Energy Efficiency for Business Technology

Sacramento Municipal Utility District

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Handouts

- You can get a copy of the handouts in PDF format as follows:
  - Enter the following link into your web browser:
    http://hightech.lbl.gov/training/dc-training.html
  - Look under “Past Trainings” for today’s talk

Introduction

- Who are you?
  - Facility Operations
  - Facility Engineering
  - IT
  - Consultant
  - Contractor
  - Vendor
  - Other
- What brings you here?

Course objectives

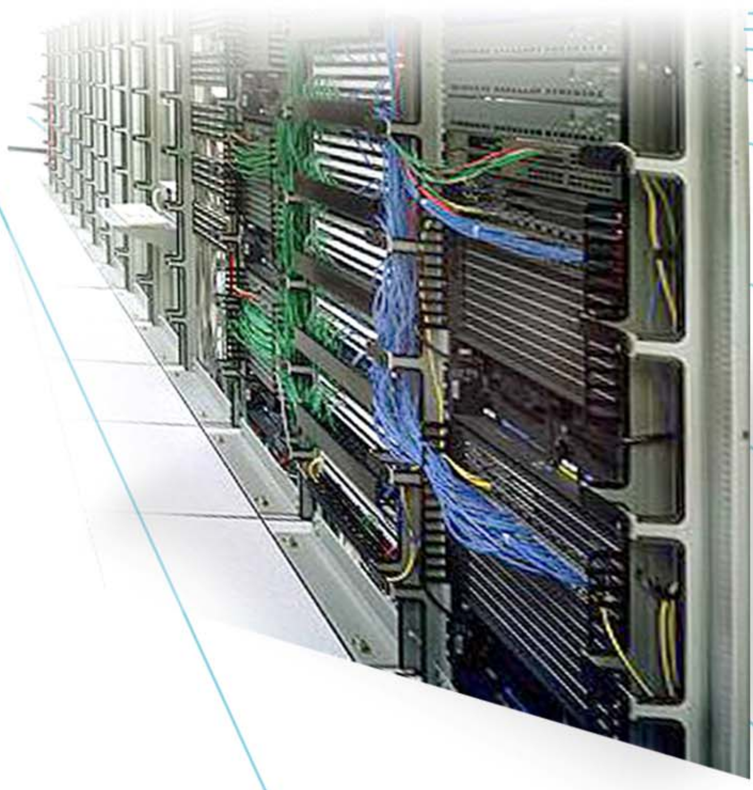
- Raise awareness of data center energy efficiency opportunities
- Provide resources for on-going use
- Group interaction for common issues and possible solutions

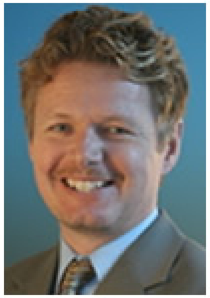
What we will cover

- Major energy use in data centers
- Opportunities to increase computational efficiency and the multiplier effect
- Energy intensity growth
- Benchmarking
- Best practices to improve infrastructure efficiency
- Extending the life and effective capacity of existing data centers
- Technologies coming down the R&D pipeline and lessons learned from demonstrations
- Government programs
- Information and technical assistance resources

Agenda

Topic	Speaker
Intro and IT Opportunities	Mark Bramfitt
Overview and Benchmarking	Steve Greenberg
Environmental Conditions	Steve Greenberg
Air System Design	Peter Rumsey
Break	
Free Cooling	Peter Rumsey
Liquid Cooling	Peter Rumsey
Lunch	
Central Plants	Peter Rumsey
Controls & CX	Peter Rumsey
Break	
Electrical Systems	Steve Greenberg
Government Programs	Steve Greenberg
Assessment Tools and Protocols	Steve Greenberg
Resources	Steve Greenberg





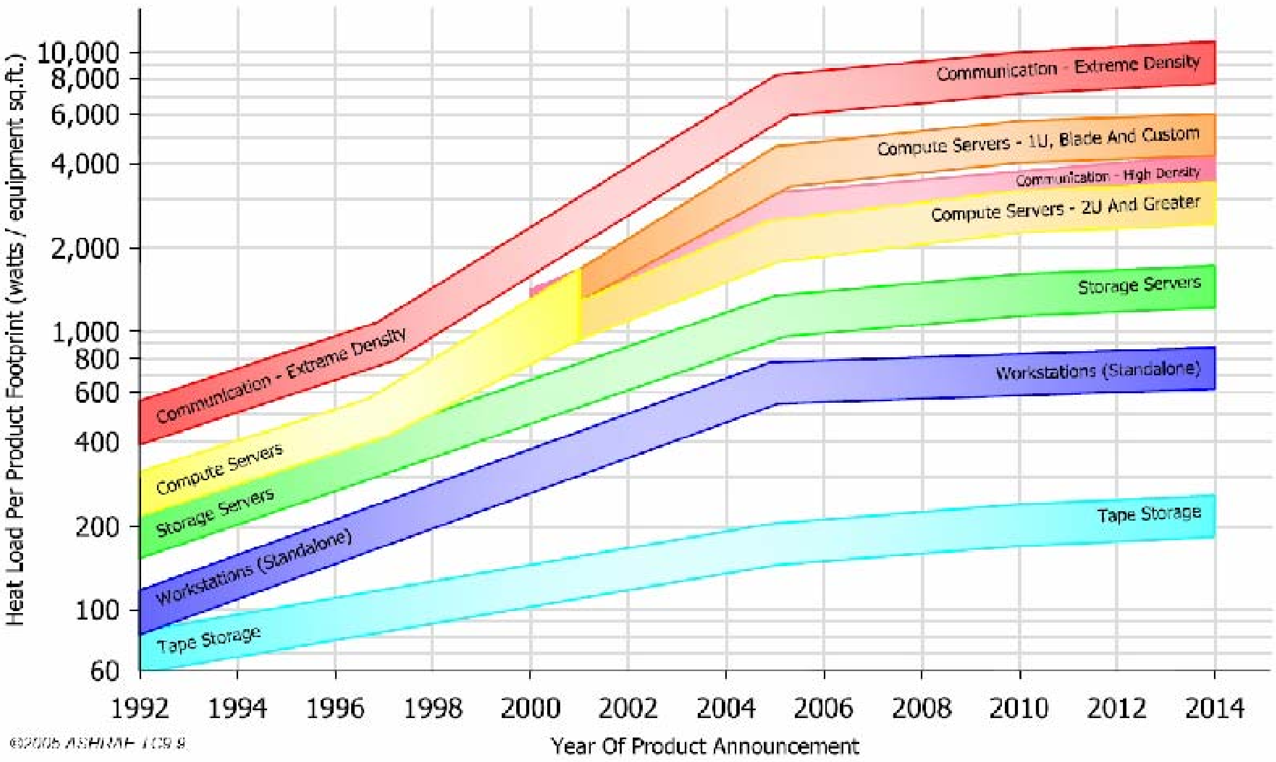
IT Equipment Efficiency

Mark Bramfitt, PE

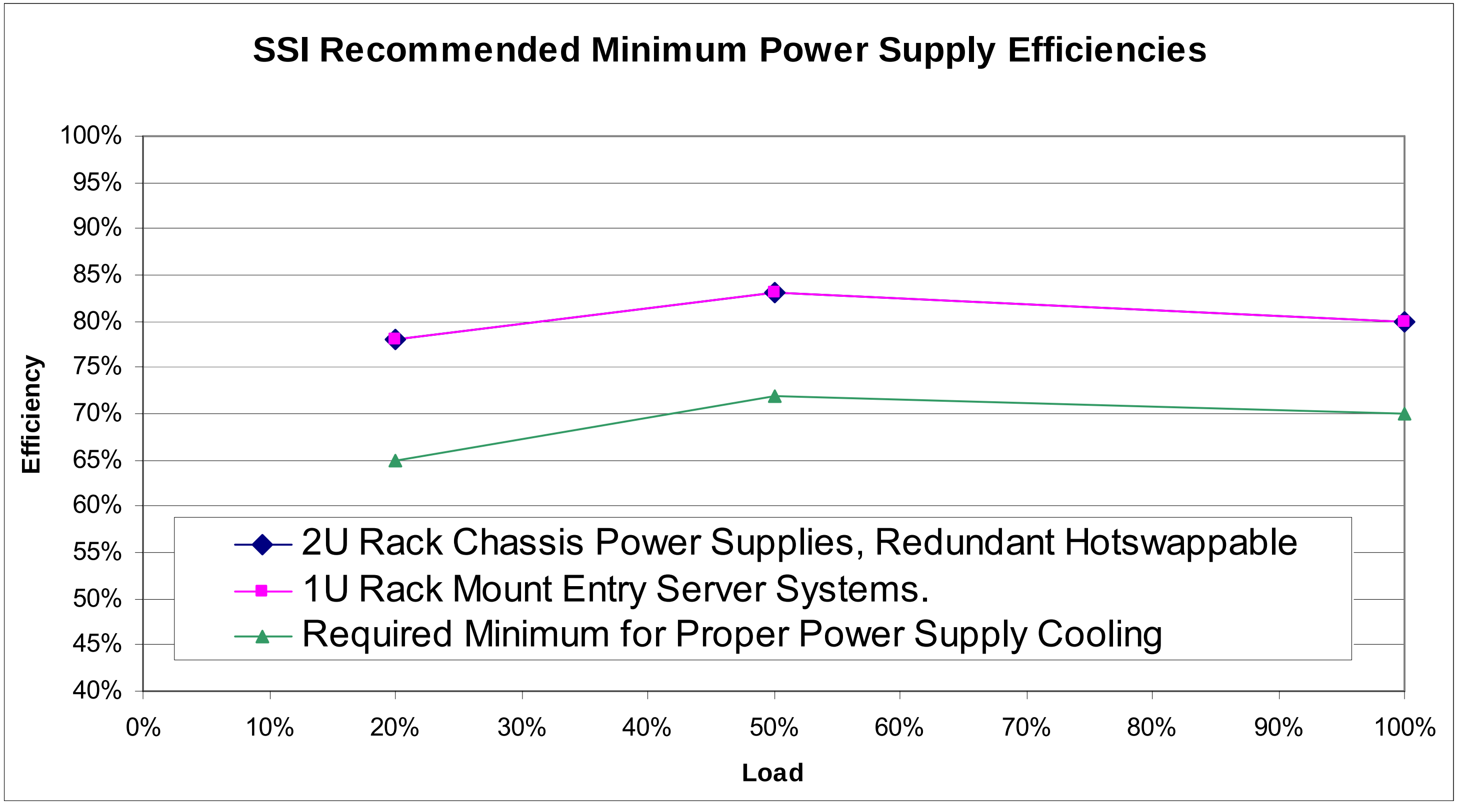
IT equipment load

- Predicting IT loads
  - Over sizing, at least initially, is common
  - Implement modular and scalable approaches
  - Over sizing of IT can lead to inefficiencies in electrical and mechanical system and higher installed system costs
- IT loads can be controlled
  - Power supply options
  - Server efficiency
  - Software efficiency (Virtualization, MAID, etc.)
  - Redundancy and back-up power
  - Low power modes
- Reducing IT load has a multiplier effect

ASHRAE prediction of intensity trend



Efficient power supplies



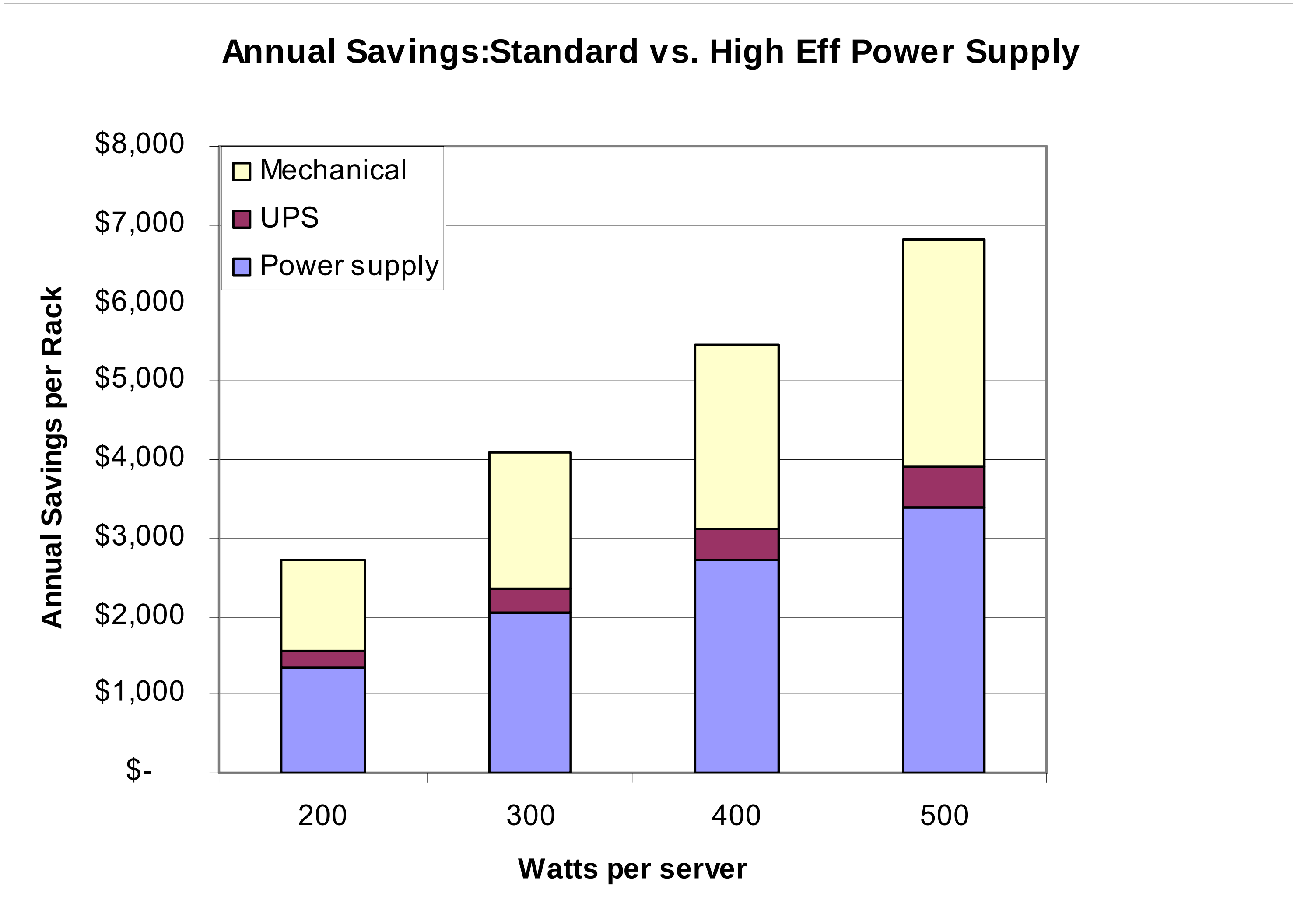
Server System Infrastructure (SSI) Initiative (SSI members include Dell, Intel, and IBM)

Power supply, per server savings

Power Supplied Per Server (Watts)	Annual Savings Using a SSI Recommended Minimum Efficiency Supply[1]	Annual Savings Including Typical Cooling Energy[2]
200	$ 37	$ 65
300	$ 56	$ 97
400	$ 74	$ 130
500	$ 93	$ 162

- 1. Assuming $0.10/kWh, 8760 hr/yr, 85% efficient UPS supply, 72% efficiency baseline PS
- 2. Cooling electrical demand is estimated 75% of rack demand, the average ratio of 12 benchmarked datacenter facilities

Power supply savings add up

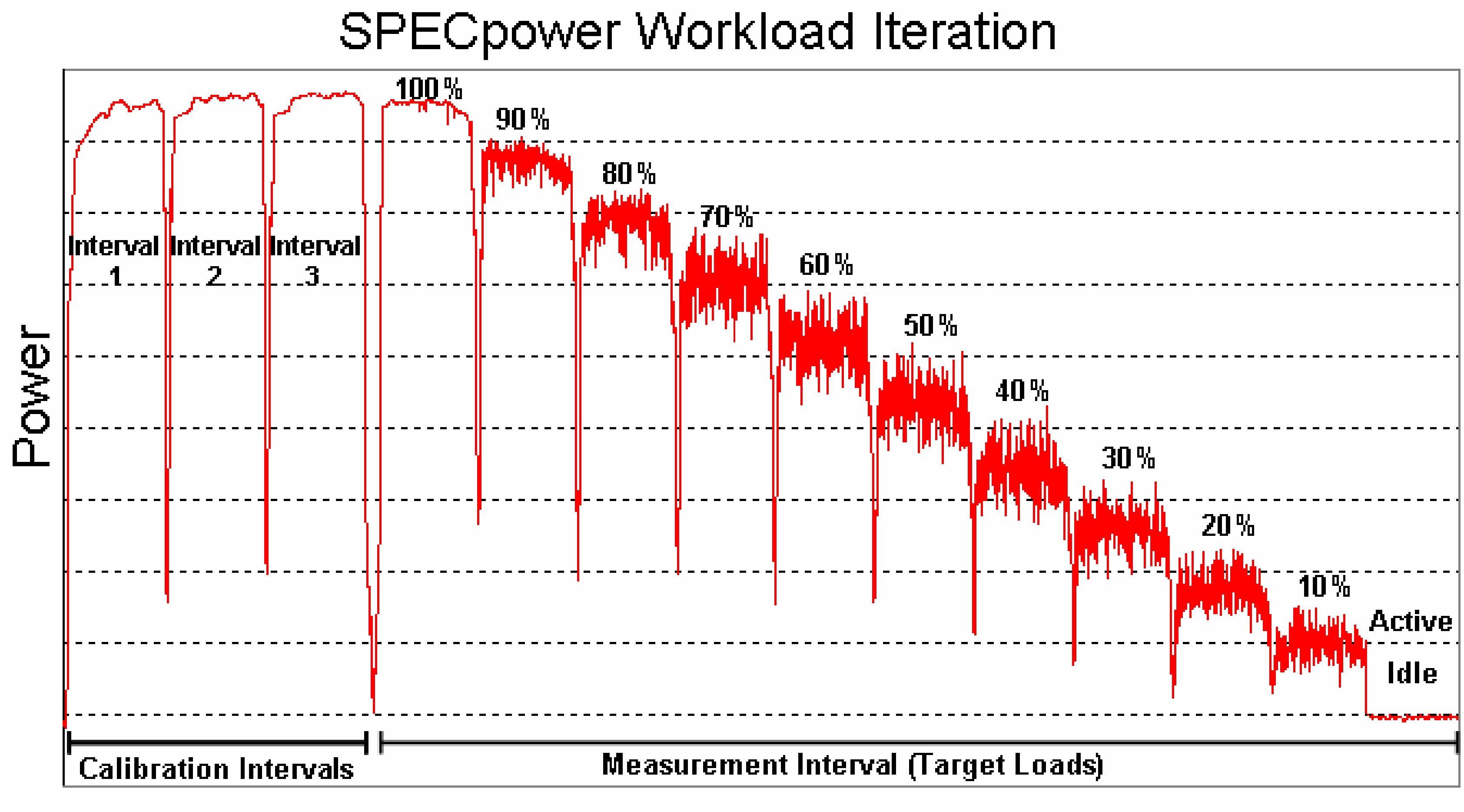


High efficiency servers

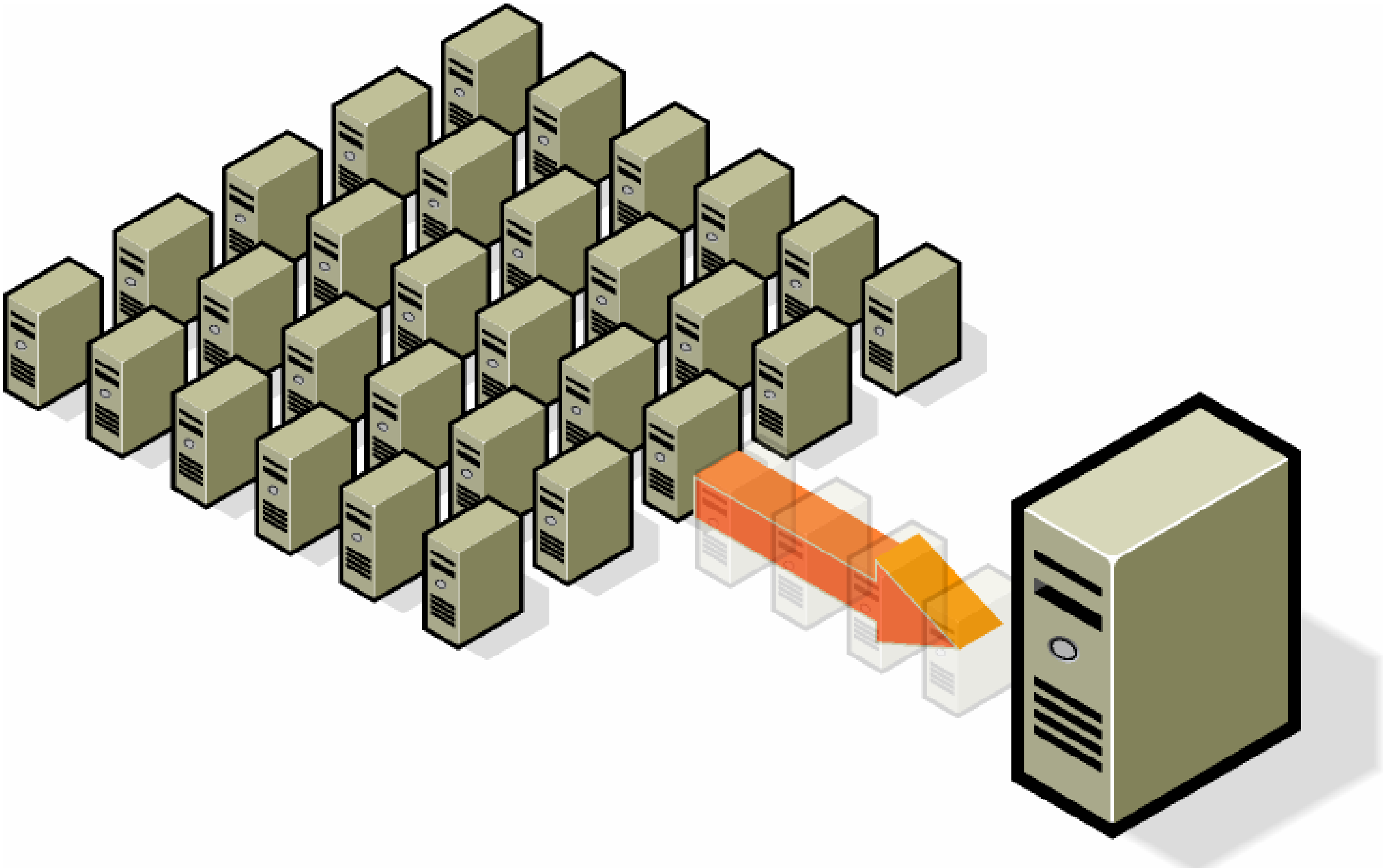
Energy savings and potential utility incentive for installation of **three** new High Efficiency Servers.

	Baseline Usage	Installed Usage	Energy Savings	Electric Cost Savings	PG&E Incentive	Incremental Installation Cost
	kWh/yr	kWh/yr	kWh/yr	$/yr	$	$
Install High Efficiency Servers - Direct Energy Savings	24,538	4,941	19,598	$ 2,352	$ 1,960	n/a
Install High Efficiency Servers - Indirect HVAC Savings	9,003	1,813	7,190	$ 863	$ 1,007	n/a
Combined	33,541	6,753	26,788	$ 3,215	$ 2,967	n/a

Coming soon - power performance metrics e.g. Standard Performance Evaluation Corp (SPEC)



Server virtualization



Server virtualization

- Energy savings and potential utility incentive for Server Virtualization.
- Number of servers before virtualization: 50.
- Number of servers after virtualization: 30.

	Baseline Usage	Installed Usage	Energy Savings	Electric Cost Savings	PG&E Incentive	Total Installation Cost
	kWh/yr	kWh/yr	kWh/yr	$/yr	$	$
Install Virtual Server - Direct Energy Savings	98,550	59,130	39,420	$ 4,730	$ 3,154	$ 70,000
Install Virtual Server - Indirect Equipment Support Savings	60,636	36,382	24,254	$ 2,911	$ -	$ -
Combined	159,186	95,512	63,674	$ 7,641	$ 3,154	$ 70,000

Thin clients

- Typical Desktop Computer, 75 – 100 Watts, $500
- Typical Laptop Computer, 10 – 15 Watts, $1,000
- Typical Thin Client, 4 – 6 Watts, $300

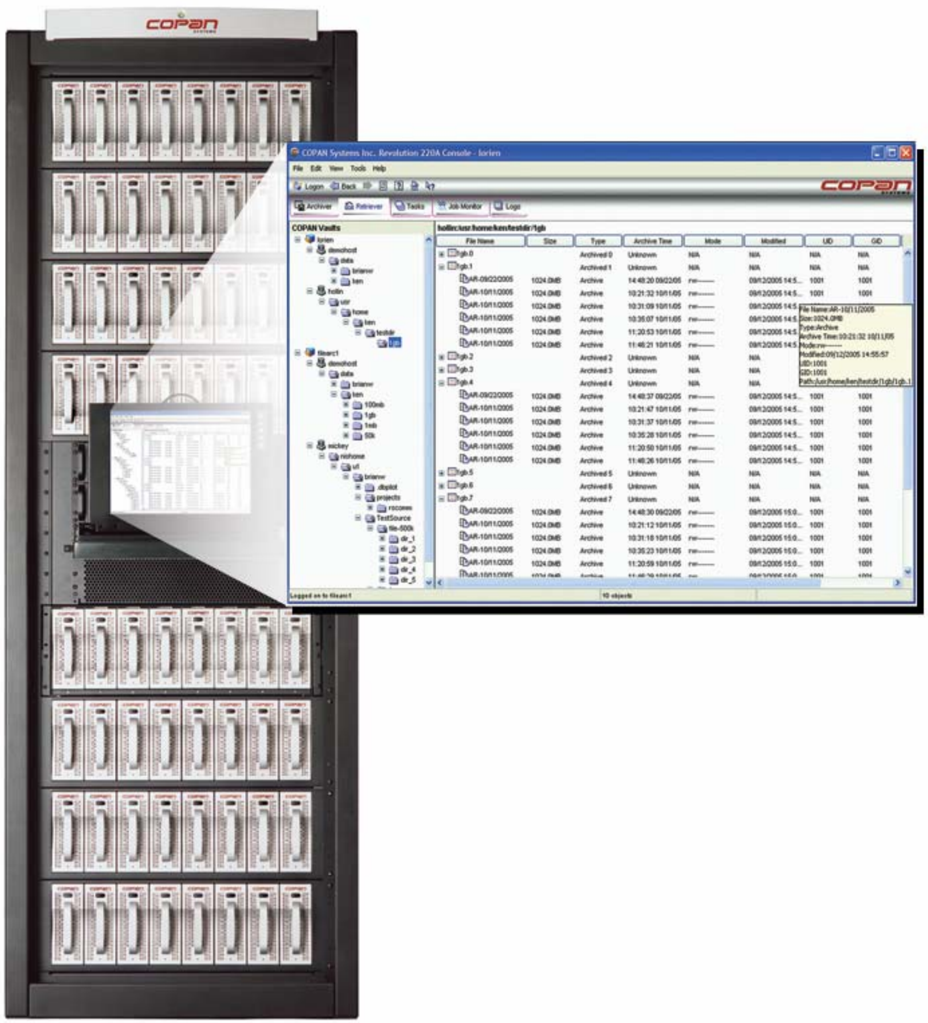
Thin clients

- Energy savings and utility incentive for implementation of a Thin Client network.
- Replace 50 generic workstations with 50 Thin Client terminals.

	Baseline Usage	Installed Usage	Energy Savings	Electric Cost Savings	PG&E Incentive	Total Installation Cost
	kWh/yr	kWh/yr	kWh/yr	$/yr	$	$
Install Thin Client Computers - Direct Energy Savings	35,040	15,626	19,414	$ 2,330	$ 1,553	$ 25,000
Install Virtual Server - Indirect HVAC Savings	12,856	5,733	7,123	$ 855	$ -	$ -
Combined	47,896	21,359	26,537	$ 3,184	$ 1,553	$ 25,000

Massive array of idle disks (MAID)

- MAID is designed for Write Once, Read Occasionally (WORO) applications.
- In a MAID each drive is only spun up on demand as needed to access the data stored on that drive.



Massive array of idle disks (MAID)

- Energy savings and possibly utility incentive for installation of a MAID system.
- Install one fully-loaded MAID cabinet with a total storage capacity of 448TB in lieu of a traditional cabinet of the same capacity.

	Baseline Usage	Installed Usage	Energy Savings	Electric Cost Savings	PG&E Incentive	Incremental Installation Cost
	kWh/yr	kWh/yr	kWh/yr	$/yr	$	$
Install Maid System - Direct Energy Savings	278,450	75,118	203,332	$ 26,551	$ 16,267	$ 224,000
Install Maid System - Indirect HVAC Savings	102,163	27,561	74,602	$ 9,742	$ 10,444	$ -
Combined	380,613	102,679	277,934	$ 36,293	$ 26,711	$ 224,000

The value of one watt saved at the server CPU

1 Watt at CPU

= 1.25 Watts at entry to server (80% efficient power supply)

= 1.56 Watts at entry to UPS (80% efficient power supply)

= 2.5 Watts including cooling (2.0 PUE)

= 22 kWh per year

= $2.20 per year (assuming $0.10/kWh)

= $6 of infrastructure cost (assuming $6/W)

- **Total Cost of Ownership (TCO) Perspective = $12.60 (assuming three year life of server)**
- **Typical added cost of 80 plus power supply $3 - $5.**
- **Typical value - $170 (assumes 15 Watts saved at power supply not CPU)**

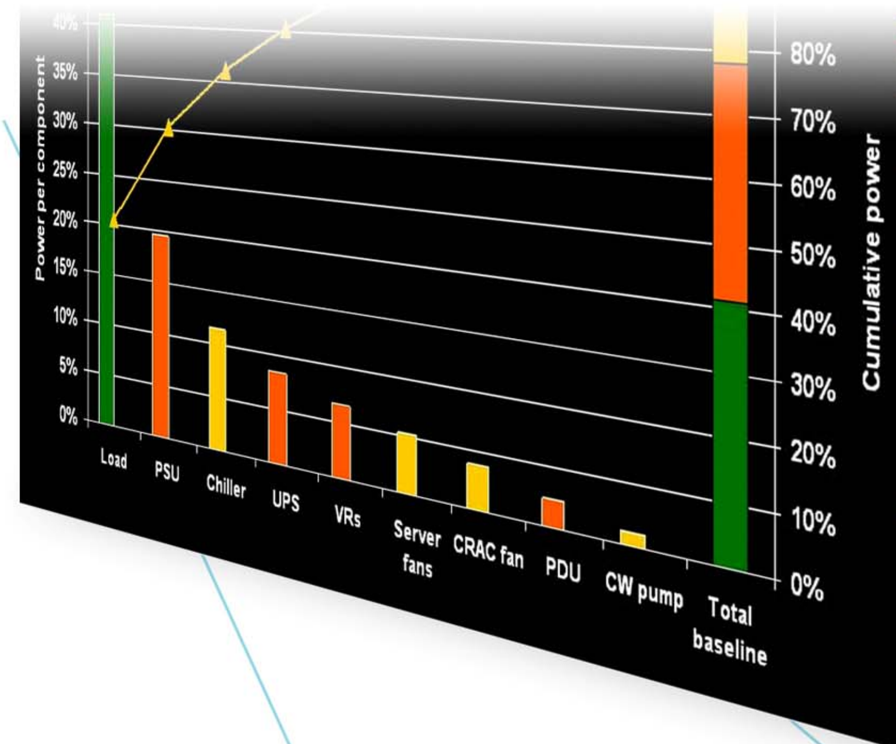
$$\text{Energy} \quad \frac{15w \times 2.0PUE \times \$0.10/kw \times 8{,}760hrs/yr}{1{,}000w/kW} \times 3yrs \approx \$80$$

$$\text{Infrastructure } 15\text{w} \times \$6/\text{watt} = \$90$$

$$\text{Total } \$80 + \$90 = \$170$$

IT take aways

- Efficient power supplies have large annual savings
- Efficient power supplies reduce infrastructure power consumption
- Efficient servers are orders of magnitude more efficient than older equipment
- Public utility incentives may be available
- Virtualization can eliminate many servers
- Thin clients are economical and great energy savers
- Software to limit spinning discs has large promise
- Saving one watt at the server saves 2.5 watts overall



Overview and Benchmarking of Energy Use in Data Centers

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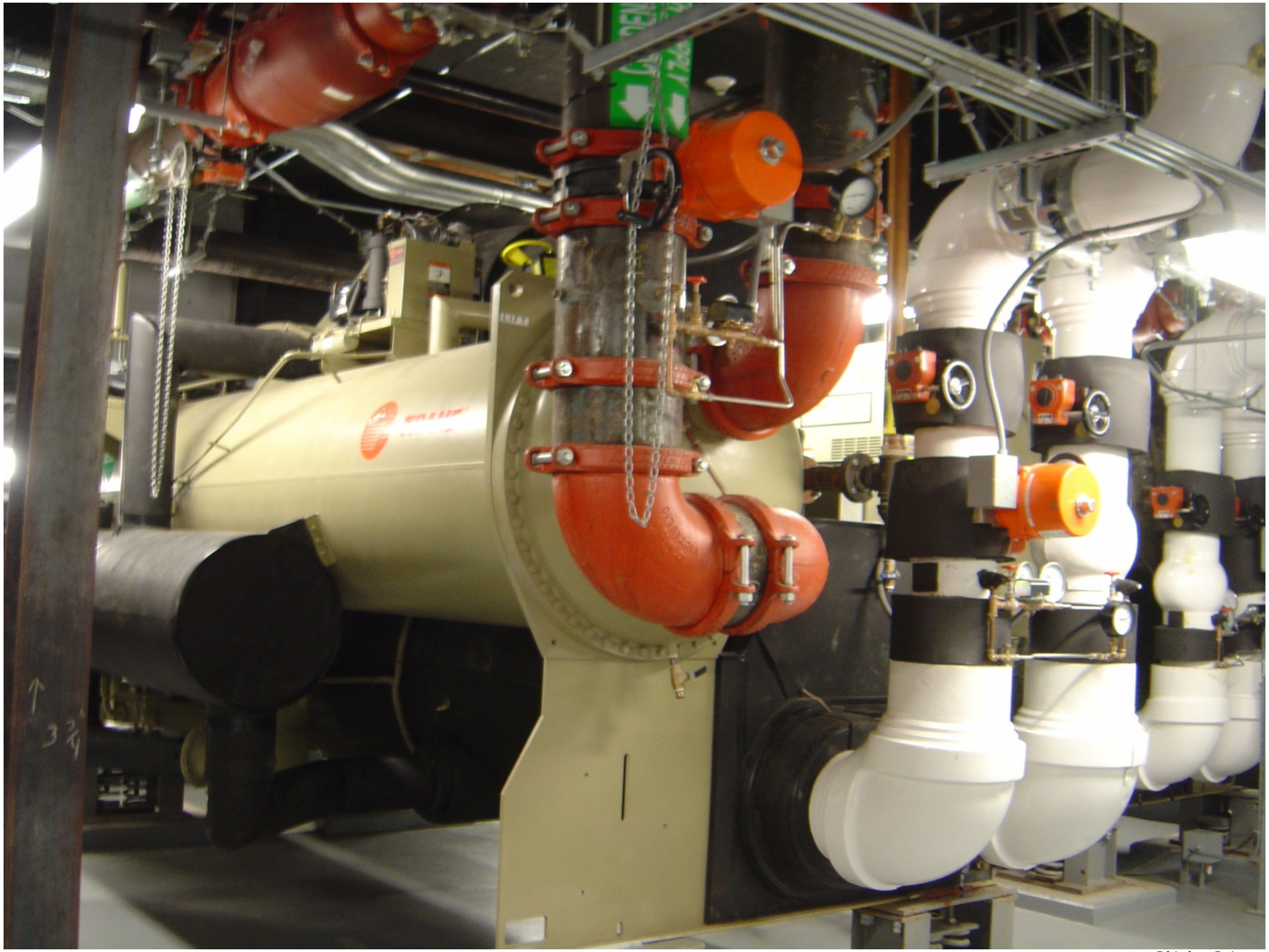
Data Centers are INFORMATION FACTORIES

- Data centers are energy intensive facilities
  - Server racks now designed for more than 25+ kW
  - Surging demand for data storage
  - Typical facility ~ 1MW, can be > 20 MW
  - Nationally 1.5% of US Electricity consumption in 2006
- Projected to double in next 5 years
- Significant data center building boom
  - Power and cooling constraints in existing facilities

...Resembling large industrial facilities




CONDENSER WATER RETURN

Also with specialized equipment

Energy issues abound

- Over the next five years, power failures and limits on power availability will halt data center operations at more than 90% of all companies

  (AFCOM *Data Center Institute's Five Bold Predictions, 2006)*

- By 2008, 50% of current data centers will have insufficient power and cooling capacity to meet the demands of high-density equipment

  (Gartner press release, 2006)

- Survey of 100 data center operators: 40% reported running out of power, cooling capacity, and to a lesser extent - space without sufficient notice

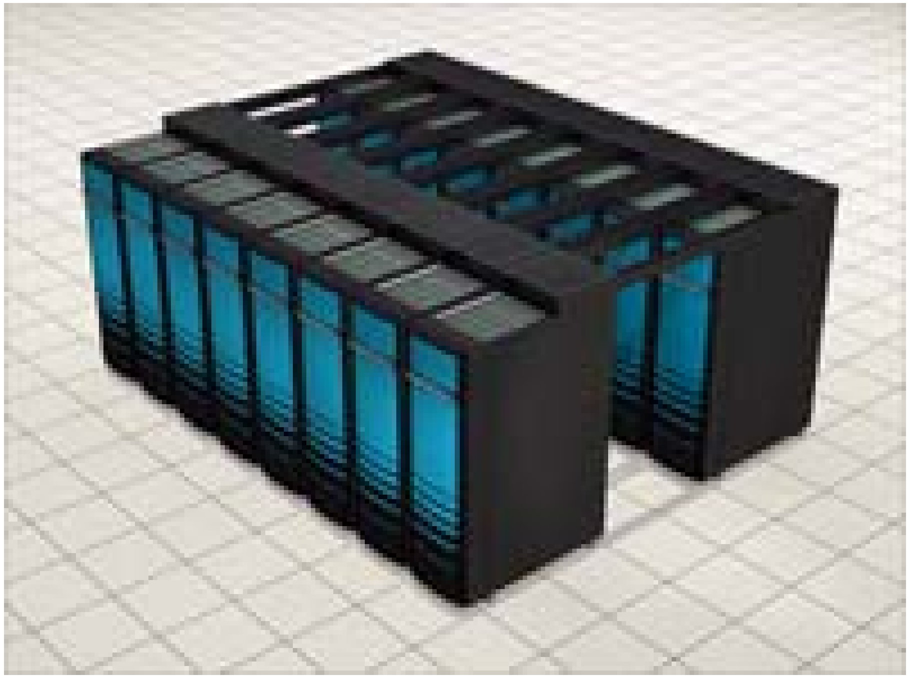
  (Aperture Research Institute)

The rising cost of ownership

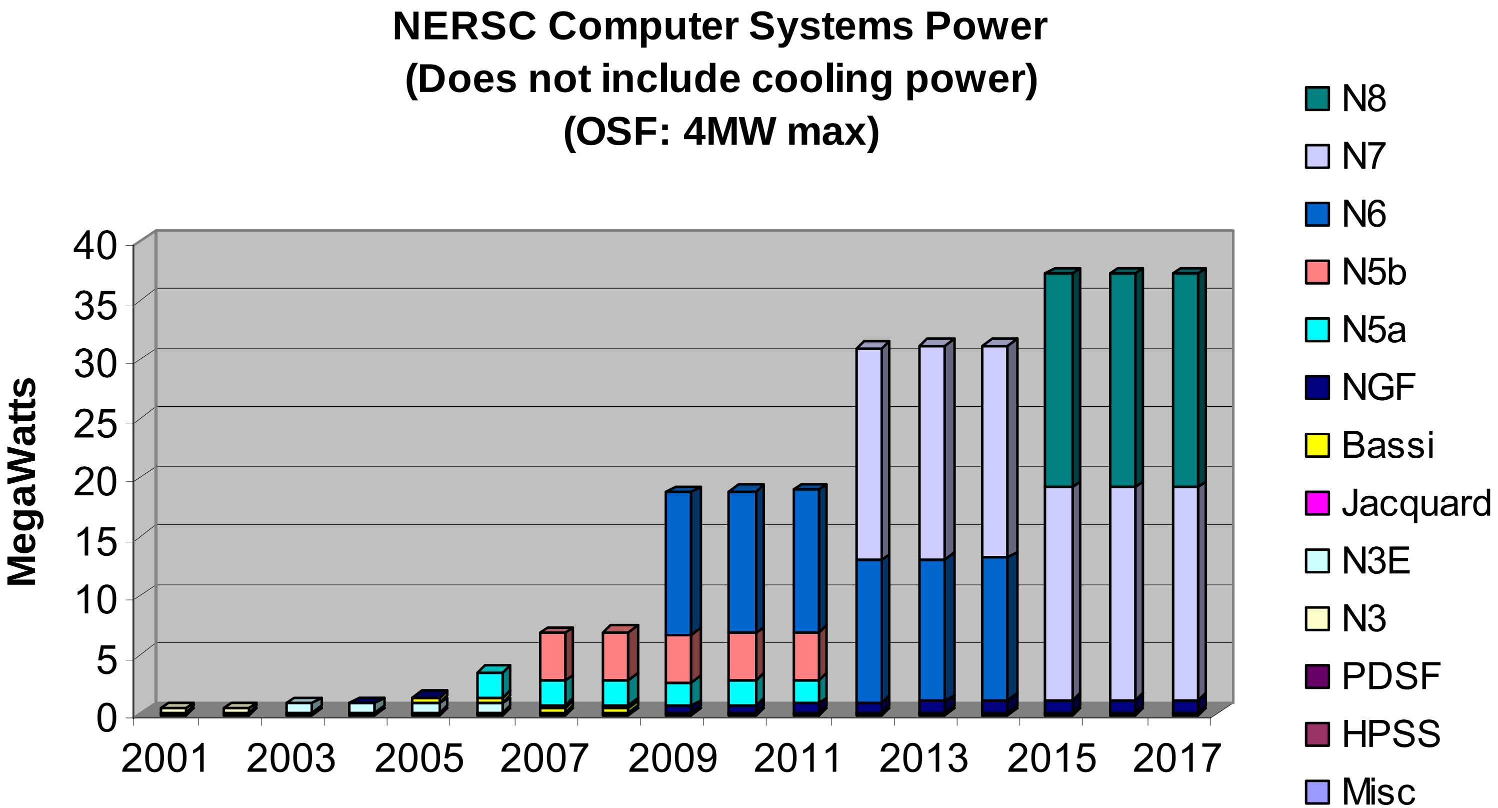
- From 2000 – 2006, computing performance increased 25x but energy efficiency only 8x
- Cost of electricity and supporting infrastructure now surpassing capital cost of IT equipment
- Perverse incentives -- IT and facilities costs separate

Source: The Uptime Institute, 2007

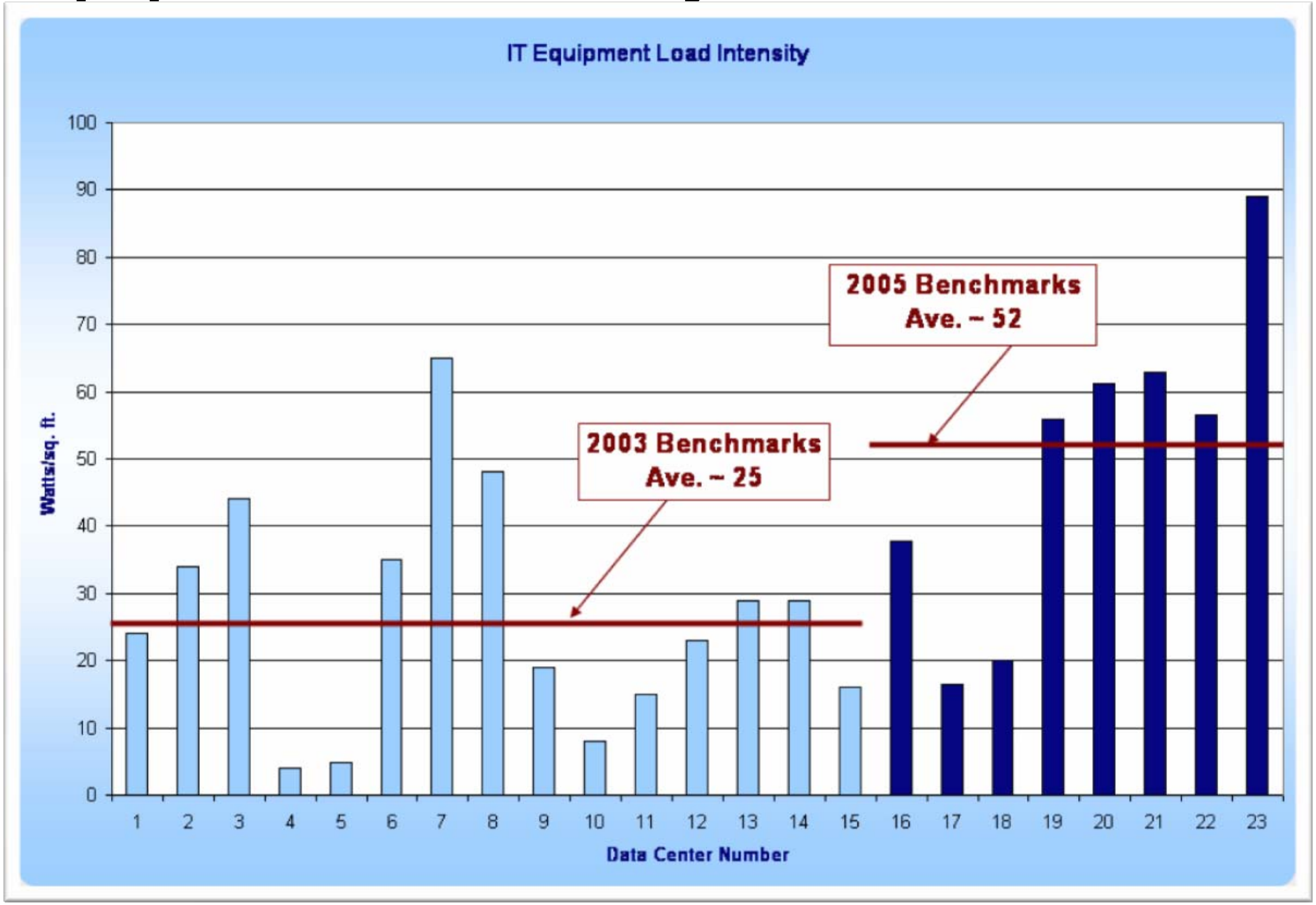
LBNL feels the energy cost pain!



LBNL super computer systems power:



IT equipment load density



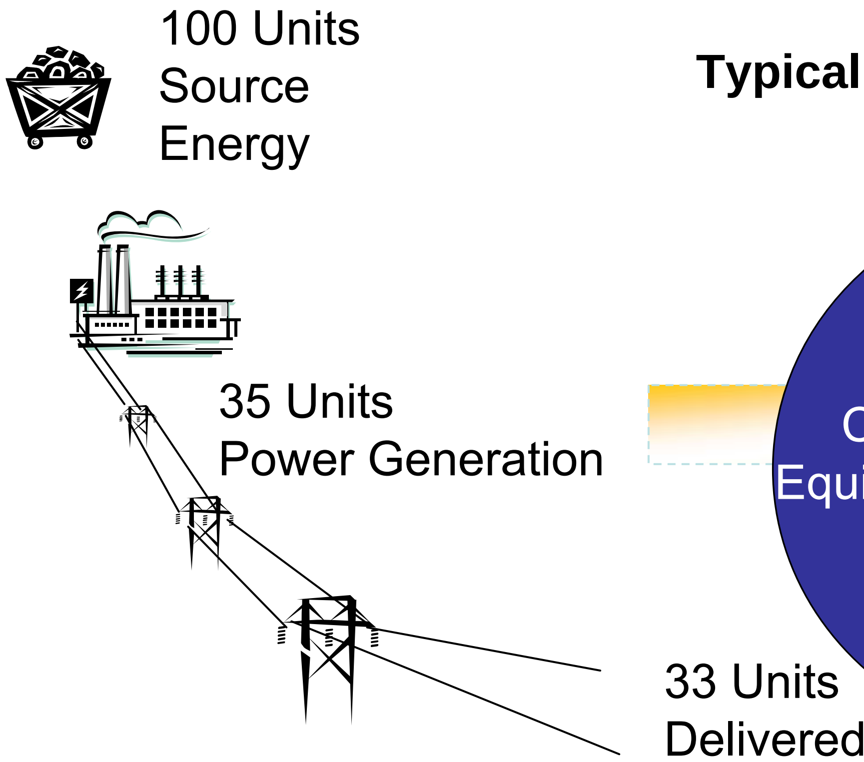
Data center definitions

- Server closet < 200 sf
- Server room < 500 sf
- Localized data center <1,000 sf
- Mid-tier data center <5,000 sf
- Enterprise class data center 5,000+ sf

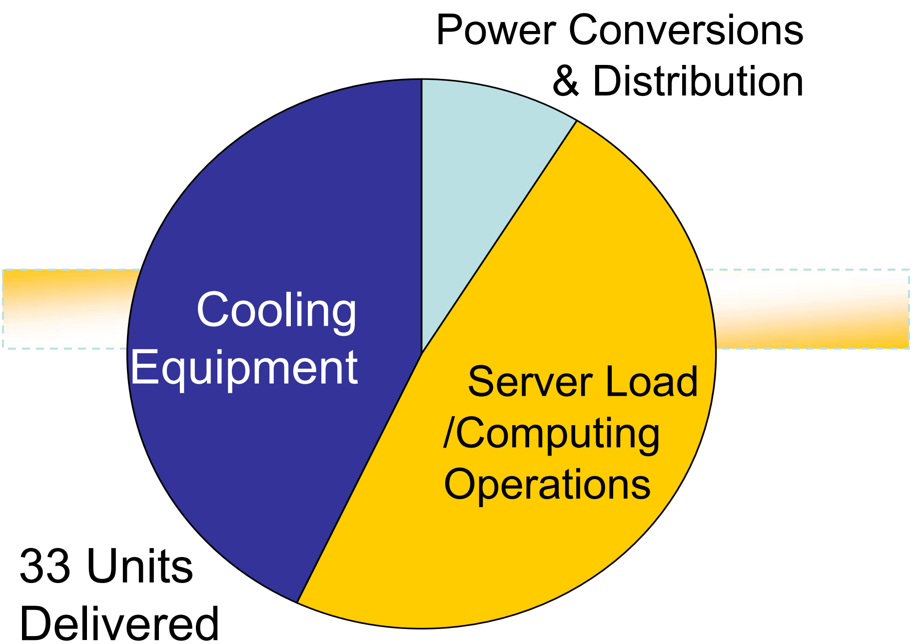
Today's training focuses on larger data centers — however most principles apply to any size center

Data center energy efficiency = 15% (or less)

Energy Efficiency = Useful computation / Total Source Energy



Typical Data Center Energy End Use



Data center efficiency opportunities

Benchmarking over 30 centers consistently lead to opportunities

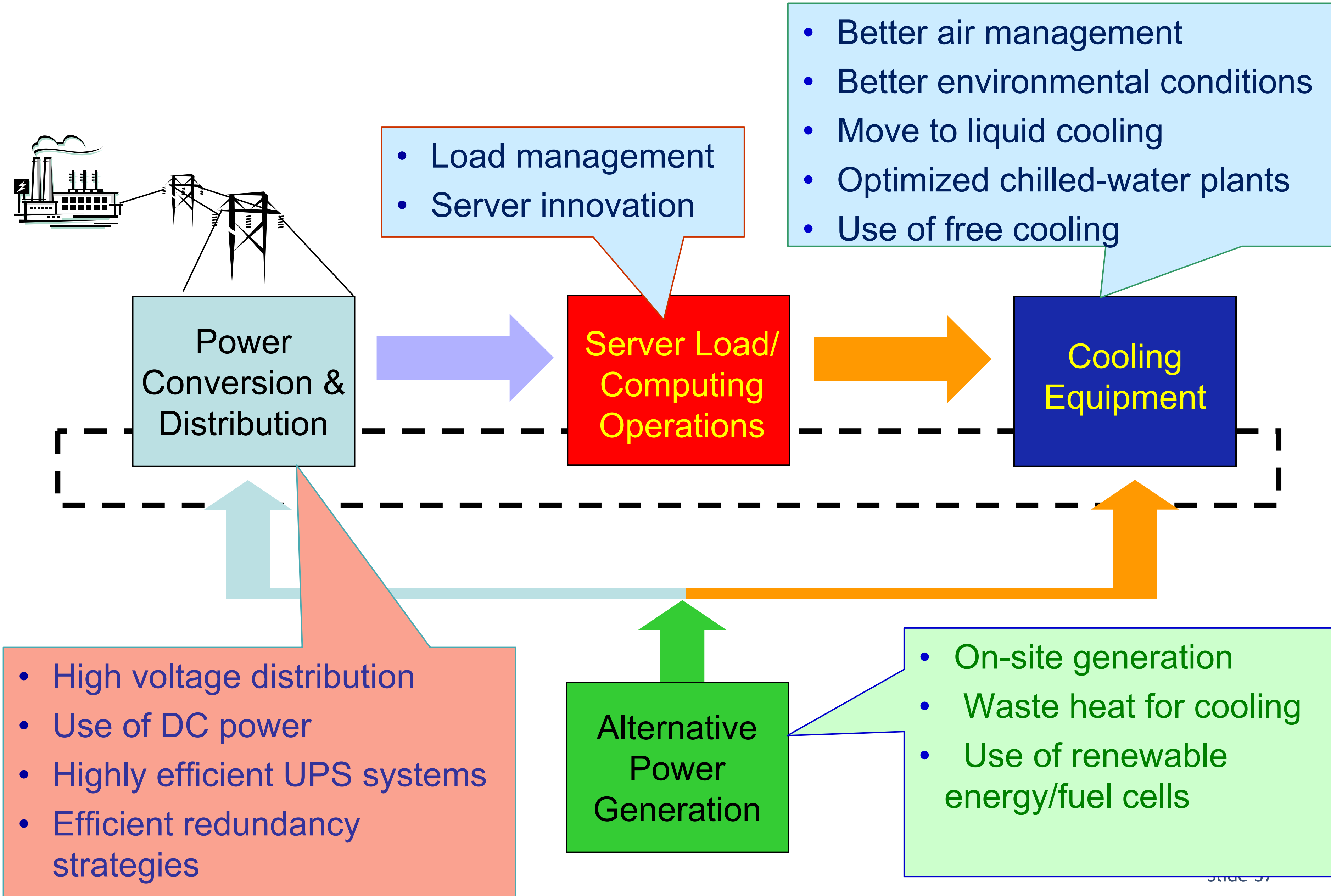
→

No silver bullet

→

Lots of silver bb's

Energy efficiency opportunities are everywhere



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

Potential savings

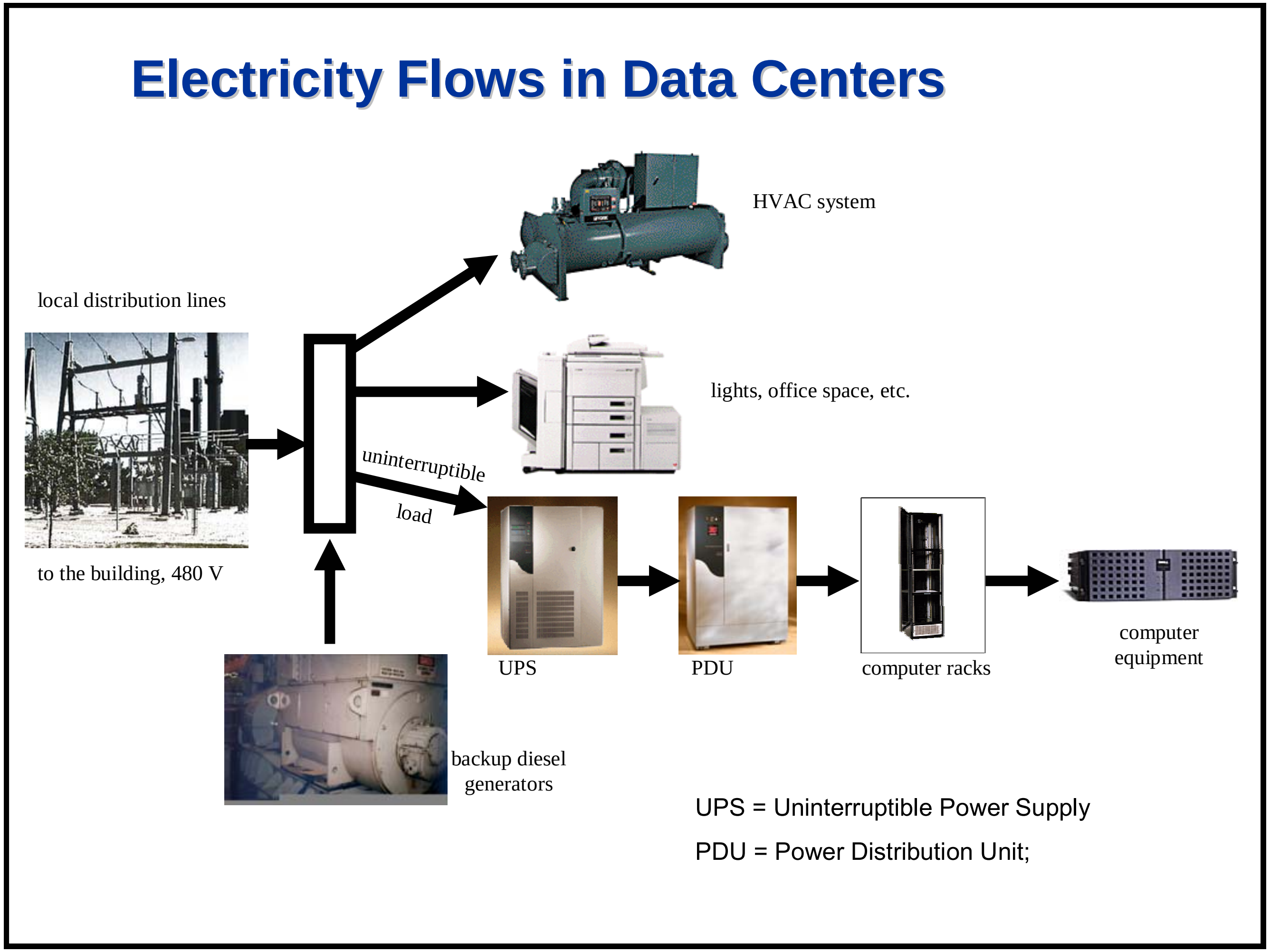
- 20-40% savings are typically possible
- Aggressive strategies – better than 50% savings
- Paybacks are short – 1 to 3 years are common
- Potential to extend life and capacity of existing data center infrastructure
- Some opportunities need to be integrated with infrastructure upgrades
- Most centers don’t know if they are good or bad

Benchmarking to find energy performance improvement:

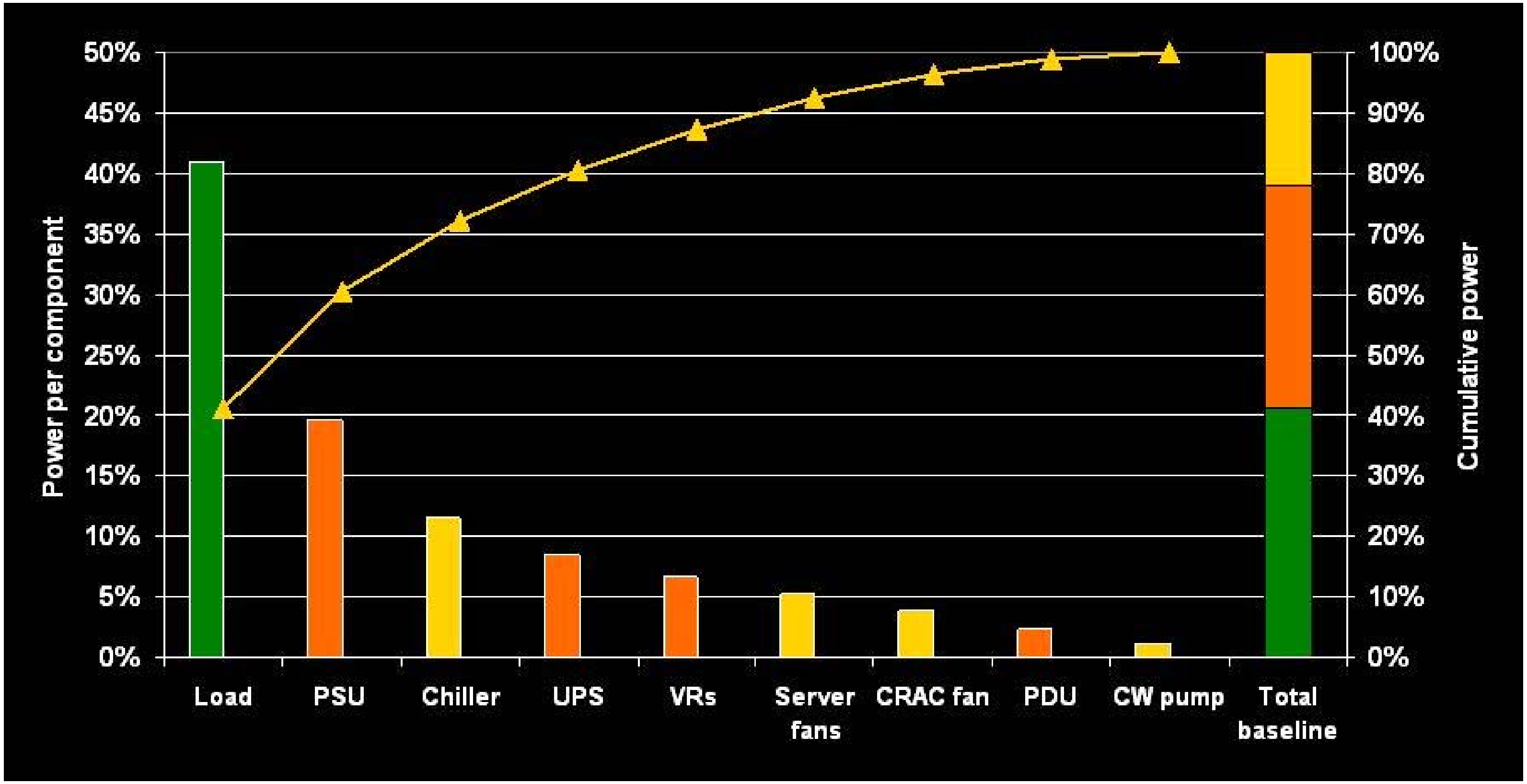
Energy benchmarking can be effective in helping to identify better performing designs and strategies.

As new strategies are implemented (e.g. liquid cooling), energy benchmarking will enable comparison of performance.

