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# Data Center Air Management: The First Improvement

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# The Early Days at LBNL

It was cold, but hot spots were everywhere:



Fans were used to redirect air

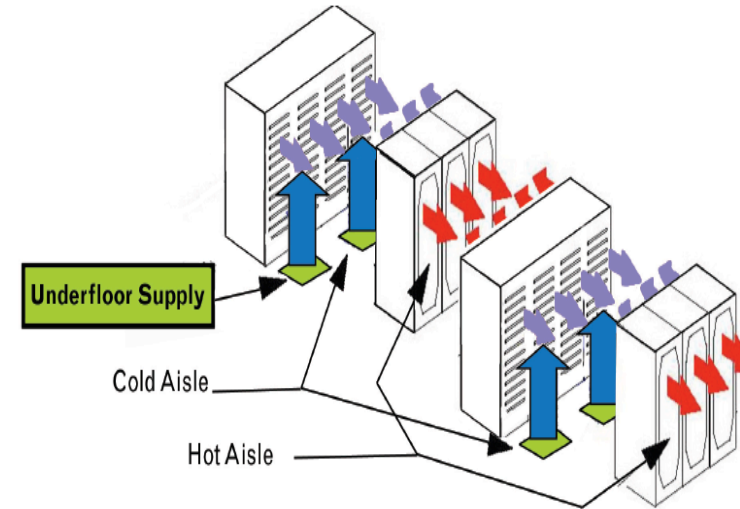


High-flow tiles reduced air pressure



# Air Management

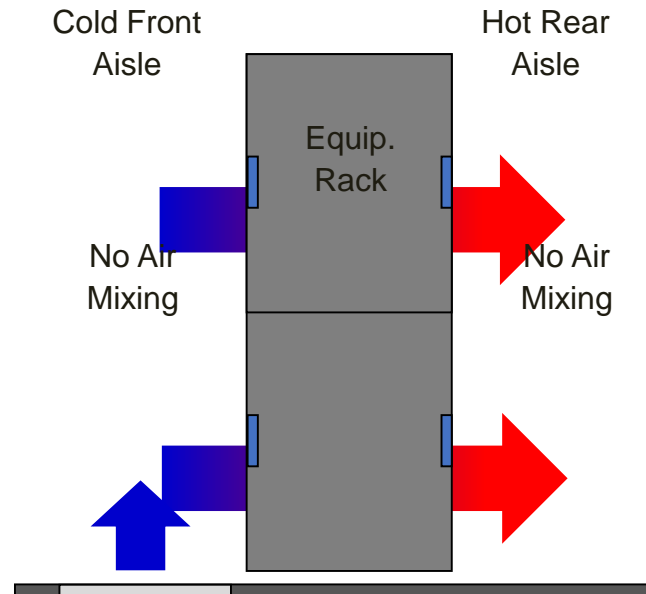
- Problems:
  - By-pass air
  - Re-circulation air
- Solution:
  - Air Management
- Use hot and cold aisles
- Improve isolation of hot and cold aisles
  - Reduce fan energy
  - Improve air-conditioning efficiency
  - Increase cooling capacity



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

# Separating Cold from Hot Airflow

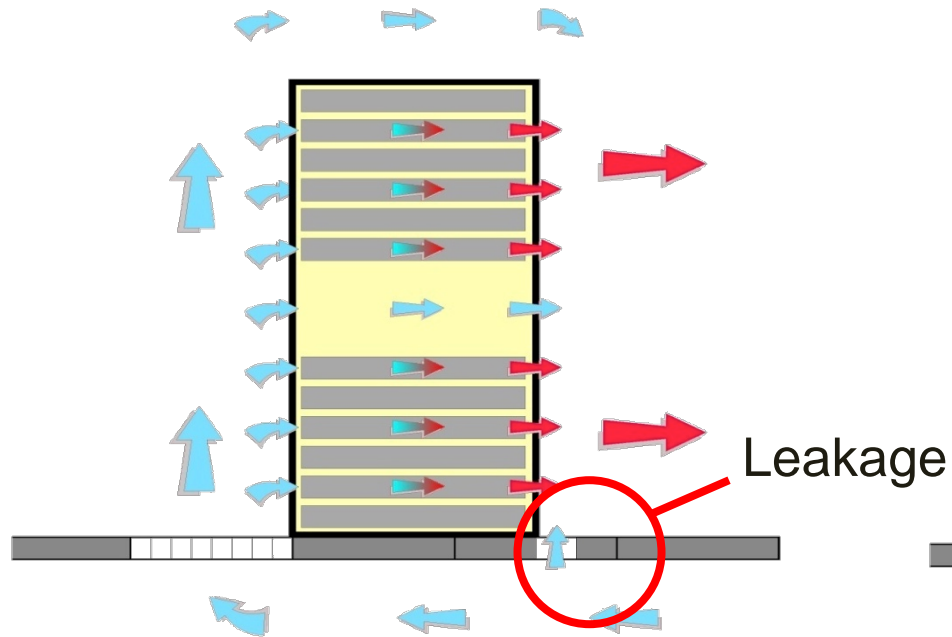
- Supply cold air as close to the rack inlet as possible
- Reduce mixing with ambient air and hot rack exhaust
- Air moves from the front cold aisle to the rear hot aisle



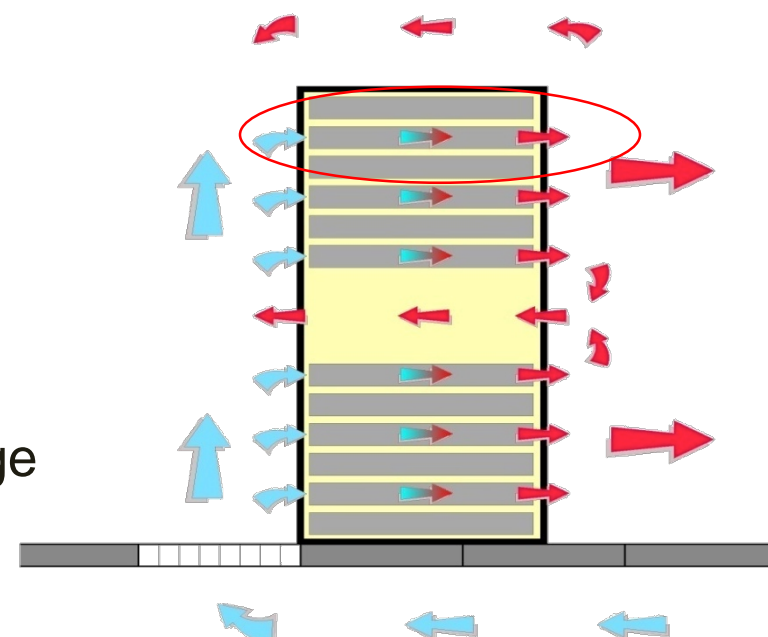
# Reduce By-Pass and Recirculation Air

Bypass Air / Short-Circuiting

Recirculation



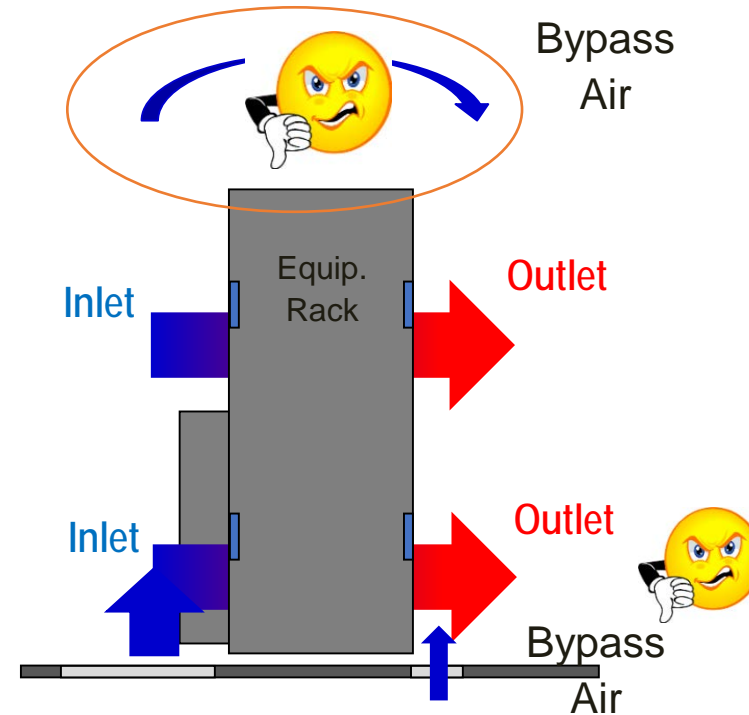
Wastes fan energy as well as cooling energy and capacity



Increases inlet temperature to servers

# Bypass Air – Common Causes

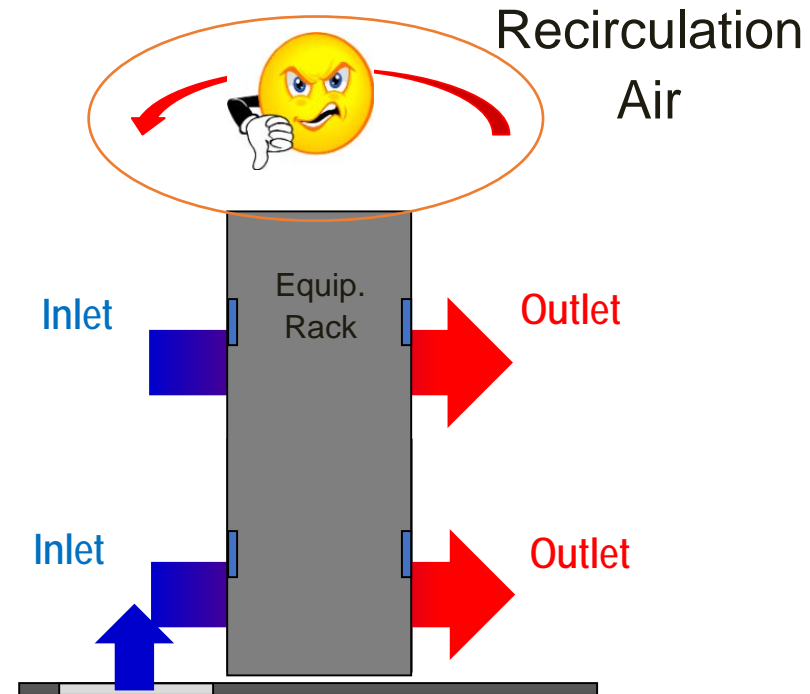
- Too much supply airflow
- Misplaced perforated tiles
- Leaky cable penetrations
- Too-high tile exit velocity





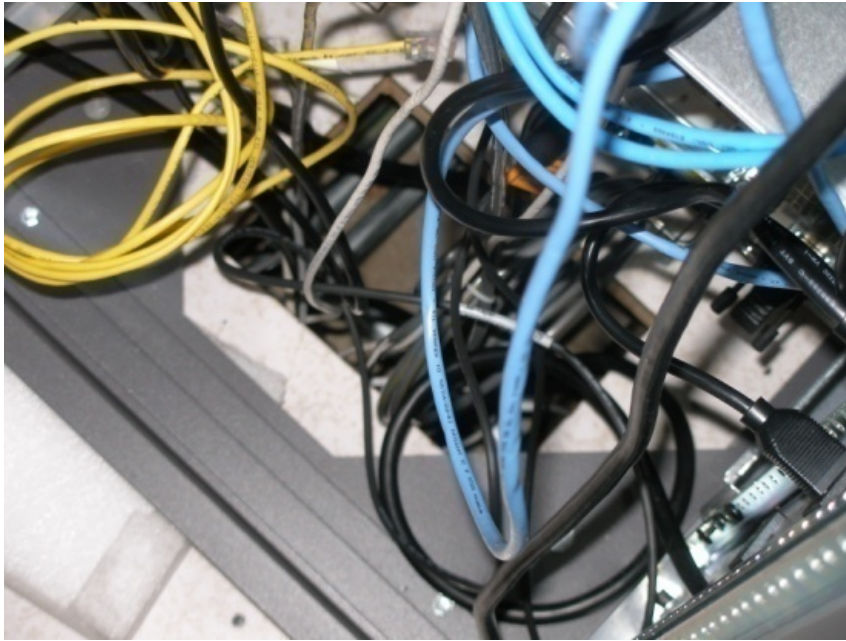
# Recirculation Air – Common Causes

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



# Maintaining Raised-Floor Seals

Maintain seals of all potential leaks in the raised floor plenum



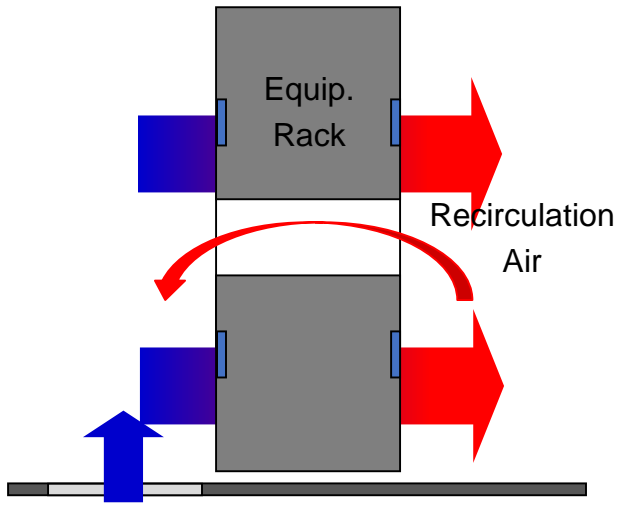
Unsealed cable penetration (inside rack)



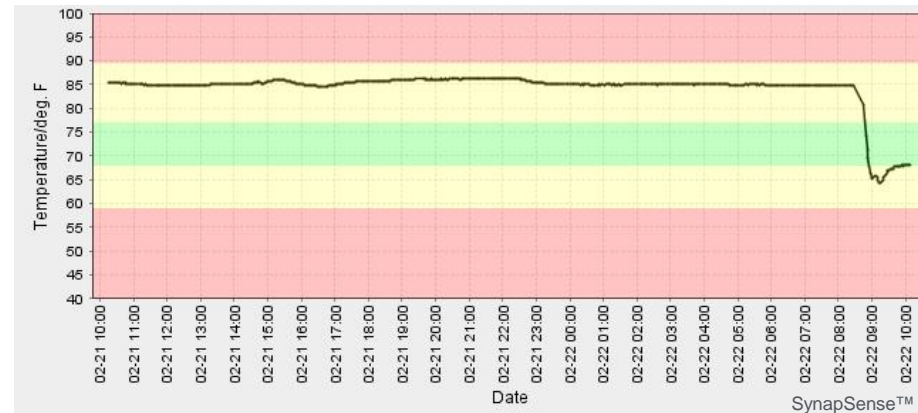
Sealed cable penetration

# Managing Blanking Panels

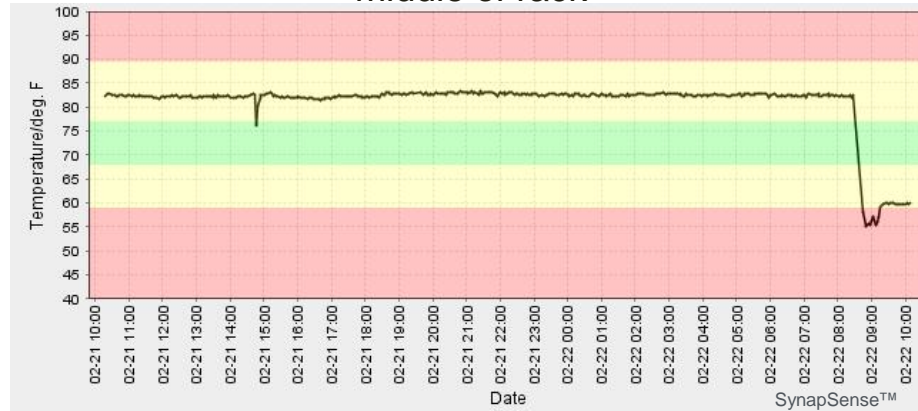
- Any opening will degrade the separation of hot and cold air
- Maintain blanking panels
  - One 12" blanking panel reduced temperature  $\sim 20^{\circ}\text{F}$



