ASHRAE Winter Meeting

Demonstrations to Illustrate Energy Efficiency Opportunities in Data Centers

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Data center demonstrations

- “Air management” demonstration
- Air economizer demonstration
- DC powering demonstrations
- Use of infrared thermography
Data center performance varies

The relative percentages of energy powering IT equipment varies considerably.
Benchmarks of ratios of electricity delivered to IT equipment

IT Power to Total Data Center Power

Average .57

Higher is better
Benchmark results helped to find best practices

The ratio of IT equipment power to the total is an indicator of relative overall efficiency.

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

Best practices and new strategies are being demonstrated to stimulate the market to improve energy performance.
# Best practice topics - identified through benchmarking

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“Air Management” demonstration

Air distribution in data centers is often an energy efficiency and reliability improvement opportunity
Goal:
Demonstrate better cooling and measure energy savings through improvements in air distribution in a high density environment.

“Air Management” demonstration
Demonstration description

- An area containing two high-intensity rows and three computer room air conditioning units was physically isolated from rest of the center – approximately 175W/sf in this area
- The as-found conditions were monitored
  - Temperatures
  - Fan energy
  - IT equipment energy
Demonstration description, con’t

- Two configurations were demonstrated
- Air temperatures monitored at key points
- IT equipment and computer room air conditioner fans energy were measured
- Chilled water temperature was monitored
- Chilled water flow was not able to be measured
First configuration – completely isolate cold and hot
Second isolation scheme
Demonstration procedure

- Once test area was isolated, air conditioner fan speed was reduced using existing variable speed drives
- Temperatures at the servers were monitored
- IT equipment and fan energy were monitored
- Chilled water temperatures were monitored
- Hot aisle return air temperatures were monitored – ΔT was determined
Measured fan energy savings - 75%

Since there was no mixing of cold supply air with hot return air - fan speed could be reduced
Temperature guidelines - at the inlet to IT equipment

ASHRAE TEMPERATURE GUIDELINES

- Allowable range
- Recommended range
Temperatures were more uniform
The temperature in the entire center could have been raised

Axes:
- Y-axis: Temperature (deg F)
- X-axis: Time

Baseline: 
- Low
- Med
- High

Alternate 1: 
- Setup
- Alternate 2

ASHRAE Recommended Range

Ranges during demonstration
## Best practices - Free cooling with air economizers

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Encouraging use of air economizers

**Issue:**
- Data center operators are reluctant to use air economizers
- Concerns over contamination and humidity control

**Goal:**
- Encourage use of outside air economizers where climate is appropriate

**Strategy:**
- Address concerns: measure contamination level and monitor humidity levels
- Quantify energy savings benefits
Limited literature on failure mechanisms - only documented pollutant problem:

- Over time, deposited particles can bridge isolated conductors
- High relative humidity (greater than 80%) causes particles to absorb moisture
- Particles dissociate, become electrically conductive
- Can cause current leakage
Particle measurements

- Measurements taken at eight data centers
  - Some centers using economizers and some not using economizers
  - Inside and outside measurements taken
- Approximately week long measurements
- Before and after capability at three centers
- Continuous monitoring equipment in place at one center (data collection over several months)
In many locations there are many hours of free cooling.
Some reference concentrations

Fine Particulate Matter

Particle Conc. ($\mu$g/m$^3$)

- One manufacturer’s standard
- EPA 24-Hour Health Standard
- EPA Annual Health Standard and ASHRAE Standard
Outdoor measurements

Outdoor Measurements
Fine Particulate Matter

Particle Conc. (μg/m³)

One manufacturer’s Standard
Annual Health Standard and ASHRAE Standard

LBNL
NERSC
Center 3
Center 4
Center 5
Center 6
Center 7
Center 8
Indoor Measurements
Fine Particulate Matter

Measurements inside the centers

One Manufacturer's Standard

24-Hour Health Standard

Annual Health Standard and ASHRAE Standard
Indoor measurements

Particle Conc. (μg/m³)

Note scale
Data center w/ economizer

Center 8
w/economizer
0.3-5 Particulate Matter

Note scale
Humidity measurements

Indoor Relative Humidity

ASHRAE Allowable Upper Limit
ASHRAE Recommended Upper Limit
ASHRAE Recommended Lower Limit
ASHRAE Allowable Lower Limit
Conclusions

