Agenda

- Brief overview of LBNL data center energy efficiency research activities
- Data center resources
- Demonstration Projects
- Discussion
### LBNL resources involved with Data Center energy efficiency

- Bill Tschudi
- Dale Sartor
- Steve Greenberg
- Tim Xu
- Evan Mills
- Bruce Nordman
- Jon Koomey
- Ashok Gadgil
- Paul Mathew
- Arman Shehabi

### Subcontractors
- Ecos Consulting
- EPRI Solutions
- EYP Mission Critical Facilities
- Rumsey Engineers
- Syska & Hennesy
LBNL sponsors

- California Energy Commission – PIER program
- Pacific Gas and Electric Company
- New York State Energy and Development Agency (NYSERDA)
- US - Environmental Protection Agency
- US – Department of Energy
A “research roadmap” was developed for the California Energy Commission. This outlined key areas for energy efficiency research, development, and demonstration and includes strategies that can be implemented in the short term.
Data Center research activities

- Benchmarking and 23 data center case studies
- Self-benchmarking protocol
- Power supply efficiency study
- UPS systems efficiency study
- Standby generation losses
- Performance metrics – Computation/watt
- Market study
- EPA report to Congress
LBNL Data Center demonstration projects

- Outside air economizer demonstration (PG&E)
  - Contamination concerns
  - Humidity control concerns
- DC powering demonstrations (CEC-PIER)
  - Facility level
  - Rack level
- “Air management” demonstration (PG&E)
Case studies/benchmarks

- Banks/financial institutions
- Web hosting
- Internet service provider
- Scientific Computing
- Recovery center
- Tax processing
- Storage and router manufacturers
- Computer animation
- others
IT equipment load density

IT Equipment Load Intensity

Watts/sq. ft.

2003 Benchmarks
Ave. ~ 25

2005 Benchmarks
Ave. ~ 52
Benchmarking energy end use

Electricity Flows in Data Centers

local distribution lines

to the building, 480 V

HVAC system

lights, office space, etc.

UPS

PDU

computer racks

computer equipment

UPS = Uninterruptible Power Supply
PDU = Power Distribution Unit;
Overall power use in Data Centers

Courtesy of Michael Patterson, Intel Corporation
Data Center performance differences

Variation in Data Center Energy End Uses

- Other
- Lighting
- UPS Losses
- Total HVAC
- DC Equipment
- Servers

Facility Number

% of total energy use

AVERAGE 1 2 3 4.1 4.5 5 6.1 6.2 7 8 8.2 9
Performance varies

The relative percentages of the energy actually doing computing varied considerably.
Percentage of power delivered to IT equipment

*All values are shown as a fraction of the respective data center total power consumption.*

**Average 0.49**
HVAC system effectiveness

We observed a wide variation in HVAC performance.
Benchmark results were studied 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 topics identified through benchmarking

<table>
<thead>
<tr>
<th><strong>HVAC</strong></th>
<th><strong>Facility Electrical Systems</strong></th>
<th><strong>IT Equipment</strong></th>
<th><strong>Cross-cutting / misc. issues</strong></th>
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</thead>
<tbody>
<tr>
<td>Air delivery</td>
<td>Cooling plant optimization</td>
<td>UPS systems</td>
<td>Power Supply efficiency</td>
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<tr>
<td>Air management</td>
<td>Free cooling</td>
<td>Self generation</td>
<td>Sleep/standby loads</td>
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<tr>
<td>Air economizers</td>
<td>Variable speed pumping</td>
<td>AC-DC Distribution</td>
<td>IT equip fans</td>
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<td>Humidification controls alternatives</td>
<td>Variable speed Chillers</td>
<td>Standby generation</td>
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<td>Centralized air handlers</td>
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<td>Direct liquid cooling</td>
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<td>Low pressure drop air distribution</td>
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<tr>
<td>Fan efficiency</td>
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<td>Heat recovery</td>
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<td>Redundancies</td>
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<td></td>
<td></td>
<td></td>
<td>Method of charging for space and power</td>
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<tr>
<td></td>
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<td></td>
<td>Building envelope</td>
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</tbody>
</table>
Design guidelines were developed in collaboration with PG&E

Guides available through PG&E’s Energy Design Resources Website
Design guidance is summarized in a web based training resource

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

- Computer benchmark programs assess relative computing performance. Measuring energy use while running benchmark programs will yield Computations/Watt (similar to mpg)
- Energy Star interest
- First such protocol was issued for trial use
Encouraging outside air economizers

