Overview of Liquid Cooling Systems
AGENDA

8:15  Introductions - Group Identify Problems/Interest
8:45  Overview and Design Issues in Data Centers
9:30  HVAC Air System Issues
10:00 Break
10:15 Liquid Cooling
10:40 Electrical Distribution Issues
11:10 IT Issues
11:30 SCE Programs
12:00 Wrap-up
Outline

• What is liquid cooling?
• Energy Benefits
• What is water side economizer
• Combined benefits
Why Liquid Cooling?

Heat Capacity of this much air = Heat Capacity of this much water
Fans move energy less efficiently

3/4 HP FAN

1000 CFM

20" DUCT

1/10 HP PUMP

2 GPM

1" TUBING
Liquid Cooling

- Closer coupling between cooling source and server
Liquid Cooled Racks

• Racks with integral coils
Server cabinet technology with outstanding benefits

... up to 35kW cooling capacity

Blade server optimized!
Yesterday
## Comparison of Conventional Cooling to Liquid Cooling - 1,000 kW data center load

<table>
<thead>
<tr>
<th></th>
<th>Cooling Towers and Pumps</th>
<th>Chiller</th>
<th>Chilled Water Pumps</th>
<th>Fans</th>
<th>Other</th>
<th>Total Power (kW)</th>
<th>% SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traditional System - 45 Deg F Chilled Water</strong></td>
<td>70</td>
<td>500</td>
<td>50</td>
<td>150</td>
<td>n/a</td>
<td>770</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Liquid Cooled with Fans in the Rack - 55 Deg F Chilled Water</strong></td>
<td>70</td>
<td>425</td>
<td>50</td>
<td>100</td>
<td>n/a</td>
<td>645</td>
<td>16%</td>
</tr>
<tr>
<td><strong>Liquid Cooled without fans in the rack - 55 Deg F Chilled Water</strong></td>
<td>70</td>
<td>425</td>
<td>50</td>
<td>0</td>
<td>n/a</td>
<td>545</td>
<td>29%</td>
</tr>
<tr>
<td><strong>Liquid Cooled directly couple with CPU - 70 to 80 deg F Chilled Water</strong></td>
<td>70</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>Room A/C - 245</td>
<td>365</td>
<td>53%</td>
</tr>
</tbody>
</table>
Free Cooling

• Use cooling towers and heat exchanger to produce chilled water
• Turn off chiller
Ultra Low Energy Liquid Cooled Rack

Servers

Cooling Coils

90°F

70°F

Cooling Tower

70°F

Pump
Three – Well Suited For 24 hr Load

Facility B Data Center
Chiller 4 Power, Load and Efficiency - Oct 5 and 6

![Graph showing power, load, and efficiency over time for Chiller 4 at Facility B Data Center.](image-url)
In Series with Chiller, Free Cooling Can Improve Reliability
Free Cooling

- RH = 20%
- RH = 40%
- RH = 60%
- RH = 80%

- h = 20 Btu/lb → h = 30 Btu/lb → h = 40 Btu/lb → h = 50 Btu/lb

- 3200 hours minimum of free cooling

Dry Bulb Temperature (F) vs. Humidity Ratio (lbs H₂O per lbs dry air) graph.
Free Cooling Opportunity

Free Cooling Potential (Hours per Year)

Chilled Water Design Temperature (Degrees F)
# Comparison of Conventional Cooling to Liquid Cooling - 1,000 kW data center load With Free Cooling

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<td>770</td>
<td>N/A</td>
</tr>
<tr>
<td>Liquid Cooled with Fans in the Rack - 55 Deg F Chilled Water</td>
<td>70</td>
<td>255</td>
<td>50</td>
<td>100</td>
<td>n/a</td>
<td>475</td>
<td>38%</td>
</tr>
<tr>
<td>Liquid Cooled without fans in the rack - 55 Deg F Chilled Water</td>
<td>70</td>
<td>255</td>
<td>50</td>
<td>0</td>
<td>n/a</td>
<td>375</td>
<td>51%</td>
</tr>
<tr>
<td>Liquid Cooled directly couple with CPU - 70 to 80 deg F Chilled Water</td>
<td>70</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>Room A/C - 150</td>
<td>270</td>
<td>65%</td>
</tr>
</tbody>
</table>
Take Aways

• Liquid has greater heat removal capacity
• Pumps are more efficient than fans
• Coupling heat removal to the source eliminates mixing
• Commercially available liquid solutions are available
• Water side free cooling provides cooling with reduced chiller operation for much of the year in California
Electrical Systems Efficiency
Electrical Systems Efficiency

• Electrical distribution systems

• Lighting

• Standby generation

• On-site generation
Electrical Distribution

• Every power conversion (AC → DC, DC → AC, AC → AC) loses some power and creates heat

• Distributing higher voltage is more efficient and saves capital cost (wire size is smaller)

• Uninterruptible power supplies (UPS’s) efficiency varies

• Power supplies in IT equipment efficiency varies
Overall Power Use in Data Centers