Benchmarking energy end use



Electrical end use in one center



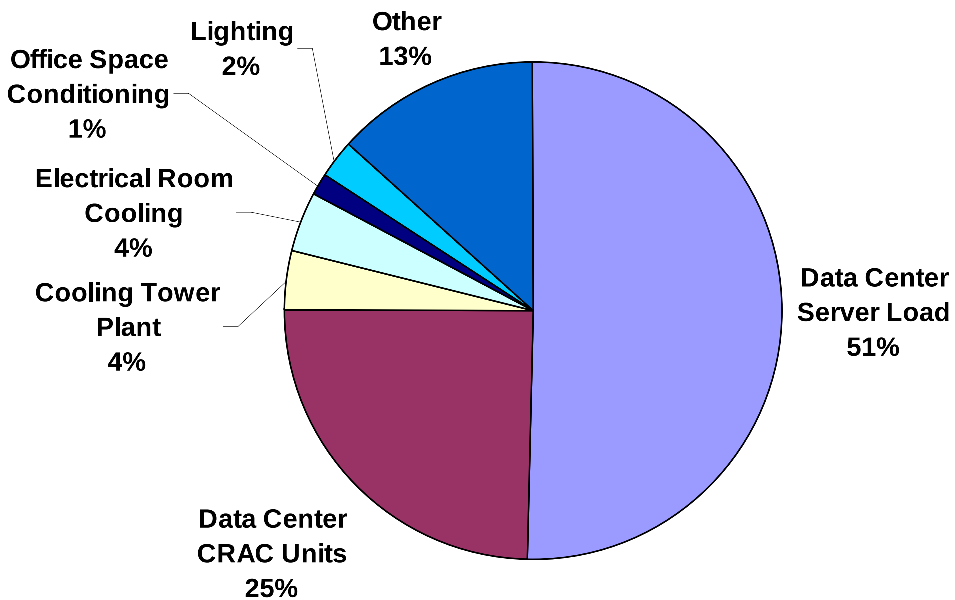
Courtesy of Michael Patterson, Intel Corporation

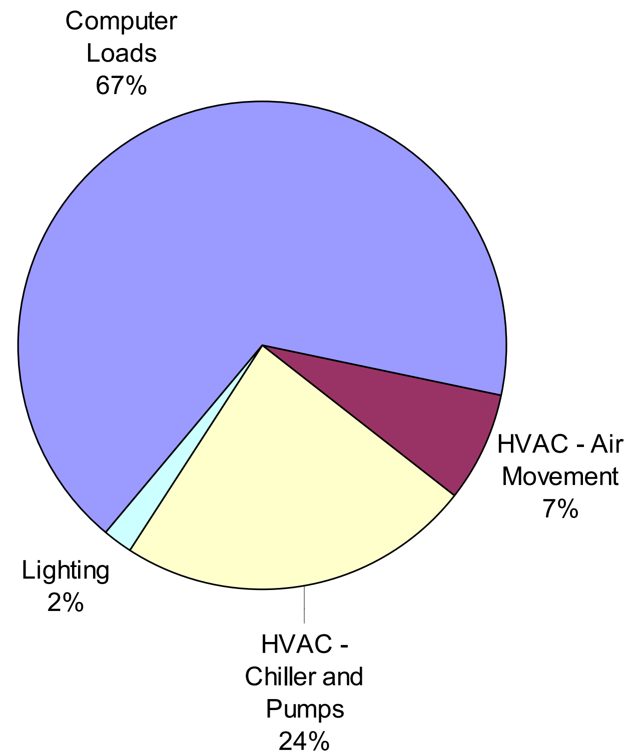
LBNL benchmarked and performed assessments of over 30 data centers:

- We observed a wide variation in performance
- Better performing systems were studied
- Best practices were identified

Your mileage will vary

The relative percentages of the energy doing computing varied considerably.





Data center cooling and power conversion performance varies

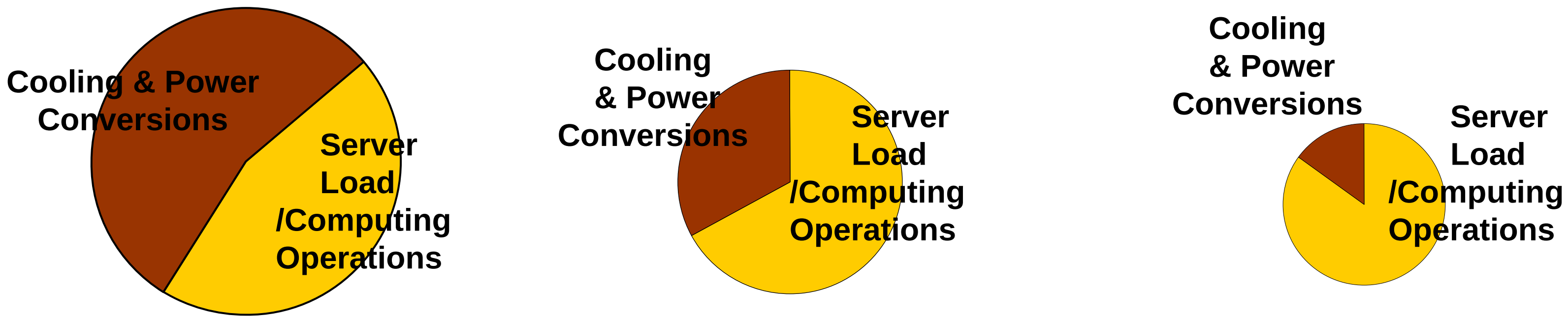
DCiE (Data Center Infrastructure Efficiency) ~ 0.5

- Power and cooling systems are not optimized
- Currently, power conversion and cooling systems consume half or more of the electricity used in a data center: <u>*Less than half of the power is for the servers*</u>

DCiE

Data Center Infrastructure Efficiency

$$\text{DCiE} = \frac{\text{Energy for IT Equipment}}{\text{Total Energy for Data Center}}$$

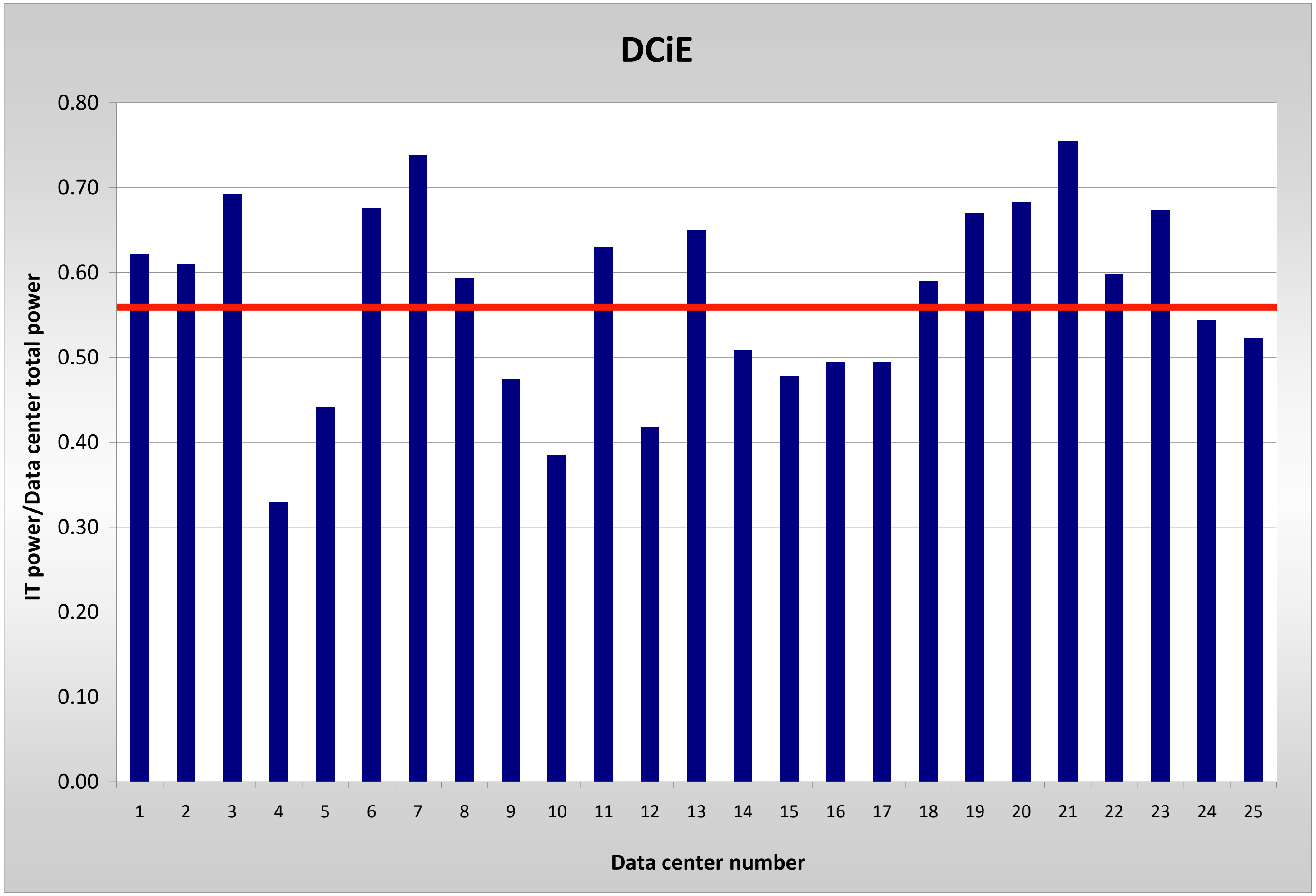


Typical Practice
DCiE < 0.5

Better Practice
DCiE = 0.7

Best Practice
DCiE = 0.85

High level metric – IT/total



Average .57

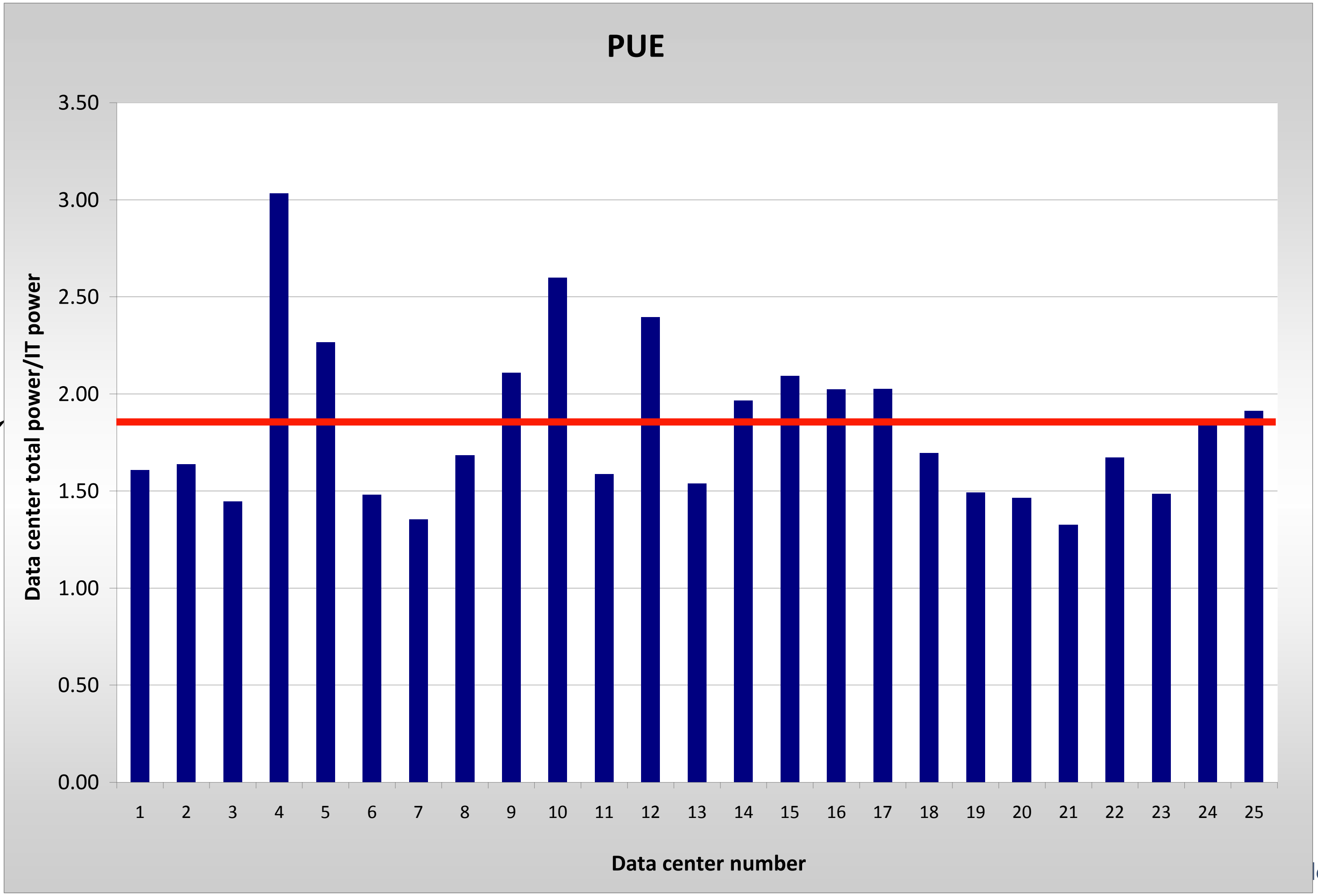
Higher is better

Source: LBNL

Inverse metric —total/IT (PUE)

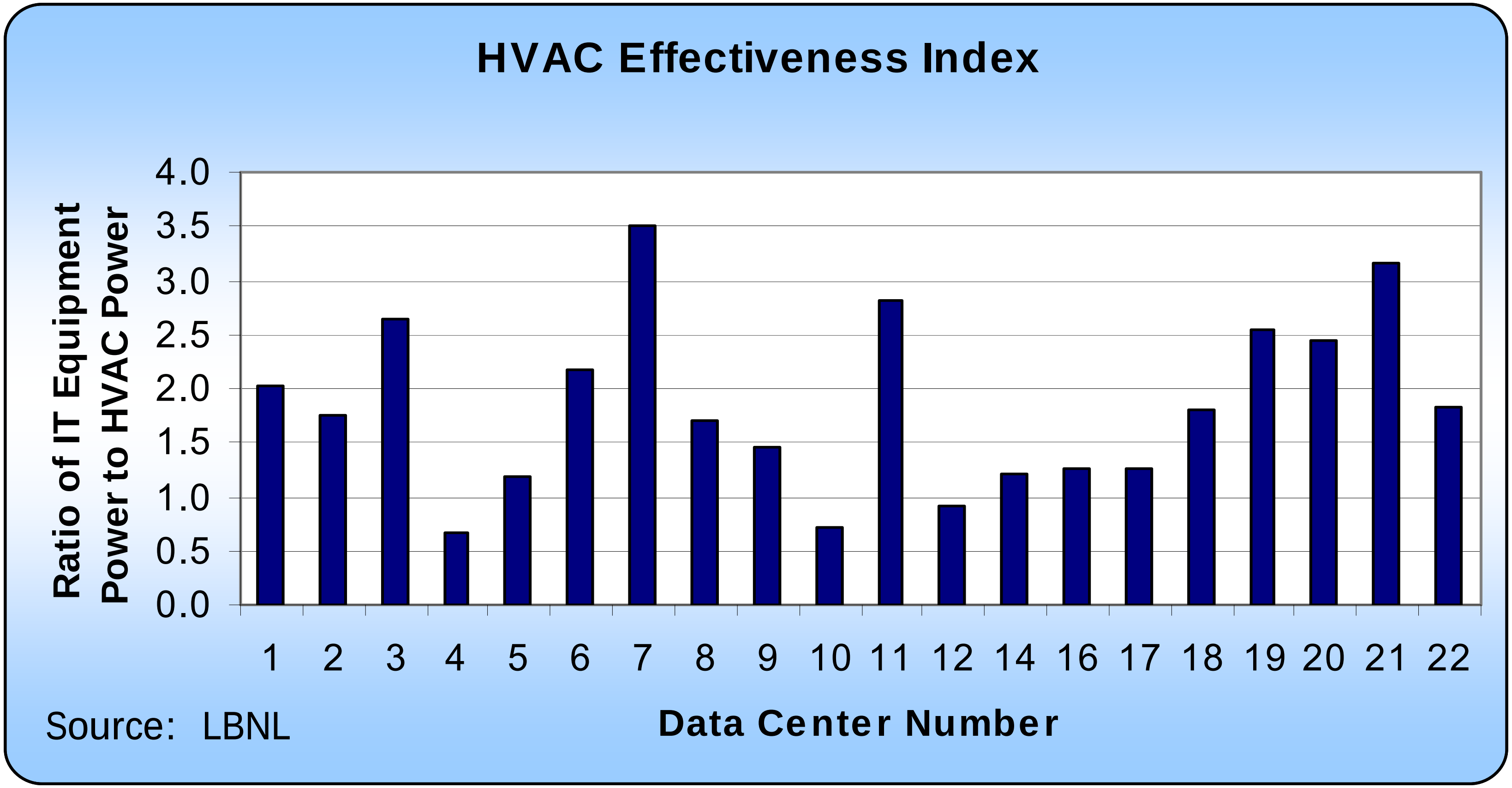
Average 1.83

Lower is better



HVAC system effectiveness

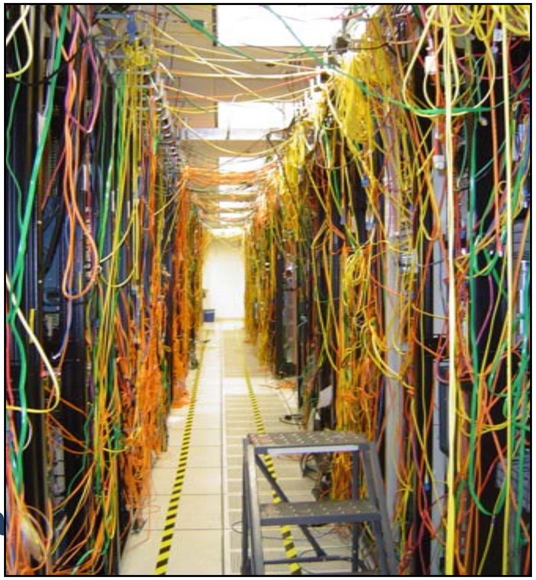
We observed a wide variation in HVAC performance



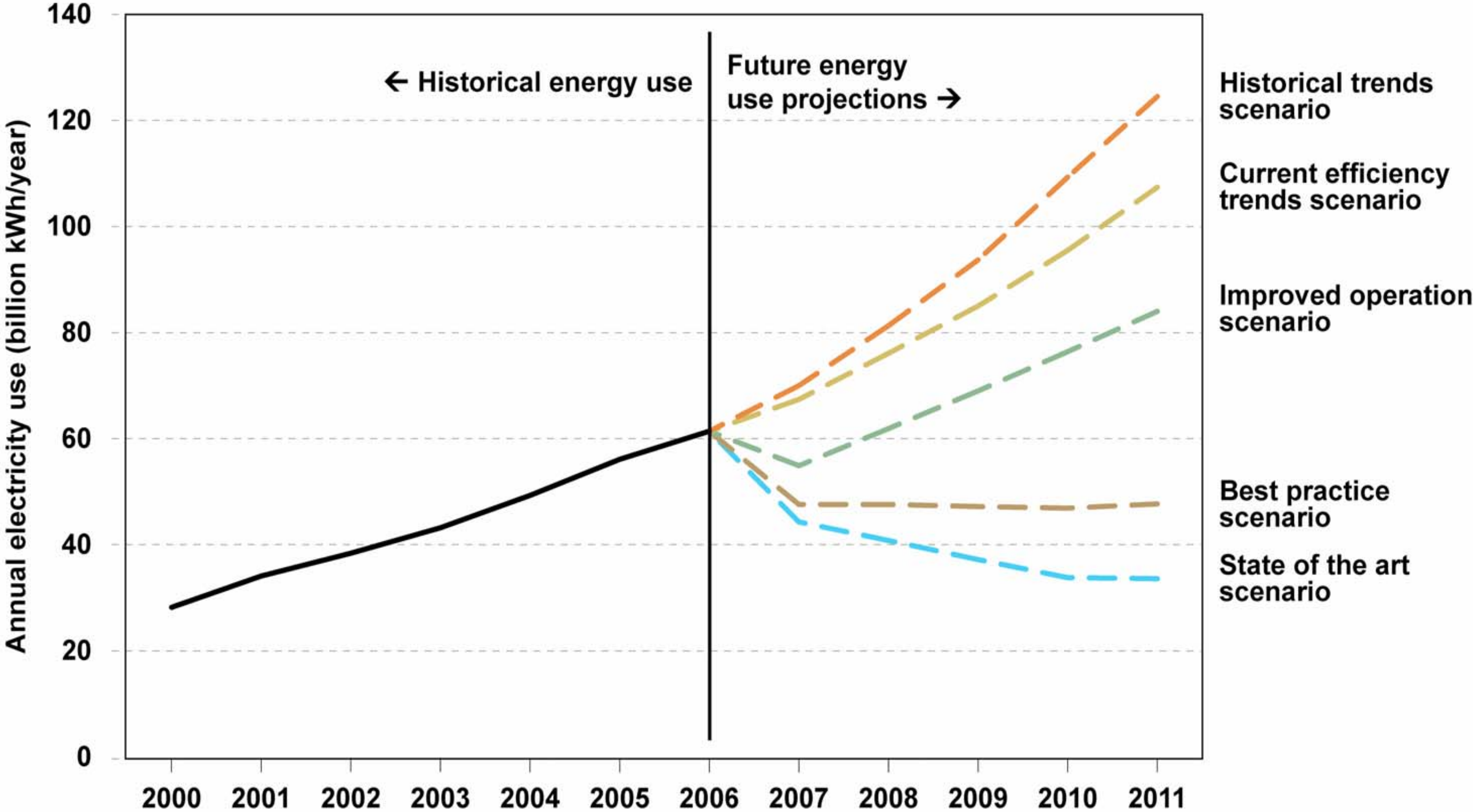
Benchmark results help identify best practices:

Examination of individual systems and components in the centers that performed well helped to identify best practices:

- Right-sizing and modular approaches
- Appropriate environmental conditions
- Central plant optimization
- Efficient air handling/ air management
- Free cooling
- Humidity control
- Liquid cooling
- Power conversion losses: UPS, PDU, transformers, a power supplies
- On-site generation
- Design, maintenance, and operational processes



Scenarios of projected energy use from EPA report to Congress 2007 - 2011

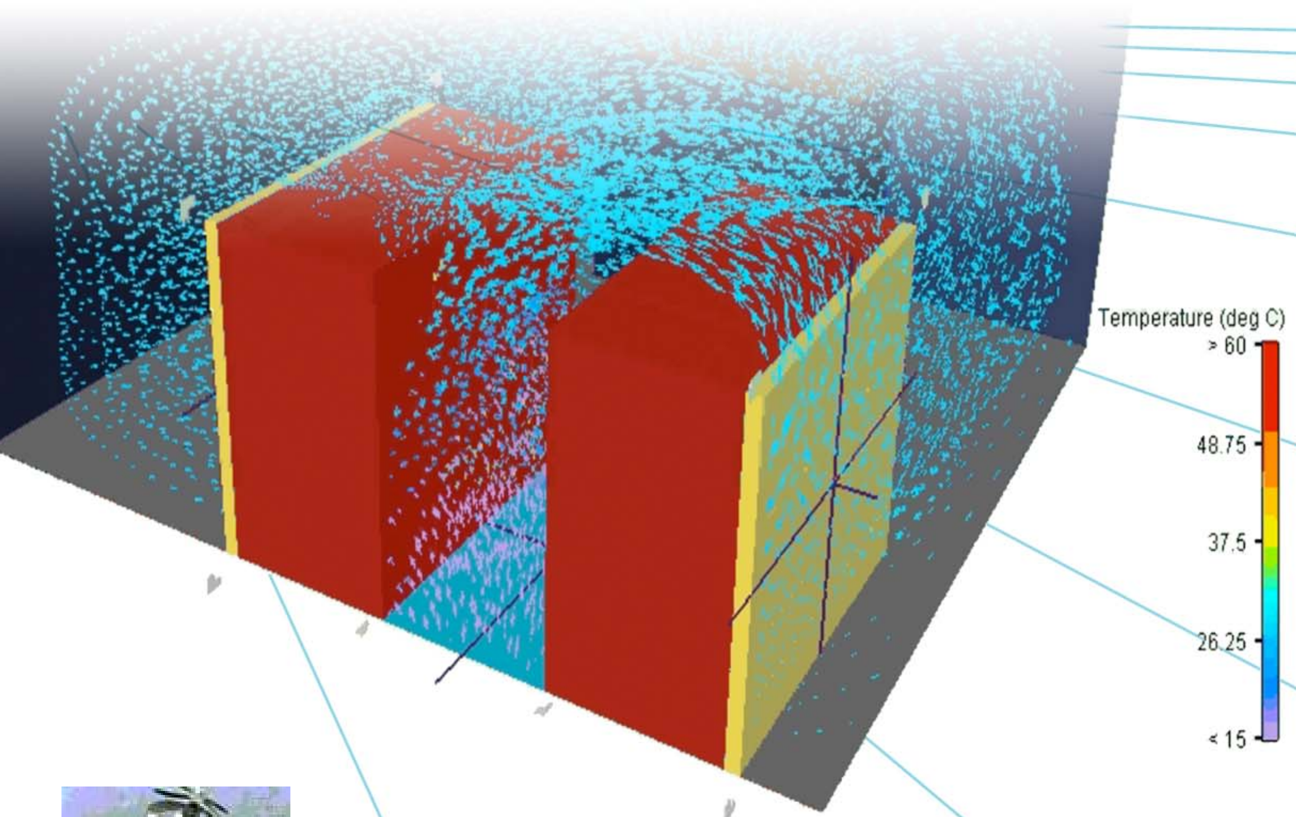


The good news:

- Industry is taking action
  - IT manufacturers
  - Infrastructure equipment manufacturers
- Industry Associations are active:
  - ASHRAE
  - Green Grid
  - Uptime Institute
  - Afcom
  - Critical Facilities Roundtable
  - 7 X 24 Exchange
- Utilities and governments initiating programs to help

Overview take aways

- Various meanings for “data centers”
- Benchmarking helps identify performance
- Benchmarking suggests best practices
- Efficiency varies
- Large opportunity for savings
- Industry is taking action
- Resources are available

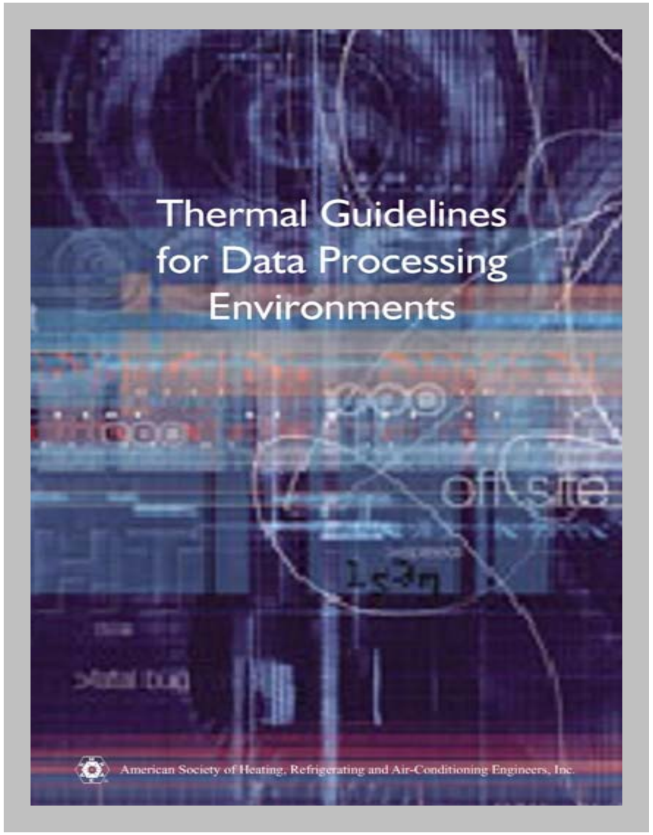


Environmental Conditions

Steve Greenberg, PE

Environmental conditions

- ASHRAE - consensus between IT equipment manufacturers and HVAC professionals on appropriate temperature and humidity conditions
- Recommended and allowable ranges of temp and humidity
- Standard reporting of requirements



Design conditions - at inlet to IT equipment

Class 1 => Data Center
Class 2 => IT Space, Lab or Office Space
NEBS => Telecom standard

Recommended => Design and Ops Target
Allowable => Equipment Specs.
(may result in diminished reliability or operation)

ble 2
Class 1, Class 2 and NEBS Design Conditions

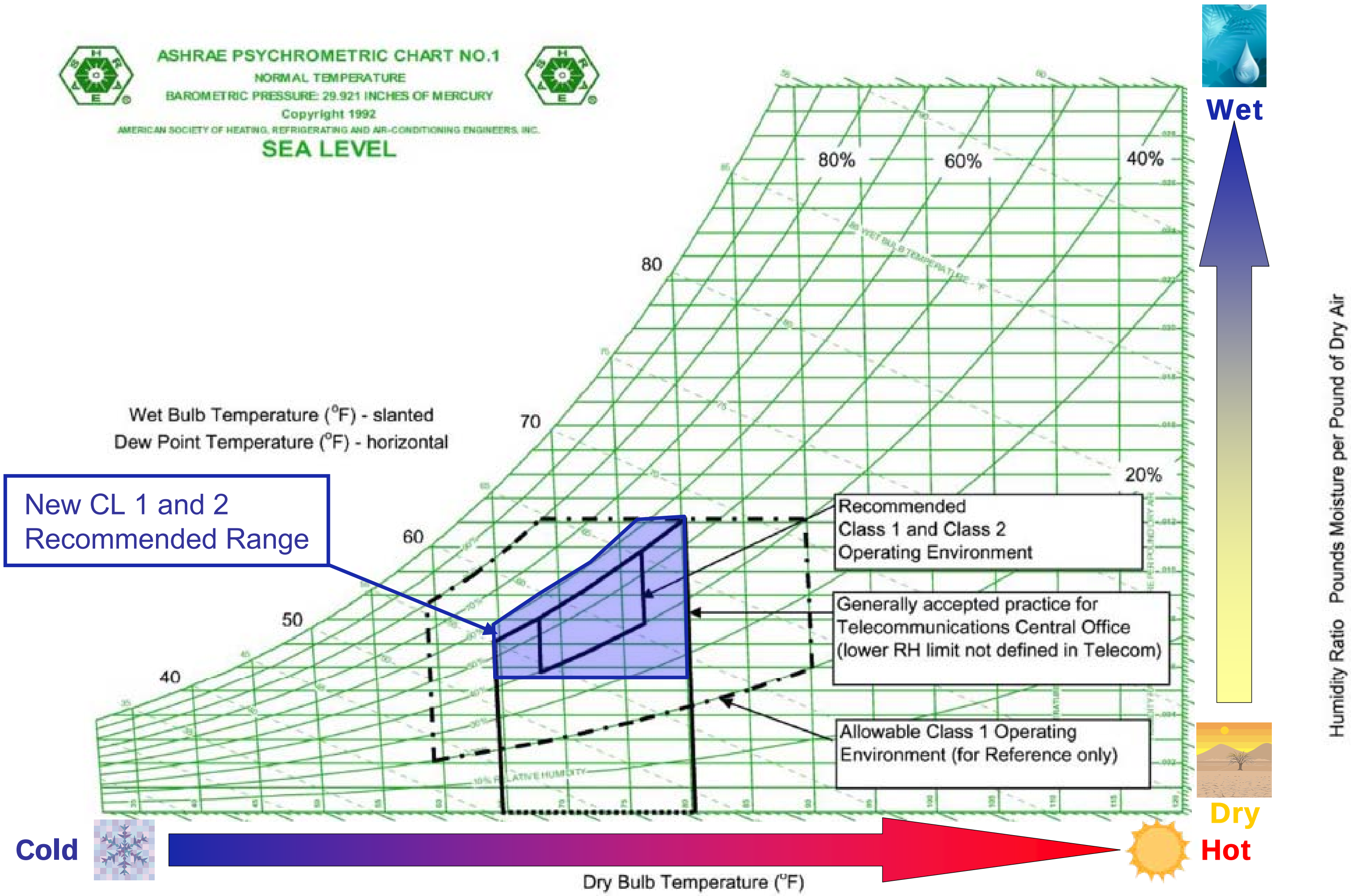
Condition	Class 1 / Class 2		NEBS	
	Allowable Level	Recommended Level	Allowable Level	Recommended Level
Temperature control range	59°F – 90°F[a,f] (Class 1) 50°F – 95°F[a,f] (Class 2)	68°F – 77°F[a]	41°F – 104°F[c,f]	65°F – 80°F[d]
Maximum temperature rate of change	9°F. per hour[a]		2.9°F/min. [d]	
Relative humidity control range	20% - 80% 63°F. Max Dewpoint[a] (Class 1) 70°F. Max Dewpoint[a] (Class 2)	40% - 55%[a]	5% to 85% 82°F Max Dewpoint[c]	Max 55%[e]
Filtration quality	65%, min. 30%[b] (MERV 11, min. MERV 8)[b]			

[a]These conditions are inlet conditions recommended in the ASHRAE Publication *Thermal Guidelines for Data Processing Environments* (ASHRAE, 2004).
[b]Percentage values per ASHRAE *Standard* 52.1 dust-spot efficiency test. MERV values per ASHRAE Standard 52.2. Refer to Table 8.4 of this publication for the correspondence between MERV, ASHRAE 52.1 & ASHRAE 52.2 Filtration Standards.
[c]Telecordia 2002 GR-63-CORE
[d]Telecordia 2001 GR-3028-CORE
[e]Generally accepted telecom practice. Telecom central offices are not generally humidified, but grounding of personnel is common practice to reduce ESD.
[f]Refer to Figure 2.2 for temperature derating with altitude

Design conditions at the inlet to IT equipment: recently revised by ASHRAE

	2004 Version	2008 Version
Low End Temperature	20°C (68 °F)	18°C (64.4 °F)
High End Temperature	25°C (77 °F)	27°C (80.6 °F)
Low End Moisture	40% Relative Humidity	5.5°C Dew Point (41.9 °F)
High End Moisture	55% Relative Humidity	60% Relative Humidity & 15°C Dew Point (59 °F Dew Point)

Design conditions at the inlet to IT equipment



Example server specification:
(Dell PowerVault MD3000)

Environmental

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

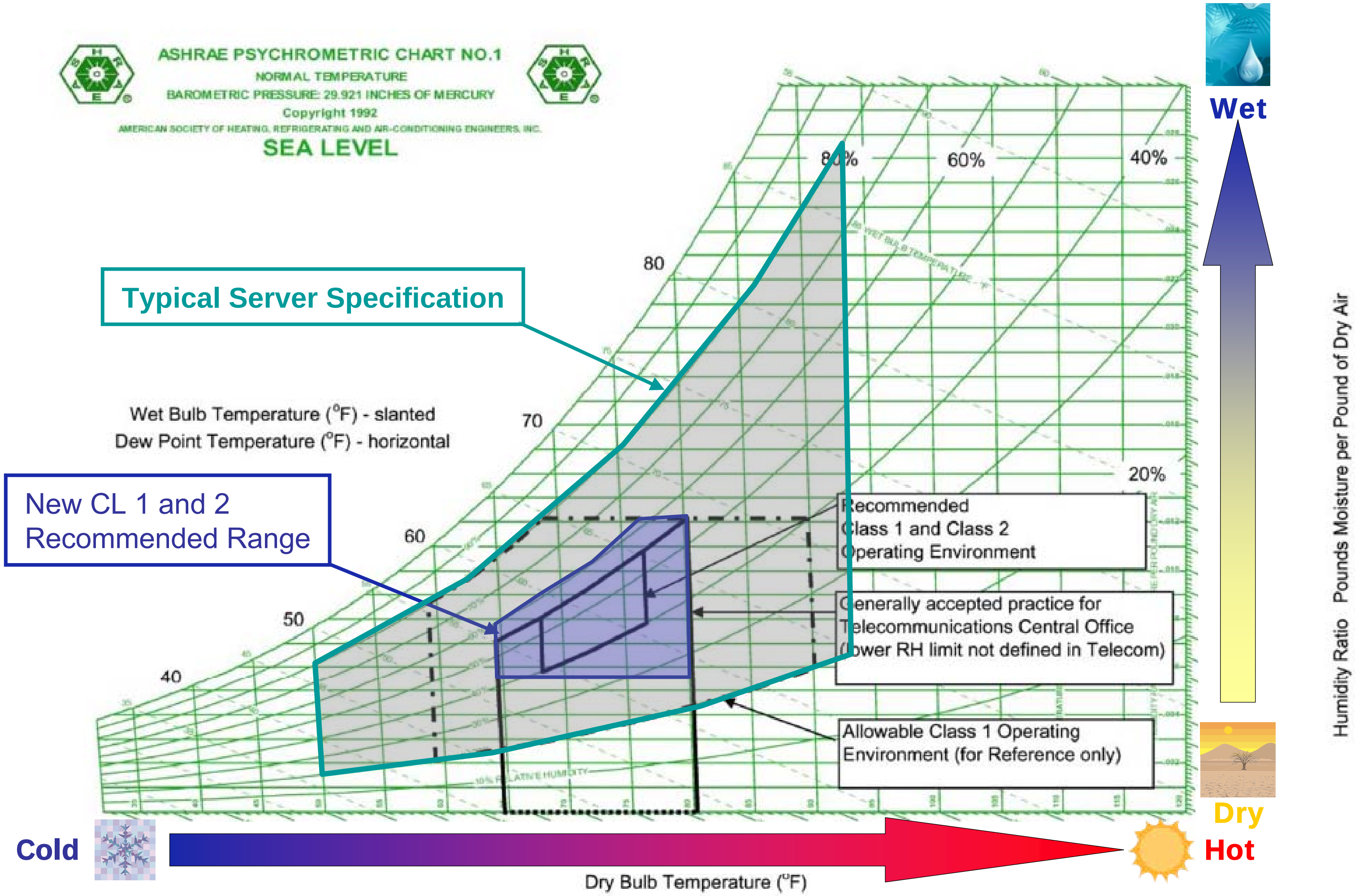
Relative humidity
- Operating: 20% to 80% (non-condensing)
- Storage: 5% to 95% (non-condensing)

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

Example server specification: Supermicro SYS-6015T

Operating Environment / Compliance	
Environmental Specifications	▪ Operating Temperature: 10°C to 35°C (50°F to 95°F) ▪ Non-operating Temperature: -40°C to 70°C (-40°F to 158°F) ▪ Operating Relative Humidity: 8% to 90% (non-condensing) ▪ Non-operating Relative Humidity: 5% to 95% (non-condensing)

Server specs exceed ASHRAE ranges



Microsoft's data center in a tent

http://www.datacenterknowledge.com/archives/2008/09/22/new-from-microsoft-data-centers-in-tents/

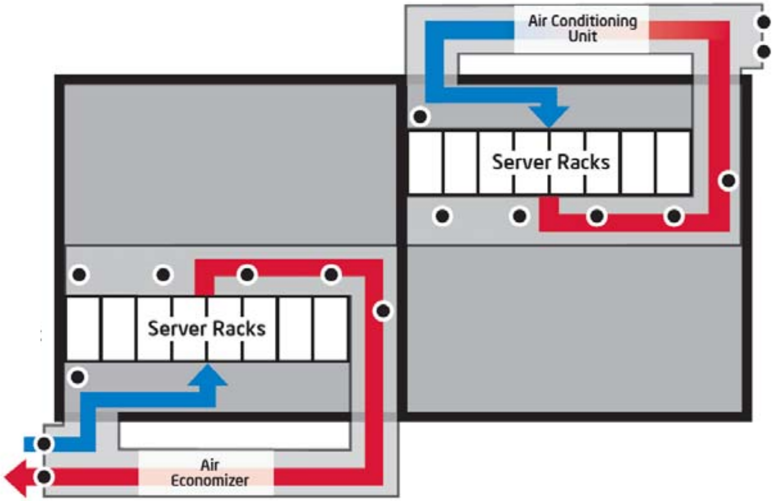
"Inside the tent, we had five HP DL585s running Sandra from November 2007 to June 2008 and we had **ZERO failures** or 100% uptime. In the meantime, there have been a few anecdotal incidents:

- Water dripped from the tent onto the rack. The server continued to run without incident.
- A windstorm blew a section of the fence onto the rack. Again, the servers continued to run.
- An itinerant leaf was sucked onto the server fascia. The server still ran without incident."

And from Intel a side-by-side comparison

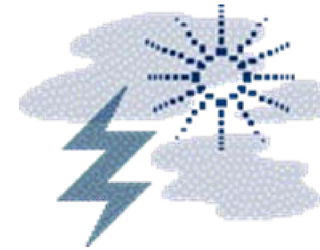
Intel conducted a 10-month test to evaluate the impact of using only outside air to cool a high-density data center, even as temperatures ranged between 64 and 92 degrees and the servers were covered with dust.

- Intel's result: "We observed no consistent increase in server failure rates as a result of the greater variatio in temperature and humidity, and the decrease in air quality," Intel's Don Atwood and John Miner write in their white paper. "This suggests that existing assumptions about the need to closely regulate these factors bear further scrutiny



See http://www.datacenterknowledge.com/archives/2008/09/18/intel-servers-do-fine-with-outside-air/

Lower humidity limit



Electrostatic discharge (ESD)

- Recommended mitigation procedures
  - Personnel grounding
  - Cable grounding
- Recommended equipment
  - Grounding wrist straps on racks
  - Grounded plate for cables
  - Grounded flooring
  - Servers rated for ESD resistance
- Industry practices
  - Telecom industry has no lower limit
  - The Electrostatic Discharge Association has removed humidity control as a primary ESD control measure in their ESD/ANSI S20.20 standard

Lower humidity limit

- Tight humidity control is a legacy issue from days when paper products and tape were widely used
- Humidity controls are a point of failure and are hard to maintain
- Many data centers today operate without humidification
- More research is needed
- Humidity may be required for some physical media (tape storage, printing and bursting)
  - Old technology not found in many data centers
  - It is best to segregate these items rather than humidify the entire data center

Bay area data centers without humidification controls

A dozen different organizations including:

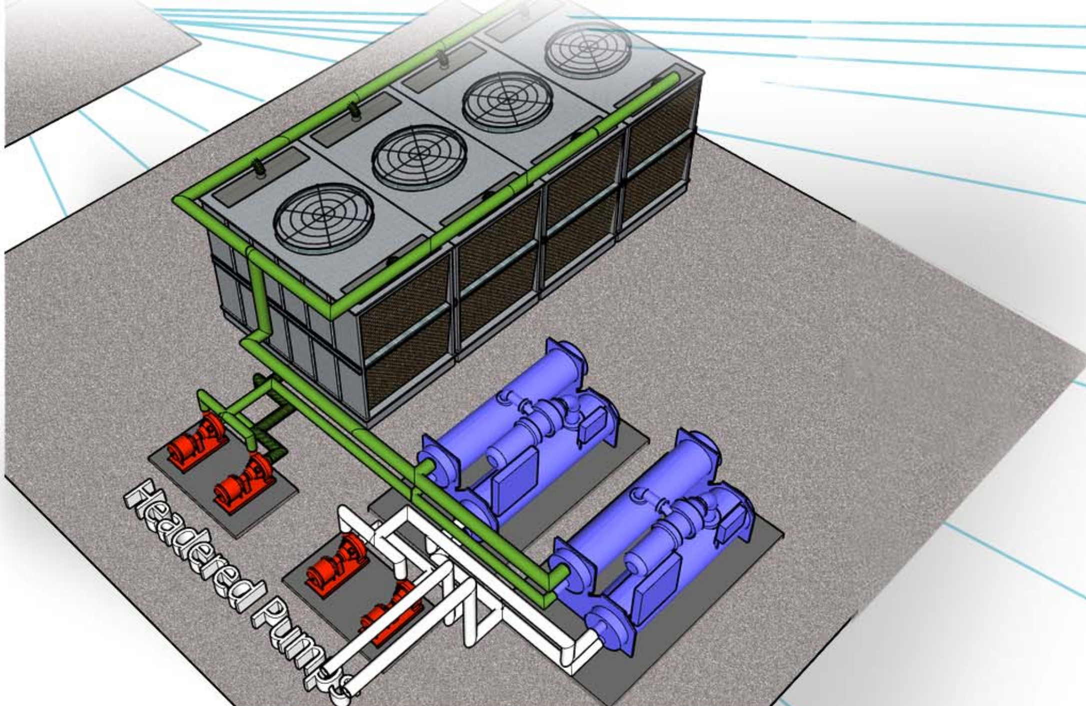
- Bank
- Medical service provider
- Server manufacturers
- Software firms
- Colocation facilities
- Major chip manufacturer
- Supercomputer facilities
- Animation studio

High humidity limit

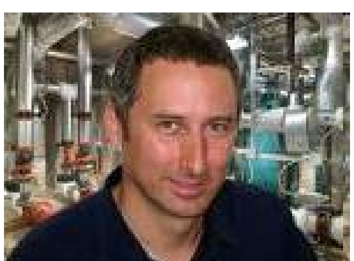
- Some contaminants (hydroscopic salts) in combination with high humidity can (over time) deposit and bridge across circuits causing current leakage or shorts.
- Unless you operate with very high humidity (≥80%) in a contaminated environment for long periods of time this phenomenon should not be a problem.
- Do you tightly control humidity for your home computer?
- More research is needed to determine if there is a basis for concern.

Environmental conditions take aways

- Use the entire ASHRAE recommended range in data center operation.
  - Provide the warmest supply temperatures that satisfy the equipment inlet conditions.
  - Control to the widest humidity range.
- Humidification does not protect against ESD, consider grounding and personnel practices in lieu of humidification.
- There is no scientific evidence that high humidity causes equipment problems
- Isolate equipment that needs tighter humidity or temperature control.



Air System Design



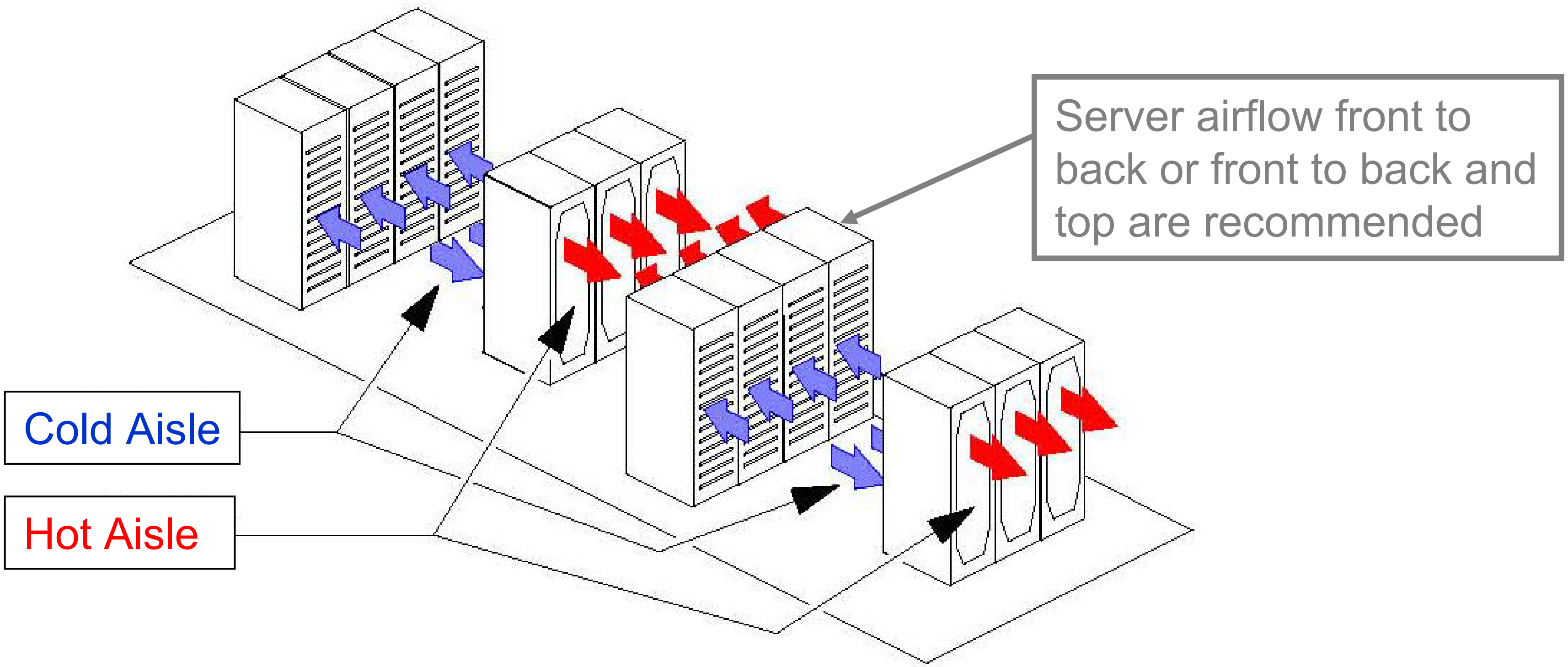
Peter Rumsey, P.E.

RUMSEY ENGINEERS INC

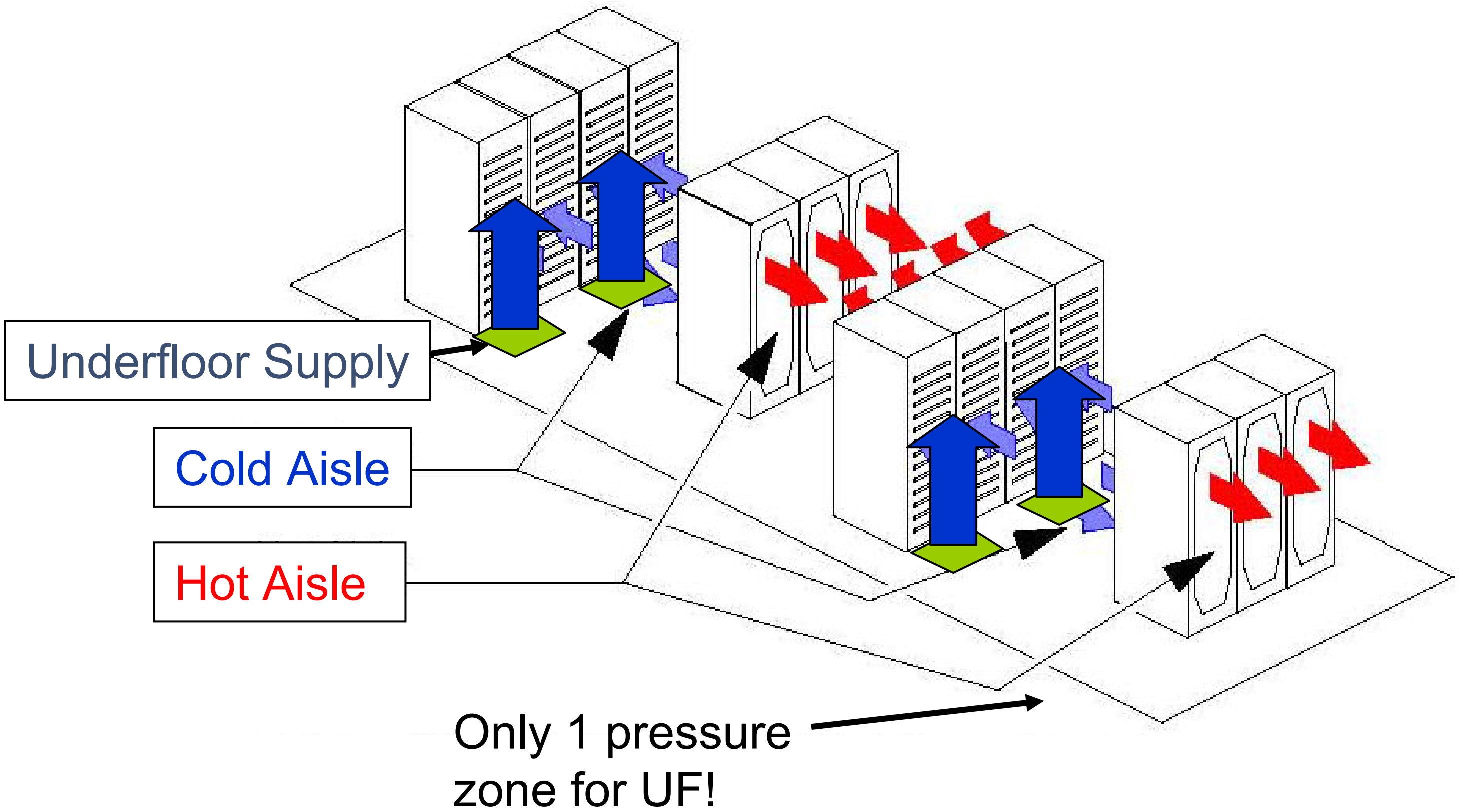
Air system design overview

- Data center layout
- Airflow configurations
  - Distribution: overhead or underfloor
  - Control: constant or variable volume
- Air management issues

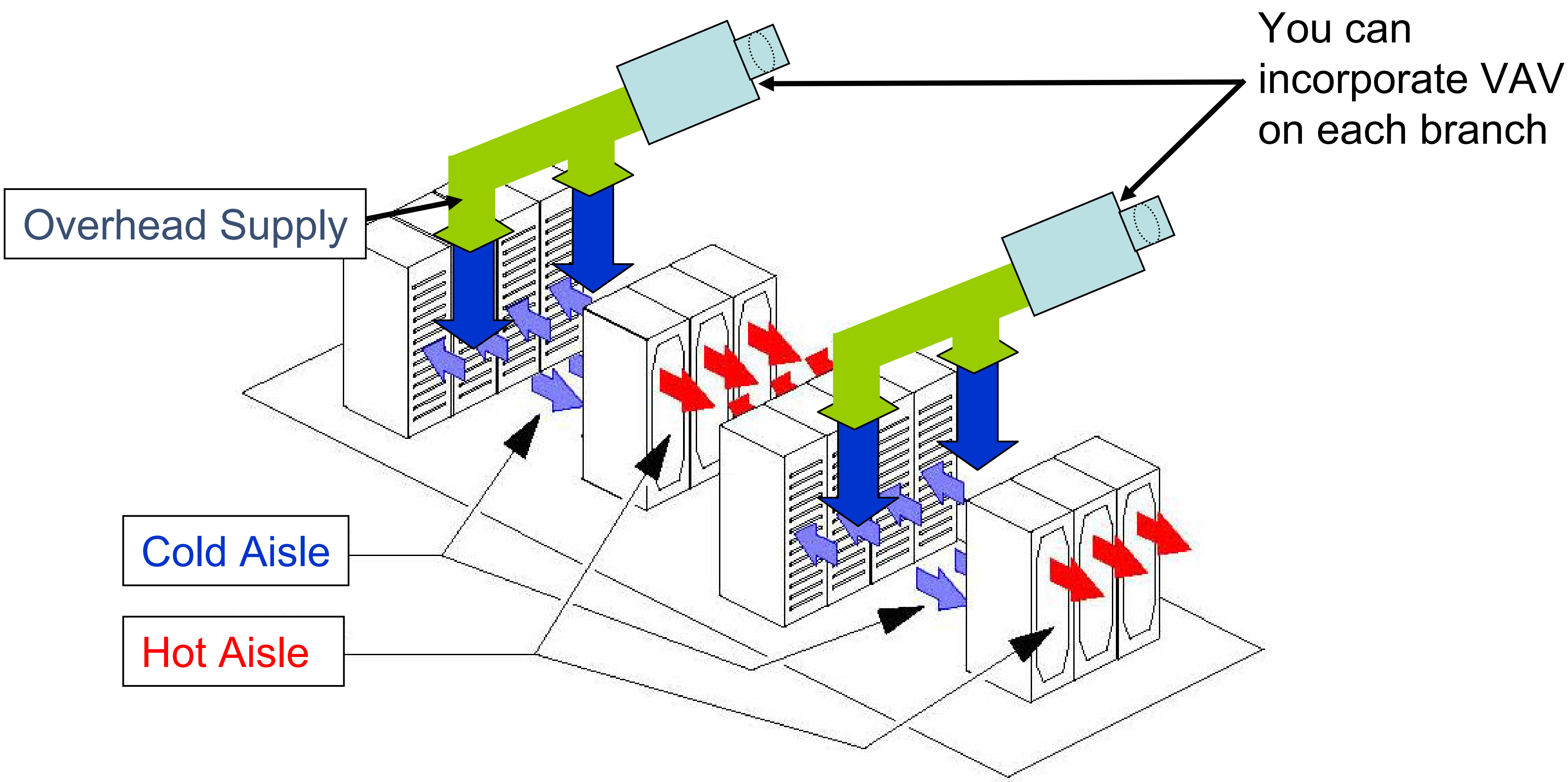
Data center layout



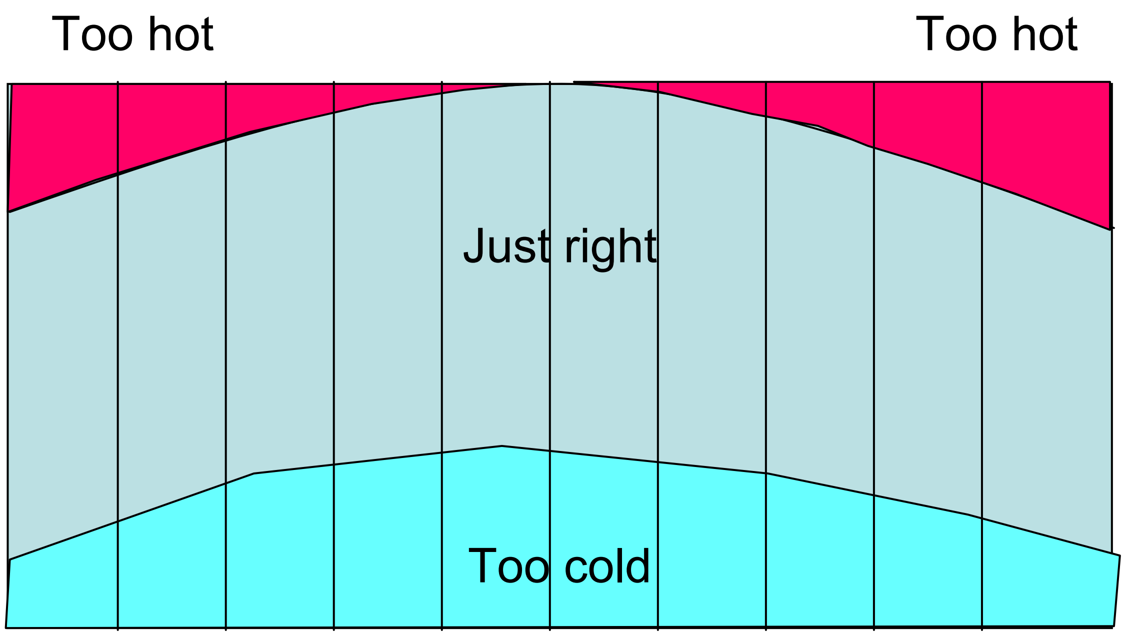
Underfloor supply



Overhead supply



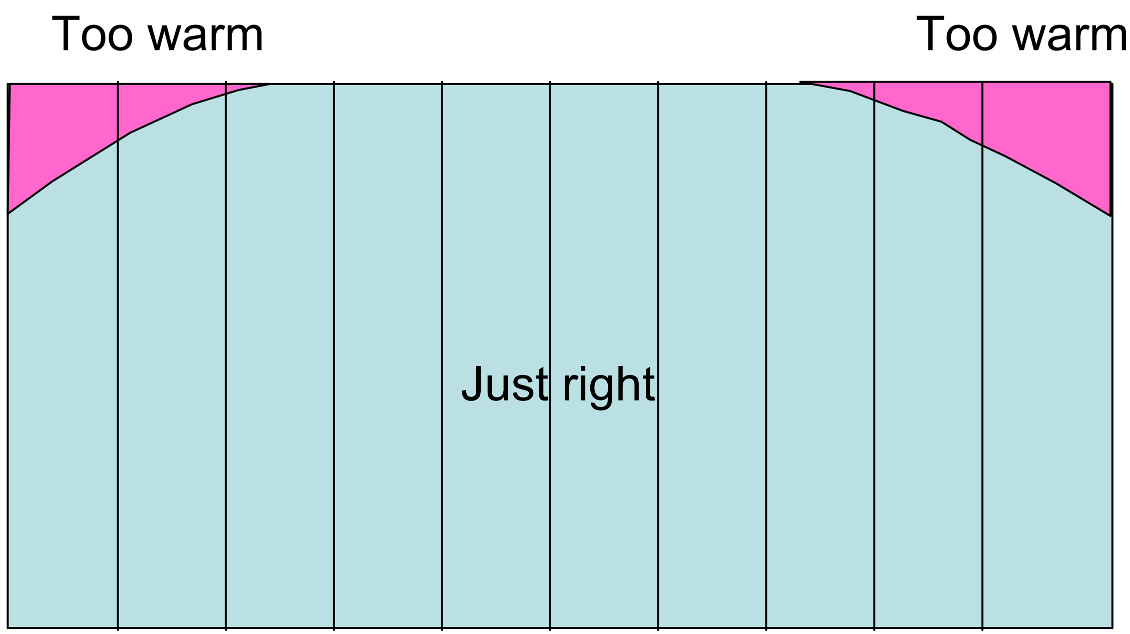
Typical temperature profile with underfloor supply



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

Typical temperature profile with overhead supply



Elevation at a cold aisle looking at racks

Overhead (OH) vs. underfloor (UF)

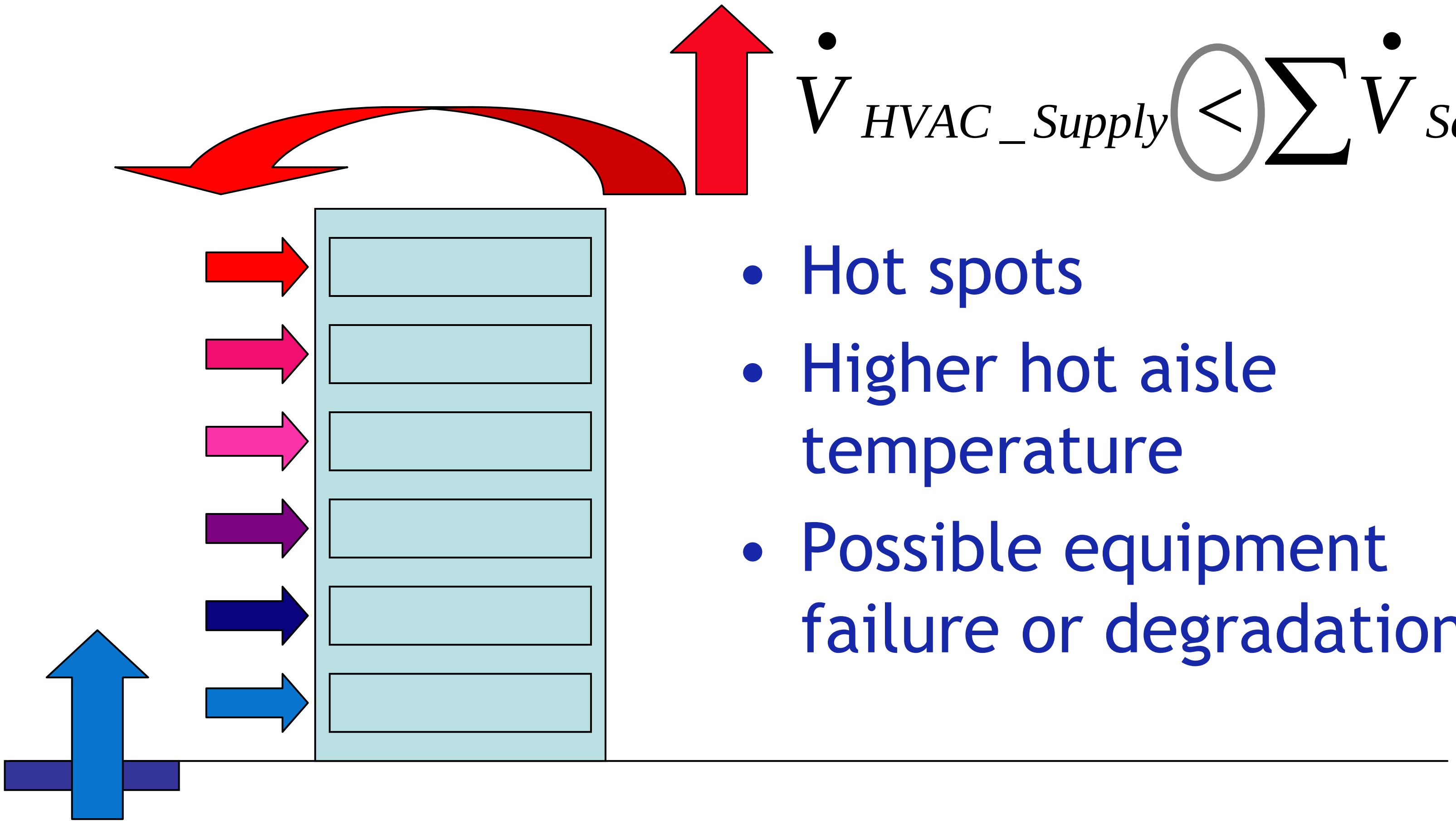
Issue	**Overhead (OH) Supply**	**Underfloor (UF) Supply**
Capacity	Limited by space and aisle velocity.	Limited by free area of floor tiles.
Balancing	Continuous on both outlet and branch.	Usually limited to incremental changes by diffuser type. Some tiles have balancing dampers. Also underfloor velocities can starve floor grilles!
Control	Up to one pressure zone by branch.	Only one pressure zone per floor, can provide multiple temperature zones.
Temperature Control	Most uniform.	Commonly cold at bottom and hot at top.
First Cost	Best (if you eliminate the floor).	Generally worse.
Energy Cost	Best.	Worst.
Flexibility	Harder to reconfigure	Easiest
Aisle Capping	Hot or cold aisle possible.	Hot or cold aisle possible.

Airflow design disjoint

- IT departments select servers and racks – each having airflow requirements
- Engineers size the facility fans and cooling capacity
- What's missing in this picture?

What happens when the HVAC systems have less airflow than the servers?