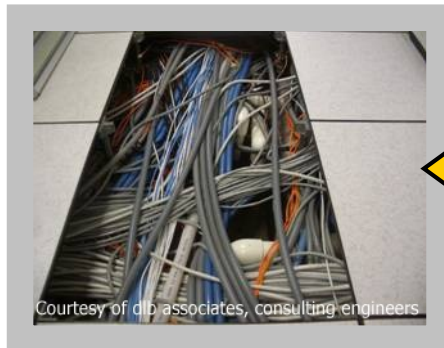
top of rack



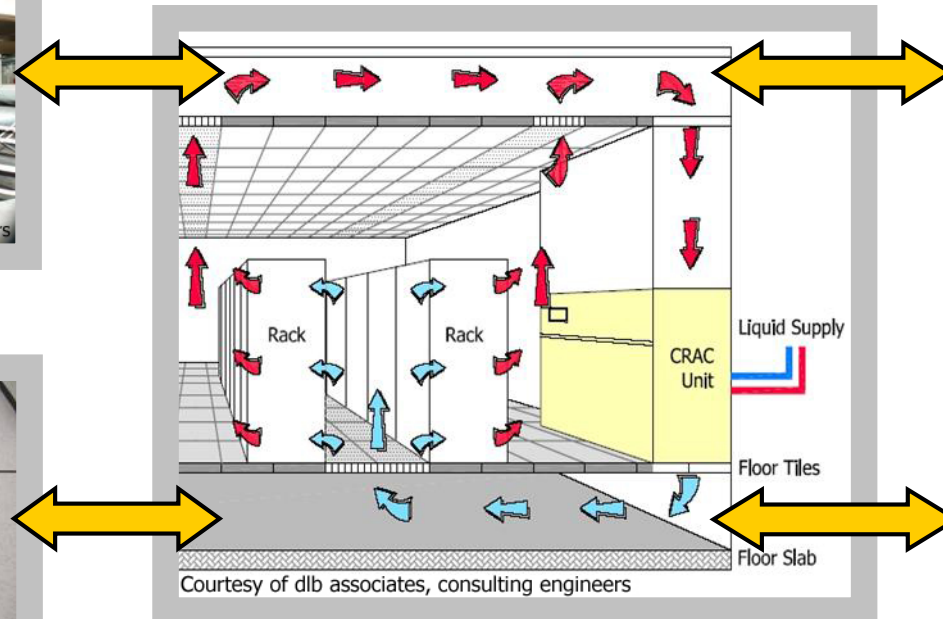
middle of rack



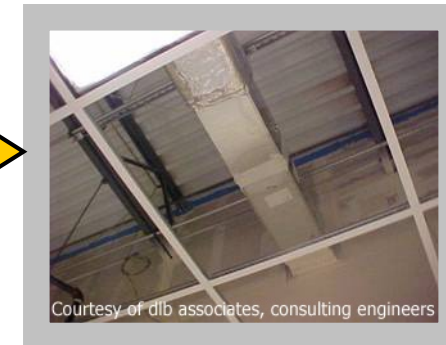
# Reduce Airflow Restrictions & Congestion



Congested Floor & Ceiling Cavities



Consider the Impact that Congestion Has on the Airflow Patterns

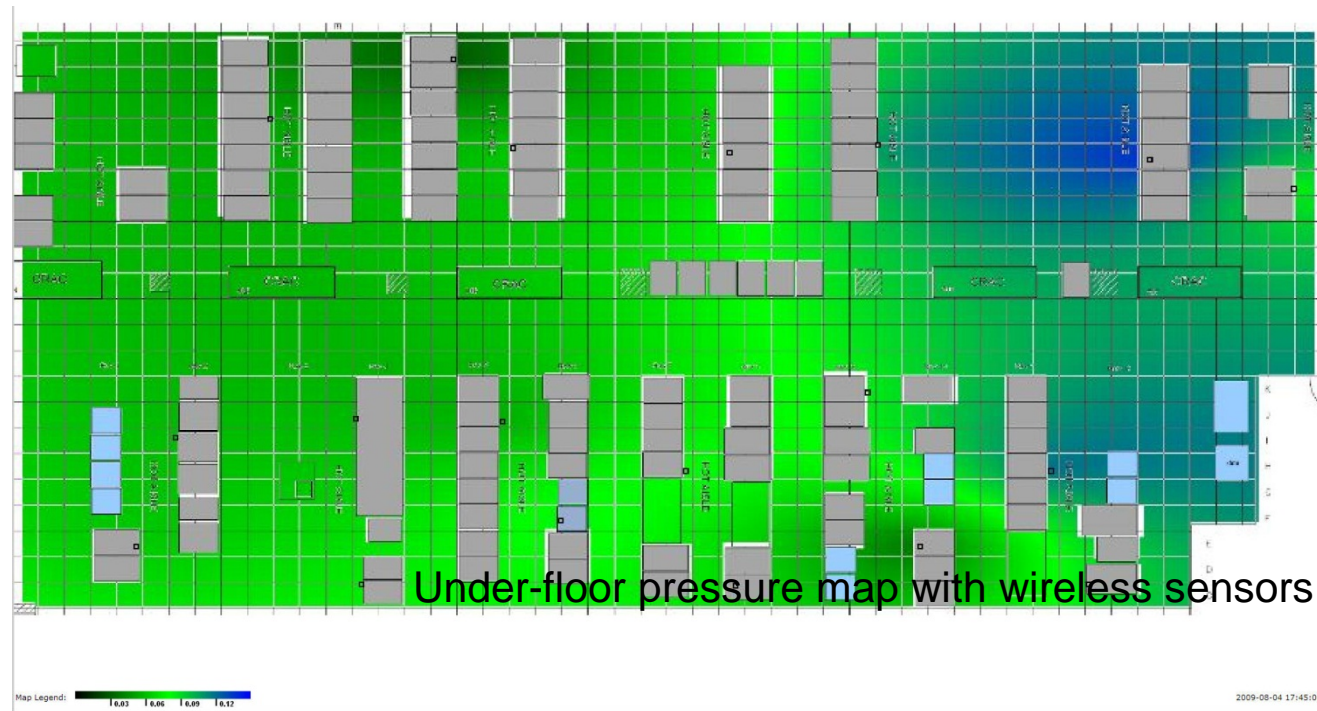


Empty Floor & Ceiling Cavities



# Resolve Airflow Balancing

- Balancing is required to optimize airflow
- Rebalance with new IT or HVAC equipment
- Place perforated floor tiles *only* in cold aisles

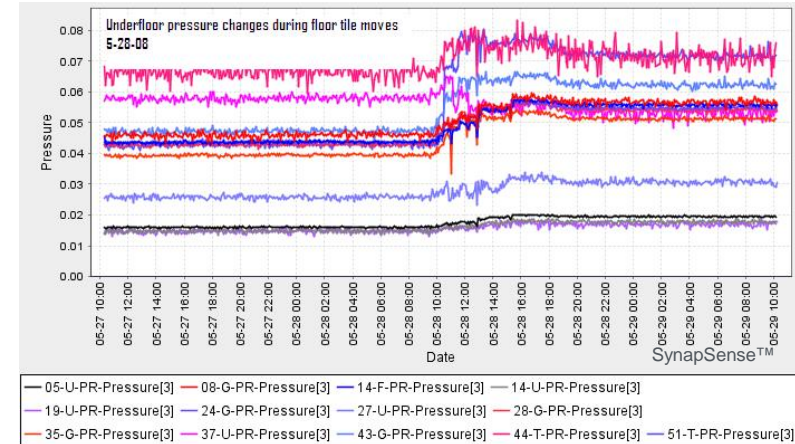


# Results: Tune Floor Tiles

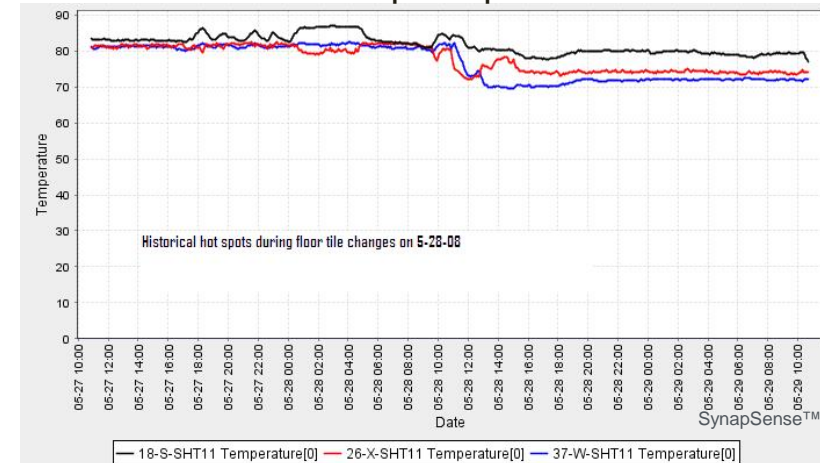


- Too many permeable floor tiles
- If airflow is optimized
  - under-floor pressure ↑
  - rack-top temperatures ↓
  - data center capacity increases
- Measurement and visualization assisted the tuning process

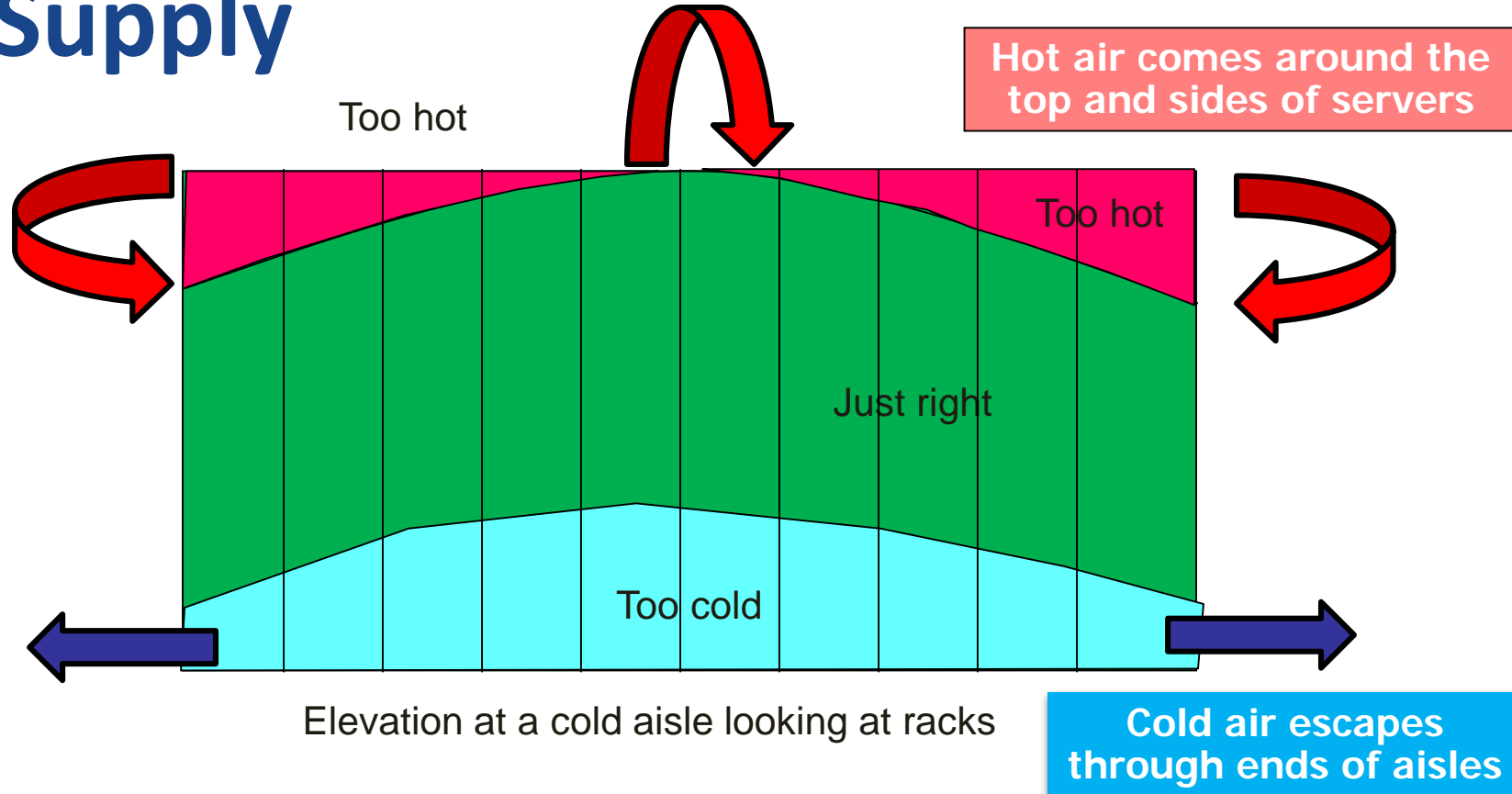
under-floor pressures



rack-top temperatures



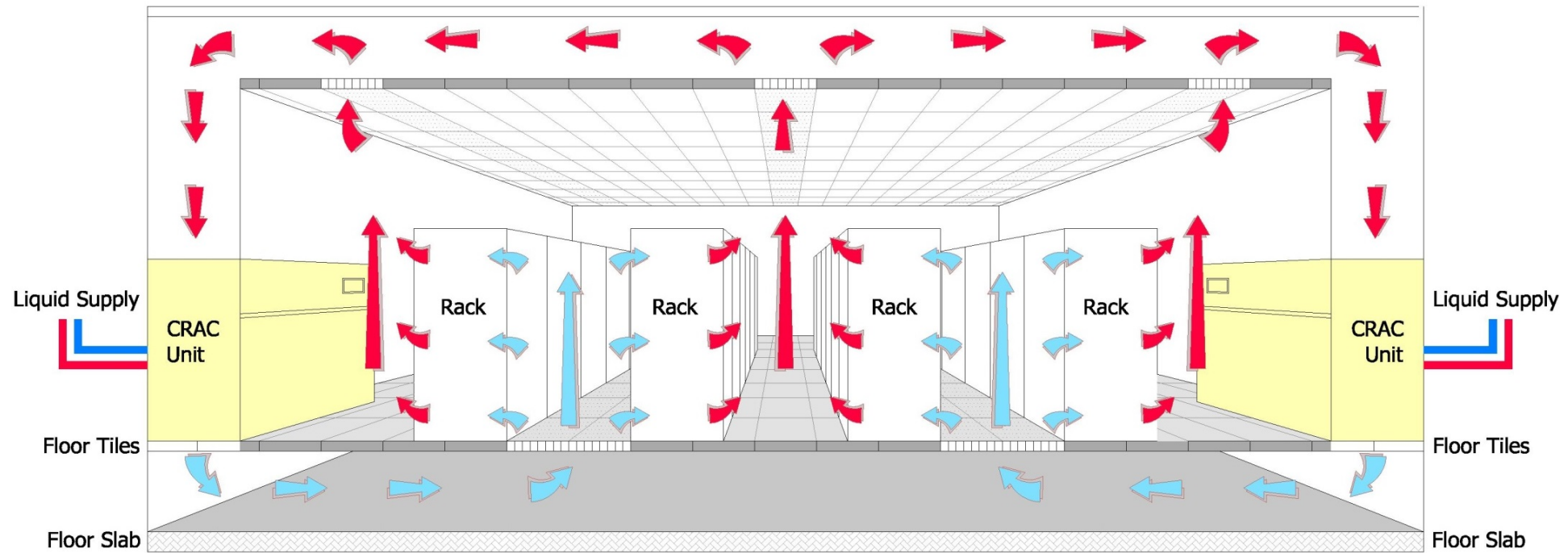
# Typical Temperature Profile with Under-floor Supply



There are numerous references in ASHRAE.

