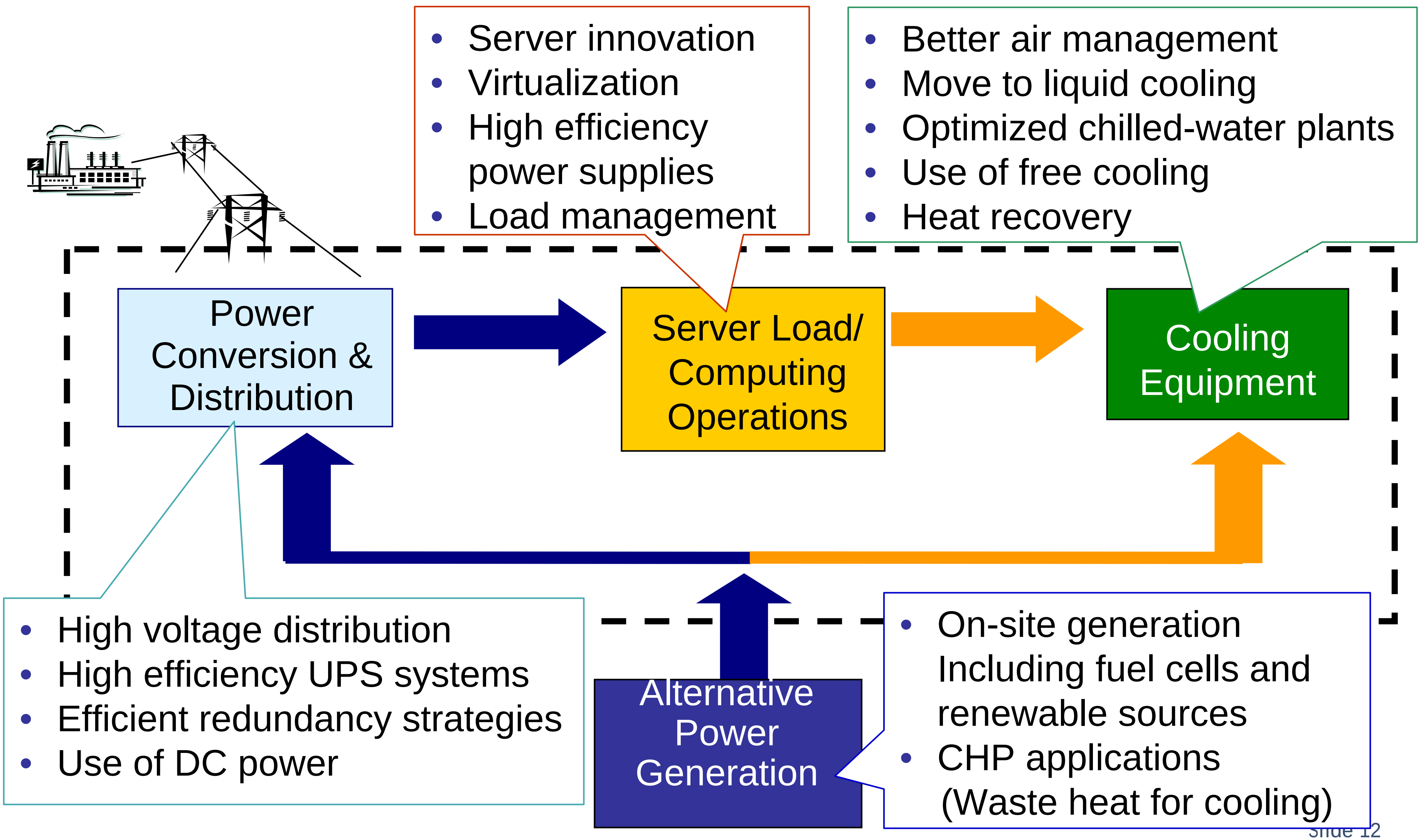
Data Center Energy Efficiency = 15% (or less)

(Energy Efficiency = Useful computation / Total Source Energy)

Typical Data Center Energy End Use



Energy Efficiency Opportunities



Potential Benefits of Data Center Energy Efficiency:

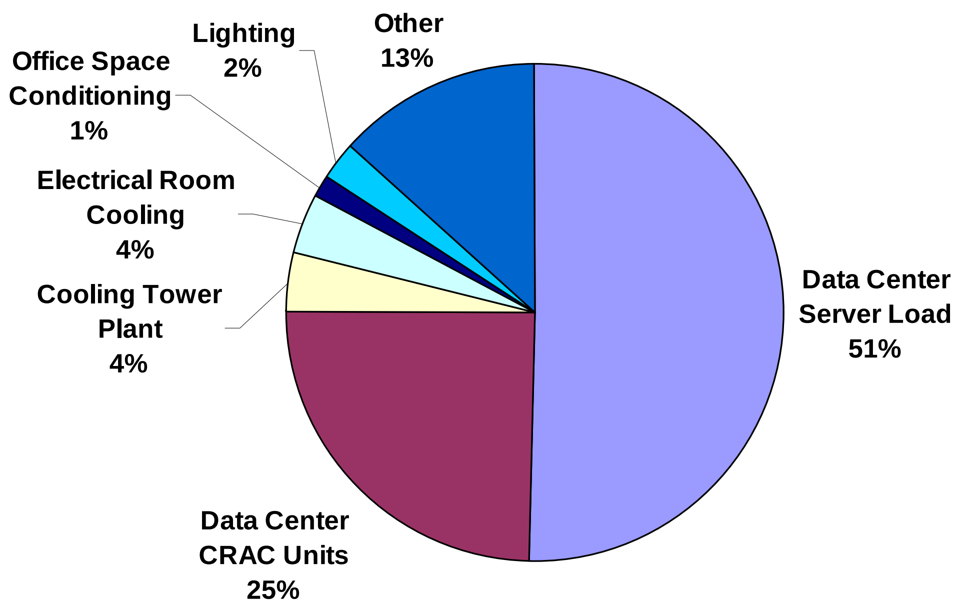
- 20-40% savings typical
- Aggressive strategies can yield 50+% savings
- Extend life and capacity of infrastructures
- But is mine good or bad?

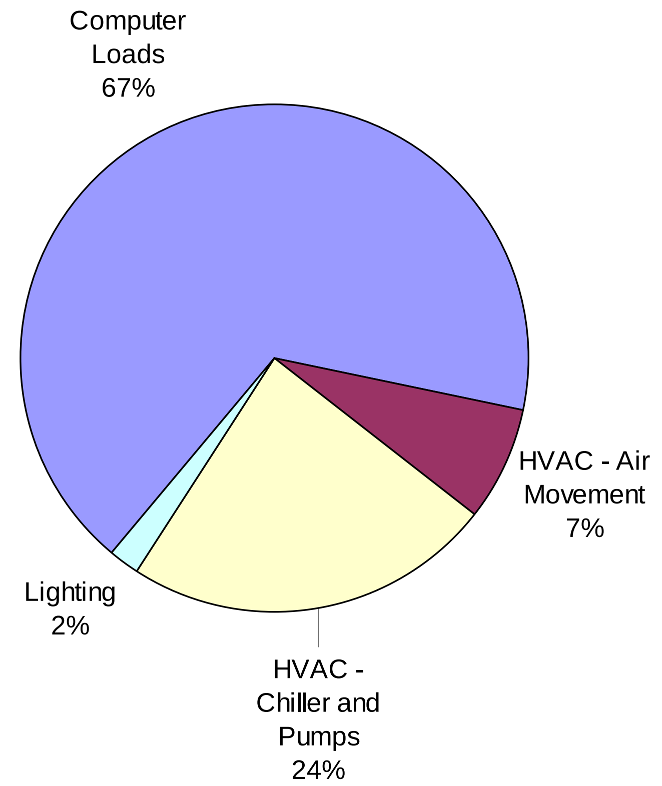
Benchmark Energy Performance

- Compare to peers
  - Wide variation
- Identify best practices
- ID opportunities
- Track performance
  - Can’t manage what isn’t measured

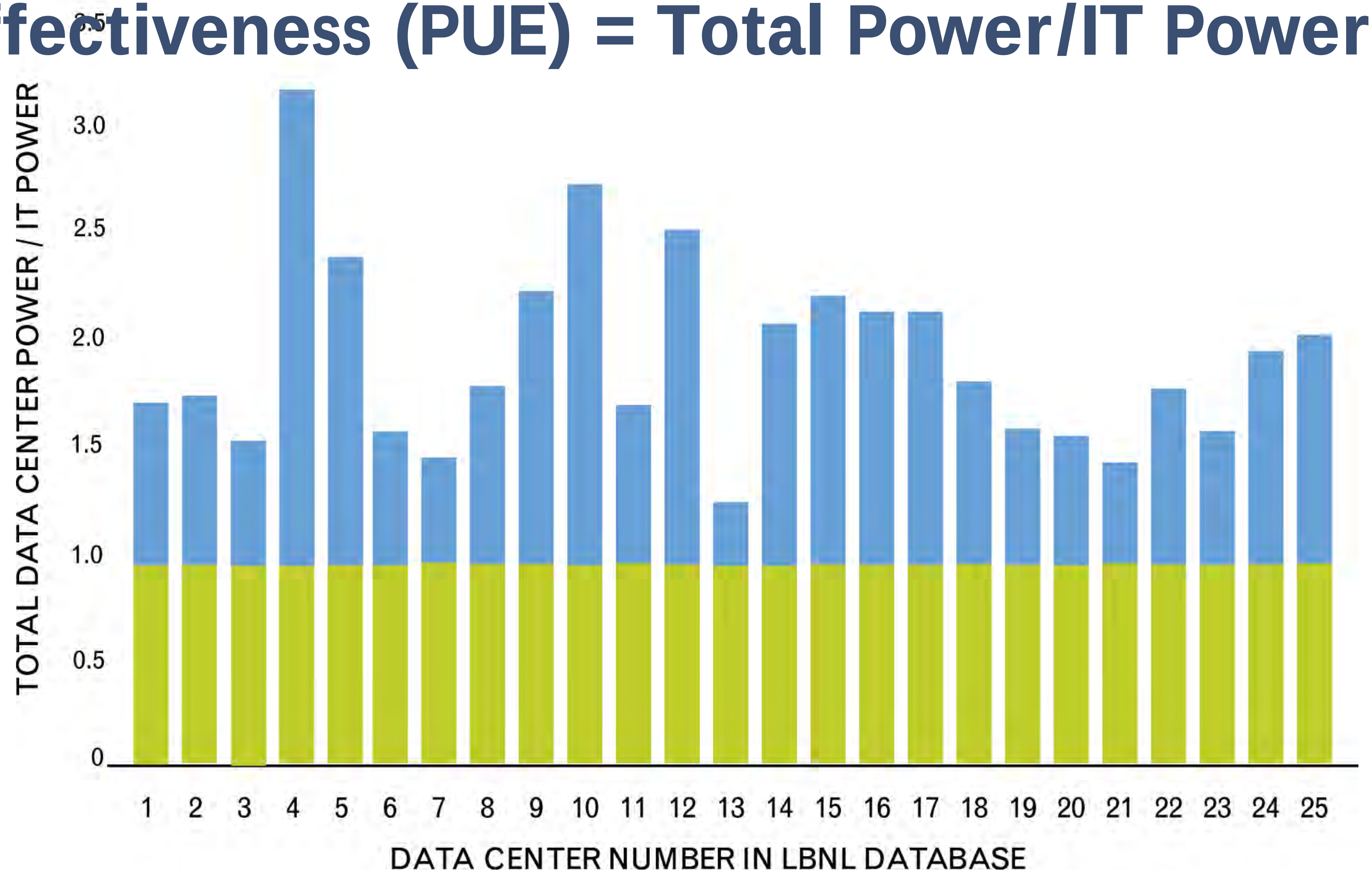
Your Mileage Will Vary

The relative percentages of the energy actually doing computing varied considerably.