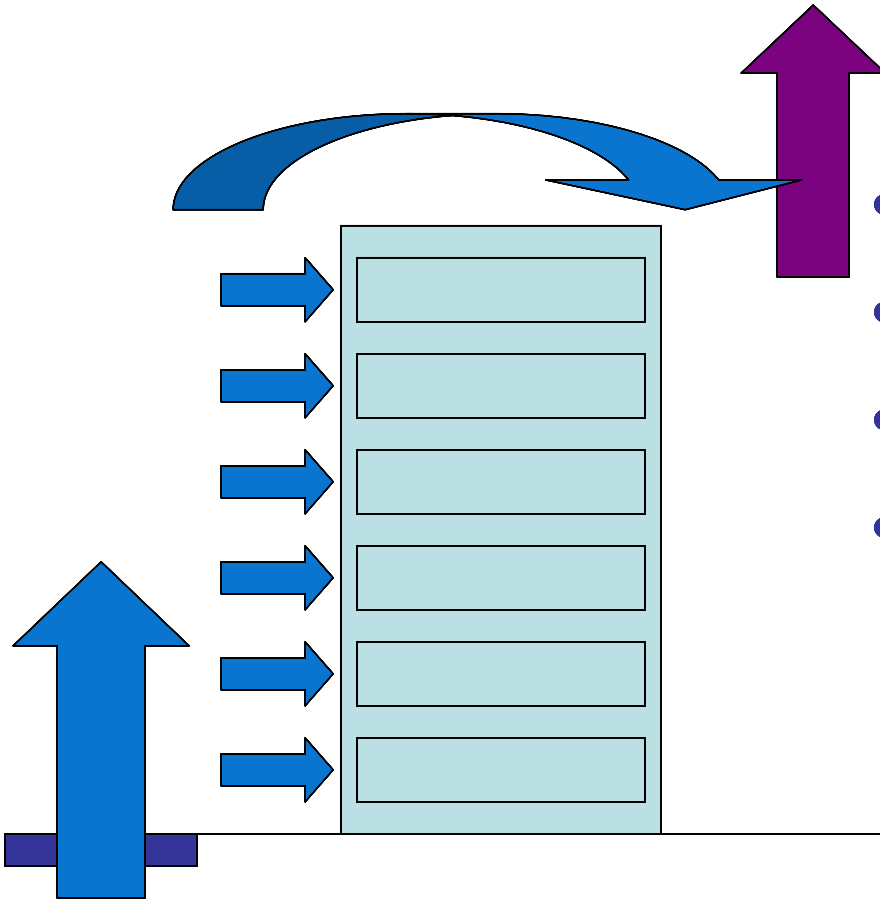
$$\dot{V}_{HVAC\_Supply} < \sum \dot{V}_{Servers}$$



- Hot spots
- Higher hot aisle temperature
- Possible equipment failure or degradation

What happens when the HVAC systems have more airflow than the servers?

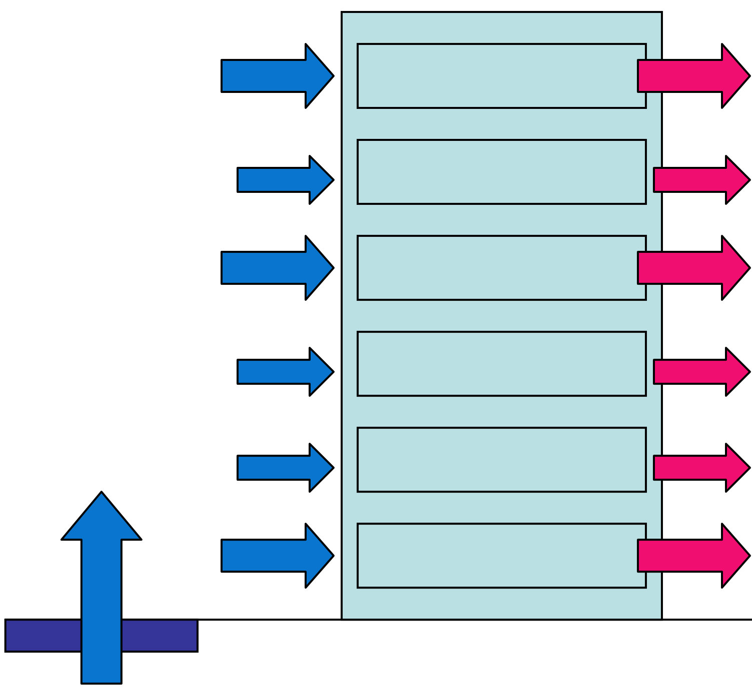
$$\dot{V}_{HVAC\_Supply} > \sum \dot{V}_{Servers}$$



- Least hot spots
- Higher air velocities
- Higher fan energy
- Reduced economizer effectiveness (due to lower return temperatures)

In a perfect world, variable flow supply and server fans…

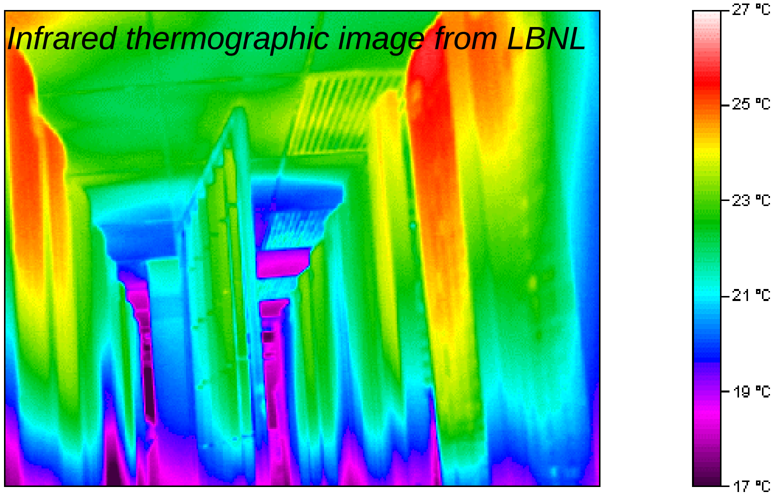
$$\dot{V}_{HVAC\_Supply} \approx \sum \dot{V}_{Servers}$$



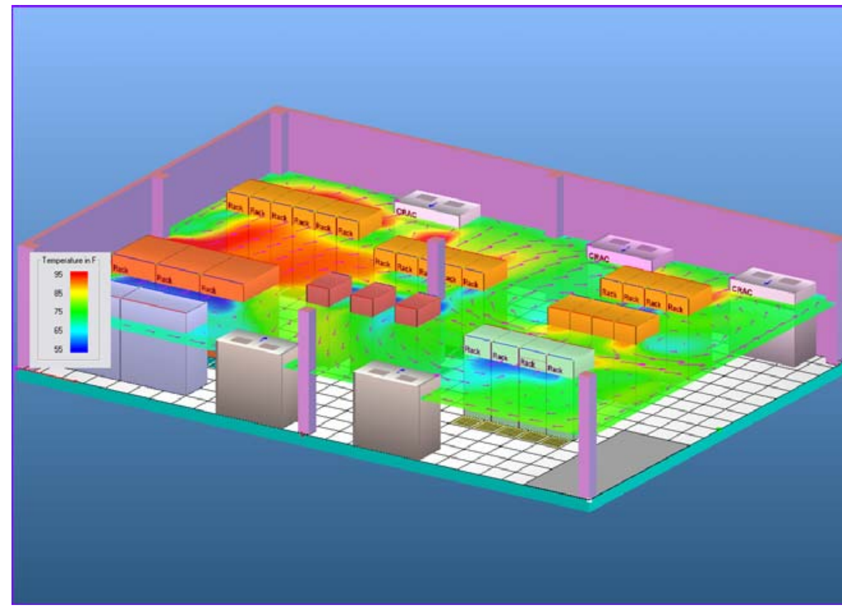
- Partial flow condition
- Best energy performance but tricky to control
- Works best with aisle containment

How do you balance airflow?

- Spreadsheet
- CFD
- Monitoring, infrared thermography or other site measurements
- Using aisle containment

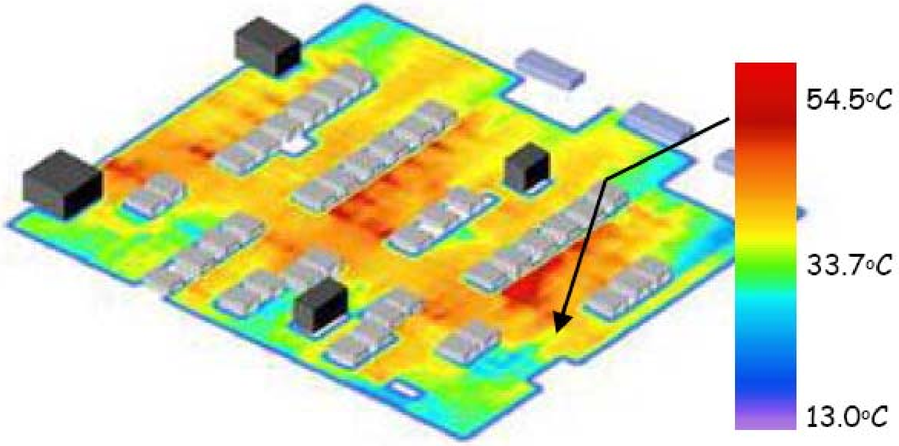


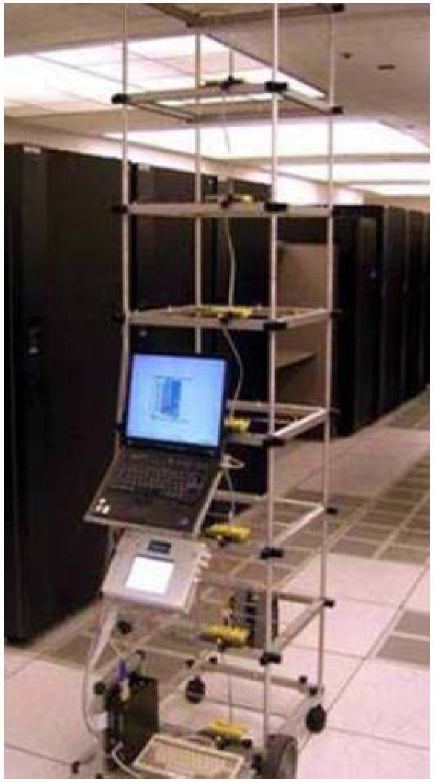
Infrared thermographic image from LBNL



CFD image from TileFlow http://www.inres.com/Products/TileFlow/tileflow.html, Used with permission from Innovative Research, Inc.

IBM’s MMT technology





This is a single snapshot, but the data center is dynamic

SynapSense Wireless Sensor Network

- Wireless sensor network
- “Self-organizing” nodes
- 802.15.4 (not 802.11)
- Multi-hop routing
- Non-invasive installation
- 2 internal & 6 external sensors per node
- Can measure temp., humidity, pressure, current, liquid flow, liquid presence & particle count.
- Approximately $90/point installed (10%-20% of standard DDC costs)

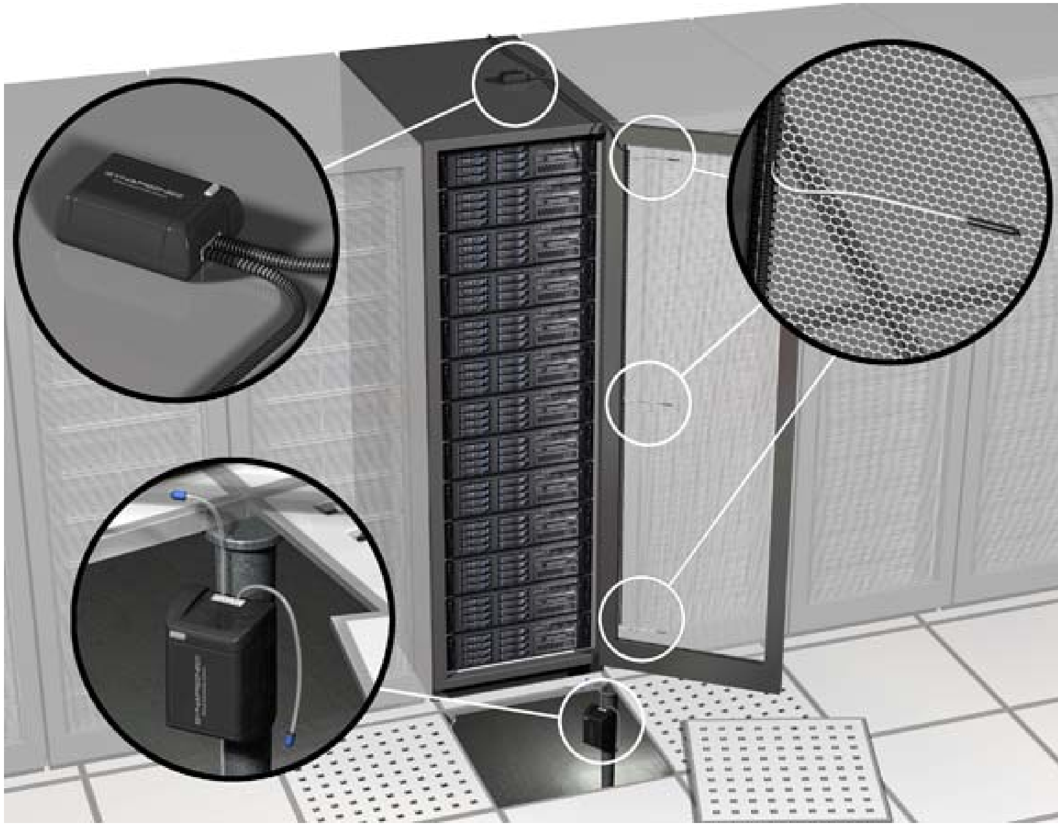
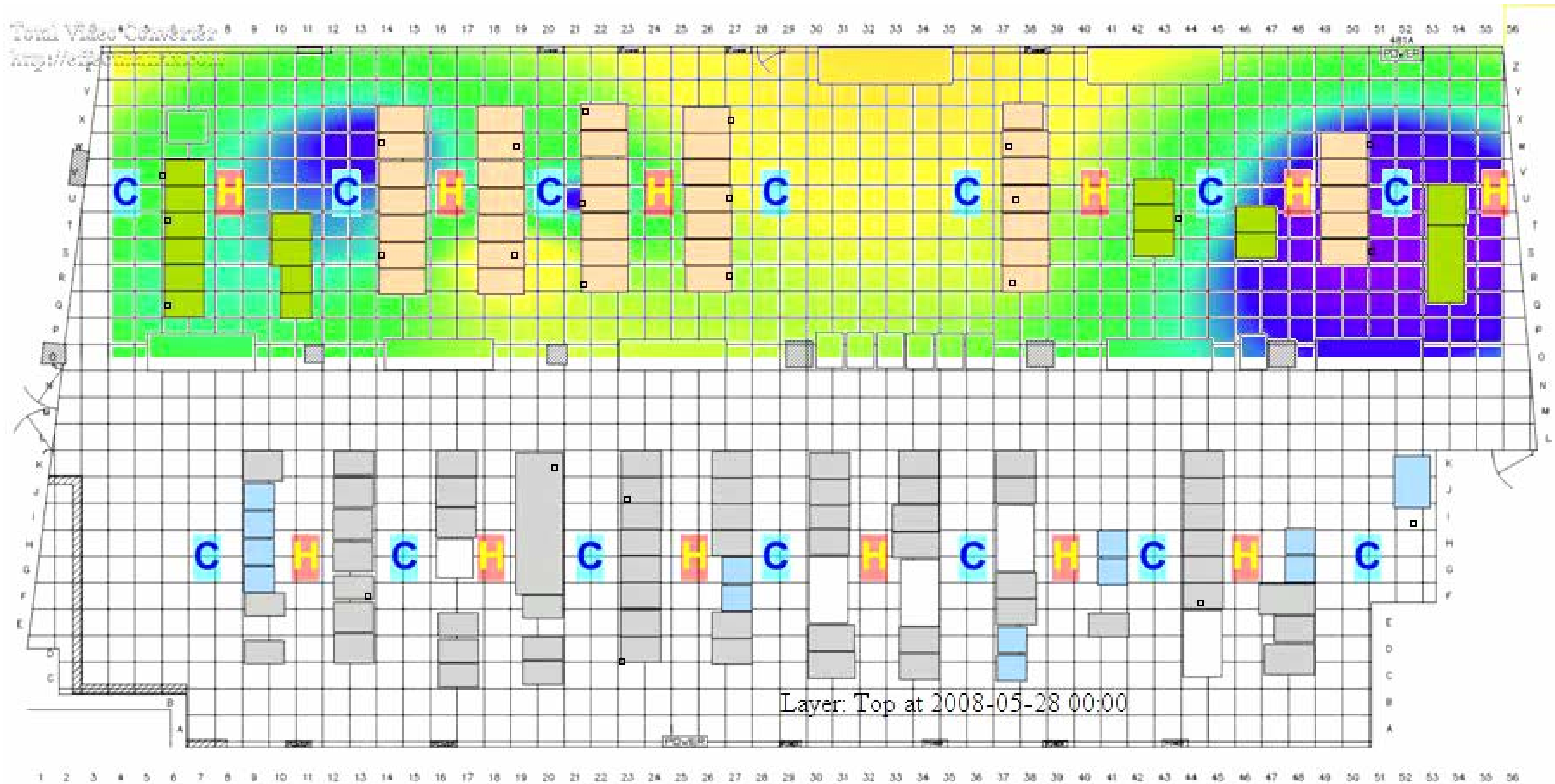


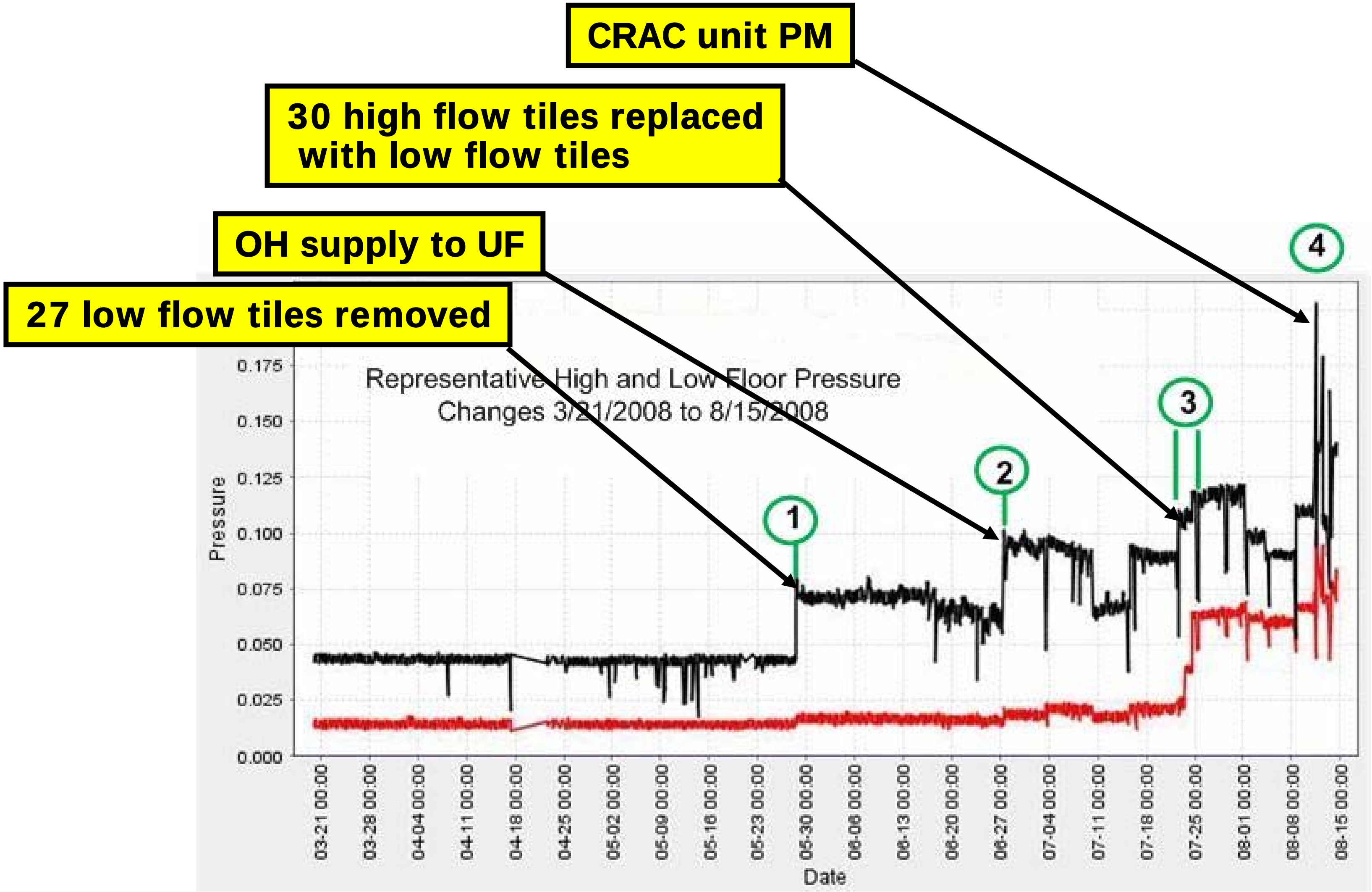
Image: SynapSense

SynapSense ‘LiveImaging’



This is a dynamic and tracks progress of the retrofits

SynapSense case study



SynapSense case study results (so far)

- 7% increase (~30kW) in IT load with 8% less fan energy
- CRAC unit setpoints 3°F warmer
- Fewer hot spots
- (1) 15 ton unit turned off
- (1) extra 15 ton unit on-line but redundant
- The wireless sensor network enabled facilities to visualize, track and fine tune many changes in the data center including tuning of the floor tiles

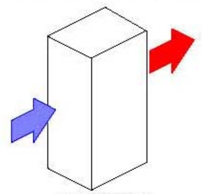
ASHRAE Thermal Report

XYZ Co. Model abc Server: Representative Configurations

Description	Condition: Voltage 110 Volts — Typical Heat Release (watts)	Airflow[a], Nominal (cfm)	Airflow[a], Nominal (m^3/h)	Airflow, Maximum at 35°C (cfm)	Airflow, Maximum at 35°C (m^3/h)	Weight (lbs)	Weight (kg)	Overall System Dimensions[b] (W × D × H) (in.)	Overall System Dimensions[b] (W × D × H) (mm)
Minimum Configuration	*1765*	*400*	*680*	*600*	*1020*	*896*	*406*	*30 × 40 × 72*	*762 × 1016 × 1828*
Full Configuration	*10740*	*750*	*1275*	*1125*	*1913*	*1528*	*693*	*61 × 40 × 72*	*1549 × 1016 × 1828*
Typical Configuration	*5040*	*555*	*943*	*833*	*1415*	*1040*	*472*	*30 × 40 × 72*	*762 × 1016 × 1828*

ASHRAE Class

1, 2, 3



Minimum Configuration	*1 CPU-A, 1 GB, 2 I/O*
Full Configuration	*8 CPU-B, 16 GB, 64 I/O (2 GB cards, 2 frames)*
Typical Configuration	*4 CPU-A, 8 GB, 32 I/O (2 GB cards, 1 frame)*

a. The airflow values are for an air density of 1.2 kg/m^3 (0.075 lb/ft^3). This corresponds to air at 20°C (68°F), 101.3 kPA (14.7 psia), and 50% relative humidity.
b. Footprint does not include service clearance or cable management, which is zero on the sides, 46 in. (1168 mm) in the front, and 40 in. (1016 mm) in the rear.

From ASHRAE's Thermal Guidelines for Data Processing Environments

What’s the IT equipment airflow?

	SUN	SUN	DELL	DELL
	V490	V240	2850	6850
num fans	9	3	n/a	n/a
total CFM (max)	150	55.65	42	185
total CFM (min)			27	126
fan speed	single speed	variable	2 speed	2 speed
fan control	n/a	inlet temp.	77F inlet	77F inlet
Form Factor (in U's)	5	2	2	4
heat min config (btuh)		798		454
heat max config (btuh)	5,459	1,639	2,222	4,236
heat max (watts)	1,599	480	651	1,241
dT min config	-	13	-	3
dT max config	33	27	48	21
servers per rack	8	21	21	10
CFM/rack (hi inlet temp)	1,200	1,169	882	1,850
CFM/rack (low inlet temp)	1,200		567	1,260
max load / rack (kW)	13	10	14	12

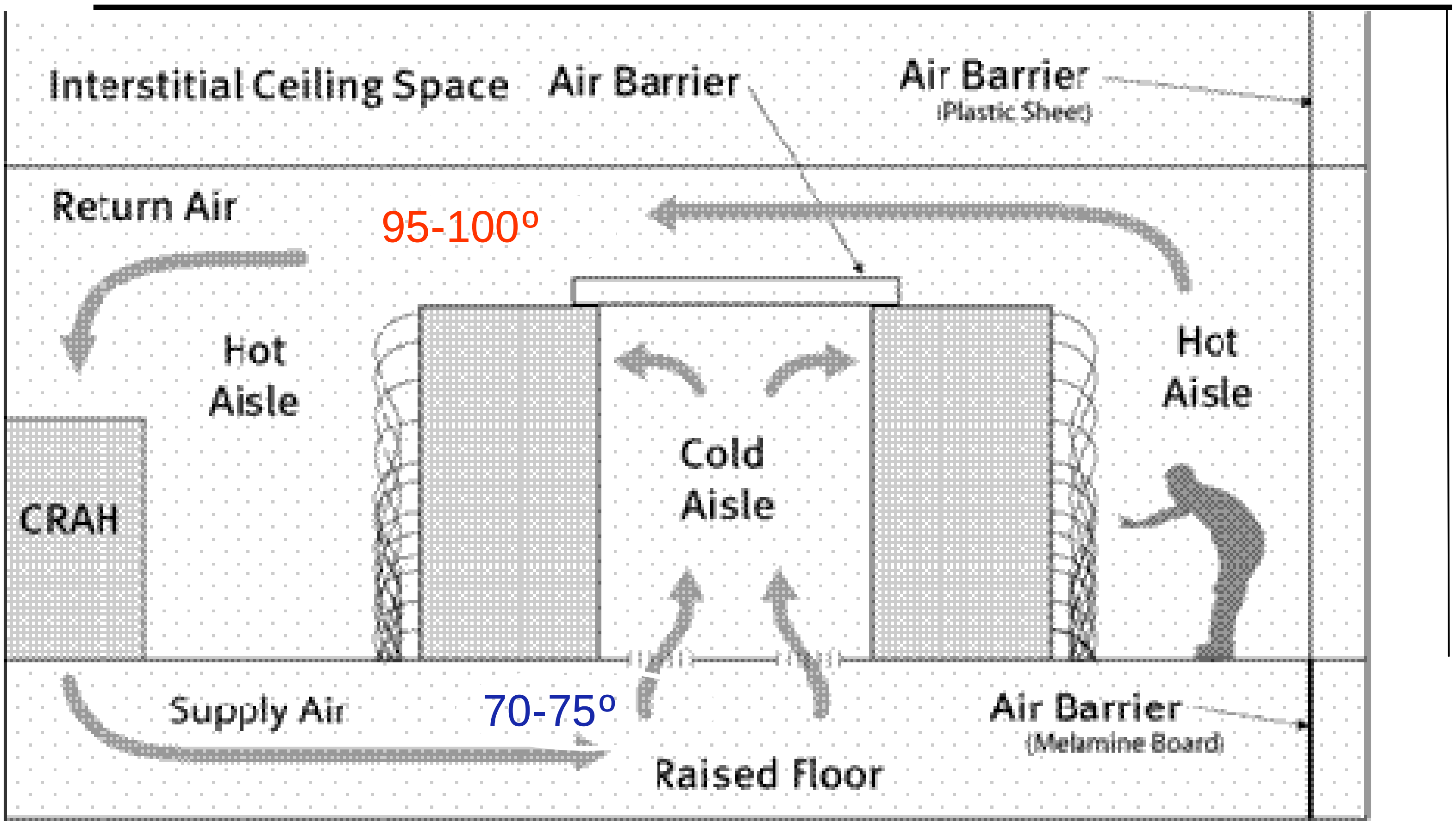
Higher DT means lower fan energy
Minimum server DT recommended for the Energy Star server specification

Isolating hot or cold aisles

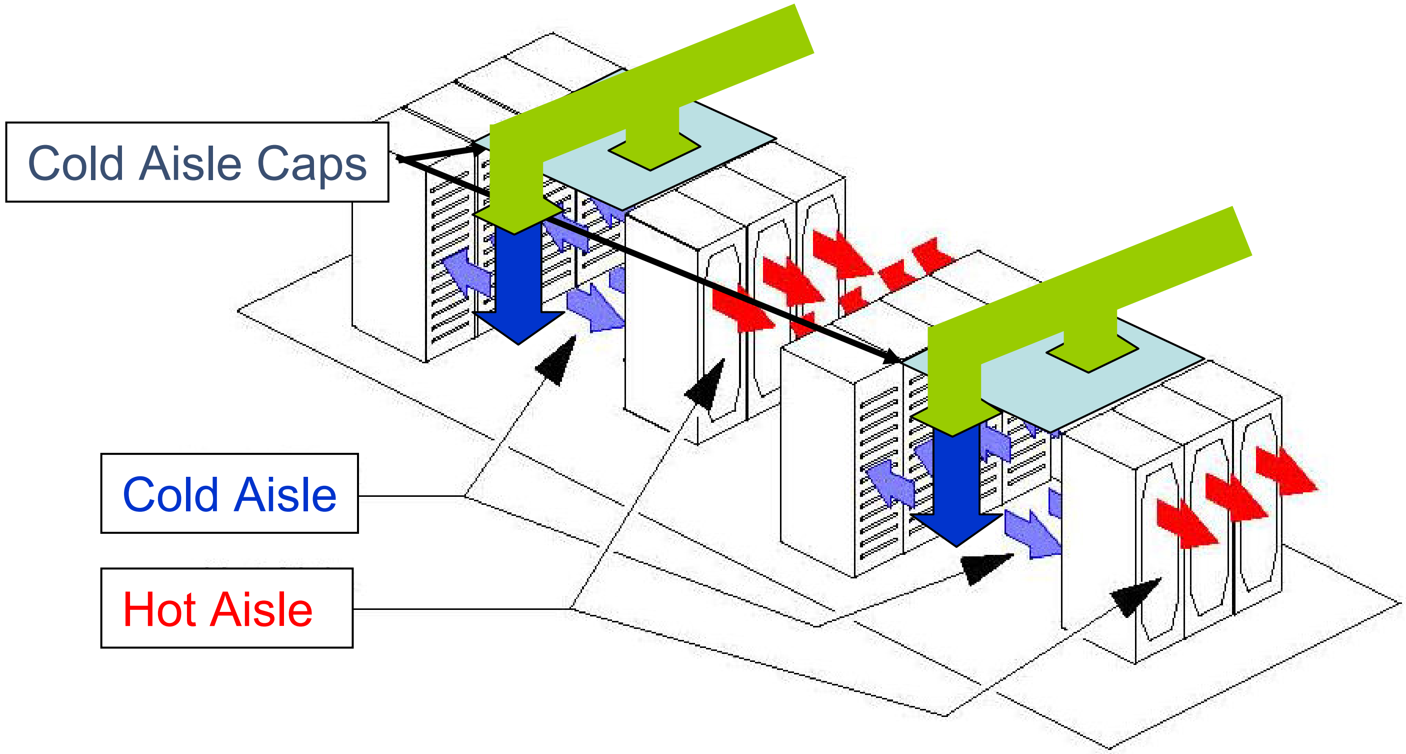
- Energy intensive IT equipment needs good isolation of “cold” inlet and “hot” discharge.
- Supply airflow can be reduced if no mixing occurs.
- Overall temperature can be raised in the data center if air is delivered to equipment without mixing.
- Cooling systems and economizers use less energy with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

Cold aisle containment, underfloor supply

With cold aisle containment, the general data center is hot 85-100F

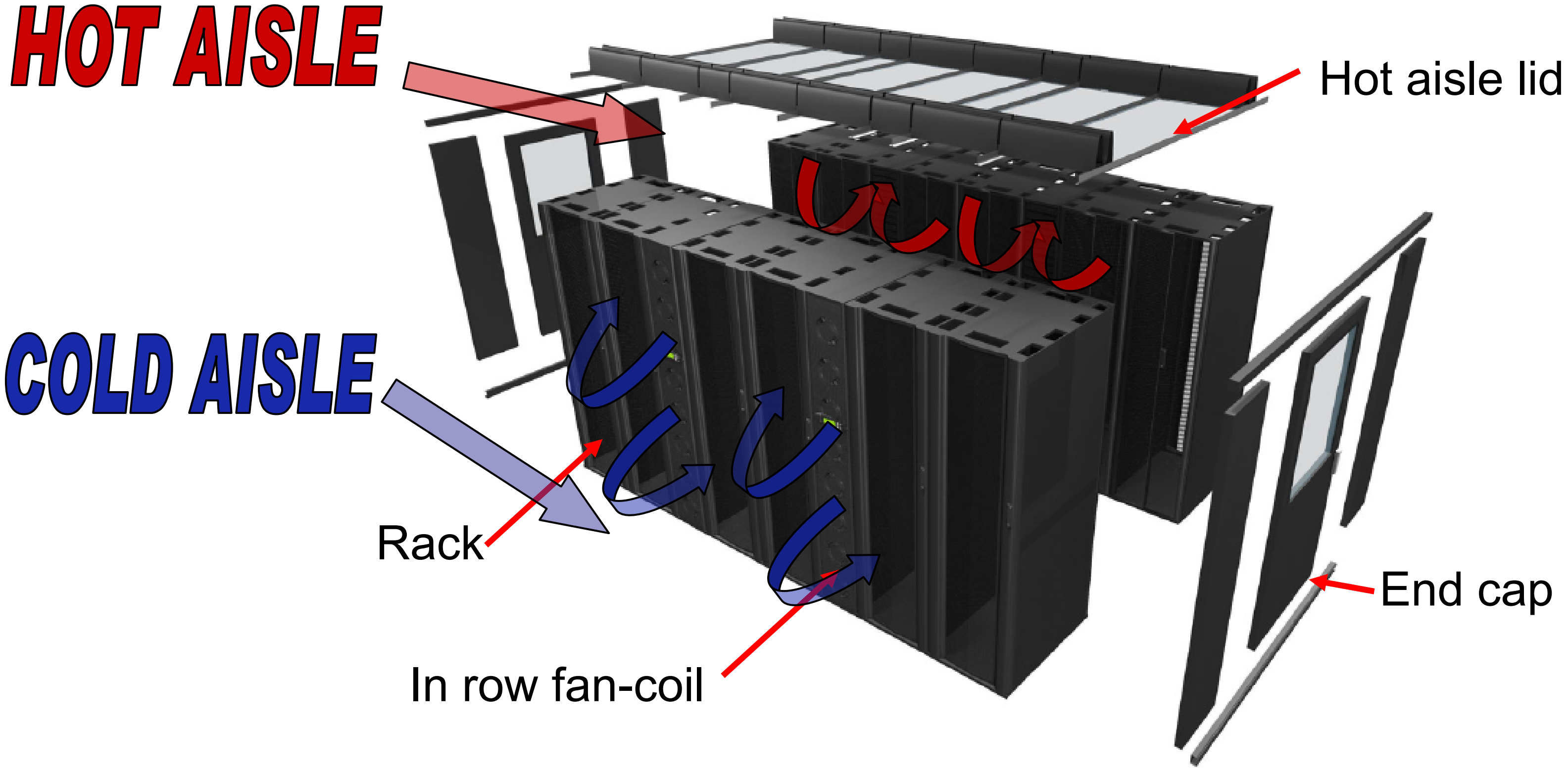


Cold aisle containment, overhead supply

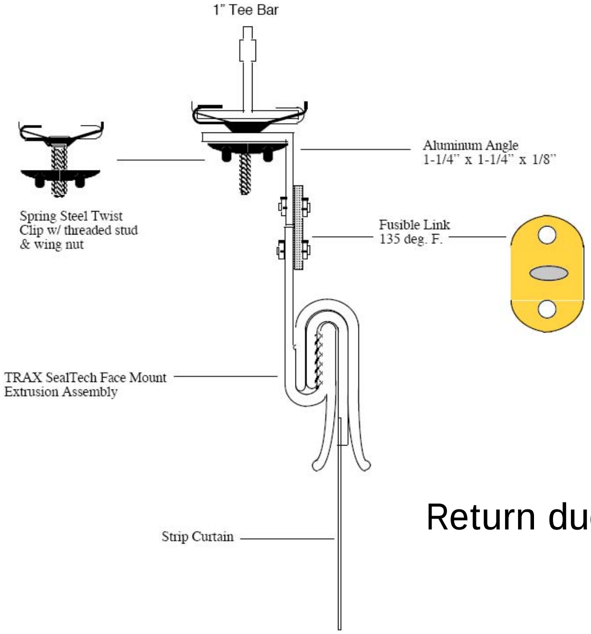


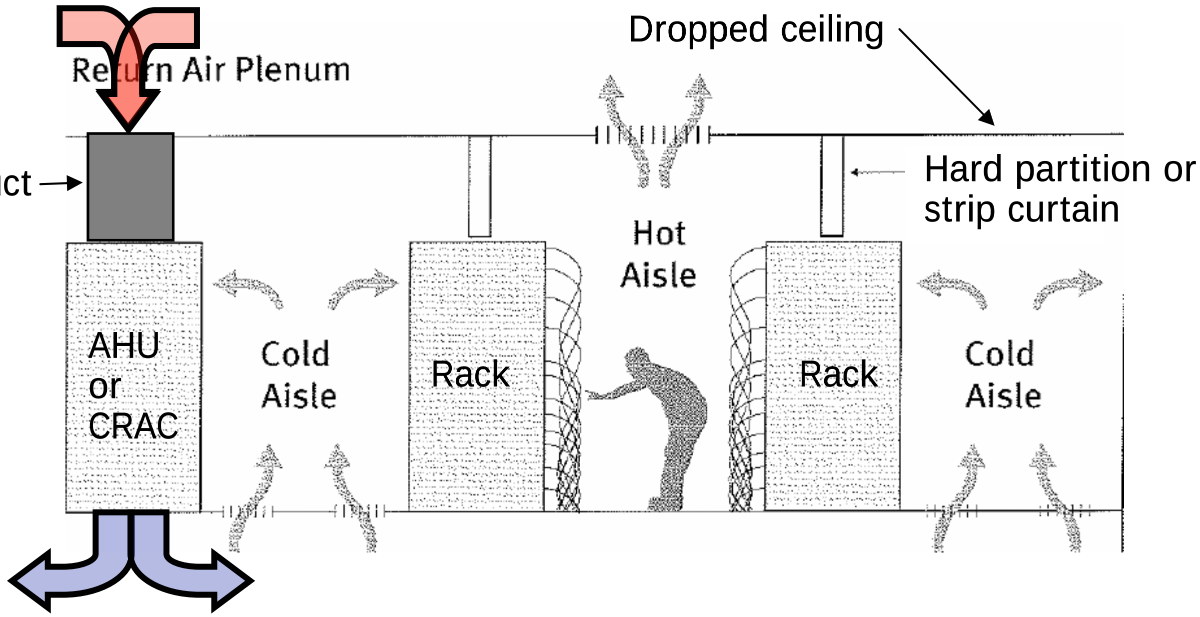
Hot aisle containment with in row cooling

With hot aisle containment, the general data center is neutral (70-75F)



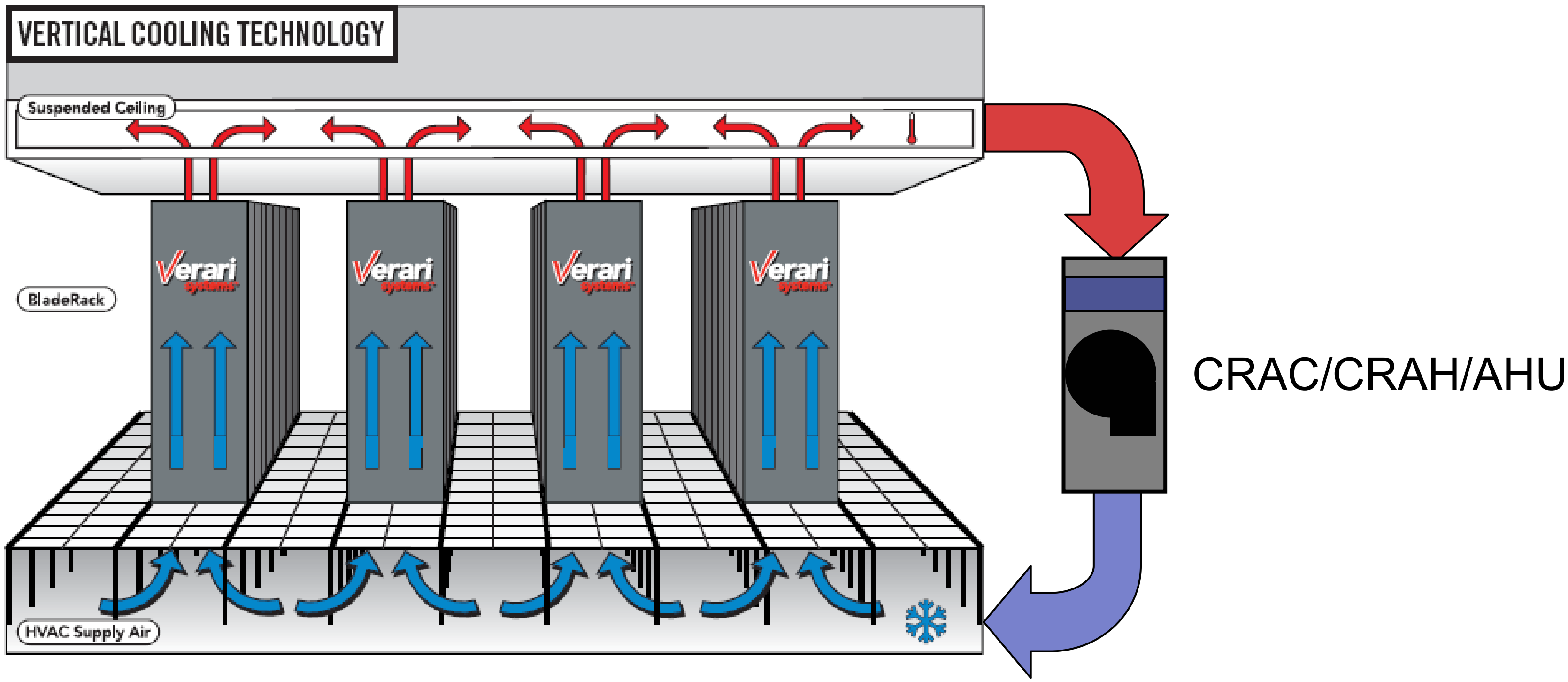
Hot aisle containment the frugal way





Combined hot and cold aisle containment

In this model the data center can be controlled for comfort



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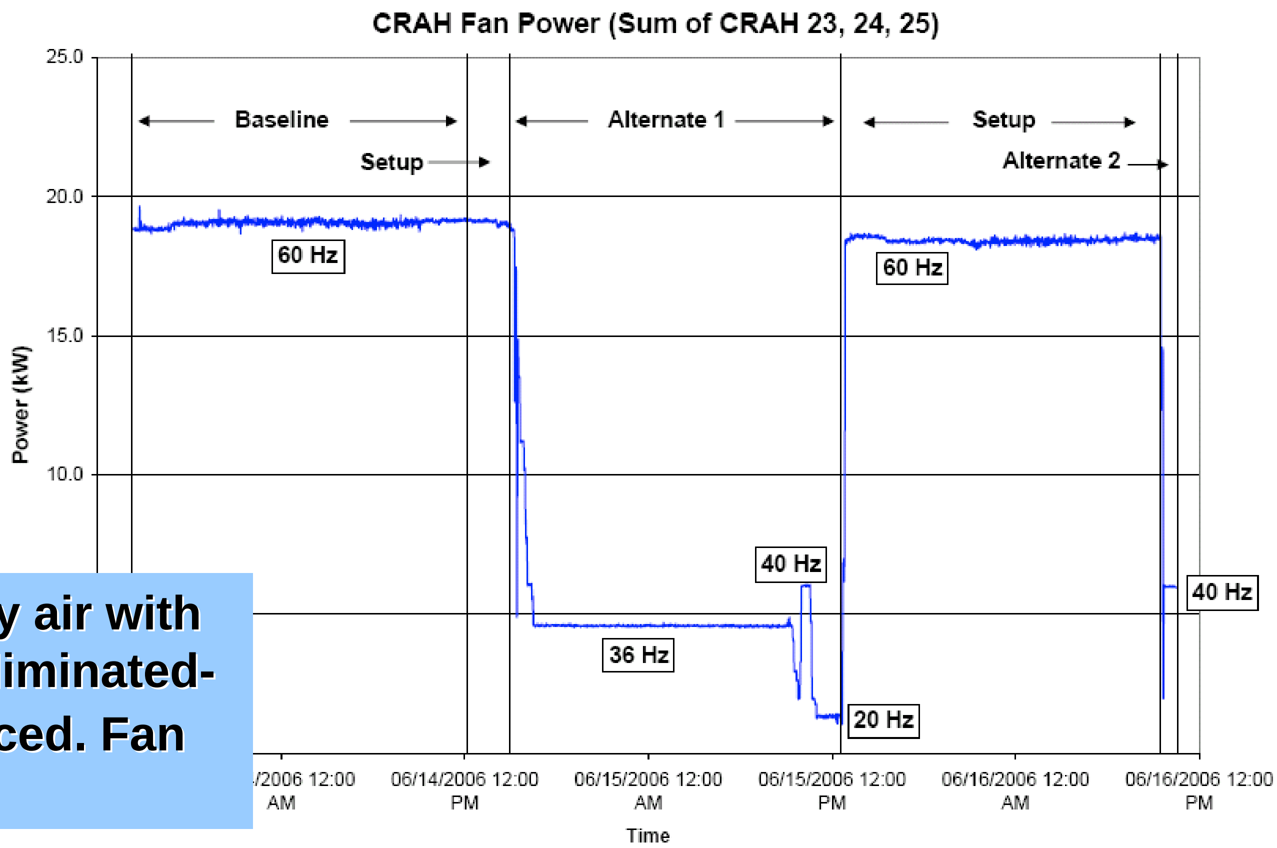
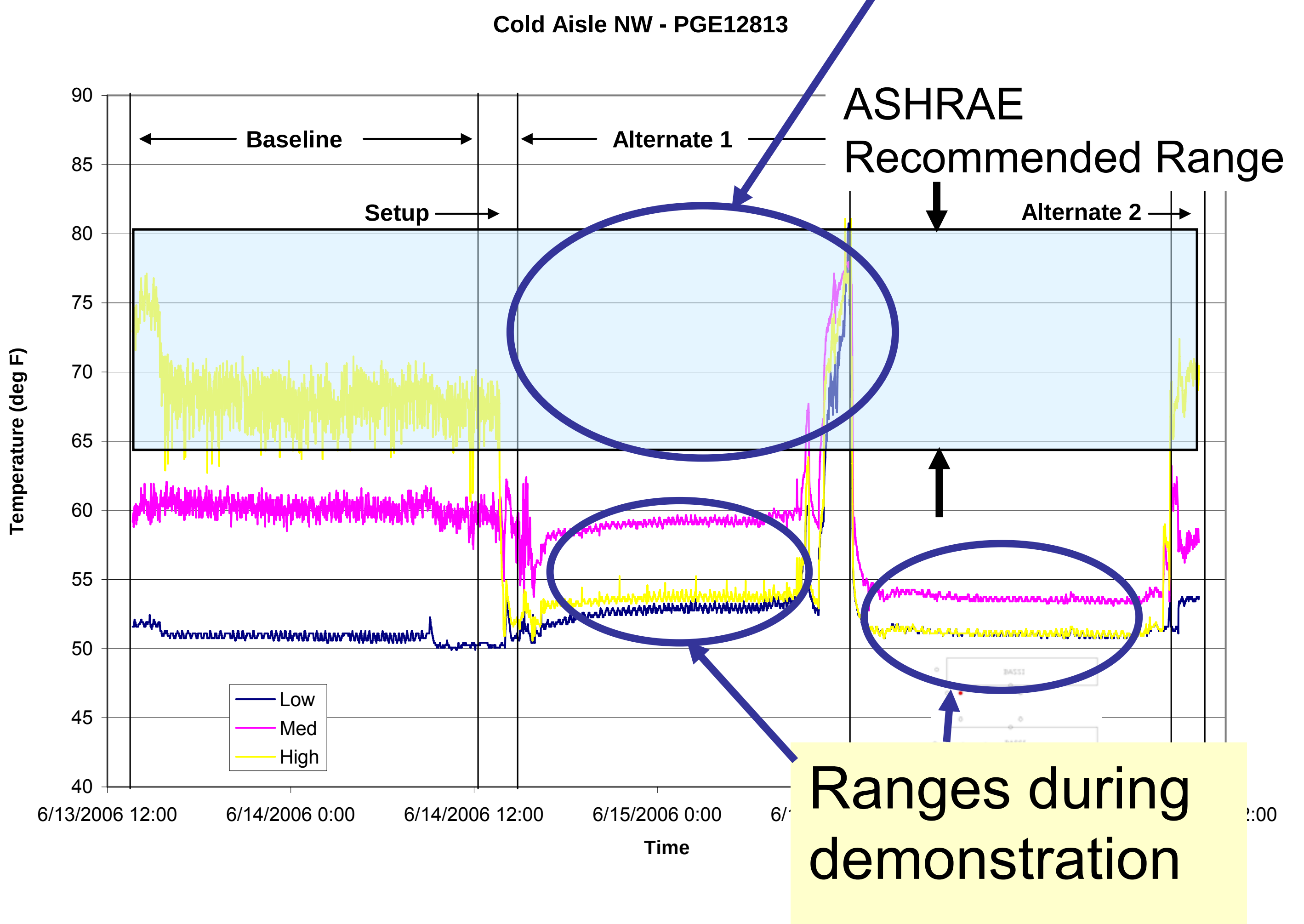
LBNL cold aisle containment demo



If mixing of cold supply air with hot return air can be eliminated- fan speed can be reduced. Fan Energy Savings ~ 75%

LBNL cold aisle containment demo

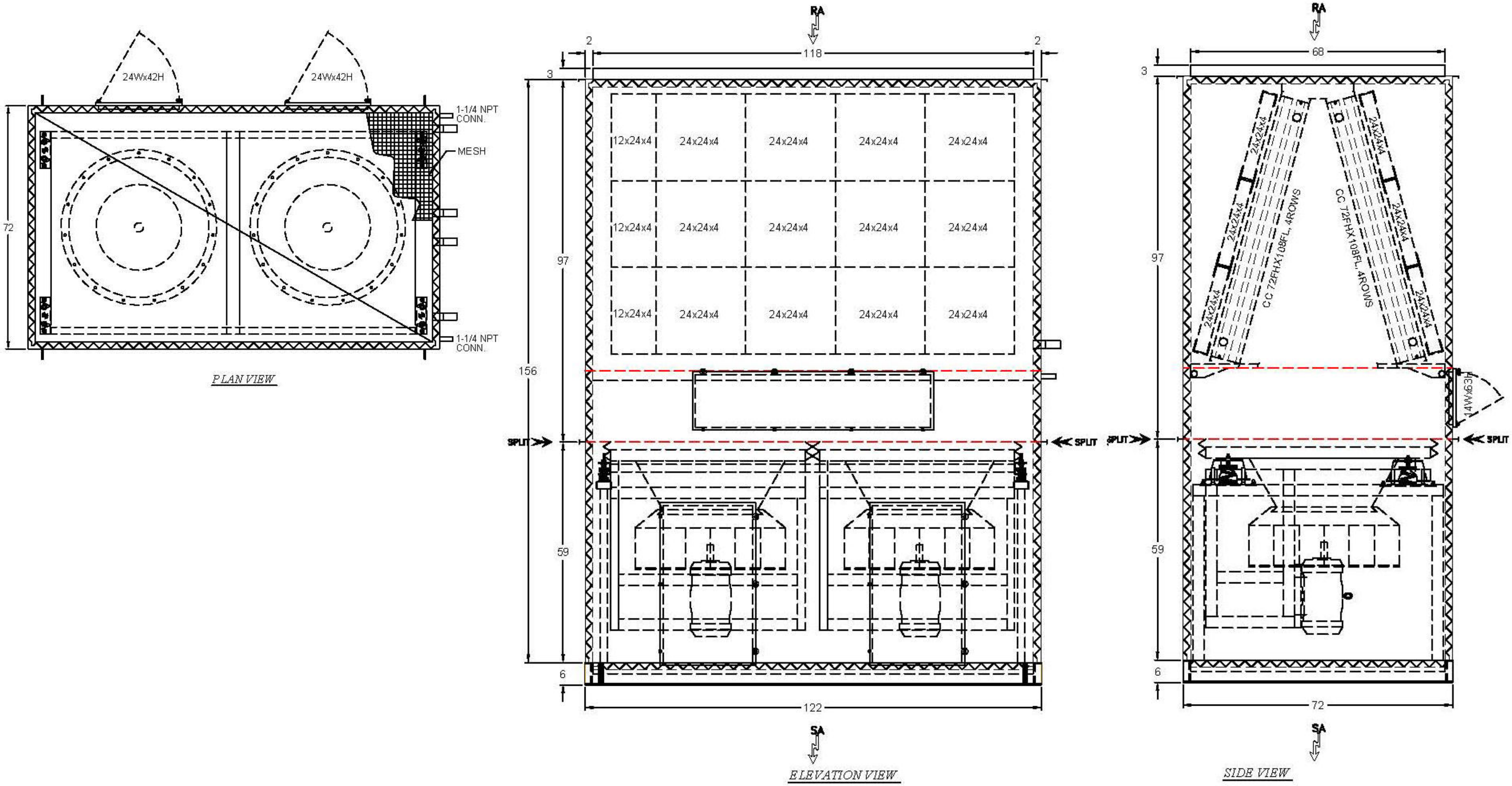
Better airflow management permits warmer supply temperatures!



Aisle capping review

- Can be retrofit.
- Both hot and cold aisle containment work.
- Hot aisle (or in-rack containment) will make the general data center more comfortable.
- You have to think about fire protection with containment (sprinkler and FM200).
- Containment is more important than the location of the supply (OH vs UF).

Custom air handling units



Example custom CRAH unit comparison

	Option 1	Option 2	
Model	Std CRAC	Custom Model 1	Custom Model 2
Budget Cost	$ 16,235	$ 23,000	$ 41,000
Number of units	21	13	4
net total cooling (btuh)	434,900	410,000	841,000
net sensible (btuh)	397,400	399,000	818,000
sensible (tons)	33.1	33.3	68.2
CFM	16,500	25,000	50,000
SAT	49.90	59.30	59.00
airside dT	25.10	15.70	16.00
Internal SP	2	0.8	0.8
		1.8	1.8
no. fans	3	3	2
fan type	Centrifugal	Plenum	Plenum
no. motors	1	3	2
HP/motor	15	5	15
total HP	15	15	30
BHP/motor	15	4.7	11.5
Unit BHP	15	14.1	23
unit width	122	122	122
depth	35	36	72
height	76	156	168
filter type	ASHRAE 20%	MERV 13	MERV 13
Water PD (ft)	13.5 ft	11.1	11.1
CHW dT	14F	20	20
GPM	66.80	44.00	88.00
Total GPM	1,403	924	66%
Total BHP	315	275	87%

Example CRAH unit comparison

- 34% less water flow
- 13% less fan energy
  - More if you consider the supply air temperature and airflow issues
- Excess fan capacity on new units
- 36% higher cost for units, but
  - Fewer piping connections
  - Fewer electrical connections
  - Fewer control panels
  - No need for control gateway
  - Can use the existing distribution piping and pumps
  - Can use high quality sensors and place them where they make sense

CRAH Bid 2, 39 Units (~37 tons each)

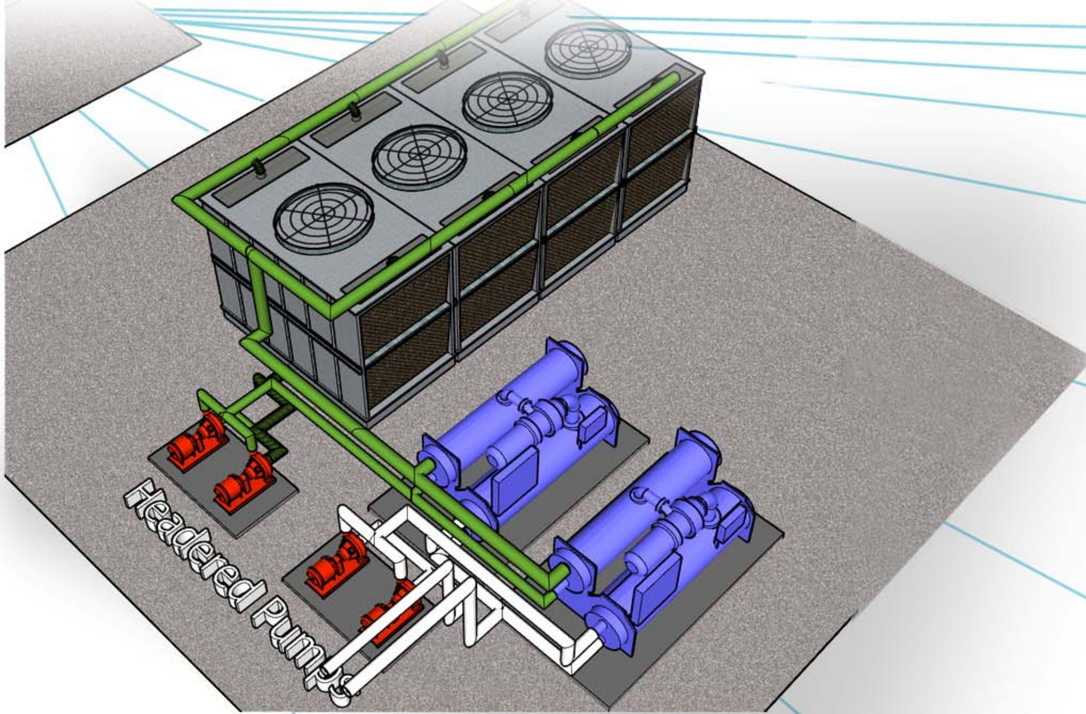
	Unit A	Unit B	B-A	(B-A)/A
First Cost	$ 779,680	$ 1,019,768	$ 240,088	31%
Airflow	666,900	702,000	35,100	5%
Fan bhp	10.65	7.6	(3.0)	-29%
Coil Flow (gpm)	59.1	44	(15)	-26%
DT (F)	15	20.1	5	34%
DP (feet)	14	7	(7)	-50%
kWh/yr	1,169,517	826,249	(343,268)	-29%
$/yr	$ 140,342	$ 99,150	$ (41,192)	-29%
NPV	$ 2,246,084	$ 2,055,764	(190,321)	-8%

- Comparison of 39 (n) CRAH units
- Unit B 30% higher installed costs but...
- Lower LCC: $40K/yr energy savings, $290K NPV
- Not included in this analysis:
  - Plant pumps dropped 50=>40hp (typ 5) and 20=>15hp (typ 6)
  - TES pipes dropped from 16”=>14” (~200 l.f. piping)
  - Chillers and pumps dropped from 10”=>8” (lots of appurtenances like valves, flow meters...)
  - 16% increase in TES ton-hrs with no change in the tank size

Best air delivery practices

- Arrange racks in hot aisle/cold aisle configuration.
- Plug leaks in floor and racks!
- Try to match or exceed server airflow by aisle.
  - Get thermal report data from IT if possible.
  - Plan for worst case.
- Get variable speed or two speed fans on servers if possible.
- Provide variable airflow fans for CRAC/H or AHU supply.
- Consider using air handlers rather than CRAHs for improved performance.
- Provide aisle capping (either hot or cold aisle works).
- Draw return from as high as possible.
- Consider CFD to inform design.
- Consider wireless sensors or thermal imaging to help balance the airflow.


Break



Free Cooling

Peter Rumsey, P.E.