See for example V. Sorell et al; "Comparison of Overhead and Underfloor Air Delivery Systems in a Data Center Environment Using CFD Modeling"; ASHRAE Symposium Paper DE-05-11-5; 2005.

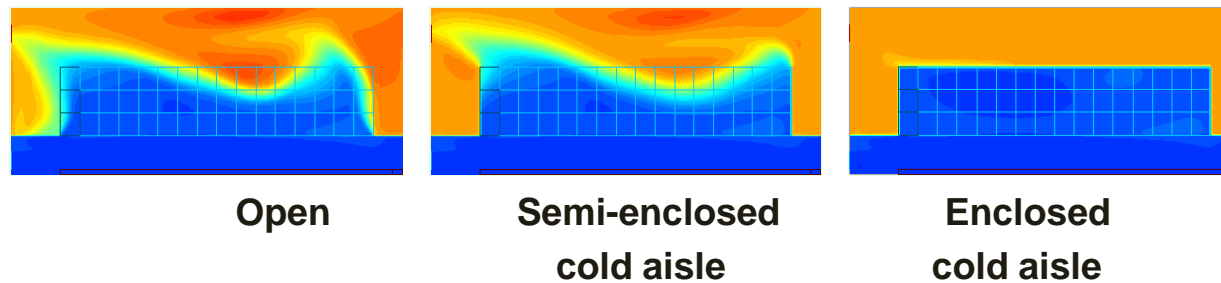
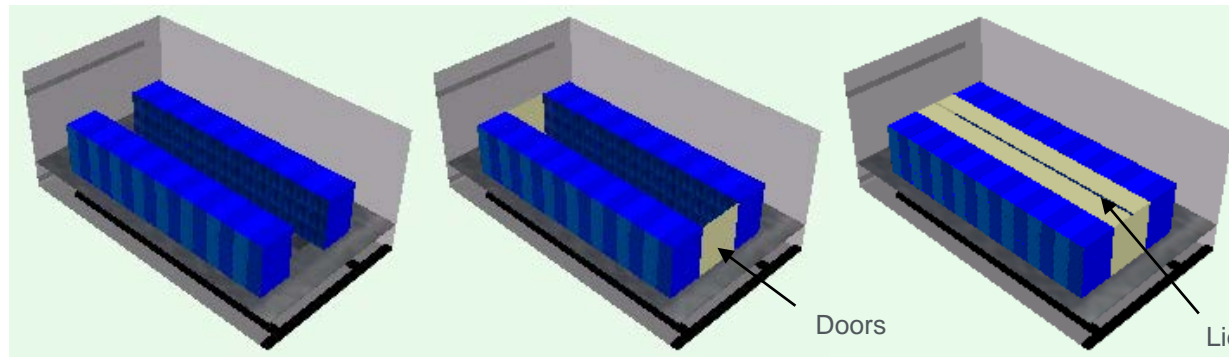
# Next step: Air Distribution Return-Air Plenum





# Enhanced Isolation Options

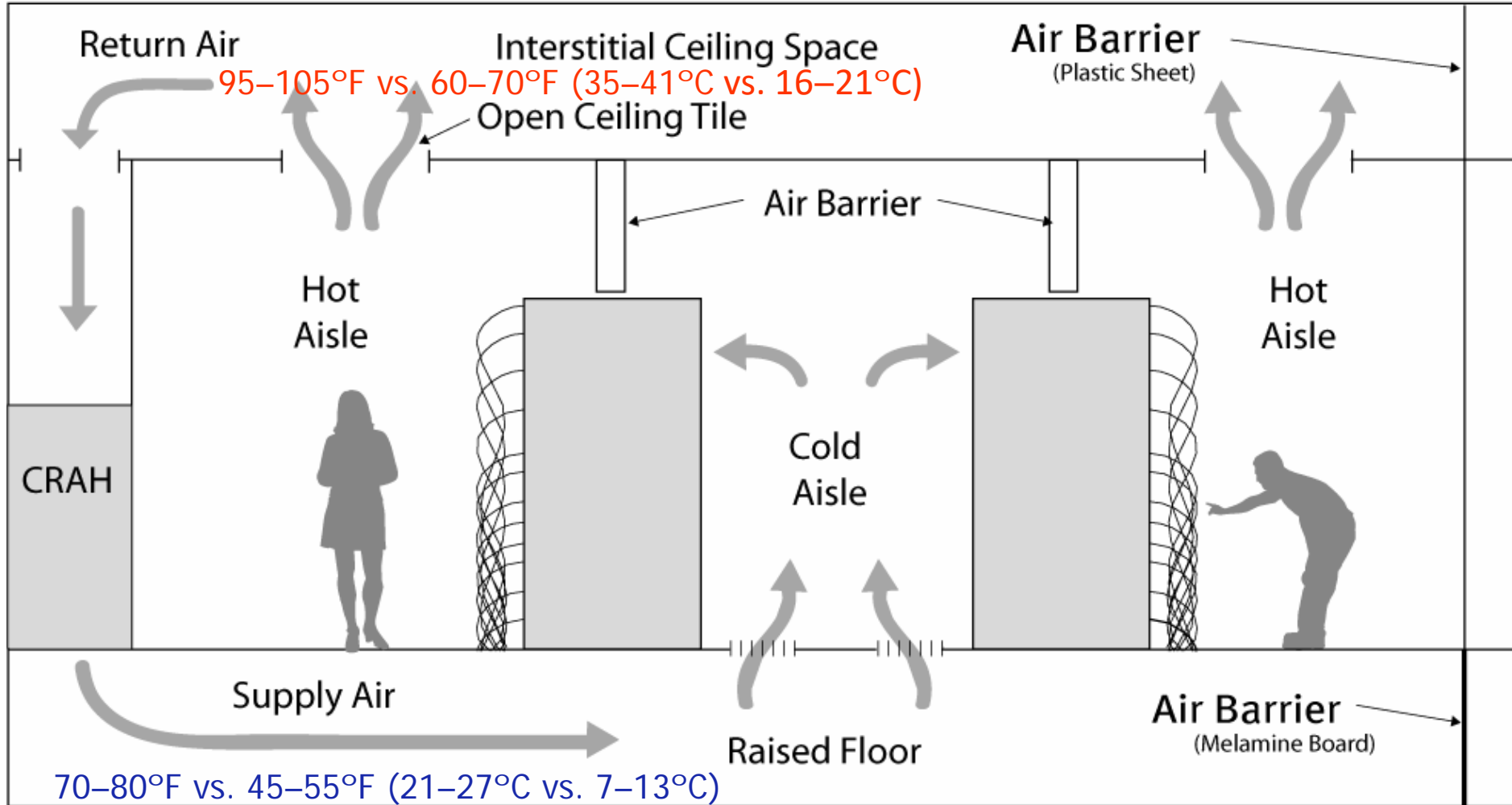
- Physical barriers enhance separate hot and cold airflow
- Barrier placement must comply with fire codes
- Curtains, doors, or lids have been used successfully



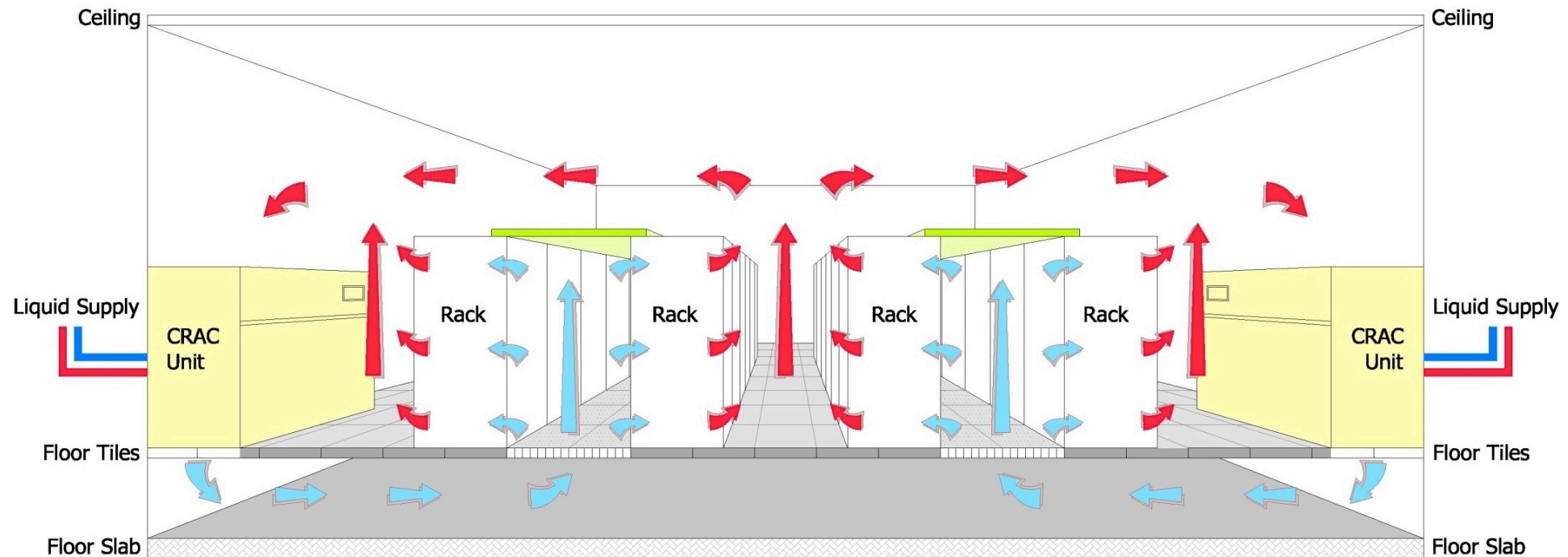
# Adding Air Curtains for Hot/Cold Isolation



# Air Management: Separate Cold and Hot Air



# Cold Aisle Airflow Containment Example

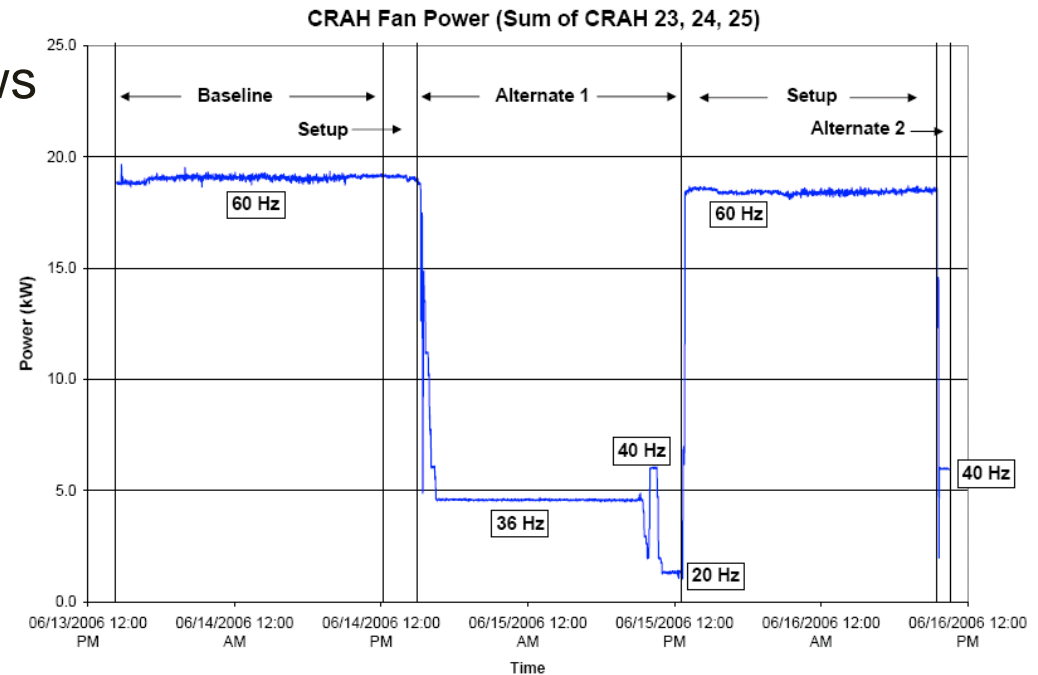


LBNL's Cold Aisle Containment study achieved fan energy savings of ~75%



# Fan Energy Savings

- Isolation significantly reduces bypass air, which in turn allows reduction of supply airflow
- Fan speed can be reduced, and fan power is proportional to nearly the cube of the flow
- Fan energy savings of 70%–80% is possible with variable air volume (VAV) fans