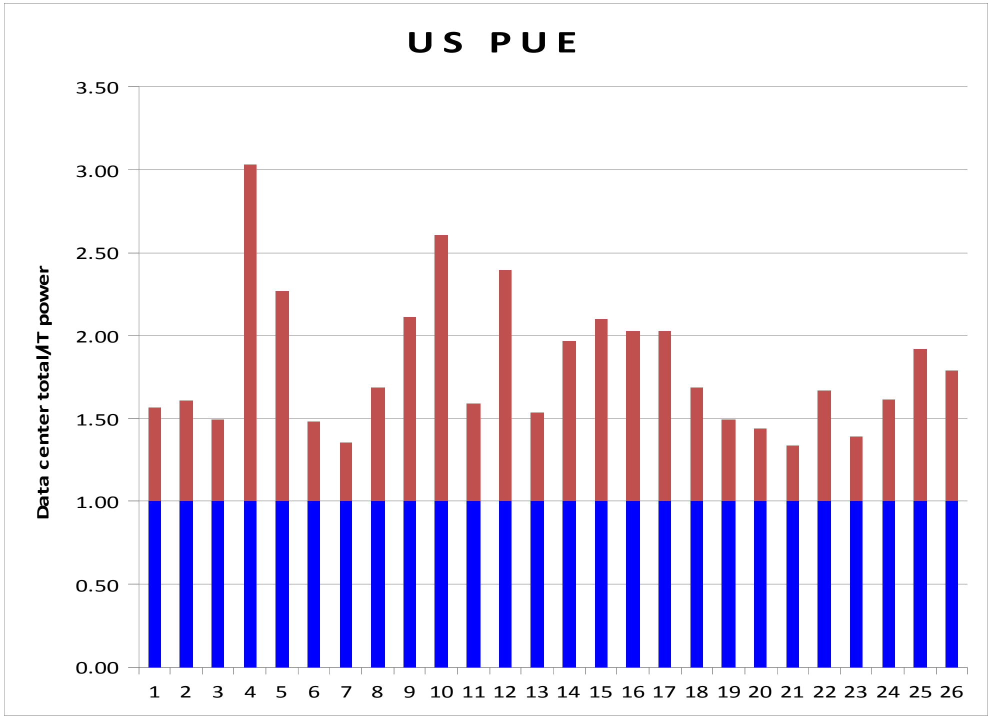


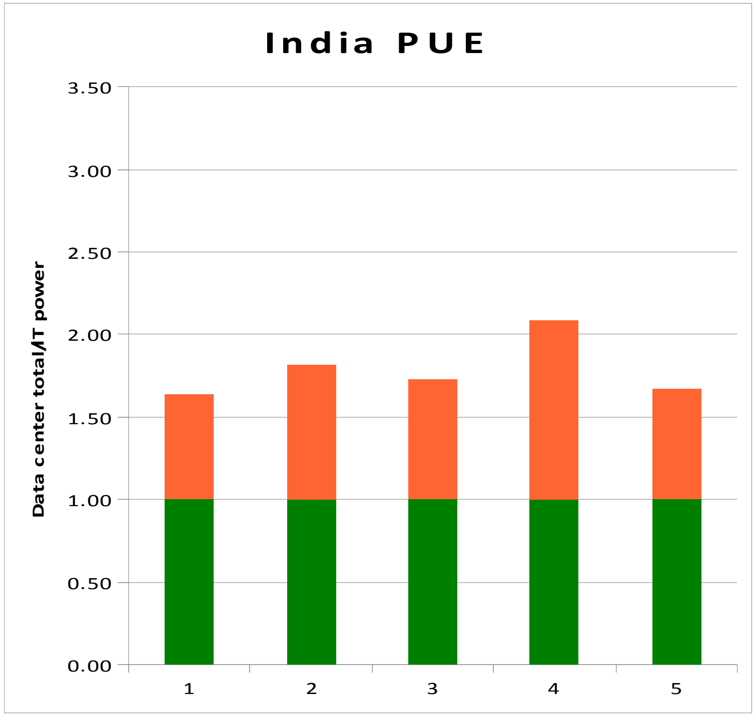


High Level Metric: Power Utilization Effectiveness (PUE) = Total Power/IT Power



Power Usage Effectiveness (PUE)





Indian Data Center Benchmarking Sources Thanks To:

- Intel
- Hewlett Packard
- APC
- Maruti
- Texas Instruments

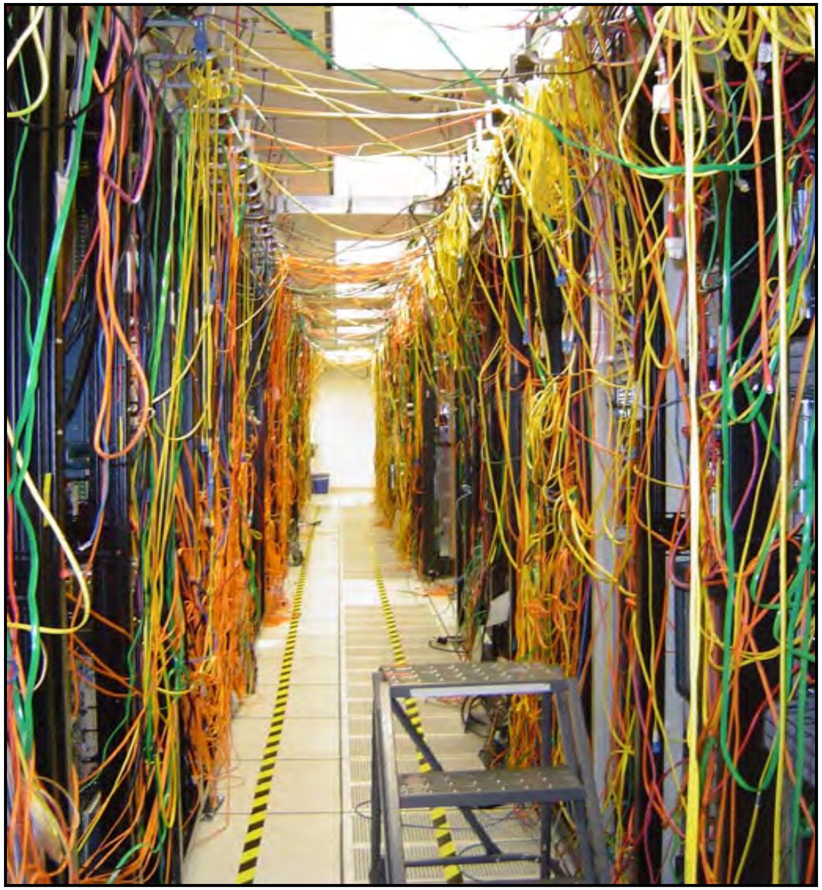
More Needed!

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

Best practices based on benchmark results:

- **IT equipment efficiency**
- **Use IT to save energy in IT**
- **Environmental conditions**
- **Air management**
- Right-sizing
- Central plant optimization
- Efficient air handling
- **Liquid cooling**
- **Free cooling**
- **Humidity control**
- **Improve power chain**
- On-site generation
- **Design and M&O processes**



Applying Best Practices at LBNL

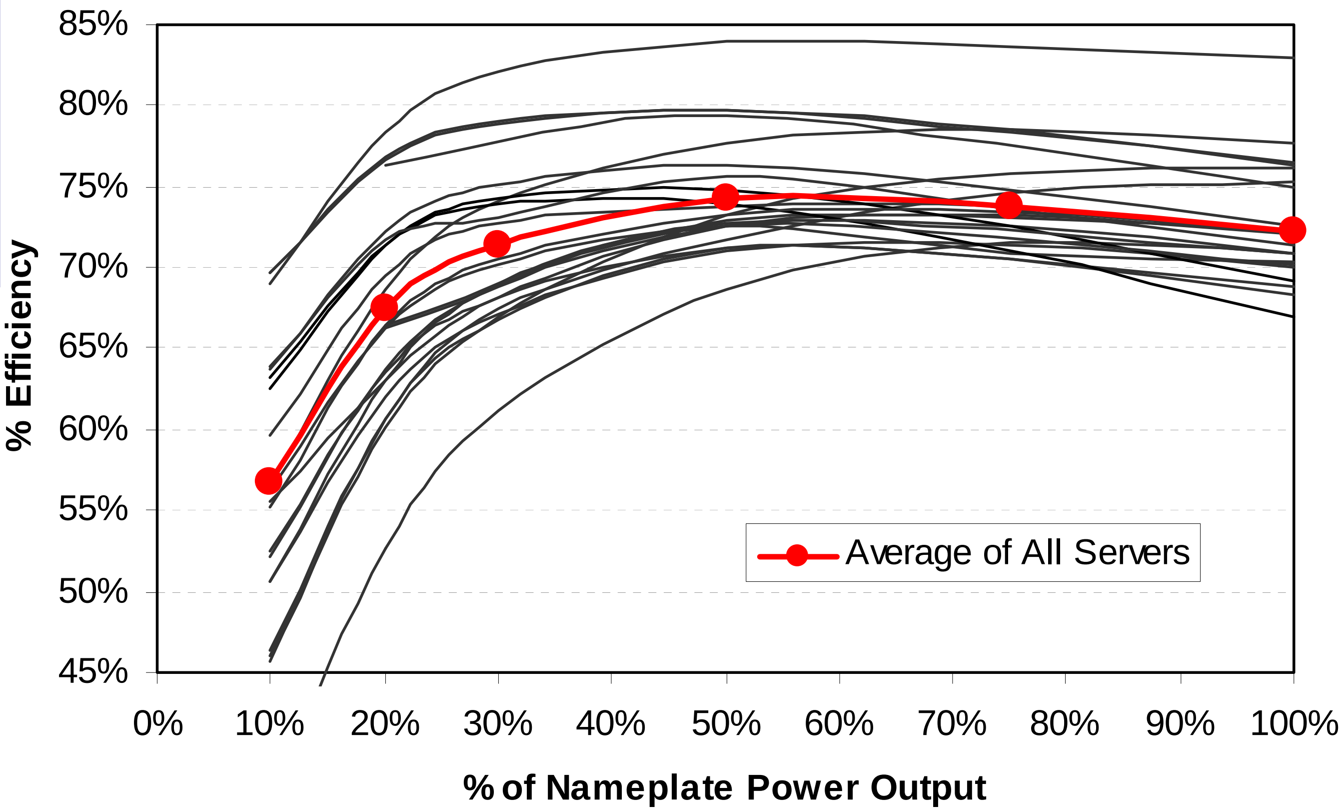
- Partnership between CIO, CS, and energy efficiency researchers, facilities
- Existing data centers relatively efficient
  - ➢ NERSC: PUE = 1.3 (1.4), takes advantage of central plant
  - ➢ 50B-1275: PUE = 1.45 (1.65), tower cooled CRACs
- Increased efficiency frees up needed “capacity”
- New data centers much better (PUE = 1.1)
- Leveraging data centers as test beds to create an impact beyond Berkeley Lab
- Working with vendors to develop new products and strategies

IT equipment load can be controlled:

Computations per Watt is improving, but computation demand is increasing even faster so overall energy is increasing. Lifetime electrical cost will soon exceed cost of IT equipment.

