# Agenda

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</table>
Environmental Conditions

Bill Tschudi, PE
Environmental conditions

• ASHRAE - consensus between IT equipment manufacturers and HVAC professionals on appropriate temperature and humidity conditions

• Recommended and allowable ranges of temp and humidity

• Standard reporting of requirements
## Design conditions - at inlet to IT equipment

### Table 2.1
Class 1, Class 2 and NEBS Design Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Class 1 / Class 2</th>
<th>NEBS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Allowable Level</td>
<td>Recommended Level</td>
</tr>
<tr>
<td>Temperature control range</td>
<td>$59^\circ F - 90^\circ F^{(a)}$ (Class 1)</td>
<td>$68^\circ F - 77^\circ F$</td>
</tr>
<tr>
<td></td>
<td>$50^\circ F - 95^\circ F^{(b)}$ (Class 2)</td>
<td></td>
</tr>
<tr>
<td>Maximum temperature rate of change</td>
<td>$9^\circ F$ per hour$^{(a)}$</td>
<td></td>
</tr>
<tr>
<td>Relative humidity control range</td>
<td>$20% - 80%^{(c)}$ (Class 1)</td>
<td>$40% - 55%^{(a)}$</td>
</tr>
<tr>
<td></td>
<td>$63^\circ F$. Max Dewpoint$^{(g)}$ (Class 1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$70^\circ F$. Max Dewpoint$^{(h)}$ (Class 2)</td>
<td></td>
</tr>
<tr>
<td>Filtration quality</td>
<td>$65%$, min. $30%^{(i)}$ (MERV 11, min. MERV 8)$^{(b)}$</td>
<td></td>
</tr>
</tbody>
</table>

---

*These conditions are inlet conditions recommended in the ASHRAE Publication *Thermal Guidelines for Data Processing Environments* (ASHRAE, 2004).

$^{(a)}$Percentage values per ASHRAE *Standard* 52.1 dust-spot efficiency test. MERV values per ASHRAE *Standard* 52.2. Refer to Table 8.4 of this publication for the correspondence between MERV, ASHRAE 52.1 & ASHRAE 52.2 Filtration Standards.

$^{(b)}$Telecordia 2002 GR-63-CORE

$^{(c)}$Telecordia 2001 GR-3028-CORE

$^{(d)}$Generally accepted telecom practice. Telecom central offices are not generally humidified, but grounding of personnel is common practice to reduce ESD.

$^{(e)}$Refer to Figure 2.2 for temperature derating with altitude.
## Design conditions at the inlet to IT equipment: recently revised by ASHRAE

<table>
<thead>
<tr>
<th></th>
<th>2004 Version</th>
<th>2008 Version</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low End Temperature</strong></td>
<td>20 °C (68 °F)</td>
<td>18 °C (64.4 °F)</td>
</tr>
<tr>
<td><strong>High End Temperature</strong></td>
<td>25 °C (77 °F)</td>
<td>27 °C (80.6 °F)</td>
</tr>
<tr>
<td><strong>Low End Moisture</strong></td>
<td>40% Relative Humidity</td>
<td>5.5 °C Dew Point (41.9 °F)</td>
</tr>
<tr>
<td><strong>High End Moisture</strong></td>
<td>55% Relative Humidity</td>
<td>60% Relative Humidity &amp; 15 °C Dew Point (59 °F Dew Point)</td>
</tr>
</tbody>
</table>
ASHRAE Thermal Report

**XYZ Co. Model abc Server: Representative Configurations**

<table>
<thead>
<tr>
<th></th>
<th>Condition</th>
<th>Overall System Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voltage 110 Volts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Typical Heat Release</td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>watts</td>
<td>lbs</td>
</tr>
<tr>
<td>Minimum Configuration</td>
<td>1765</td>
<td>896</td>
</tr>
<tr>
<td></td>
<td>m³/h</td>
<td>kg</td>
</tr>
<tr>
<td>Full Configuration</td>
<td></td>
<td>406</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>in.</td>
</tr>
<tr>
<td>Typical Configuration</td>
<td></td>
<td>30 x 40 x 72</td>
</tr>
<tr>
<td></td>
<td>5040</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>762 x 1016 x 1828</td>
</tr>
<tr>
<td></td>
<td>Airflow, Nominal</td>
<td>lbs</td>
</tr>
<tr>
<td></td>
<td>Airflow, Maximum at 35°C</td>
<td>kg</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
<td>in.</td>
</tr>
<tr>
<td></td>
<td>Overall System Dimensions</td>
<td></td>
</tr>
<tr>
<td>ASHRAE Class</td>
<td>Airflow Diagram</td>
<td>Minimum Configuration</td>
</tr>
<tr>
<td>1, 2, 3</td>
<td>Cooling scheme F-R</td>
<td>1 CPU-A, 1 GB, 2 I/O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Full Configuration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 CPU-B, 16 GB, 64 I/O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2 GB cards, 2 frames)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Typical Configuration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 CPU-A, 8 GB, 32 I/O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2 GB cards, 1 frame)</td>
</tr>
</tbody>
</table>

a. The airflow values are for an air density of 1.2 kg/m³ (0.075 lb/ft³). This corresponds to air at 20°C (68°F), 101.3 kPa (14.7 psia), and 50% relative humidity.
b. Footprint does not include service clearance or cable management, which is zero on the sides, 46 in. (1168 mm) in the front, and 46 in. (1168 mm) in the rear.

From ASHRAE’s Thermal Guidelines for Data Processing Environments
Design conditions at the inlet to IT equipment

New CL 1 and 2 Recommended Range
Example server specification:
(Dell PowerVault MD3000)

<table>
<thead>
<tr>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature:</strong></td>
</tr>
<tr>
<td>• Operating: 10°C to 35°C (50°F to 95°F)</td>
</tr>
<tr>
<td>• Storage: -40°C to 65°C (-40°F to 149°F)</td>
</tr>
<tr>
<td><strong>Relative humidity</strong></td>
</tr>
<tr>
<td>• Operating: 20% to 80% (non-condensing)</td>
</tr>
<tr>
<td>• Storage: 5% to 95% (non-condensing)</td>
</tr>
<tr>
<td><strong>Altitude</strong></td>
</tr>
<tr>
<td>• Operating: -15 to 3048 m (-50 to 10,000 ft)</td>
</tr>
<tr>
<td>• Storage: -15 to 10,668 m (-50 to 35,000 ft)</td>
</tr>
</tbody>
</table>
Example server specification: Supermicro SYS-6015T

<table>
<thead>
<tr>
<th>Environmental Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operating Temperature:</strong></td>
</tr>
<tr>
<td>10°C to 35°C (50°F to 95°F)</td>
</tr>
<tr>
<td><strong>Non-operating Temperature:</strong></td>
</tr>
<tr>
<td>-40°C to 70°C (-40°F to 158°F)</td>
</tr>
<tr>
<td><strong>Operating Relative Humidity:</strong></td>
</tr>
<tr>
<td>8% to 90% (non-condensing)</td>
</tr>
<tr>
<td><strong>Non-operating Relative Humidity:</strong></td>
</tr>
<tr>
<td>5% to 95% (non-condensing)</td>
</tr>
</tbody>
</table>
Server specs exceed ASHRAE ranges

Typical Server Specification

New CL 1 and 2 Recommended Range
Microsoft’s data center in a tent

“Inside the tent, we had five HP DL585s running Sandra from November 2007 to June 2008 and we had **ZERO failures** or 100% uptime. In the meantime, there have been a few anecdotal incidents:

- Water dripped from the tent onto the rack. The server continued to run without incident.
- A windstorm blew a section of the fence onto the rack. Again, the servers continued to run.
- An itinerant leaf was sucked onto the server fascia. The server still ran without incident.”