Without Enclosure

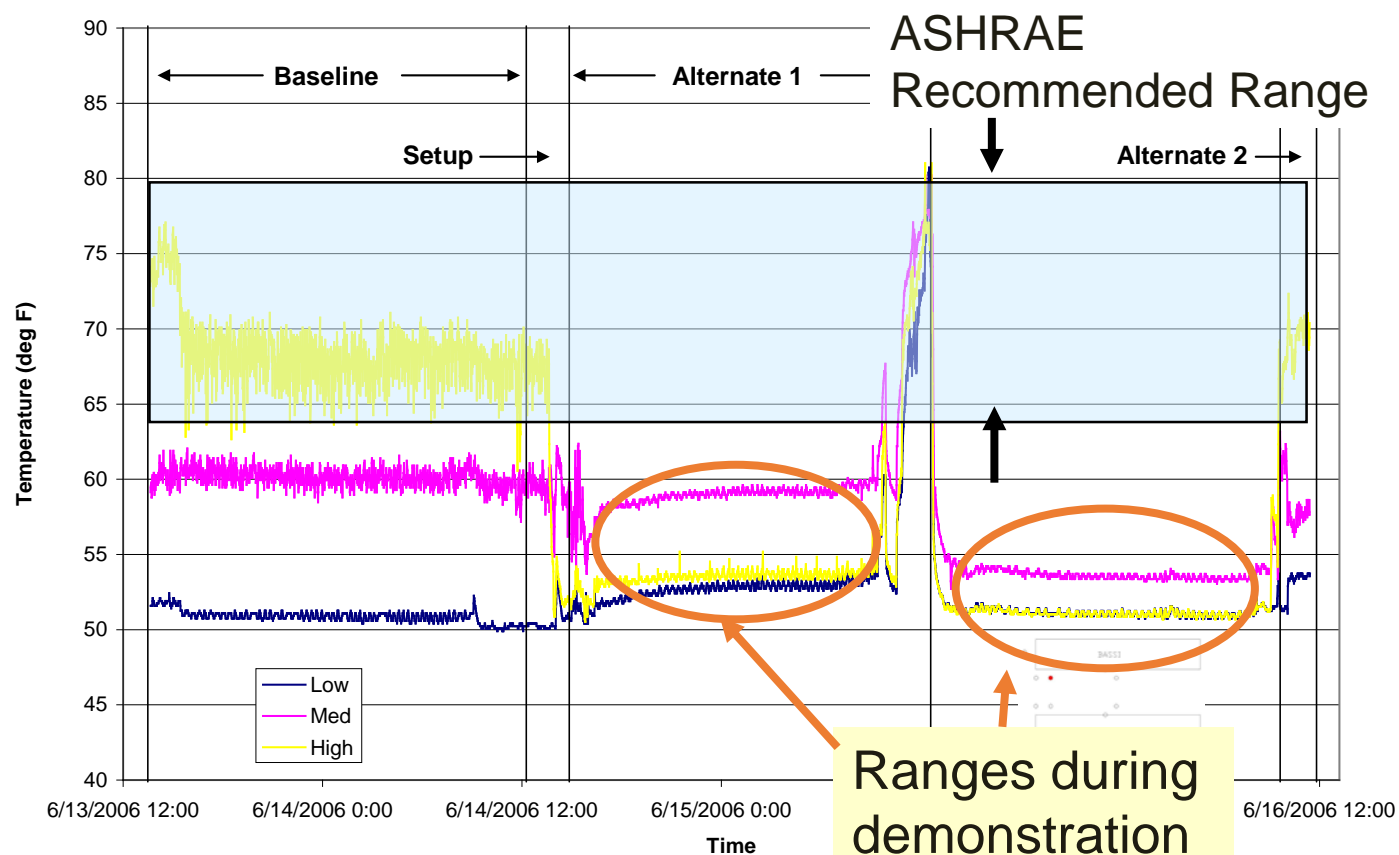
With Enclosure

Without Enclosure

# LBNL Air Management Demonstration

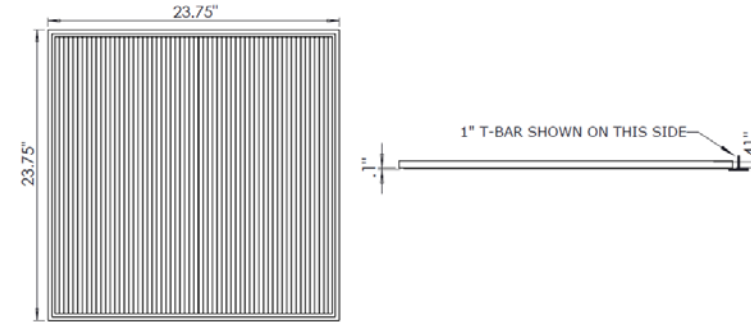
Better airflow management permits warmer supply temperatures!

Cold Aisle NW - PGE12813



# Hot and Cold Aisle Containment

## Subzero Cold Aisle Containment



## Ceilume Heat Shrink Tiles



## APC Hot Aisle Containment (with in-row cooling)

# Isolated Hot Return



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





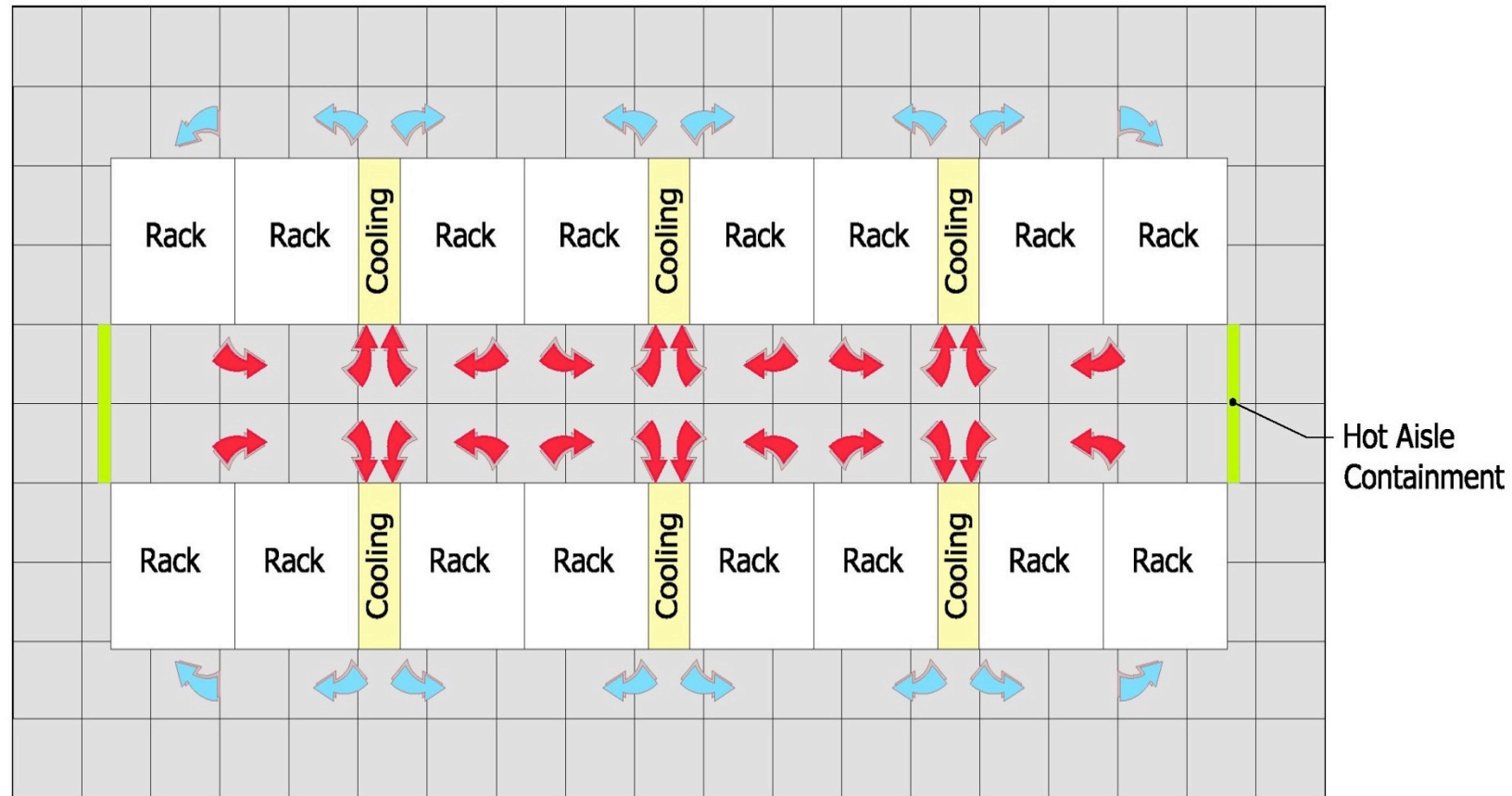
# Isolating Hot and Cold Aisles Summary

- Energy intensive IT equipment needs good isolation of “cold” intake and “hot” exhaust
- Supply airflow can be reduced if no bypass occurs (assuming VFD fans)
- Supply temperature can be raised if air is delivered without mixing
- Chillers and economizers are more efficient with warmer return air temperatures
- Cooling and raised-floor capacity increase with air management

# Efficient Alternatives to Under-Floor Air Distribution

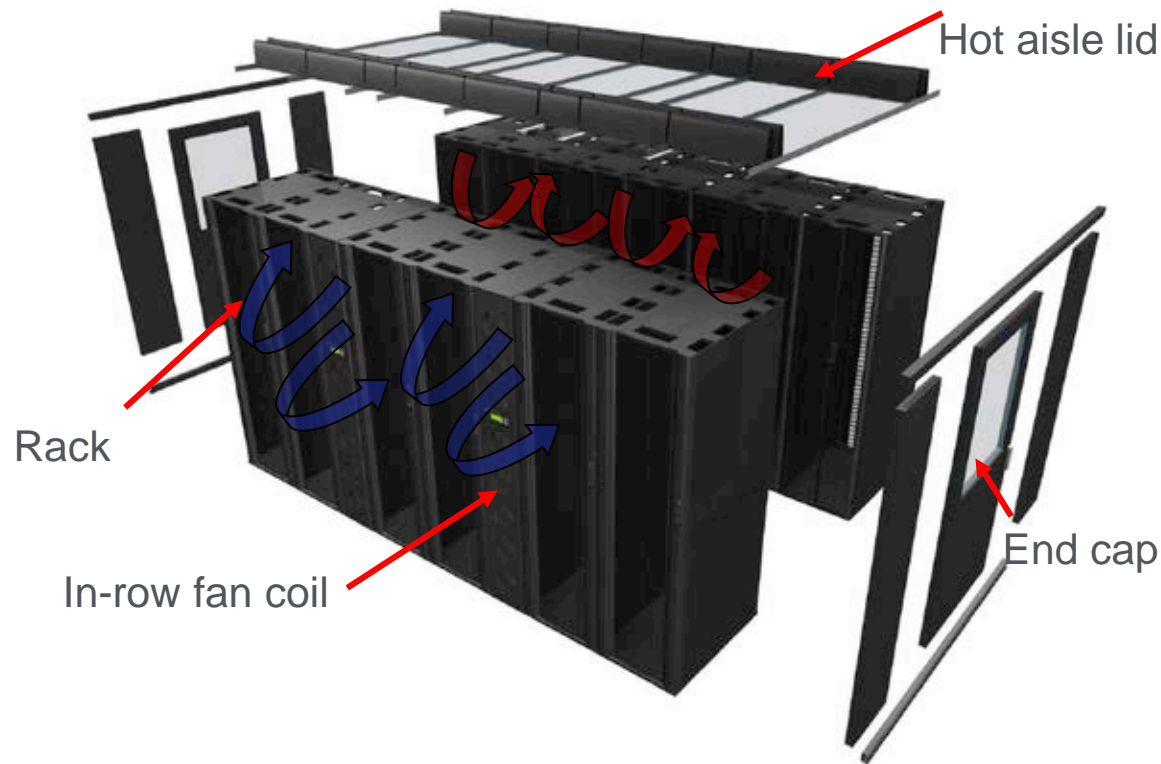
- Localized air cooling systems with hot and cold isolation can supplement or replace under-floor systems
- Examples
  - Row-based cooling units
  - Rack-mounted heat exchangers
- Both options “pre-engineer” hot and cold isolation

## Example - Local In-Row Based Cooling



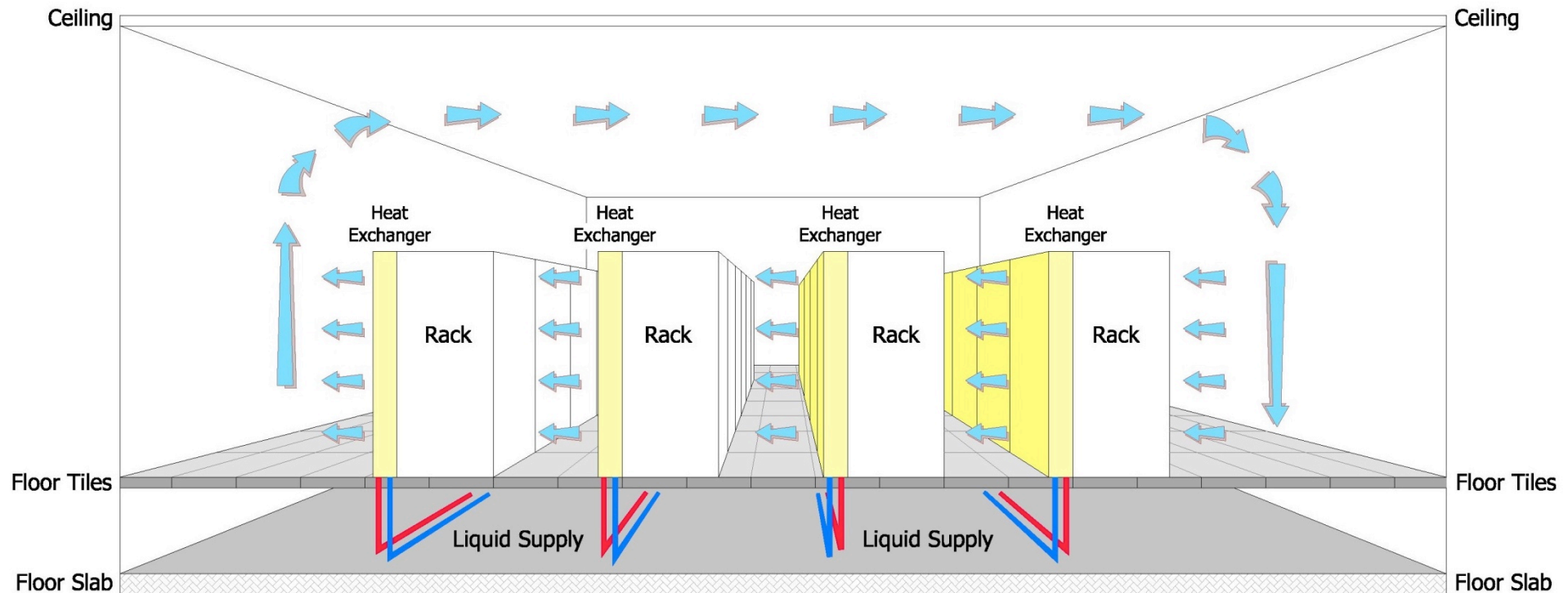
# In-Row Cooling System

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





# Rack-Mounted Heat Exchangers (“Rear Doors”)



Energy  
Exchange

Better Buildings<sup>®</sup>  
**SUMMIT**

# Air Management Review

## Air management techniques:

- Seal air leaks in floor (e.g., cable penetrations)
- Prevent recirculation with blanking panels in racks and between racks
- Manage floor tiles (e.g., no perforated tiles in hot aisle)
- Improve isolation of hot and cold air (e.g., return air plenum, curtains, or complete isolation)

## Impact of good isolation:

- Supply airflow reduced
  - Fan savings up to 75%+
- Supply air temperature can be raised
  - Chiller efficiency improves
  - Greater opportunity for economizer operation (“free” cooling)
- Cooling and raised-floor capacity increases.