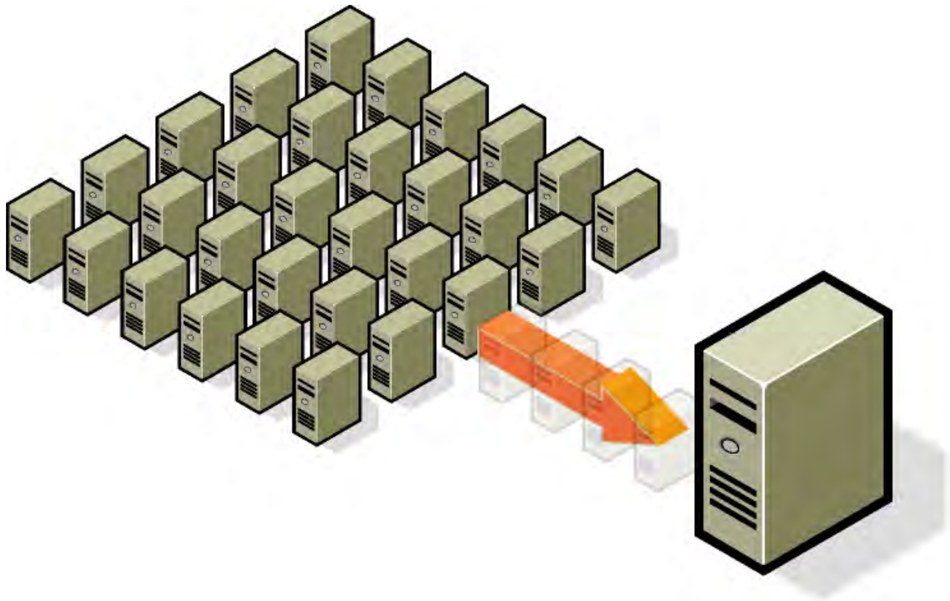
- **Consolidation**
- **Server efficiency (Use Energy Star servers)**
  - **Flops per watt**
  - **Efficient power supplies and less redundancy**
- **Software efficiency:**
  - **Virtualize for higher utilization**
  - **Data storage management**
- **Enable power management**
- **Reducing IT load has a <u>multiplier effect</u>**
  - **Equivalent savings +/- in infrastructure**

Select and Configure Power Supplies for Greater Efficiency



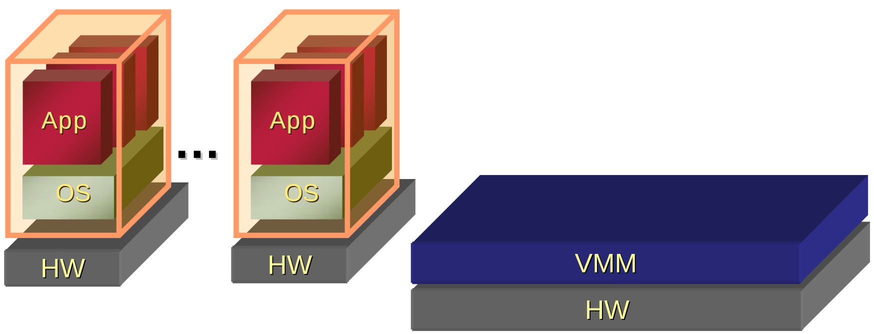
Virtualize and Consolidate Servers and Storage

- 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



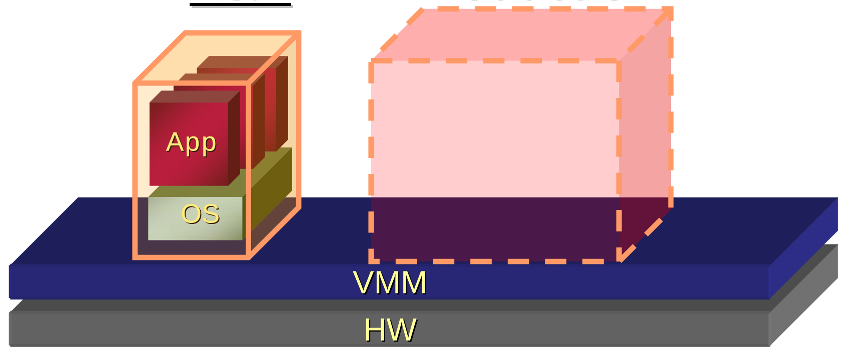
Virtualization: Workload provisioning

Server Consolidation



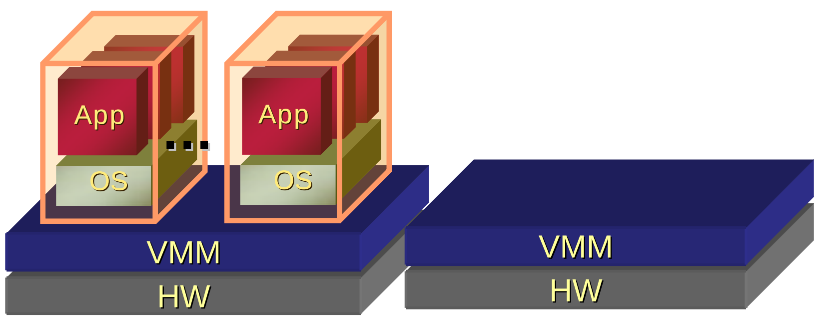
10:1 in many cases

R&D Production



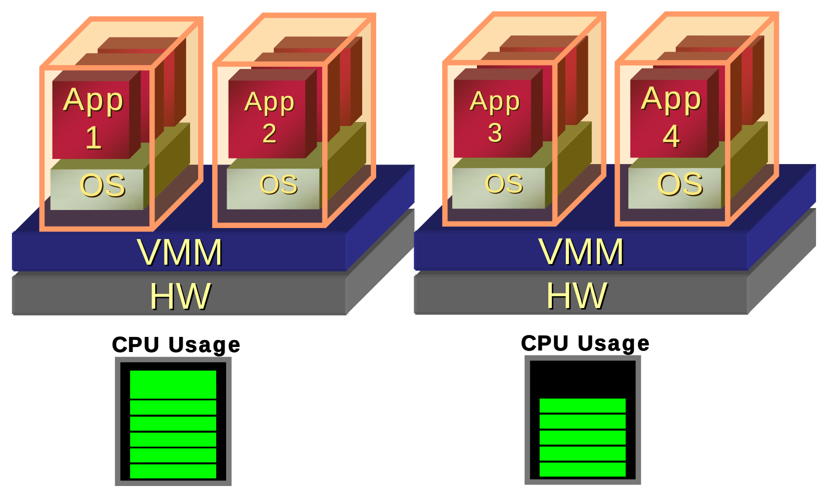
Enables rapid deployment,
reducing number of idle, staged servers

Disaster Recovery



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

Dynamic Load Balancing

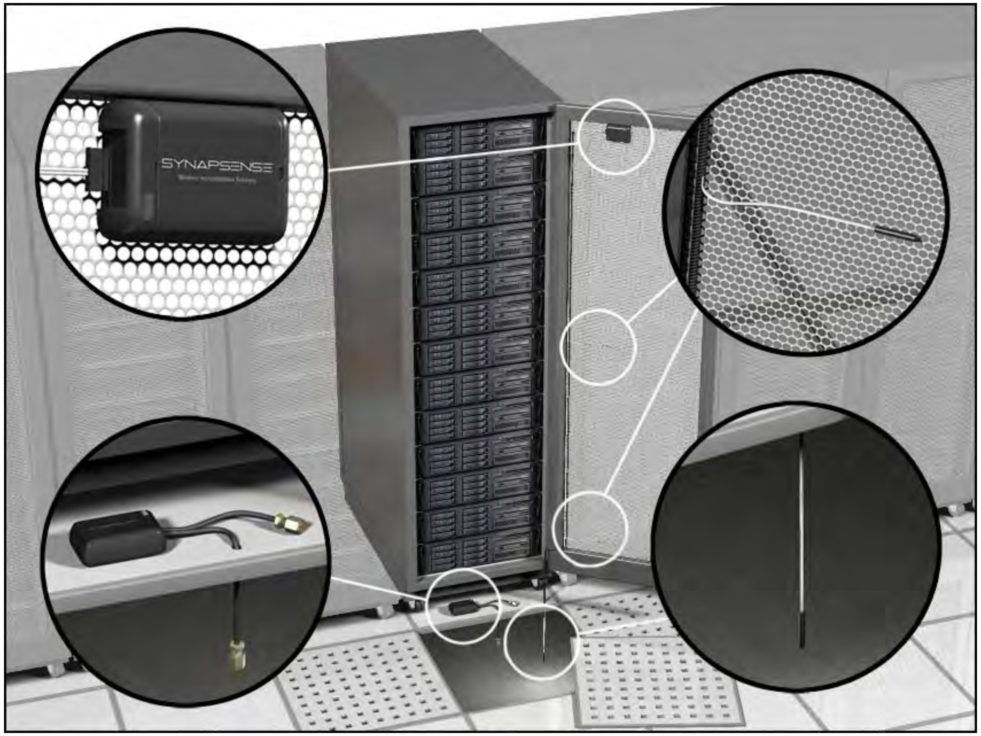


Balancing utilization with head room

Using IT to Save Energy in IT

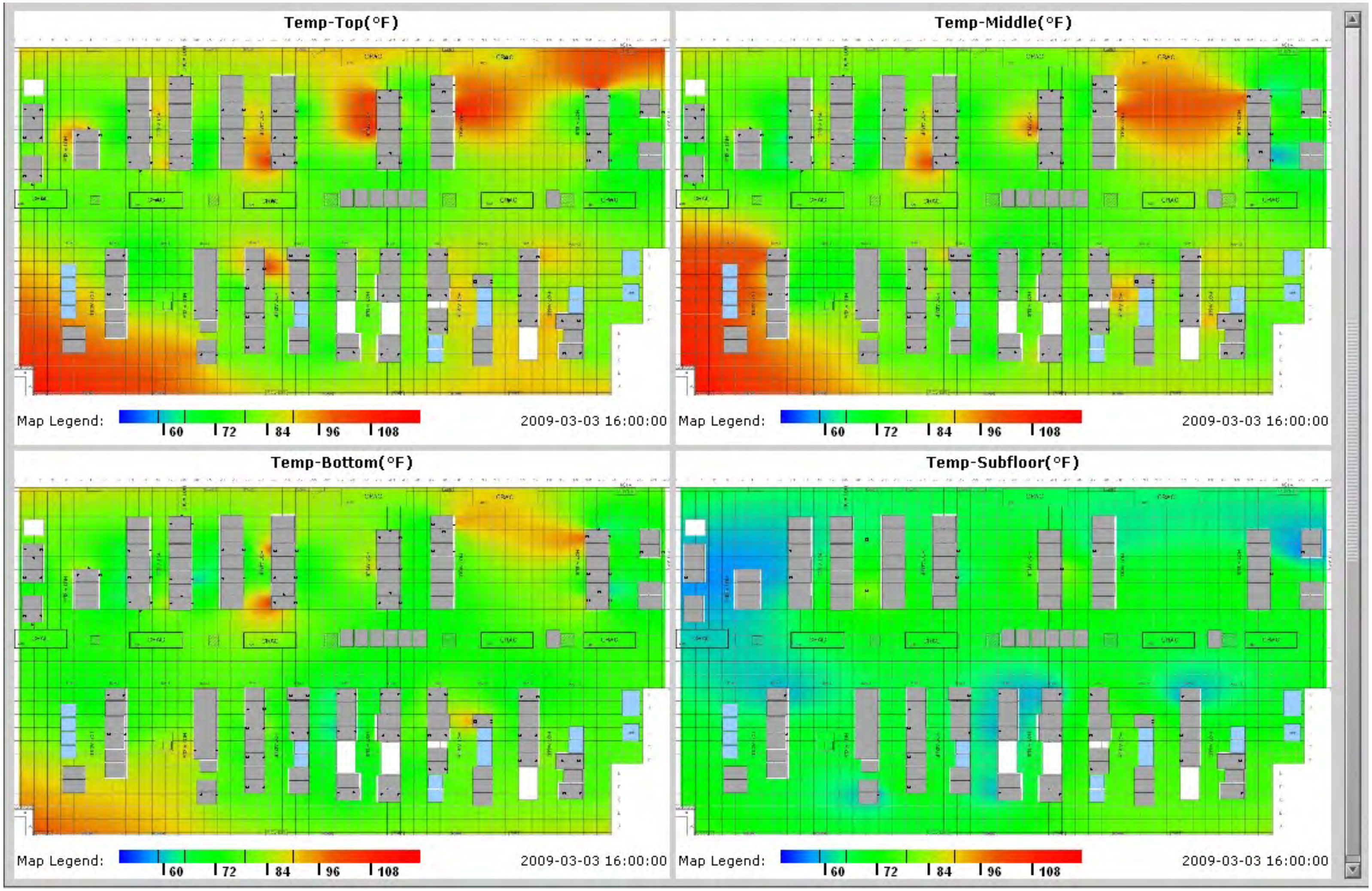
- Operators lack visibility into data center environment
- Provide same level of monitoring and visualization of the physical space as we have for the IT environment
- Measure and track performance
- Spot problems early
- 800 point SynapSense system
  - Temperature, humidity, under-floor pressure, current

