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

Wastes fan energy as well as cooling energy and capacity

Recirculation

Increases inlet temperature to servers

Leakage
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
Managing Blanking Panels

- Any opening will degrade the separation of hot and cold air
- Maintain blanking panels
  - One 12” blanking panel reduced temperature ~20°F
Reduce Airflow Restrictions & Congestion

Consider the Impact that Congestion Has on the Airflow Patterns

Congested Floor & Ceiling Cavities

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
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

Results: Tune Floor Tiles
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

- Return Air: 95–105°F vs. 60–70°F (35–41°C vs. 16–21°C)
- Interstitial Ceiling Space: Open Ceiling Tile
- Air Barrier: (Plastic Sheet)
- CRAH
- Supply Air: 70–80°F vs. 45–55°F (21–27°C vs. 7–13°C)
- Hot Aisle
- Cold Aisle
- Hot Aisle
- Raised Floor
- Air Barrier: (Melamine Board)
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
LBNL Air Management Demonstration
Better airflow management permits warmer supply temperatures!

Better airflow management permits warmer supply temperatures!
Hot and Cold Aisle Containment

Subzero Cold Aisle Containment

APC Hot Aisle Containment
(with in-row cooling)

Ceilume Heat Shrink Tiles
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
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.

Efficient Alternatives to Under-Floor Air Distribution
Example - Local In-Row Based Cooling
With hot aisle containment, the general data center space is neutral (75°F–80°F).
Rack-Mounted Heat Exchangers ("Rear Doors")
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

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 ft², 250 lbs/ft²
- 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

Back blanks put on empty racks

Record High DB Temp.
Bath Tub Effect Breaks

Upper part of rack gets suddenly warmer

Increased supply air pressure/velocity
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

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

<table>
<thead>
<tr>
<th>Measure Title</th>
<th>Energy Savings (kWh)</th>
<th>Water Savings</th>
<th>Gallons</th>
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<tbody>
<tr>
<td>1 Optimize Cooling Tower Fan and Pump Controls</td>
<td>-</td>
<td>310,000</td>
<td>(300,000)</td>
</tr>
<tr>
<td>2 Optimize Closed Loop Pump Control</td>
<td>-</td>
<td>1,050,000</td>
<td>110,000</td>
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<tr>
<td>3 Optimize AHU SAT and Flow Control</td>
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<td>-</td>
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<tr>
<td>4 Reset Cooling Water Supply Temperature</td>
<td>400,000</td>
<td>400,000</td>
<td>220,000</td>
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<tr>
<td>5 and Optimize CRAY Controls</td>
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<tr>
<td>5 Install Firmware to Enable ESS Mode for UPs</td>
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<td>6 Replace Bypass Valves</td>
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<tr>
<td>7 Cold Aisle Partial Containment</td>
<td>100,000</td>
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<td>-</td>
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</tbody>
</table>

Total: 800,000 kWh, 2,150,000 gal water, 150,000 gal water
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

  - 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 is 100% Energy Self-Sufficient
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 whatever 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)
Air Management Enabler – Variable Speed Fans

- (32) Belt-driven Squirrel Cage Fans w/ Constant Speed Motors
- (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
- 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
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 Energy Usage - CY 2018

CRAH Fan Upgrade Project Started

Usage Reduced 5000 kWh/Day

CRAH Fan Upgrade Project Complete

Usage Reduced 5000 kWh/Day
Data Center Air Management Impacts

Data Center Power Usage Effectiveness (PUE) Start-up to Present

CRAH Fan Upgrade Project Started

Combined Heat & Power (CHP) Facility On-line
Impacts of Uninterruptible Power Supplies (UPS)

Upgraded our metering
= Better insight into UPS losses
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)
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