# Questions





# Air Systems at NERSC: An Easier Climate has Different Challenges

Norm Bourassa  
August 22, 2018

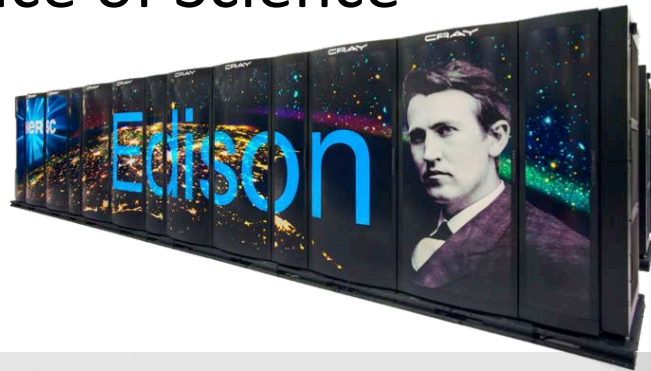
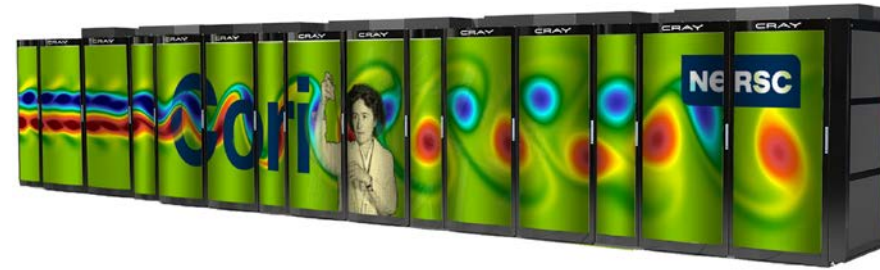
Energy Exchange | Better Buildings Summit 2018  
Data Center Air Management: The First Improvement





# What is NERSC?

- NERSC is the National Energy Research Scientific Computing Center
- Founded in 1974
- Focused on open science
- Located at Lawrence Berkeley National Laboratory
- Operated for the U.S. Department of Energy (DOE) Office of Science



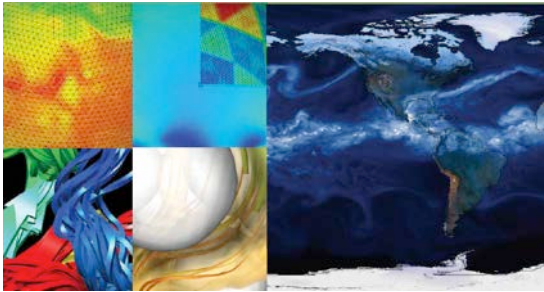
# NERSC Provides HPC and Data Resources for DOE Office of Science Research



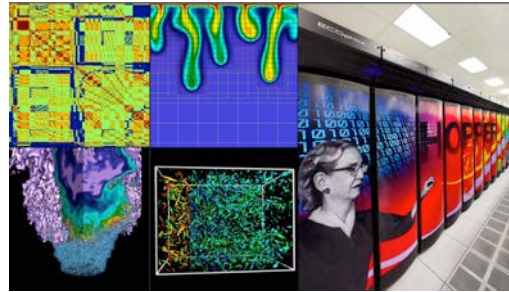
U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

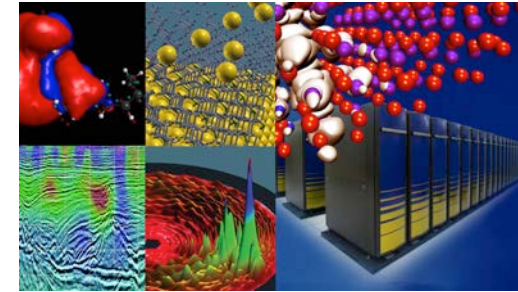
Largest funder of physical  
science research in U.S.



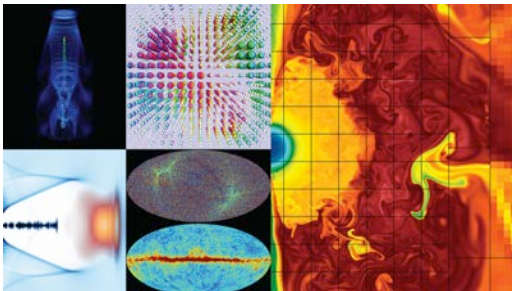
Biology, Environment



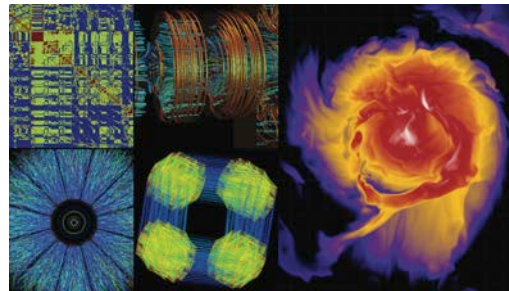
Computing



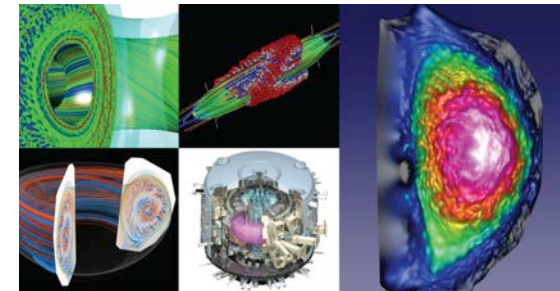
Materials, Chemistry,  
Geophysics



Particle Physics,  
Astrophysics



Nuclear Physics  
~7000 Users world wide



Fusion Energy,  
Plasma Physics

# Moved from Oakland Site in 2015



- 11 MW power (6+5MW)
- 19,000 ft<sup>2</sup>, 250 lbs/ft<sup>2</sup>
- Chilled Air + Water
- **PUE ~ 1.3**
- Extensive environmental and energy-usage monitoring
- ESnet @ 10Gb/s & 100Gb/s
- Control room staffed 24 × 365
- 6.5 miles from LBNL main campus



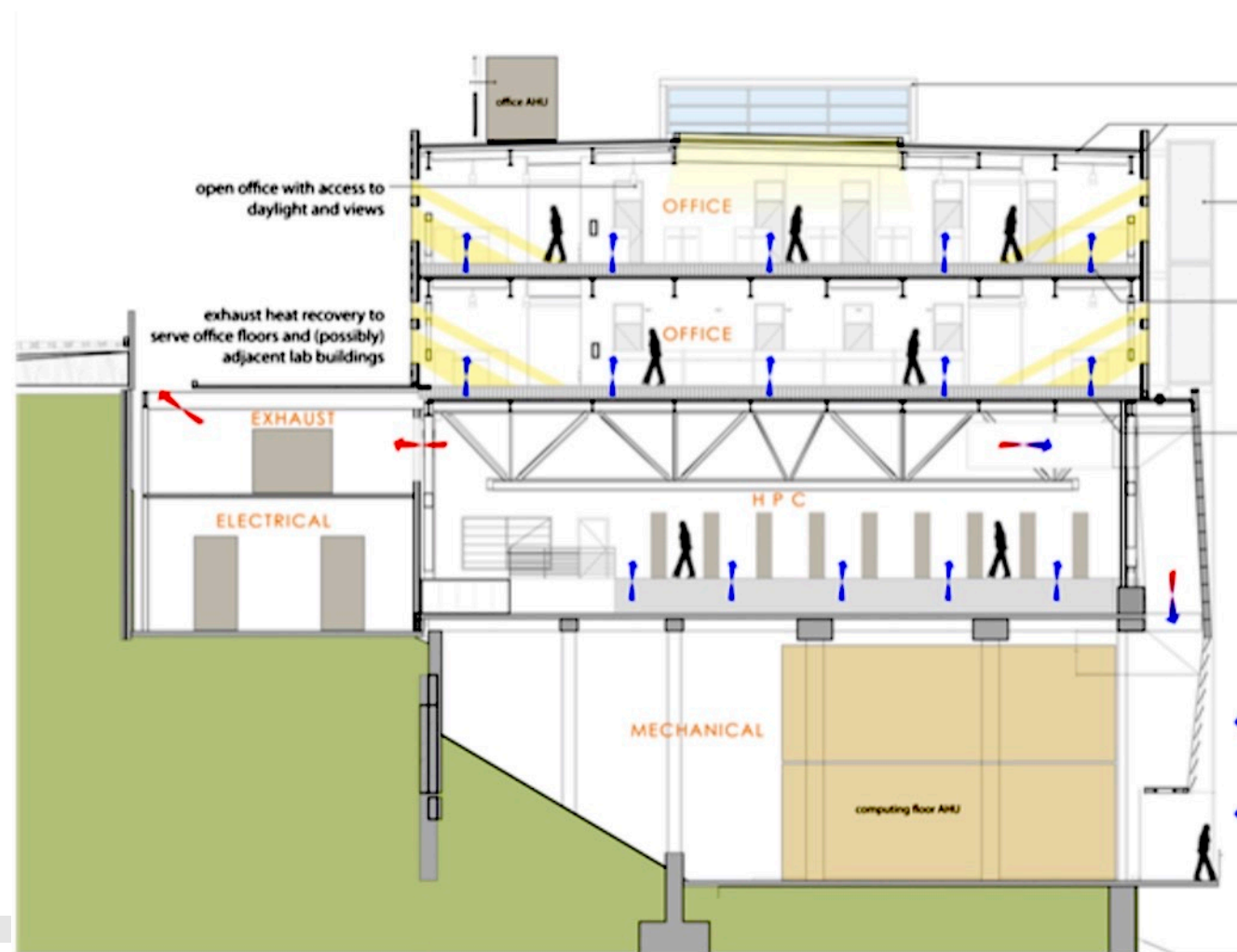
# Shyh Wang Hall (B59) completed June 2015

- Four story 150,000 GSF
  - Two 20ksf office floors, 300 offices
  - 20k -> 28ksf HPC floor
  - 12.5MW expandable to 20+MW
  - Current demand is ~7MW
- Energy Efficient
  - Year-round compressor free air and water cooling
  - LEED Gold
  - **PUE < 1.1**
- Extensively Instrumented
  - Substations, panels, PDUs, UPS
  - Cray Systems SEDC
  - One-wire Temp & RH sensors
  - BMS through ALC/BACNET
  - Indoor Particle counters
  - Weather station





# NERSC Building 59 - Cross Section

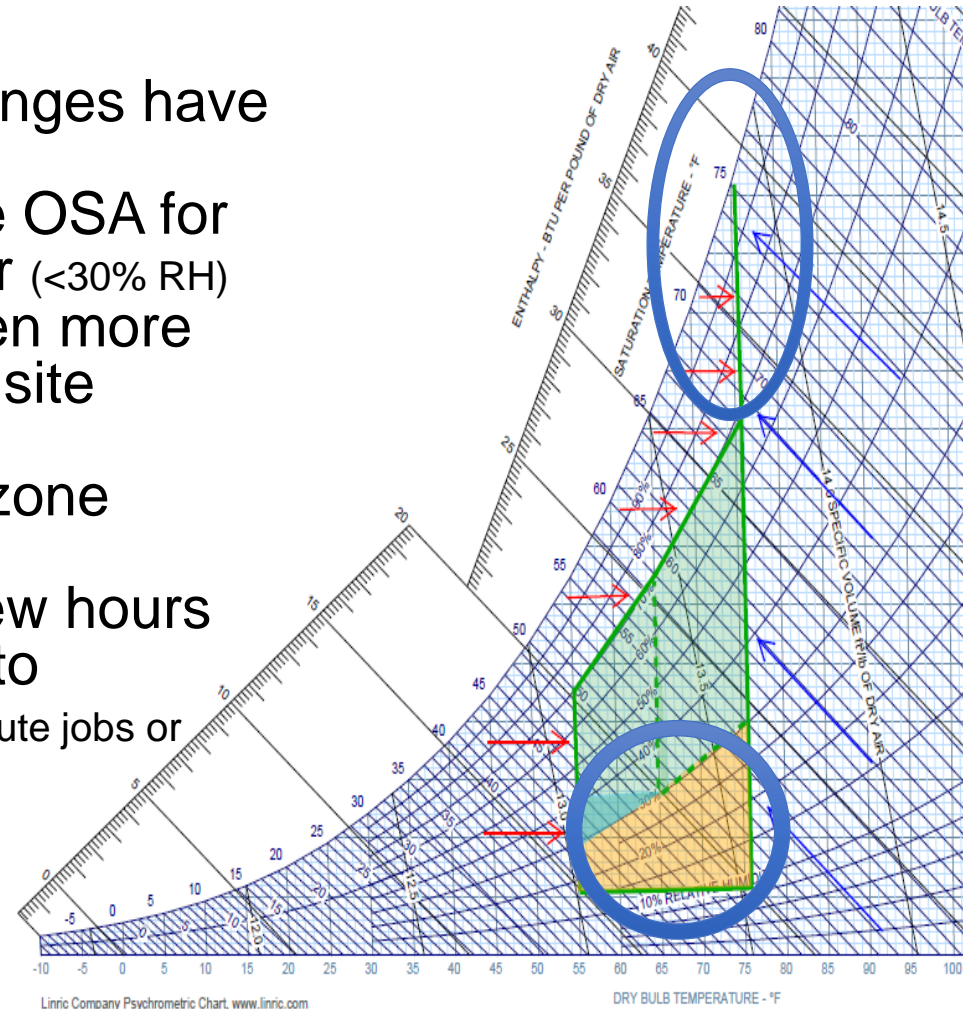


# Air Cooling

- Air handler units (AHUs)
  - Can use outside air (air economizer)
  - Optionally cooled with cooling tower water (Indirect Evap.)
  - Heated with HPC room return air for humidity & temperature control
  - Direct evaporative media cooling option
  - HPC room exhaust heat recovered for office space
- Specs
  - Supply <75°F air year round, <70°F for 85% of year
  - 30% to 70% RH, but can change quickly
  - (3+1) x Air handling units
    - 60k CFM each
    - Room to grow

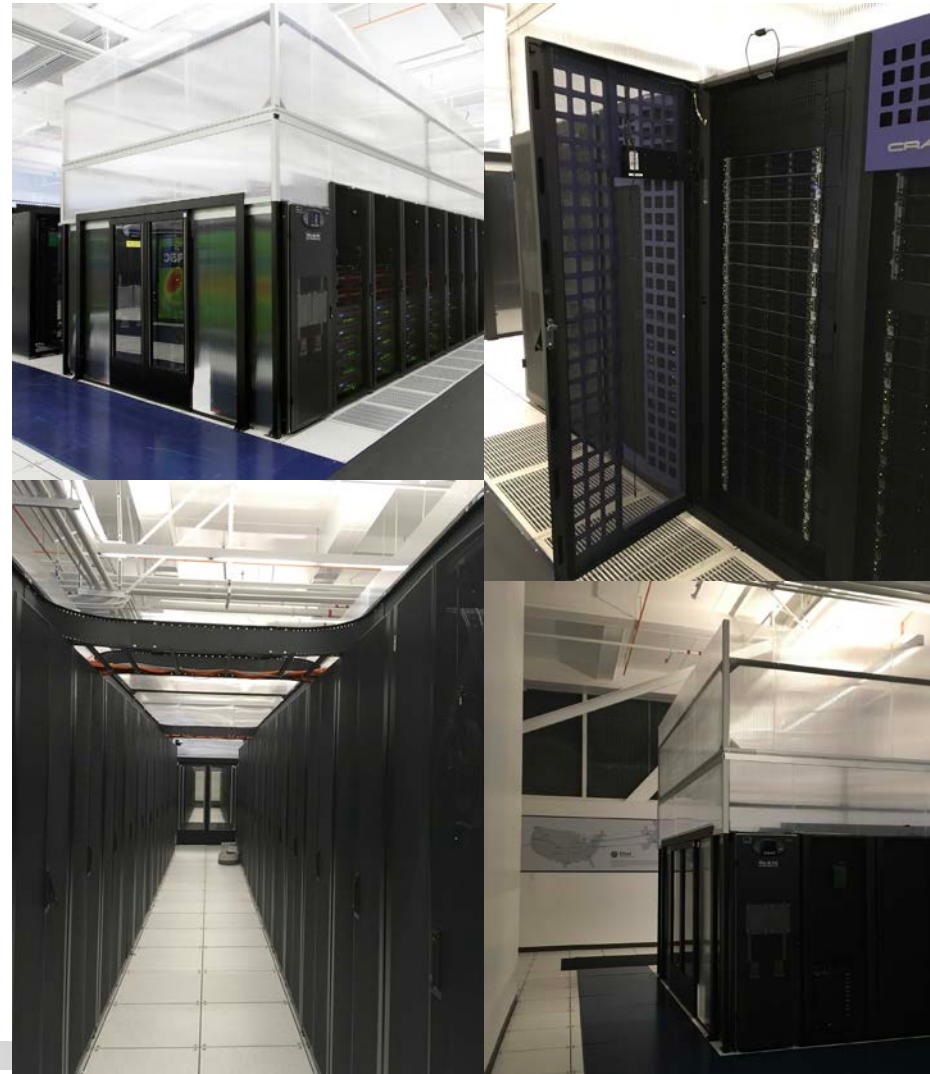
# Taking Full Advantage of Recommended Ranges