RUMSEY ENGINEERS INC

Free Cooling Overview

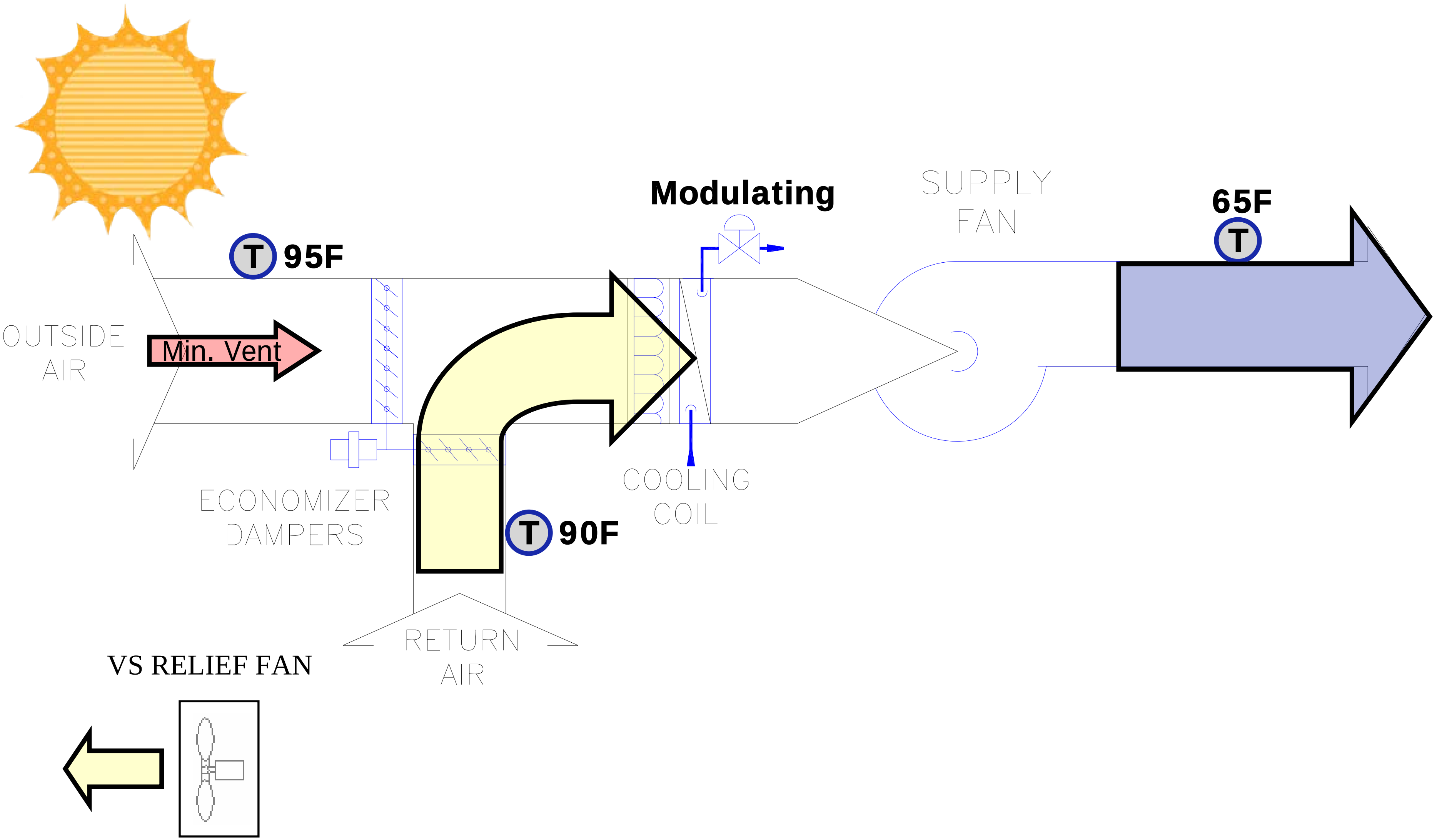
Air side economizers

- An overview of air-side economizers
- The potential energy savings of air-side economizers in the 16 ASHRAE climates
- The relationship of humidification and air-side economizers
- Challenges to implementing air-side economizers
- A combined air-side economizer with direct evaporative cooling (an emerging technology)
- Non-energy benefits of air-side economizers

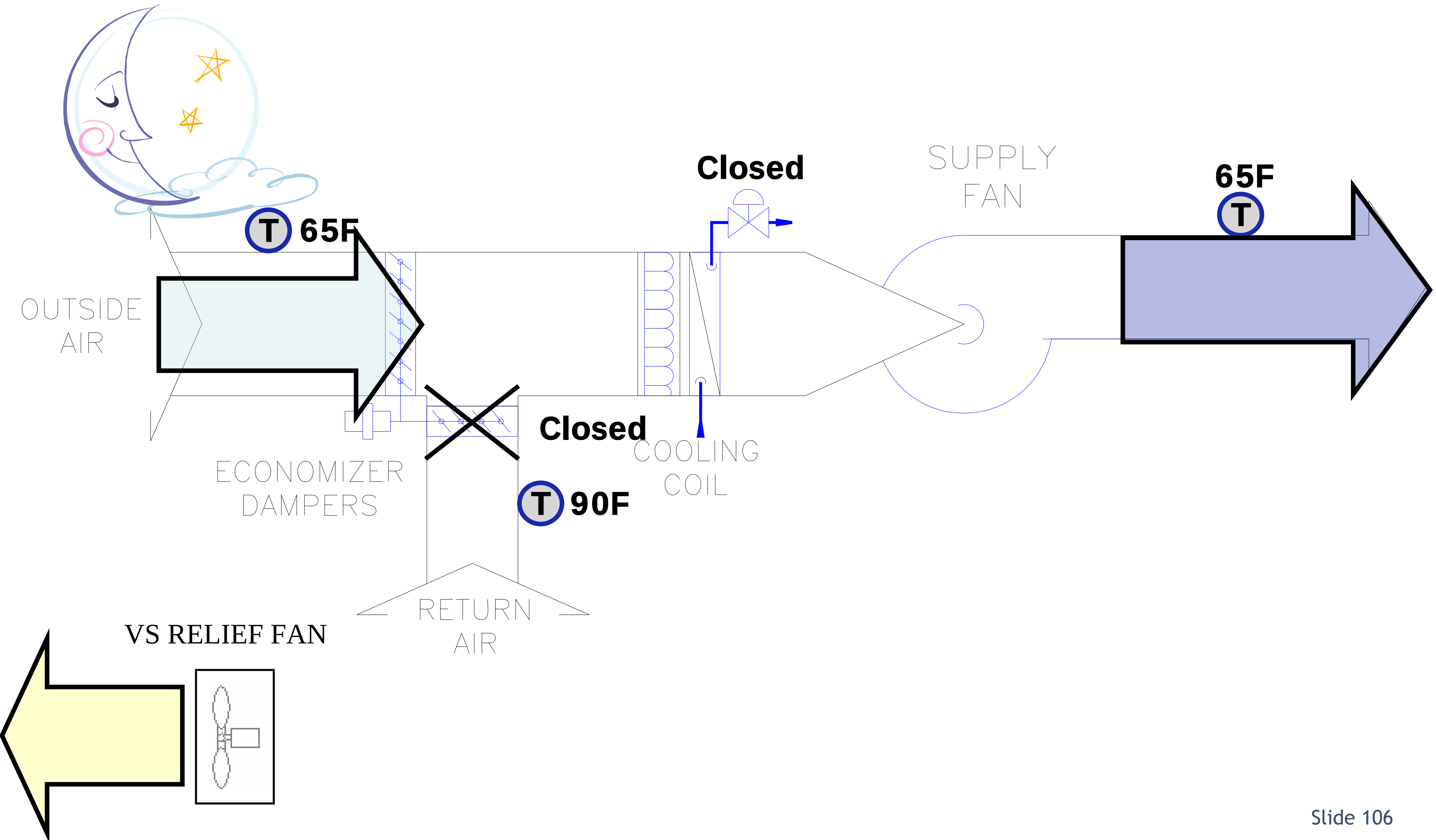
Water side economizers

- An overview of water-side economizers
- The potential energy savings of water-side economizers
- Challenges to implementing water-side economizers
- Non-energy benefits of water-side economizers

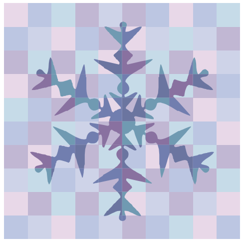
Air-side economizer

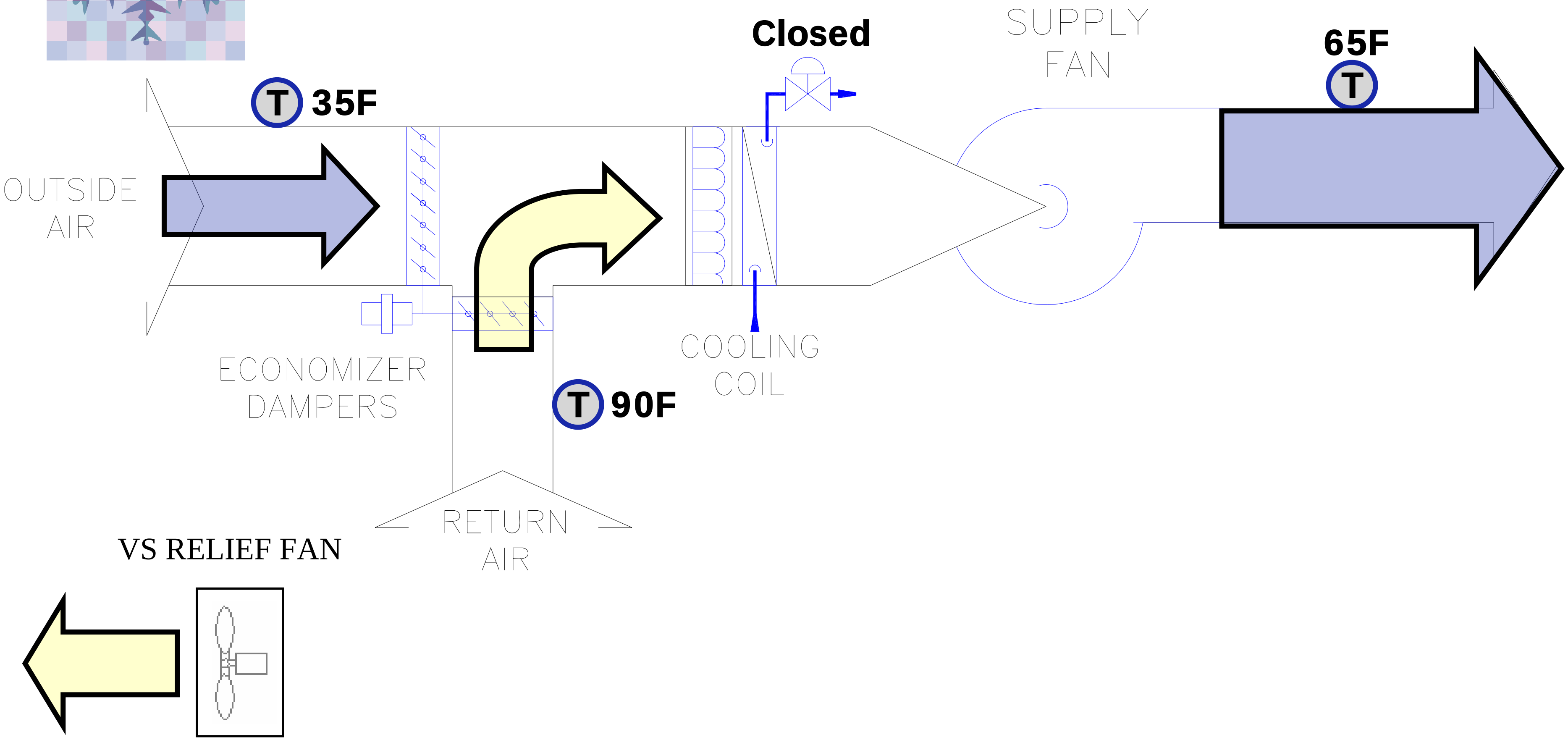


Air-side economizer



Air-side economizer

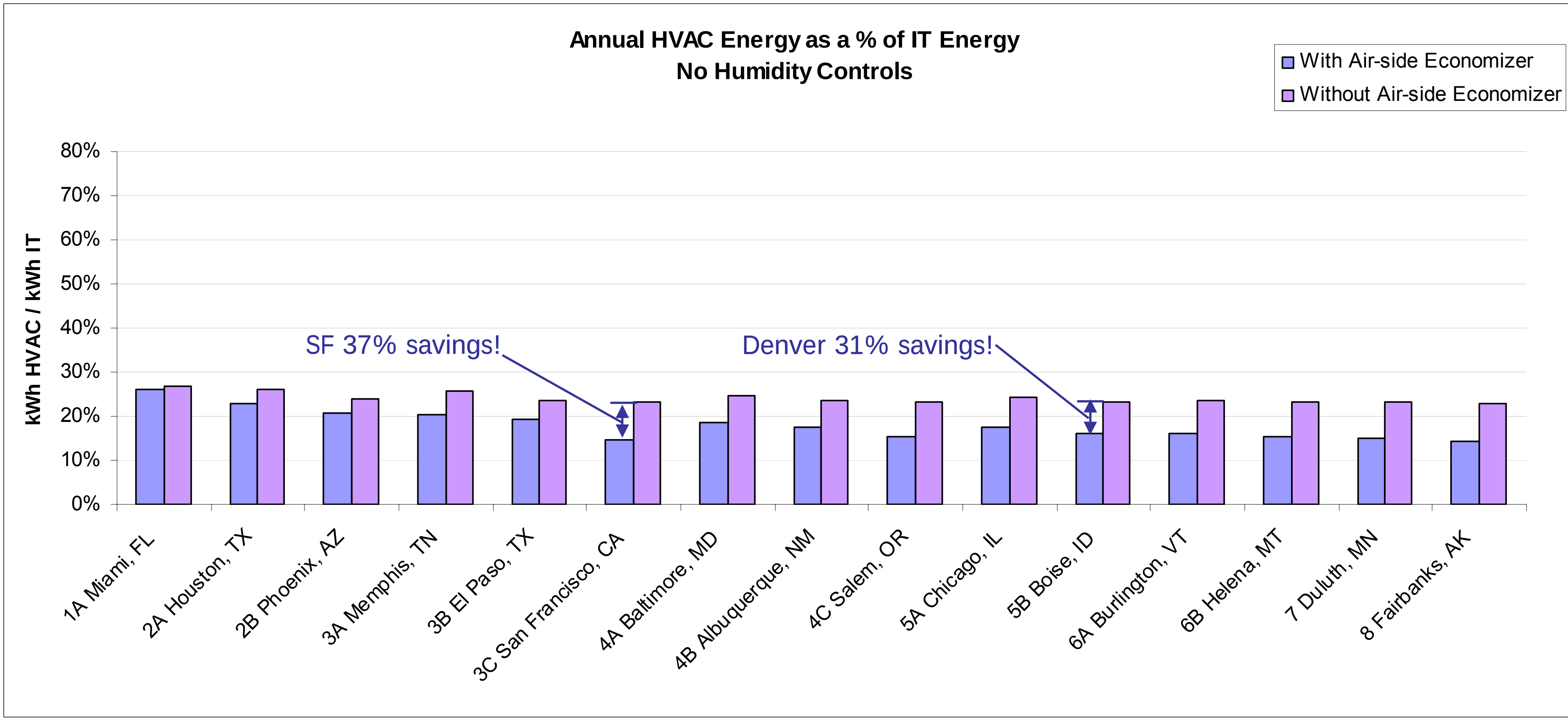




Air side economizer elements

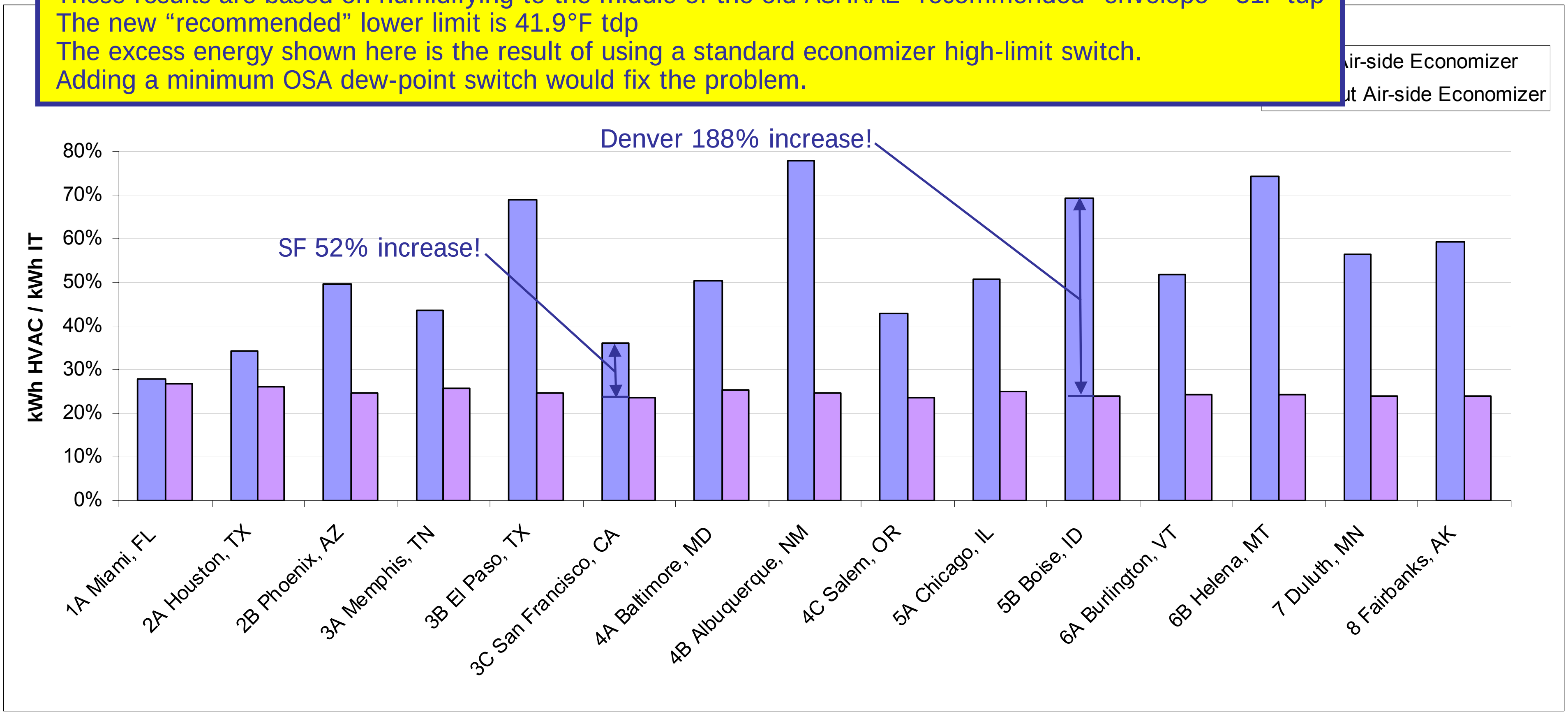
- Dampers
  - OSA
  - RA
- Temperature sensors
  - SAT
  - RAT
  - OAT
- High limit switch
- Minimum position control (ventilation)
- Space pressure control
  - Barometric or powered

Air-side economizer savings: no humidification and code minimum water-cooled chilled water plant

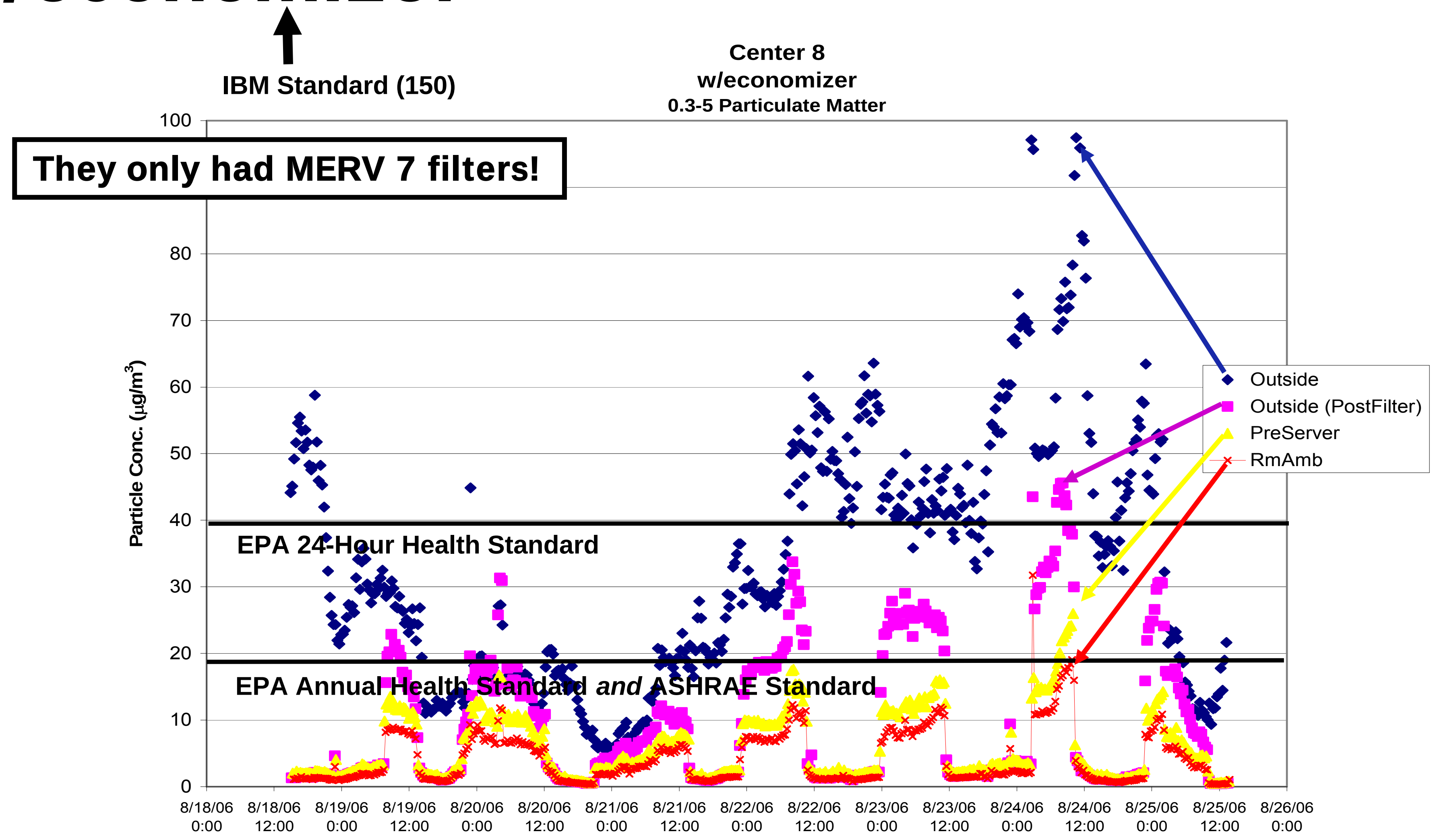


Air-side economizer savings? with humidification and code minimum water-cooled chilled water plant

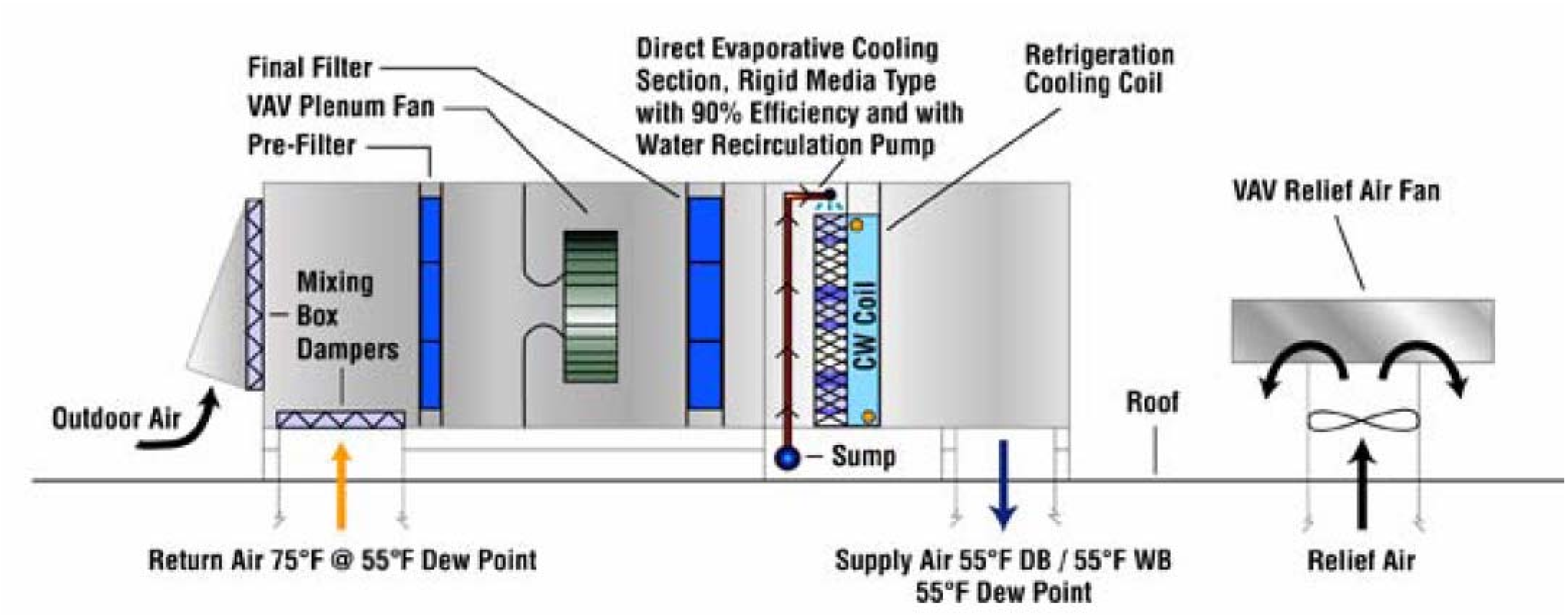
These results are based on humidifying to the middle of the old ASHRAE "recommended" envelope ~51F tdp
The new "recommended" lower limit is 41.9°F tdp
The excess energy shown here is the result of using a standard economizer high-limit switch.
Adding a minimum OSA dew-point switch would fix the problem.



LBNL particulate study at data center w/economizer



The “wet-bulb” economizer



Source: Mike Scofield and Tom Weaver Conservation Mechanical Systems

Economizers as emergency back-up

Direct Evaporative Cooling as Refrigeration Backup

Location	ASHRAE 0.4% Summer Design °F DB / WB	Resultant Room Condition with Ventilation Only °F DB / % RH	Resultant Room Condition with Evaporative Cooling °F DB / % RH
San Francisco, CA	83/63	103°F @ 18%	85°F @ 45%
Reno, NV	95/61	115°F @ 7%	84.4°F @ 43%
Salt Lake City, UT	96/62	116°F @ 8%	85.4°F @ 44%
Denver, CO	93/60	113°F @ 7%	83.3°F @ 43%
Albuquerque, NM	96/60	116°F @ 7%	83.6°F @ 42%

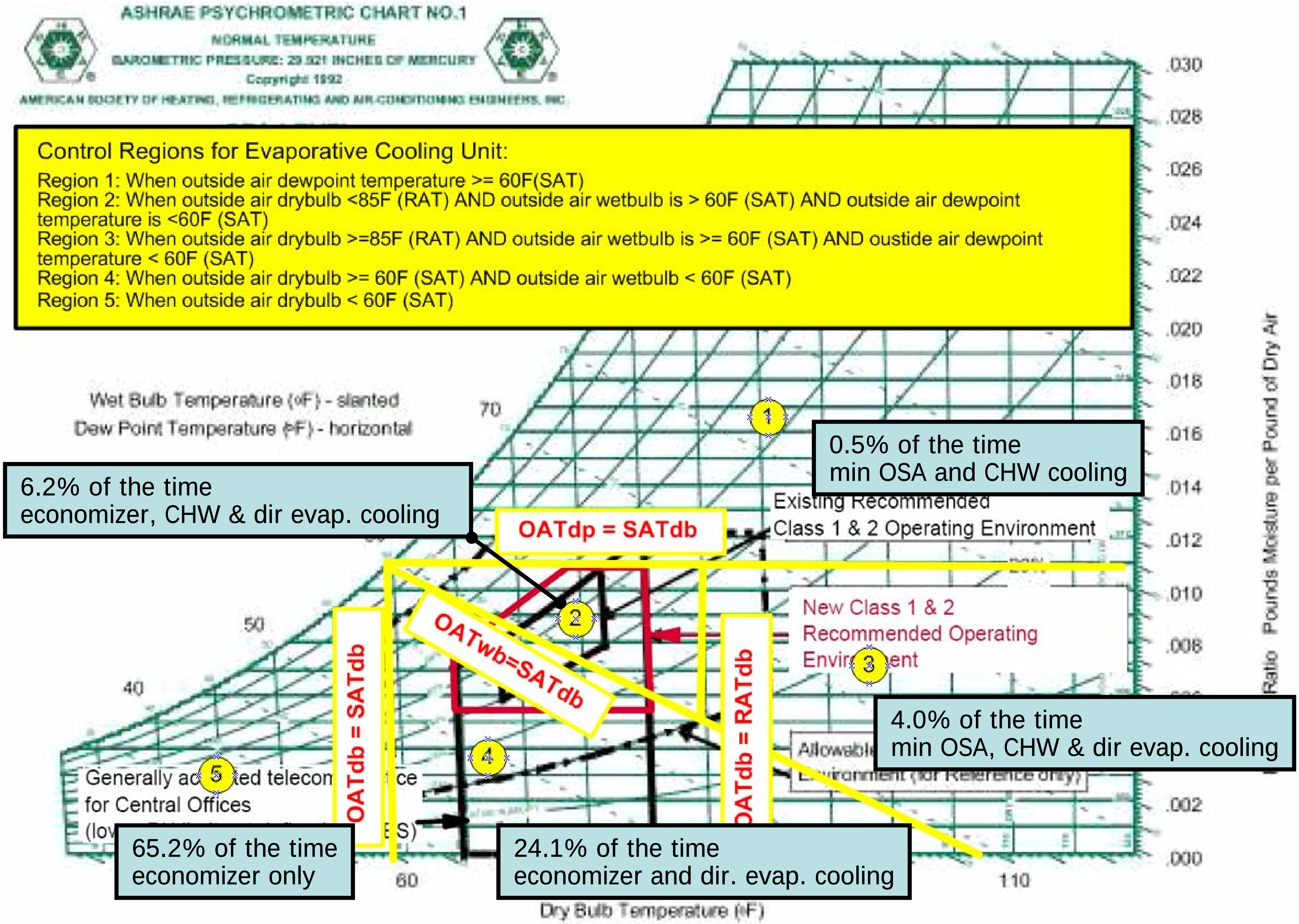
1- Western climates offer the potential for emergency cooling of a data center should refrigeration fail on the hottest day of the year.

2- Assuming a 20°F temperature rise due to room heat load, the third column shows room equilibrium temperatures with ventilation cooling only without refrigeration.

3- Column 4 shows room equilibrium conditions on a design summer day with a 90% efficient direct evaporative cooling device and no refrigeration.

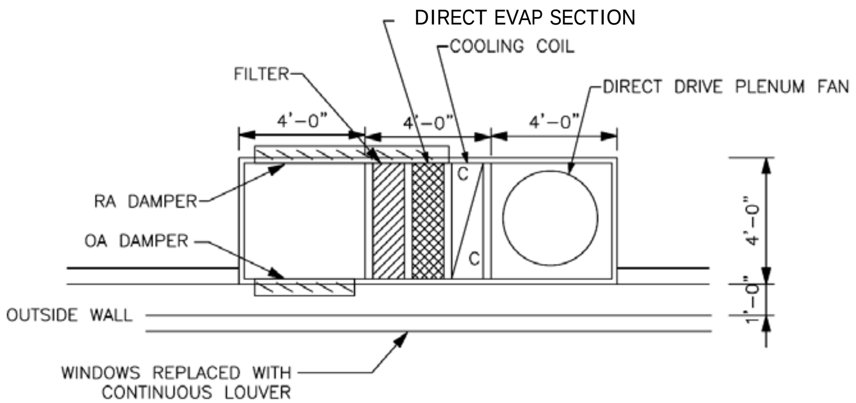
4- Room resultant temperatures with direct evaporative cooling only are within data center Class 1 through 4 operating limits.

Source: Mike Scofield and Tom Weaver Conservation Mechanical Systems

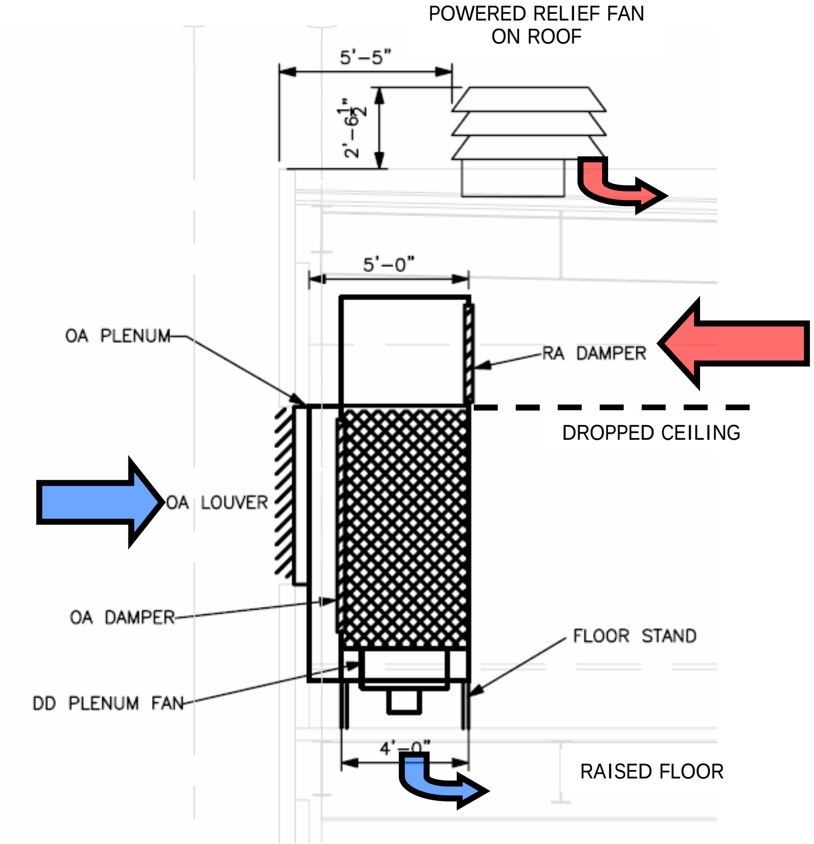


ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 29.921 INCHES OF MERCURY
Copyright 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
Control Regions for Evaporative Cooling Unit:
Region 1: When outside air dewpoint temperature >= 60F(SAT)
Region 2: When outside air drybulb <85F (RAT) AND outside air wetbulb is > 60F (SAT) AND outside air dewpoint temperature is <60F (SAT)
Region 3: When outside air drybulb >=85F (RAT) AND outside air wetbulb is >= 60F (SAT) AND oustide air dewpoint temperature < 60F (SAT)
Region 4: When outside air drybulb >= 60F (SAT) AND outside air wetbulb < 60F (SAT)
Region 5: When outside air drybulb < 60F (SAT)
Wet Bulb Temperature (°F) - slanted
Dew Point Temperature (°F) - horizontal
70
50
40
1
2
3
4
5
0.5% of the time
min OSA and CHW cooling
6.2% of the time
economizer, CHW & dir evap. cooling
OATdp = SATdb
Existing Recommended
Class 1 & 2 Operating Environment
New Class 1 & 2
Recommended Operating
Environment
OATwb=SATdb
OATdb = SATdb
OATdb = RATdb
4.0% of the time
min OSA, CHW & dir evap. cooling
Generally accepted telecom practice
for Central Offices
65.2% of the time
economizer only
24.1% of the time
economizer and dir. evap. cooling
60
110
Dry Bulb Temperature (°F)
Humidity Ratio - Pounds Moisture per Pound of Dry Air
.030
.028
.026
.024
.022
.020
.018
.016
.014
.012
.010
.008
.002
.000

Data center system design

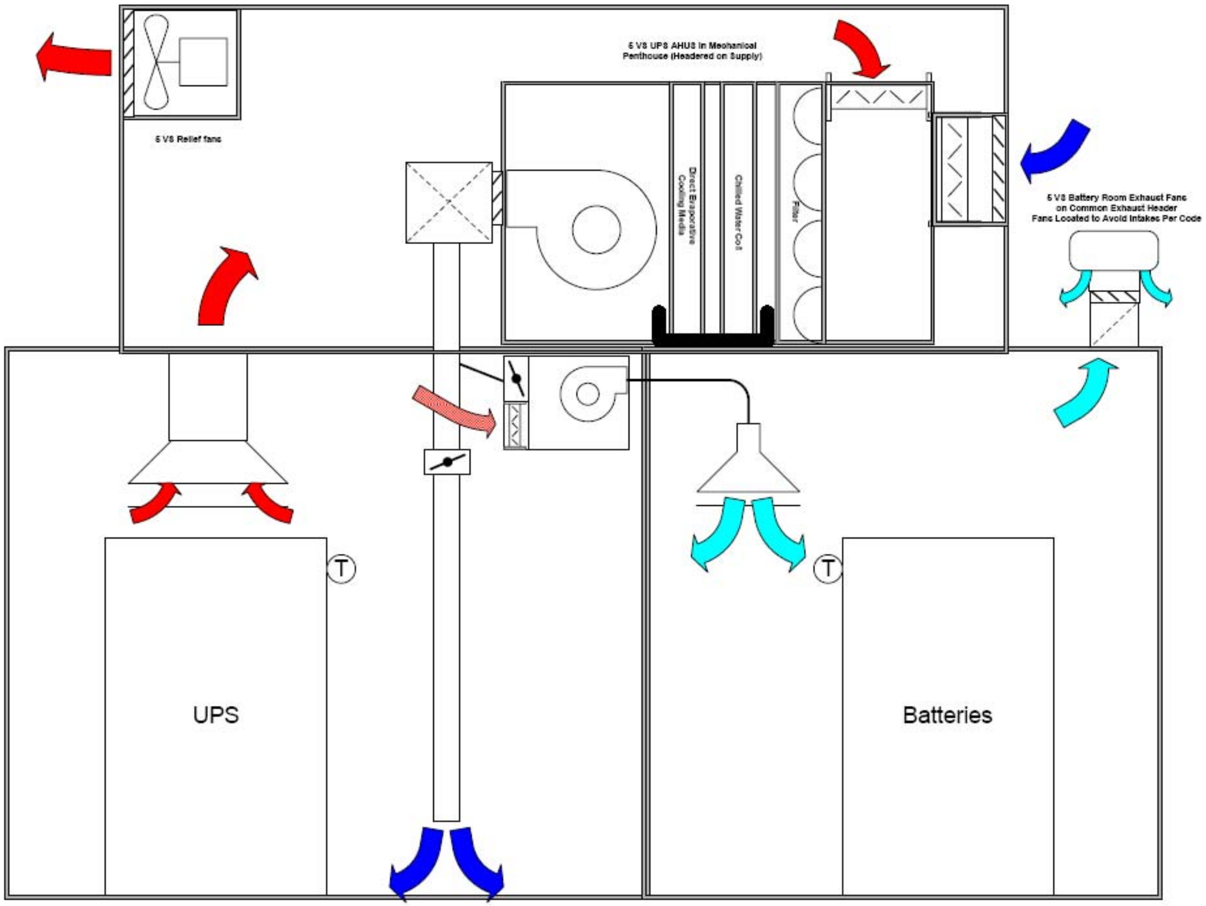


Plan View



Elevation

UPS system design

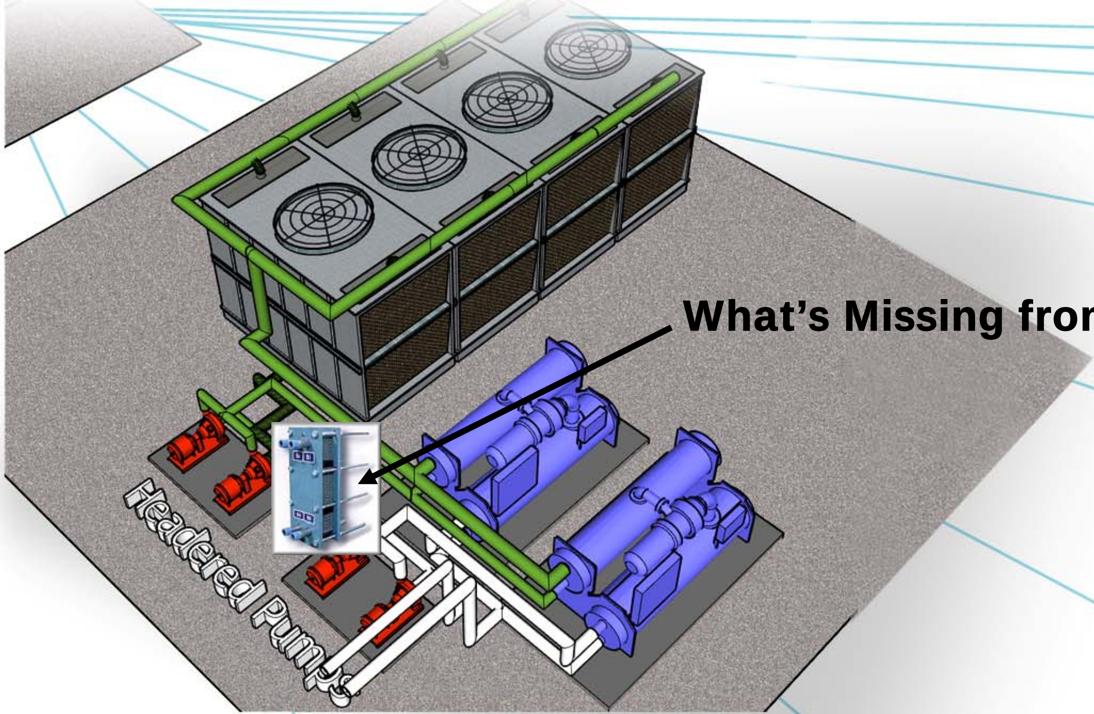


Wet-bulb economizer review

- Advantages
  - Extends hours of free cooling
  - Provides non-compressor cooling
  - Provides minimum humidification (if you care)
  - Improves air filtration (including gaseous contaminants)
  - Increases reliability by providing a redundant non-compressor
- Disadvantages
  - Increased fan energy
  - Water in the data center
  - Spatial requirements

Air-side economizer summary

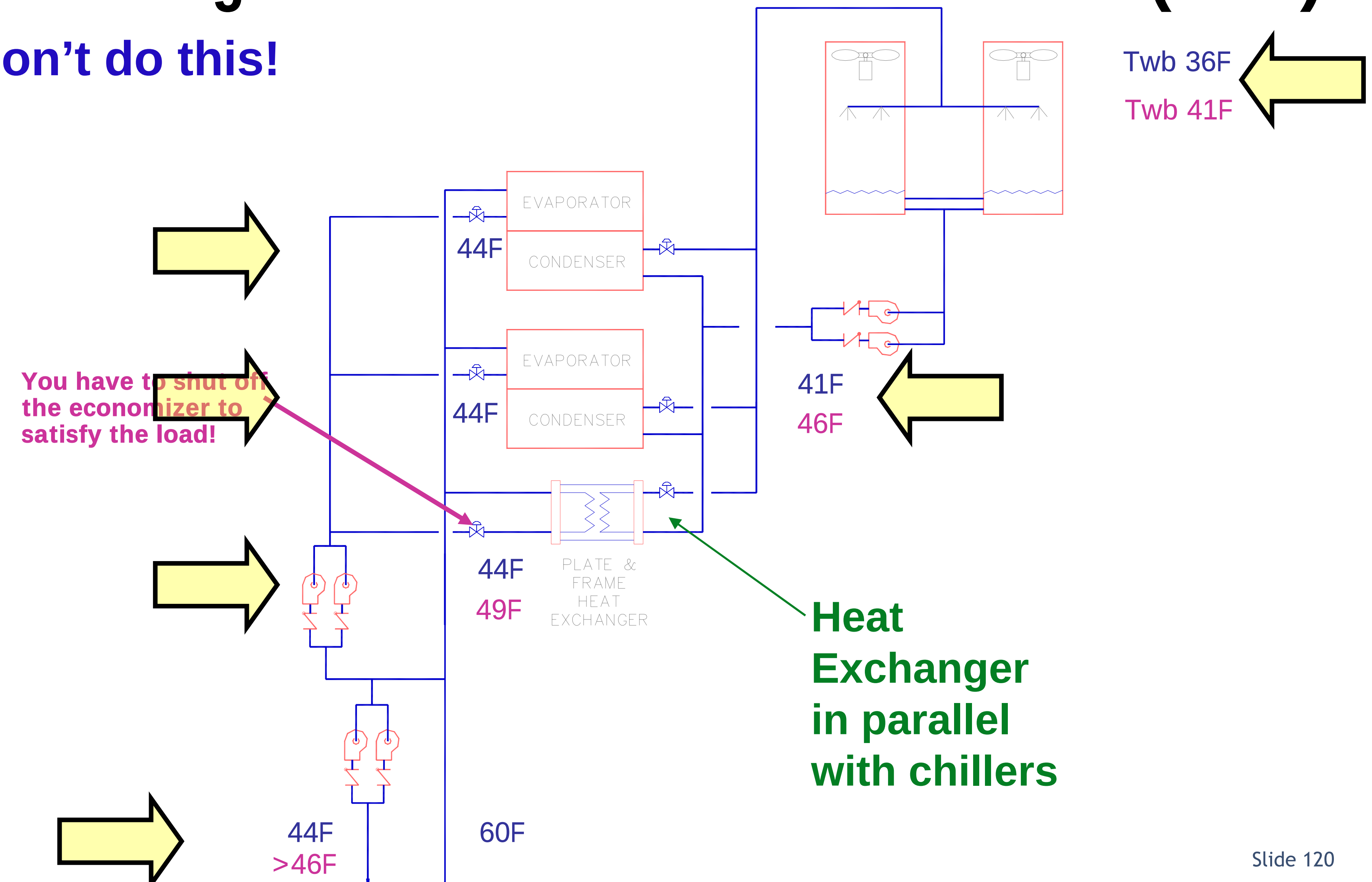
- Use differential temperature high limit switches in all but the most humid climates
- Can improve the reliability of the plant
- Generally improves indoor air quality
- Humidity control can negate savings
  - If used, lock out the economizers when the OSA is below the humidity control dewpoint temperature setpoint
- Particulates shouldn’t be an issue with good filtration (MERV 13 or higher)
- Work best with high return temperatures (aisle containment)
- Consider a direct evaporative stage to increase the hours of free cooling
- Consider controls to prevent smoke from outside being pulled into the data center (e.g. grass fire)



Water Side Economizers

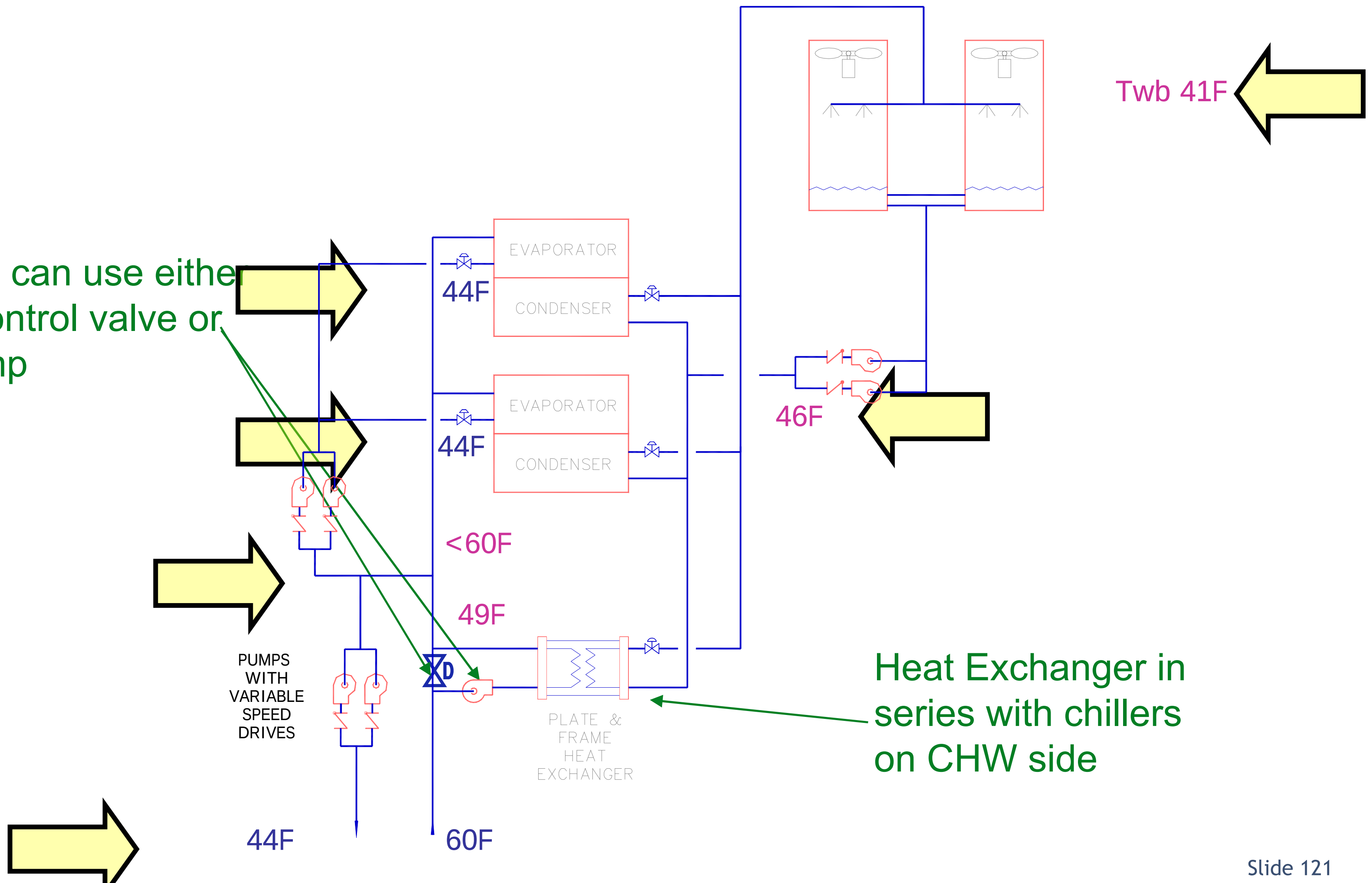
Non-integrated water-side economizer (WSE)

Don't do this!



Integrated water-side economizer (WSE)

You can use either a control valve or pump

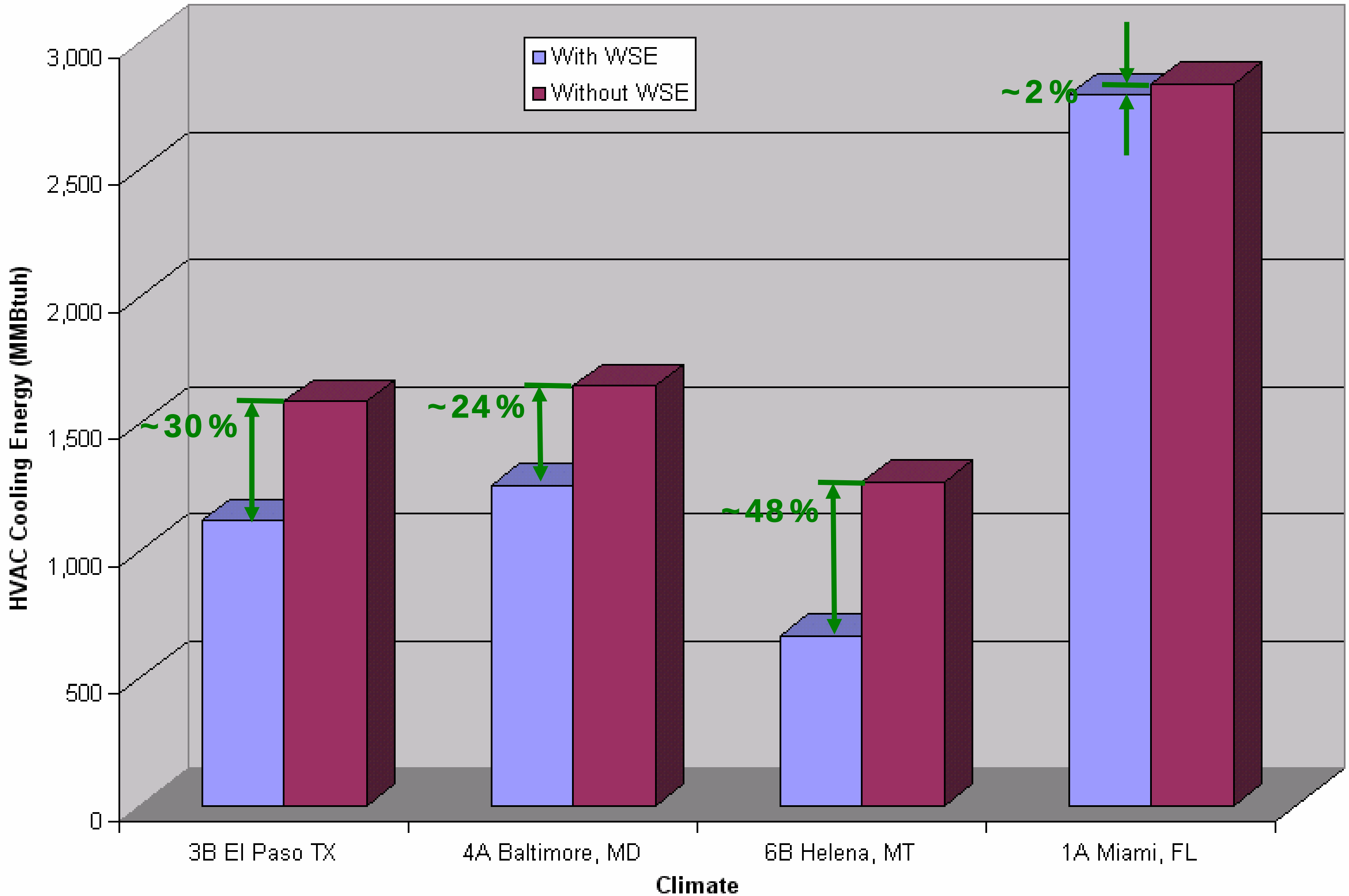


Heat Exchanger in series with chillers on CHW side

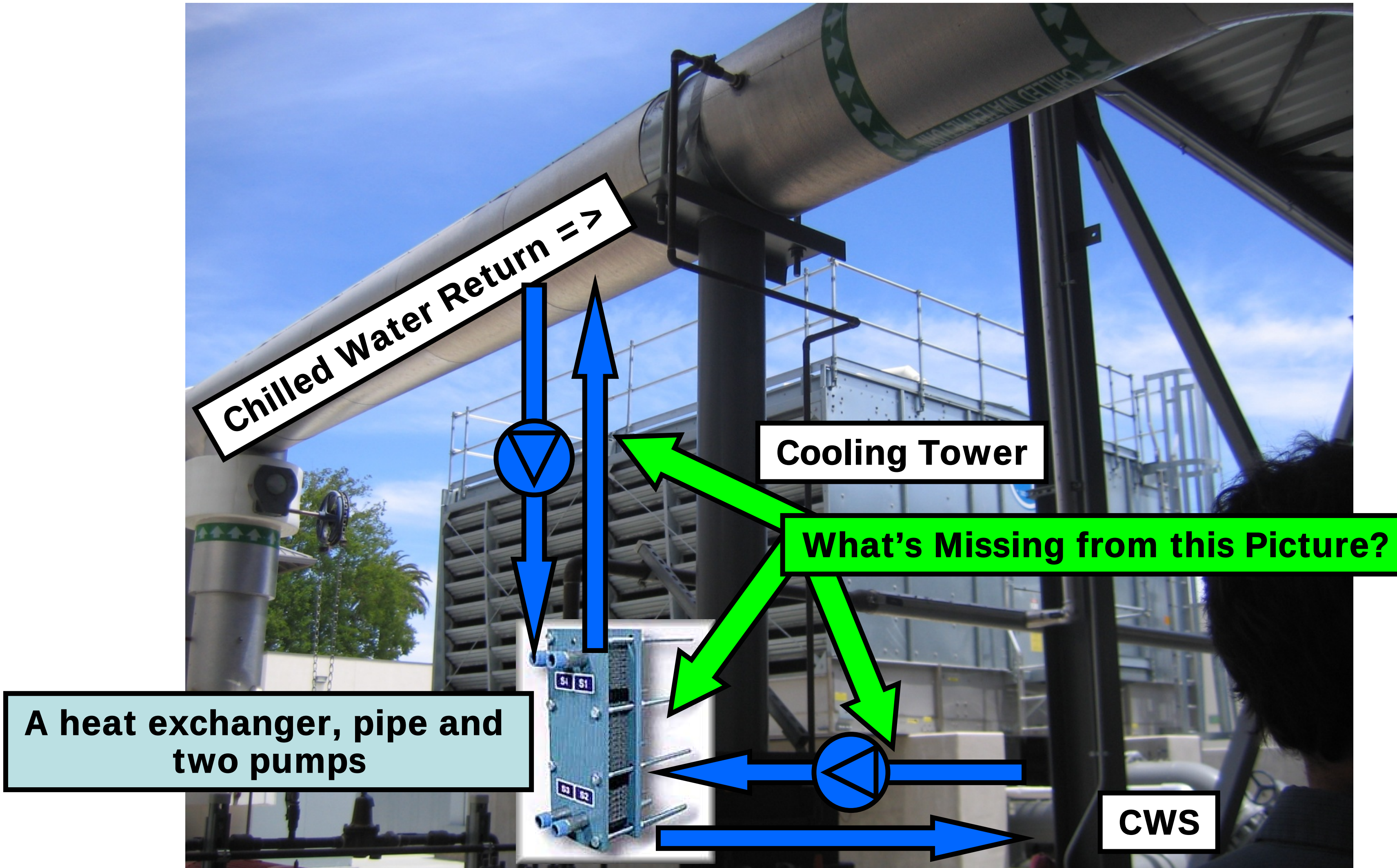
Example WSE Savings

- Example based on 200,000 sf office building with ~ 110 tons of data center load.
- Location Pleasanton CA (ASHRAE Climate 3B)
- (2) 315 ton chillers (630 tons total).
- Building has air-side economizer.
- Data center has CRAH units.
- Water-side economizer on central plant with HX (integrated, see previous slide)

Example WSE Savings



Real Plant in Santa Clara



Implementing WSEs

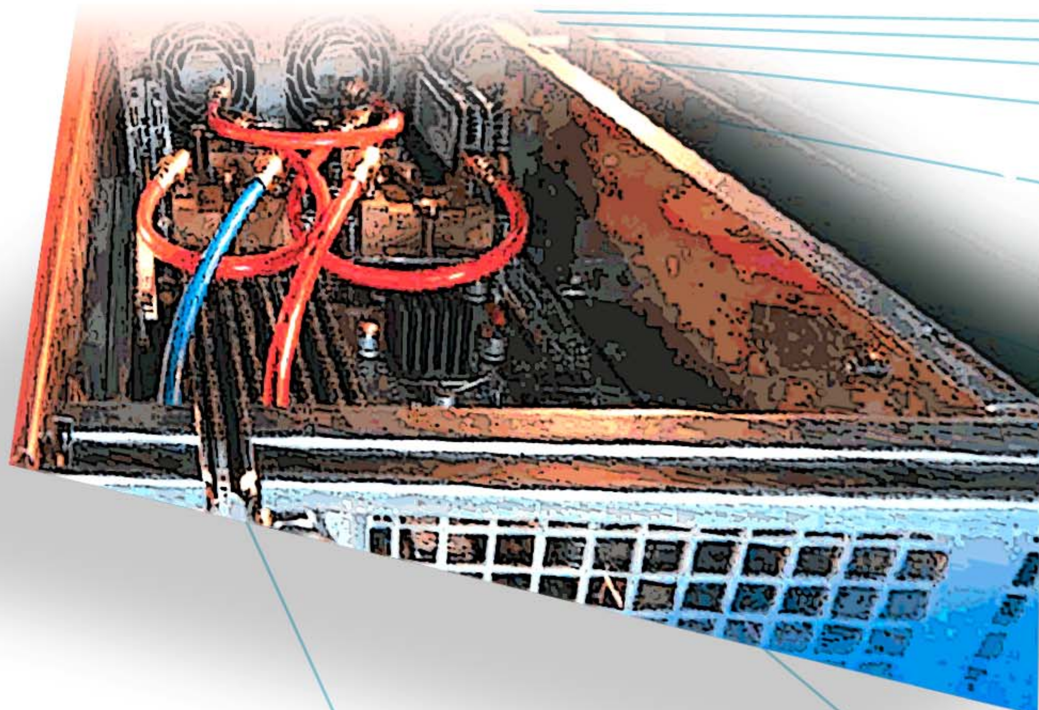
- Put the HX on the plant CHW return line in series NOT in parallel with the chillers
- You need head pressure controls for chillers and other water-cooled equipment
- Works best with CHW reset (the warmer the better)
- Works best if you design coils for high Delta-T
- Consider oversizing towers
- Design towers for low flow

Non-energy advantages of WSEs

- Redundancy
- Limited ride-through if chillers trip
- Utilizes redundant towers

Free cooling take aways

- Air- and water economizers can save significant energy if properly designed and controlled.
- Air- economizers can increase energy usage if you have humidity controls.
- Air-economizers do increase particulates but these can be addressed with standard filtration.
- Water economizers should be integrated by installing free cooling heat exchanger in series with the chillers.
- Big rebates from some utilities for economizer systems.

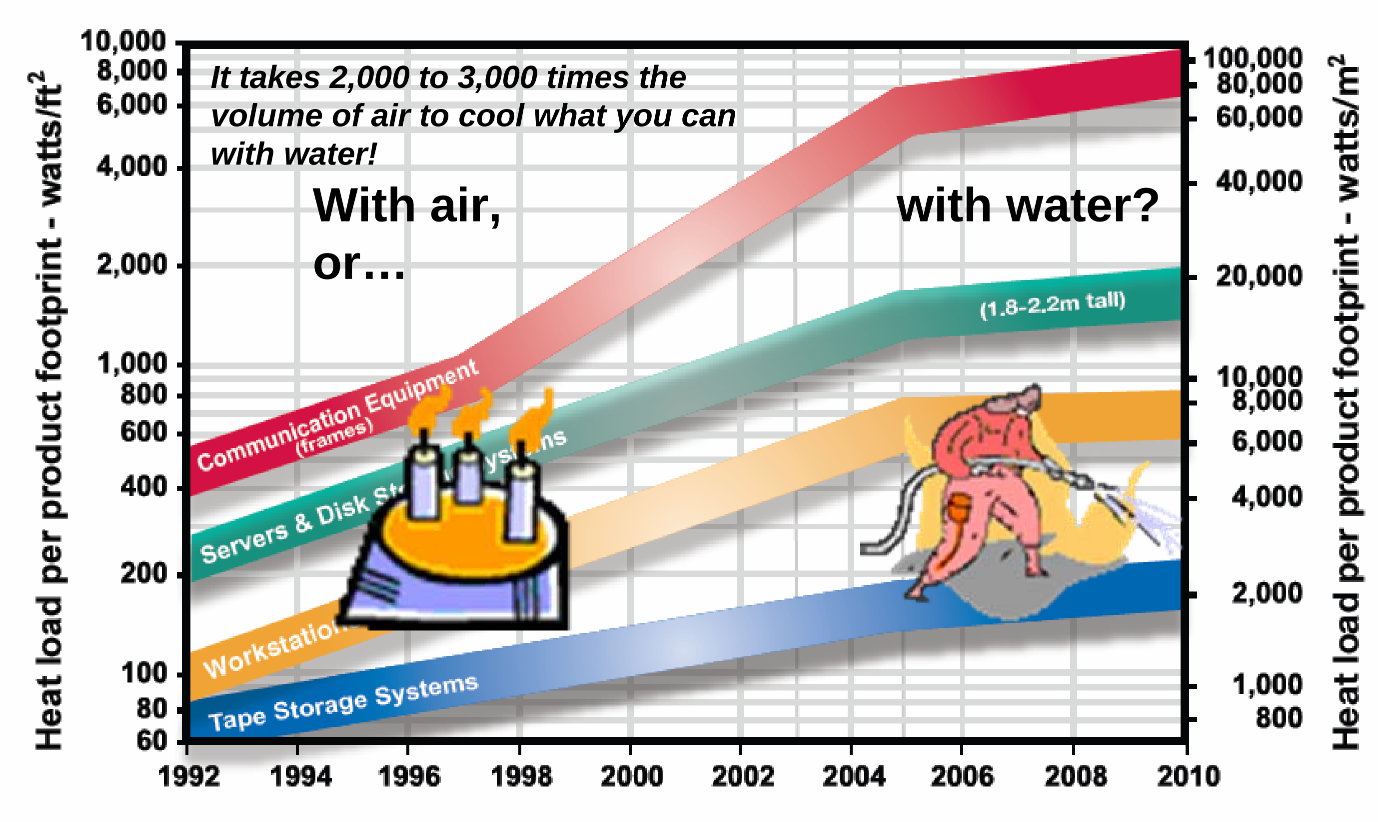


Liquid Cooling Systems

Peter Rumsey, P.E.

RUMSEY ENGINEERS INC

How do you effectively fight a fire?