Courtesy of Michael Patterson, Intel Corporation
Data Center Power Conversions

Uninterruptible Power Supply (UPS)

Battery/Charger Rectifier

Inverter

Bypass

AC

DC

AC/DC Multi output Power Supply

AC/DC

PWM/PFC Switcher

Unregulated DC to Multi Output Regulated DC Voltages

Internal Drive

External Drive

I/O

Memory Controller

μ Processor

SDRAM

Graphics Controller

Voltage Regulator Modules

Power Distribution Unit (PDU)

Power Supply

Server
UPS Factory Measurements

Factory Measurements of UPS Efficiency
(tested using linear loads)

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

Typical Operation
Measured Power Supply Efficiency

Measured Server Power Supply Efficiencies (all form factors)

- **80 Plus**
- **Non-PFC Power Supplies**
- **PFC Power Supplies**
Typical AC Distribution Today

480 Volt AC

AC/DC → DC/AC → UPS → PDU → AC/DC → DC/DC → PSU → 12 V → Server

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

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
Rack-Level DC Distribution

480 Volt AC

AC/DC → DC/AC → UPS → PDU → AC/DC → 380 VDC → DC/DC

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

Loads using Legacy Voltages

Loads using Silicon Voltages

Server

Rack

PSU
AC System Loss Compared to DC

7-7.3% measured improvement

2-5% measured improvement
Video of DC Demonstration is Available
Data Center Lighting

• Lights are on and nobody’s home
• Lighting controls are well proven – why not use them?
• Small benefit but easy to accomplish – also saves HVAC energy
• DC lighting would compliment DC distribution
Standby Generation Loss

• Several load sources
  ■ Heaters
  ■ Battery chargers
  ■ Transfer switches
  ■ Fuel management systems

• Heaters (many operating hours) use more electricity than the generator will ever produce (few operating hours)

• Opportunity may be to reduce or eliminate heating, batteries, and chargers
Standby Generator Block Heater

Generator Standby Power Loss

Date & Time

6/22/04 0:00, 6/22/04 12:00, 6/23/04 0:00, 6/23/04 12:00, 6/24/04 0:00, 6/24/04 12:00, 6/25/04 0:00, 6/25/04 12:00, 6/26/04 0:00
On-Site Generation

• On-site generation with utility back-up
• Thermal host required for combined heat and power
  – Absorption or adsorption chillers
  – Other campus use
• Renewable sources (future)
  – Fuel cells
  – Solar
  – Wind
Take Aways

• Distributing higher voltage (AC or DC) is more efficient
• Electrical power conversions are inefficient
• Highly efficient UPS’s should be specified
• Highly efficient IT equipment power supplies should be specified
• Lighting is a small but low hanging opportunity
• Standby generation losses can be minimized
• On-site generation can improve reliability and efficiency
IT Equipment Efficiency
Efficient Power Supplies

SSI Recommended Minimum Power Supply Efficiencies

- 40%
- 45%
- 50%
- 55%
- 60%
- 65%
- 70%
- 75%
- 80%
- 85%
- 90%
- 95%
- 100%

Load

Efficiency

- 2U Rack Chassis Power Supplies, Redundant Hotswappable
- 1U Rack Mount Entry Server Systems
- Required Minimum for Proper Power Supply Cooling
### Efficient Power Supplies, Per Server Savings

<table>
<thead>
<tr>
<th>Power Supplied Per Server (Watts)</th>
<th>Annual Savings Using a SSI Recommended Minimum Efficiency Supply&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Annual Savings Including Typical Cooling Energy&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>$37</td>
<td>$65</td>
</tr>
<tr>
<td>300</td>
<td>$56</td>
<td>$97</td>
</tr>
<tr>
<td>400</td>
<td>$74</td>
<td>$130</td>
</tr>
<tr>
<td>500</td>
<td>$93</td>
<td>$162</td>
</tr>
</tbody>
</table>
Power Supply Savings Add Up

Annual Savings: Standard vs. High Eff Power Supply

- Mechanical
- UPS
- Power supply

Annual Savings per Rack

<table>
<thead>
<tr>
<th>Watts per server</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$3,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$4,000</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$5,000</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$6,000</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>$7,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$8,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Resources

- www.ssiforums.org
- www.80plus.org
High Efficiency Servers

Energy savings and PG&E incentive for installation of three new High Efficiency Servers.