And from Intel a side-by-side comparison

Intel conducted a 10-month test to evaluate the impact of using only outside air to cool a high-density data center, even as temperatures ranged between 64 and 92 degrees and the servers were covered with dust.

- Intel’s result: “We observed no consistent increase in server failure rates as a result of the greater variation in temperature and humidity, and the decrease in air quality. This suggests that existing assumptions about the need to closely regulate these factors bear further scrutiny.”

Lower humidity recommendation

Concern is electrostatic discharge (ESD)

- Recommended mitigation procedures
  - Personnel grounding
  - Cable grounding

- Recommended equipment
  - Grounding wrist straps on racks
  - Grounded plate for cables
  - Grounded flooring
  - Servers rated for ESD resistance

- Industry practices
  - Telecom industry has no lower limit
  - The Electrostatic Discharge Association has removed humidity control as a primary ESD control measure in their ESD/ANSI S20.20 standard
Lower humidity limit

- Tight humidity control is a legacy issue from days when paper products and tape were widely used.
- Humidity controls are a point of failure and are hard to maintain.
- Many data centers today operate without humidification or with malfunctioning humidity control.
- Humidity control, if desired, should be provided through make-up air only.
- More research is needed.
- Humidity may be required for some physical media (tape storage, printing, etc.).
  - Old technology requiring humidification is not found in many data centers.
  - It is best to segregate these items rather than humidify the entire data center.
Many data centers have no humidification controls and operate successfully

Many different organizations including:

- Banks
- Medical service providers
- Server manufacturers
- Software firms
- Colocation facilities
- Major chip manufacturer
- Supercomputer facilities
- Animation studios
High humidity recommendation

Concern is over condensation and circuit bridging

- Some contaminants (hydroscopic salts) in high concentrations in combination with high humidity can deposit and bridge across circuits over time, causing current leakage or shorts.

- Unless you operate with very high humidity (≥80%) in a contaminated environment for long periods of time this phenomenon should not be a problem.

- Do you tightly control humidity for your home computer?

- More research is needed to determine if there is a basis for concern.
Environmental conditions take aways

- Use the entire ASHRAE recommended range in data center operation.
  - Provide the warmest supply temperatures that satisfy the equipment inlet conditions.
  - Control to the widest humidity range.
- Humidification does not protect against ESD, consider grounding and personnel practices in lieu of humidification.
- There is published scientific evidence that high humidity in combination with hydrosscopic salts causes equipment problems.
- Isolate equipment that needs tighter humidity or temperature control.
Air System Design
Air system design overview

- Data center layout
- Airflow configurations
  - Distribution: overhead or underfloor
  - Control: constant or variable volume
- Air management issues
Underfloor supply

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Vertical overhead (VOH) air distribution

Figure 5.3 – Example Data Center with VOH Cooling Architecture
Overhead supply

You can incorporate VAV on each branch

Overhead Supply

Cold Aisle

Hot Aisle

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Elevation at a cold aisle looking at racks

There are numerous references in ASHRAE. See for example V. Sorell et al; “Comparison of Overhead and Underfloor Air Delivery Systems in a Data Center Environment Using CFD Modeling”; ASHRAE Symposium Paper DE-05-11-5; 2005
Typical temperature profile with overhead supply

Elevation at a cold aisle looking at racks
## Overhead vs. underfloor

<table>
<thead>
<tr>
<th>Issue</th>
<th>Overhead (OH) Supply</th>
<th>Underfloor (UF) Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Limited by space and aisle velocity.</td>
<td>Limited by free area of floor tiles.</td>
</tr>
<tr>
<td>Balancing</td>
<td>Continuous on both outlet and branch.</td>
<td>Usually limited to incremental changes by diffuser type. Some tiles have balancing dampers. Also underfloor velocities can starve floor grilles!</td>
</tr>
<tr>
<td>Control</td>
<td>Up to one pressure zone by branch.</td>
<td>Only one pressure zone per floor, can provide multiple temperature zones.</td>
</tr>
<tr>
<td>Temperature</td>
<td>Most uniform.</td>
<td>Commonly cold at bottom and hot at top.</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First Cost</td>
<td>Best (if you eliminate the floor).</td>
<td>Generally worse.</td>
</tr>
<tr>
<td>Energy Cost</td>
<td>Best.</td>
<td>Worst.</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Harder to reconfigure</td>
<td>Easiest</td>
</tr>
<tr>
<td>Aisle Capping</td>
<td>Hot or cold aisle possible.</td>
<td>Hot or cold aisle possible.</td>
</tr>
</tbody>
</table>
Airflow design disjoint

- IT departments select servers and racks - having airflow and cooling requirements
- Engineers size the facility fans and cooling capacity
- What’s missing in this picture?
What happens when the HVAC systems have less airflow than the servers?

- Hot spots
- Higher hot aisle temperature
- Possible equipment failure or degradation

\[ V_{HVAC\ Supply} < \sum V_{Servers} \]
What happens when the HVAC systems have more airflow than the servers?

- Least hot spots
- Higher air velocities
- Higher fan energy
- Reduced economizer effectiveness (due to lower return temperatures)

\[ V_{HVAC\_Supply} > \sum V_{Servers} \]
In a perfect world, variable supply and server fans...

- Partial flow condition
- Best energy performance but tricky to control
- Works best with aisle containment
How do you balance airflow?

- Spreadsheet
- CFD
- Monitoring, infrared thermography or other site measurements
- Using aisle containment

Infrared thermographic image from LBNL

CFD image from TileFlow
http://www.inres.com/Products/TileFlow/tileflow.html, Used with permission from Innovative Research, Inc.
Wireless Sensor Network

- Wireless sensor network
- “Self-organizing” nodes
- 802.15.4 (not 802.11)
- Multi-hop routing
- Non-invasive installation
- 2 internal & 6 external sensors per node
- Can measure temp., humidity, pressure, current, liquid flow, liquid presence & particle count.
- Low cost (10%-20% of standard DDC costs)
real time visualization

This is a dynamic picture and tracks progress when making retrofits
Case study

- CRAC unit PM
- 30 high flow tiles replaced with low flow tiles
- OH supply to UF
- 27 low flow tiles removed

Graph: Representative High and Low Floor Pressure Changes 3/21/2008 to 8/15/2008
Case study results (so far)

- 7% increase (~30kW) in IT load with 8% less fan energy
- CRAC unit setpoints 3 °F warmer
- Fewer hot spots
- (1) 15 ton unit turned off
- (1) extra 15 ton unit on-line but redundant
- The wireless sensor network enabled facilities to visualize, track and fine tune many changes in the data center including tuning of the floor tiles
Isolating hot or cold aisles

- Energy intensive IT equipment needs good isolation of “cold” inlet and “hot” discharge.
- Supply airflow can be reduced if no mixing occurs.
- Overall temperature can be raised in the data center if air is delivered to equipment without mixing.
- Cooling systems and economizers use less energy with warmer return air temperatures.
- Cooling coil capacity increases with warmer air temperatures.
Cold aisle containment, underfloor supply

With cold aisle containment, the general data center is hot 95-100°F
Cold aisle containment, overhead supply

Cold Aisle Caps

Cold Aisle

Hot Aisle

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Hot aisle containment with in row cooling

With hot aisle containment, the general data center is neutral (70-75F)
Hot and cold isolation the frugal way

- AHU or CRAC
- Cold Aisle
- Rack
- Hot Aisle
- Rack
- Cold Aisle
- Dropped ceiling
- Hard partition or strip curtain

**Diagram Details:**
- Return duct
- Strip curtain
- Aluminum Angle 1-1/4 x 1-1/4 x 1/8"
- Fuse Link 130V deg. F.
- Spring Steel T nut
- Cup w/ threaded stud & wing nut
LBNL air management demonstration

If mixing of cold supply air with hot return air can be eliminated, fan speed can be reduced.