LBNL Wireless Monitoring System



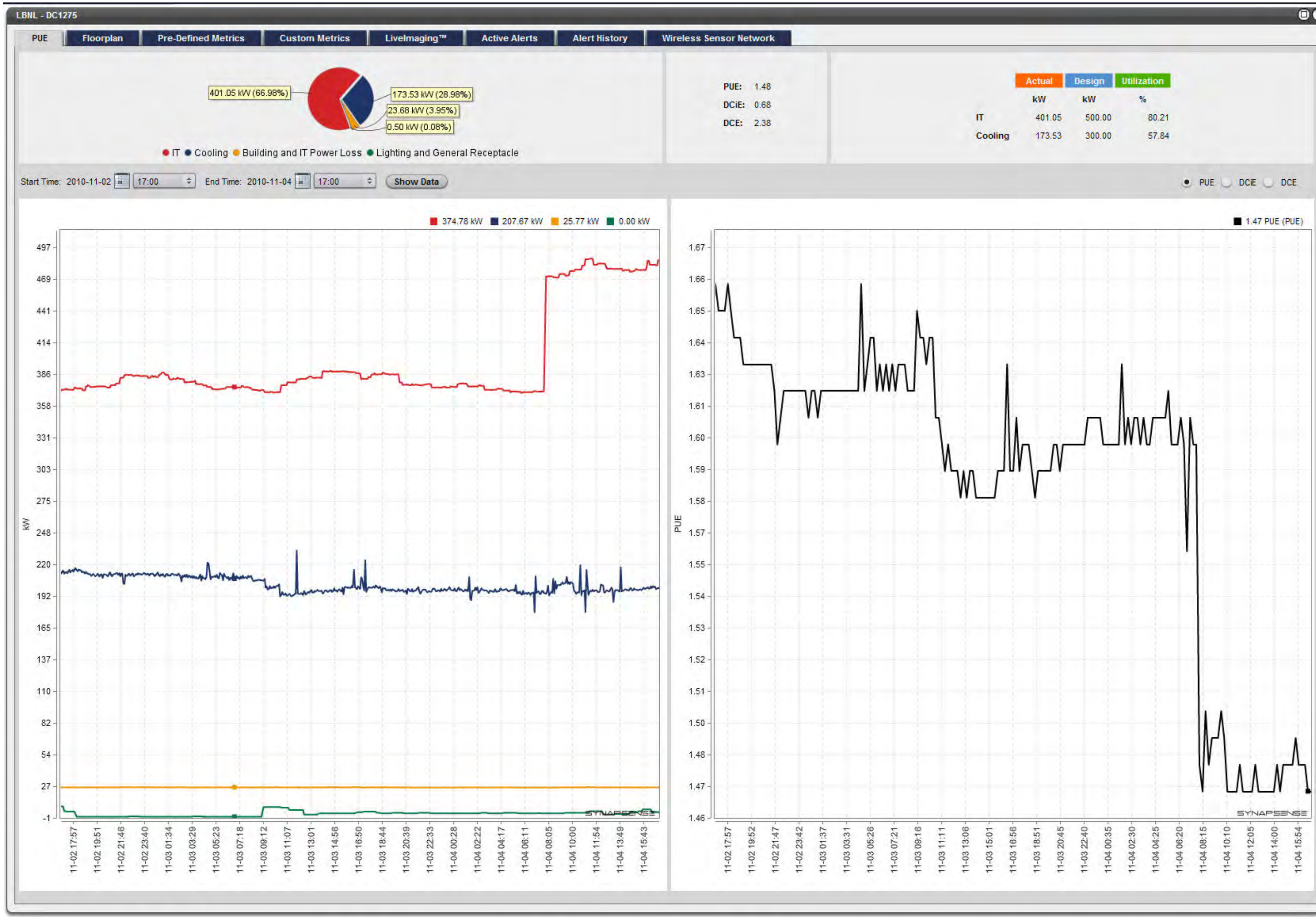
source: SynapSense

Visualization getting much better



SynapSense™

Real-time PUE Display



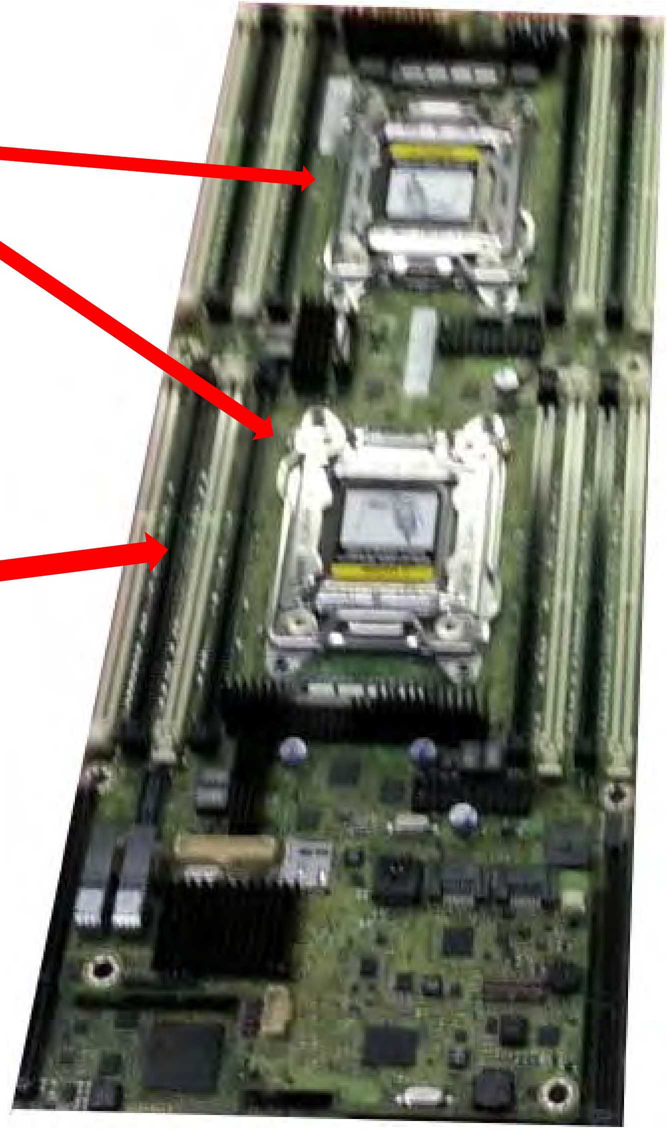
Environmental conditions: Safe Temperature Limits

CPUs

~65C
(149F)

Memory

~85C
(185F)



GPUs

~75C
(167F)

So why do we need jackets in data centers?

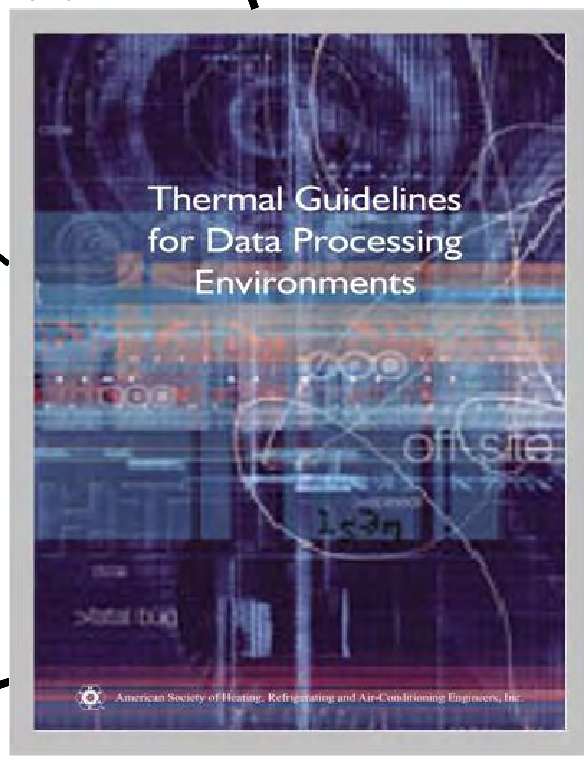
CPU, GPU & Memory, represent ~75-90% of heat load …

ASHRAE Thermal Guidelines
The defacto standard in the industry

Provides common understanding between IT and facility staff.

Developed with IT manufacturers

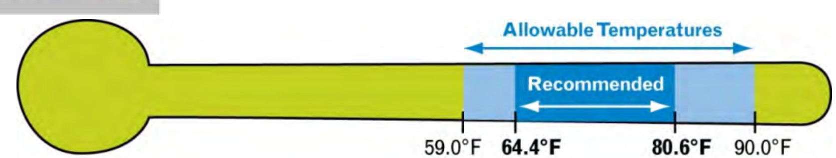
Recommends temperature range up to 80.6°F with “allowable” much higher.



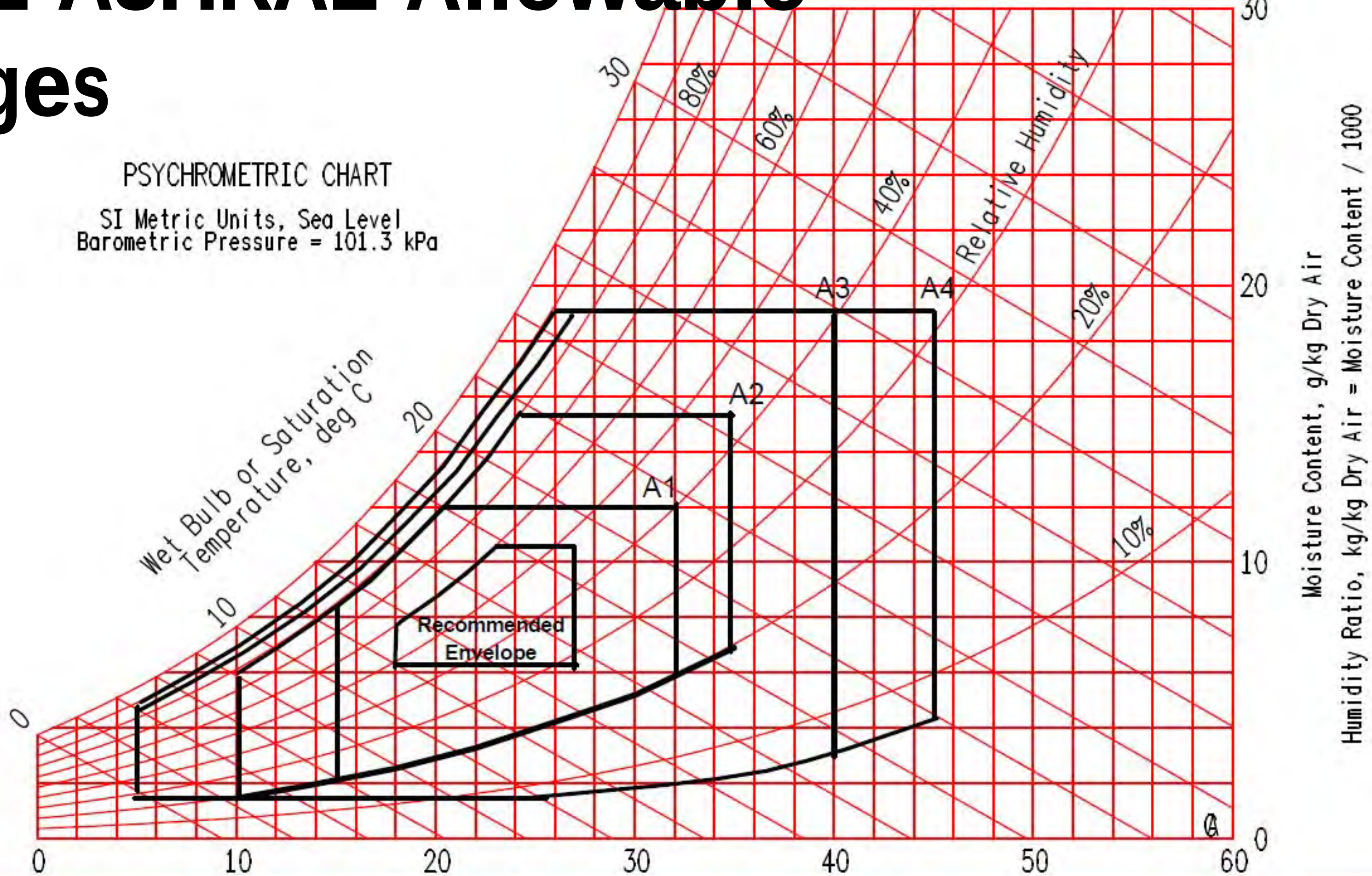
Six classes of equipment identified with wider allowable ranges to 45° C (113°F).