- **Issue:**
  - Many are reluctant to use economizers
  - Outdoor pollutants and humidity control considered equipment risk

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

- **Strategy:**
  - Address concerns: contamination/humidity control
  - Quantify energy savings benefits
Project objectives

- Identify potential failure mechanisms
- Measure contamination levels in data centers
- Observe humidity control
- Evaluate economizer effect on contamination levels
- Compare particle concentrations to guidelines
- Document economizers use in data centers
Data center contamination guidelines

- Limited literature connecting pollutants to equipment failure

- ASHRAE Technical Committee
  - “Design Considerations for Data/Com Equipment Centers”
  - Guidelines for particles, gases, humidity
  - Industry Sources: Telcordia GR-63-CORE/IEC 60721-3-3
  - Designed for telephone switching centers
  - Based on research over 20 years old

- Primary concern: current leakage caused by particle bridging

<table>
<thead>
<tr>
<th>Contaminants</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne Particles (TSP)</td>
<td>20 µg/m³</td>
</tr>
<tr>
<td>Coarse Particles</td>
<td>&lt;10 µg/m³</td>
</tr>
<tr>
<td>Fine Particles</td>
<td>15 µg/m³</td>
</tr>
<tr>
<td>Water Soluble Salts</td>
<td>10 µg/m³ max-total</td>
</tr>
<tr>
<td>Sulfate</td>
<td>10 µg/m³</td>
</tr>
<tr>
<td>Nitrites</td>
<td>5 µg/m³</td>
</tr>
<tr>
<td>Total</td>
<td>55 µg/m³</td>
</tr>
</tbody>
</table>
Particle bridging

Only documented pollutant problem

- Over time, deposited particles bridge isolated conductors
- Increased relative humidity causes particles to absorb moisture
- Particles dissociate, become electrically conductive
- Causes current leakage
- Can damage equipment
Particle measurements

- Measurements taken at eight data centers
- Approximately week long measurements
- Before and after capability at three centers
- Continuous monitoring equipment in place at one center (data collection over several months)
Some reference concentrations

Fine Particulate Matter

- IBM Standard
- EPA 24-Hour Health Standard
- EPA Annual Health Standard and ASHRAE Standard
Outdoor measurements

Outdoor Measurements
Fine Particulate Matter

IBM Standard

EPA Annual Health Standard and ASHRAE Standard

Note scale
Indoor measurements

Indoor Measurements
Fine Particulate Matter

IBM Standard

EPA 24-Hour Health Standard

EPA Annual Health Standard and ASHRAE Standard

Note scale
Indoor measurements

Indoor Measurements
Fine Particulate Matter

Particle Conc. (µg/m³)

Note scale
Data center w/economizer

Center 8
w/economizer
0.3-5 Particulate Matter

EPA 24-Hour Health Standard
EPA Annual Health Standard and ASHRAE Standard

Note scale
**Improved Filtration**

Center 8 at Server Rack

<table>
<thead>
<tr>
<th>Particle Diameter (µm)</th>
<th>Particle Conc. (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3-05</td>
<td>0.60</td>
</tr>
<tr>
<td>0.5-0.7</td>
<td>0.80</td>
</tr>
<tr>
<td>0.7-1.0</td>
<td>1.20</td>
</tr>
<tr>
<td>1.0-2.0</td>
<td>0.80</td>
</tr>
<tr>
<td>2.0-5.0</td>
<td>1.20</td>
</tr>
<tr>
<td>&gt;5.0</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Filter Efficiency
- ASHRAE 40%
- ASHRAE 85%
Humidity measurements without economizer
Humidity measurements with economizer

Indoor Relative Humidity w/economizer

ASHRAE Allowable Upper Limit
ASHRAE Recommended Upper Limit
ASHRAE Recommended Lower Limit
ASHRAE Allowable Lower Limit
Findings

- Water soluble salts in combination with high humidity can cause failures
- It is assumed that very low humidity can allow potentially damaging static electricity
- ASHRAE particle limits are drastically lower than manufacturer standard
- Particle concentration in closed centers is typically an order of magnitude lower than ASHRAE limits
- Economizers, without other mitigation, can allow particle concentration to approach ASHRAE limits
- Filters used today are typically 40% (MERV 8) efficiency
Next steps for encouraging air economizers

- Analyze material captured on filters
- Collaborate with ASHRAE data center technical committee
- Determine failure mechanisms
- Research electrostatic discharge
- Evaluate improved filtration options
DC powering data centers