<table>
<thead>
<tr>
<th></th>
<th>Baseline Usage</th>
<th>Installed Usage</th>
<th>Energy Savings</th>
<th>Electric Cost Savings</th>
<th>PG&amp;E Incentive</th>
<th>Incremental Installation Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install High Efficiency Servers - Direct Energy Savings</td>
<td>24,538</td>
<td>4,941</td>
<td>19,598</td>
<td>$ 2,352</td>
<td>$ 1,960</td>
<td>n/a</td>
</tr>
<tr>
<td>Install High Efficiency Servers - Indirect HVAC Savings</td>
<td>9,003</td>
<td>1,813</td>
<td>7,190</td>
<td>$ 863</td>
<td>$ 1,007</td>
<td>n/a</td>
</tr>
<tr>
<td>Combined</td>
<td>33,541</td>
<td>6,753</td>
<td>26,788</td>
<td>$ 3,215</td>
<td>$ 2,967</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Coming Soon - Power Performance Metrics
e.g. Standard Performance Evaluation Corp (SPEC)
Server Virtualization
## Server Virtualization

- Energy savings and PG&E incentive for Server Virtualization.
- Number of servers before virtualization: 50.
- Number of servers after virtualization: 30.

<table>
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<tr>
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<th>Baseline Usage</th>
<th>Installed Usage</th>
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<th>Electric Cost Savings</th>
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<th>Total Installation Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kWh/yr</td>
<td>kWh/yr</td>
<td>kWh/yr</td>
<td>$/yr</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Install Virtual Server - Direct Energy Savings</td>
<td>98,550</td>
<td>59,130</td>
<td>39,420</td>
<td>$4,730</td>
<td>$3,154</td>
<td>$70,000</td>
</tr>
<tr>
<td>Install Virtual Server - Indirect Equipment Support Savings</td>
<td>60,636</td>
<td>36,382</td>
<td>24,254</td>
<td>$2,911</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Combined</td>
<td>159,186</td>
<td>95,512</td>
<td>63,674</td>
<td>$7,641</td>
<td>$3,154</td>
<td>$70,000</td>
</tr>
</tbody>
</table>
Thin Clients

• Typical Desktop Computer, 75 – 100 Watts, $500
• Typical Laptop Computer, 10 – 15 Watts, $1,000
• Typical Thin Client, 4 – 6 Watts, $300
Thin Clients

- Energy savings and PG&E incentive for implementation of a Thin Client network.
- Replace 50 generic workstations with 50 Thin Client terminals.

<table>
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<th>Total Installation Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install Thin Client Computers - Direct Energy Savings</td>
<td>35,040 kWh/yr</td>
<td>15,626 kWh/yr</td>
<td>19,414 kWh/yr</td>
<td>$2,330</td>
<td>$1,553</td>
<td>$25,000</td>
</tr>
<tr>
<td>Install Virtual Server - Indirect HVAC Savings</td>
<td>12,856 kWh/yr</td>
<td>5,733 kWh/yr</td>
<td>7,123 kWh/yr</td>
<td>$855</td>
<td>$-</td>
<td>$-</td>
</tr>
<tr>
<td>Combined</td>
<td>47,896 kWh/yr</td>
<td>21,359 kWh/yr</td>
<td>26,537 kWh/yr</td>
<td>$3,184</td>
<td>$1,553</td>
<td>$25,000</td>
</tr>
</tbody>
</table>
Massive Array of Idle Disks (MAID)

- MAID is designed for Write Once, Read Occasionally (WORO) applications.

- In a MAID each drive is only spun up on demand as needed to access the data stored on that drive.
MAID

- Energy savings and PG&E incentive for installation of a MAID system.
- Install one fully-loaded MAID cabinet with a total storage capacity of 448TB in lieu of a traditional cabinet of the same capacity.

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<tbody>
<tr>
<td>Install Maid System</td>
<td>278,450</td>
<td>75,118</td>
<td>203,332</td>
<td>$26,551</td>
<td>$16,267</td>
<td>$224,000</td>
</tr>
<tr>
<td>Direct Energy Savings</td>
<td>102,163</td>
<td>27,561</td>
<td>74,602</td>
<td>$9,742</td>
<td>$10,444</td>
<td>$-</td>
</tr>
<tr>
<td>Install Maid System</td>
<td>380,613</td>
<td>102,679</td>
<td>277,934</td>
<td>$36,293</td>
<td>$26,711</td>
<td>$224,000</td>
</tr>
</tbody>
</table>
The Value of One Watt Saved at the Server CPU

1 Watt at CPU
= 1.25 Watts at entry to server (80% efficient power supply)
= 1.56 Watts at entry to UPS (80% efficient power supply)
= 2.5 Watts including cooling (1.6 PUE)
= 21.9 kWh per year
= $2.19 per year (assuming $0.10/kWh)
= $6 of infrastructure cost (assuming $6/W)

• Total Cost of Ownership (TCO) Perspective = $12.60 (assuming three year life of server)
• Typical added cost of 80 plus power supply $3 - $5.
• Typical value - $168 (assumes 15 Watts saved at power supply not CPU)
Take Aways

• Efficient power supplies have large annual savings

• Efficient power supplies reduce infrastructure power consumption

• Efficient servers are orders of magnitude more efficient than older equipment

• CA public utilities incentives are available

• Virtualization can eliminate many servers

• Thin clients are economical and great energy savers

• Software to limit spinning discs has large promise

• Saving one watt at the server saves 2.5 watts overall
Thank You
website:
http://hightech.lbl.gov/datacenters/
SCE Incentive Programs