Fan Energy Savings ~ 75%
LBNL air management demonstration

Better airflow management permits warmer supply temperatures!

ASHRAE Recommended Range

Ranges during demonstration
Cold and hot isolation review

- Can be retrofit.
- Either hot or cold aisle containments work.
- Hot aisle (or in-rack containment) will make the general data center more comfortable.
- You have to think about fire protection with containment (sprinkler and FM200).
- Isolation of hot and cold is more important than the type of supply (overhead or underfloor).
Best practices for air delivery

- Arrange racks in hot aisle/cold aisle configuration.
- Plug leaks in floor and racks
- Try to match or exceed server airflow by aisle.
  - Get thermal report data from IT if possible.
  - Plan for worst case.
- Get variable speed or two speed fans on servers if possible.
- Provide variable airflow fans for CRAC/H or AHU supply.
- Consider using air handlers rather than CRAHs for improved performance (and ability to use outside air).
- Provide hot and cold isolation.
- Draw hot air return from as high as possible.
- Consider CFD or other visualization techniques to inform the design.
Free Cooling
Free cooling overview

Air side economizers

- The potential energy savings of air-side economizers in the 16 ASHRAE climates
- The relationship of humidification and air-side economizers
- Challenges to implementing air-side economizers
- A combined air-side economizer with direct evaporative cooling (an emerging technology)
- Non-energy benefits of air-side economizers

Water side economizers

- The potential energy savings of water-side economizers
- Challenges to implementing water-side economizers
- Non-energy benefits of water-side economizers
Air-side economizers
Air-side economizer

- OUTSIDE AIR
- Min. Vent
- ECONOMIZER DAMPERS
- RETURN AIR
- COOLING COIL
- MODULATING VENT SYSTEM
- VS RELIEF FAN
- SUPPLY FAN
- 95°F
- 90°F
- 75°F
Air-side economizer

- OUTSIDE AIR
  - ECONOMIZER DAMPERS
  - VS RELIEF FAN
  - RETURN AIR
- COOLING COIL
- SUPPLY FAN
- T 65F
- T 90F
- Closed
- 75F
Air-side economizer
Air-side economizer savings: no humidification and code minimum water-cooled chilled water plant

SF 37% savings!
Air-side economizer savings: with humidification and code minimum water-cooled chilled water plant

These results are based on humidifying to the middle of the old ASHRAE “recommended” envelope ~51°F tdp. The new “recommended” lower limit is 41.9°F tdp. The excess energy shown here is the result of using a standard economizer high-limit switch. Adding a minimum OSA dew-point switch would fix the problem.
What about contamination?
“My center must be closed.”
Outdoor measurements

Outdoor Measurements
Fine Particulate Matter

IBM Standard

EPA 24-Hour Health Standard

EPA Annual Health Standard and ASHRAE Standard

Particle Conc. (µg/m³)
Indoor measurements

Indoor Measurements
Fine Particulate Matter

IBM Standard

EPA 24-Hour Health Standard

EPA Annual Health Standard and ASHRAE Standard
Indoor measurements

Indoor Measurements
Fine Particulate Matter

Particle Conc. (µg/m³)

LBNL
NERSC
Center 3
Center 4
Center 5
Center 6
Center 7
Center 8

0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0

12:00 PM 6:00 PM 12:00 AM 6:00 AM 12:00 PM 6:00 PM 12:00 AM 6:00 AM 12:00 PM 6:00 PM 12:00 AM 6:00 AM 12:00 PM 6:00 PM 12:00 AM 6:00 AM 12:00 PM 6:00 PM 12:00 AM 6:00 AM
LBNL particulate study - data center w/economizer

They only had MERV 7 filters!
Wet-bulb air economizer review

- **Advantages**
  - Extends hours of free cooling
  - Provides non-compressor cooling
  - Provides minimum humidification (if you care)
  - No outside air introduced (if you worry about that)
  - Increases reliability by providing a redundant non-compressor

- **Disadvantages**
  - Capital cost
  - Increased fan energy
  - Spatial requirements
Air-side economizer summary

- Can improve the reliability of the plant
- Generally improves indoor air quality
- Humidity control can negate savings
  - If used, lock out the economizers when the OSA is below the humidity control dewpoint temperature setpoint
- Particulates shouldn’t be an issue better filtration could be provided for added assurance (MERV 13 or higher)
- Work best with high return temperatures (aisle containment)
- Consider a direct evaporative stage to increase the hours of free cooling
- Consider controls to prevent smoke from outside being pulled into the data center (e.g. grass fire)
What’s Missing from this Picture?

Water Side Economizers
Free cooling

- Use cooling towers and heat exchanger to produce chilled water
- Turn off chiller
**indirect water-side economizer**
Integrated water-side economizer

You can use either a control valve or pump.

Heat Exchanger in series with chillers on CHW side
Example water side economizer savings

- Example based on 200,000 sf office building with ~ 110 tons of data center load.
- Location Pleasanton CA (ASHRAE Climate 3B)
- (2) 315 ton chillers (630 tons total).
- Building has air-side economizer.
- Data center has CRAH units.
- Water-side economizer on central plant with HX (integrated, see previous slide)
Example water side economizer savings

- ~30%
- ~24%
- ~48%
- ~2%
Chilled water plant in Santa Clara, CA

What’s Missing from this Picture?

A heat exchanger, pipe and two pumps
Implementing water economizers

• Put the HX on the plant CHW return line in series NOT in parallel with the chillers
• You need head pressure controls for chillers and other water-cooled equipment
• Works best with CHW reset (the warmer the better)
• Works best if you design coils for high Delta-T
• Consider oversizing towers
• Design towers for low flow
Non-energy advantages of water side economizers

• Redundancy

• Limited ride-through if chillers trip

• Utilizes redundant towers
Free cooling take aways

- Air- and water economizers can save significant energy if properly designed and controlled.
- Air- economizers can increase energy usage if you have humidity controls.
- Air-economizers do increase particulates but these can be addressed with standard filtration.
- Water economizers should be integrated by installing free cooling heat exchanger in series with the chillers.
- Many utilities offer rebates for economizer systems.
Liquid Cooling Systems
Outline

• Why liquid cool
• Liquid cooling options
  - Rack and row cooling
  - On board cooling
• Energy Benefits
• Interface with free cooling
Air cooling issues