Provides more justification for operating above the recommended limits

Provides wider humidity ranges



2011 ASHRAE Allowable Ranges



Dry Bulb Temperature

2011 ASHRAE Thermal Guidelines

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 by 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)

Air Management: The Early Days

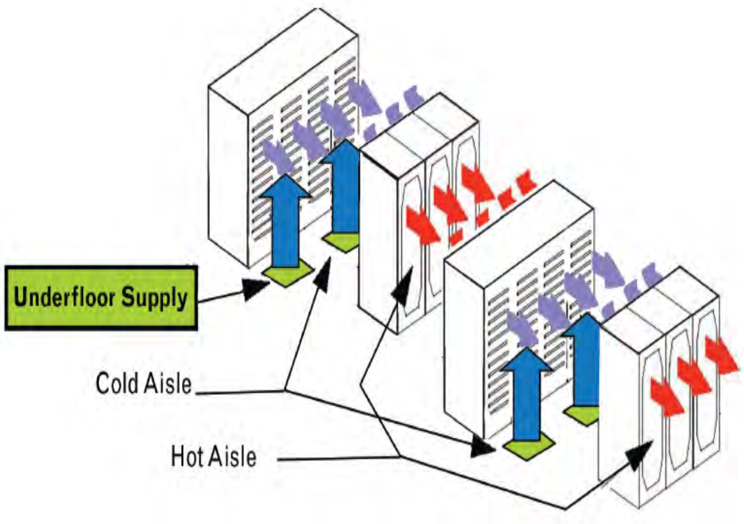
It was cold but hot spots were everywhere

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



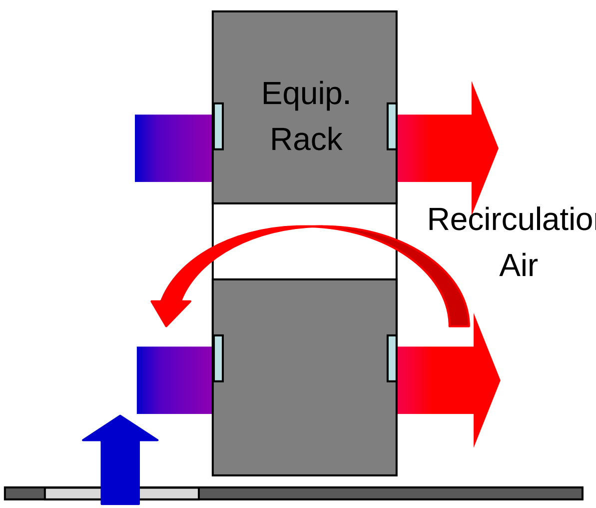
Hot aisle / cold aisle configuration decreases mixing of intake & exhaust air, promoting efficiency.

Air Management Improvement Effort:

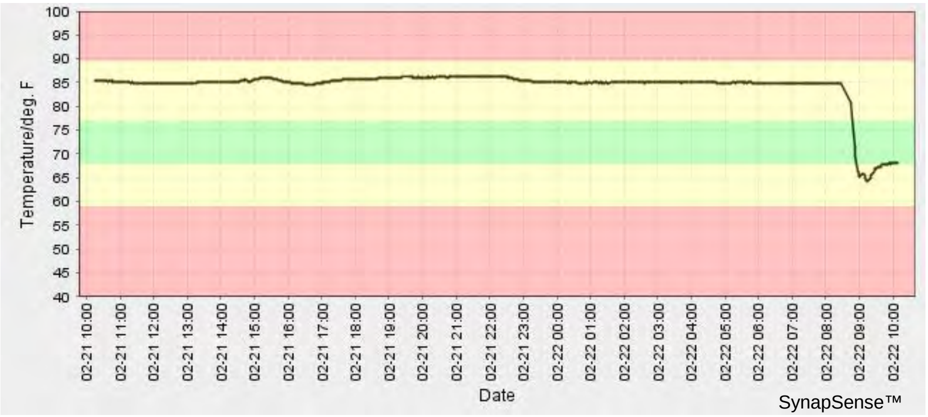
- Performed CFD
- Deployed wireless monitoring system
- Identified opportunities for improvement
  - Enforce hot aisle/cold aisle arrangement
  - Use blanking panels
  - Improve airflow and under floor pressure by tuning floor tiles
  - Reduce mixing and short circuits
  - Convert overhead plenum to hot-air return
  - Extend CRAC intakes into overhead
  - Add air curtains to improve isolation

Results: Blanking Panels

One 25 cm blanking panel reduced temperature ~11°C

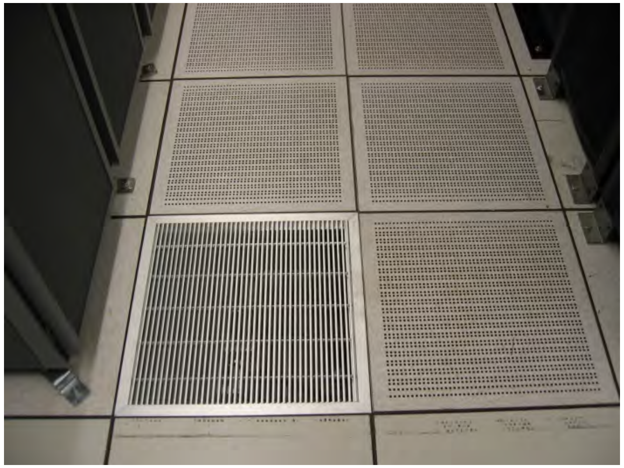


top of rack

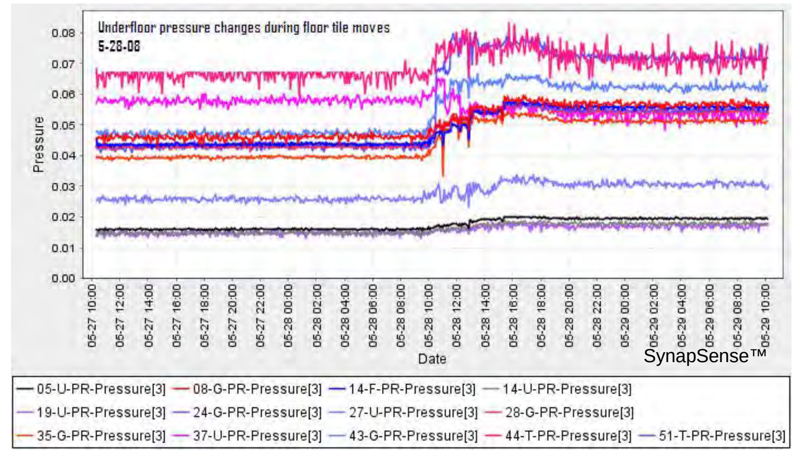


middle of rack

Results: Tune Floor Tiles

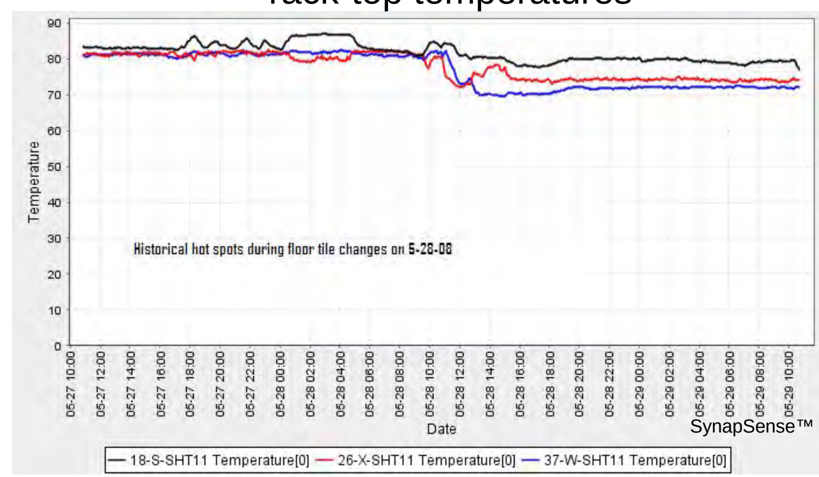


under-floor pressures



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

rack-top temperatures



Improve Air Management:

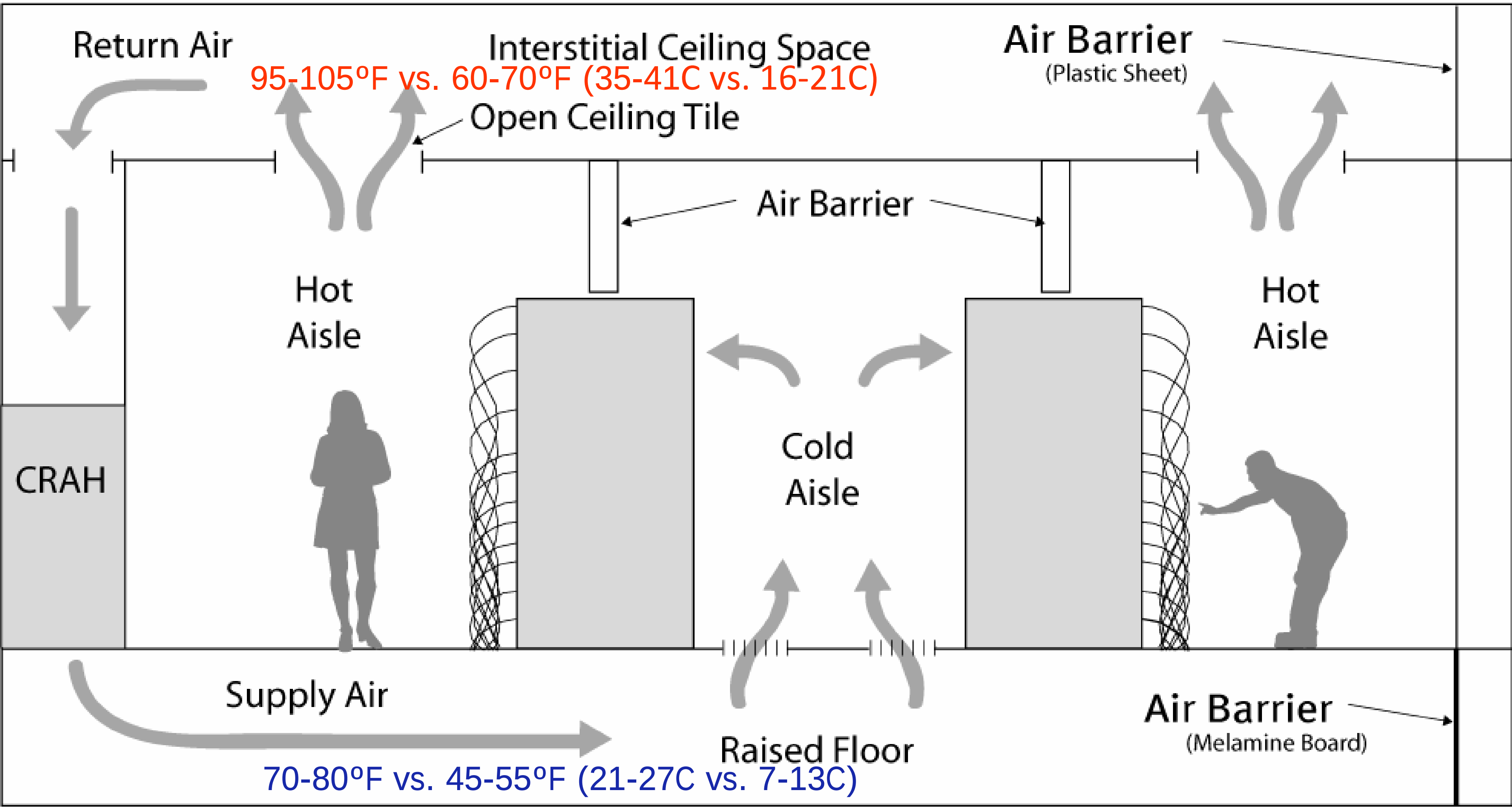
- Overhead plenum converted to hot-air return
- CRAC intakes extended to overhead
- Return registers placed over hot aisle