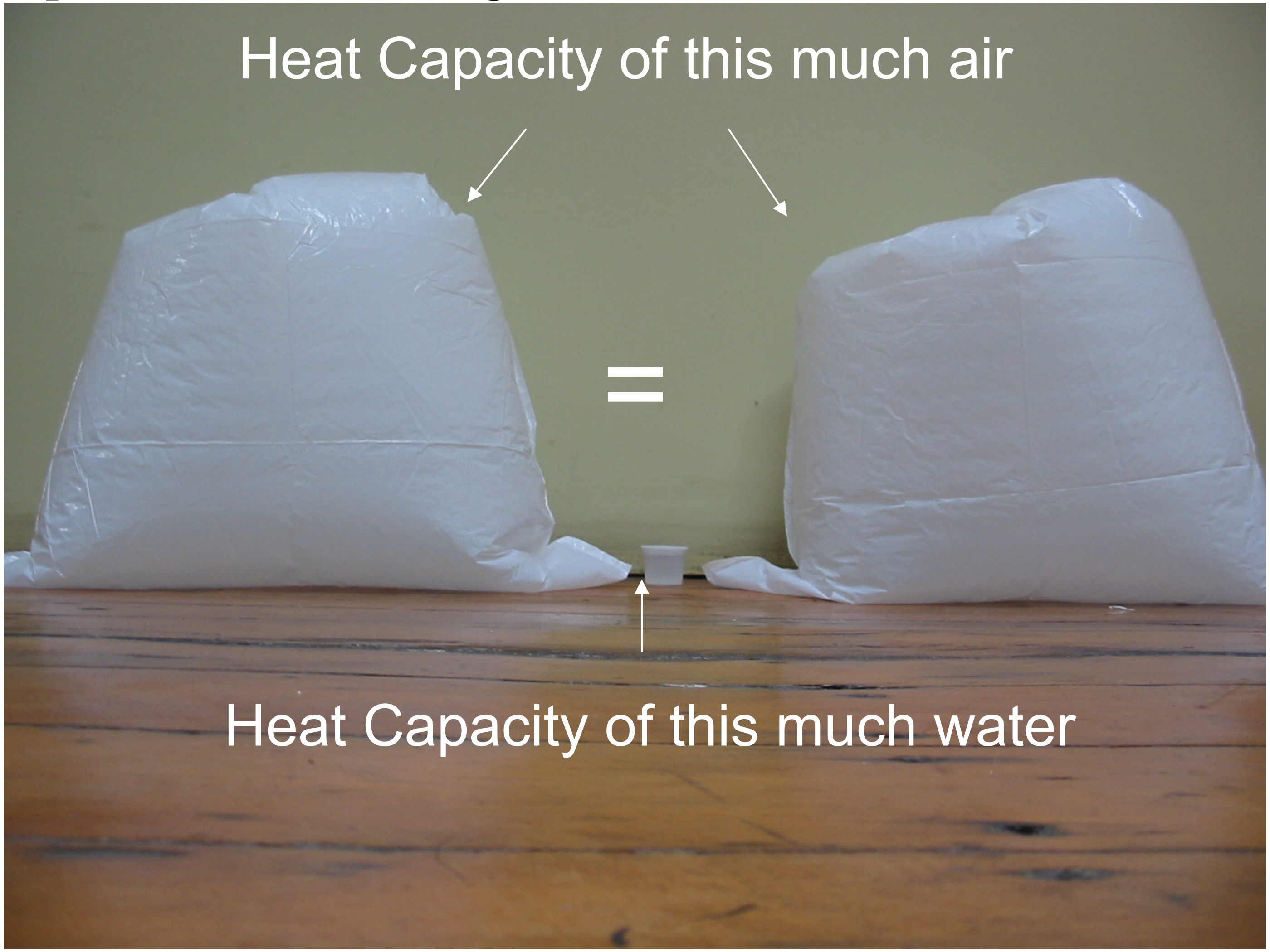
Outline

- Why liquid cool
- Liquid cooling options
  - Rack and row cooling
  - On board cooling
- Energy Benefits
- Interface with free cooling

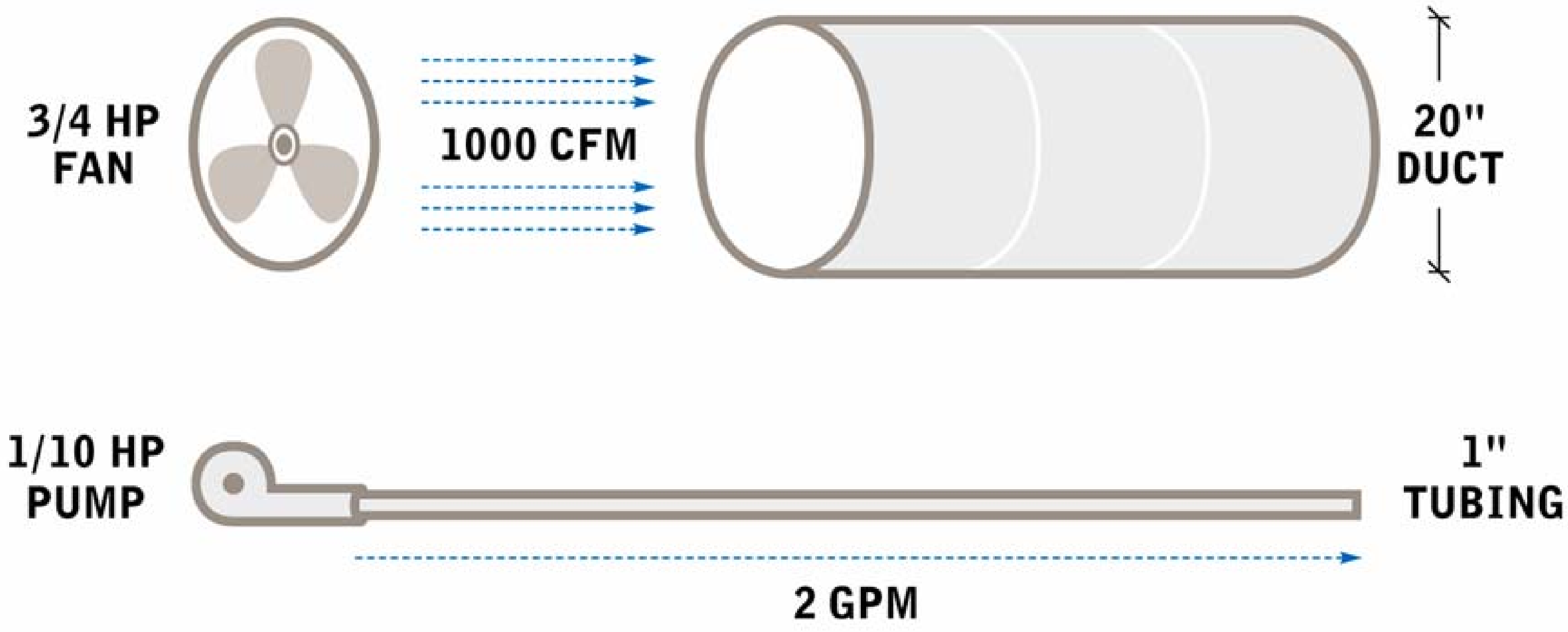
Air cooling issues

- Limitations on the data densities served (~200 W/sf)
  - Air delivery limitations
  - Real estate
- Working conditions
  - Hot aisles are (should be) uncomfortably hot
- Costly infrastructure
- High energy costs
- Management over time
- Reliability
  - Loss of power recovery
  - Particulates

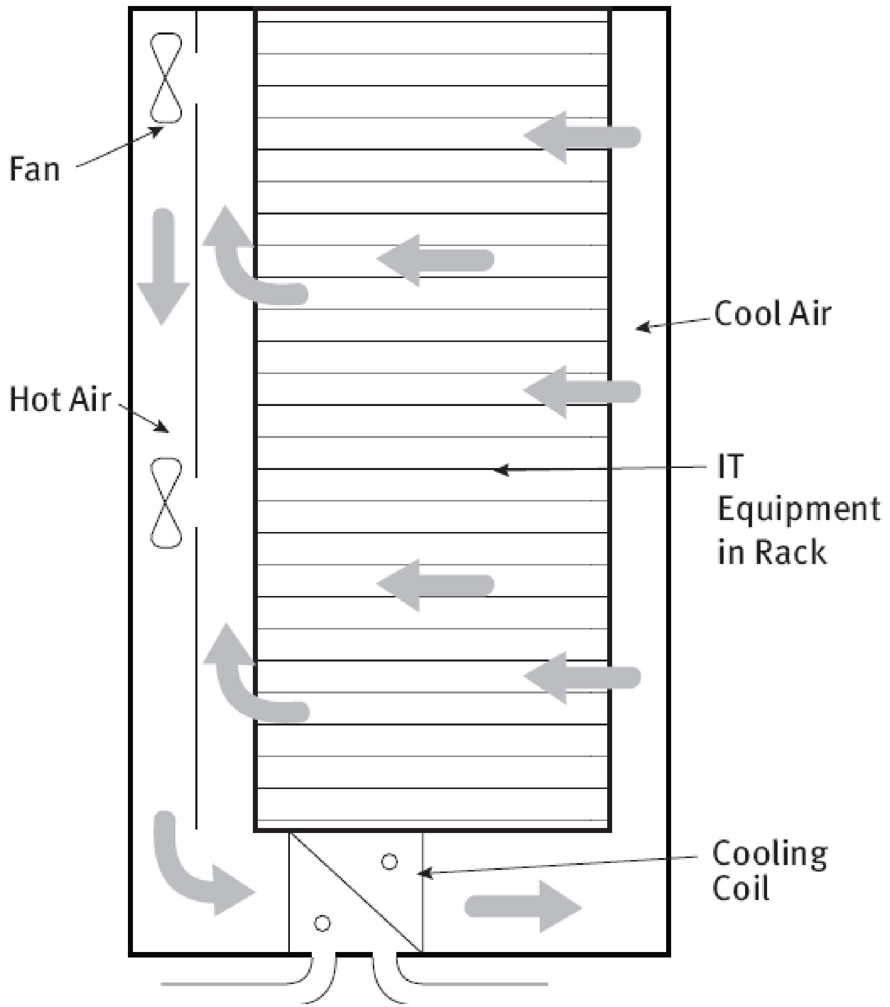
Why Liquid Cooling?



Fans move energy less efficiently



In rack liquid cooling



Close coupling between cooling source and server

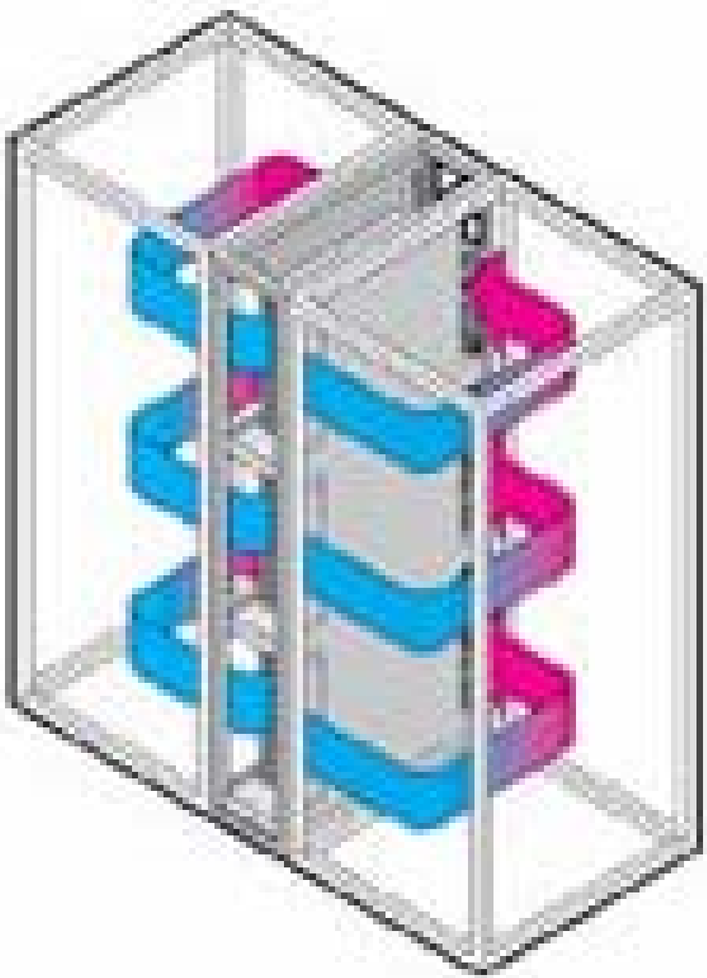
However, some of these solutions might present challenges to redundancy and increase maintenance

In rack liquid cooling

- Racks with integral coils

Rear door cooling

In row cooling



On board cooling

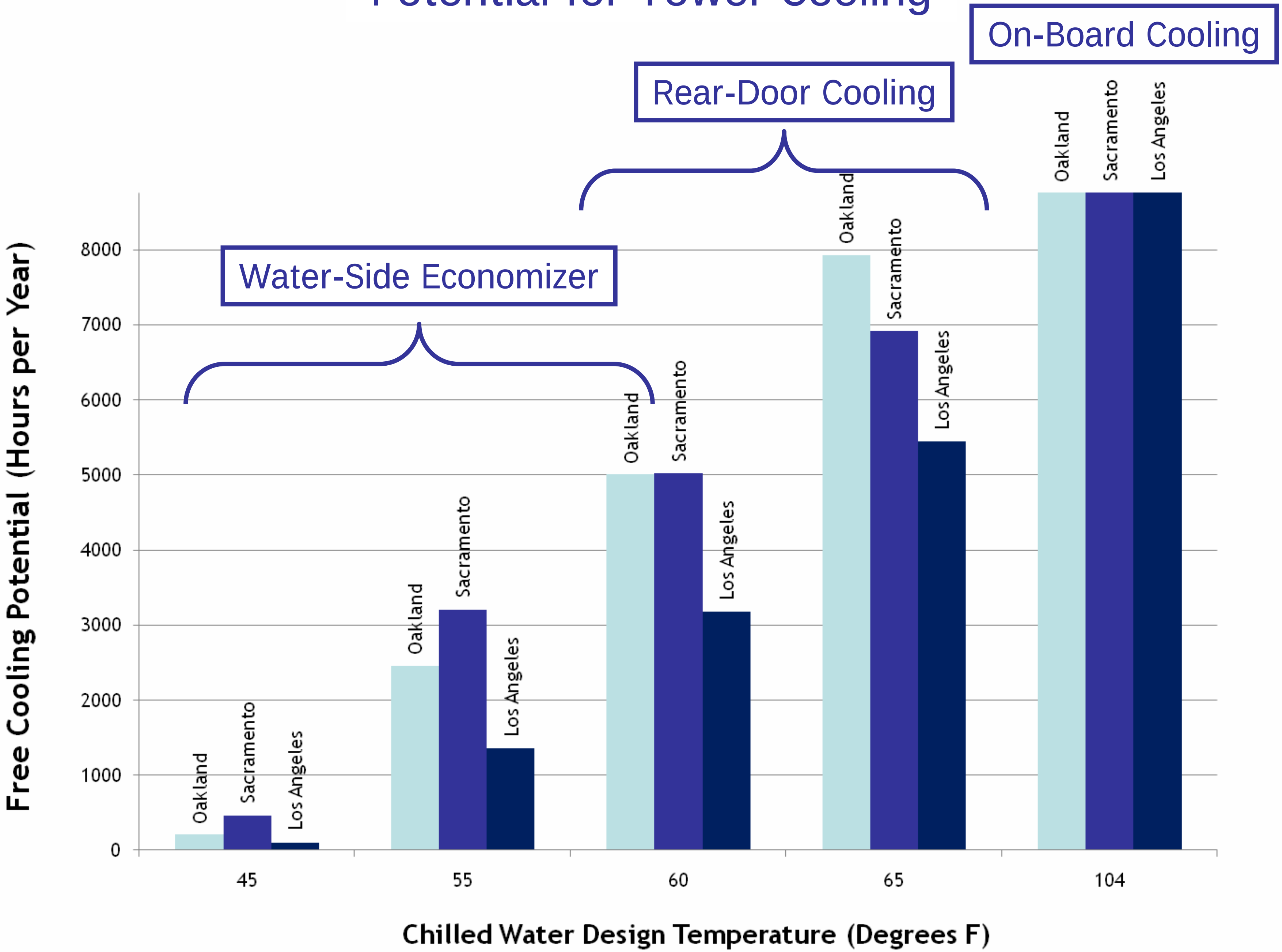
Comparison of conventional cooling to liquid cooling – 1,000 kW data center load

	Cooling Towers and Pumps	Chiller	Chilled Water Pumps	Fans	Other	Total Power (kW)	% SAVINGS
Traditional System - 45 Deg F Chilled Water	70	500	50	150	n/a	770	N/A
Liquid Cooled with Fans in the Rack - 55 Deg F Chilled Water	70	425	50	100	n/a	645	16%
Liquid Cooled without fans in the rack - 55 Deg F Chilled Water	70	425	50	0	n/a	545	29%
Liquid Cooled directly couple with CPU - 70 to 80 deg F Chilled Water	70	0	50	0	Room A/C - 245	365	53%

Free cooling

- Use cooling towers and heat exchanger to produce chilled water
- Turn off chiller

Potential for Tower Cooling



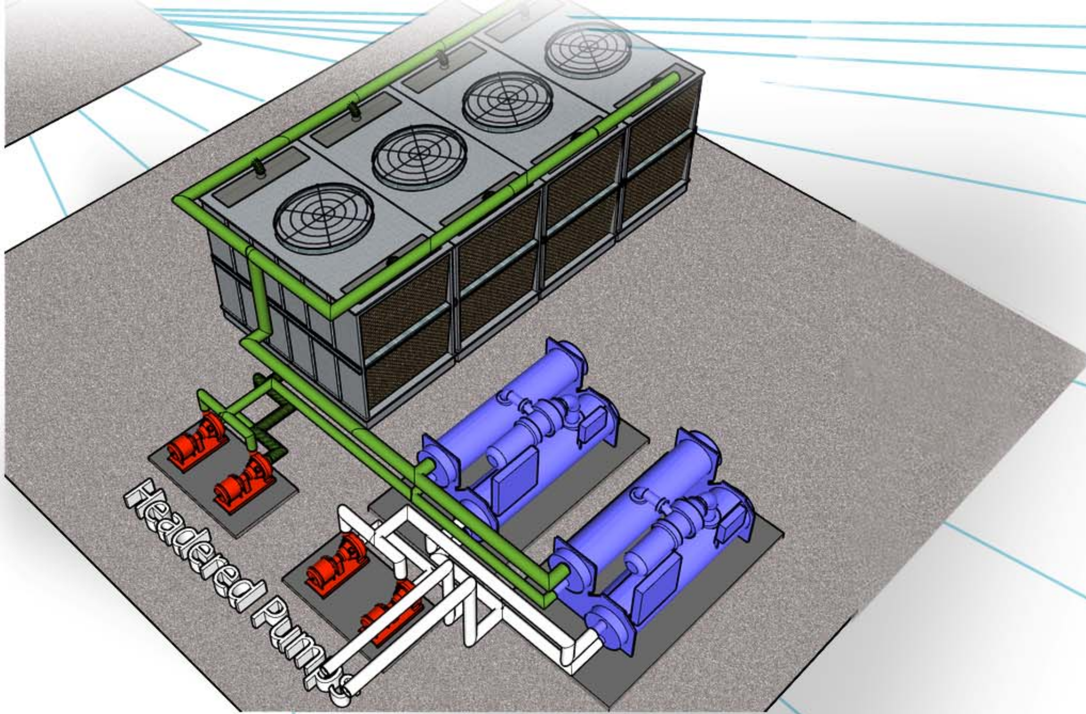
How to compare apples and coconuts

- The California Energy Commission's "Chill Off" at Sun Microsystems is documenting field performance of liquid cooling options
  - Collaboration of LBNL and Silicon Valley Leadership Group (and manufacturers)
  - Testing is complete for Chill Off 1
  - Chill Off 2 in progress
  - Stay tuned at http://hightech.lbl.gov for results

Liquid cooling take aways

- Liquid has greater heat removal capacity
- Pumps use less energy than fans
- Coupling heat removal to the source eliminates mixing
- A wide variety of commercially available liquid solutions are available
- The potential for energy savings is large
- Redundancy is a challenge for some liquid cooling technologies
- Water side free cooling can provide cooling with reduced chiller operation for much of the year


Lunch
Worth1000.com



Central Cooling Plants

Peter Rumsey, P.E.

RUMSEY ENGINEERS INC

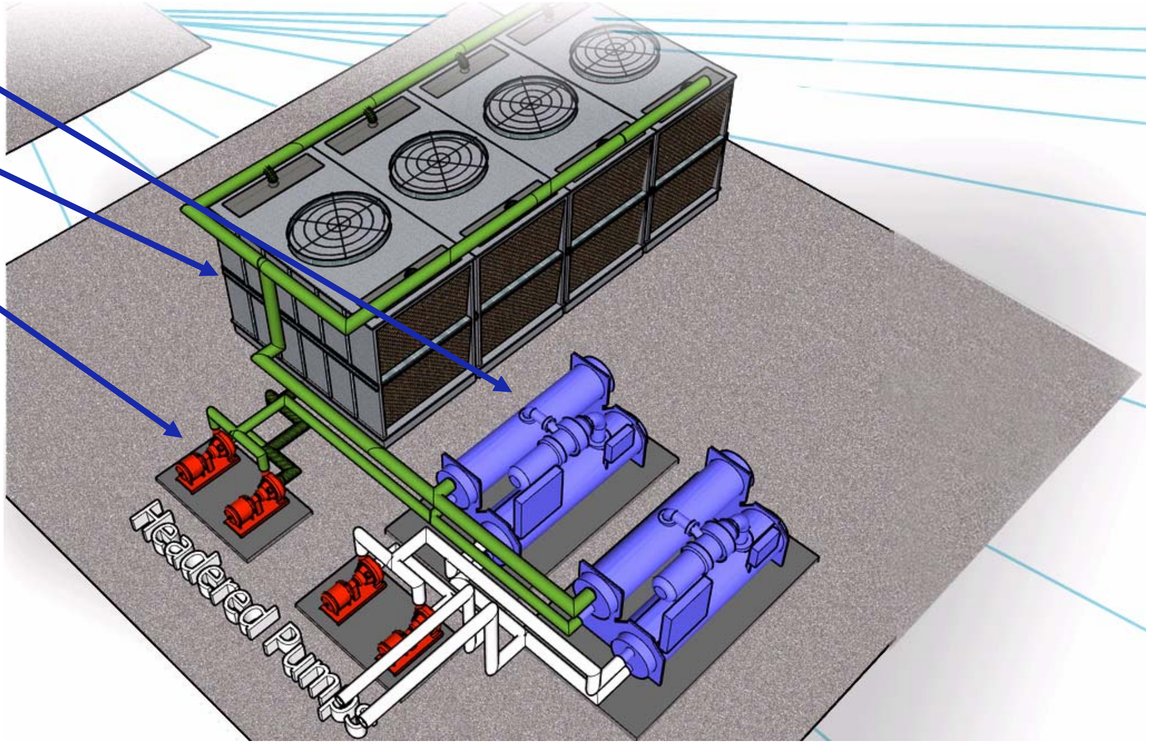
Central Plant Overview

- CHW Configurations
  - Loads
  - Plant
- Pumping Options
- Cooling Tower Issues
- Air- vs Water-Cooled Chillers
- Best Practices

This is only the tip of the iceberg!

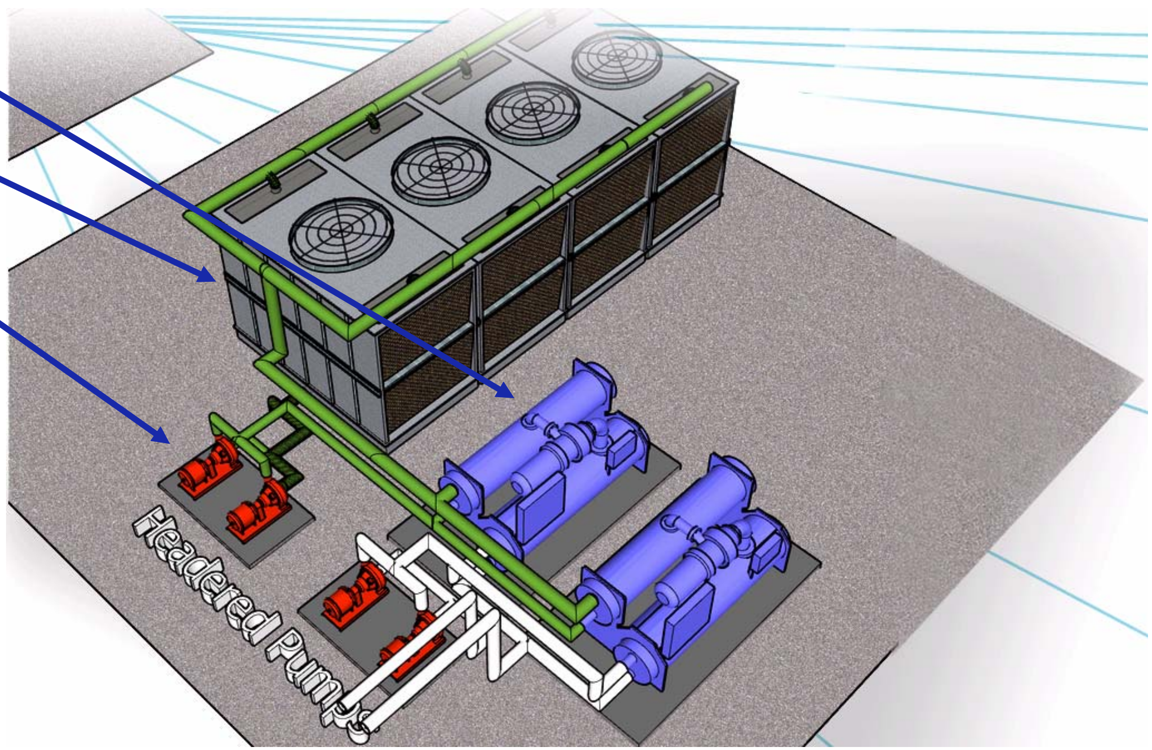
Pop Quiz 1

- What happens to component energy usage if we lower CWS setpoint?
  - ⇩ Chiller
  - ⇧ Towers
  - – Pumps



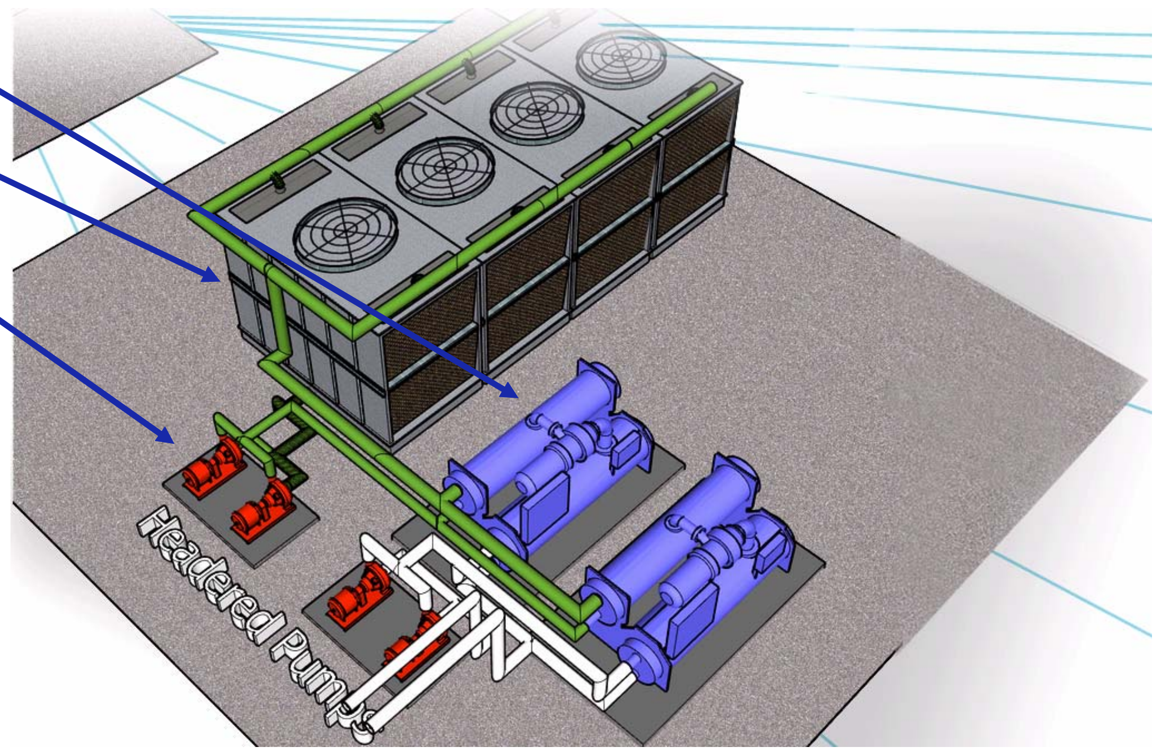
Pop Quiz 2

- What happens to component energy usage if we lower CW flow?
  - ⇧ Chiller
  - ⇩ Towers
  - ⇩ Pumps



Pop Quiz 3

- What happens to component energy usage if we lower CW flow AND the CWS setpoint?
  - ? Chiller
  - ? Towers
  - ↓ Pumps



Options for Balancing Variable Flow Systems

- No balancing (relying on 2-way control valves to automatically provide balancing)
- Manual balance, most commonly using calibrated balancing valves (CBVs) to measure and adjust flow
- Automatic flow limiting valves (AFLVs)
- Reverse-return
- Oversized main piping
- Undersized branch piping
- Undersized control valves
- Pressure independent control valves

Data from the October 2002 ASHRAE Journal article, "Balancing Variable Flow Hydronic Systems," by Steve Taylor and Jeff Stein

Ranks

	Balancing Method	Controllability (all conditions)	Pump Energy Costs	First Costs
1	No balancing	7	3	3
2	Manual balance using calibrated balancing valves	4	6	6
3	Automatic flow limiting valves	7	7	7
4	Reverse-return	2	2	5
5	Oversized main piping	3	1	4
6	Undersized branch piping	6	4	2
7	Undersized control valves	5	4	1
8	Pressure independent control valve	1	8	8

Pop Quiz 4

- Why should you use 3-way valves in a data center?
  a. They cost less to install.
  b. They reduce pumping energy.
  c. They provide better control.
  d. You need them to provide flow in the system.
  e. All of the above.
  f. None of the above.

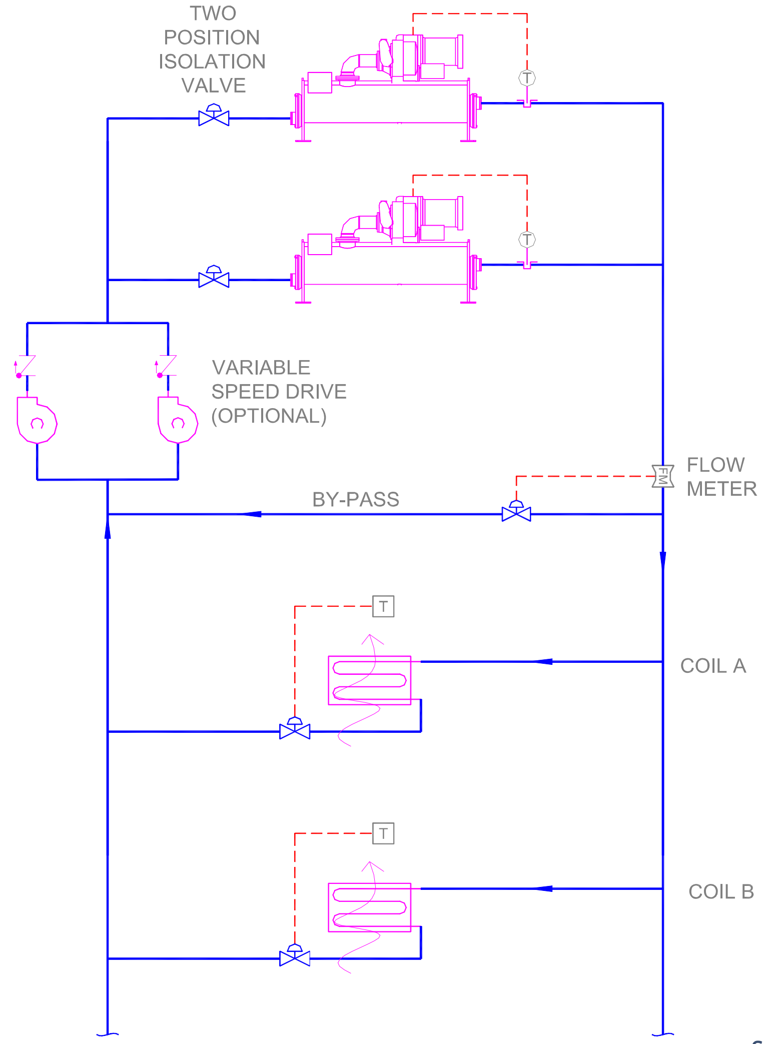
Balancing Variable Flow Systems

- Balancing Recommendations at Coils:
  - For data centers, use 2 way valves everywhere, it saves first cost and energy.
  - Automatic flow-limiting valves and calibrated balancing valves are not recommended on any variable flow system.
    - Few or no advantages and high first costs and energy costs.
  - Reverse-return and oversized mains may have reasonable pump energy savings payback on 24/7 chilled water systems like data centers.
  - Loop distribution systems for data centers are also recommended for reduced power and increased reliability.
  - For other than very large distribution systems, option 1 (no balancing) appears to be the best option
    - Low first costs with minimal or insignificant operational problems
- Balancing Recommendations at Pumps:
  - Do **not** use pump balancing valves (e.g. triple duty valves) with variable speed pumps.
  - For data centers the chilled water pumps should always have VSDs.

Variable Flow

Primary-only, Multiple Chillers

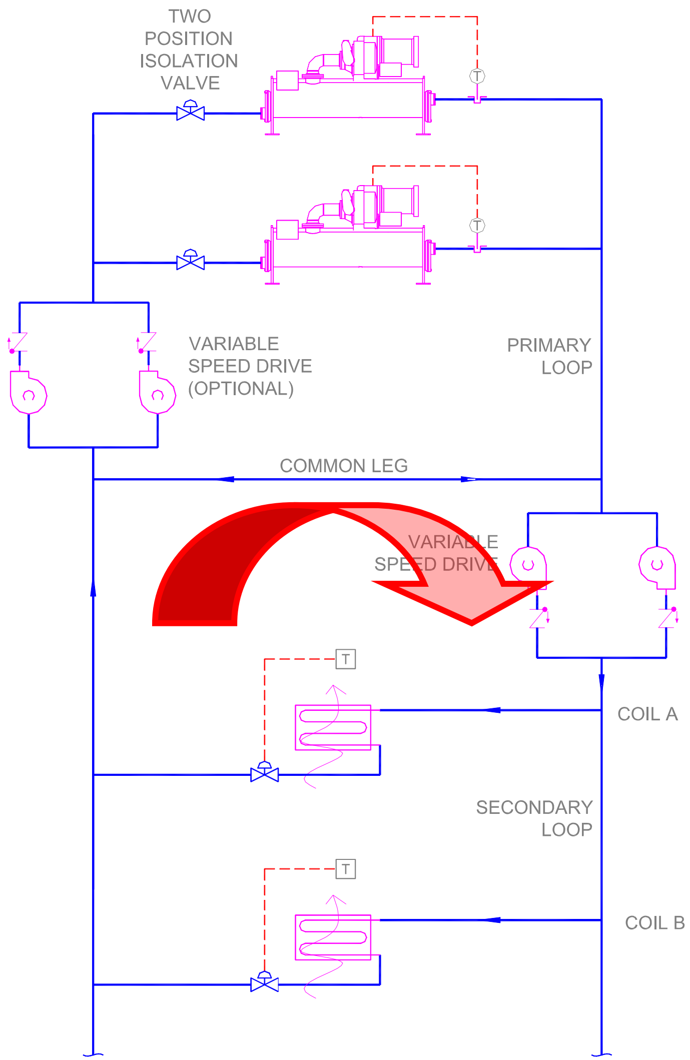
- Advantages
  - Low installed cost.
  - Low energy cost.
- Disadvantages
  - More complex controls.
  - Can lose chillers if you don't stage them correctly.



Variable Flow

Primary/Secondary, Multiple Chillers and Coils

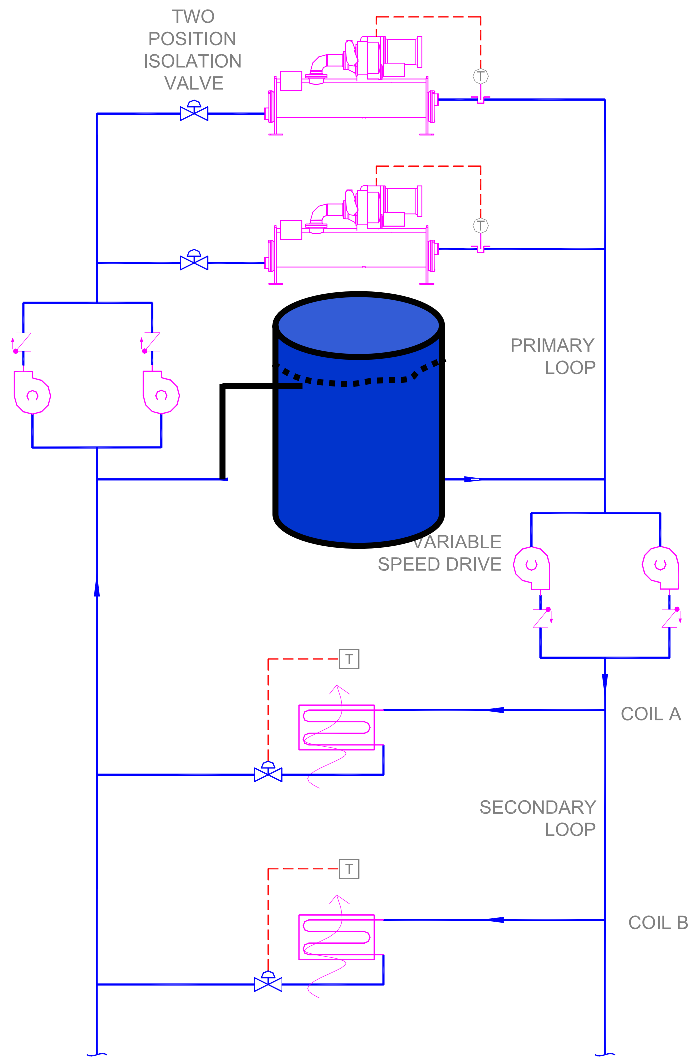
- Advantages
  - Simpler controls.
  - Easier to keep chillers on-line.
- Disadvantages
  - Higher installed cost.
  - Higher pumping energy.
  - Higher chiller energy as you have to stage the chillers on flow not load.
- Mitigation
  - Stage chillers by flow.
  - Put check valve in common leg.



Variable Flow

Primary/Secondary with TES

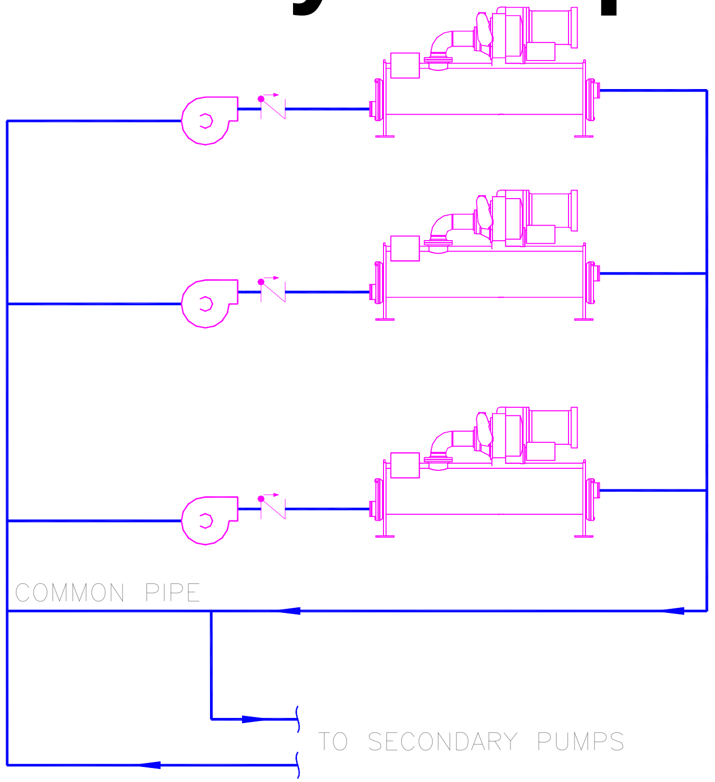
- Advantages
  - No chiller staging problems
  - Peak shaving
  - Back up data center & chillers
  - Fire protection water source
  - Secondary source for cooling towers
- Disadvantages
  - Installed cost
  - Space

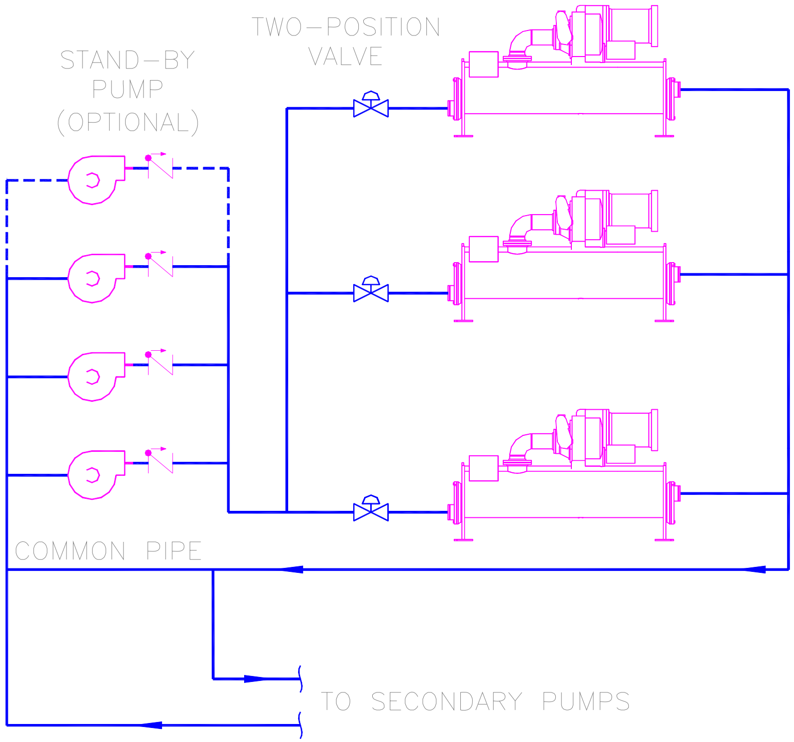


Primary-only vs. Primary/Secondary

- Use primary-only systems for:
  - Plants with many chillers (more than three) and with fairly high base loads where the need for bypass is minimal or nil and flow fluctuations during staging are small due to the large number of chillers; and
  - Plants where design engineers and future on-site operators understand the complexity of the controls and the need to maintain them.
- Otherwise use primary-secondary
- Consider Primary-secondary with TES

Primary Pump Options

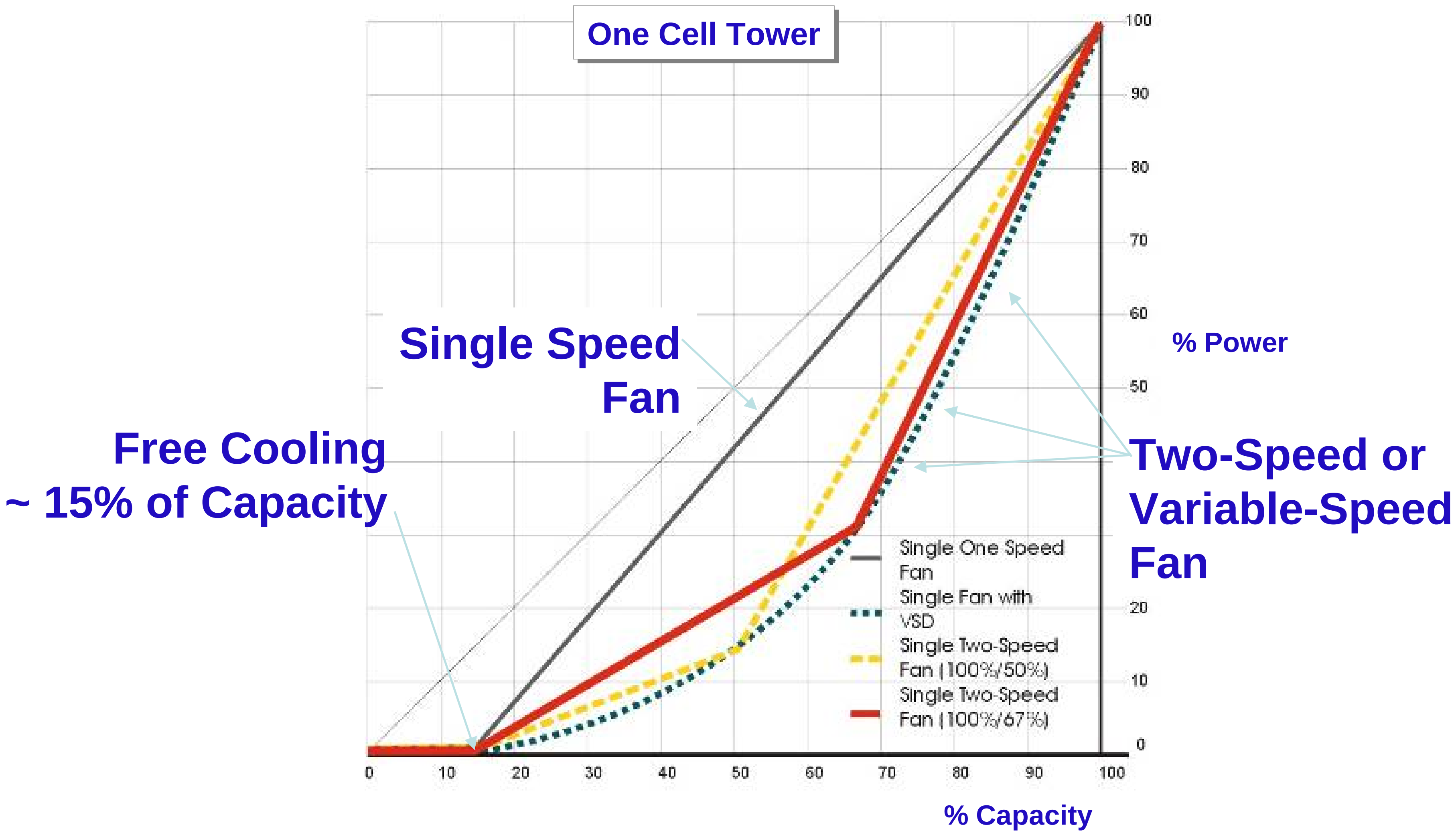




Dedicated Pumping Advantages:
- Less control complexity
- Custom pump heads w/ unmatched chillers
- Usually less expensive

Headered Pumping Advantages:
- Better redundancy
- Valves can "soft load" chillers with primary-only systems
- Easier to incorporate stand-by pump

Tower Fan Control



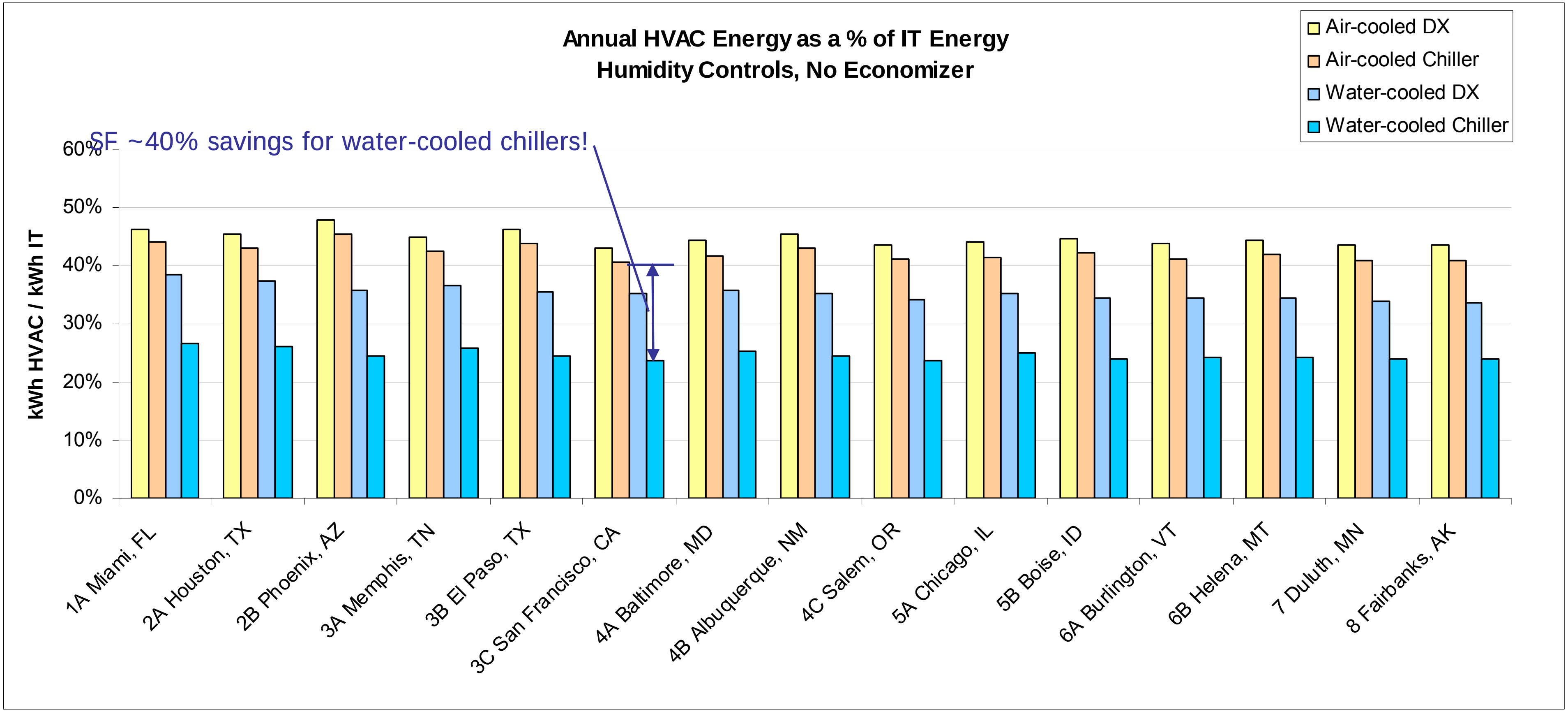
Tower Fan Control

- One-speed control is almost *never* the optimum strategy regardless of size, weather, or application
- Two-speed 1800/900 rpm motors typically best life cycle costs at mid-1990 VSD costs, but…
- VSDs may be best choice anyway
  - Costs continue to fall
  - Soft start reduces belt wear
  - Lower noise
  - Control savings for DDC systems (network card options)
  - More precise control
- Pony motors are more expensive than two-speed but offer redundancy
- Multiple cell towers should have speed modulation on at least 2/3 of cells (required by ASHRAE 90.1)

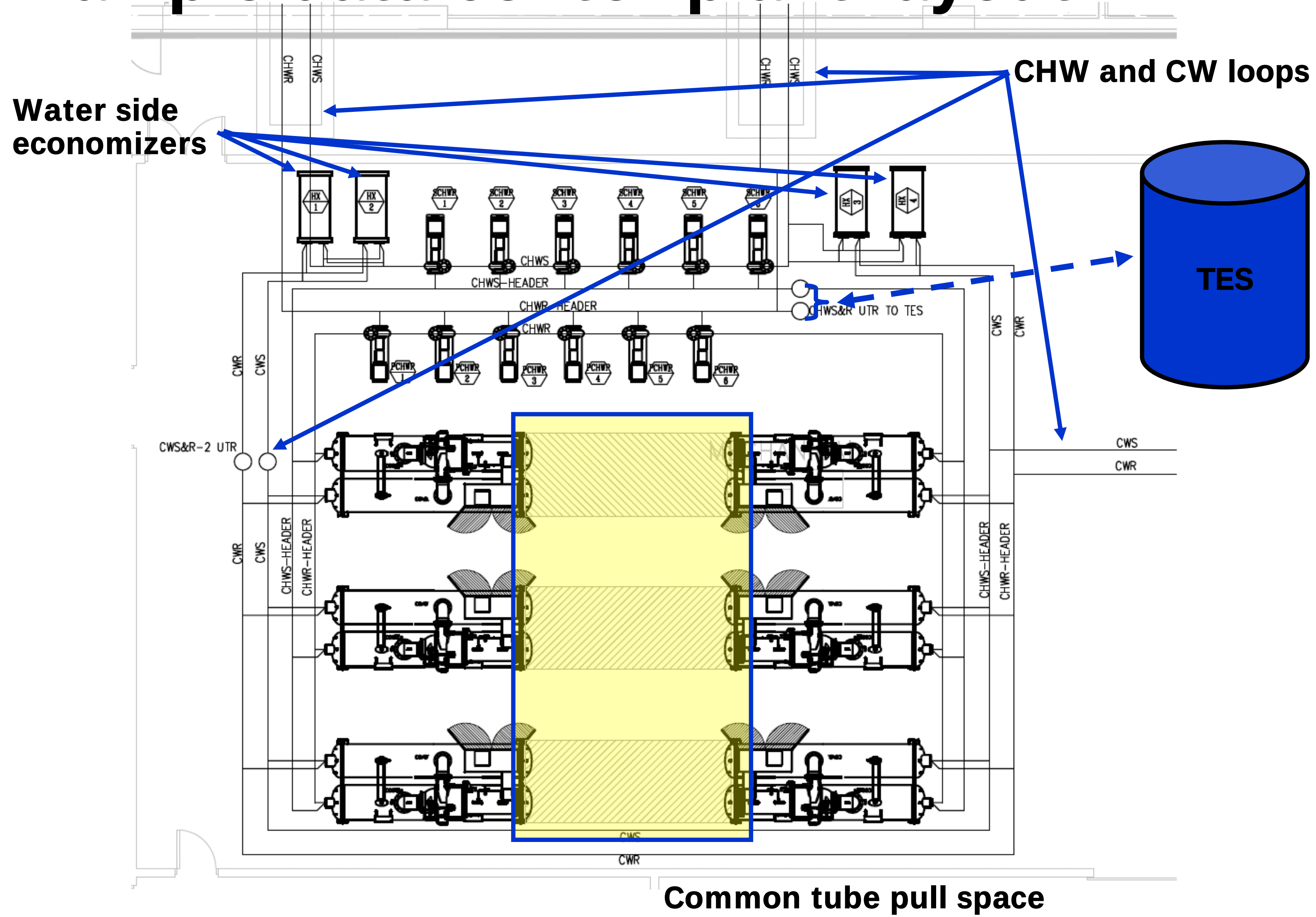
Tower Efficiency Guidelines

- Use Propeller Fans
  - Avoid centrifugal except where high static needed or where low-profile is needed and no prop-fan options available.
  - Consider low-noise propeller blade option and high efficiency tower where low sound power is required.
- For data centers and other 24/7 facilities, evaluate oversizing to 80 gpm/hp at 95°F to 85°F @ 75°F WB

Type of HVAC System, All Climates



Example data center plant layout

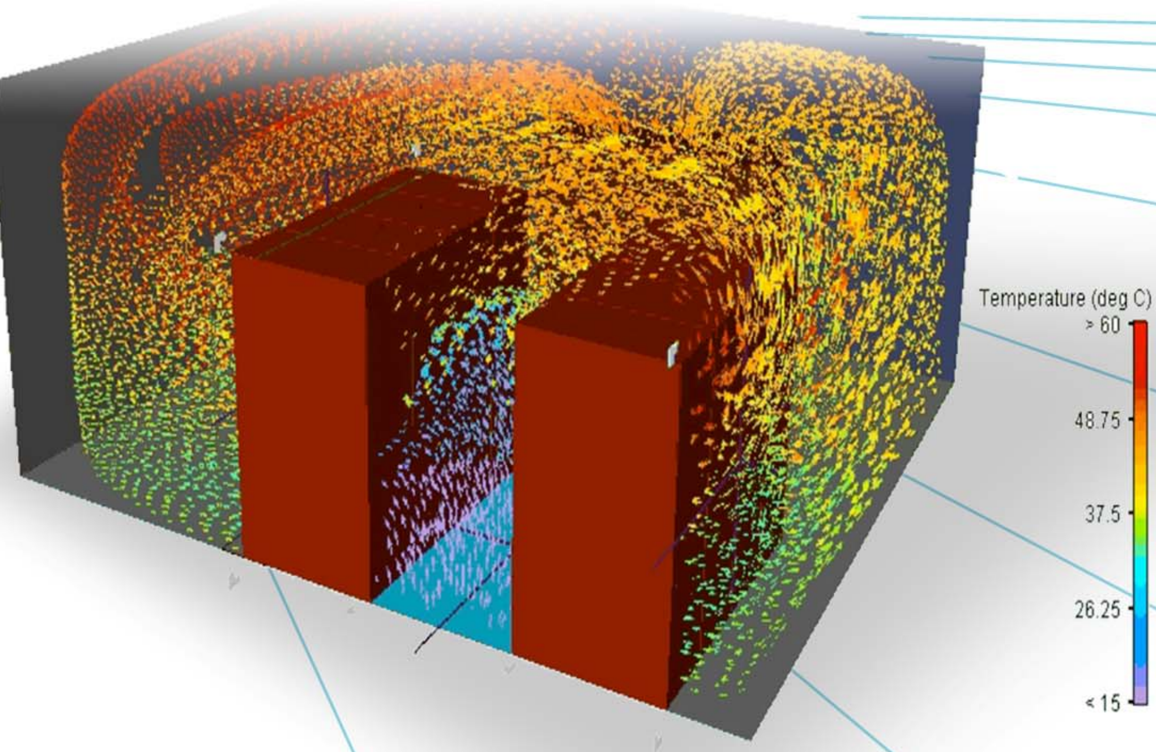


Where to Learn More

- CoolTools Design Guide
  - http://taylor-engineering.com/publications/design_guides.shtml
- Chilled Water Plant Seminars (past; future?)
  - PG&E Pacific Energy Center
  - SMUD

Chilled Water Plant Best Practices

- Use 2-way valves on all loads.
- Use oversized headers to balance loads and consider a loop type distribution system.
- Consider primary-only unless you have a TES tank (which is piped in the common leg).
- Use water-cooled chillers where possible.
  - You must have a redundant water supply for the cooling tower (typically tank or ground water pump).
- Consider chilled water storage for make-up water, peak shavings and ride-through in chiller staging.
- Put VSDs on everything (pumps, fans and chillers).



Data Center Controls

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RUMSEY ENGINEERS INC

Control issues

- Temperature Control
- Humidity Control
- Airflow Control
- Feedback and Diagnostics
- IT Integration
- Others

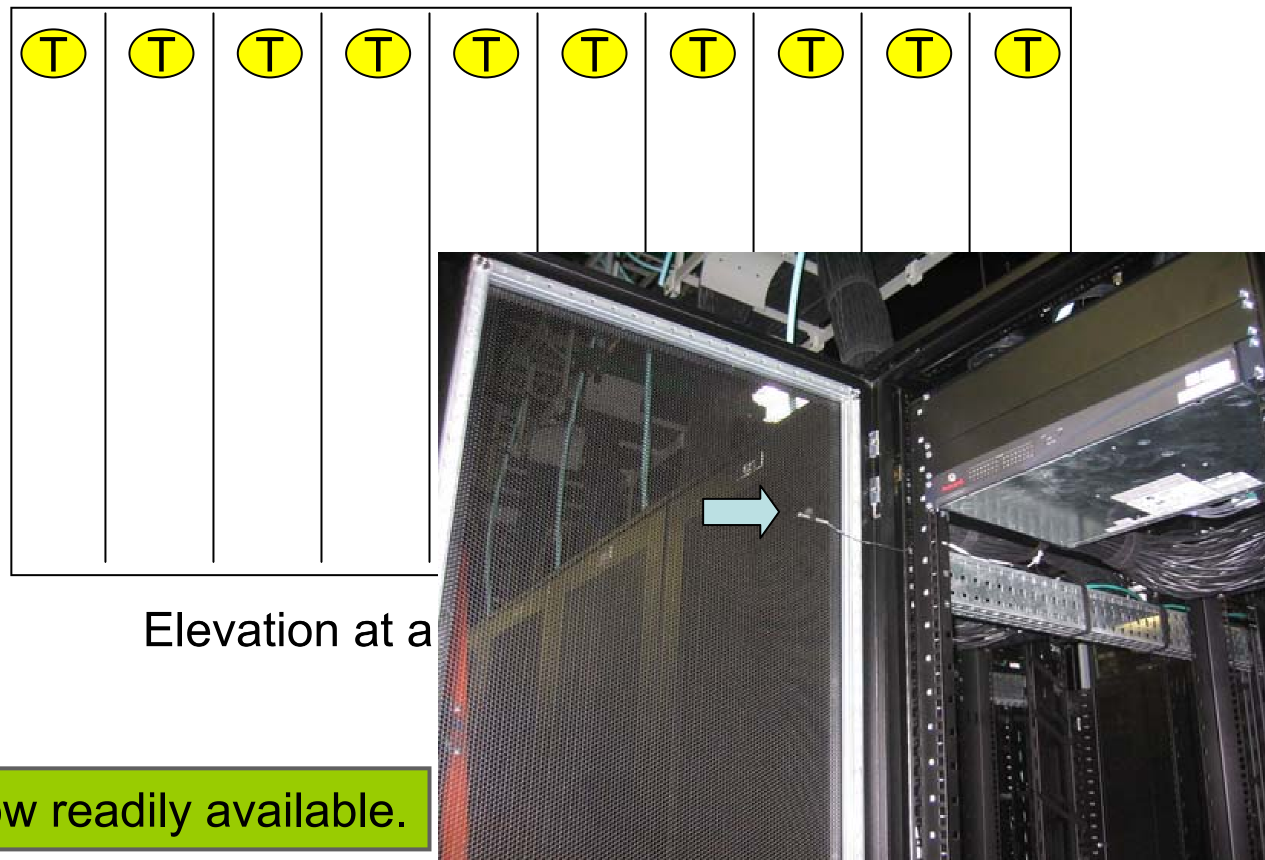
Temperature control

- Design Conditions
  - Maintain inlet conditions at servers between 64°F and 80°F.
    - 59°F to 90°F allowable.
    - At ~77°F two speed and variable speed server fans speed up (using more IT fan energy).
- Best practice
  - Provide feedback from racks.
    - Hardwired or wireless EMCS sensors.
    - Network data exchange with server on-board sensors.
  - Reset supply temperatures upward to keep most demanding rack satisfied (but below 77F).
  - Can have local temperature zones with distributed CRAC/CRAH/AH units.

Rack temperatures with UF supply

1. Reset SAT to keep rack EATs within design range

2. Keep SAT above minimum for design



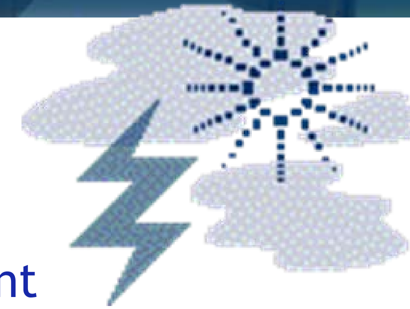
Elevation at a

Wired sensors shown.

Wireless options are now readily available.

Communication with the servers is in development (LBNL demonstration).

Humidity control



- Avoid if at all possible
  - High humidity is usually limited by cooling coil dew-point temperature.
  - Low humidity limit is not well supported (see previous slides).
- If you decide to humidify, do all of the following:
  - Use high quality dew-point sensors located in the data center floor (Vaisala see NBCIP report: http://www.buildingcontrols.org/publications.html).
  - Use adiabatic (not steam or infrared) humidifiers.
    - Direct Evaporative Media.
    - Ultrasonic (but note that DI or RO water is required)
  - Best to provide on MUA unit.
  - Control all humidifiers together if distributed.

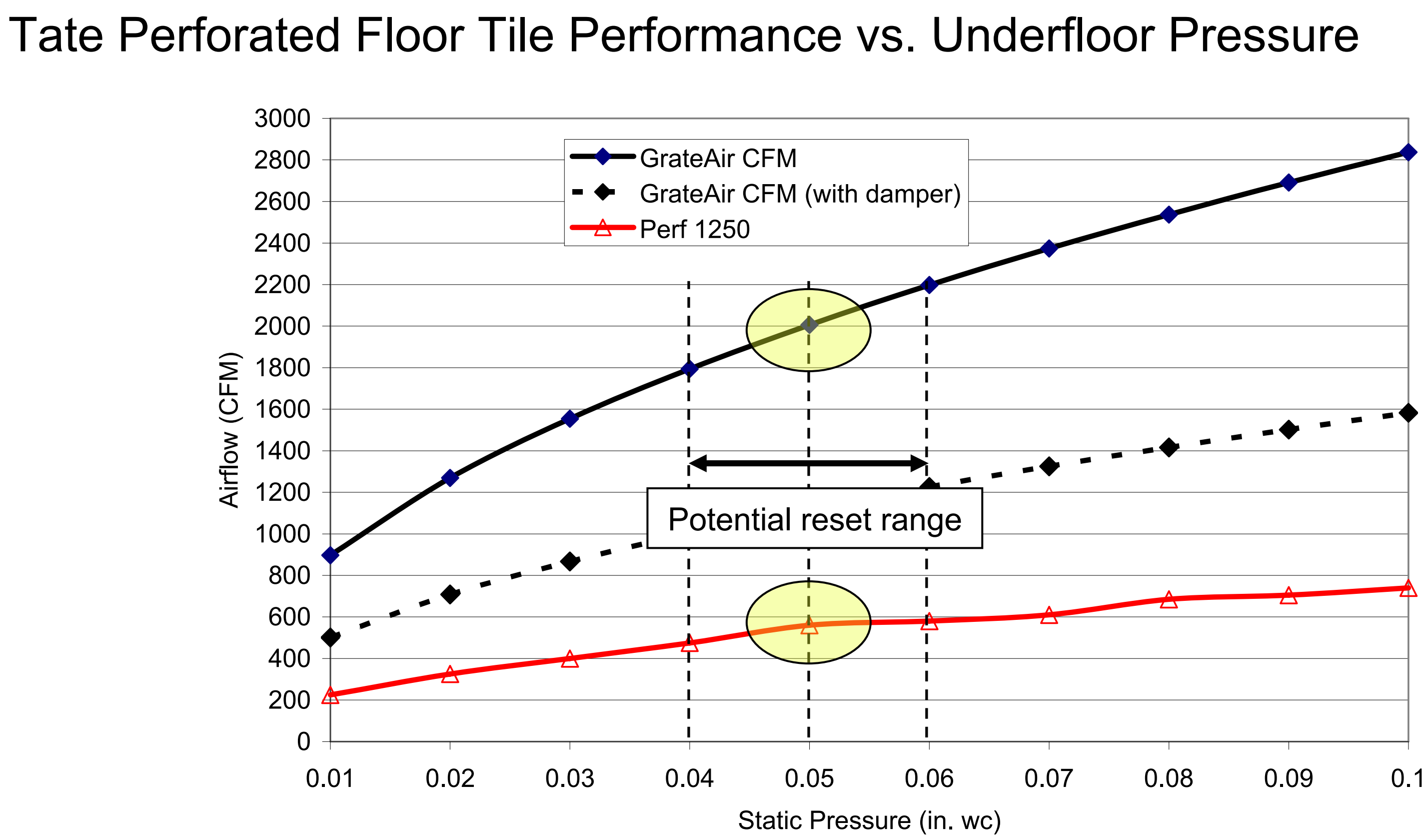
Example survey of CRACs

	Vaisala 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	

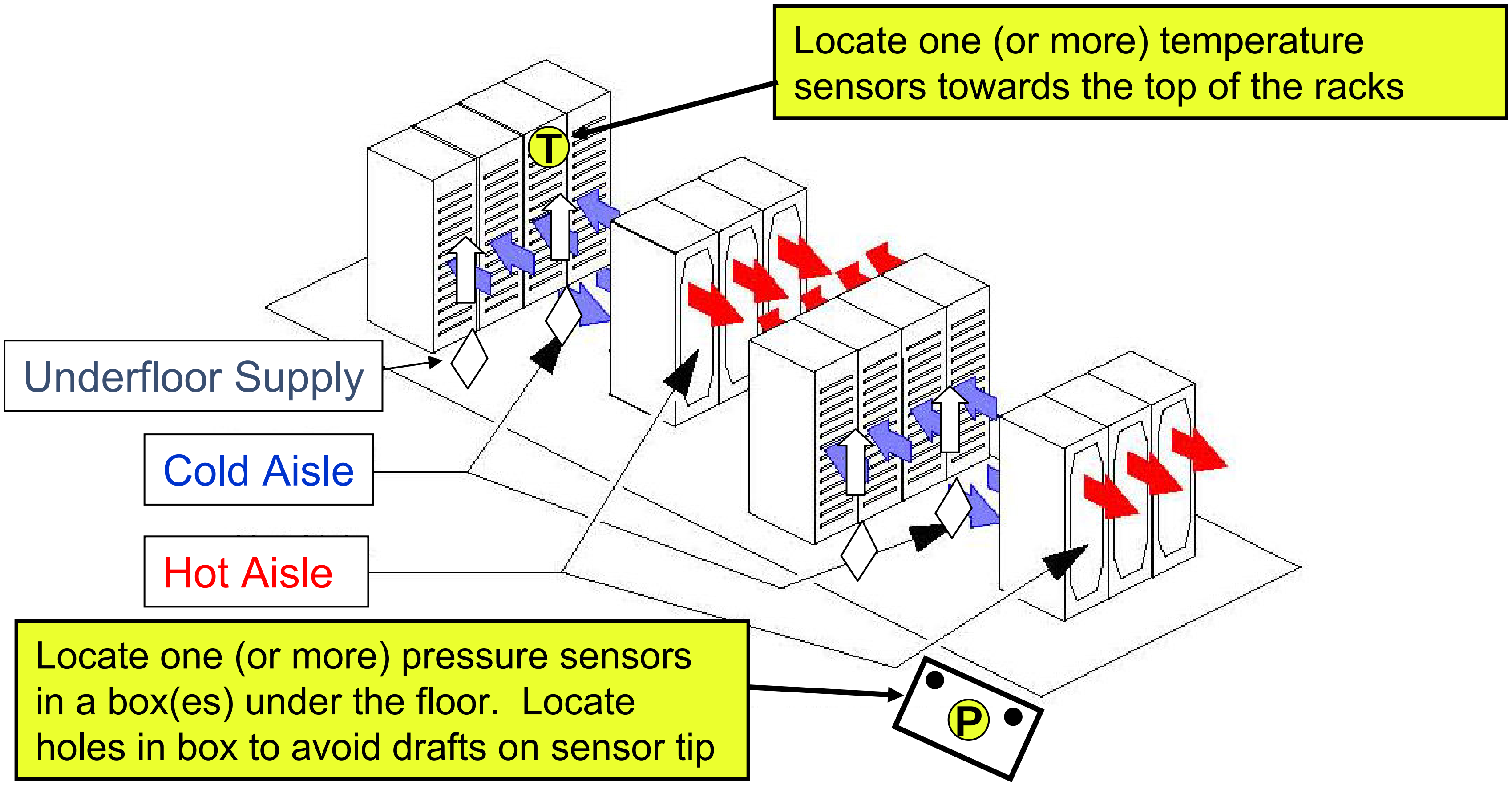
Airflow controls underfloor

- All supply fans controlled to same speed.
- Set speed to maintain differential pressure setpoint under floor (can use multiple sensors).
- Reset differential pressure setpoint by highest rack temperature (slow acting loop).