- Limitations on the data densities served
- Air delivery limitations
- Real estate
- Working conditions
  - Hot aisles are (should be) uncomfortably hot
- Costly infrastructure
- High energy costs
- Management over time
- Reliability
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
In rack liquid cooling

Close coupling between cooling source and server

However, some of these solutions might present challenges to redundancy and increase maintenance
In rack liquid cooling -
Racks with integral coils
Rear door cooling
On board cooling
Comparison of conventional cooling to liquid cooling - 1,000 kW data center load

<table>
<thead>
<tr>
<th>Method</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>Traditional System - 45 Deg F Chilled Water</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>Liquid Cooled with Fans in the Rack - 55 Deg F Chilled Water</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>Liquid Cooled without fans in the rack - 55 Deg F Chilled Water</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>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 - 245</td>
<td>365</td>
<td>53%</td>
</tr>
</tbody>
</table>
Potential for Tower Cooling

- **Water-Side Economizer**
- **Rear-Door Cooling**
- **On-Board Cooling**

Free Cooling Potential (Hours per Year)

- **Chilled Water Design Temperature (Degrees F)**
  - 45
  - 55
  - 60
  - 65
  - 104

- **Oakland**
- **Sacramento**
- **Los Angeles**

Bar chart showing the potential for free cooling in different cities at various chilled water design temperatures.
Liquid cooling take aways

- Liquid has greater heat removal capacity
- Pumps use less energy than fans to remove the same amount of heat
- Coupling heat removal to the source eliminates mixing
- A wide variety of commercially available liquid solutions are available
- The potential for energy savings is large
- Redundancy is a challenge for some liquid cooling technologies
- Water side free cooling can provide cooling with reduced chiller operation for much of the year
Central Chilled Water Plants
Central plant overview

- Most chilled water plants are sub-optimal yet run 24x7
- Efficiency issues are well understood
- Resources are available (e.g. ASHRAE)
- Air- VS Water-Cooled Chillers
- Best Practices
Variable flow
Primary-only, Multiple Chillers

• Advantages
  - Low installed cost.
  - Low energy cost.

• Disadvantages
  - More complex controls.
  - Can lose chillers if you don’t stage them correctly.
Variable flow
Primary/Secondary, Multiple Chillers and Coils

• **Advantages**
  - Simpler controls.
  - Easier to keep chillers online.

• **Disadvantages**
  - Higher installed cost.
  - Higher pumping energy.
  - Higher chiller energy as you have to stage the chillers on flow not load.

• **Mitigation**
  - Stage chillers by flow.
  - Put check valve in common leg.
Variable flow
Primary/Secondary with thermal energy storage

• Advantages
  - No chiller staging problems
  - Peak shaving
  - Back up data center & chillers
  - Fire protection water source
  - Secondary source for cooling towers

• Disadvantages
  - Installed cost
  - Space
Primary-only vs. Primary/Secondary

• Use primary-only systems for:
  - Plants with many chillers (more than three) and with fairly high base loads where the need for bypass is minimal or nil and flow fluctuations during staging are small due to the large number of chillers; and
  - Plants where design engineers and future on-site operators understand the complexity of the controls and the need to maintain them.

• Otherwise use primary-secondary

• Consider Primary-secondary with thermal energy storage
Water-cooled chillers

Sample Chiller Efficiency as a Function of Leaving Chilled Water Temperature (with Chilled Water Differential Temperature held Constant)

Leaving Water Temperature (deg F) vs. Chiller Efficiency (kW/ton)
Water-cooled chillers

Part-Load Centrifugal Chiller Efficiency Comparison - with and without Variable Frequency Drive

- Compressor Efficiency (kW/ton)
- Constant Speed Drive Efficiency
- Variable Speed Drive Efficiency

Water-cooled chillers

Prepared by DLB Associates
Water cooled chillers are significantly more efficient than air cooled, especially centrifugal variable speed chillers at low loads (Chiller 4).

Variable or primary-secondary controls are recommended.
Primary pump options

Dedicated Pumping Advantages:
- Less control complexity
- Custom pump heads w/ unmatched chillers
- Usually less expensive

Headered Pumping Advantages:
- Better redundancy
- Valves can “soft load” chillers with primary-only systems
- Easier to incorporate stand-by pump
Tower fan control

- One-speed control is almost never the optimum strategy regardless of size, weather, or application.
- Two-speed 1800/900 rpm motors typically best life cycle costs at mid-1990 VSD costs, but...
- VSDs may be best choice anyway
  - Costs continue to fall
  - Soft start reduces belt wear
  - Lower noise
  - Control savings for DDC systems (network card options)
  - More precise control
- Pony motors are more expensive than two-speed but offer redundancy
- Multiple cell towers should have speed modulation on at least 2/3 of cells (required by ASHRAE 90.1)
Tower efficiency guidelines

- Use Propeller Fans
  - Avoid centrifugal except where high static needed or where low-profile is needed and no prop-fan options available.
  - Consider low-noise propeller blade option and high efficiency tower where low sound power is required.

- For data centers and other 24/7 facilities, evaluate oversizing to 80 gpm/hp at 95 F to 85 F @ 75 F WB
Type of HVAC system, all climates

Annual HVAC Energy as a % of IT Energy
Humidity Controls, No Economizer

- Air-cooled DX
- Air-cooled Chiller
- Water-cooled DX
- Water-cooled Chiller

KWh HVAC / KWh IT

1A Miami, FL
2A Houston, TX
2B Phoenix, AZ
3A Memphis, TN
3B El Paso, TX
3C San Francisco, CA
4A Baltimore, MD
4B Albuquerque, NM
4C Salem, OR
5A Chicago, IL
5B Boise, ID
6A Burlington, VT
6B Helena, MT
7 Duluth, MN
8 Fairbanks, AK
Where to learn more

- CoolTools Design Guide
Chilled water plant best practices

- Use 2-way valves on all loads.
- Use oversized headers to balance loads and consider a loop type distribution system.
- Consider primary-only unless you have a chilled water storage tank (which is piped in the common leg).
- Use water-cooled chillers where possible.
- Consider chilled water storage for make-up water, peak shavings and ride-through in chiller staging.
- Put VSDs on everything (pumps, fans and chillers).
Data Center Controls
Control issues

- Temperature Control
- Humidity Control
- Airflow Control
- Feedback and Diagnostics
- IT Integration
- Others
Temperature control

• Design Conditions
  - Maintain inlet conditions at servers between 64°F and 80°F.
    • 59°F to 90°F allowable.
    • At ~77°F two speed and variable speed server fans speed up (using more IT fan energy).

• Best practice
  - Provide feedback from racks.
    • Hardwired or wireless EMCS sensors.
    • Network data exchange with server on-board sensors.
  - Reset supply temperatures upward to keep most demanding rack satisfied (but below 77°F).
  - Can have local temperature zones with distributed CRAC/CRAH/AH units.
Novel control strategies

- Control of computer room air handlers using wireless temperature sensors
- Control of computer room air handlers using temperature sensors inside the IT equipment
Humidity control

• Avoid if at all possible
  - High humidity is usually limited by cooling coil dew-point temperature.
  - Low humidity limit is not well supported (see previous slides).