Before

After

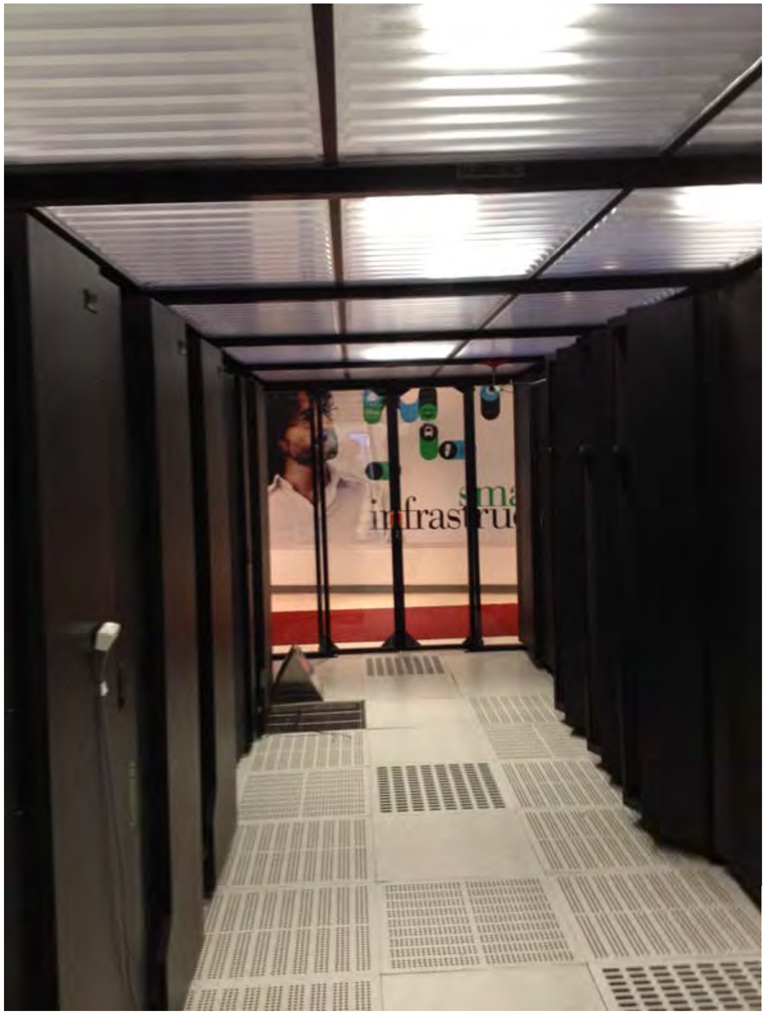
Adding Air Curtains for Hot/Cold Isolation

Isolate Cold and Hot Aisles



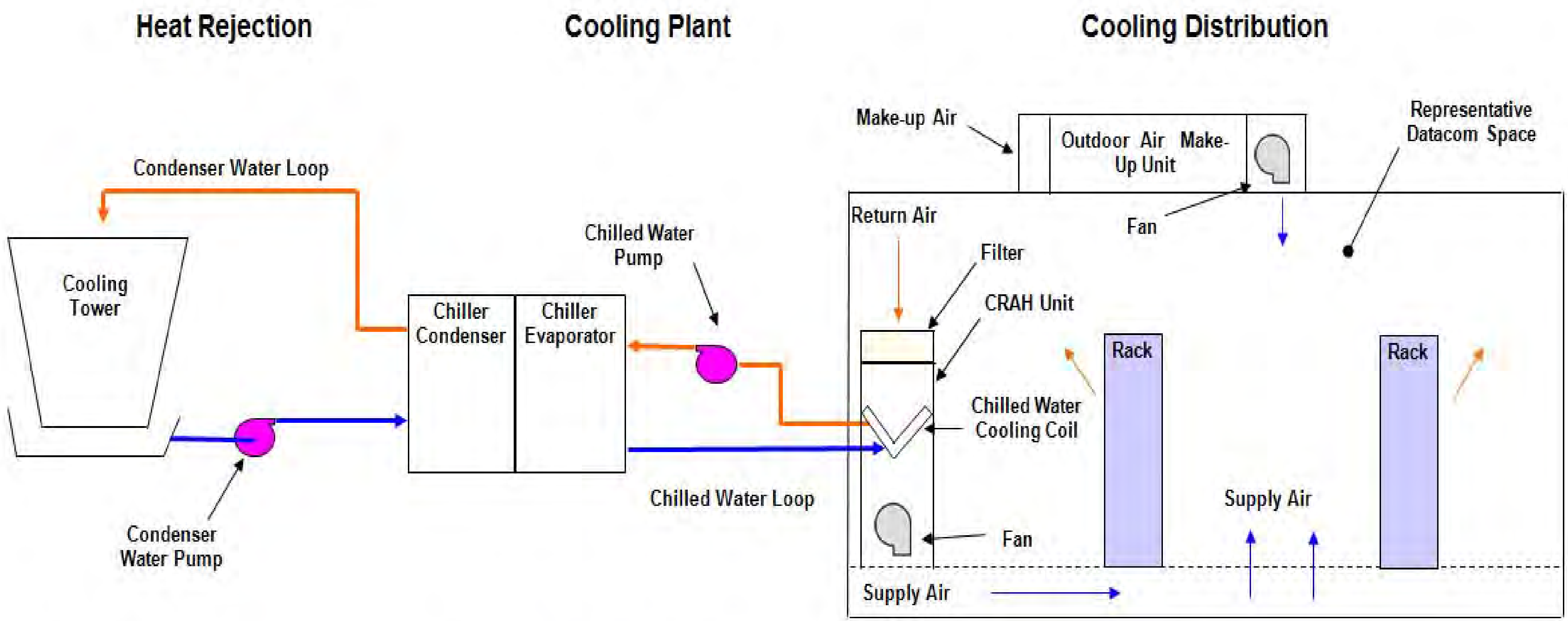
Hot and Cold Aisle Containment

Subzero Cold Aisle Containment



APC Hot Aisle Containment
(with in-row cooling)

Cooling 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)

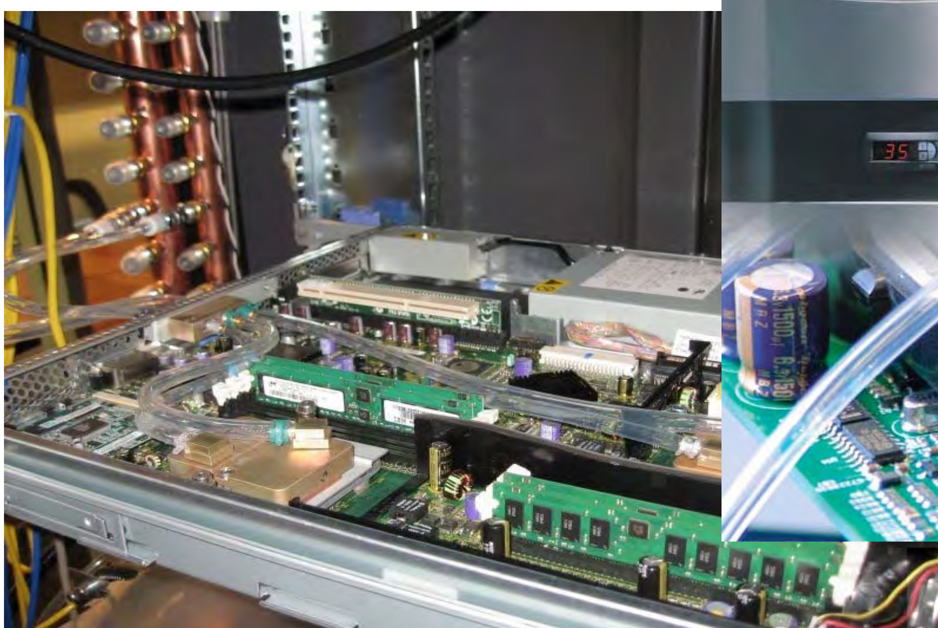
Low Eff

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

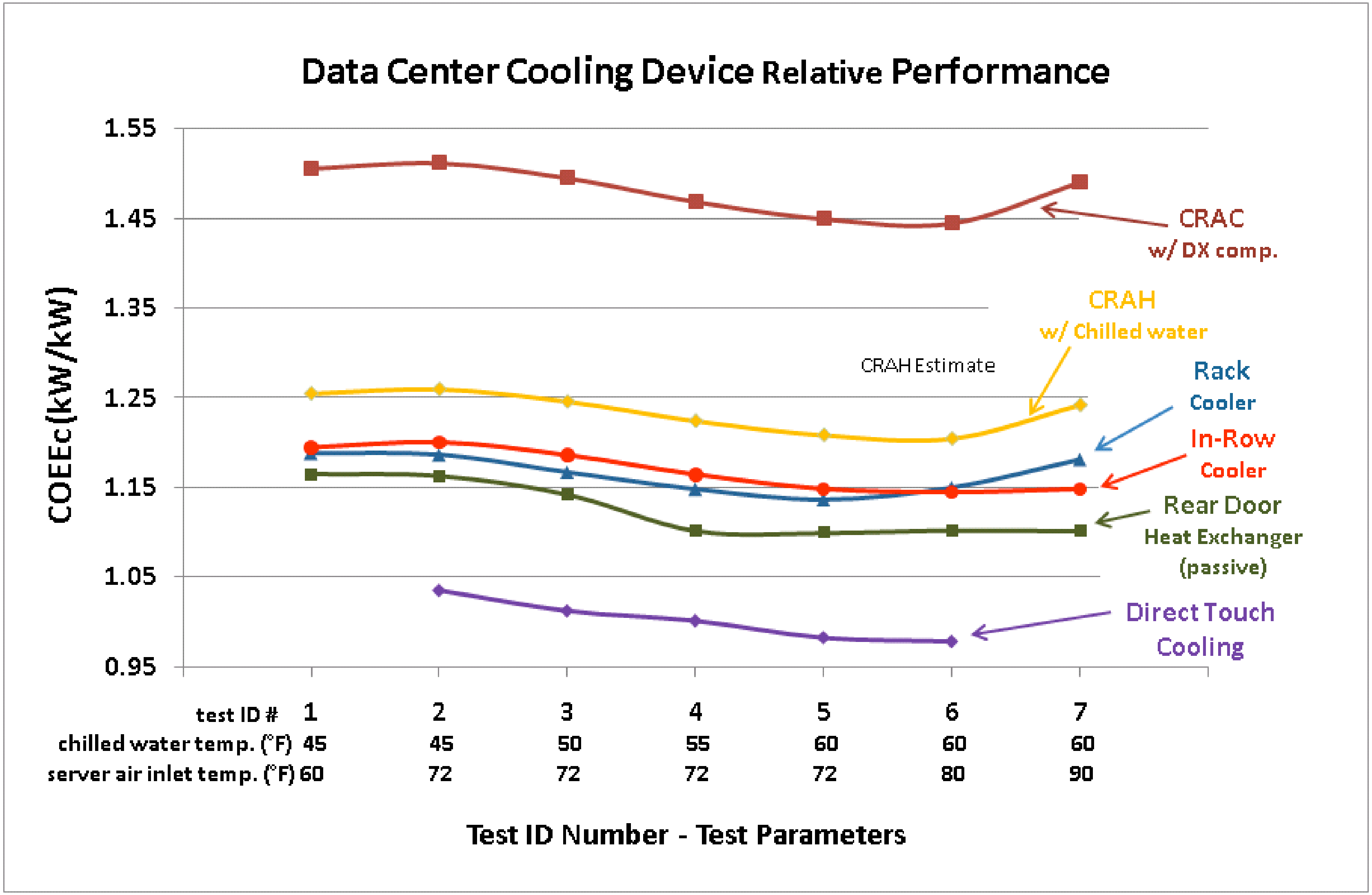
- **CRAC units**
  - Fan, direct expansion (DX) coil, and refrigerant compressor.
- **CRAH units**
  - Fan and chilled water coil
  - Typically in larger facilities with a chiller plant
- **Both often equipped with humidifiers and reheat for dehumidification**
- **Often independently controlled**
  -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