- Allowable supply air ranges have expanded (ASHRAE)
  - System able to use OSA for 100s more hours/yr (<30% RH)
  - Original design even more accommodating to site weather conditions
- High humidity danger zone (>75°F WB)
  - Fortunately, very few hours
  - If it is hit, we have to intervene (curtail compute jobs or shutdown HPC systems)



# Hot Aisle Containment – Or Hot Air “Bath Tub”

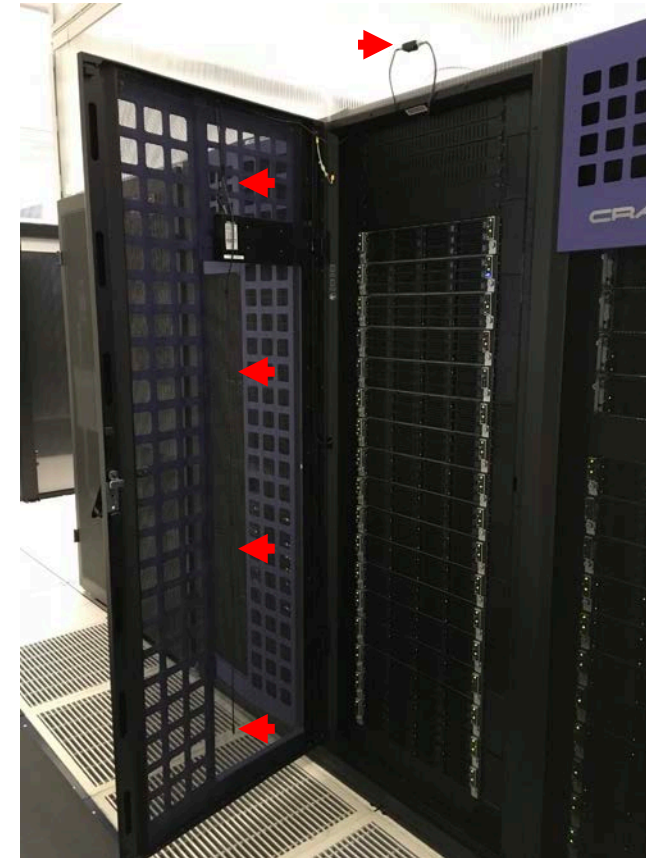
- Really is a “separation” or “chimney” system, not full containment
  - Installed in stages from 2016 -2018
  - Panelized system better accommodates equipment churn
- Helps drive hot air to ceiling
  - Exhaust fans pull hot air out of the building
  - Return fans to AHUs
- Panels located at rack front
  - Provides cabling facilitation above rack without penetrations
- Stayed away from drop ceiling
  - Seismic floor connection costs
  - Fire code complications
- Why Hot instead Cold Aisle?
  - Many visitor tours of compute room, so human comfort a factor



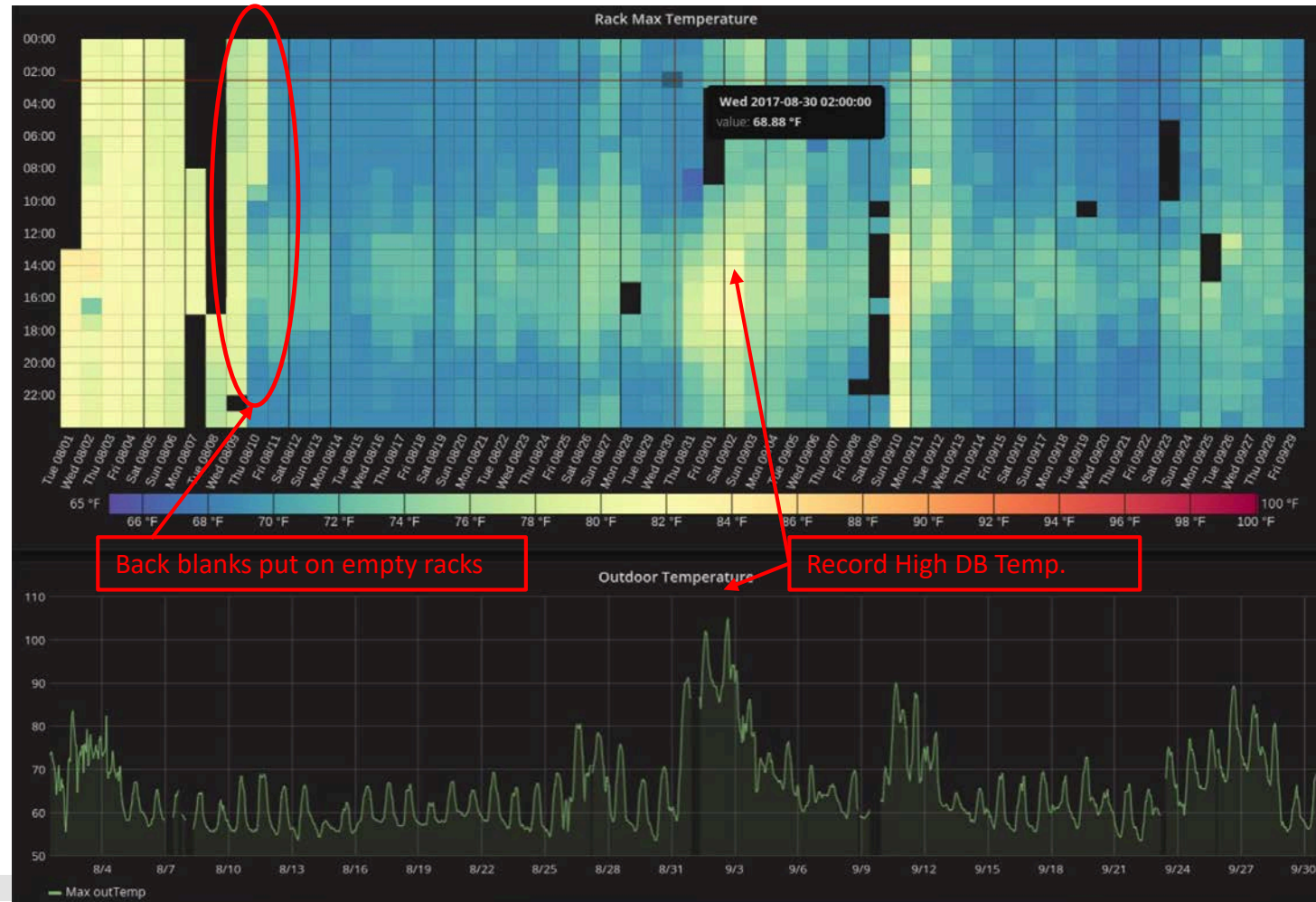


# Detailed Instrumentation of Air Temps

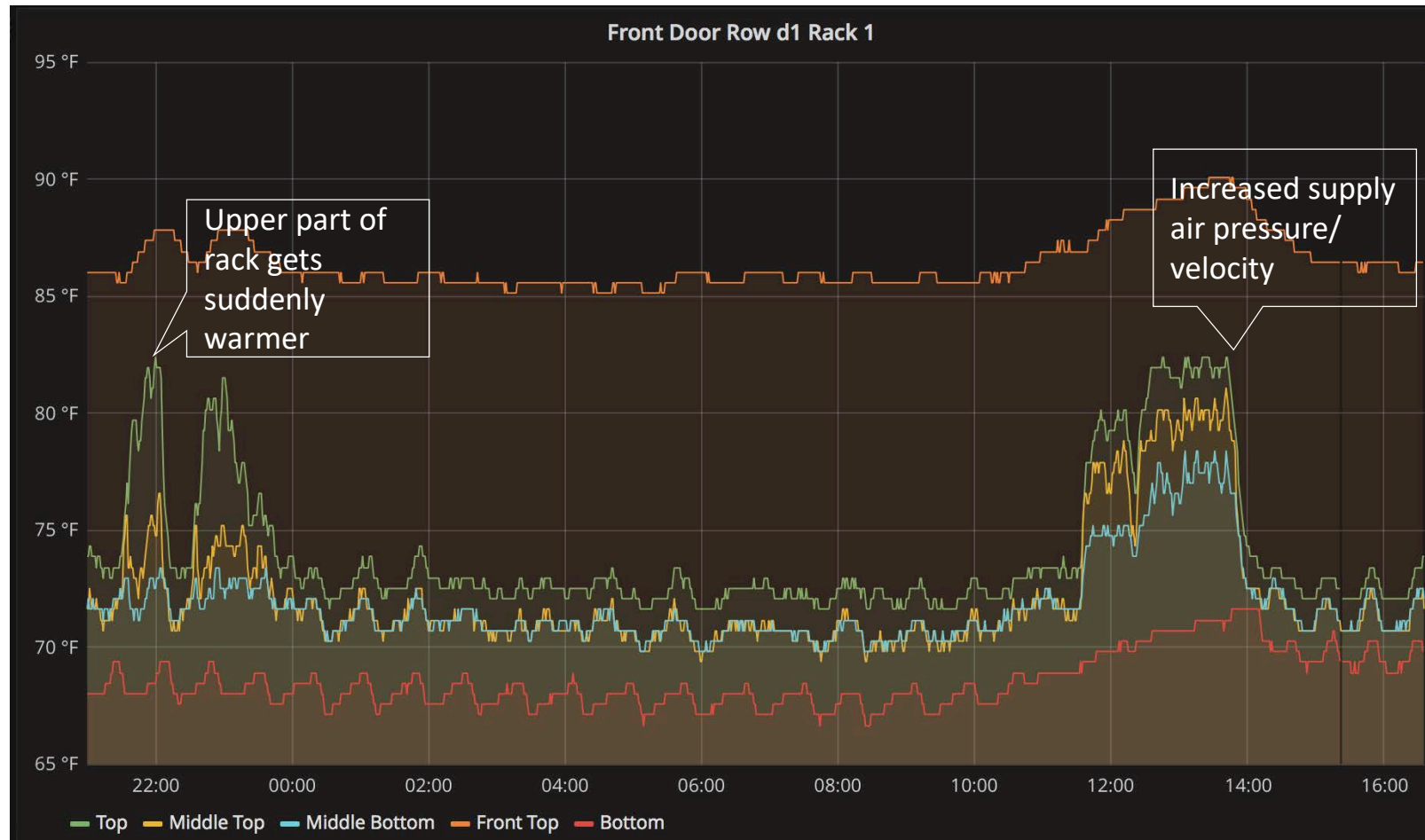
- Racks have extensive temperature sensing
  - 5 on front, 5 on back
  - Trends available for diagnostics
  - Monitors Bath Tub effect status