• If you decide to humidify, do all of the following:
  - Use high quality dew-point sensors located in the data center floor (Vaisala see NBCIP report: http://www.buildingcontrols.org/publications.html).
  - Use adiabatic (not steam or infrared) humidifiers.
    • Direct Evaporative Media.
    • Ultrasonic (but note that DI or RO water is required)
  - Best to provide on MUA unit.
  - Control all humidifiers together if distributed.
### Example survey of CRACs

<table>
<thead>
<tr>
<th>Vaisala Probe</th>
<th>CRAC Unit Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temp</strong></td>
<td><strong>RH</strong></td>
</tr>
<tr>
<td>AC 005</td>
<td>84.0</td>
</tr>
<tr>
<td>AC 006</td>
<td>81.8</td>
</tr>
<tr>
<td>AC 007</td>
<td>72.8</td>
</tr>
<tr>
<td>AC 008</td>
<td>80.0</td>
</tr>
<tr>
<td>AC 010</td>
<td>77.5</td>
</tr>
<tr>
<td>AC 011</td>
<td>78.9</td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td>72.8</td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td>84.0</td>
</tr>
<tr>
<td><strong>Avg</strong></td>
<td>79.2</td>
</tr>
</tbody>
</table>
**Airflow controls underfloor**

- All supply fans controlled to same speed.
- Set speed to maintain differential pressure setpoint under floor (can use multiple sensors).
- Reset differential pressure setpoint by highest rack temperature (slow acting loop).
Reset of floor pressure to satisfy racks

Tate Perforated Floor Tile Performance vs. Underfloor Pressure

Potential reset range
Control sensors underfloor

- Locate one (or more) temperature sensors towards the top of the racks.
- Locate one (or more) pressure sensors in a box(es) under the floor. Locate holes in box to avoid drafts on sensor tip.

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Airflow controls overhead

- All headered supply fans controlled to same speed
- Set speed to maintain pressure in supply header
- Control dampers to maintain racks at temperature
- Reset pressure setpoint to keep most open damper at or near fully open
Control sensors overhead

Pressure sensor in supply duct main

Overhead Supply

Cold Aisle

Hot Aisle

Locate one (or more) temperature sensors towards the top of the racks (and at bottom for overhead supply)

Reset pressure to keep one damper near fully open

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Control sensors with cold aisle containment

- Locate one (or more) temperature sensors towards the top of the racks.
- Locate one (or more) pressure sensors in the containment area.

- Underfloor Supply
- Cold Aisle
- Hot Aisle

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Best practice controls

- Use high quality sensors (not the ones that come with the CRAC/H units!).
- Temperature sensors should be located in the supply air stream not the return.
- If used, locate the humidity sensor in the data center floor (not in the unit return).
- Reset temp and pressure by demand at racks.
- Avoid humidity controls if possible, if necessary provide it on MUA unit.
- Provide CRAC/H or AHUs with variable speed fans and control all fans in parallel to same speed.
- Used advanced whole system metrics to track system performance.
- Commission the controls thoroughly.
Electrical Systems Efficiency

Bill Tschudi, PE
Electrical systems efficiency

- Electrical distribution systems
- Lighting
- Standby generation
- On-site generation
Root causes of electrical system inefficiency

- Physical infrastructure is typically OVERSIZED for most of its life
- Power requirements are initially greatly OVERSTATED
- Legacy INEFFICIENT equipment is incorporated
- IT equipment is on and not doing anything
- Multiple POWER CONVERSIONS – each conversion loses some power and creates heat
- Power conversion efficiency is not optimized
Electrical distribution 101

- 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.
Electricity Flows in Data Centers

- Local distribution lines to the building, 480 V
- HVAC system
- Lights, office space, etc.
- UPS = Uninterruptible Power Supply
- PDU = Power Distribution Unit
- Backup diesel generators
- Computer racks
- Computer equipment
From utility power to the chip - multiple electrical power conversions
Measured power supply efficiency

Measured Server Power Supply Efficiencies (all form factors)

- PFC Power Supplies
- Non-PFC Power Supplies

% of Nameplate Power Output

- 45%
- 50%
- 55%
- 60%
- 65%
- 70%
- 75%
- 80%
- 85%

- 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
 UPS factory measurements

Factory Measurements of UPS Efficiency
(tested using linear loads)

Typical Operation

Percent of Rated Active Power Load

Flywheel UPS
Double-Conversion UPS
Delta-Conversion UPS
Electrical power conversion efficiency varies

Factory Measurements of UPS Efficiency
(tested using linear loads)
LBNL DC power demonstration

“Today’s” AC distribution

480 V AC building power supply

480 V AC Bulk Power Supply UPS PDU AC/DC DC/AC VRM DC/DC VRM VRM VRM VRM VRM 12 V Loads using Legacy Voltages 12 V loads using Silicon Voltages 12 V 5 V 3.3 V 1.2 V 1.8 V 0.8 V Server PSU
DC power distribution

Eliminates several stages of power conversion.

Facility-Level DC Distribution

480 VAC Bulk Power Supply

AC/DC

DC UPS or Rectifier

380 VDC

DC/DC

PSU

VRM

VRM

VRM

VRM

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
AC system loss compared to DC

7-7.3% measured improvement

2-5% measured improvement
Rack-level DC distribution

480 VAC Bulk Power Supply

AC/DC \rightarrow DC/AC

UPS

AC/DC \rightarrow PDU

380 VDC

AC/DC \rightarrow 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

Rack

Loads using Legacy Voltages

Loads using Silicon Voltages
Other benefits of 380 V. DC distribution

- Easy to tie in renewable sources
- Direct use in variable speed drives
- Use of DC lighting
- Minimize power quality issues
- Reduced HVAC
- Less capital cost
- Potential for world wide standard
DC demonstration

Video available through LBL website
Redundancy

- Understand what redundancy costs - is it worth it?
- Different strategies have different energy penalties (e.g. 2N vs. N+1)
- It's possible to more fully load UPS systems and achieve desired redundancy
- Redundancy in electrical distribution always puts you down the efficiency curve
- Consider other options
Electrical systems sizing

• IT Design Load typically was historically based on IT Nameplate plus future growth

  Problem - actual IT loads are <25% of nameplate

• IT load was determined on a Watts/sf basis

  Problem - IT loads are now concentrated

• UPS systems are sized for IT load plus 20-50%

  Problem - load was already oversized by factor of 4

• Standby generators are sized for UPS load x2 or more

  Problem - block heaters
Infrastructure inefficiency

- Standby generators
  - Oversized
  - Redundancy exceeds N+1
  - Excessive block heater loads

- Transformers
  - Oversized
  - Inefficient - higher losses

- UPS
  - Low load capacity due to
    - Oversizing
    - Multi-Stage redundancy 2 (N+)
  - Inefficient UPS topology
  - Low input power factor
  - High input current THD
Infrastructure inefficiency

- **PDU**
  - Excessive use of PDUs. 4 - 6 X IT designed load
  - Inefficient transformers

- **Lights**
  - Unused floor space
  - Use of inefficient lights
  - No lighting Controls

- **IT**
  - Sizing of IT load is based on nameplate + growth
  - IT low power factor
  - IT high current harmonic THD
  - Low utilization
Managing UPS efficiency:

UPS sizing and loading can significantly affect UPS efficiency:

- Maximize UPS load capacity
- Specify UPS system that has higher efficiency at 10 - 40% load capacity
- Specify efficient UPS topology
- Consider modular UPS (an option to maximize UPS load capacity)
Managing UPS load capacity

**Example:** 10% difference in UPS efficiency per 1000 kW IT load results in approximately 900 MWhr of Energy saving per year and approx $400K of energy saving over 5 years.