Liquid Based Cooling

- Liquid is much more efficient than air for heat transfer



"Chill-off 2" evaluation of liquid cooling solutions



Use Free Cooling:

Cooling without Compressors

- Water-side Economizers
- Outside-Air Economizers

➢ Let's get rid of chillers in data centers

Water-Side Economizers

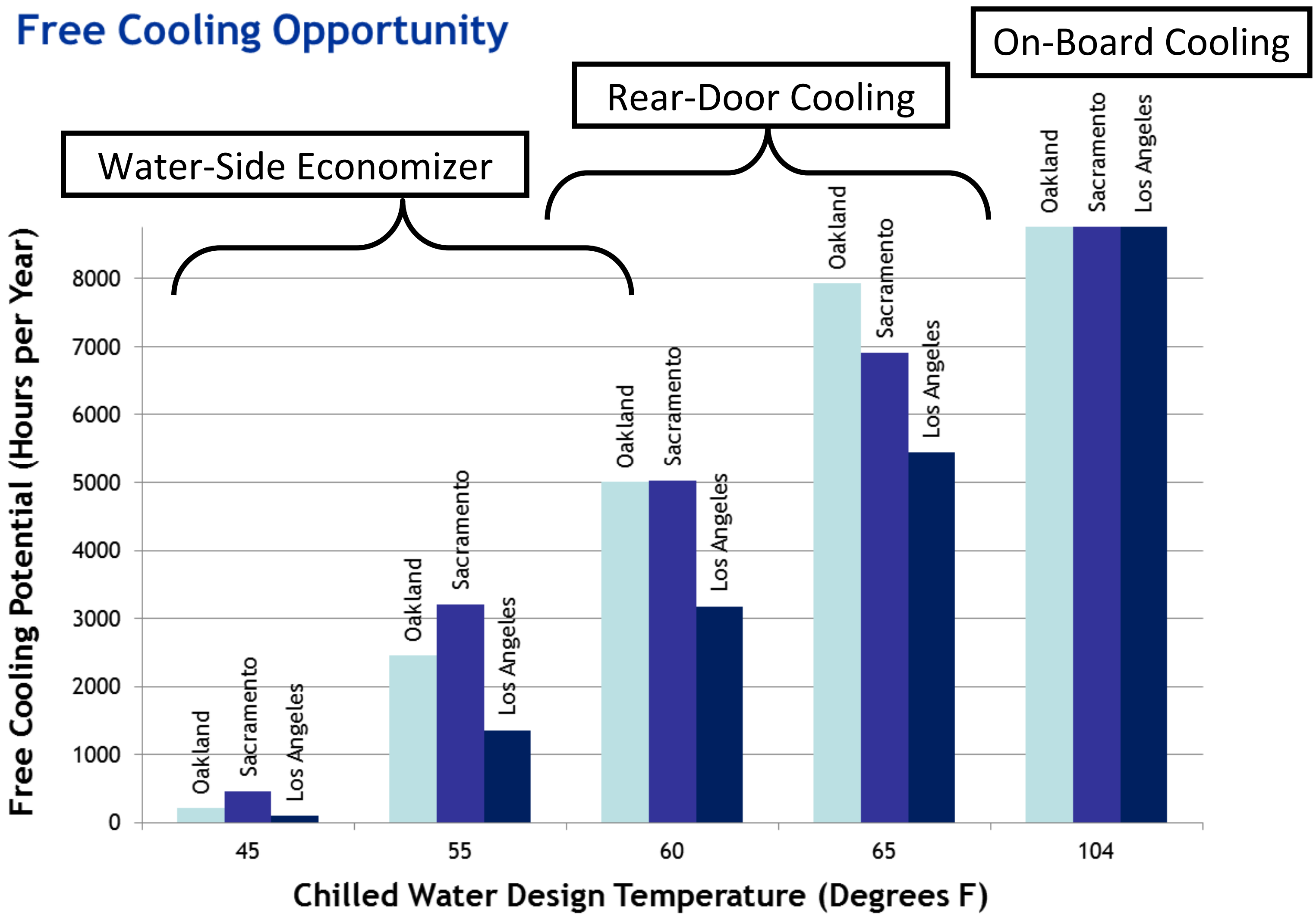
Advantages

- Liquid more efficient for heat transfer
- Easier retrofit
- Added reliability (backup in the event of chiller failure)
- No contamination questions
- Put in series with chiller

LBNL Example: Rear Door Cooling

- **Used instead of adding CRAC units**
- **Cooling with tower-only or chiller assisted**
  - **Both options significantly more efficient than existing direct expansion (DX) CRAC units.**

Potential for Tower Cooling



Reuse of Waste Heat

- Heat from Data Center can be used for:
  - Heating adjacent offices directly
  - Preheating make-up air (e.g. “run around coil” for adjacent laboratories)
- Use heat pump to elevated temperature
  - Waste heat from LBNL ALS servers captured with rear door coolers feeds heat pump providing hot water for reheat coils
- Warm water cooled computers used to heat:
  - Greenhouses, swimming pools, and district heating systems in Europe

Improve Humidity Control:

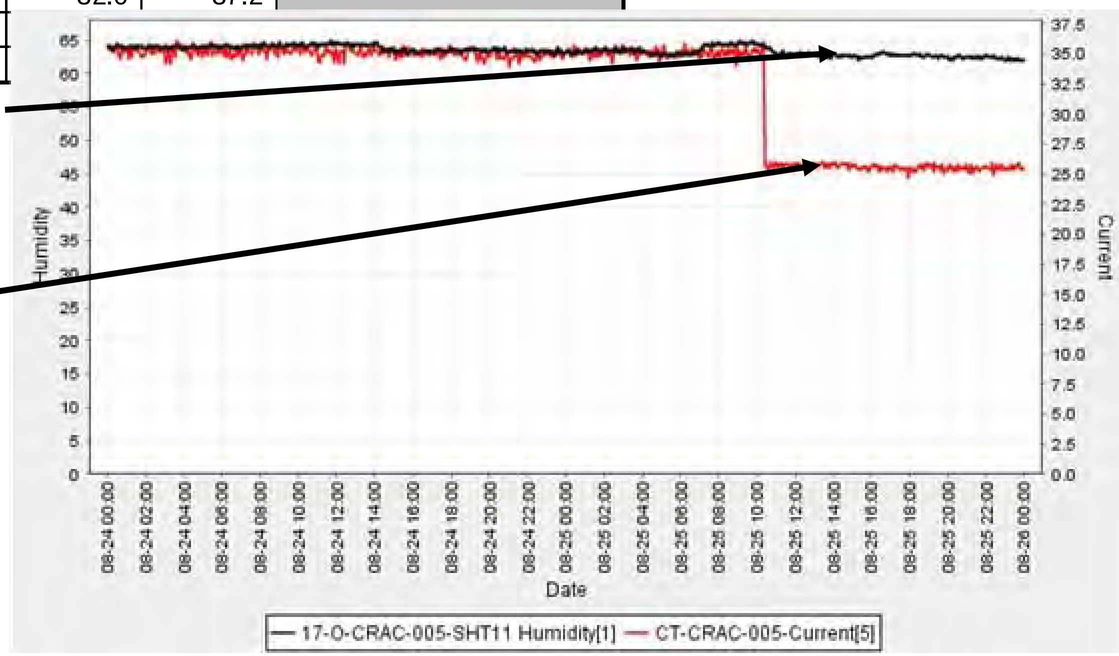
- Eliminate inadvertent dehumidification
  - Computer load is sensible only
- Use ASHRAE allowable RH and temperature
  - Many manufacturers allow even wider humidity range
- Eliminate equipment fighting
  - Coordinate controls
  - Turn off