# Data Helped identify air sealing measures

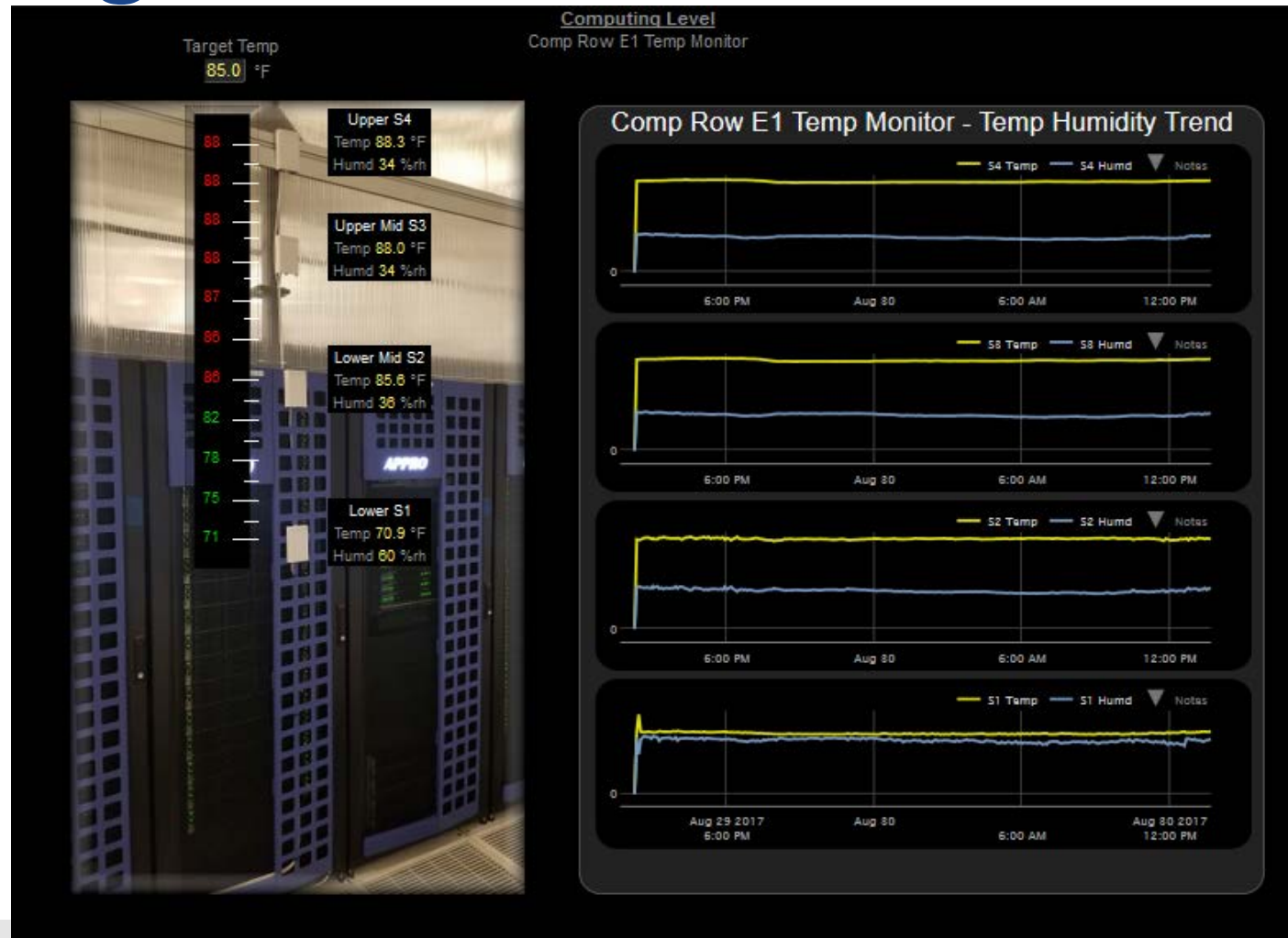


# Bath Tub Effect Breaks





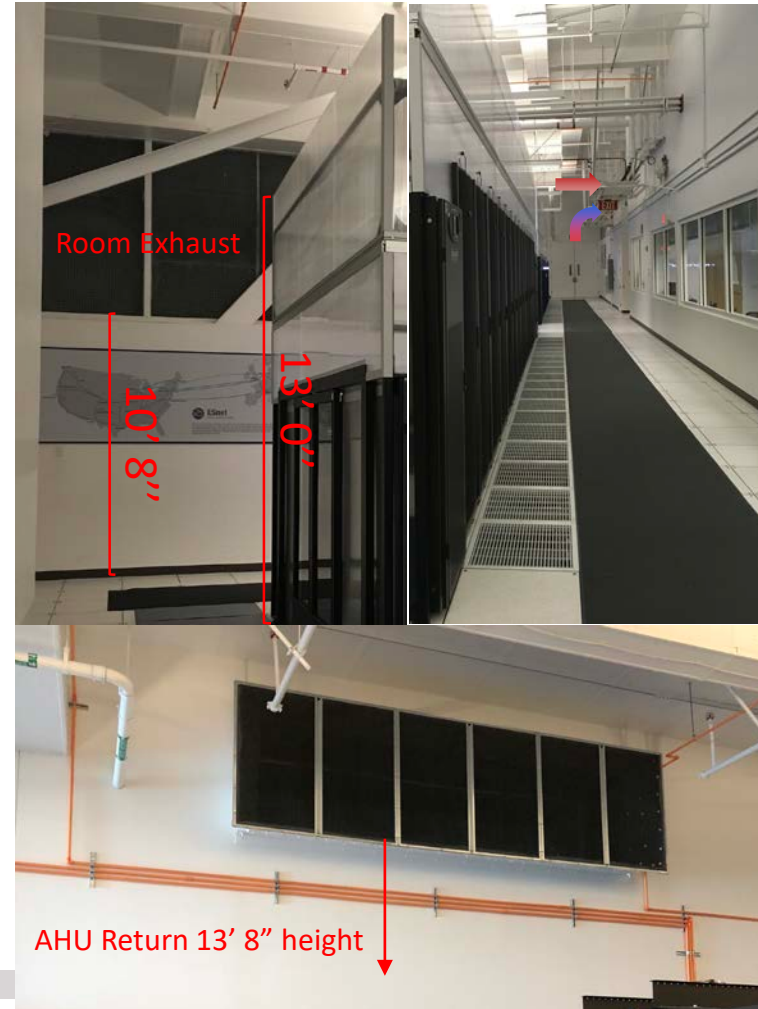
# Integrating Rack Sensors with BMS





# Still more Improvements needed

- Separation Panels help, but current Room Exhaust configuration is causing problems
  - In some areas, the exhaust is pulling cool supply air directly out
  - Should be similar to AHU Return configuration – fully above separation panel tops
  - Exhaust controls to a room positive air static of 0.03"
- Three “experiments” planned to look at this issue:
  - Block lower half of exhaust intake grille
  - Reduce exhaust fan speed
  - Reduce number of floor tile supplies or air discharge rates



# Lessons & Conclusions

- At move in, conventional HVAC expectation – Air systems handle HPC cooling load
  - However, most hours the air-side is one-pass – so more time spent cooling OSA, not computers
  - Main challenge is maintaining the quality of incoming air and HPC room air
- With compression free cooling, humidity control is tough
  - Can't de-humidify supply air, only manipulate RH
- Hot Aisle Separation panel system works, but
  - Potentially requires manual control adjustments during heat storms
  - Important to seal leakage gaps in separation panels and racks
  - Room exhaust configuration is an important factor
  - Containments are difficult to balance with IT equipment maintenance & reconfigurations
  - Possibly better to have a drop ceiling plenum but,
    - For our location, seismic isolation floor value engineered it out
    - Retrofit also not possible now due to fire code compliance costs
- Highly detailed air temp sensing provided beneficial information for operation improvements, but not without work overhead
  - BMS automation has proved to be difficult and expensive
  - Data analysis can be difficult – Good visualization tools a necessity
  - Keeping the system running requires considerable admin attention

# NERSC Optimization Project - Ongoing

- Saved ~2,150,000 kWh & 150,000 gal water over the last year
  - Estimated 0.045 PUE improvement
  - 1,800,000 kWh Non-IT savings
  - 750,000 kWh IT savings

	Measure Title	Energy Savings (kWh)		Water Savings
		Estimated	Verified	Gallons
1	Optimize Cooling Tower Fan and Pump Controls	-	310,000	(300,000)
2	Optimize Closed Loop Pump Control	-	1,050,000	110,000
3	Optimize AHU SAT and Flow Control	300,000	-	-
4	Reset Cooling Water Supply Temperature and Optimize CRAY Controls	400,000	400,000	220,000
5	Install Firmware to Enable ESS Mode for UPSs	-	350,000	120,000
6	Replace Bypass Valves	-	40,000	-
7	Cold Aisle Partial Containment	100,000	-	-
Total		800,000	2,150,000	150,000

**Still more savings on the table: ~600,000 kWh/year**

- supply air fan optimization
- Cray Dynamic Fan Speed Control
  - CW plant inter-tie
- Bypass valves for pumping
- HPC Water HX heat reclaim



# NERSC

**National Energy Research Scientific Computing Center**

Norm Bourassa, [njbourassa@lbl.gov](mailto:njbourassa@lbl.gov)



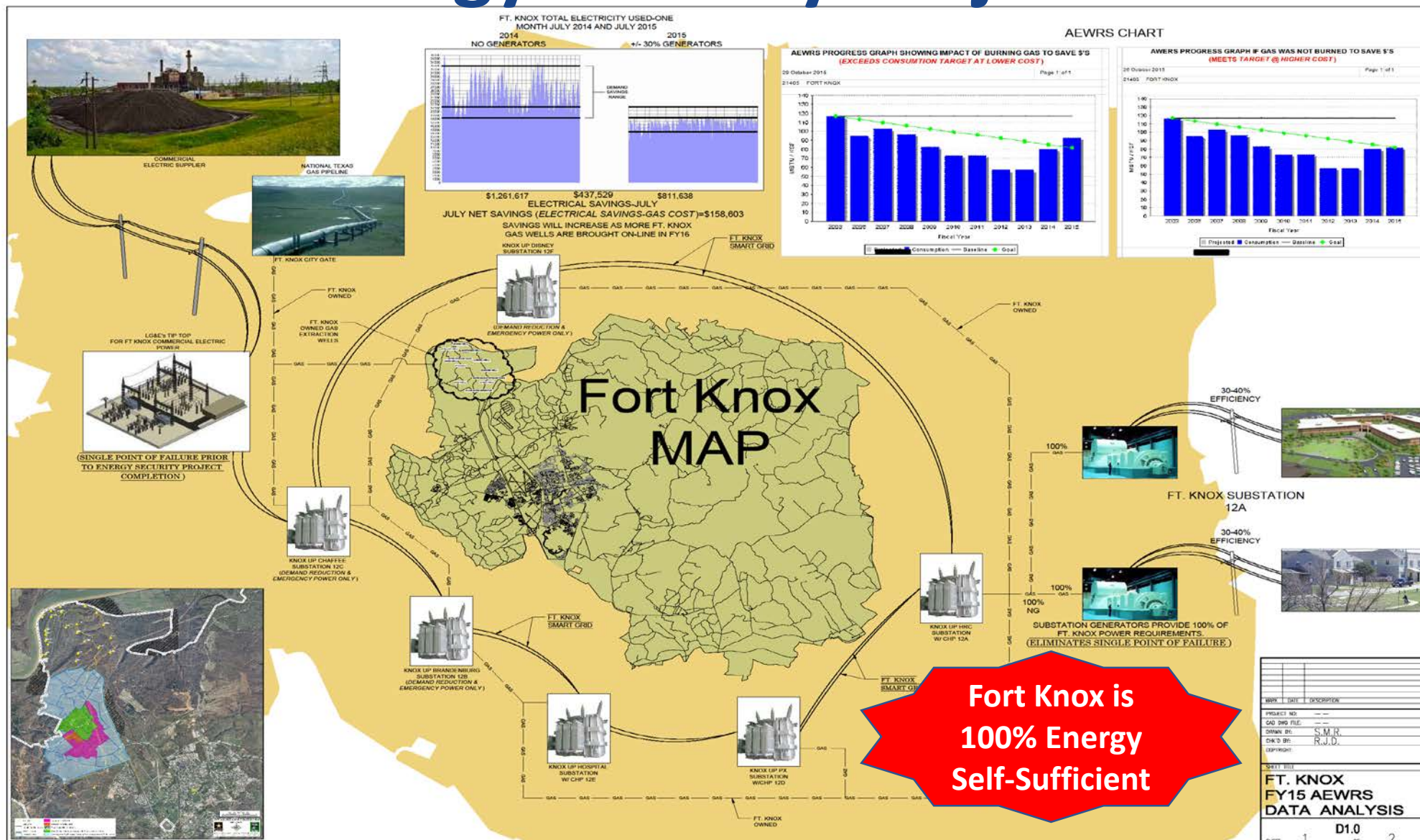
# Data Center Air Management: The First Improvement

U.S. Army Fort Knox  
Directorate of Public Works Energy Management  
Office and Human Resources Command  
Terry Dewitt and Robert Dyrdek

# Fort Knox Energy Program Drivers

- SUBJECT: Army Directive 2017-07 (Installation Energy and Water Security Policy)
  - This directive says the Army will reduce risk to critical missions by being capable of providing necessary energy and water for a minimum of 14 days.
  - Establishes requirements for providing secure and reliable access to energy and water resources to sustain critical capabilities
- SUBJECT: Army Directive 2016-38 (Migration of Army Systems and Applications to Approved Hosting Environments and Consolidation of Data Centers)
  - This directive says the Army will consolidate between 1500 – 2000 existing data centers down to 4, one of which is at Fort Knox, KY (Human Resources Command)

# Fort Knox Energy Security Project Efforts





# Combined Heat & Power (CHP)



- Minimum 8MW capacity sized to address thermal loads
- Lean burn lowest emission reciprocating engine technology
- Reduces the Commercial Utility peak/base demand by 8MW
- Over 90% efficiency strategy for power generation
- Multiple configurations of heating, cooling, and domestic hot water (boilers, absorption chillers, or whatever is needed)
- 600 Ton Absorption Chiller at Human Resources Command (HRC)
- Potential for future “bolt-on” renewables such as biofuels, fuel cells or what ever comes next.





# HRC Complex Geothermal Pond

- The Geo Pond supplies cold water to Human Resources Command (HRC) Complex.
- Savings > \$10K/month in HVAC costs by providing chilled water via geo-source vs. air-to-air cooling tower.



# HRC Data Center - Attributes

*Worldwide IT Support for the DoD Human Resources Mission*

- 18K sq ft facility
- Hosts 188 HR applications and systems supporting Dept. of Defense and Army personnel
- Hosts 2700+ servers (~70% virtual)
- 60% Capacity, Room To Grow (300+ Racks In Use; Capacity For 500+ Racks)
- Exceeds Energy Efficiency Mandates from OMB Memo M-16-19, Data Center Optimization Initiative
- ~25% Power Capacity (2,725 kW Available)
- ~30% Cooling Capacity (1140 T Available)

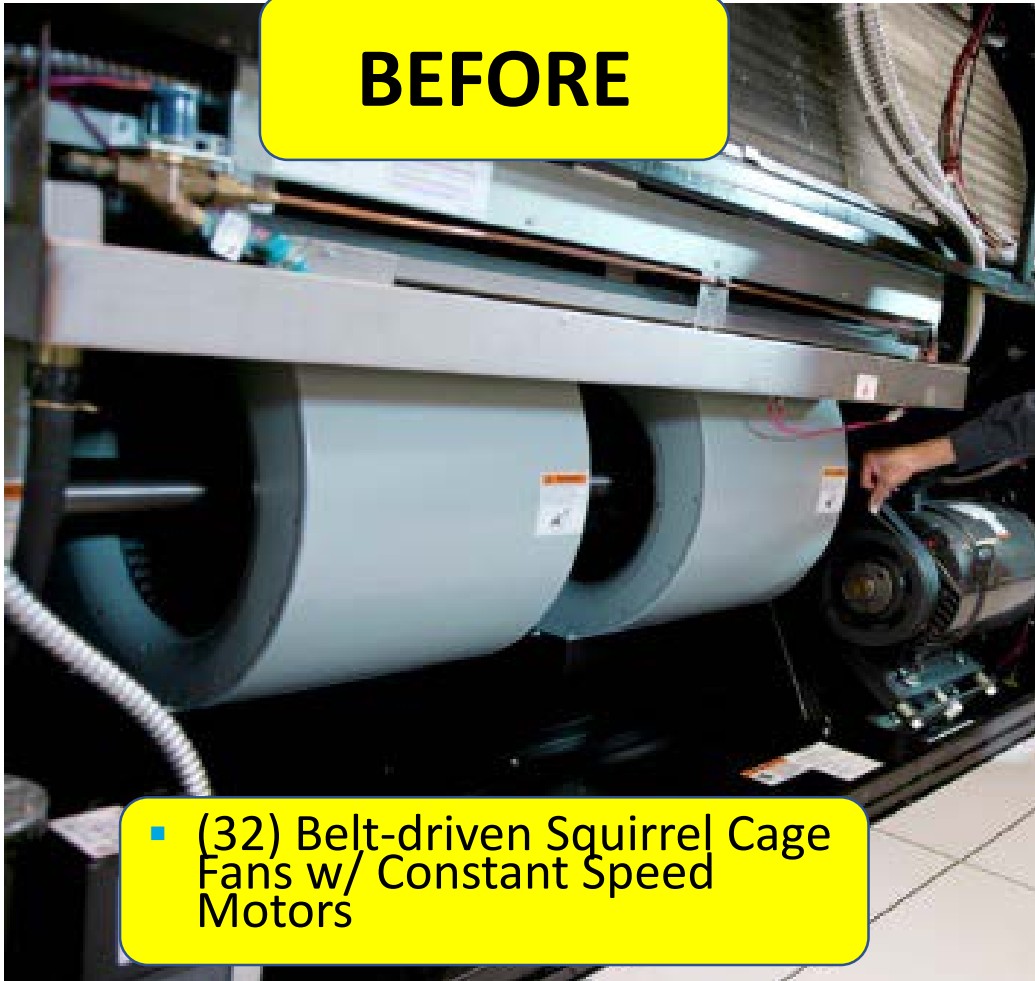
## HRC DATA CENTER





# Air Management Enabler – Variable Speed Fans

**BEFORE**



- (32) Belt-driven Squirrel Cage Fans w/ Constant Speed Motors

**AFTER**



- (21) Air Handler Units Converted to Plug Fans w/ Electrically Commutated (EC) Variable Speed Motors
- (11) Air Handler Units Converted to Variable Frequency Drive with original fans

# Fan Retrofit Map & Performance Observations



T = Return Temp, degrees

Fan Speed, %

H = Humidity, %RH

Computer Room Air  
Handlers (CRAH)

- At 60% fan speed, 81% reduction in power for fans
- At 79% fan speed, 75% reduction in power for fans
- At 100% fan speed, 35% reduction in power for fans