Most UPS units in N or N+X configuration operate at 10% to 40% load capacity.
Transformers and PDUs

- Specify high efficiency transformers
- Install low voltage (LV) transformers outside the raised floor area
- Reduce number of PDUs (with built-in transformer) inside the data center
Typical 112.5kVA nonlinear UL listed transformer

Significant variation in efficiency over load range

Courtesy of PowerSmiths
High performance vs. TP1 (EPACT 2005) transformer

45kVA Efficiency Comparisons vs. Field Data & TP-1

ESaver C3L -> Light Load optimized, C3H -> Heavy Load optimized

Courtesy of PowerSmiths
Data center lighting

- Lights are on and nobody’s home
  - Switch off lights in unused/unoccupied areas or rooms (UPS, Battery, S/Gear, etc)
  - Lighting controls such as occupancy sensors are well proven

- Small relative benefit but easy to accomplish - also saves HVAC energy

- Use energy efficient lights - Replace older coil/core Ballasts type with new efficient electronic ones

- Lights should be located over the aisles

- DC lighting would compliment DC distribution
Standby generation loss

- Several load sources
  - Heaters
  - Battery chargers
  - Transfer switches
  - Fuel management systems
- Opportunity may be to reduce or eliminate heating, batteries, and chargers
- Heaters (many operating hours) use more electricity than the generator will ever produce (few operating hours)
  - Check with the emergency generator manufacturer on how to reduce the overall energy consumption of block heaters (hot water jacket(s) - HWJ), i.e. temperature control
- Right-sizing of stand-by generator
- Maintain N+1 redundancy
Standby generator heater
Electrical system take aways

- Distributing higher voltage (AC or DC) is more efficient
- Power conversions hurt efficiency
- Highly efficient UPS systems, transformers, and power supplies in IT equipment should be specified
- Lighting energy use is small but an easy opportunity (efficiency and controls)
- Redundancy choices affect efficiency
- Standby generation losses can be minimized
- On-site generation can improve reliability and efficiency
- Consider alternative energy sources
Assessment Tools and Protocols

Bill Tschudi, PE
Online profiling tool

**INPUTS**
- Description
- Utility bill data
- System information
  - IT
  - Cooling
  - Power
  - On-site gen

**OUTPUTS**
- Overall efficiency (DCiE)
- End-use breakout
- Potential areas for energy efficiency improvement
- Overall energy use reduction potential
DOE tool suite: DC Pro

- **Profiling Tool**: profiling and tracking
  - Establish DCIE baseline and efficiency potential (few hours effort)
  - Document actions taken
  - Track progress in DCiE over time

- **Assessment tools**: more in-depth site assessments
  - Suite of tools to address major sub-systems
  - Provides savings for efficiency actions
  - ~2 week effort (including site visit)
DC Pro tools

High Level Profiling Tool
- Overall energy performance (baseline) of data center
- Performance of systems (infrastructure & IT) compared to benchmarks
- Prioritized list of energy efficiency actions and their savings, in terms of energy cost ($), source energy (Btu), and carbon emissions (Mtons)
- Points to more detailed system tools

**IT Module**
- Servers
- Storage & networking
- Software

**Cooling**
- Air handlers/conditioners
- Chillers, pumps, fans
- Free cooling

**Air Management**
- hot cold separation
- environmental conditions

**Electrical Systems**
- UPS
- PDU
- Transformers
- Lighting
- Standby gen.

**On-Site Gen**
- Renewables
- use of waste heat
Steps to saving energy:

- **Energy Profiling**
  - Assessments conducted by owners and engineering firms using DOE tools
  - Tools provide uniform metrics and approach

- **Subsystem Assessment**
  - Audits, design and implementation by engineering firms and contractors

- **Detailed Engineering Audit**

- **Engineering Design**

- **Retrofit/RCx Implementation**

- **Savings Validation (M&V)**
  - M&V by site personnel and eng firms
  - DOE tools used to document results, track performance improvements, and disseminate best practices

- **Documentation**
Getting started with an assessment

Visit:

- Assessment process description
- Assessment worksheet
- Standard report template
- Master list of actions
- Link to DC Pro profiling tool
- Electrical systems tool (Beta spreadsheet version)
DC Pro profiling tool demonstration

www.eere.energy.gov/datacenters
Assessment worksheet

- List of metrics and features
  - Priorities for metrics
  - Data required

- Data collection template

- List of actions
Example “DC Pro” recommendations

List of Actions (for Electric Distribution System)

- Avoid lightly loaded UPS systems
- Use high efficiency MV and LV transformers
- Reduce the number of transformers upstream and downstream of the UPS
- Locate transformers outside the data center
- Use 480 V instead of 208 V static switches (STS)
- Specify high-efficiency power supplies
- Eliminate redundant power supplies
- Supply DC voltage to IT rack
Data confidentiality

- All input data is treated as confidential
- Data in benchmarking charts are “anonymized” with random facility ID numbers
- Data is saved to a secure database server and cannot be accessed by the general public
Contact information

DOE Data Center Program
Paul Scheihing
DOE Industrial Technologies Program
Office of Energy Efficiency and Renewable Energy
202-586-7234
Paul.Scheihing@ee.doe.gov

DC Pro Tool Suite
Paul Mathew
Lawrence Berkeley National Laboratory
510-486-5116
pamathew@lbl.gov
Resources

Bill Tschudi, PE
Links to get started

DOE Website: Sign up to stay up to date on new developments
www.eere.energy.gov/datacenters

Lawrence Berkeley National Laboratory (LBNL)
http://high-tech.lbl.gov/datacenters/

LBNL Best Practices Guidelines (cooling, power, IT systems)
http://high-tech.lbl.gov/datacenters-bpg/

ASHRAE Data Center technical guidebooks
http://tc99.ashraetcs.org/

The Green Grid Association: White papers on metrics
http://www.thegreengrid.org/gg_content/

Energy Star® Program
http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency

Uptime Institute white papers
www.uptimeinstitute.org
Design guidelines are available

• Design Guides were developed based upon observed best practices

• Guides are available through LBNL website

http://hightech.lbl.gov/documents/DATA_CENTERS/06_DataCenters-PGE.pdf
Web based training resource

Data Center Energy Management

- Data center energy costs can be 100-times higher than those for typical buildings.
- Inefficiencies can hurt the bottom line, erode competitiveness, and reduce uptime.

http://hightech.lbl.gov/dctraining/TOP.html
ASHRAE guidelines

six books published—more in preparation


Order from http://tc99.ashraetcs.org/
ASHRAE resources

- ASHRAE (http:www.ashrae.org)
  - Additional Guidelines in Development
    - Contamination
IT power supply resources

- www.ssiforums.org
- www.80plus.org
Other resources

- Electrostatic Discharge Association (http://www.esda.org/)
- Uptime Institute (http://www.upsite.com/TUIpages/tuihome.html)
- Green Grid (http://www.thegreengrid.org/home)
- Chilled Water Plant Resources
Contact information:

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(510) 495-2417
http://hightech.LBL.gov
Questions? - Discussion

Thank you for attending
The Data Center Energy Profiler, or DC Pro, is an online software tool provided by the U.S. Department of Energy to help industries worldwide identify how energy is being purchased and consumed by their data center(s) and also identify potential energy and cost savings. DC Pro is designed so that the user can complete a data center profile in about an hour. When you complete a DC Pro case you are provided with a customized, printable report that shows the details of energy purchases for your data center, how energy is consumed by your data center, potential cost and energy savings, comparison of your data center energy utilization versus other data centers, and a list of next steps that you can follow to get you started saving energy.