Goal:
Show that a DC (direct current) system could be assembled with commercially available components. Measure actual energy savings – a proof of concept demonstration.
Data Center power conversions

Uninterruptible Power Supply (UPS)

Power Distribution Unit (PDU)

Battery/Charger Rectifier

Inverter

Bypass

AC/DC Multi output Power Supply

PWM/PFC Switcher

Unregulated DC to Multi Output Regulated DC Voltages

Voltage Regulator Modules

5V

12V

3.3V

12V

3.3V

1.5/2.5 V

1.1V-1.85V

3.3V

3.3V

12V

DC/DC

1.1V-1.85V

Internal Drive

External Drive

I/O

Memory Controller

μ Processor

SDRAM

Graphics Controller

Server

Power Distribution Unit (PDU)
Prior research illustrated large losses in power conversion

Power Supplies in IT equipment

Factory Measurements of UPS Efficiency
(tested using linear loads)

Uninterruptible Power Supplies (UPS)
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
Additional items included

- 48V. DC racks to illustrate that other DC solutions are available, however no energy monitoring was provided for this configuration.

- DC lighting
Typical AC distribution today

480 Volt AC

AC/DC → DC/AC

UPS

PDU

AC/DC → DC/DC

PSU

VRM (12 V)

Server

12 V

VRM (5 V)

VRM (3.3 V)

VRM (1.2 V)

VRM (1.8 V)

VRM (0.8 V)

Loads using Legacy Voltages

Loads using Silicon Voltages
Facility-level DC distribution

480 Volt AC

AC/DC
DC UPS or Rectifier

380V.DC

DC/DC

VRM
VRM
VRM
VRM
VRM
VRM

12 V

12 V

PSU

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 → PDU

AC/DC

DC/DC

VRM

12 V

Loads using Legacy Voltages

5 V

3.3 V

1.2 V

1.8 V

0.8 V

Server

380 VDC

PSU

Rack

Bulk Power Supply

UPS

PDU

VRM

12 V

Loads using Silicon Voltages
AC system loss compared to DC

7-7.3% measured improvement

2-5% measured improvement
Implications could be even better for a typical data center

- Redundant UPS and server power supplies operate at reduced efficiency
- Cooling loads would be reduced.
- 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
Industry Partners in the Demonstration

Equipment and Services Contributors:

Alindeska Electrical Contractors
APC
Baldwin Technologies
Cisco Systems
Cupertino Electric
Dranetz-BMI
Emerson Network Power
Industrial Network Manufacturing (IEM)

Intel
Nextek Power Systems
Pentadyne
Rosendin Electric
SatCon Power Systems
Square D/Schneider Electric
Sun Microsystems
UNIVERSAL Electric Corp.
Other firms collaborated

Stakeholders:

380voltsdc.com
CCG Facility Integration
Cingular Wireless
Dupont Fabros
EDG2, Inc.
EYP Mission Critical
Gannett
Hewlett Packard

Morrison Hershfield Corporation
NTT Facilities
RTKL
SBC Global
TDI Power
Verizon Wireless
Picture of demonstration set-up – see video for more detail
DC power – next steps

- DC power pilot installation(s)
- Standardize distribution voltage
- Standardize DC connector and power strips
- Server manufacturers develop power supply specification
- Power supply manufacturers develop prototype
- UL and communications certification
- Opportunity for world wide DC standard
“Air Management” demonstration

Goal:
Demonstrate better cooling and energy savings through improvements in air distribution in a high density environment.
Demonstration description

- The as-found conditions were monitored
  - Temperatures
  - Fan energy
  - IT equipment energy

- 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
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 - cold aisle isolation
Second configuration – hot aisle isolation
Demonstration procedure

- Once test area was isolated, air conditioner fan speed was reduced using existing VFD’s.
- 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 – $\Delta T$ was determined.
Fan energy savings – 75%

Since there was no mixing of cold supply air with hot return air - fan speed could be reduced.
Temperature variation improved
Better temperature control would allow raising the temperature in the entire data center.

ASHRAE Recommended Range

Ranges during demonstration
website:
http://hightech.lbl.gov/datacenters/
Discussion/Questions??

William Tschudi
wftschudi@lbl.gov
Supplemental slides follow
Monitoring procedure

Approach:

- Measure data center fine particle exposure
- Determine indoor proportion of outdoor particles
- MetOne optical particle counters
- Size resolution
  - 0.3 µm, 0.5 µm, 0.7 µm, 1.0 µm, 2.0 µm, 5.0 µm
- Assume 1.5 g/cm³ density
- Measure at strategic locations