The Cost of Unnecessary Humidification

	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			
Avg	79.2	31.7	46.4	68.8			

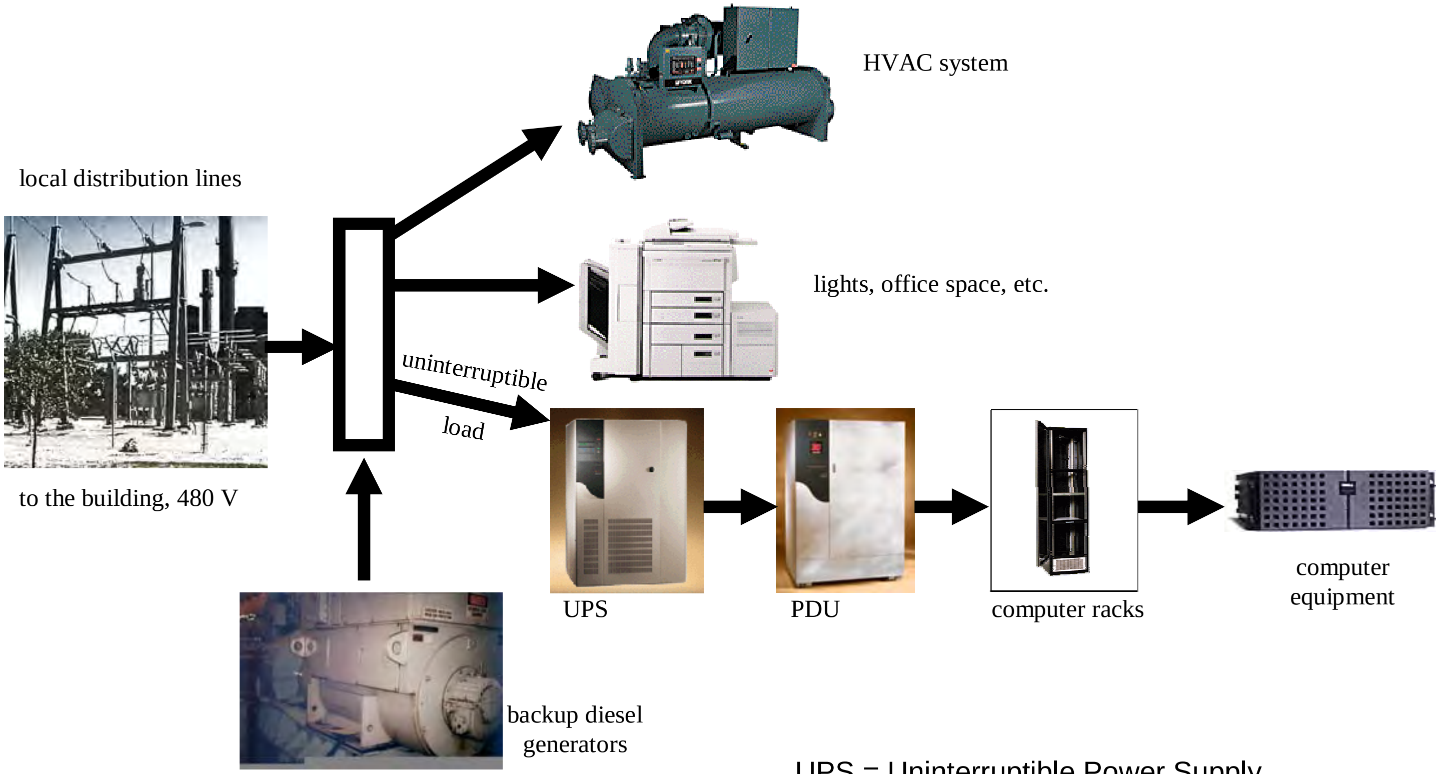
Humidity down 3%

CRAC power down 28%



Power Chain Conversions Waste Energy

Electricity Flows in Data Centers

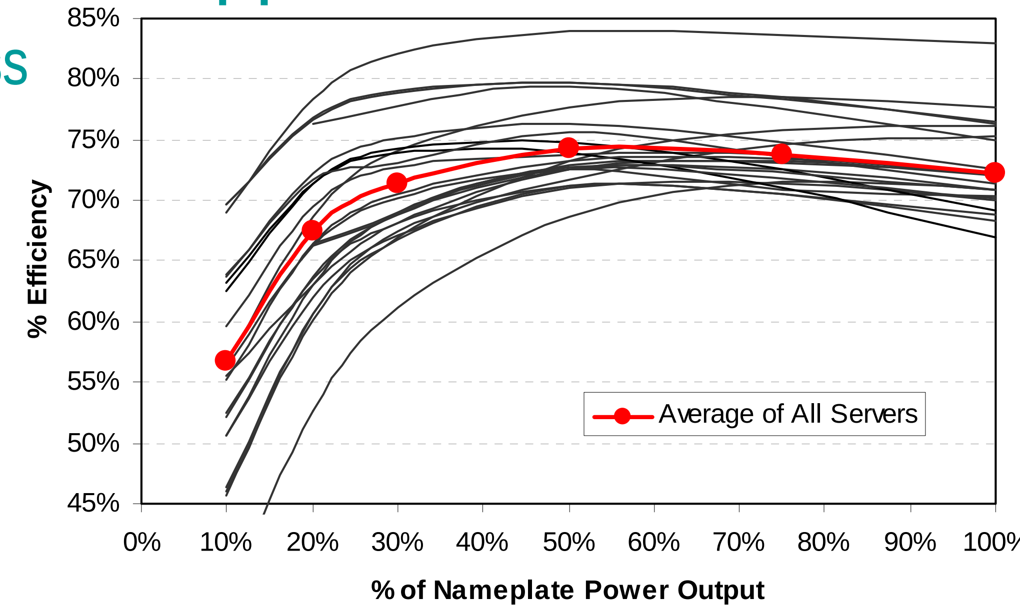


UPS = Uninterruptible Power Supply

PDU = Power Distribution Unit;

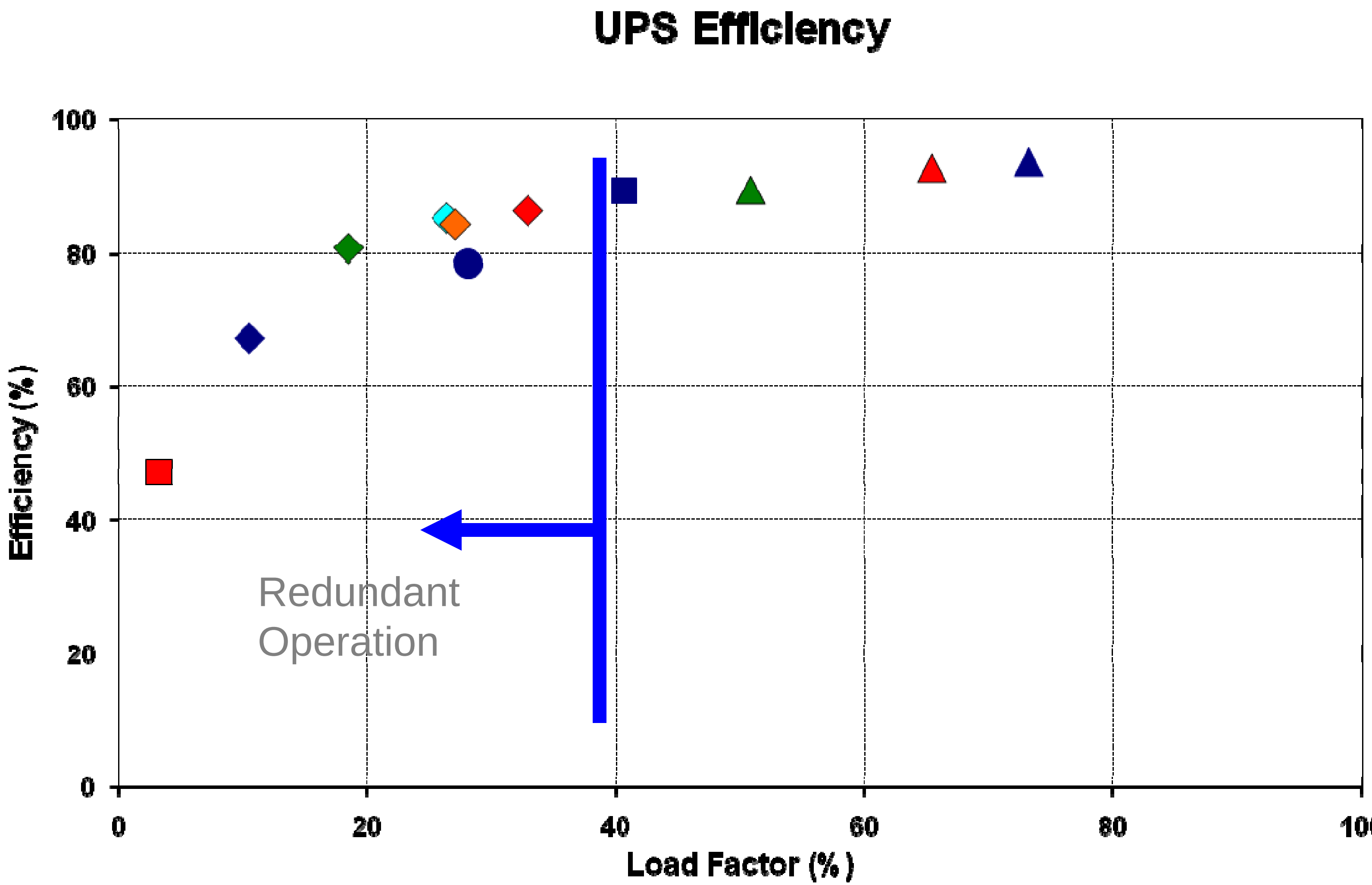
Improving the Power Chain:

- Increase distribution voltage
  - NERSC going to 480 volts to the racks
- Improve equipment power supplies
  - Avoid redundancy unless needed



- Improve UPS
  - LBNL uses minimal UPS
  - Selected to minimize losses

Measured UPS Efficiency



Redundancy

- Understand what redundancy costs – is it worth it?
- Different strategies have different energy penalties (e.g. 2N vs. N+1)
- Redundancy in electrical distribution puts you down the efficiency curve
- Redundancy in the network rather than in the data center
- LBNL minimizes use of redundant power supplies and size of UPS

Improve Design and Operations Processes:

- Get IT and Facilities people working together
- Use life-cycle total cost of ownership analysis
- Document design intent and provide training
- Benchmark and track existing facilities
- Eat your spinach (blanking panels, leaks, CRAC maintenance)
- Re-commission regularly as part of maintenance
- Keep an eye on emerging technologies (flywheel UPS, rack-level cooling, DC power) and work with vendors to improve efficiency

Results at LBNL's Legacy Data Center

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

Next Steps for LBNL's Legacy Data Center

- Integrate CRAC controls with wireless monitoring system
  - Demand based resets of pressure and temperature
- 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)

Resources

Advanced Manufacturing Office

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

Federal Energy Management Program

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

GSA

- Workshops
- Quick Start Efficiency Guide
- Technical Assistance

EPA

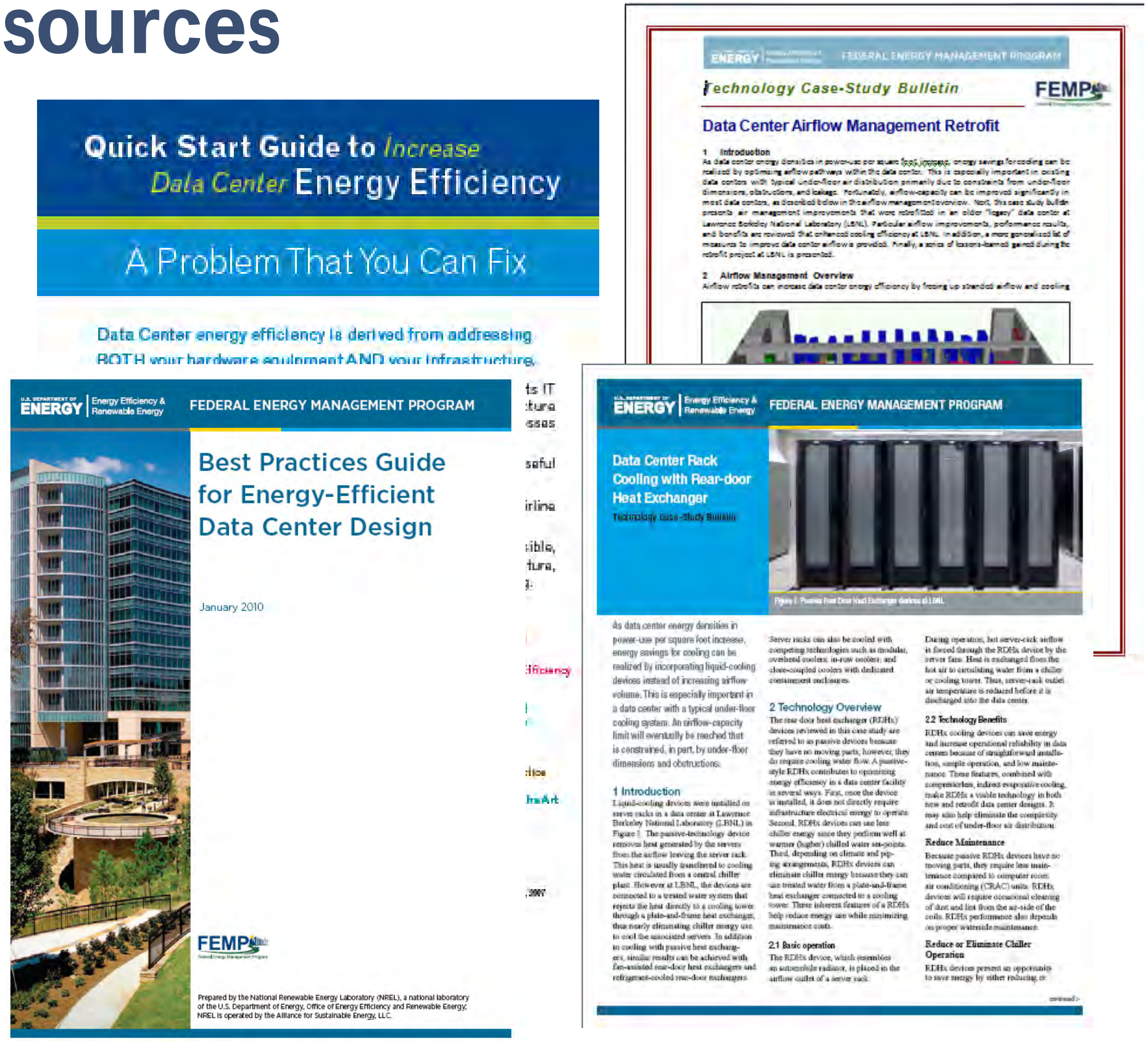
- Metrics
- Server performance rating & ENERGY STAR label
- Data center benchmarking

Industry

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

Data Center Resources

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



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

Resources

Federal Energy Management Program http://www1.eere.energy.gov/femp/program/data_center.html

Berkeley Lab http://hightech.lbl.gov/datacenters.html

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

Save Energy Now® http://www1.eere.energy.gov/industry/datacenters/

Data Center Best Practices Summary

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

Data Center Best Practices

Most importantly…

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

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