This is the beta version of DC Pro released 06/02/2008.
Welcome to DC Pro, if you are a returning user and wish to modify an existing case please select the case below. If you wish to start a new case please select "Start New Case" below.

Name: Bob Smith
Company: ABC

Existing Cases:
- Data Center Example 1mb
- KT Test

or
Start New Case

Help
- If the datacenter is truly standalone, then entering zero is OK for the Non-Data Center Floor Space.
- Contact information is optional. This information will only be used so that your contact information will display properly on the printed report.
Welcome to DC Pro, if you are a returning user and wish to modify an existing case please select the case below. If you wish to start a new case please select 'Start New Case' below.

Name: Bob Smith
 Company: ABC

Enter a name for your case and enter the company name which houses the data center. Then enter the basic information about the datacenter facility.

**Required fields are in bold**

- **Case Name**: 456
- **Data Center Company**: OWERT

**Country**
- **State/Region**
- **County**

**Floor Area (sq feet) - Non Data Center Space**
- **Total Floor Area**
- **Server Racks**

**Floor Area (sq feet) - Data Center Space**
- **Server Racks**
- **Data Center Support Space**

**Type of Data Center**
- **Data Center Tier (Uptime Institute definition)**
- **Current Data Center Buildout Level**

**Do you have premium efficiency motors on all cooling supply fans, pumps, and cooling towers that serve the data center?**
- **What is the redundancy level for HVAC systems?**

**Help**
- If the datacenter is truly stand-alone, then entering zero is OK for the Non-Data Center Floor Space
- Contact information is optional. This information will only be used so that your contact information will display properly on the printed report.
Data Center Energy Profiler

Step 2 - Energy Use Systems

Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.

- Has an energy audit or commissioning been conducted within the last 2 years? [Yes] [No]
- Is there a written energy management plan? [Yes] [No]
- Is there an energy manager directly responsible for the energy management plan? [Yes] [No]
- Has upper management accepted the energy management plan? [Yes] [No]
- Is there an energy measurement and calibration program in place? [Yes] [No]
- Is there a preventative maintenance program in place? [Yes] [No]
Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.

### Energy Management

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many CRAC/CRAH/AHUs are there that operate under normal conditions?</td>
<td>4</td>
</tr>
<tr>
<td>Is there any supplemental cooling?</td>
<td>In-Row</td>
</tr>
<tr>
<td>Does the CRAC/CRAH/AHU have a free cooling coil (water side economizer)?</td>
<td>Yes</td>
</tr>
<tr>
<td>Is there air-side free cooling?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Air Supply Path

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there a floor-tightness (sealing leaks) program in place?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Are the cable penetrations sealed?

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the cable build-up in the floor plenum or the over-head plenum more than 1/3 of the plenum height?</td>
<td>Yes</td>
</tr>
<tr>
<td>Is there a cable-mining (allow proper pressure distribution) program in place?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### IT equipment in rows?

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there a rack/lineup-tightness (using blanking panels) program in place?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Degree of current implementation of alternating hot and cold aisles?

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of current efforts to minimize recirculated air at the racks (for example, blanking panels)?</td>
<td>Fair</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of current efforts to minimize bypass air at the racks (for example, sealing cable penetrations in the floor)?</td>
<td>Fair</td>
</tr>
</tbody>
</table>
Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.

**Is there an Uninterruptible Power Supply (UPS)?**
- Yes
- No

**UPS Technology Type**
- Double Conversion

**What is the average load factor per active UPS module?**
- 50% to 100%

**UPS Redundancy Configuration**
- N+1

**Is there a standby generator?**
- Yes
- No

**Standby Generator Power Configuration**
- N

**Are there PDUs with built-in transformers?**
- Yes
- No

**What are the types of MV and LV transformer(s)?**
- Transformer >80C

**Average Load Factor per Active PDUs / Transformers**
- 25% to 43%
Please answer the following questions related to your data center. After completing the questions for one section click the next button to move to the next set of questions, after completing all of the Energy Use System questions, DC Pro will compute your data center End-Use Breakouts. If you need to modify an answer after moving to the next set, click the previous button to go back.

This screen will compute estimated data center end use. You will have the opportunity to input the actual energy use in Step 4, in whole or in part. DC Pro will modify the default breakouts to accommodate the actual energy use.
Use this screen to enter production information for your data center. This information will be used to calculate energy savings on a per unit of production basis.

The purpose of this screen is to gather some type of information that measures the activity at your data center. This information will be different for each data center. Below is a list of possible types of production information that different data centers might enter.

As you can see from the above examples you are free to enter any type of metric that measures production or activity at your data center. This information has no impact on the calculations of total energy savings by DC Pro. It is only used for your final report to show costs and savings per unit of production (or whatever metric you entered).

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Transctions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Quantity</td>
<td>1000000</td>
</tr>
<tr>
<td>Units</td>
<td>Transactions</td>
</tr>
<tr>
<td>Period</td>
<td>Monthly</td>
</tr>
</tbody>
</table>

Help
- The product name can be anything that you wish.
- If you want to enter production information, all fields are required. If you choose to skip this step, please leave all fields blank.
Use the next four screens to enter data from utility bills and/or submeters recordings, entering this data is optional but doing so will help DC Pro more accurately profile your facility. If you do not enter data, DC Pro will use the default energy end-use percentages from Step 2. Enter data only for those meters that support -- either partly or wholly -- the DC load and/or the DC cooling system. You will be allowed to distribute any of the energy streams across the end-use breakout categories in the next step (Step 5) of the DC Pro process. If your facility does not use one or more of the energy stream simply leave that screen blank and click the next button.

For each energy stream you will need to enter account information for each meter or sub-meter you have data on. For each account enter a Meter ID, select whether or not the meter is a sub-meter (if so what meter it is a sub of), enter the average quantities and units purchased, and select the period for which this purchase reflects. Entering different period intervals for different energy streams is acceptable, as DC Pro will calculate the annual data, but do not enter more than 1 year of data.

<table>
<thead>
<tr>
<th>Electricity</th>
<th>Fuel</th>
<th>Steam</th>
<th>chilled Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter ID</td>
<td>On Site</td>
<td>Sub-Meter Of</td>
<td>Use per Period</td>
</tr>
<tr>
<td>001</td>
<td>No</td>
<td>002</td>
<td>250,000</td>
</tr>
<tr>
<td>002</td>
<td>No</td>
<td>001</td>
<td>50,000</td>
</tr>
<tr>
<td>213</td>
<td>No</td>
<td></td>
<td>25,865</td>
</tr>
</tbody>
</table>
Use the next four screens to enter data from utility bills and/or submeters recordings, entering this data is optional but doing so will help DC Pro more accurately profile your facility. If you do not, DC Pro will use the default energy end-use percentages from Step 2. Enter data only for those meters that support -- either partly or wholly -- the DC load and/or the DC cooling system. You will be allowed to distribute any of the energy streams across the end-use breakout categories in the next step (Step 5) of the DC Pro process. If your facility does not use one or more of the energy streams simply leave that screen blank and click the Next button.