Reset of floor pressure to satisfy racks



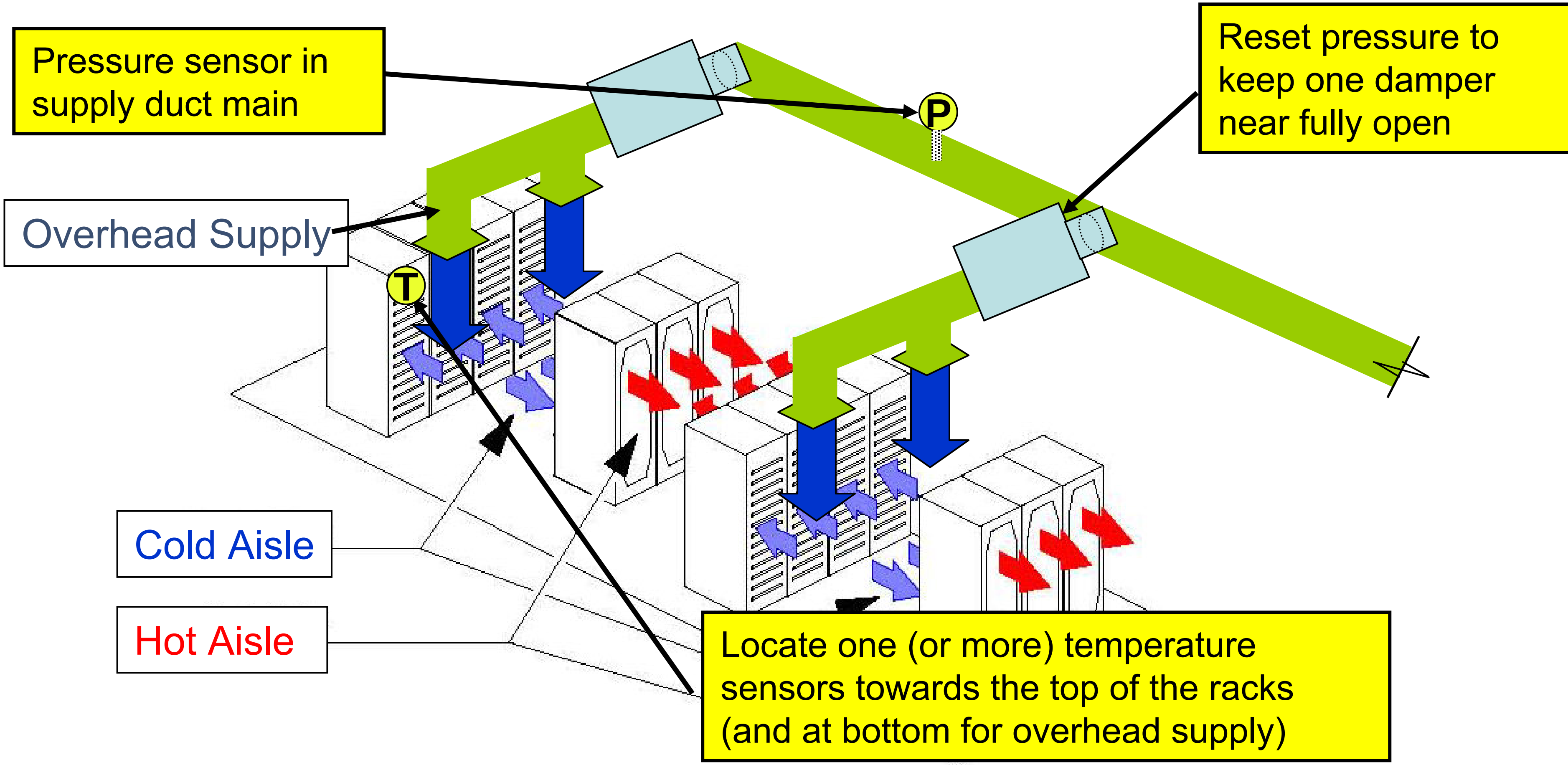
Control sensors underfloor



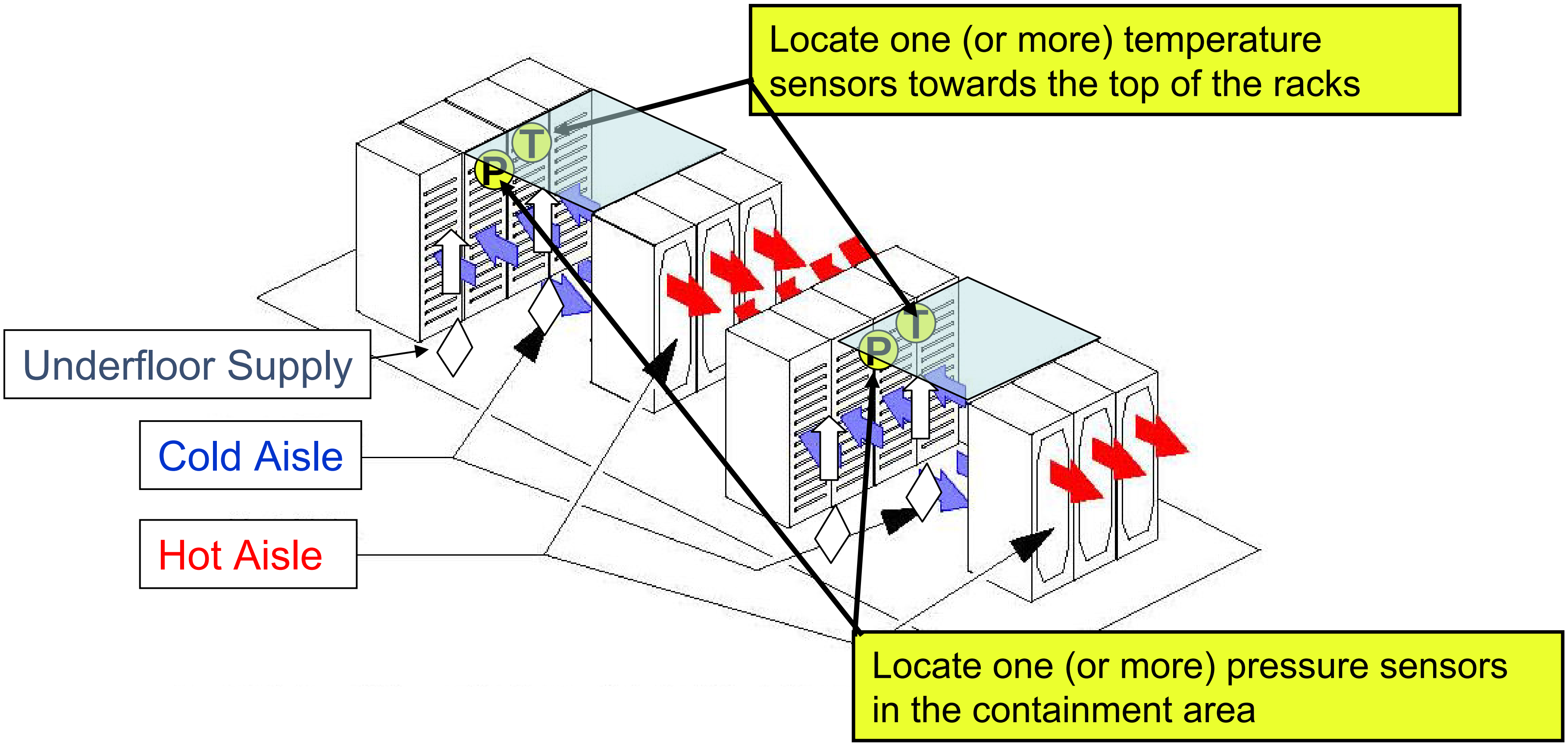
Airflow controls overhead

- All headered supply fans controlled to same speed
- Set speed to maintain pressure in supply header
- Control dampers to maintain racks at temperature
- Reset pressure setpoint to keep most open damper at or near fully open

Control sensors overhead



Control sensors with cold aisle containment



Feedback and diagnostics

- Normal Indices
  - SAT (or RAT)
  - CHWS
  - Equipment Status
  - Space Temp
  - Space RH (or return RH)
- Improved Indices
  - Rack Cooling Index (see next slide)
  - Plant kW/ton
  - LBNL's Data Center Metric Phvac/Pservers
  - Most open valve status (and location)
  - Most open damper status (and location)
  - Air management

$$\frac{\Delta T_{ACs/AHUs}}{\Delta T_{Servers}} = \text{Return Temperature Index (RTI)}$$

Rack cooling indices

$$RCI_{HIGH} = \left(1 - \frac{\sum_i (T_i - 77)}{n \times (90 - 77)} \right) X100\%$$

$$RCI_{LOW} = \left(1 - \frac{\sum_j (68 - T_j)}{n \times (68 - 59)} \right) X100\%$$

Herrlin, M. K. 2005. Rack Cooling Effectiveness in Data Centers and Telecom Central Offices: The Rack Cooling Index (RCI). ASHRAE Transactions, Volume 111, Part 2, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

IT integration

- Control system server
  - Who provides it
  - Where is it located
- Control CRAC/CRAH/AHU based on IT temperature sensors – LBNL is doing a demonstration of this.
- Gateways
  - CRAC/H unit controls
  - VSDs
  - Electrical Panels

Other issues

- Power down restart sequences
- Control system redundancy (e.g. chillers)
  - Distributed controllers (one per chiller)
  - Redundant controllers (with heartbeat and transfer switches)
  - See Engineered Systems September 2007 Article "Mission Critical Building Automation."
- Testing coordination
- Remote access/security

Best practice controls

- Use high quality sensors (not the ones that come with the CRAC/H units!).
- If used, locate the humidity sensor in the data center floor (not in the unit return).
- Reset temp and pressure by demand at racks.
- Avoid humidity controls if possible, if necessary provide it on MUA unit.
- Provide CRAC/H or AHUs with variable speed fans and control all fans in parallel to same speed.
- Used advanced whole system metrics to track system performance.
- Commission the controls thoroughly.

Data Center Commissioning

Peter Rumsey, P.E.

RUMSEY ENGINEERS

Data center Cx overview

- Roles and Responsibilities
- Cx Timeline
- Prefunctional Testing
- Functional Testing
- Trend Reviews
- Other Issues

Commissioning

- Level of commissioning
  - No "right" answer – it depends on amount owner is willing to spend vs. perceived and real benefit of a functioning system
  - Typically follows 80-20 rule: 80% of benefit achieved with 20% of effort, and to eliminate the last 20% of problems requires 80% more effort
  - Make the level appropriate for the building type and complexity of systems
    - Non-critical: Small retail and office
    - More critical: Large, complex buildings
    - **Most critical**: **Data centers**, central plants, labs

Current Cx practice

- Includes:
  - Submittal review
  - Post construction walk-through
- Typically no testing
  - Note that acceptance tests are currently part of many state and municipal energy codes and are being considered for 90.1

Data center comprehensive Cx

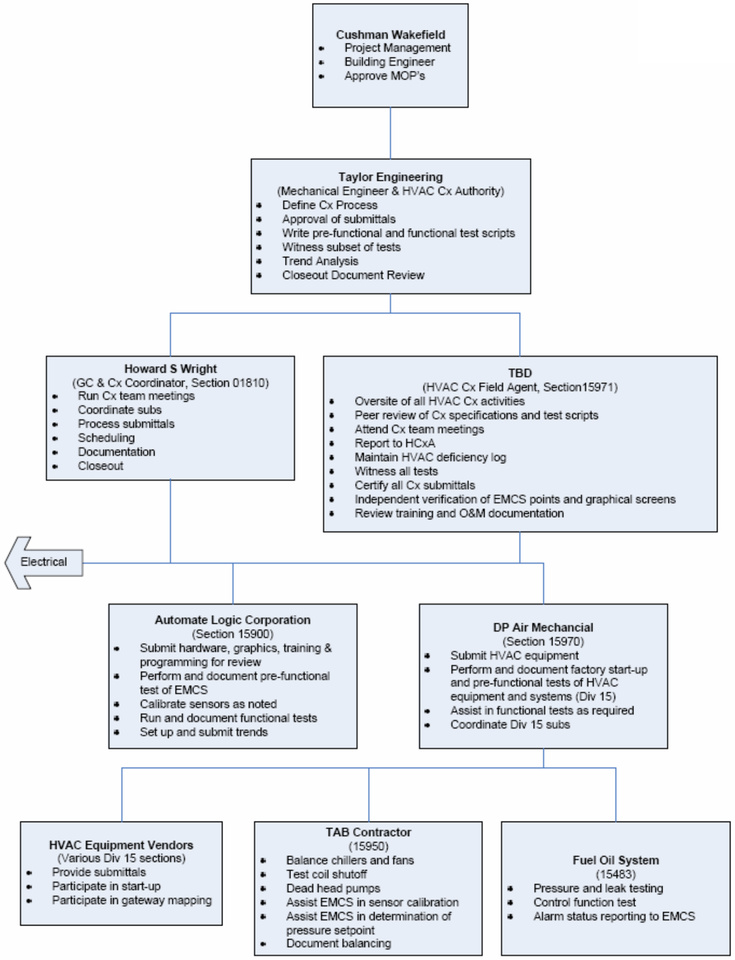
- Comprehensive Cx:
  - 3rd party peer review of design and sequences
  - Detailed submittal review
  - Detailed programming review including simulations
  - Prepare pre-functional and functional test forms
  - Pre-functional test verification
  - Perform functional tests
    - All main systems
  - Post-construction trend review
  - Post-occupancy trend review
  - Pre-warranty trend review
  - Fully documented all steps and submit Cx report

Who does commissioning?

- Contractor
  - Current practice
  - Largely ineffective due to competitive pressures, lack of oversight
- Design engineer
  - Most familiar with design, but often not sufficiently experienced with controls
  - Cx not included in standard fees
- 3rd Party
  - No conflict of interest, but most expensive and can be disruptive
- Combination of above
  - Split work among various parties to minimize cost, take advantage of expertise
- Cx Plan must be clearly detailed in spec’s!

Roles and responsibilities

Specification Section	Owner/CM (Cushman Wakefield)	Engineer (Taylor, CxA)	HCxFA 15971	GC (HSWCC, CxC) 01810	HVAC (DP Air) Div 15	EMCS (ALC) 15900	TAB 15975	Vendors
	Approve	Create	Review		Review	Review	Review	Review
01810, 15050 & 15900	Review and Enforce	Specify and Approve		Review	Provide	Provide	Provide	Provide
01810	Attend as Required	Chair		Manage and Document	Attend All	Attend All	Attend as Required	Attend as Required
01810	Review and Enforce	Specify and Approve	Review	Create & Maintain	Support	Support	Support	Support
01810	Attend as Required	Attend as Required	Attend All	Manage and Document	Attend All	Attend All	Attend as Required	Attend as Required
01810	Review, Approve and Enforce	Support	Review	Create & Maintain	Support	Support	Support	Support
01810	Review and Enforce	Specify and Approve	Create & Maintain	Support	Execute	Execute	Support	Support
Div 15 Sections	Review and Enforce	Specify and Approve	Review	Review	Execute & Submit	Execute & Submit	Support	Support
Div 15 Sections	Review and Enforce	Approve	Witness & Certify	Support	Execute & Submit	Execute & Submit	Support	Specify and Support
15050	Review and Enforce	Specify and Approve	Witness & Certify	Support	Support		Execute & Submit	
15950	Review and Enforce	Specify and Approve	Witness & Certify	Support	Support	Execute & Submit	Support	Support
01810	Review and Enforce	Specify and witness	Witness & Certify	Support	Support	Execute & Submit	Support	Support
01810	Review and Enforce	Specify and Approve	Witness & Certify	Support		Execute & Submit		
15971	Review and Enforce	Specify and Approve	Execute and Submit	Support	Execute & Submit	Execute & Submit		
15900	Review and Enforce	Specify and Approve	Review & Certify	Support	Execute & Submit	Execute & Submit		Support
15050	Review and Enforce	Specify and Approve	Review & Certify	Support	Provide	Execute & Submit	Provide	Support
15050 & 15900	Review and Enforce	Specify and Approve	Review & Certify	Support	Execute & Submit	Execute & Submit		Support
15050 & 15900	Review and Enforce	Specify and Approve	Witness & Certify	Support	Support	Support	Support	Support
15050 & 15900	Approve	Recommend	Witness & Certify	Support				
01810	Review	Specify and Approve		Execute & Submit	Support	Support	Support	Support



Prefunctional tests

- Augments and documents manufacturer’s start up procedures for equipment
- Includes some system testing like
  - Pipe pressure testing
  - Duct leakage testing
  - Valve leakage tests
- May include factory witness testing (e.g. chillers)

Control system pre-functional tests

- General
  - Inspect the installation of all devices.
  - Verify integrity/safety of all electrical connections.
  - Verify that all sensor locations are as indicated on drawings
- Digital Outputs
  - Verify DOs operate properly and that the normal positions are correct.
- Digital Inputs
  - Adjust setpoints, where applicable.
- Analog Outputs
  - Verify start and span are correct and control action is correct.
- Analog Input Calibration
  - Calibrated as specified on the points list
  - Inaccurate sensors must be replaced if calibration is not possible.
- Gateway points (bi-directional)

Calibration Log

ID No.	Cal.Temp	Reading	Offset
AHU-1 SAT	53.2	53.2	0
Ahu-2 SAT	53.7	51.7	2
Ahu-3 SAT	52.6	51.4	1.2
Ahu-4 SAT	53.1	52.4	0.7
Ahu-5 SAT	58.6	59.9	-1.3
BLDG HW Supply	150	150.1	-0.1
BLDG HW Return	150	149.7	0.3
Primary HW Supply	150	150	0
BLDG CHW Supply	80	79.7	0.3
BLDG CHW Return	80	79.6	0.4
Primary CHW Supply	80	79.9	0.1

Pre-functional tests, continued

- Alarms and Interlocks:
  - Check each alarm separately by including an appropriate signal at a value that will trip the alarm
  - Verify internal and external response to alarm (email, page)
- Gateways
  - Verify operation and map across points
- Loop Tuning
  - Achieve specified stability
- Operator Interfaces
  - Verify that all elements on the graphics, functional and are bound to physical devices
  - Verify hyperlinks
- Trending/Network Traffic Test
- TAB tests
  - Setpoint Determination, e.g. DP and minimum outdoor air damper position

Functional tests

- Scope
  - Test every sequence
  - For data centers typically we test every piece of equipment
- Format
  - Test form to include setup, steps, expected response, and actual response
- Who prepares and performs tests?
  - May be contractor, engineer, or 3rd party Cx agent
  - We often have the engineer prepare and witness them and the contractor performs them

Functional tests

I. Chilled Water Pumping System

The following is from the specifications for bypass valve, minimum flow control:

Chiller Stage	Chillers operating	Minimum Flow
1	1 small, 0 big	250
2	2 small, 0 big	480
3	1 small, 1 big	595
4	2 small, 1 big	825
5	1 small, 2 big	940
6	2 small, 2 big	1,170
7	3 small, 2 big	1,400
8	4 small, 2 big	1,605

The following is from the specifications for pump staging:

CHW Pumps Operating	Nominal flow	Stage up to this stage if flow exceeds this for 5 minutes	Stage down to lower stage if flow is below this for 5 minutes*
1	650 gpm	--	--
2	1,300 gpm	650 gpm	490 gpm
3	1,950 gpm	1,300 gpm	975 gpm
4	2,600 gpm	1,950 gpm	1,450 gpm

Unit(s) Tested:		**Tested by: Mark P & Gary K.**	
Action	**Expected Response**	**Observed Response**	**Date/Time**
At the chillers and the EMCS system, read and record the flowrates from each of the operating chillers. Read and record the EMCS calculated plant flowrate. **Chillers were locked on.**	The plant flow rate should equal the sum of the flow meters on all of the operating chillers The EMCS flow rate should	Flowrates (gpm) At Meter | At EMCS CH-1: **245.1** | **245.5** CH-2: **274.0** | **274.5** CH-3: **124.6** | **124.6** CH-4: **off** | **off**	11/16/06 3:23pm

Functional tests

Unit(s) Tested:		**Tested by: Mark P & Gary K.**	
Action	**Expected Response**	**Observed Response**	**Date/Time**
	match the flowrate on the faceplate of the flow meters	CH-5: **off** | **off** CH-6: **off** | **off** Plant: ----N/A------|	
For each pump, read and record the minimum speed setpoint in the drive **20% ---100% BAS** **20Hz----60Hz VFD**	Either the VSD minimum or the EMCS minimum should be 0. The other should be set to 10% (6HZ)	Minimum setting VSD EMCS P-1: **20Hz** | **20%** P-2: **20Hz** | **20%** P-3: **20Hz** | **20%** P-4: **20Hz** | **20%**	11/16/06 3:30pm
Read and record the following data: • Total plant flowrate (EMCS, gpm) • Current DP setpoint (EMCS, psi) • Current DP at the sensors in the distribution loop (EMCS, psi) • Which pumps are running • Current pump speeds (both at the EMCS and on the VSD panel) At the EMCS increase the DP setpoint by 10% to 15%. Wait 3 minutes. Read and record the following data: • Total plant flowrate (EMCS, gpm) • Current DP setpoint (EMCS, psi) • Current DP at the sensors in the distribution loop (EMCS, psi)	DP sensor reading should be stable at DP sensor setpoint. The VSD should have sped up to get the DP sensor reading to the new setpoint. There should be no hunting of the VSD speed or actual loop pressure. The plant flow rate should not change appreciably. The number of pumps running should be as follows: • 1 for flow between 0 and 490 gpm • 1 or 2 for flow between	**As-is data** Plant flowrate: **637.5** DP setpoint: **15#** DP reading 1: **14.8 #** DP reading 2: **NA** Pump Speeds/Status (0=OFF) VSD EMCS P-1: **49.9** | **83.5** P-2: **0** | P-3: **0** | P-4: **0** | **Post setpoint change data** Plant flowrate: **695.8** DP setpoint: **17.0** DP reading 1: **16.5** DP reading 2: **NA** Pump Speeds/Status (0=OFF)	

More functional tests

- Shut off devices and watch system response (e.g. start of backup pump)
- Check alarms and response
- Override setpoints and watch system response
- Push system to extremes (requires load banks)
- Power system down and check recovery
- Check control system panel failure (if designed for redundancy)
- Power down restart sequences
- Observe system as it operates

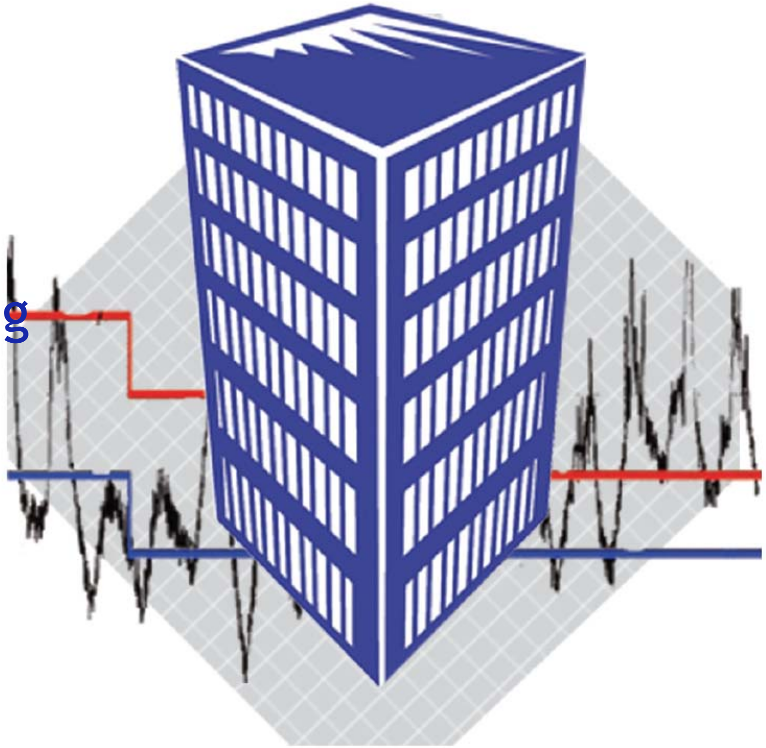
Trend reviews

- Required even when detailed functional tests are performed
  - Functional tests mimic control sequences – they prove programming matches sequences but cannot identify bugs in sequences
- Less expensive than comprehensive functional testing with proper analysis tools
  - But trends do not generally show faults – they must be tested in the field since they may not occur during trend period
- Requires experienced eye – design engineer with controls experience who is very familiar with sequences and HVAC systems

DDC trend reviews

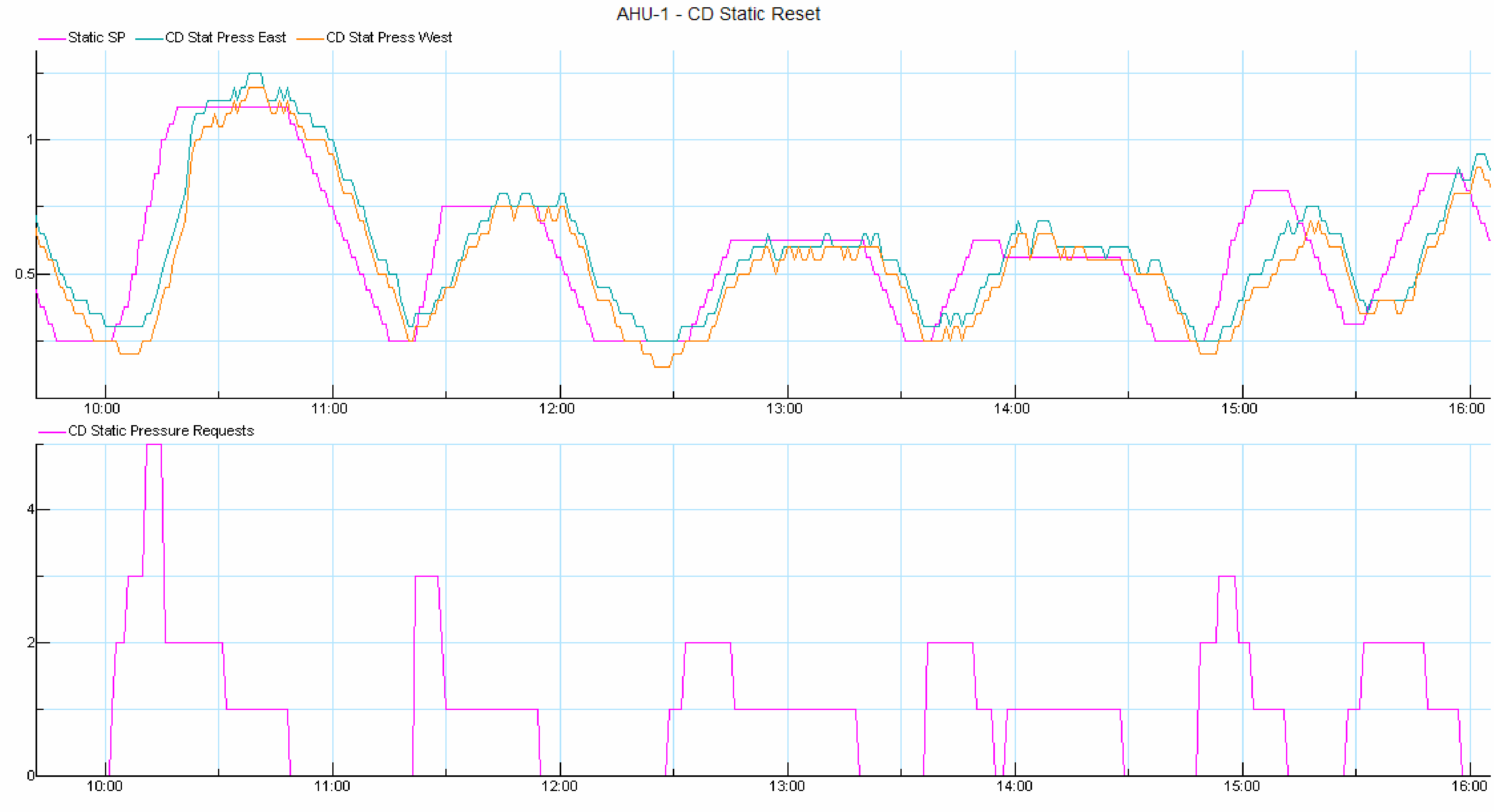
1. Collect trends using DDC system
2. Massage data
   - Universal Translator software tool enables import, normalization, sorting, grouping and exporting of trends:

     http://www.utonline.org/
3. Perform statistical analysis
4. Graph selected variables
5. Analyze results



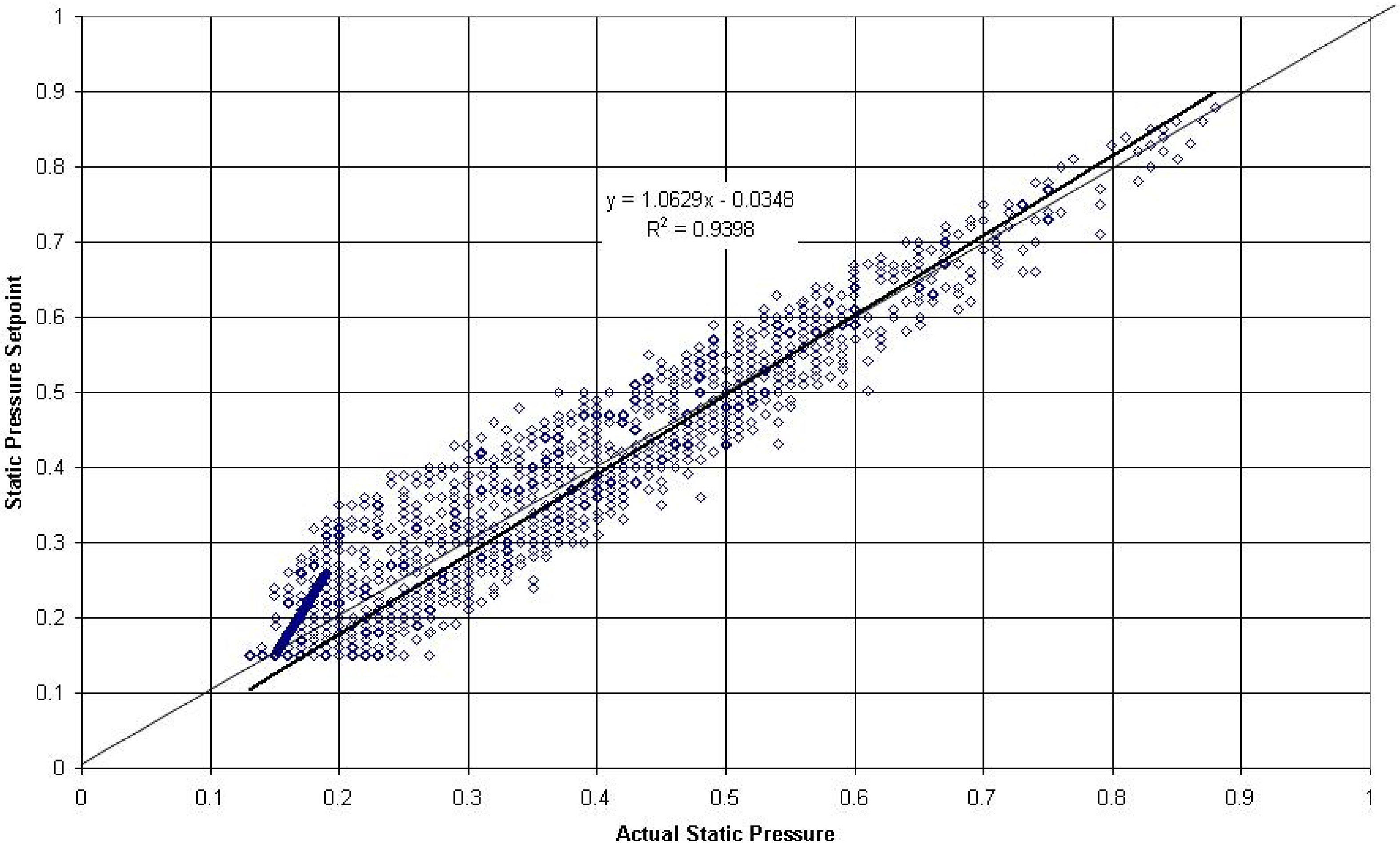
Time Series

Static Pressure Reset



Scatter Plot

Loop Tuning, Reset



Statistics

Date	Minutes of Warmup	Average OAT	Minimum OAT	Minimum N	Minimum E	Minimum W	Minimum S	Maximum N	Maximum E	Maximum W	Maximum S	Day of Week
Occupied Hours												
12/12/2001	0	51	45	67	70	69	70	73	73	73	74	Wed
12/13/2001	0	49	44	67	70	69	70	70	73	71	73	Thurs
12/14/2001	0	50	44	66	70	68	69	69	73	72	74	Fri
12/17/2001	0	52	48	64	66	66	67	72	73	72	77	Mon
12/18/2001	0	50	43	65	68	67	68	72	73	72	74	Tues
12/19/2001	0	51	44	65	67	-	68	73	75	72	74	Wed
12/20/2001	0	48	46	66	69	68	68	72	74	72	75	Thurs
12/21/2001	0	44	44	64	67	67	67	66	69	68	71	Fri
12/26/2001	0	45	45	68	69	68	69	68	69	68	69	Wed
12/27/2001	0	49	45	69	70	69	70	73	72	71	75	Thurs
12/28/2001	0	49	47	68	68	69	69	73	73	71	75	Fri
12/31/2001	0	56	51	65	66	67	67	72	73	71	74	Mon
1/2/2002	0	52	50	65	66	67	67	71	73	73	72	Wed
Unoccupied Hours												
12/12/2001	0	49	47	68	71	70	70	71	71	71	72	Wed
12/13/2001	18	46	44	66	69	69	69	70	72	70	71	Thurs
12/14/2001	19	45	43	66	70	69	68	69	72	70	73	Fri
12/15/2001	0	46	41	64	67	67	67	66	70	72	72	Sat
12/16/2001	0	48	44	63	66	66	66	65	68	68	68	Sun
12/17/2001	18	48	45	63	66	66	66	71	71	70	72	Mon
12/18/2001	18	45	43	65	68	67	67	71	71	71	71	Tues
12/19/2001	0	46	44	65	68	67	67	72	72	70	71	Wed
12/20/2001	19	45	43	66	68	68	68	72	70	71	72	Thurs
12/21/2001	0	44	43	64	67	67	67	66	68	68	68	Fri
12/27/2001	16	49	45	68	69	68	69	70	70	70	71	Thurs
12/28/2001	18	48	46	67	68	69	69	71	71	70	72	Fri
12/29/2001	0	48	46	66	67	68	68	67	69	69	69	Sat
12/30/2001	0	51	49	65	66	67	67	66	67	68	68	Sun
12/31/2001	18	52	50	65	66	67	66	71	71	70	71	Mon
1/1/2002	0	52	50	65	67	67	67	67	68	69	69	Tues
1/2/2002	0	51	50	65	66	67	67	66	67	67	67	Wed

Pivot table or summation query

CT1_SS	CT2_SS	Instances (5 min)	Avg. CH1 CWST	Avg. CH2 CWST	Set Point	Pct
FAST	FAST	197	68.2	66.2	VHIGH	7%
FAST	SLOW	16	65.2	64.9	VHIGH	1%
FAST	**STOP**	**24**	**65.0**	**65.8**	**N/A**	**1%**
SLOW	FAST	86	66.4	65.0	VHIGH	3%
SLOW	SLOW	4	65.2	65.5	VLOW	0%
SLOW	STOP	39	63.7	64.1	VLOW	1%
STOP	**FAST**	**787**	**65.9**	**67.9**	**N/A**	**27%**
STOP	SLOW	1798	62.8	66.7	VLOW	61%
STOP	STOP	1	60.2	64.8	VLOW	0%

Other Cx issues

- One person on site must coordinate all Cx activities
- Hold regular weekly Cx meetings
- Coordination of load banks with electrical
- Detail recovery procedures for testing on live data centers
- Carefully coordinate electrical, mechanical and control testing to save time and costs
  - Mechanical and control testing in general should not overlap electrical system testing

Best practices for Cx

- Specify thorough commissioning for data centers
- Be specific on roles and responsibilities
- Have an experienced Cx coordinator on the site
- Hold weekly Cx meetings with all trades represented
- Carefully coordinate electrical, mechanical and control system testing

Take aways

- No “right” way to perform commissioning
- Comprehensive Cx involves many steps
- Various approaches—contractor, engineer, 3rd party, combo
- Commissioning plan must be in specifications
- Controls programming should be reviewed
- Prefunctional and functional tests verify system and component function
- Trend reviews while not as comprehensive can identify problems
- Coordination is important during commissioning

Break

Electrical Systems Efficiency

Steve Greenberg, PE

Electrical Systems Efficiency

- Electrical distribution systems
- Lighting
- Standby generation
- On-site generation

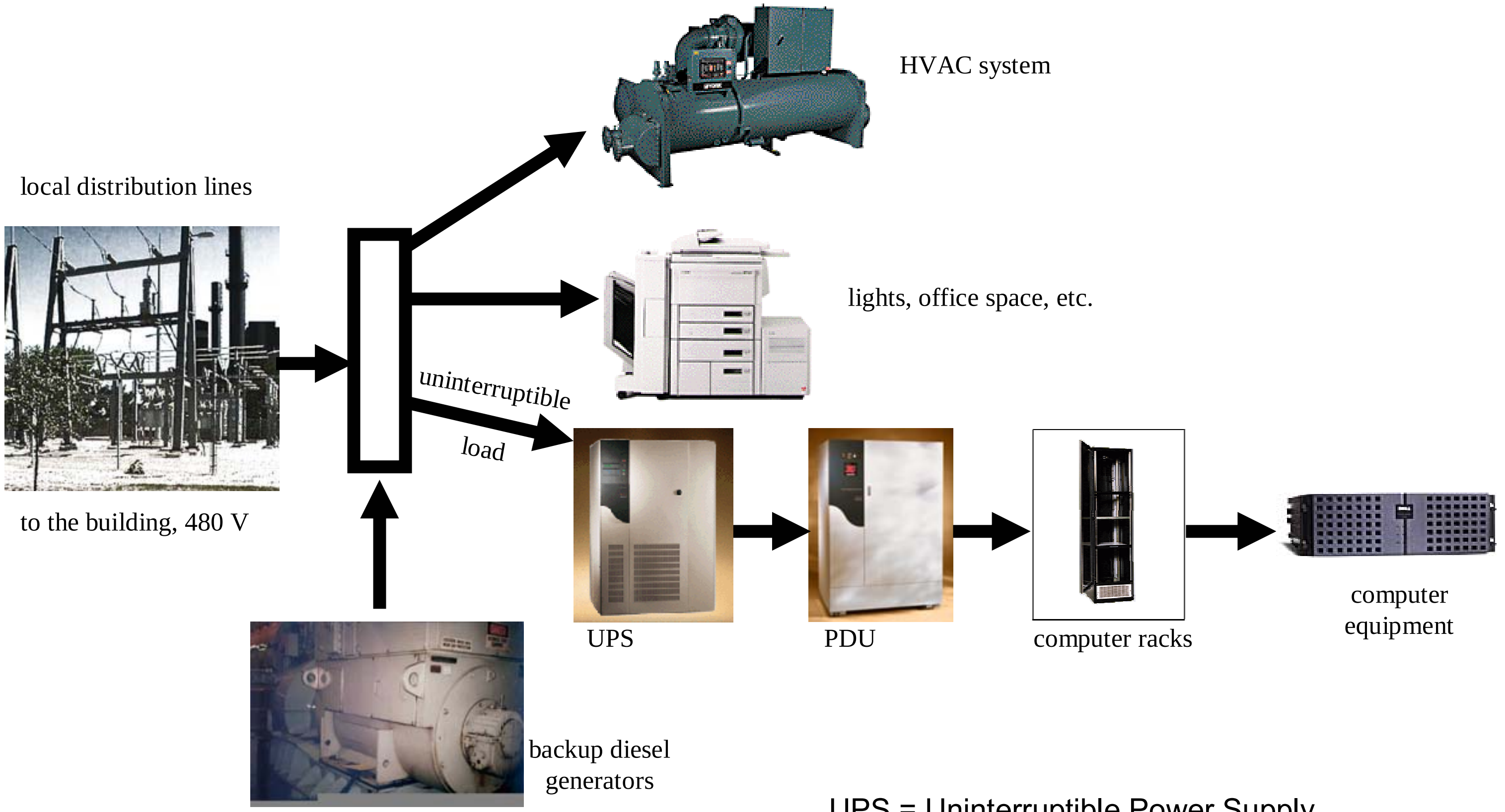
Root causes of electrical system inefficiency

- Physical infrastructure is typically OVERSIZED
- Power requirements are initially greatly OVERSTATED
- Legacy INEFFICIENT equipment is incorporated
- IT equipment is on and not doing anything
- Multiple POWER CONVERSIONS – each conversion loses some power and creates heat
- Power conversion efficiency is not optimized

Electrical Distribution 101

- Every power conversion (AC-DC, DC-AC, AC-AC) loses some power and creates heat
- Distributing higher voltage is more efficient and saves capital cost (wire size is smaller)
- Uninterruptible power supplies (UPS's) efficiency varies
- Power supplies in IT equipment efficiency varies

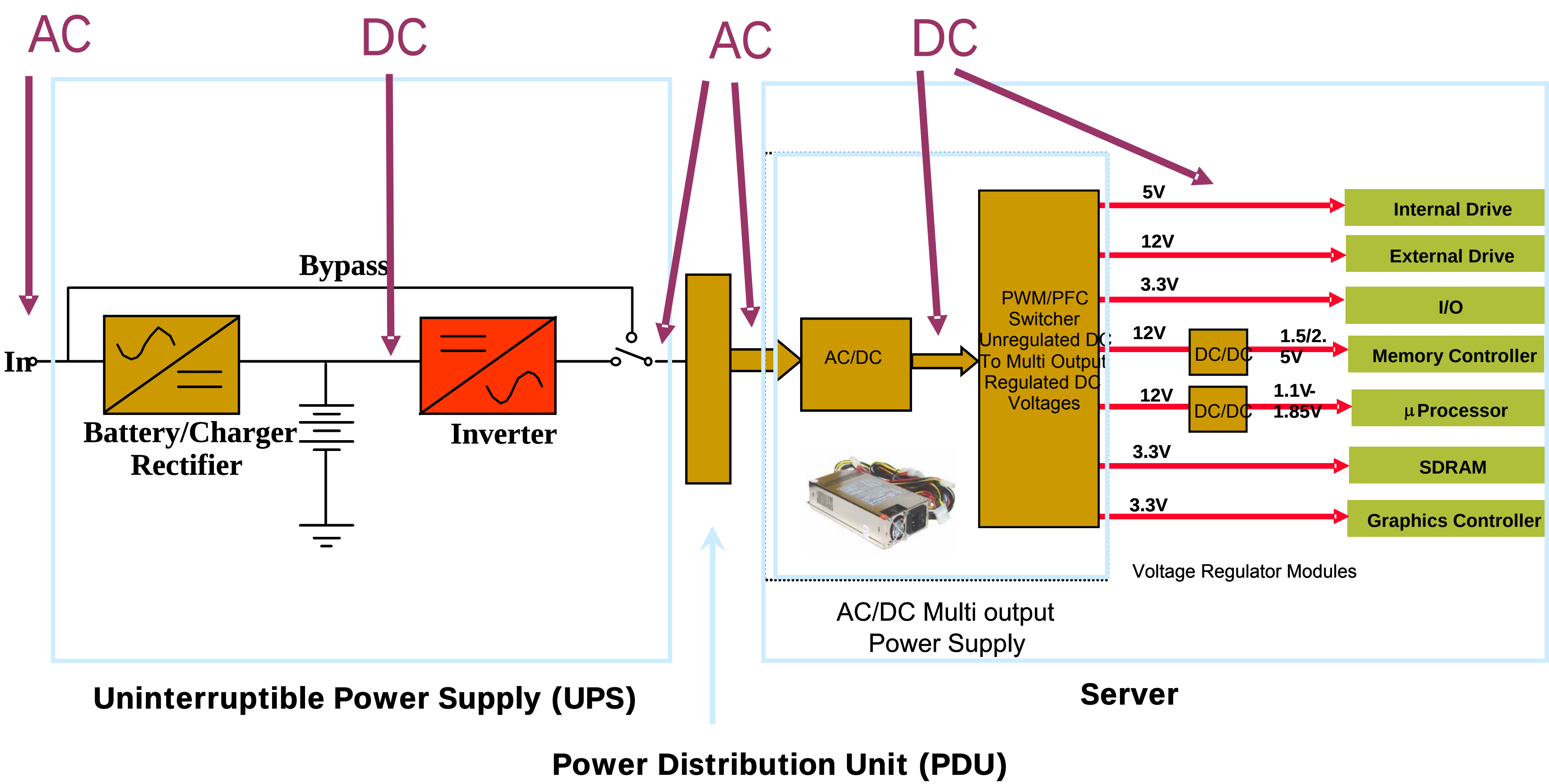
Electricity Flows in Data Centers



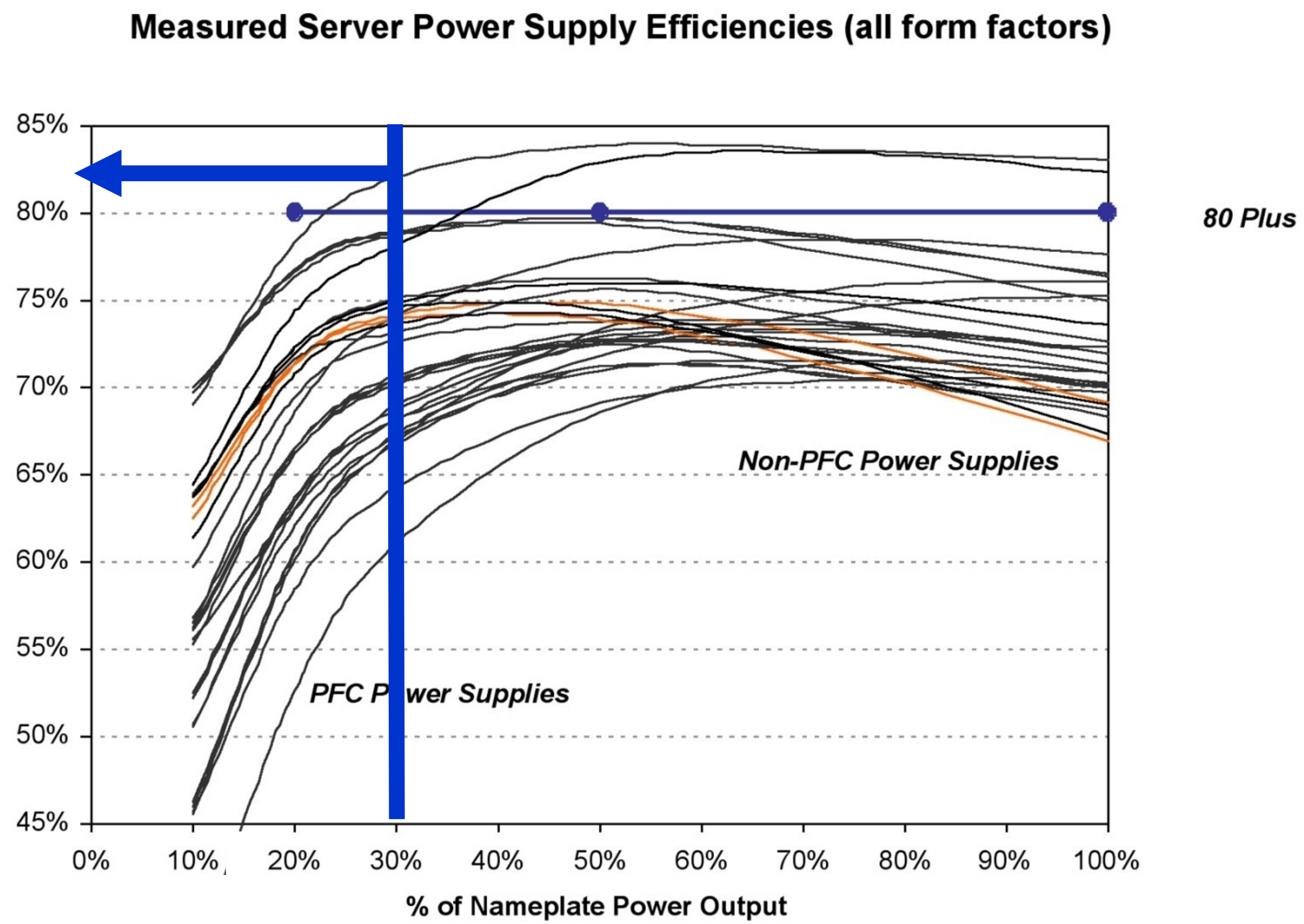
UPS = Uninterruptible Power Supply

PDU = Power Distribution Unit;

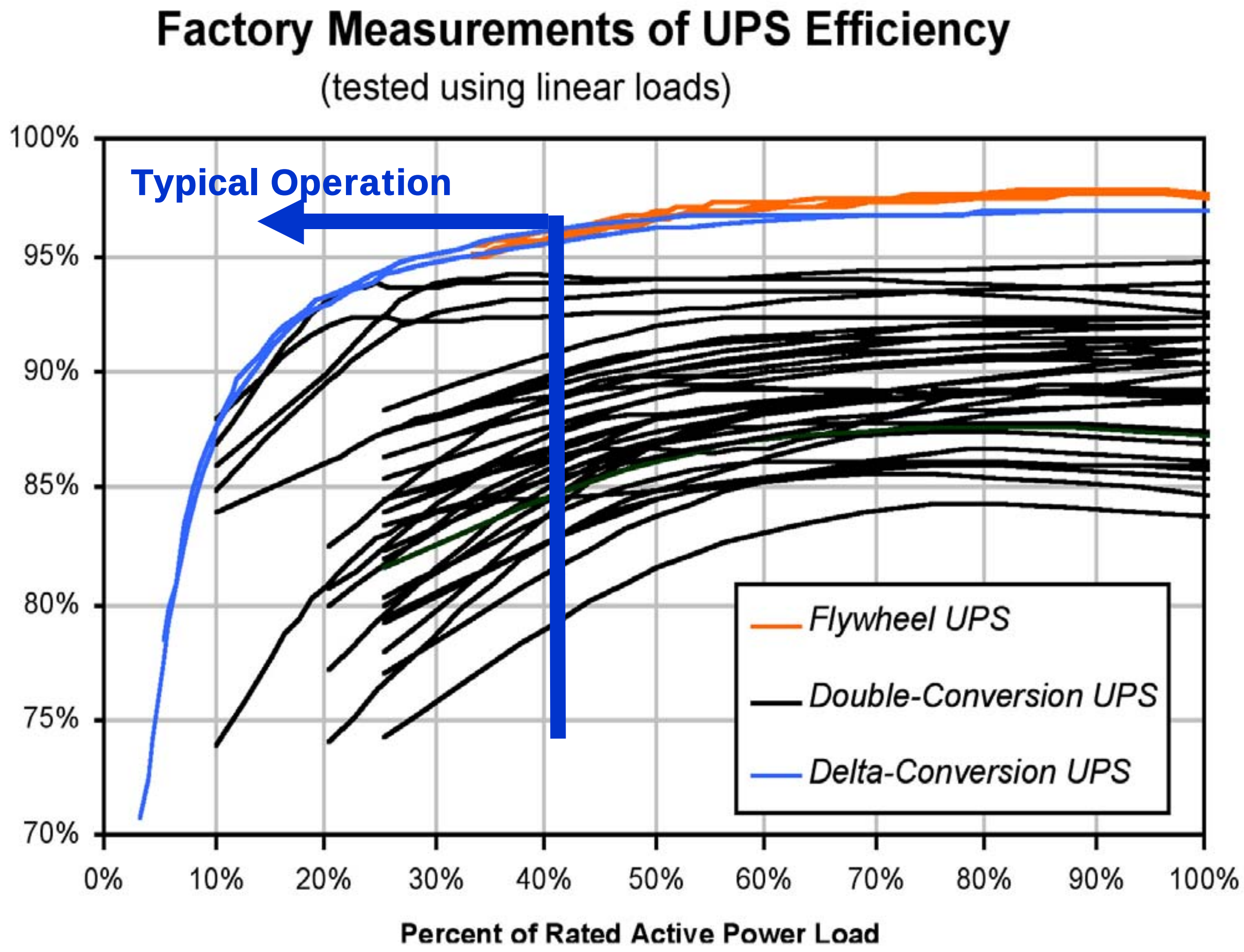
From utility power to the chip -multiple electrical power conversions



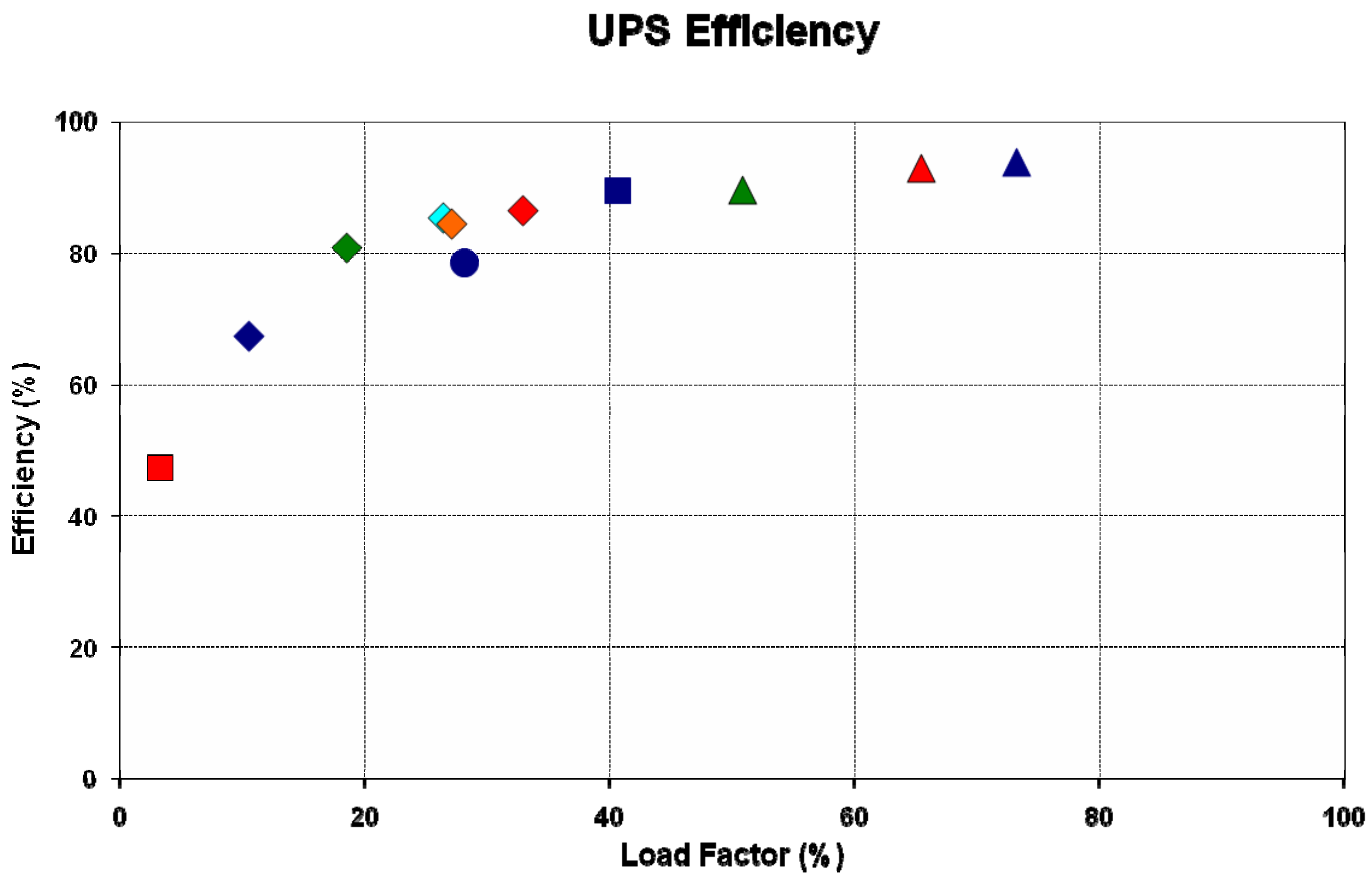
Measured power supply efficiency



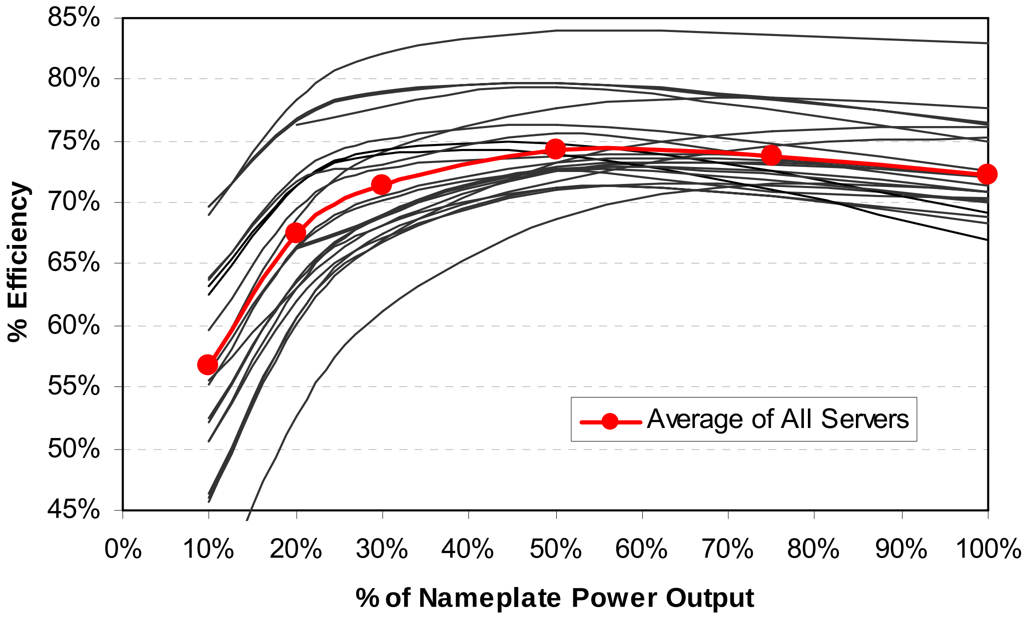
UPS factory measurements

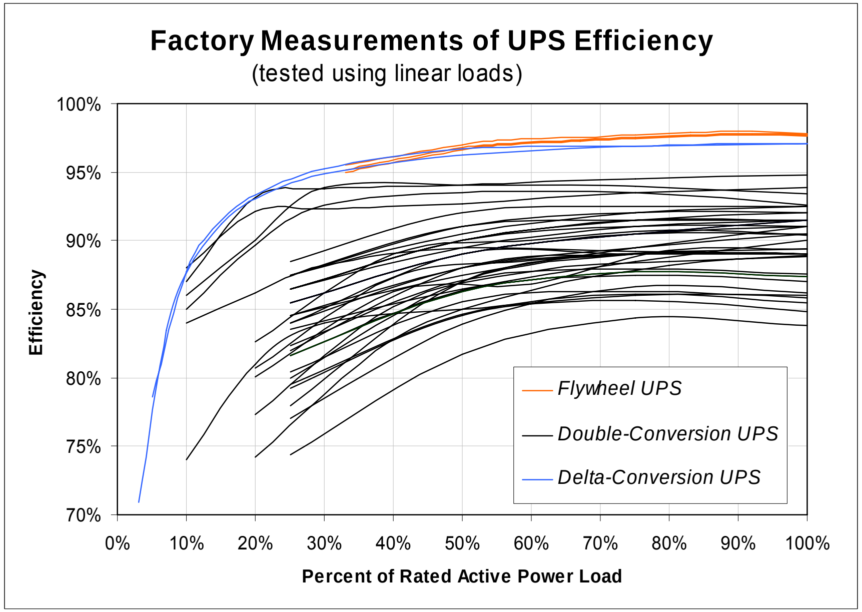


Field measured UPS performance



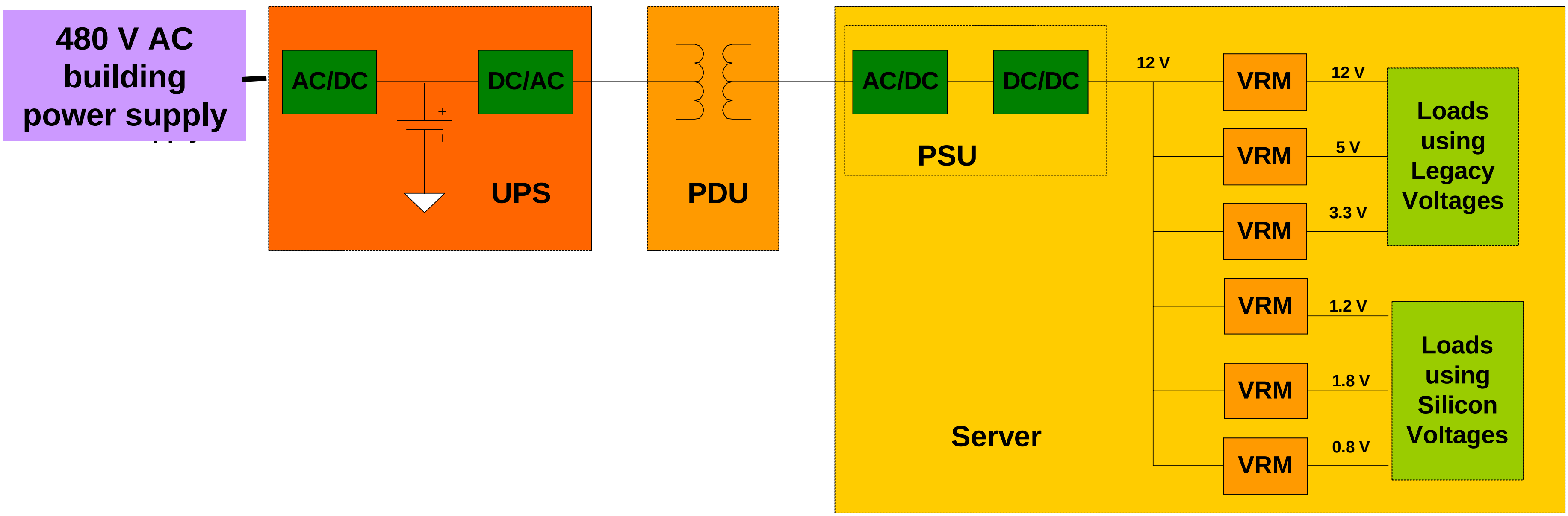
Electrical power conversion efficiency varies





LBNL DC power demonstration

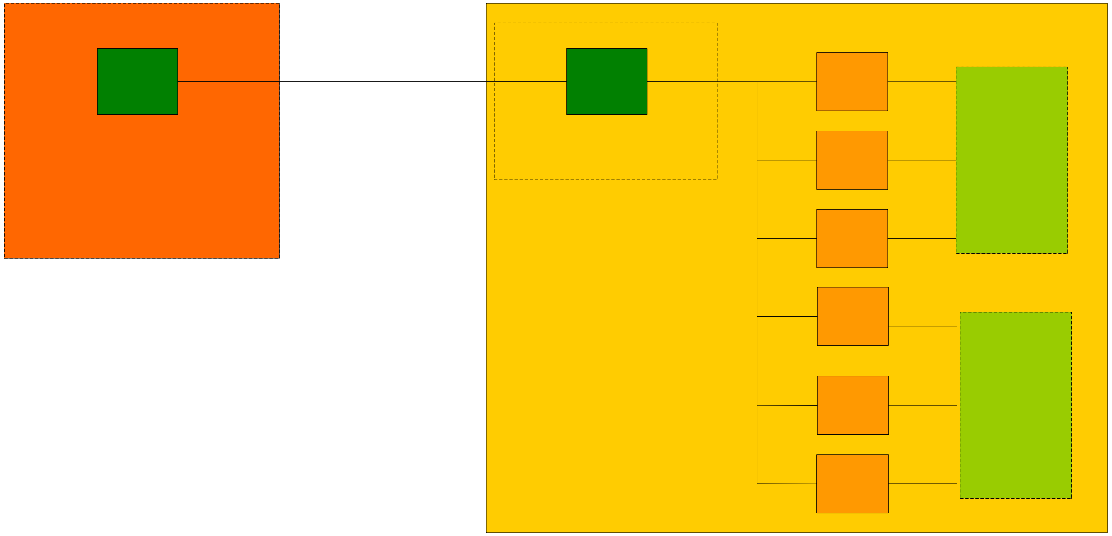
"Today's" AC distribution



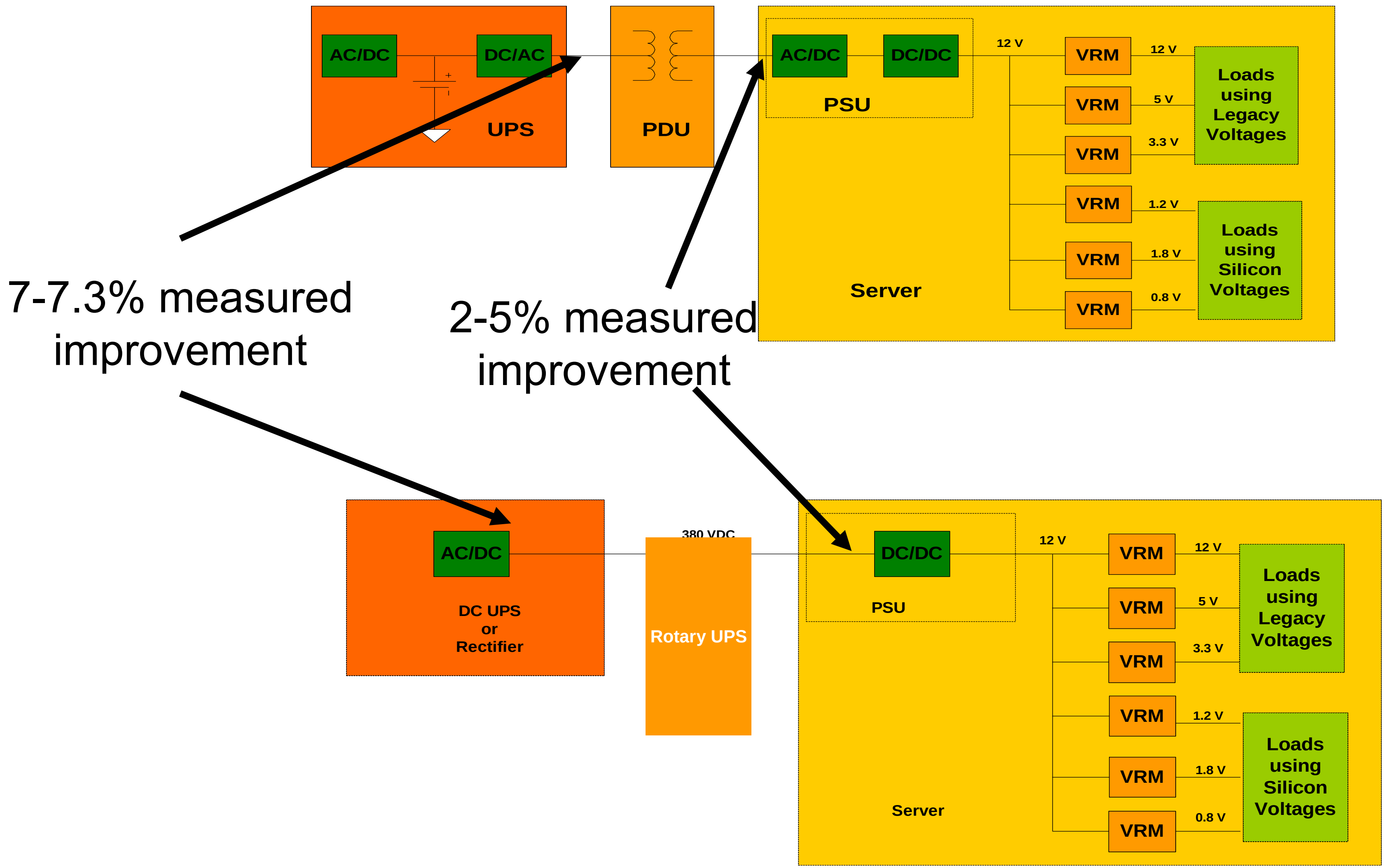
DC power distribution

Eliminates several stages of power conversion.