Compared to  
original drive/fan  
configuration



# Data Center Air Management Impacts

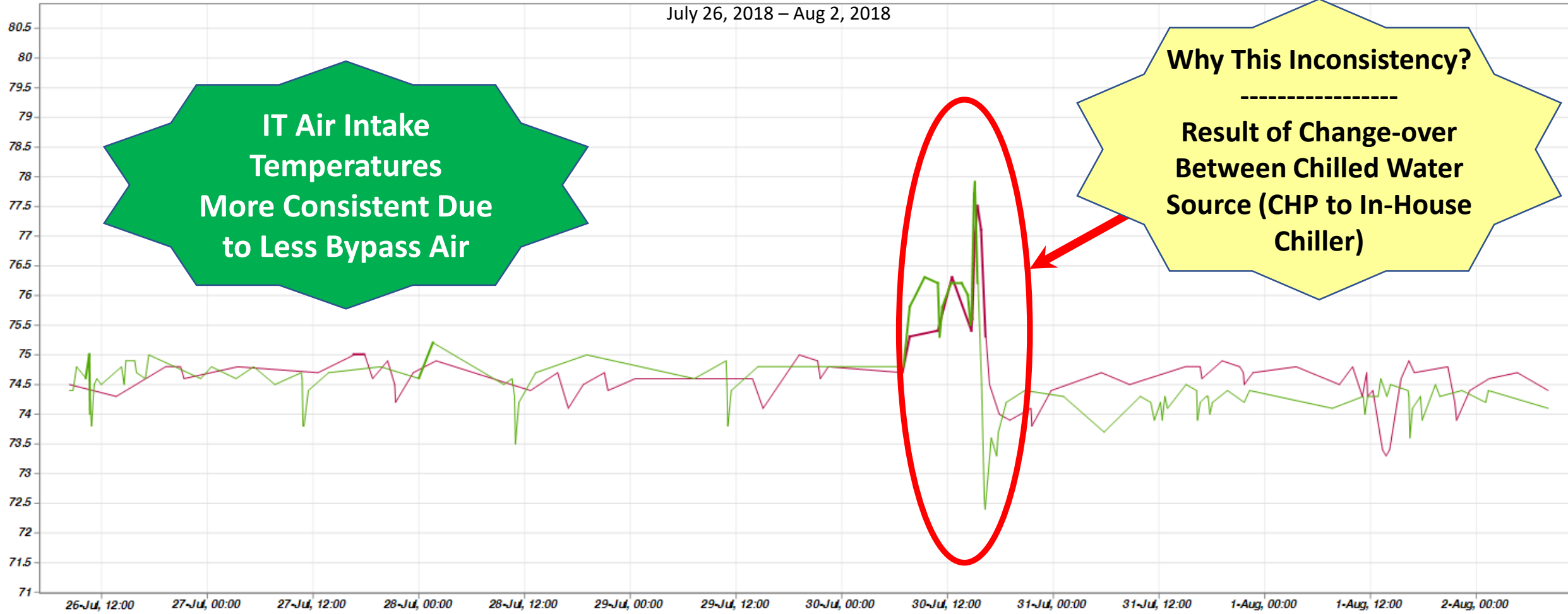
## Temperature Profile

July 26, 2018 – Aug 2, 2018

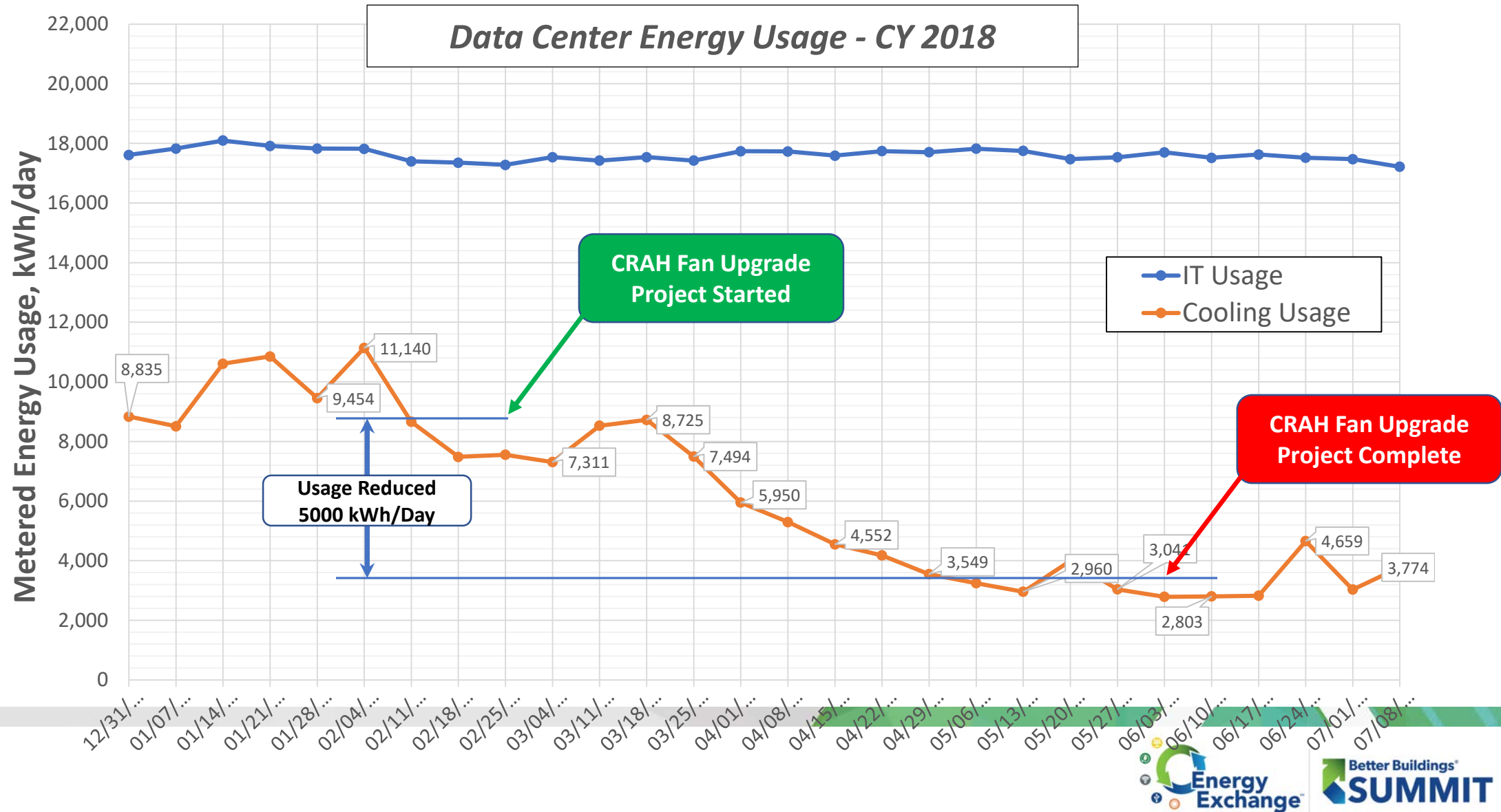
**IT Air Intake  
Temperatures  
More Consistent Due  
to Less Bypass Air**

**Why This Inconsistency?**

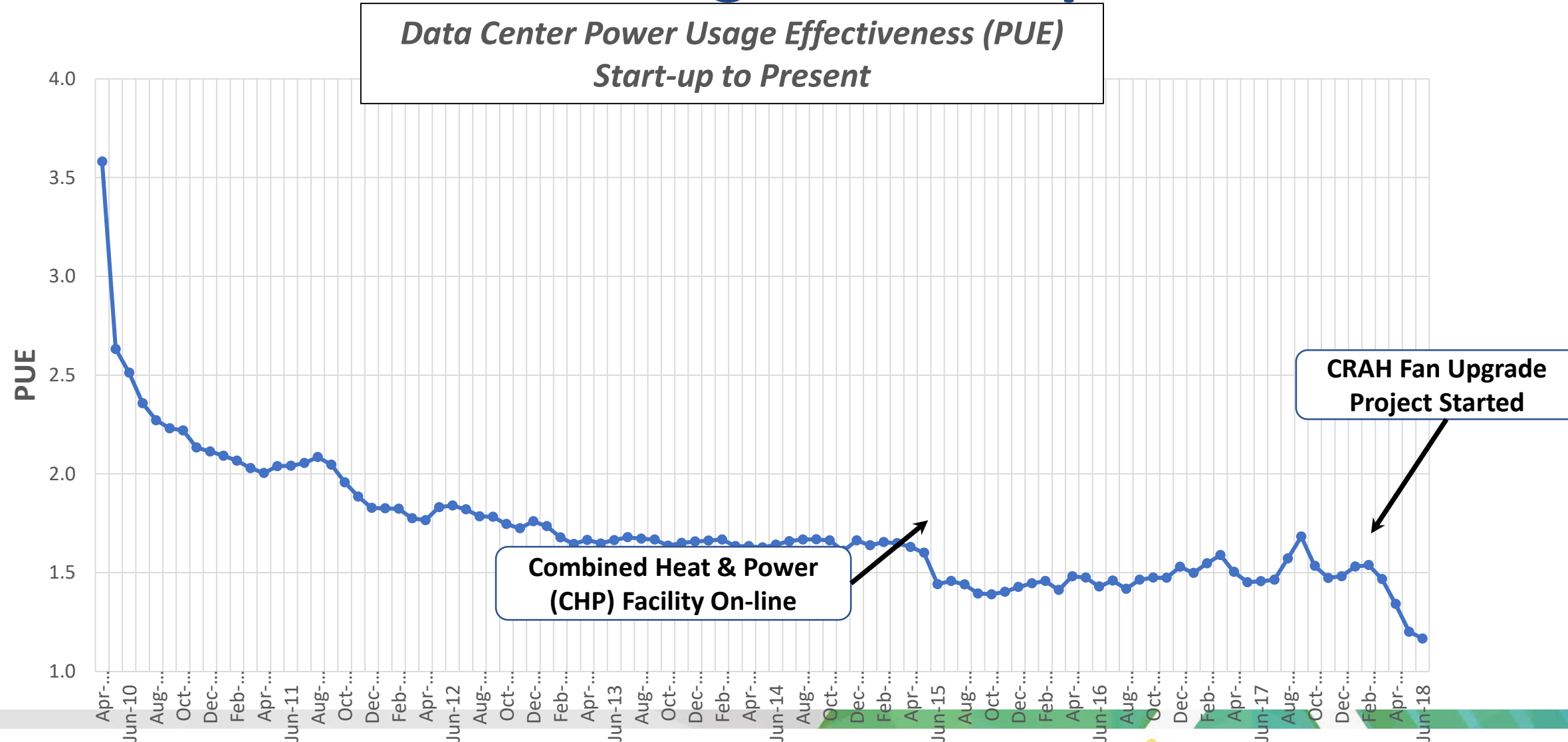
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**Result of Change-over  
Between Chilled Water  
Source (CHP to In-House  
Chiller)**



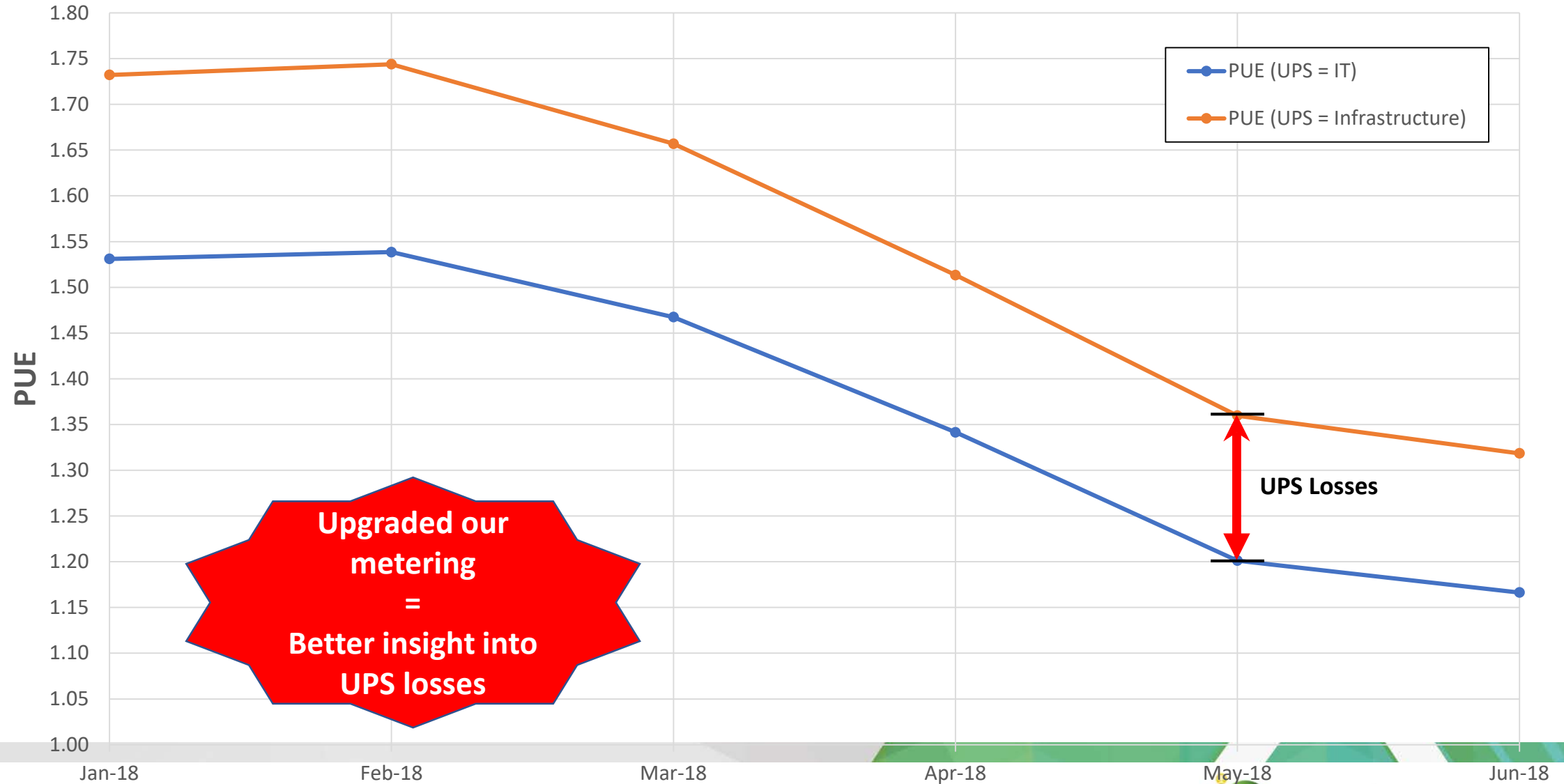
# Data Center Air Management Impacts



# Data Center Air Management Impacts



# Impacts of Uninterruptible Power Supplies (UPS)





# Data Center Best Practices Summary

1. Measure and Benchmark Energy Use
2. Identify IT Opportunities, and modify procurement processes to align with the procurement policy
3. Improve Air Management
4. Optimize Environmental Conditions
5. Evaluate Cooling Options
6. Improve Electrical Efficiency
7. Use IT to Control IT
8. Keep Abreast of Evolving Technologies (all areas)

# Data Center Best Practices Summary

## 9. Most importantly:

Get IT and Facilities people talking  
and working together as a team!!!

- Ensure they know what each other is doing
- Consider impact of each on the other, including energy costs