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Subcontractors
- Ecos Consulting
- EPRI Solutions
- EYP Mission Critical Facilities
- Rumsey Engineers
- Syska & Hennesy
A “research roadmap” was developed for the California Energy Commission and outlined key areas for energy efficiency research, development, and demonstration.
Data Center research activities

- Benchmarking and 22 data center case studies
- Self-benchmarking protocol
- Power supply efficiency study
- UPS systems efficiency study
- Standby generation losses
- Performance metrics – Computation/watt
- Market analysis
LBNL Data Center demonstrations

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

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

IT Equipment Load Intensity

2003 Benchmarks Ave. ~ 25

2005 Benchmarks Ave. ~ 52
Electricity Flows in Data Centers

- Local distribution lines
- HVAC system
- UPS = Uninterruptible Power Supply
- PDU = Power Distribution Unit
- UPS PDU computer racks
- Backup diesel generators
- Lights, office space, etc.
- 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

<table>
<thead>
<tr>
<th>Facility Number</th>
<th>Server Percentage</th>
<th>UPS Losses Percentage</th>
<th>DC Equipment Percentage</th>
<th>HVAC Percentage</th>
<th>Lighting Percentage</th>
<th>Other Percentage</th>
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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
We observed a wide variation in HVAC performance.
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 topics identified through benchmarking

<table>
<thead>
<tr>
<th>HVAC - Air Delivery</th>
<th>Facility Electrical Systems</th>
<th>IT Equipment</th>
<th>Cross-cutting / misc. issues</th>
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<tbody>
<tr>
<td>Air management</td>
<td>Cooling plant optimization</td>
<td>Power Supply efficiency</td>
<td>Motor efficiency</td>
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<td>Air economizers</td>
<td>Free cooling</td>
<td>Sleep/ standby loads</td>
<td>Right sizing</td>
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<td>Humidification controls alternatives</td>
<td>Variable speed pumping</td>
<td>AC-DC Distribution</td>
<td>IT equip fans</td>
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<td>Centralized air handlers</td>
<td>Variable speed Chillers</td>
<td>Standby generation</td>
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<td>Direct liquid cooling</td>
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<td>Maintenance</td>
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<td>Low pressure drop air distribution</td>
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<td>Commissioning/ continuous benchmarking</td>
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<td>Fan efficiency</td>
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<td>Redundancies</td>
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<td>Method of charging for space and power</td>
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<td>Building envelope</td>
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</tbody>
</table>
Design guidelines for 10 “Best Practices” were developed in collaboration with PG&E

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

A web-based training resource is available

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

- Couple existing computing benchmark programs with energy use
- Computations/Watt (similar to mpg)
- Energy Star interest
- Jon Koomey led effort to establish first protocol
Encourage improved “Air Management”

Goal:
Obtain better cooling and energy savings through improvements in air distribution.
Concepts

- Better isolation of hot and cold aisles will improve temperature control and allow air system optimization.
- Airflow (fan energy) can be reduced if air is delivered without mixing.
- Air system and chilled water systems operate more efficiently at higher temperature differences.
- Temperatures in entire center can be raised if mixing is eliminated. It may be possible to cool with tower water rather than use of chillers.
Isolation scheme - cold aisle isolation
Isolation scheme - hot aisle isolation
Fan energy savings - 75%

If there is no mixing of cold supply air with hot return air - fan speed can be reduced
Temperature control can be improved
Better temperature control allows raising the temperature in the entire data center.

![Graph showing temperature control and ASHRAE recommended ranges.]

- **Baseline**
- **Alternate 1**
- **Alternate 2**

**Setup**

Ranges with aisles isolated.
Incentives for outside air economizers

Issue:
- Many data centers are reluctant to use economizers
- Concerns are outdoor pollutants and humidity control

Incentive strategy:
- Encourage use of outside air economizers where climate is appropriate
- Address concerns: contamination/humidity control
- Quantify energy savings benefits
Overcoming barriers

- Identify potential failure mechanisms
- Address contamination in data centers
- Address humidity control
- Illustrate that contamination is within guidelines or easily controlled
- Case studies of economizers in data centers
Particle bridging

Only documented pollutant problem

- Deposited particles bridge isolated conductors
- Increased RH cause particles to absorb moisture
- Particles dissociate, become electrically conductive
- Causes current leakage
- Can damage equipment
LBNL measurements

Features of study:

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

- Water soluble salts in combination with high humidity can cause failures
- Static electricity can occur with very low humidity
- New ASHRAE particle limits drastically lower than manufacturer standard
- Particle concentration typically (no economizer) an order of magnitude lower than new ASHRAE limits
- Economizers, without other mitigation, cause particle concentration to reach new ASHRAE limits
- Current filters are only Class II 40% efficiency
DC powering data centers

Goal:
Show that a DC system could be assembled with commercially available components and measure actual energy savings – a proof of concept demonstration.
Data Center power conversions

AC voltage conversions

Battery/Charger Rectifier

Inverter

Bypass

AC/DC Multi output PS

PWM/PFC Switcher

Unregulated DC to Multi Output Regulated DC Voltages

5V
12V
3.3V
12V
3.3V
12V
3.3V
1.1V-1.85V

Voltage Regulator Modules

Internal Drive
External Drive
I/O
Memory Controller
μ Processor
SDRAM
Graphics Controller
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)
UPS draft labeling standard

- Based upon proposed European Standard
- Possible use in incentive programs
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

- Racks distributing 48 volts 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 \rightarrow DC/AC \rightarrow UPS \rightarrow PDU \rightarrow AC/DC \rightarrow DC/DC

PSU

Server

12 V

VRM

VRM

VRM

VRM

VRM

VRM

VRM

VRM

VRM

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
Facility-level DC distribution

480 Volt AC

- **AC/DC**
  - DC UPS or Rectifier

**380V.DC**

- **DC/DC**
  - PSU

**Output Voltages**

- 12 V
- 5 V
- 3.3 V
- 1.2 V
- 1.8 V
- 0.8 V

**Load Types**

- **VRM**
  - Loads using Legacy Voltages
  - Loads using Silicon Voltages

- **Server**
Rack-level DC distribution

480 Volt AC

AC/DC → DC/AC

UPS

PDU

AC/DC

380 VDC

DC/DC

VRM

VRM

VRM

VRM

VRM

负荷使用旧电压

负荷使用硅电压
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:

<table>
<thead>
<tr>
<th>Alindeska Electrical Contractors</th>
<th>Intel</th>
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<tbody>
<tr>
<td>APC</td>
<td>Nextek Power Systems</td>
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<tr>
<td>Baldwin Technologies</td>
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<td>Square D/Schneider Electric</td>
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<td>Emerson Network Power</td>
<td>Sun Microsystems</td>
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<tr>
<td>Industrial Network Manufacturing (IEM)</td>
<td>UNIVERSAL Electric Corp.</td>
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</table>
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
website:
http://hightech.lbl.gov/datacenters/
Discussion/ Questions??