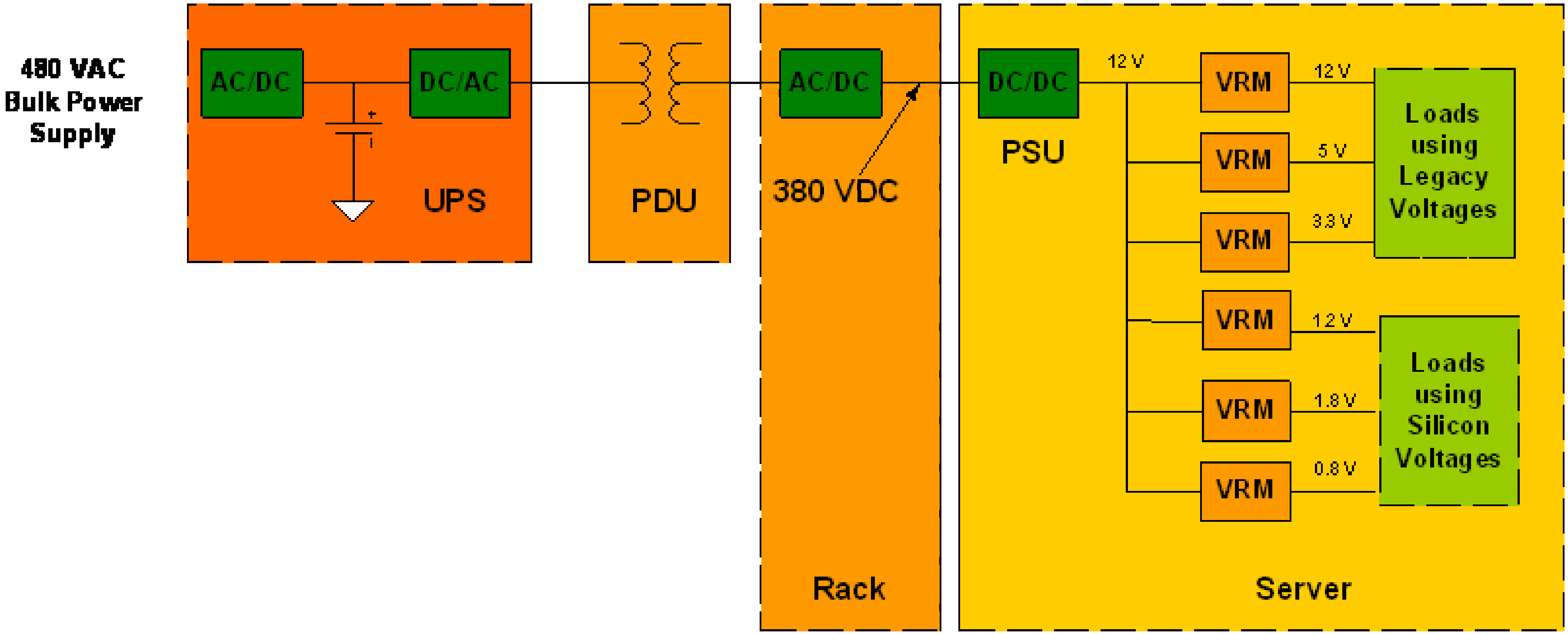
Facility-Level DC Distribution



AC system loss compared to DC



Rack-level DC distribution



Other benefits of 380 V. DC distribution

- Easy to tie in renewable sources
- Direct use in variable speed drives
- Use of DC lighting
- Minimize power quality issues
- Reduced HVAC
- Less capital cost
- Potential for world wide standard

DC demonstration

Video available through LBL website

Redundancy

- Understand what redundancy costs –
  is it worth it?
- Different strategies have different energy penalties (e.g. 2N vs. N+1)
- Its possible to more fully load UPS systems and achieve desired redundancy
- Redundancy in electrical distribution always puts you down the efficiency curve
- Consider other options

Electrical systems sizing

- IT Design Load typically was historically based on IT Nameplate plus future growth

  Problem - actual IT loads are <25% of nameplate

- IT load was determined on a Watts/sf basis

  Problem -IT loads are now concentrated

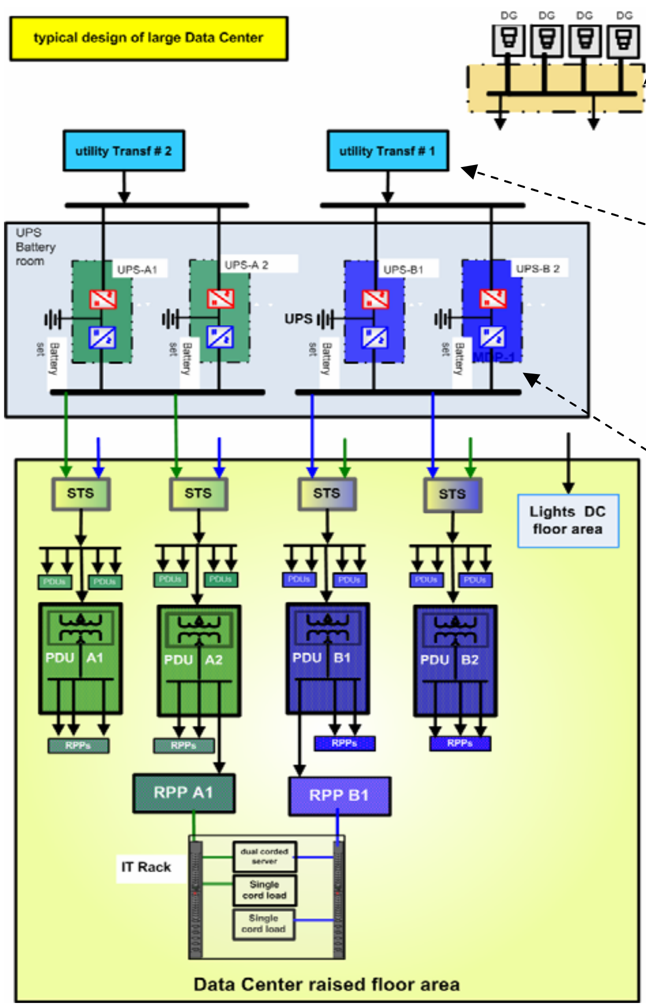
- UPS systems are sized for IT load plus 20-50%

  Problem - load was already oversized by factor of 4

- Standby generators are sized for UPS load x2 or more

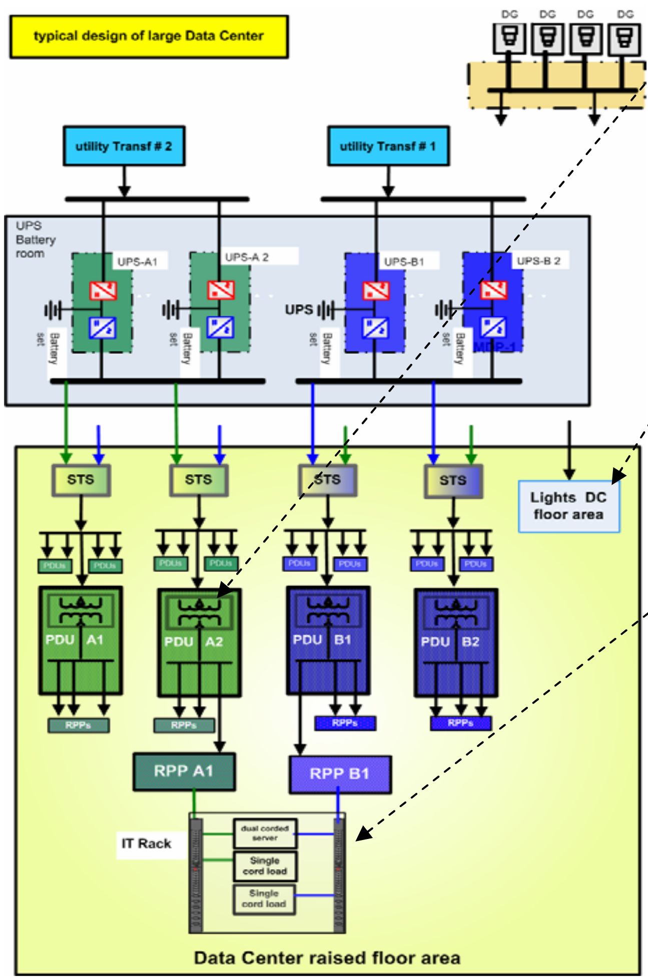
  Problem - block heaters

Infrastructure inefficiency



- **Standby generators**
  - Oversized
  - Redundancy exceeds N+1
  - Excessive block heater loads
- **Transformers**
  - Oversized
  - Inefficient - higher losses
- **UPS**
  - Low load capacity due To
    - Oversizing
    - Multi-Stage redundancy 2 (N+)
  - Inefficient UPS topology
  - Low input power factor
  - High input current THD

Infrastructure inefficiency



- **PDU**
  - Excessive use of PDUs. 4 – 6 X IT designed load
  - Inefficient transformers
- **Lights**
  - Unused floor space
  - Use of inefficient lights
  - No lighting Controls
- **IT**
  - Sizing of IT load is based on nameplate + growth
  - IT low power factor
  - IT high current harmonic THD
  - Low utilization

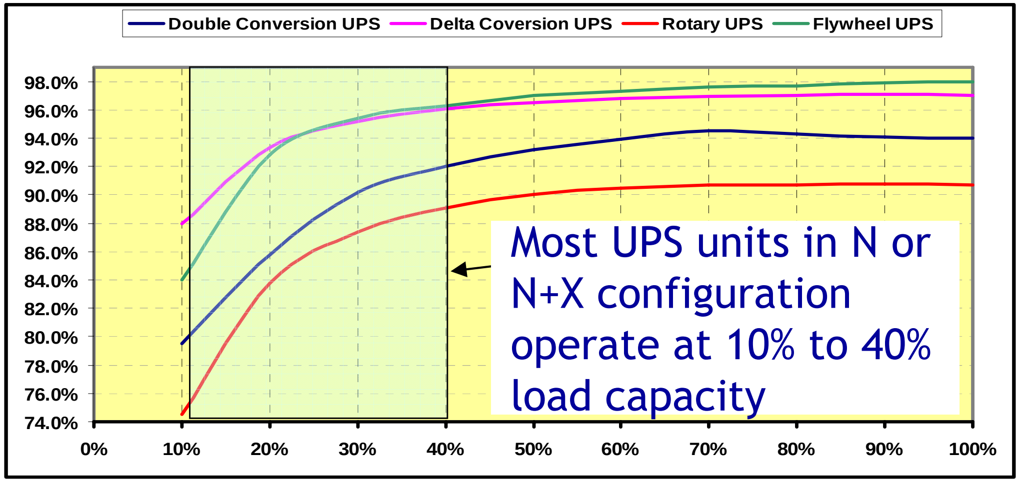
Managing UPS efficiency:

UPS sizing and loading can significantly affect UPS efficiency:

- Maximize UPS load capacity
- Specify UPS system that has higher efficiency at 10 – 40% load capacity
- Specify efficient UPS topology
- Consider modular UPS (an option to maximize UPS load capacity)

Managing UPS load capacity

Example: **10% difference in UPS efficiency per 1000 kW IT load results in approximately 900 MWhr of Energy saving per year and approx $400K of energy saving over 5 years.**



UPS input specifications

- Specify UPS system with lower input current THD at 10- 40% load capacity
- Specify UPS system with higher power factor at 10– 40% load capacity.

NOTE:
Input Current THD increases, and PF decreases when UPS operates at lower load capacity

UPS without Filter			
Load %	P.F.	THD	Losses
10	0.650	63.0	15.00%
25	0.695	60.5	12.80%
50	0.764	40.5	8.40%
75	0.800	30.0	7.30%

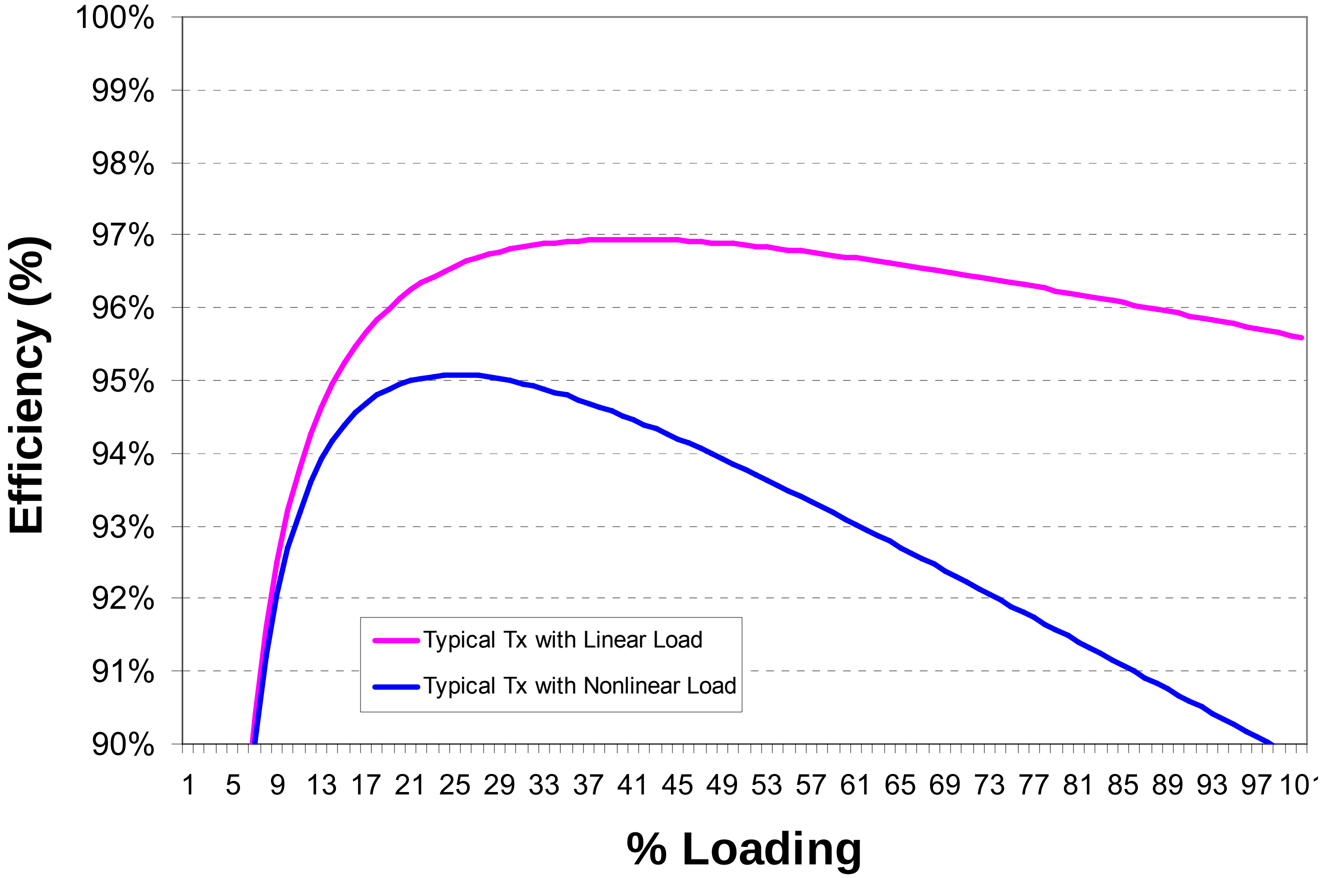
UPS with Filter			
Load %	P.F.	THD	Losses
10	0.770	25.0	15.00%
25	0.820	10.0	8.00%
50	0.840	6.0	6.00%
75	0.900	5.0	5.60%

Example: **10% difference in input current THD per 1000 kW IT load results in approximately 900 MWhr of energy saving per year and approx $400K of energy saving over 5 years.**

Transformers and PDUs

- Specify high efficiency transformers
- Install low voltage (LV) transformers outside the raised floor area
- Reduce number of PDUs (with built-in transformer) inside the data center

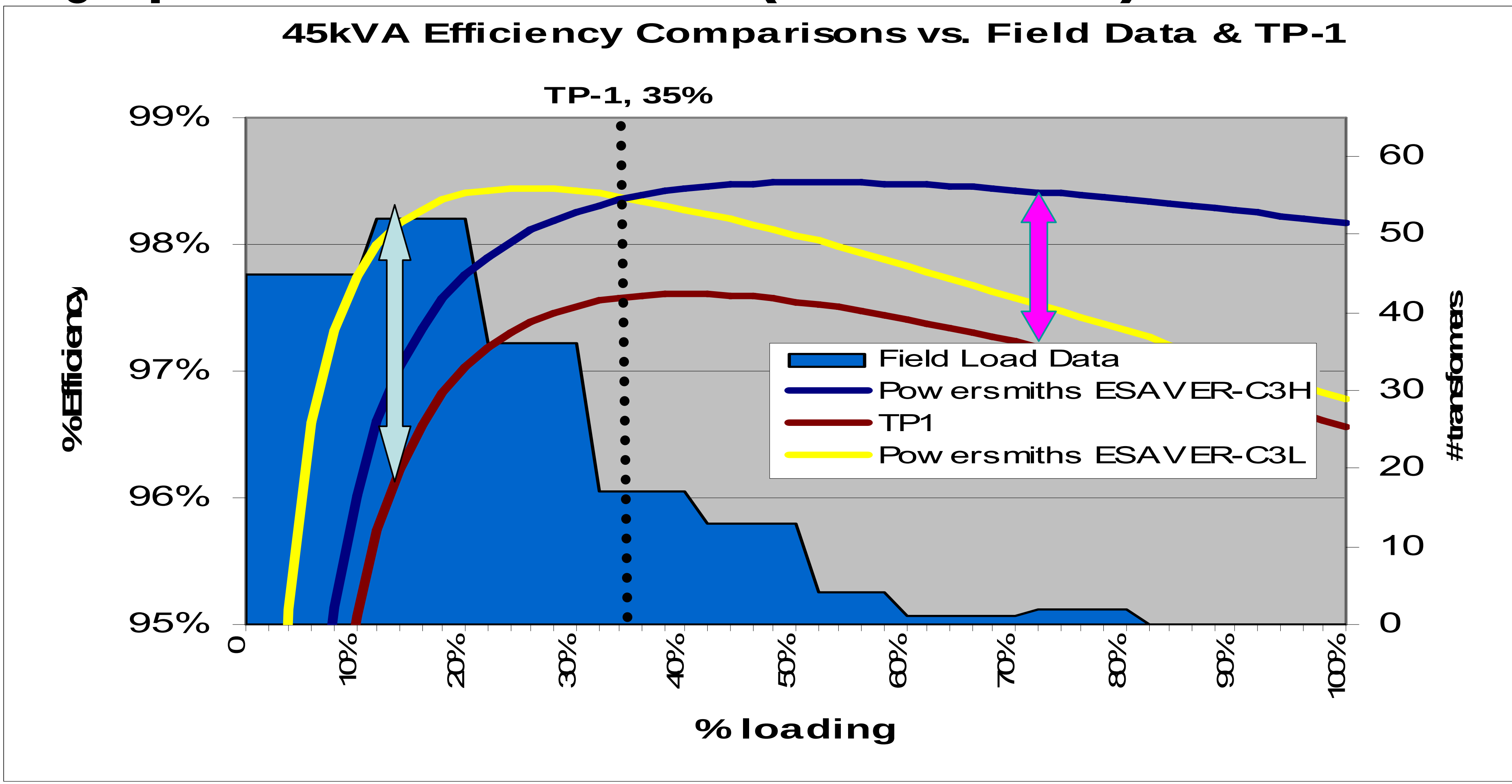
Typical 112.5kVA nonlinear UL listed transformer



Significant variation in efficiency over load range

Courtesy of PowerSmiths

High performance vs. TP1 (EPACT 2005) transformer



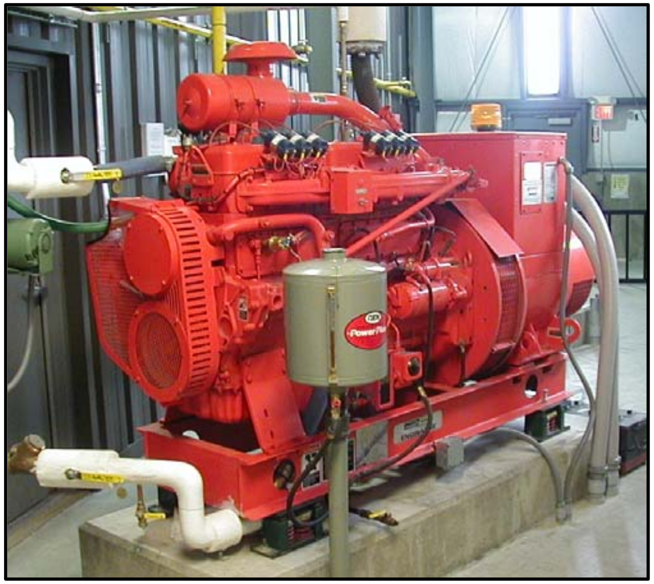
ESAVER C3L -> Light Load optimized, C3H -> Heavy Load optimized

Courtesy of PowerSmiths

Data center lighting

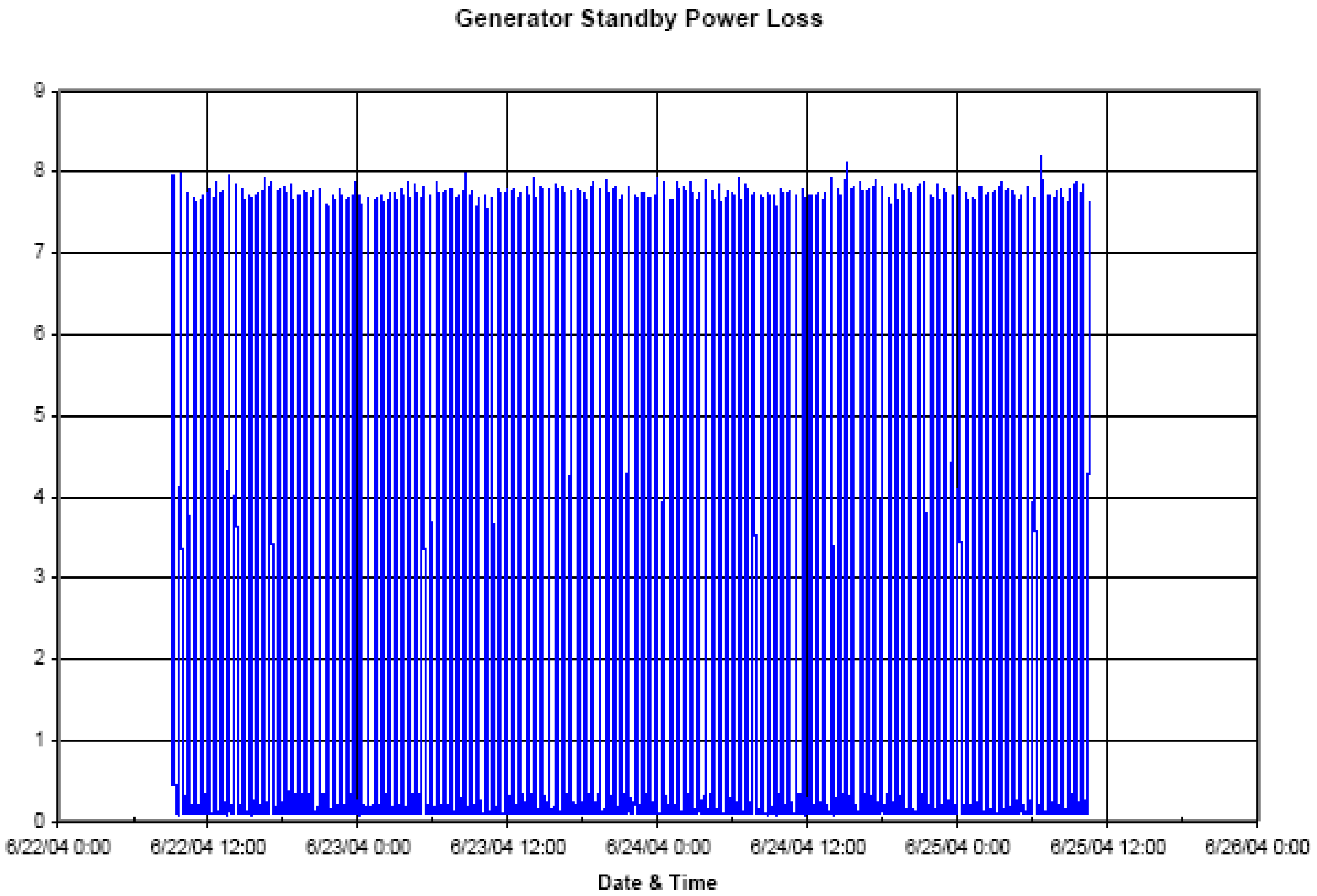
- Lights are on and nobody's home
  - Switch off lights in unused/unoccupied areas or rooms (UPS, Battery, S/Gear, etc)
  - Lighting controls such as occupancy sensors are well proven
- Small relative benefit but easy to accomplish – also saves HVAC energy
- Use energy efficient lights -Replace older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

Standby generation loss



- Several load sources
  - Heaters
  - Battery chargers
  - Transfer switches
  - Fuel management systems
- Opportunity may be to reduce or eliminate heating, batteries, and chargers
- Heaters (many operating hours) use more electricity than the generator will ever produce (few operating hours)
  - Check with the emergency generator manufacturer on how to reduce the overall energy consumption of block heaters (hot water jacket(s) - HWJ), i.e. temperature control
- Right-sizing of stand-by generator
- Maintain N+1 redundancy

Standby generator heater

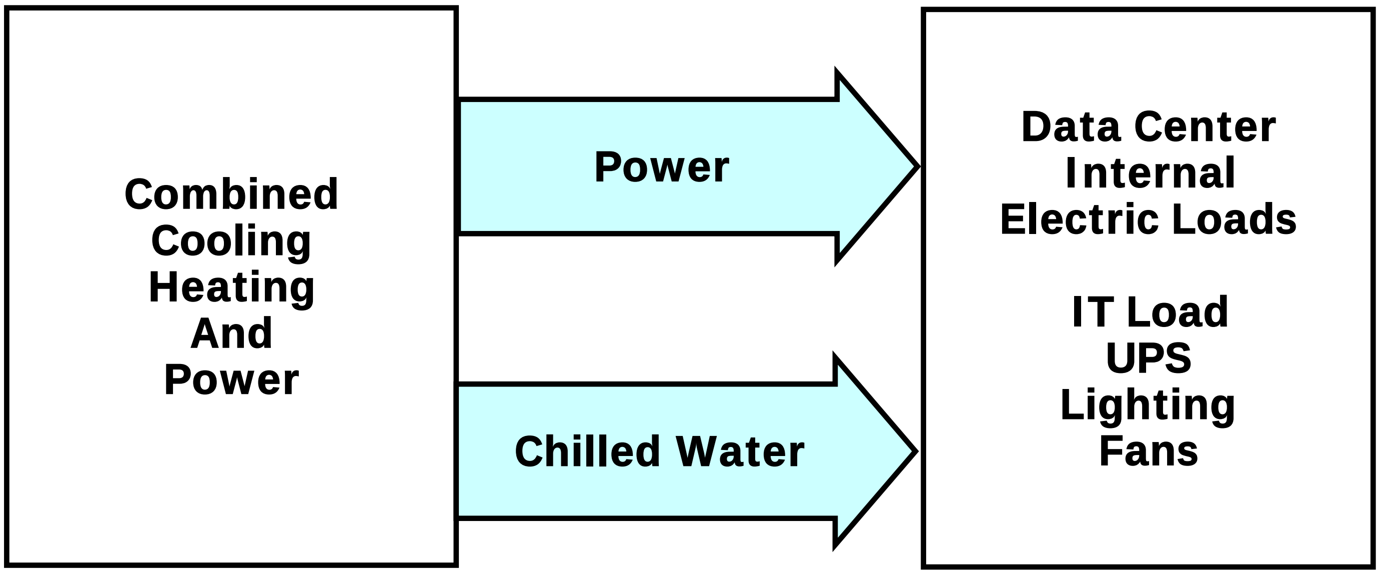


On-site (distributed) generation

- Swap role with Utility for back-up
  - Diesel or Gas- Fired Generators
  - Gas Turbines
  - Micro-Turbines
  - Fuel Cells
  - Bio-Mass
  - Solar
  - Wind
- Can use power plant waste heat
  - For cooling using absorption or adsorption chillers
  - Or other near by use (e.g. campus, laundry, swimming pool, etc.)
- Renewable sources (for dedicated loads such as generator engine block heaters, lights, etc.)

Data center CHP application

1 kW of electric load adds 3412 Btu of heat (.28 tons of cooling load) That must be removed from the building



1 kW of of CHP electricity can also provide .11 to .55 tons of thermally activated cooling depending on the prime mover technology and chiller type

CHP in data centers

- There are currently 16 data centers with CHP, representing 16.2 MW of capacity
- What can CHP do for data centers?
  - Reduce Energy Costs
  - Increase Reliability
  - Support Facility Expansion
  - Reduce Emissions

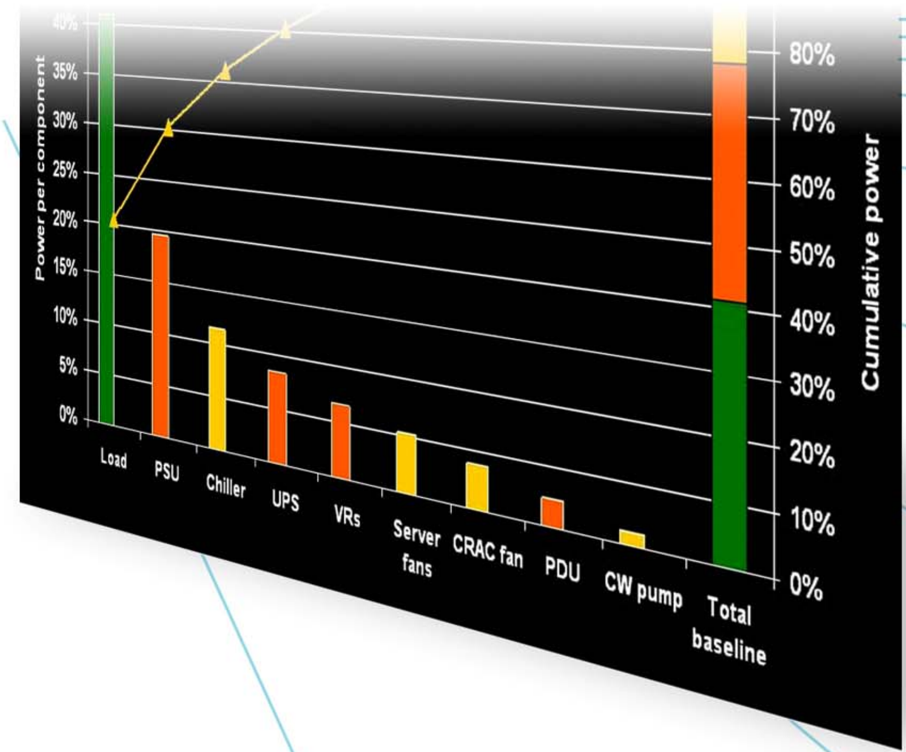
- Notable Examples
  - Verizon Garden City – 1.4 MW fuel cell (pictured above)
  - Network Appliance – 1.1 MW reciprocating engine
  - Qualcomm – 7.2 MW

Awareness and energy management

- Perform an Infra-Red (IR) test for the main transformers and other electrical systems
- Improve load balance between phases
- Change UPS DC capacitors if older than 5 years
- Metering:
  - Measure real time DCiE values
  - Monitor system efficiency and performance
  - Monitor IT loads at rack and power strip levels

Electrical system take aways

- Distributing higher voltage (AC or DC) is more efficient
- Power conversions hurt efficiency
- Highly efficient UPS systems, transformers, and power supplies in IT equipment should be specified
- Lighting energy use is small but an easy opportunity (efficiency and controls)
- Redundancy choices affect efficiency
- Standby generation losses can be minimized
- On-site generation can improve reliability and efficiency
- Consider alternative energy sources



Government Programs

Steve Greenberg, PE

Industrial Technologies Program

- Tool suite & training
- Metrics & energy baselining
- Qualified specialists
- Case studies
- Certification of continual improvement
- Recognition of high energy savers
- Best practice information
- Best-in-Class guidelines
- R&D - technology development

EPA

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

Federal Energy Management Program

- Best practices showcased at Federal data centers
- Pilot adoption of Best-in-Class guidelines at Federal data centers
- Adoption of to-be-developed industry standard for Best-in-Class at newly constructed Federal data centers

Industry

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

Public Law 109-431: EPA report

- **Purpose**: assess energy impacts on and from datacenters, identify energy efficiency opportunities, and recommend strategies to drive the market for efficiency
- **Goals**:
  - Inform Congress & other policy makers of important market trends, forecasts, opportunities
  - Identify and recommend potential short and long term efficiency opportunities and match them with the right policies

Report findings

Trends in Data Center energy use

- Sector consumed about 61 billion KWh in 2006
  - Equates to ~1.5% total U.S. electricity consumption and ~$4.5 billion
  - Federal sector: ~6 billion kWh and ~$450 million

- Projected to increase to 100 billion kWh in 2011
  - Equates to ~2.5% of total U.S. electricity consumption and ~$7.4 billion

Report findings

Identified key barriers to energy efficiency

- Lack of efficiency definitions for equipment and data centers
  - Service output difficult to measure, varies among applications
  - Need for metrics and more data: *How do we account for computing performance?*
- Split incentives
  - Disconnect between IT and facilities managers
- Risk aversion
  - Fear of change and potential downtime – energy efficiency perceived as a change with uncertain value and risk

Report recommendations

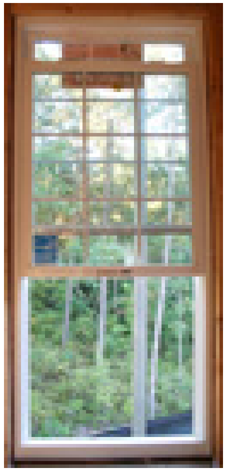
- Standardized performance measurements for IT equipment and data centers
  - Development of benchmark/metric for data centers
  - ENERGY STAR label for servers, considering storage and network equipment
- Leadership by federal government
- Private Sector Challenge
  - CEOs conduct **DOE Save Energy Now** energy efficiency assessments, implement measures, and report performance
- Information on best practices
  - Raise awareness and reduce perceived risk of energy efficiency improvements in datacenter
  - Government partner with private industry: case studies, best practices
- Research and development
  - Develop technologies and practices for datacenter energy efficiency (e.g., hardware, software, power conversion)

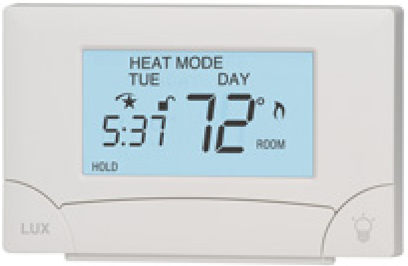
	Data Center Need	Federal Role
Standardized Measurements	**Metrics to effective use of energy and identify energy efficient components for the data center**	**Adopt performance metrics for data centers and IT equipment**
Leadership by Fed. Government	**Real life examples of best practices in efficient data center design with benchmark numbers for comparison**	**Measure federal data centers and publicly report results** **Leadership in designing efficient DCs**
Private Sector Challenge	**Impetus to convince management to improve the efficiency of facilities**	**challenge industry and provides an opportunity for companies to compete on efficiency of facilities**
Research and Development	**Further investigation into methods of increasing the efficiency of data centers**	**Support for research and development**
Information on Best Practices	**Examples of currently available technology and solutions to improve data center performance and reduce power usage**	**collects information on best practices and makes public for industry**

Federal Government activities

- Benchmark for data centers was core recommendation of the EPA report
- Energy Star Products and Buildings
- Save Energy Now
- FEMP
- RD&D

ENERGY STAR products





ENERGY STAR for servers

- Goal: Create protocol to measure server energy efficiency to allow fair competition
- Initial focus on volume servers and blade servers/chassis
- Technical specification developed in 2 steps:
  - Tier 1 considerations
    - Power supply efficiency and/or net power consumption
    - Standard reporting requirements (standardized data sheet)
    - Power and temperature reporting requirements
    - Idle power
    - Power management and virtualization “hooks”
  - Tier 2 considerations – utilize industry developed energy performance benchmarks to derive requirements

ENERGY STAR

ENERGY STAR Qualified Product Data Sheet
(SERVER MODEL NAME AND NUMBER)

- System Characteristics
  - Form factor (e.g., 1u, 2u, tower, blade chassis, etc.)
  - Available processor sockets
  - Processor information (model number, speed, # of cores, etc.)
  - Memory information (memory types, # Dimms, Dimm Size, etc.)
  - Power supply – number, redundancy, and size (Watts)
  - NIC information (#, speed)
  - Hard drive information (#, speed, size)
  - Installed operating systems (for purposes of testing)
  - OS listed as being supported
  - Other hardware features / accessories
- Air Flow Rate Information/Delta T
  - Total power dissipation for max load configuration
  - Delta T at exhaust of server for max load configuration (i.e., temperature rise across system at 100% load)
  - Size, position, and porosity of the inlet and exhaust grids/vents, including open, perforated, slotted, grille, mesh, etc.
  - Airflow at maximum fan speed (CFM)
  - Airflow at minimum fan speed (CFM)
- Available Power Management Features
- Virtualization Capability (e.g., embedded hypervisor, pre-installed software, etc.)
- Power and Temperature Measurement and Reporting
  - Compatible protocols for data collection
  - Ac / Input power available?
  - Dc power available (power supply output)
  - Input temperature available?
  - Output temperature available?
  - Processor utilization available?
- Power and Performance Data for base, typical and maximum configurations
  - Benchmark used and type of workload
  - Benchmark performance score
  - Maximum power[3]
  - Minimum power[3]
  - Idle power[3]
  - Power supply performance/net power consumption
  - Estimated kWh/year (*Assumptions TBD*)
- Link to manufacturer supplied savings calculator for customer specific configuration

Performance Data Sheet

- System characteristics
- Air flow rate/delta T
- Available power management features
- Virtualization capabilities
- Power and temperature measurement and reporting
- Power and performance data (base, typical, max configuration)
- Link to savings calculator

Timeline

- Draft 4 now out for review; Tier 1 specification finalized by May 2009
- Goal: Tier 1 specification finalized by May 2009
- More Information
  - www.energystar.gov/productdevelopment (click on New Specs in Development)
  - Andrew Fanara, EPA, fanara.andrew@epa.gov

ENERGY STAR buildings

- Allows for peer group comparison
  - Compares a building's energy performance to its national peer group.
  - Allows owners with multiple facilities to compare performance across a portfolio of buildings.
- Based on actual as-billed energy data.
- Serves as a whole building indicator
  - Captures the interactions of building systems not individual equipment efficiency.

Goals for ENERGY STAR data center rating

- Build on existing ENERGY STAR methods and platforms. Methodology similar to existing ENERGY STAR ratings (1-100 scale).
- Usable for both stand-alone data centers, as well as data centers housed within office or other buildings.
- Assess performance at the building level to explain how a building performs, not why it performs a certain way.
- Offer the ENERGY STAR label to data centers with a rating of 75 or higher (performance in the top quartile).
- Rating to be based on Data Center Infrastructure Efficiency (DCiE)

Label criteria

Express DCiE ranking (IT Energy/Total Energy) as an ENERGY STAR 1 to 100 rating

- Each point on rating scale equals 1 percentile of performance.
- Adjust for operating constraints outside of the owner/operators control (e.g. climate or tier level).
- Factors for adjustment to be determined based on results of data collection and analysis.

EPA Energy Star plan

- Gather monthly data from at least 100 data centers for a 12-month period (over 200 have signed up)
- A variety of information is being provided, including :
  - Climate zone (zip code)
  - Type of data center (function)
  - Reliability (Tier Level)
  - Total IT plug energy (12 months of data)
  - Total facility energy usage (12 months of data for all fuels)
- Data collected from a wide variety of facilities (large/small, stand-alone/within larger bldg, etc.)
- Analyze data to develop rating models.
- Launch ENERGY STAR Data Center Infrastructure Rating in Portfolio Manager.

DOE Industrial Technologies Program

Working to improve the energy efficiency of U.S. industry

U.S. industry consumes 32 quadrillion Btu per year -- almost 1/3 of all energy used in the nation

Partnerships with energy-intensive industries are key to ITP’s success:

- 5 quads of energy savings, 86 MMTCE reduction

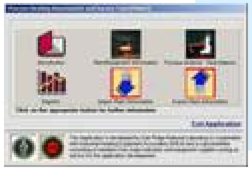
Save Energy Now is working to reduce industrial energy intensity 25% by 2017

Data centers are an important and growing industry:

- Consumed 1.5% of all electricity in the U.S. in 2006
- Power demand is growing about 12% per year
- Power and cooling systems are “industrial” in scale and complexity

Save Energy Now: products & services

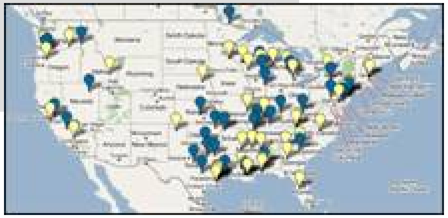
Tools
- Process Heating
- Steam Systems
- Plant Energy Profiler
- Motors & Pumps
- Fans



Information
- Website
- Information Center
- Tip Sheets
- Case studies
- Webcasts

Training
- Basic
- Advanced
- Qualified Specialist

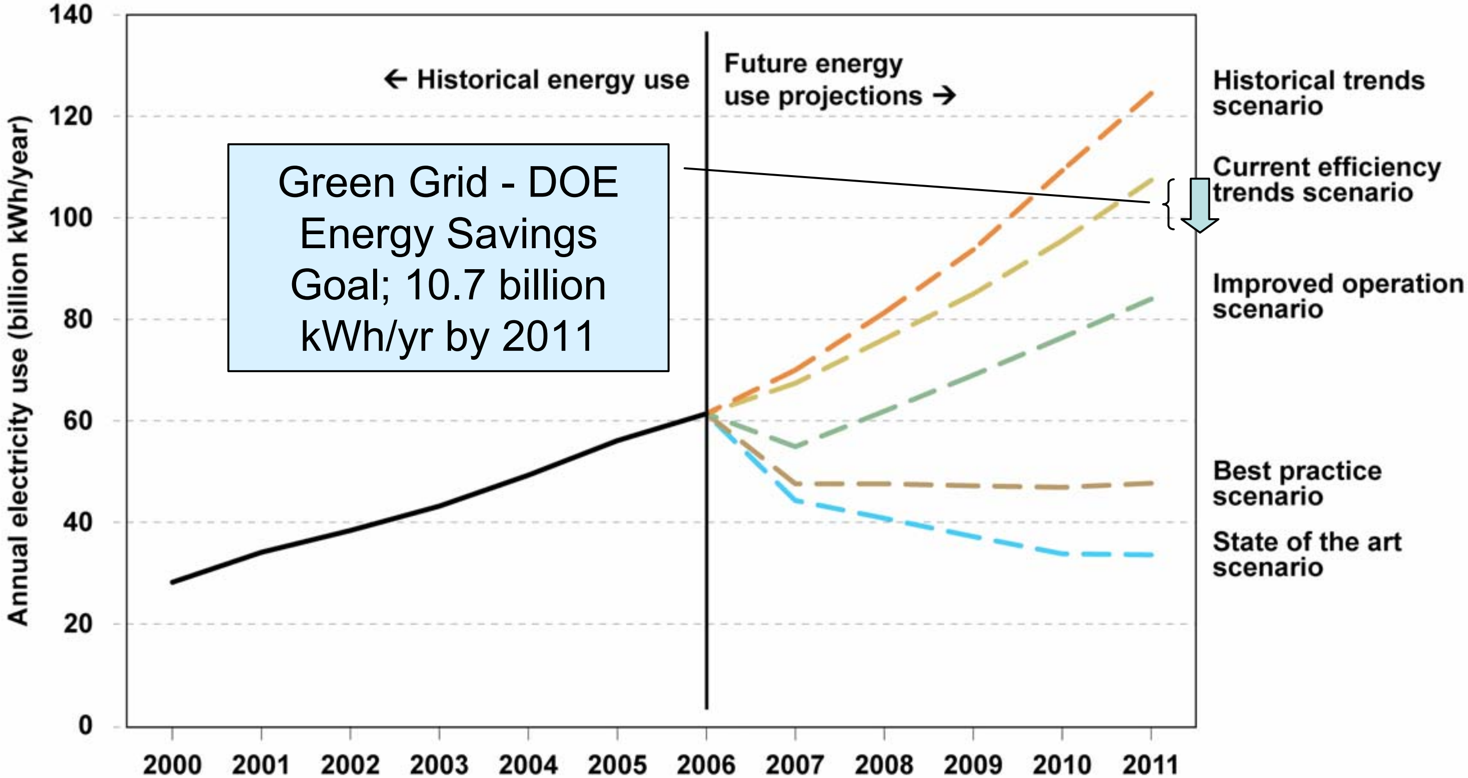
Assessments
- Energy Savings Assessments
- Industrial Assessment Centers



DOE-Green Grid partnership goals

2011 goal is 10% energy savings overall in U.S. data center

- 10.7 billion kWh
- Equivalent to electricity consumed by 1 million typical U.S. households
- Reduces greenhouse gas emissions by 6.5 million metrics tons of CO_2 per year



Collective goals

By 2011:

- 3,000 data centers completed awareness training through classes or webcasts via partners
- 1,500 mid-tier and enterprise-class data centers will have applied Assessment Protocols and Tools to improve data center energy efficiency by 25% (on average)
  - 200 enterprise-class data centers will have improved their energy efficiency by 50% (on average) via such aggressive measures as accelerated virtualization, high-efficiency servers, high-efficiency power systems, optimized cooling, and combined heat and power systems (e.g., fuel cells)
- 200 Qualified Specialists certified to assist data centers

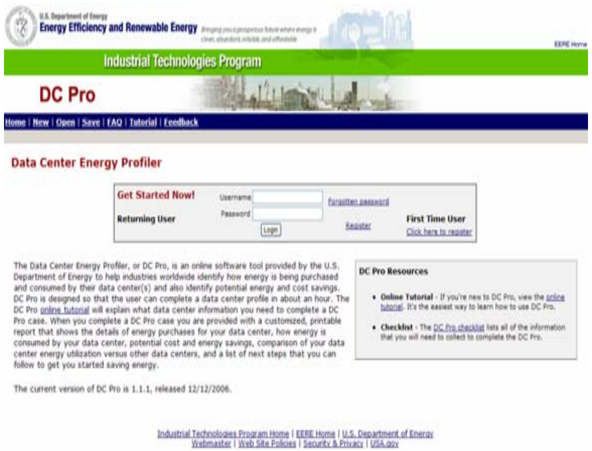
DOE Save Energy Now data center program

1. Establish metrics for data center energy intensity
   - IT and infrastructure
   - Energy cost ($), source energy (MBtu), and carbon emissions (M tons)
   - Specified Best-in-Class targets for various types of data centers
2. Create technologies, tools and guidelines to drive continuous improvement
   - Develop and test “DC Pro” Software using pilot energy assessments
   - Create and publicize Save Energy Now case studies
3. Create best practice information and a training curriculum
4. Develop Qualified Specialists program for Data Centers
5. Support third-party certification process to validate energy intensity improvement and Best-in-Class
6. Provide recognition for data centers that achieve a certain level of energy savings
7. Create guidelines for “Best-in-Class” data centers and validate with Technology Demonstrations
8. Create and implement a collaborative research program with industry

“DC Pro” tool suite

Tools to define baseline energy use of data center and identify key energy-saving opportunities

- Determine general performance of the data center
- Benchmark subsystems
- Assess energy savings potential
- Track energy intensity improvement
- Provide quantification of key metrics including cost ($), primary energy (Btu), and carbon



Key milestones

• DC Pro Profiling tool version 1.0 release	Oct ‘08
• DC Pro Electrical system tool release	Dec ‘08
• DC Pro Air Management tool release	Feb ’09
• DC Pro IT tool release	May ‘09
• Qualified Specialist pilot training, exam	Nov ’09
• DC Pro HVAC tool release	Dec ‘09

By 2011

Save ENERGY Now

Products

- DC Pro tool
- Assessment protocols
- Training
- Case studies
- Best practices
- Best-in-Class guidelines
- Technology demonstrations

Market Delivery

- 200 Qualified Specialists
- Suppliers
- Engineering firms
- Utilities
- Associations and technical societies

Data Center Results

- 10 billion kWh per year saved
- 3,000 people trained on tools and assessment protocols
- 1,500 data centers improve energy efficiency > 25%
- 200 data centers improve energy efficiency >50%

DOE Data Center program

Paul Scheihing

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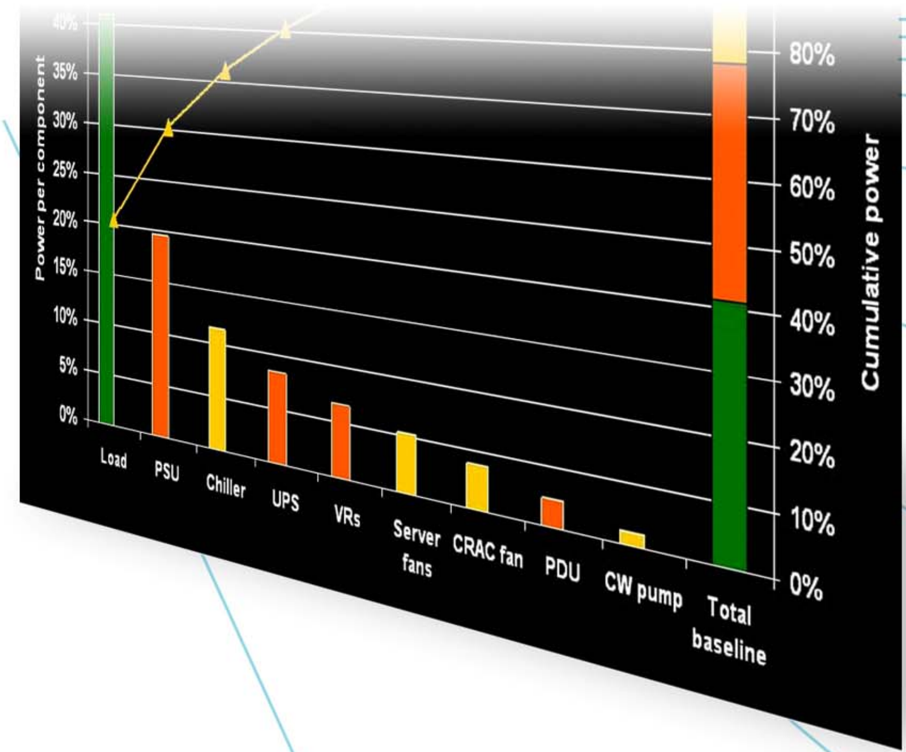
Information Tech. R&D program

Gideon Varga

www.eere.energy.gov/industry

gideon.varga@ee.doe.gov

202-586-0082



Assessment Tools and Protocols

Steve Greenberg, PE

Steps to saving energy:

Energy Profiling → Subsystem Assessment → Detailed Engineering Audit → Engineering Design → Retrofit/RCx Implementation → Savings Validation (M&V) → Documentation

Energy Profiling / Subsystem Assessment

- Assessments conducted by owners and engineering firms using DOE tools
- Tools provide uniform metrics and approach

Detailed Engineering Audit / Engineering Design / Retrofit/RCx Implementation

- Audits, design and implementation by engineering firms and contractors

Savings Validation (M&V) / Documentation

- M&V by site personnel and eng firms
- DOE tools used to document results, track performance improvements, and disseminate best practices

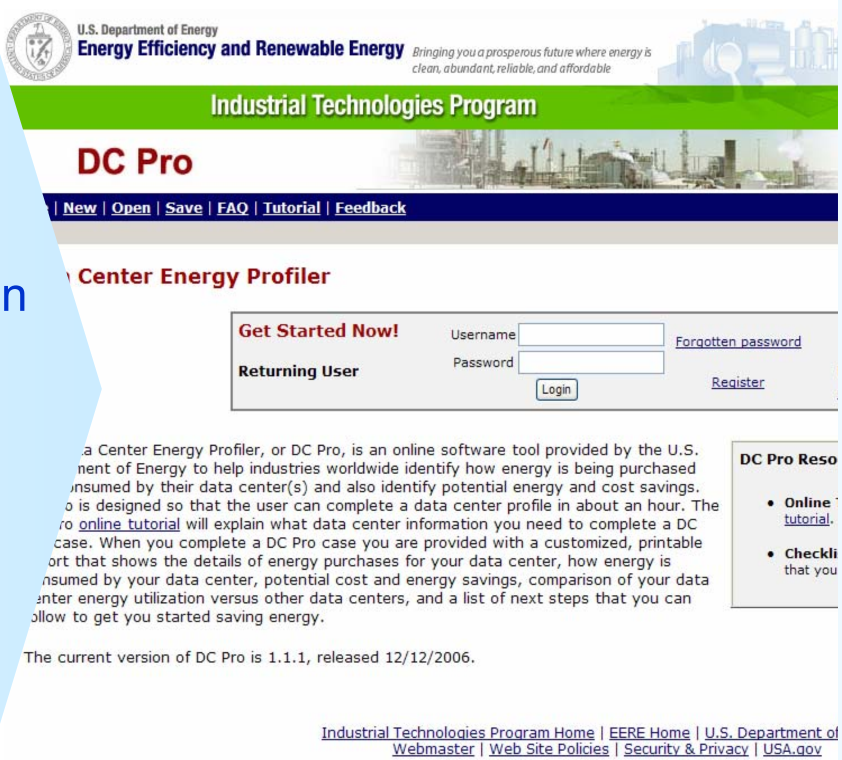
DOE tool suite: DC Pro

- Profiling Tool: profiling and tracking
  - Establish DCIE baseline and efficiency potential (few hours effort)
  - Document actions taken
  - Track progress in DCiE 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)

Online profiling tool

INPUTS

- Description
- Utility bill data
- System information
  - IT
  - Cooling
  - Power
  - On-site gen

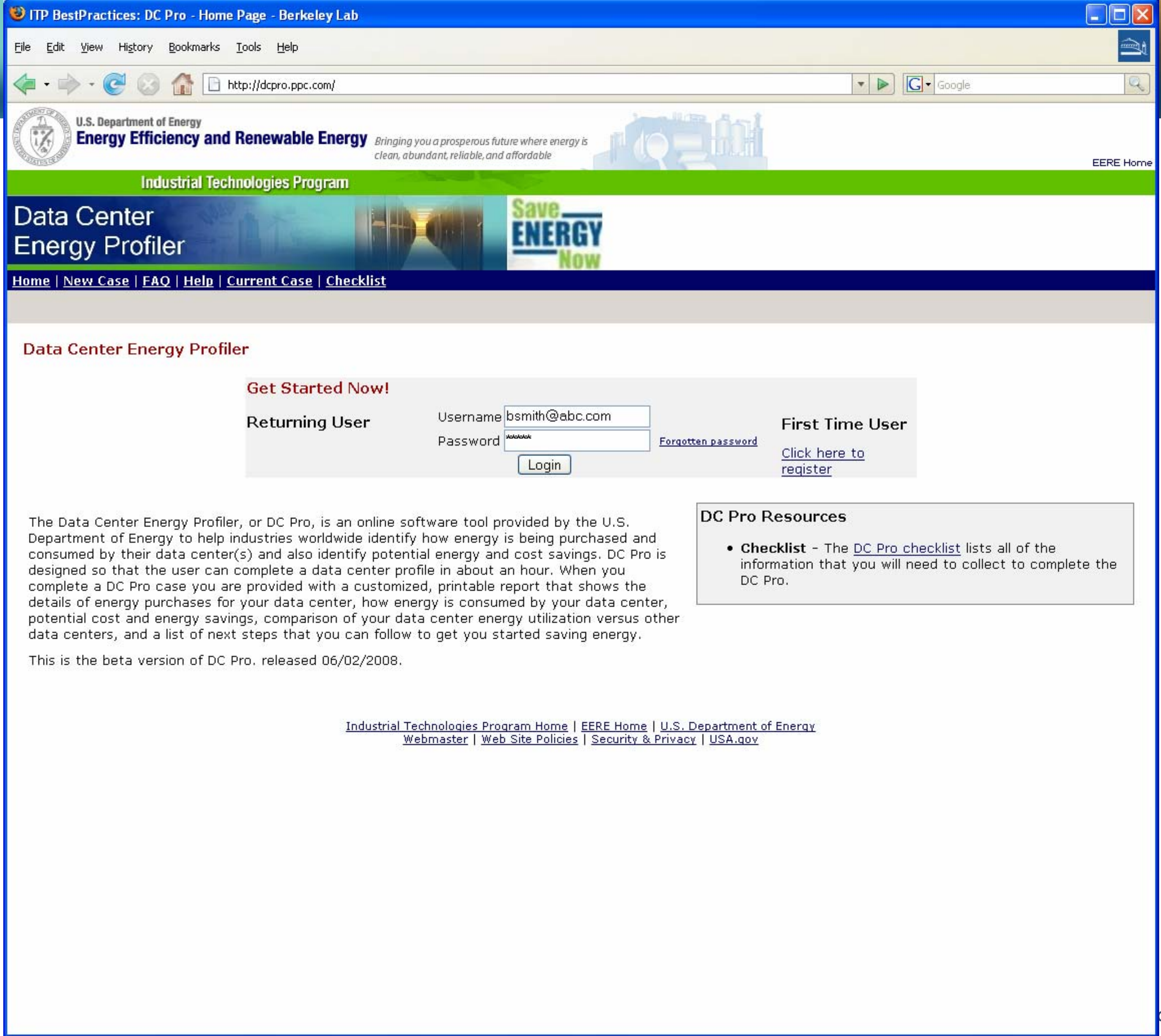


OUTPUTS

- Overall efficiency (DCiE)
- End-use breakout
- Potential areas for energy efficiency improvement
- Overall energy use reduction potential

DC Pro profiling tool demonstration

www.eere.energy.gov/datacenters


ITP BestPractices: DC Pro - Home Page - Berkeley Lab

File Edit View History Bookmarks Tools Help

http://dcpro.ppc.com/

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

EERE Home

Industrial Technologies Program

Data Center Energy Profiler

Save ENERGY Now

Home | New Case | FAQ | Help | Current Case | Checklist

Data Center Energy Profiler

Get Started Now!

Returning User

Username bsmith@abc.com

Password *****

Forgotten password

Login

First Time User

Click here to register

The Data Center Energy Profiler, or DC Pro, is an online software tool provided by the U.S. Department of Energy to help industries worldwide identify how energy is being purchased and consumed by their data center(s) and also identify potential energy and cost savings. DC Pro is designed so that the user can complete a data center profile in about an hour. When you complete a DC Pro case you are provided with a customized, printable report that shows the details of energy purchases for your data center, how energy is consumed by your data center, potential cost and energy savings, comparison of your data center energy utilization versus other data centers, and a list of next steps that you can follow to get you started saving energy.

This is the beta version of DC Pro. released 06/02/2008.

DC Pro Resources

- **Checklist** - The DC Pro checklist lists all of the information that you will need to collect to complete the DC Pro.