- Water soluble salts in combination with high humidity can cause current leakage
- ASHRAE particle limits are drastically lower than one manufacturer’s standard
- Particle concentration inside centers is typically an order of magnitude lower than ASHRAE limits
- Using economizers, particle concentration were within ASHRAE limits
- Filters used today are typically 40% (MERV 8)
- Humidity control within ASHRAE ranges is attainable
Next steps

- Analyze material captured on filters
- Collaborate with TC 9.9 on contamination book
- Research failure mechanisms and collect failure data from IT equipment manufacturers
- Evaluate and demonstrate improved filtration options – for those still concerned
- Research electrostatic discharge and lower limits of humidity
# Best practices - Electrical distribution options

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Goals:
- Show that a high voltage DC (direct current) system could be assembled with commercially available components and identify any gaps in implementation.
- Measure actual energy savings – a proof of concept demonstration.
- Identify next steps to encourage implementation.
Typical data center power conversions

AC — DC

Battery/Charger Rectifier

Inverter

Bypass

AC/DC Multi output Power Supply

Uninterruptible Power Supply (UPS)

Server

Power Distribution Unit (PDU)

DC — AC

PWM/PFC Switcher Unregulated DC to Multi Output Regulated DC Voltages

Voltage Regulator Modules

5V

12V

3.3V

Unregulated DC

To Multi Output Regulated DC Voltages

Internal Drive

External Drive

I/O

Memory Controller

μ Processor

SDRAM

Graphics Controller

Typical data center power conversions
Prior research illustrated large losses in power conversion.

**Power Supplies in IT equipment**

![Diagram showing efficiency of different types of UPS](chart.png)

- **Flywheel UPS**
- **Double-Conversion UPS**
- **Delta-Conversion UPS**

Efficiency is measured as a % of Nameplate Power Output, with an average of all servers showing a trend.

**Uninterruptible Power Supplies (UPS)**

Factory Measurements of UPS Efficiency (tested using linear loads)

- Efficiency vs. Percent of Rated Active Power Load
- Average of All Servers
Measured UPS efficiency

UPS Efficiency

Efficiency (%) vs. Load Factor (%) graph showing various data points colored and shaped differently, with a note indicating 'Redundant Operation' near the graph.
Measured Power Supply Efficiency

Measured Server Power Supply Efficiencies (all form factors)

- PFC Power Supplies
- Non-PFC Power Supplies

80 Plus
UPS factory measurements

Factory Measurements of UPS Efficiency
(tested using linear loads)

Percent of Rated Active Power Load

Flywheel UPS
Double-Conversion UPS
Delta-Conversion UPS

Typical Operation
Included in the demonstration

- Side-by-side comparison of traditional AC system with new DC system
  - Facility level distribution
  - Rack level distribution
- Power measurements at conversion points
- Servers modified to accept 380 V. DC
- Artificial loads to more fully simulate data center
Typical AC distribution today

480 VAC Bulk Power Supply

480 Volt AC

AC/DC → DC/AC

UPS

480 Volt AC

AC/DC → DC/DC

PSU

12 V

VRM

12 V

VRM

5 V

VRM

3.3 V

VRM

1.2 V

VRM

1.8 V

VRM

0.8 V

Server

Loads using Legacy Voltages

Loads using Silicon Voltages
Facility-level DC distribution

480 Volt AC

AC/DC
DC UPS or Rectifier

380V.DC

Rotary UPS

DC/DC
PSU

VRM

12 V

12 V

5 V

3.3 V

1.2 V

1.8 V

0.8 V

Server

Loads using Legacy Voltages

Loads using Silicon Voltages
Rack-level DC distribution

480 Volt AC

AC/DC — DC/AC — UPS

AC/DC — PDU — 380 VDC

DC/DC — PSU — Rack

VRM: 12 V, 5 V, 3.3 V, 1.2 V, 1.8 V, 0.8 V

loads using Legacy Voltages

loads using Silicon Voltages
AC system loss compared to DC

7-7.3% measured improvement

2-5% measured improvement
Comparison to a typical data center would show greater savings

- Redundant UPS and server power supplies operate at reduced efficiency
- Cooling loads would be reduced so depending upon cooling efficiency, savings translates into facility level savings
- Both UPS systems used in the AC base case were “best in class” systems and performed better than benchmarked systems – efficiency gains compared to typical systems could be higher
- Further optimization of conversion devices/voltages is possible
Visualizing air flow
Visualizing Air Flow

- Computational Fluid Dynamics (CFD) modeling
- Temperature sensor networks
- Infrared thermography
Infrared thermography

visualization and troubleshooting
Thank You.

Questions???