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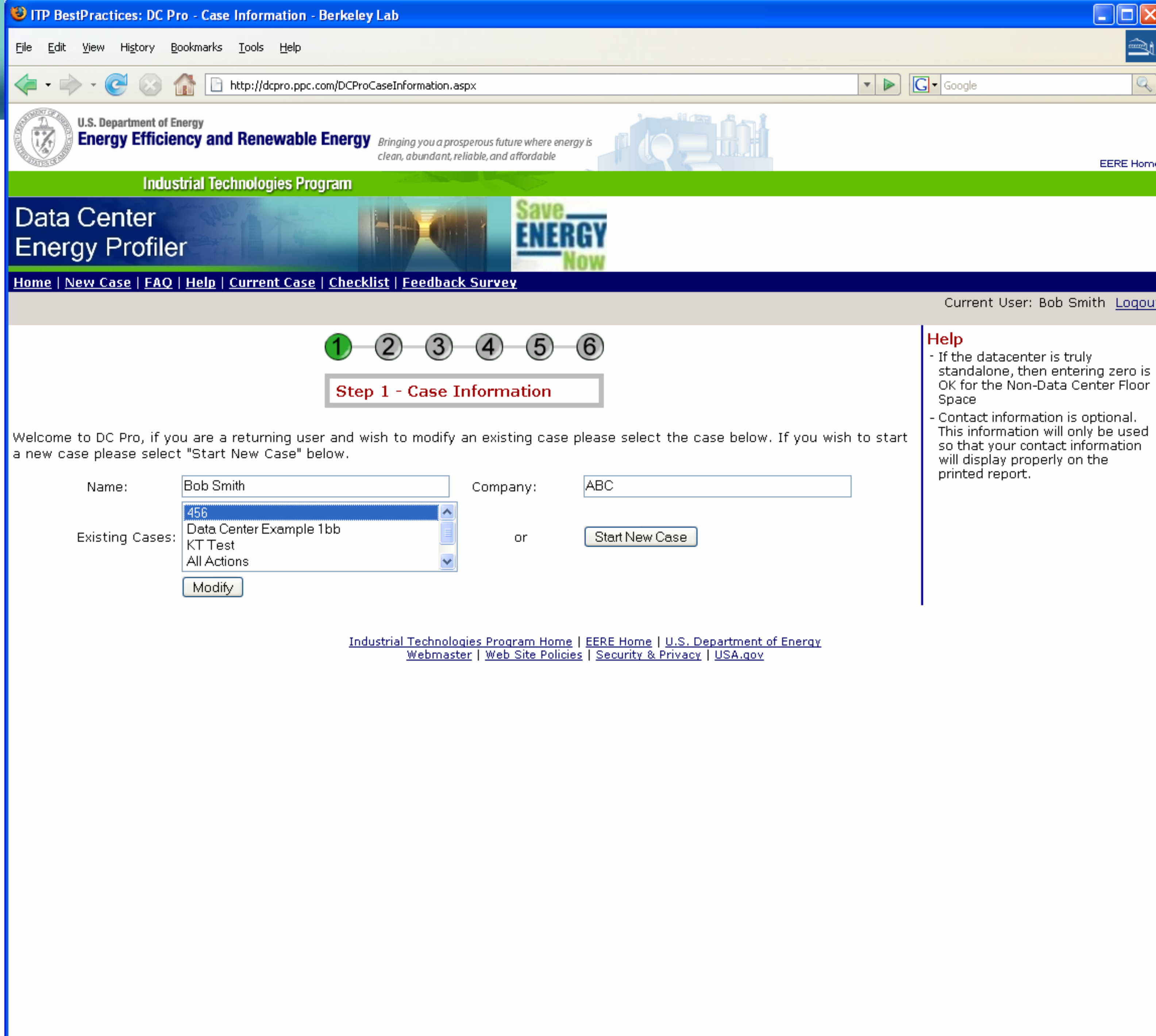
ITP BestPractices: DC Pro - Case Information - Berkeley Lab
File Edit View History Bookmarks Tools Help
http://dcpro.ppc.com/DCProCaseInformation.aspx
Google
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable
EERE Home
Industrial Technologies Program
Data Center Energy Profiler
Save ENERGY Now
Home | New Case | FAQ | Help | Current Case | Checklist | Feedback Survey
Current User: Bob Smith Logout
1 2 3 4 5 6
Step 1 - Case Information
Welcome to DC Pro, if you are a returning user and wish to modify an existing case please select the case below. If you wish to start a new case please select "Start New Case" below.
Name: Bob Smith
Company: ABC
Existing Cases: 456
Data Center Example 1bb
KT Test
All Actions
Modify
or
Start New Case
Help
- If the datacenter is truly standalone, then entering zero is OK for the Non-Data Center Floor Space
- Contact information is optional. This information will only be used so that your contact information will display properly on the printed report.
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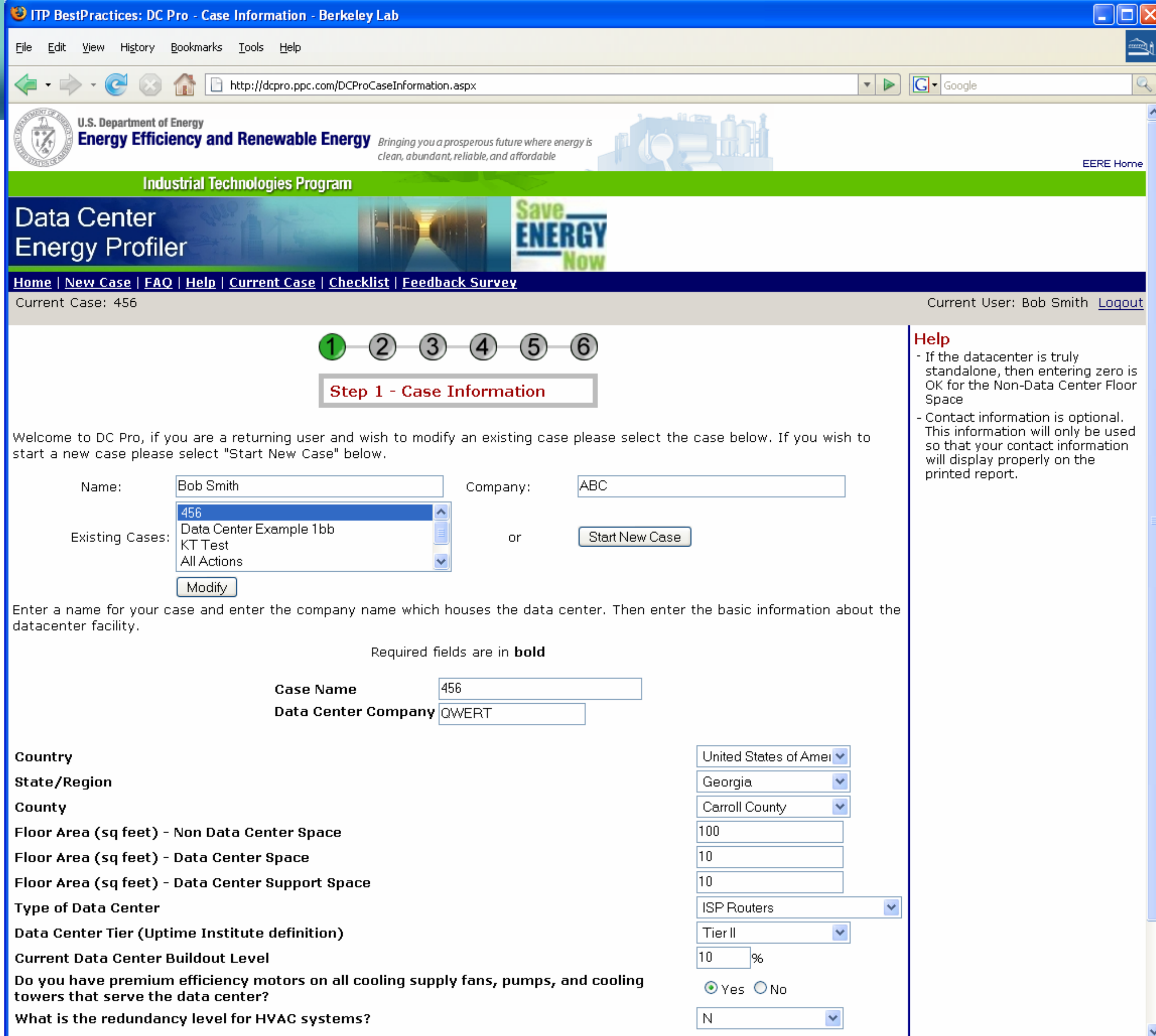
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Data Center Energy Profiler
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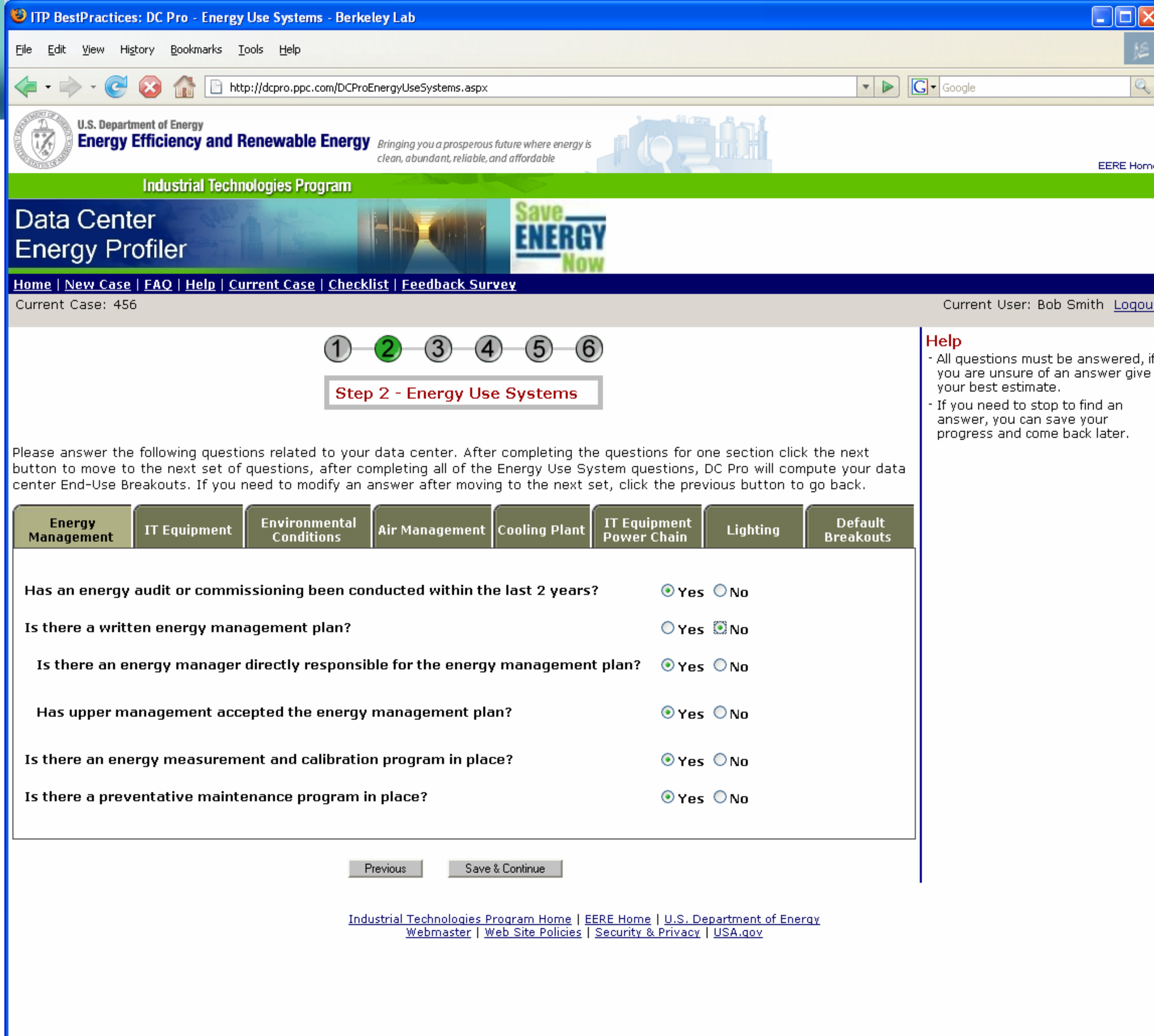
Home | New Case | FAQ | Help | Current Case | Checklist | Feedback Survey
Current Case: 456
Current User: Bob Smith Logout
1 2 3 4 5 6
Step 1 - Case Information
Welcome to DC Pro, if you are a returning user and wish to modify an existing case please select the case below. If you wish to start a new case please select "Start New Case" below.
Name: Bob Smith
Company: ABC
Existing Cases: 456 / Data Center Example 1bb / KT Test / All Actions
or
Start New Case
Modify
Enter a name for your case and enter the company name which houses the data center. Then enter the basic information about the datacenter facility.
Required fields are in bold
Case Name 456
Data Center Company QWERT
Country United States of Amei
State/Region Georgia
County Carroll County
Floor Area (sq feet) - Non Data Center Space 100
Floor Area (sq feet) - Data Center Space 10
Floor Area (sq feet) - Data Center Support Space 10
Type of Data Center ISP Routers
Data Center Tier (Uptime Institute definition) Tier II
Current Data Center Buildout Level 10 %
Do you have premium efficiency motors on all cooling supply fans, pumps, and cooling towers that serve the data center? Yes No
What is the redundancy level for HVAC systems? N
Help
- If the datacenter is truly standalone, then entering zero is OK for the Non-Data Center Floor Space
- Contact information is optional. This information will only be used so that your contact information will display properly on the printed report.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1 2 3 4 5 6
Step 2 - Energy Use Systems
Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.
Energy Management
IT Equipment
Environmental Conditions
Air Management
Cooling Plant
IT Equipment Power Chain
Lighting
Default Breakouts
Has an energy audit or commissioning been conducted within the last 2 years? Yes No
Is there a written energy management plan? Yes No
Is there an energy manager directly responsible for the energy management plan? Yes No
Has upper management accepted the energy management plan? Yes No
Is there an energy measurement and calibration program in place? Yes No
Is there a preventative maintenance program in place? Yes No
Previous
Save & Continue
Help
- All questions must be answered, if you are unsure of an answer give your best estimate.
- If you need to stop to find an answer, you can save your progress and come back later.
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Step 2 - Energy Use Systems

Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.

Energy Management | IT Equipment | Environmental Conditions | **Air Management** | Cooling Plant | IT Equipment Power Chain | Lighting | Default Breakouts

How many CRAC/CRAH/AHUs are there that operate under normal conditions?	4
Is there any supplemental cooling?	In-Row
Does the CRAC/CRAH/AHU have a free cooling coil (water side economizer)?	(•) Yes ( ) No
Is there air-side free cooling?	(•) Yes ( ) No
Air Supply Path	Underfloor Plenum
Is there a floor-tightness (sealing leaks) program in place?	(•) Yes ( ) No
Are the cable penetrations sealed?	11% to 89%
Is the cable build-up in the floor plenum or the over-head plenum more than 1/3 of the plenum height?	(•) Yes ( ) No
Is there a cable-mining (allow proper pressure distribution) program in place?	(•) Yes ( ) No
IT equipment in rows?	(•) Yes ( ) No
Is there a rack/lineup-tightness (using blanking panels) program in place?	(•) Yes ( ) No
Degree of current implementation of alternating hot and cold aisles?	Fair
Degree of current efforts to minimize recirculated air at the racks (for example, blanking panels)?	Fair
Degree of current efforts to minimize bypass air at the racks (for example, sealing cable penetrations in the floor)?	Fair

Help

- All questions must be answered, if you are unsure of an answer give your best estimate.
- If you need to stop to find an answer, you can save your progress and come back later.

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Step 2 - Energy Use Systems

Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.

Energy Management	IT Equipment	Environmental Conditions	Air Management	Cooling Plant	IT Equipment Power Chain	Lighting	Default Breakouts

Is there an Uninterruptible Power Supply (UPS)?	◉ Yes ○ No
UPS Technology Type	Double Conversion
What is the average load factor per active UPS module?	50% to 100%
UPS Redundancy Configuration	N+1
Is there a standby generator?	◉ Yes ○ No
Standby Generator Power Configuration	N
Are there PDUs with built-in transformers?	◉ Yes ○ No
What are the types of MV and LV transformer(s)?	Temp rise >80C
Average Load Factor per Active PDUs / Transformers	25% to 49%

Previous | Save & Continue

Help

- All questions must be answered, if you are unsure of an answer give your best estimate.
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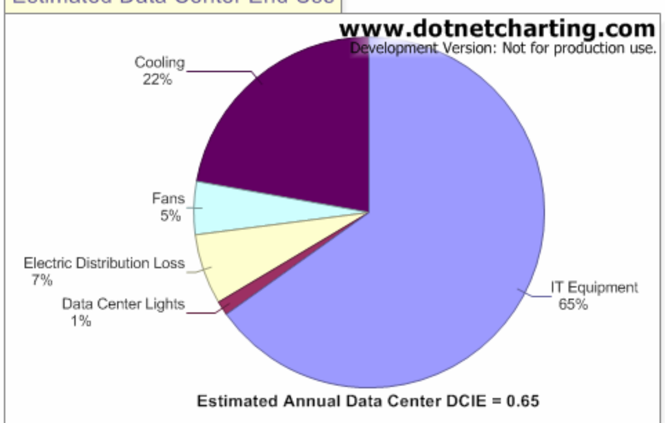
Step 2 - Energy Use Systems

Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.

Energy Management | IT Equipment | Environmental Conditions | Air Management | Cooling Plant | IT Equipment Power Chain | Lighting | Default Breakouts

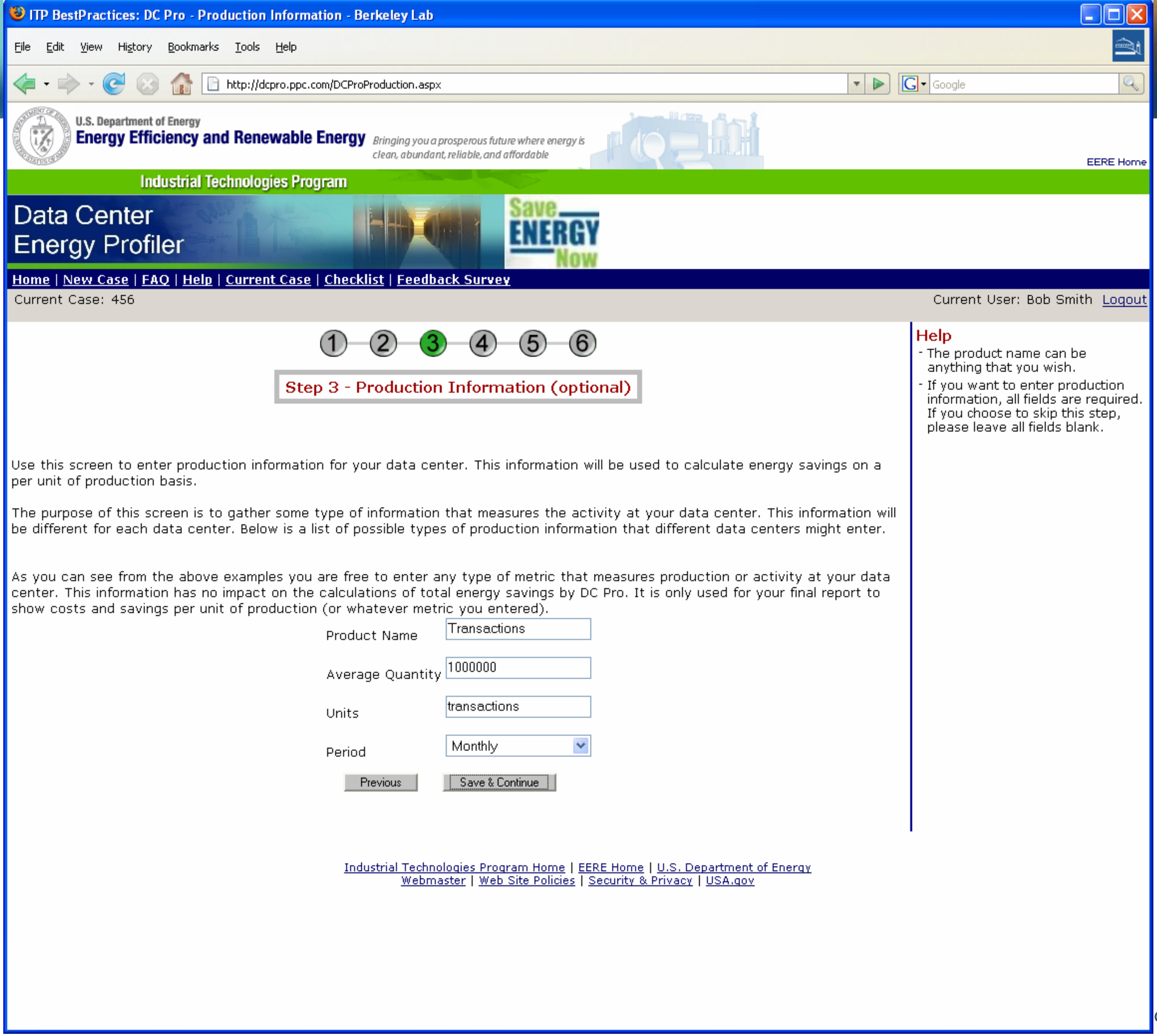
This screen will compute estimated data center end use. You will have the opportunity to input the actual energy use in Step 4, in whole or in part. DC Pro will modify the default breakouts to accommodate the actual energy use.

Estimated Data Center End Use



Help

- All questions must be answered, if you are unsure of an answer give your best estimate.
- If you need to stop to find an answer, you can save your progress and come back later.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Step 3 - Production Information (optional)
Use this screen to enter production information for your data center. This information will be used to calculate energy savings on a per unit of production basis.
The purpose of this screen is to gather some type of information that measures the activity at your data center. This information will be different for each data center. Below is a list of possible types of production information that different data centers might enter.
As you can see from the above examples you are free to enter any type of metric that measures production or activity at your data center. This information has no impact on the calculations of total energy savings by DC Pro. It is only used for your final report to show costs and savings per unit of production (or whatever metric you entered).
Product Name
Transactions
Average Quantity
1000000
Units
transactions
Period
Monthly
Previous
Save & Continue
Help
- The product name can be anything that you wish.
- If you want to enter production information, all fields are required. If you choose to skip this step, please leave all fields blank.
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Step 4 - Supplied Energy (optional)

Use the next four screens to enter data from utility bills and/or submeters recordings, entering this data is optional but doing so will help DC Pro more accurately profile your facility. If you do not, DC Pro will use the default energy end-use percentages from Step 2. Enter data only for those meters that support -- either partly or wholly -- the DC Load and/or the DC cooling system. You will be allowed to distribute any of the energy streams across the end-use breakout categories in the next step (Step 5) of the DC Pro process. If your facility does not use one or more of the energy stream simply leave that screen blank and click the Next button.

For each energy stream you will need to enter account information for each meter or sub-meter you have data on. For each account enter a Meter ID, select whether or not the meter is a sub-meter (and if so what meter it is a sub of), enter the average quantities and units purchased, and select the period for which this purchase reflects. Entering different period intervals for different energy streams is acceptable, as DC Pro will calculate the annual data, but do not enter more than 1 year of data.

Electricity | Fuel | Steam | Chilled Water

	Meter ID	On Site	Sub-Meter Of	Use per Period	Units	Period	Bills per Period	Annual Use	Units	Annual Bills
Edit Delete	001	No		250,000	kWh	Monthly	$1,110.00	3,000,000	kWh	$13,320.00
Edit Delete	002	No	001	50,000	kWh	Monthly	$250.00	600,000	kWh	$3,000.00
Edit Delete	213	No		25,555	kWh	Monthly	$12,345.00	306,660	kWh	$148,140.00
Save										

Previous | Save & Continue | Skip Step 4

Help

- You may enter as many meter accounts as you wish for each energy stream.
- If you do enter data for a particular stream, all fields are required.
- Remember to enter the average cost and quantity for the selected period.
- The cost that you enter should be the TOTAL cost of the energy stream for the selected period. This should include the cost of energy plus the total of all other charges including demand charges and any other recurring charges.
- Don't forget to enter energy that is generated on site at your plant. When entering on site generation just check the Generated On Site checkbox, but remember DO NOT ASSIGN ANY COST TO THIS.
- Click the information icons to display the tooltip popup. Tooltips help to better understand what the question is asking.

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1 2 3 4 5 6

Step 4 - Supplied Energy (optional)

Use the next four screens to enter data from utility bills and/or submeters recordings, entering this data is optional but doing so will help DC Pro more accurately profile your facility. If you do not, DC Pro will use the default energy end-use percentages from Step 2. Enter data only for those meters that support -- either partly or wholly -- the DC Load and/or the DC cooling system. You will be allowed to distribute any of the energy streams across the end-use breakout categories in the next step (Step 5) of the DC Pro process. If your facility does not use one or more of the energy stream simply leave that screen blank and click the Next button.

For each energy stream you will need to enter account information for each meter or sub-meter you have data on. For each account enter a Meter ID, select whether or not the meter is a sub-meter (and if so what meter it is a sub of), enter the average quantities and units purchased, and select the period for which this purchase reflects. Entering different period intervals for different energy streams is acceptable, as DC Pro will calculate the annual data, but do not enter more than 1 year of data.

Electricity | Fuel | Steam | Chilled Water

	Meter ID	Sub-Meter Of	Use per Period	Units	Bills per Period	Period	Annual Use	Units	Annual Bills
Edit Delete	1234		1,111	ton-hours	$111.00	Monthly	13,332	ton-hours	$1,332.00
Save									

Previous | Save & Continue | Skip Step 4

Help

- You may enter as many meter accounts as you wish for each energy stream.
- If you do enter data for a particular stream, all fields are required.
- Remember to enter the average cost and quantity for the selected period.
- The cost that you enter should be the TOTAL cost of the energy stream for the selected period. This should include the cost of energy plus the total of all other charges including demand charges and any other recurring charges.
- Don't forget to enter energy that is generated on site at your plant. When entering on site generation just check the Generated On Site checkbox, but remember DO NOT ASSIGN ANY COST TO THIS.
- Click the information icons to display the tooltip popup. Tooltips help to better understand what the question is asking.

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Current Case: 456 — Current User: Bob Smith Logout

1 2 3 4 5 6

Step 5 - Energy Use Distribution (optional)

Use these screens to allocate the annual energy use for each meter identified in Step 4 across the Energy End-Use Breakout Categories.

If you do not know what the allocations are for a given meter, it is OK to skip this screen or enter estimates. All of the energy use for a given meter does not have to be allocated to the breakout categories. If the meter serves more than just the data center, it is OK to leave a portion of the energy in the Remainder column.

NOTE: DC Pro provides default percentages for you based on the information entered in Step 2. You may use these default percentages if you are unsure of the actual percentages that each energy use system uses. However, for more accurate results you should estimate your actual percentages and enter them in the boxes below.

Electricity | Fuel | Steam | Chilled Water | Summary

Meter ID	Total Annual Site Energy Use	Site Energy End-Use Breakout Categories (Recalculate)													
		IT Load		Lights		Electric Distribution Losses		Fans		Cooling & Humidity Controls		Site Energy Use Related to Data Center		Remainder (Non-Data Center Use)	
	kWh/yr	kWh/yr	%	kWh/yr	%	kWh/yr	%	kWh/yr	%	kWh/yr	%	kWh/yr	%	kWh/yr	%
001	3,000,000	1700000	57%	90000	3%	350000	12%	600000	20%	90000	3%	2,830,000.0	94%	170,000	6%
002	600,000	400000	67%	60000	10%	90000	15%	18000	3%	12000	2%	580,000.0	97%	20,000	3%
213	306,660	153330	50%	91998	30%	0	0%	9199.8	3%	9199.8	3%	263,727.6	86%	42,932.4	14%
Totals		2,253,330	58%	241,998	6%	440,000	11%	627,199.8	16%	111,199.8	3%	3,673,727.6	94%	232,932.4	6%
Is this all the electricity associated with the breakout categories being used by the data center?		Yes		Yes		Yes		Yes		Yes					

Previous | Save & Continue

Help

- Please enter a value for each meter or sub-meter. If the meter or sub-meter does not use any energy from a given category, enter zero.
- The total annual energy use for each meter are the values calculated in Step 4. If you notice a problem with a meter or need to modify one, go back to Step 4 by clicking the circle on the top of this page.
- The percentages in the "Energy Use Related to Data Center" and "Remainder" column for a given meter MUST equal 100%, DC Pro will not let you move onto the next page if they do not.
- You must select "Yes" or "No" in the final row before proceeding to the next energy type. Select "Yes" if there is no additional energy being used by the data center for a given breakout category. Select [illegible]

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Step 6 - Results

Open the Report in PDF

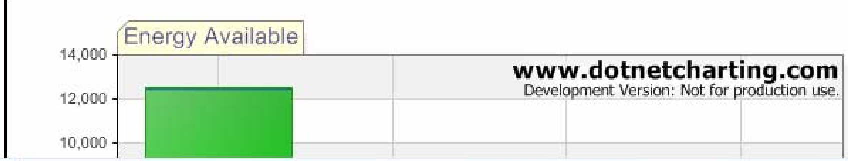
This is your customized DC Pro Summary Report. The report is broken into five basic sections. If you wish to go back and edit any of your values or add more dat page to navigate to the desired screen.

1. Case Information - your basic case information including energy consumption and savings on a per unit of production basis.
2. Annual Energy Use - a summary of your data center's annual energy purchases and consumption broken down by energy category.
3. Potential Annual Energy Savings - an estimation of potential annual energy savings for your data center's energy use systems displayed in MMBtu and dollar
4. Potential Annual CO2 Savings - an estimation of the potential annual reduction of CO2 emissions.
5. Suggested Next Steps - a customized list of suggested next steps for you to take to realize potential energy and cost savings.

Case Information

Case Name	456
Name	Bob Smith
Email	bsmith@abc.com
Company	ABC
Data Center Company	QWERT
County	Carroll County
State	Georgia

Annual Energy Use



	Total Amount Generated On Site	Total Amount	Unit
Electricity	0	12,535	MMBTU/yr
Fuel	0	4,980	MMBTU/yr

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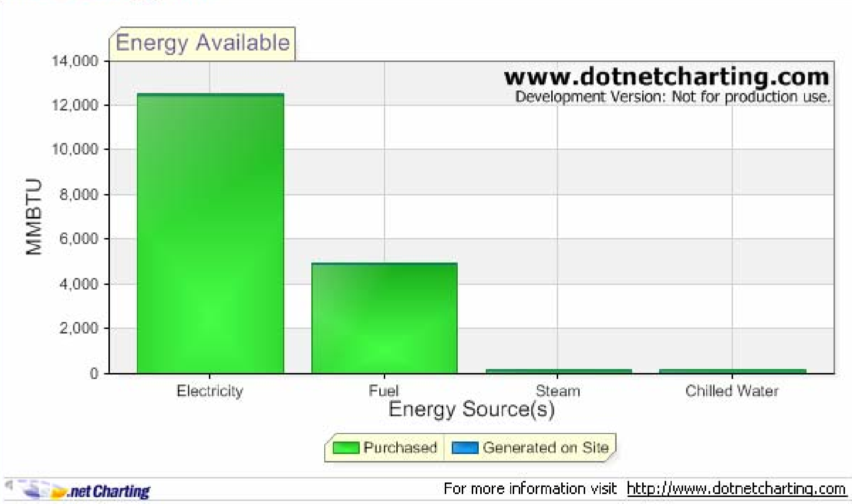
Annual Energy Use



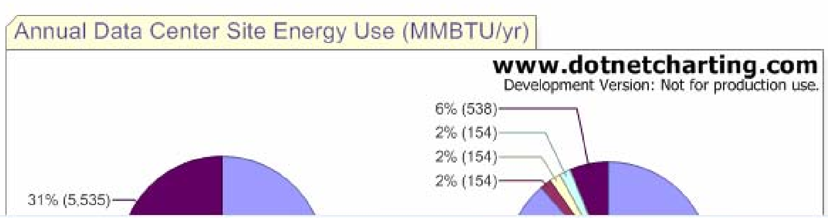
	Total Amount Generated On Site	Total Amount	Unit
Electricity	0	12,535	MMBTU/yr
Fuel	0	4,980	MMBTU/yr
Steam	0	176	MMBTU/yr
Chilled Water	0	160	MMBTU/yr
Total	0	17,851	MMBTU/yr

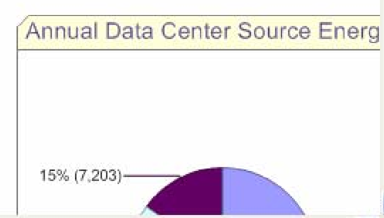
Potential Annual Energy Savings

Suggested Next Steps

The following chart and data table summarize your data center's potential annual energy savings by breakout catergory.
NOTE: The energy and money savings listed below are only estimates based on the data you entered and the estimated costs associated with the data center su

Breakout Category	Current Energy Use				Potential Energy Use				Potential Sa
	Site Energy		Source Energy		Site Energy		Source Energy		
	MMBTU/yr	%	MMBTU/yr	%	MMBTU/yr	%	MMBTU/yr	%	MMBTU/yr
IT Equipment	7,689	43%	25,872	54%	7,689	88%	25,872	88%	0
Data Center Lights	826	5%	2,779	6%	154	2%	517	2%	672
Electric Distribution Losses	1,501	8%	5,052	11%	154	2%	517	2%	984
Fans	2,140	12%	7,201	15%	154	2%	517	2%	1,623
Cooling	5,535	31%	7,203	15%	538	6%	1,811	6%	3,724
Total	17,691	100%	48,107	100%	8,688	100%	29,236	100%	7,003
DCIE		0.43		0.54		0.88		0.88	





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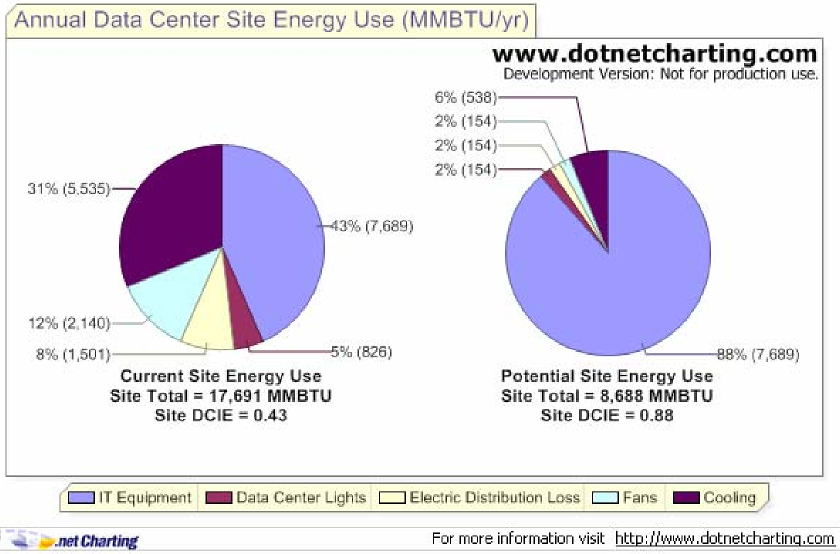
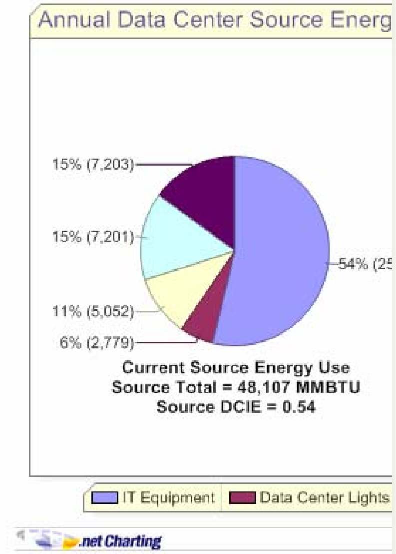
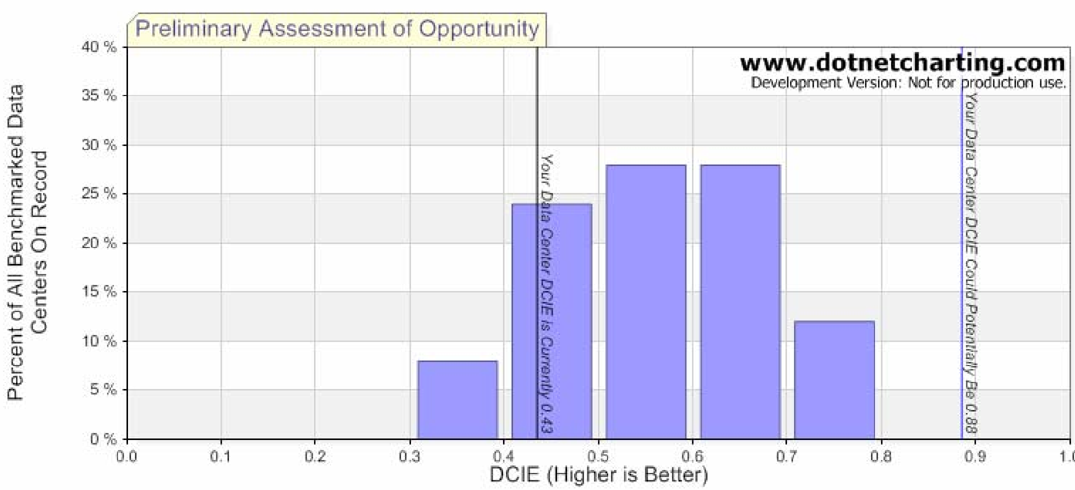
Total	17,691	100%	48,107	100%	8,688	100%	29,236	100%	7,003
DCIE		0.43		0.54		0.88		0.88	







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County	Carroll County
State	Georgia

Suggested Next Steps   Potential Annual Savings

Energy Management | IT Equipment | **Environmental Conditions** | Air Management | Cooling Plant | IT Equipment Power Chain | Lighting | Global Action

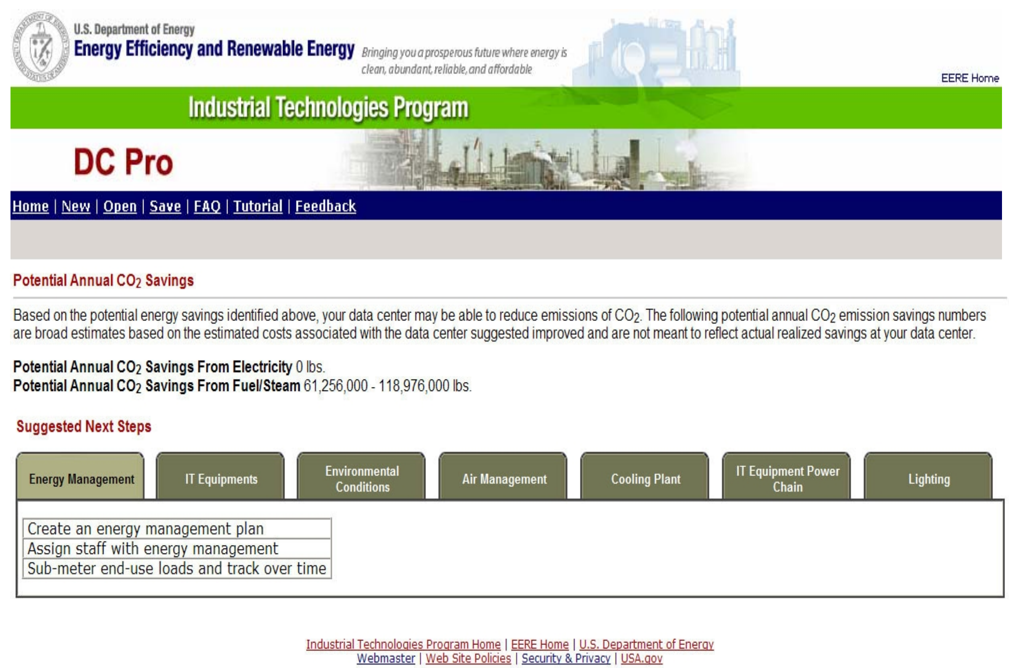
EC.A.1	Consider Air-Management measures	A low air temperature rise across the data center and/or IT equipment intake temperatures outside the recommended range suggest air management problems. A low return temperature is due to by-pass air and an elevated return temperature is due to recirculation air. Estimating the Return Temperature Index (RTI) and the Rack Cooling Index (RCI) will indicate if corrective, energy-saving actions are called for.
EC.A.2	Consider increasing the supply temperature	A low supply temperature makes the chiller system less efficient and limits the utilization of economizers. Enclosed architectures allow the highest supply temperatures (near the upper end of the recommended intake temperature range) since mixing of hot and cold air is minimized. In contrast, the supply temperature in open architectures is often dictated by the hottest intake temperature.
EC.A.4	Place temperature/humidity sensors so they mimic the IT equipment intake conditions	IT equipment manufacturers design their products to operate reliably within a given range of intake temperature and humidity. The temperature and humidity limits imposed on the cooling system that serves the data center are intended to match or exceed the IT equipment specifications. However, the temperature and humidity sensors are often integral to the cooling equipment and are not located at the IT equipment intakes. The condition of the air supplied by the cooling system is often significantly different by the time it reaches the IT equipment intakes. It is usually not practical to provide sensors at the intake of every piece of IT equipment, but a few representative locations can be selected. Adjusting the cooling system sensor location in order to provide the air condition that is needed at the IT equipment intake often results in more efficient operation.
EC.A.5	Recalibrate temperature and humidity sensors	Temperature sensors generally have good accuracy when they are properly calibrated (+/- a fraction of a degree), but they tend to drift out of adjustment over time. In contrast, even the best humidity sensors are instrinsically not very precise (+/- 5% RH is typically the best accuracy that can be achieved at reasonable cost). Humidity sensors also drift out of calibration. To ensure good cooling system performance, all temperature and humidity sensors used by the control system should be treated as maintenance items and calibrated at least once a year. Twice a year is better to begin with. After a regular calibration program has been in effect for a while, you can gauge how rapidly your sensors drift and how frequent the calibrations should be. Calibrations can be performed in-house with the proper equipment, or by a third-party service.
EC.A.6	Network the CRAC/CRAH controls	CRAC/CRAH units are typically self-contained, complete with an on-board control system and air temperature and humidity sensors. The sensors may not be calibrated to begin with, or they may drift out of adjustment over time. In a data center with many CRACs/CRAHs it is not unusual to find some units humidifying while others are simultaneously dehumidifying. There may also be significant differences in supply air temperatures. Both of these situations waste energy. Controlling all the CRACs/CRAHs from a common set of sensors avoids this.
EC.A.8	Consider disabling or eliminating humidification controls or reducing the humidification setpoint	Tightly controlled humidity can be very costly in data centers since humidification and dehumidification are involved. A wider humidity range allows significant utilization of free cooling in most climate zones by utilizing effective air-side economizers. In addition, open-water systems are high-maintenance items.
EC.A.9	Consider disabling or eliminating dehumidification controls or increasing the dehumidification setpoint	Most modern IT equipment is designed to operate reliably when the intake air humidity is between 20% and 80% RH. However, 55% RH is a typical upper humidity level in many existing data centers. Maintaining this relatively low upper limit comes at an energy cost. Raising the limit can save energy, particularly if the cooling system has an airside economizer. In some climates it is possible to maintain an acceptable upper limit without ever needed to actively dehumidify. In this case, consider disabling or removing the dehumidification controls entirely.
EC.A.10	Change the type of humidifier	Most humidifiers are heat based; ie, they supply steam to the air stream by boiling water. Electricity or natural gas are common fuel sources. The heat of the steam becomes an added load on the cooling system. An evaporative humidifier uses much less energy. Instead of boiling water, it introduces a very fine mist of water droplets to the air stream. When set up properly the droplets quickly evaporate, leaving no moisture on nearby surfaces. This has an added cooling benefit, as the droplets absorb heat from the air as they evaporate.

Previous   Save & Continue

Example “DC Pro” recommendations

List of Actions (for Electric Distribution System)

- Avoid lightly loaded UPS systems
- Use high efficiency MV and LV transformers
- Reduce the number of transformers upstream and downstream of the UPS
- Locate transformers outside the data center
- Use 480 V instead of 208 V static switches (STS)
- Specify high-efficiency power supplies
- Eliminate redundant power supplies
- Supply DC voltage to IT rack



DC Pro tools

High Level Profiling Tool

- Overall energy performance (baseline) of data center
- Performance of systems (infrastructure & IT) compared to benchmarks
- Prioritized 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

Power Systems

- UPS
- Transformers
- Lighting
- Standby gen.

On-Site Gen

- Renewables
- use of waste heat

Data confidentiality

- All input data is treated as confidential
- Data in benchmarking charts are “anonymized” with random facility ID numbers
- Data is saved to a secure database server and can not be accessed by the general public

Assessment worksheet

- List of metrics and features
  - Priorities for metrics
  - Data required
- Data collection template
- List of actions

Data Center Assessment Inputs: Features and Metrics
DRAFT 1-24-08

Notes:
1. Each assessment area has two types of inputs: features and metrics
2. The features checklist can be used for stage 1 assessment (prior to site visit), and to prioritize metrics for stage 2 assessment
3. Input fields are shaded in blue - defaults are provided for priorities
4. Priority levels for metrics: 1 - Must have; 2 - Important, subject to ease of data collection; 3 - collect only if easily available

1. Overall Energy Management	
Has an audit or commissioning been conducted within the last 2 years?	
Is there a written energy management plan?	
Are there staff with explicit energy management responsibility?	
What is the redundancy level for Electrical systems? (N, N+x, 2N)	
What is the redundancy level for HVAC systems? (N, N+x, 2N)	
What is the current usage factor? (% of space?)	

Metrics	*Unit*	*Data Required*	*Priority*	*Value*
Overall Energy Effectiveness (IT energy use / total energy use)	-	IT Equipment Energy Use Total DC Energy Use (Site)	1	
Site Energy Use Intensity	Site BTU/sf-yr	Total DC Energy Use (Site) DC Floor Area	2	
Source Energy Use Intensity	Source BTU/sf-yr	Total DC Energy Use (Source) DC Floor Area	3	
Purchased Energy Cost Intensity	Energy $/sf-yr	Total DC Energy Cost DC Floor Area	2	
Peak Electrical Load Intensity	Peak W/sf	Total DC Peak Elec Demand DC Floor Area	2	

2. Environmental Conditions	
What are the temperature setpoints (specify range)?	
What are the humidity setpoints (specify range)?	
Recommended and allowable intake temperatures and humidity (specify ranges)?	
Where are temperature and humidity sensors located (return, other)?	
Do CRAC/CRAH units have centralized or distributed controls?	
Are there humidity controls and does the data center need humidity control?	
Are there procedures and personnel/cable grounding equipment to prevent ESD?	
Are unit controls fighting each other (for example, simultaneously humidifying and dehumidifying)?	
Does system have capability of taking slope and offset for sensor recalibration?	

Metrics	*Unit*	*Data Required*	*Priority*	*Value*
Ratio Max Density to Average Heat Density	None	Max Heat Density Average Heat Density	2	
Actual Dew-Point Temperature	F	Data Center Dewpoint Temperature	1	
Climate Data	F	TMY/TRY/WYEC data	1	
Temperature and humidity sensor calibration	Slope and offset	Reference sensor reading	1	

3. Air Management, CRAC/CRAH/AHU	
How many CRAC/CRAH/AHUs are there? Identify which operate under normal conditions and which are standby.	
For each CRAC/CRAH/AHU collect nameplate data for unit, for each motor and submittal data identifying capacity and design conditions.	
What is the clear ceiling in feet (slab to slab minus raised floor minus dropped ceiling)?	
Is there a ceiling return plenum? If yes, what is the height and static pressure?	
Is there a floor supply plenum (raised floor)? If yes, what is the height and static pressure?	
What is the estimated floor leakage in percent of total system airflow?	
Where are cables and pipes located?	

Contact information

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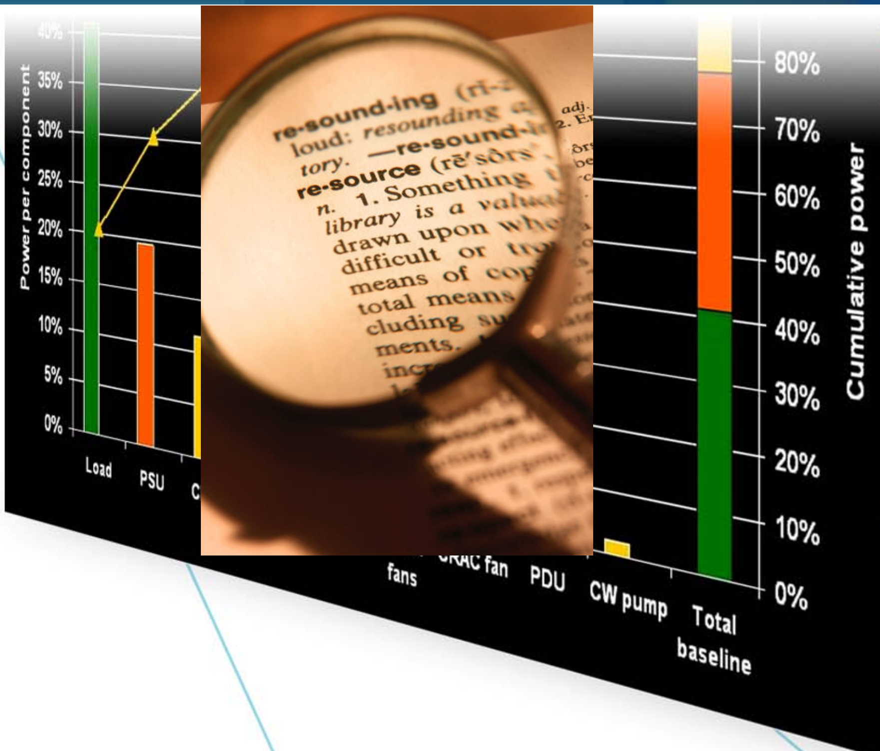


Resources

Steve Greenberg, PE

Links to get started

DOE Website: Sign up to stay up to date on new developments
www.eere.energy.gov/datacenters

Lawrence Berkeley National Laboratory (LBNL)
http://hightech.lbl.gov/datacenters/

LBNL Best Practices Guidelines (cooling, power, IT systems)
http://hightech.lbl.gov/datacenters-bpg/

ASHRAE Data Center technical guidebooks
http://tc99.ashraetcs.org/

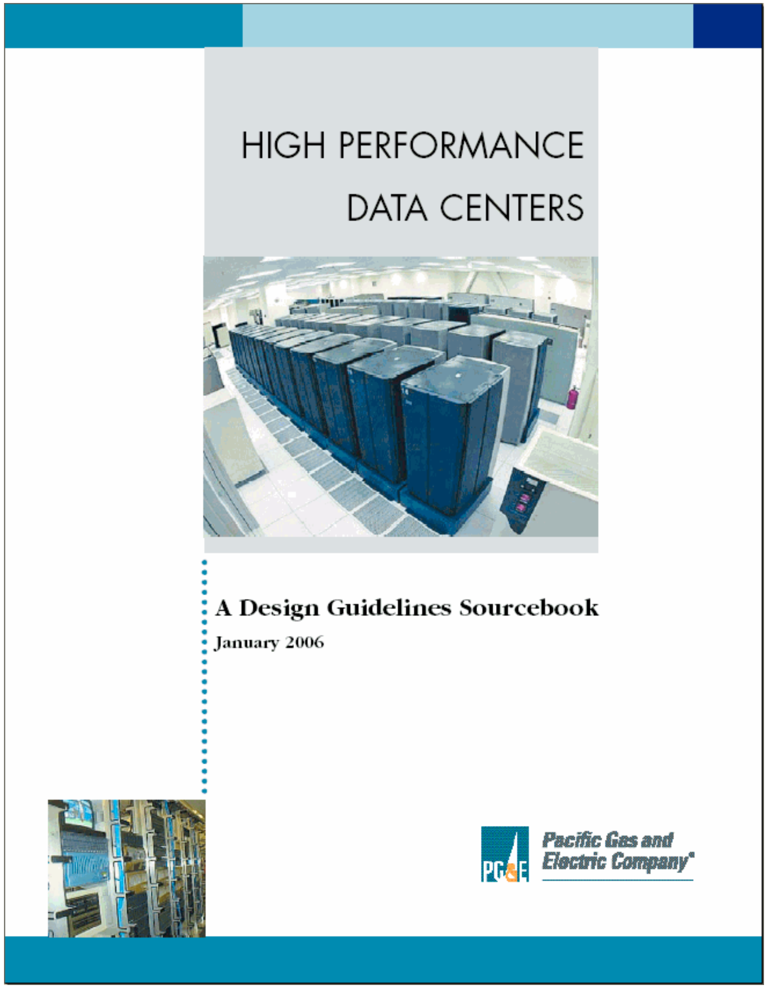
The Green Grid Association: White papers on metrics
http://www.thegreengrid.org/gg_content/

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

Uptime Institute white papers
www.uptimeinstitute.org

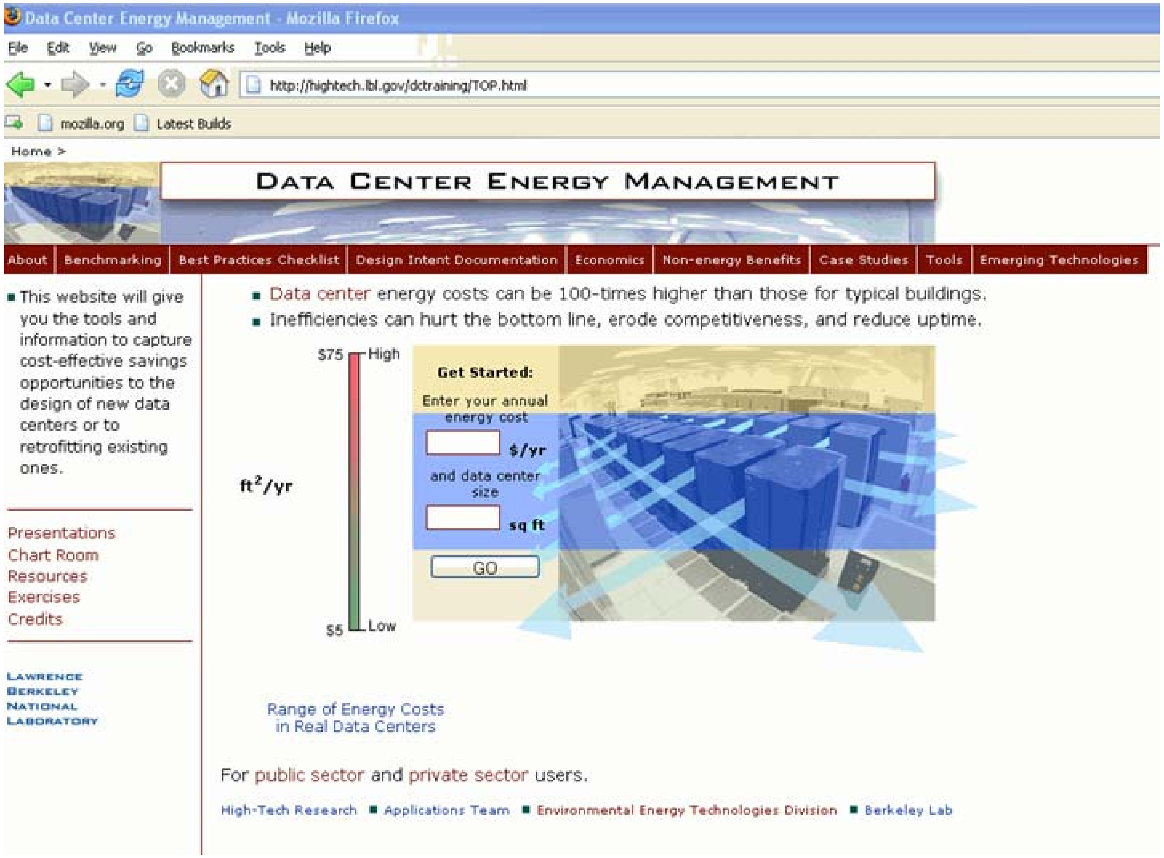
Design guidelines are available

- Design Guides were developed based upon observed best practices
- Guides are available through PG&E and LBNL websites



http://hightech.lbl.gov/documents/DATA_CENTERS/06_DataCenters-PGE.pdf

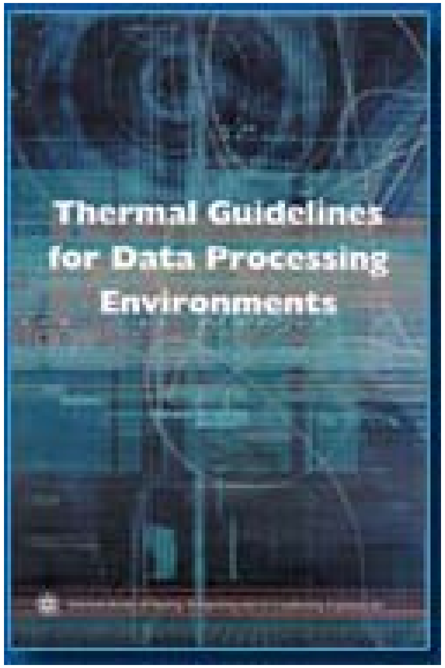
Web based training resource

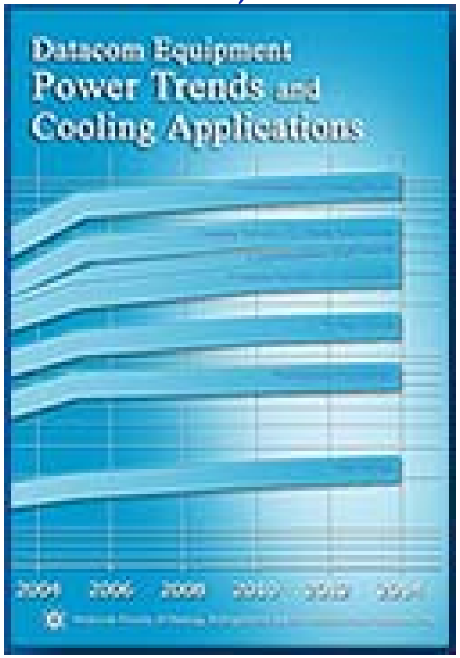


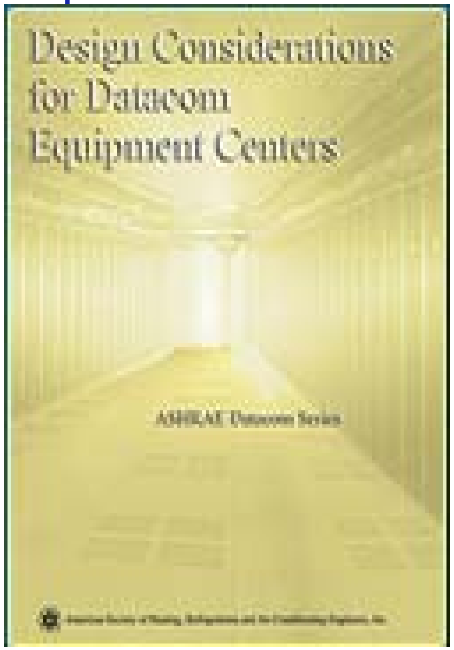
http://hightech.lbl.gov/dctraining/TOP.html

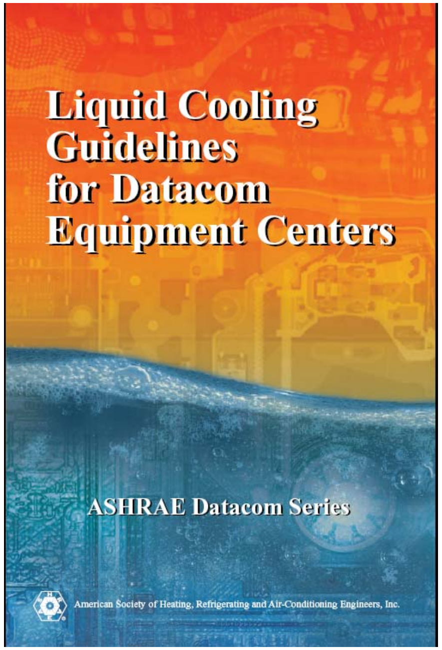
ASHRAE guidelines

Seven books published (also Best Practices for Energy Efficiency, High Density centers, and Structural/Vibration considerations)—more in preparation









ASHRAE, Thermal Guidelines for Data Processing Environments, 2004, Datacom Equipment Power Trends and Cooling Applications, 2005, Design Considerations for Datacom Equipment Centers, 2005, Liquid Cooling Guidelines for Datacom Equipment Centers, 2006, © American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org

Order from http://www.ashrae.org/publications/page/1900

ASHRAE resources

- ASHRAE (http:\\www.ashrae.org)
  - Technical Committee (TC) 9.9 Mission Critical Facilities http://tc99.ashraetcs.org/
  - Additional Guidelines in Development
    - Contamination
- DOE/ASHRAE Training (200 sessions starting mid’09)

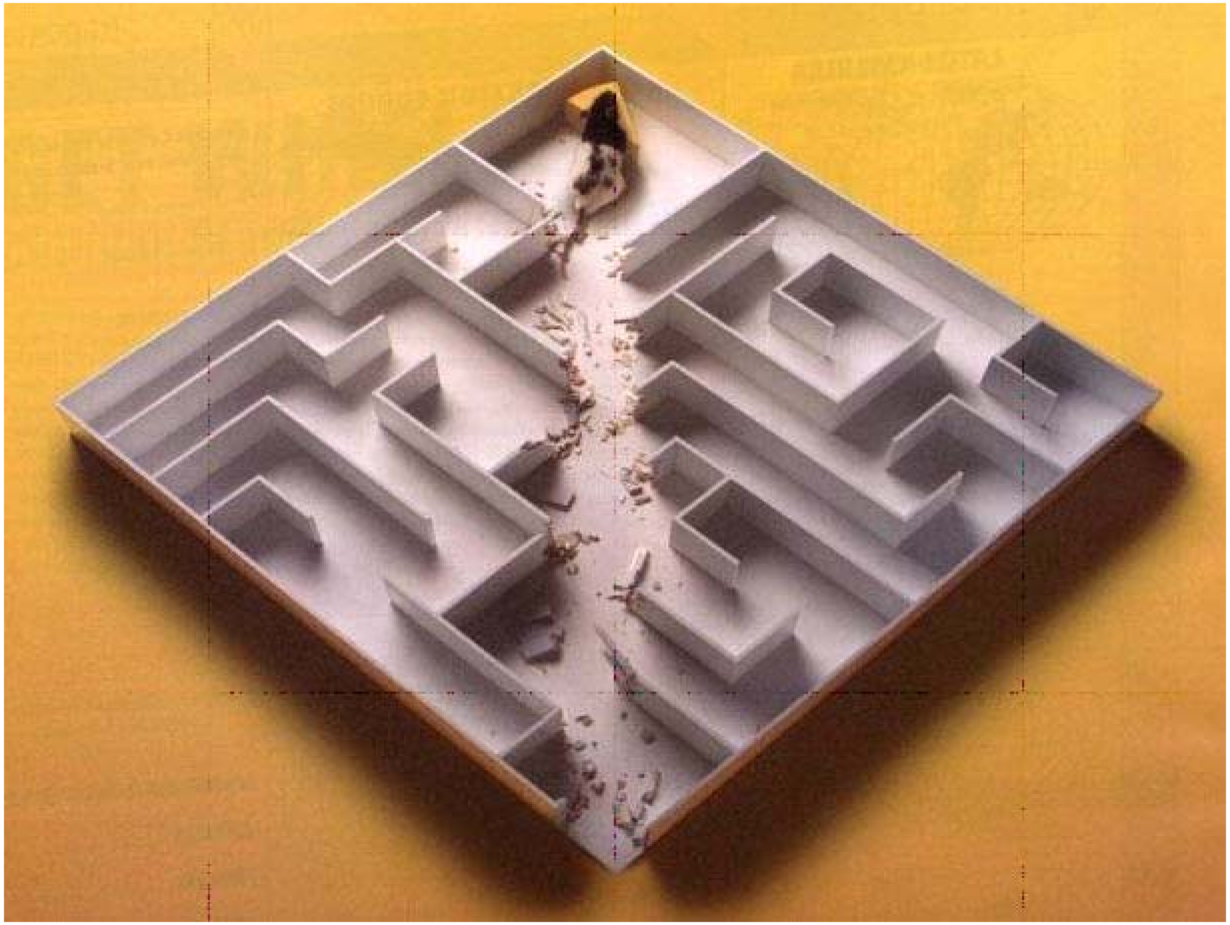
IT power supply resources

- www.ssiforums.org
- www.80plus.org

Other resources

- Electrostatic Discharge Association (http://www.esda.org/)
- Uptime Institute (http://www.upsite.com/TUIpages/tuihome.html)
- Green Grid (http://www.thegreengrid.org/home)
- Chilled Water Plant Resources
  - PG&E CoolTools™ Chilled Water Plant Design Guide (http://taylor-engineering.com/publications/design_guides.shtml)
  - ASHRAE Journal article, "Balancing Variable Flow Hydronic Systems" and other CHW articles on TE website at http://www.taylor-engineering.com/publications/articles.shtml
- Control and Commissioning Resources
  - DDC Online (http://www.ddc-online.org)
  - AutomatedBuildings (http://www.automatedbuildings.com/). This site is an e-zine on building automation and controls.
  - ASHRAE Guideline 13-2000, "Specifying Direct Digital Control System."
  - Control Spec Builder an on-line resource for developing control specifications (http://www.CtrlSpecBuilder.com)
  - National Building Controls Information Program (NBCIP, http://www.buildingcontrols.org/)
  - CSU Control and CX Guidelines (http://www.calstate.edu/cpdc/ae/guidelines.shtml)
  - California Commissioning Collaborative (CaCx, http://www.cacx.org)

Questions? - Discussion



Thank you for attending