For each energy stream you will need to enter account information for each meter or sub-meter you have data on. For each account enter a Meter ID, select whether or not the meter is a sub-meter (and if so what meter it is a sub of), enter the average quantities and units purchased, and select the period for which this purchase reflects. Entering different period intervals for different energy streams is acceptable, as DC Pro will calculate the annual data, but do not enter more than 1 year of data.

<table>
<thead>
<tr>
<th>Electricity</th>
<th>Fuel</th>
<th>Steam</th>
<th>Chilled Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter ID</td>
<td>Sub-Meter Of</td>
<td>Use per Period</td>
<td>Units</td>
</tr>
<tr>
<td>1234</td>
<td>1.111</td>
<td>ton-hours</td>
<td>$111.00</td>
</tr>
</tbody>
</table>
Step 5 - Energy Use Distribution (optional)

Use these screens to allocate the annual energy use for each meter identified in Step 4 across the Energy End-Use Breakout Categories.

If you do not know what the allocations are for a given meter, it is OK to skip this screen or enter estimates. All of the energy use for a given meter does not have to be allocated to the breakout categories. If the meter serves more than just the data center, it is OK to leave a portion of the energy in the Remainder column.

NOTE: DC Pro provides default percentages for you based on the information entered in Step 2. You may use these default percentages if you are unsure of the actual percentages that each energy use system uses. However, for more accurate results you should estimate your actual percentages and enter them in the boxes below.

<table>
<thead>
<tr>
<th>Meter ID</th>
<th>Total Annual Site Energy Use</th>
<th>IT Load kWh/yr</th>
<th>Lights kWh/yr</th>
<th>Electric Distribution Losses kWh/yr</th>
<th>Fans kWh/yr</th>
<th>Cooling &amp; Humidity Controls kWh/yr</th>
<th>Site Energy Use Related to Data Center kWh/yr</th>
<th>Remainder (Non-Data Center Use) kWh/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>3,000,000</td>
<td>170,000</td>
<td>90,000</td>
<td>30,000</td>
<td>60,000</td>
<td>30,000</td>
<td>2,830,000</td>
<td>170,000</td>
</tr>
<tr>
<td>002</td>
<td>600,000</td>
<td>40,000</td>
<td>10,000</td>
<td>12,000</td>
<td>200,000</td>
<td>20,000</td>
<td>580,000</td>
<td>20,000</td>
</tr>
<tr>
<td>213</td>
<td>300,000</td>
<td>150,000</td>
<td>90,000</td>
<td>10,000</td>
<td>150,000</td>
<td>150,000</td>
<td>263,727</td>
<td>14,000</td>
</tr>
<tr>
<td>Totals</td>
<td>2,253,330</td>
<td>241,998</td>
<td>241,998</td>
<td>241,998</td>
<td>241,998</td>
<td>241,998</td>
<td>2,337,727</td>
<td>232,992</td>
</tr>
</tbody>
</table>

Is this all the electricity associated with the breakout categories being used by the data center? (Check only the categories that are included.

- Yes
- No

Recalculate

Note: Please enter a value for each meter or sub-meter. If the meter or sub-meter does not use any energy from a given category, enter zero.

- The total annual energy use for each meter are the values calculated in Step 4. If you notice a problem with a meter or need to modify one, go back to Step 4 by clicking the icon on the top of the page.

- The percentages in the “Energy Use Related to Data Center” and “Remainder” column for a given meter MUST equal 100%. DC Pro will not let you move onto the next page if they do not.

- You must select “Yes” or “No” in the final row before proceeding to the next energy type. Select “Yes” if there is no additional energy being used by the data center for a given breakout category. Select “No” if there is additional energy being used.
This is your customized DC Pro Summary Report. The report is broken into five basic sections. If you wish to go back and edit any of your values or add more data page to navigate to the desired screen.

1. **Case Information** - your basic case information including energy consumption and savings on a per unit of production basis.
2. **Annual Energy Use** - a summary of your data center’s annual energy purchases and consumption broken down by energy category.
3. **Potential Annual Energy Savings** - an estimation of potential annual energy savings for your data center’s energy use systems displayed in MMBtu and dollar
5. **Suggested Next Steps** - a customized list of suggested next steps for you to take to realize potential energy and cost savings.

**Case Information**

<table>
<thead>
<tr>
<th>Case Name</th>
<th>456</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Bob Smith</td>
</tr>
<tr>
<td>Email</td>
<td><a href="mailto:bsmith@abc.com">bsmith@abc.com</a></td>
</tr>
<tr>
<td>Company</td>
<td>ABC</td>
</tr>
<tr>
<td>Data Center Company</td>
<td>QWERT</td>
</tr>
<tr>
<td>County</td>
<td>Carroll County</td>
</tr>
<tr>
<td>State</td>
<td>Georgia</td>
</tr>
</tbody>
</table>

**Annual Energy Use**

<table>
<thead>
<tr>
<th>Energy Available</th>
<th>Total Amount Generated On Site</th>
<th>Total Amount</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,000</td>
<td>0</td>
<td>12,535</td>
<td>MMBTU/yr</td>
</tr>
<tr>
<td>12,000</td>
<td>0</td>
<td>4,580</td>
<td>MMBTU/yr</td>
</tr>
<tr>
<td>10,000</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Potential Annual Energy Savings

The following chart and data table summarize your data center's potential annual energy savings by breakout category.

**NOTE:** The energy and money savings listed below are only estimates based on the data you entered and the estimated costs associated with the data center site.

<table>
<thead>
<tr>
<th>Breakout Category</th>
<th>Current Energy Use</th>
<th>Potential Energy Use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site Energy</td>
<td>Source Energy</td>
</tr>
<tr>
<td></td>
<td>MMBTU/yr</td>
<td>%</td>
</tr>
<tr>
<td>IT Equipment</td>
<td>7,689</td>
<td>43%</td>
</tr>
<tr>
<td>Data Center Lights</td>
<td>825</td>
<td>5%</td>
</tr>
<tr>
<td>Electric Distribution Losses</td>
<td>1,501</td>
<td>8%</td>
</tr>
<tr>
<td>Fans</td>
<td>2,140</td>
<td>12%</td>
</tr>
<tr>
<td>Cooling</td>
<td>5,633</td>
<td>31%</td>
</tr>
<tr>
<td>Total</td>
<td>17,691</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Suggested Next Steps**

[For more information visit: http://www.dotnetcharting.com]
## Suggested Next Steps

<table>
<thead>
<tr>
<th>Energy Management</th>
<th>IT Equipment</th>
<th>Environmental Conditions</th>
<th>Air Management</th>
<th>Cooling Plant</th>
<th>IT Equipment Power Chain</th>
<th>Lighting</th>
<th>Global Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EC.A.1</strong></td>
<td>Consider Air-Management measures</td>
<td>A low air temperature rise across the data center and/or IT equipment intake temperatures outside the recommended range suggest air management problems. A low return temperature is due to by-pass air and an elevated return temperature is due to recirculation air. Estimating the Return Temperature Index (RTI) and the Rack Cooling Index (RCI) will indicate if corrective, energy-saving actions are called for.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EC.A.2</strong></td>
<td>Consider increasing the supply temperature</td>
<td>A low supply temperature makes the chiller system less efficient and limits the utilization of economizers. Enclosed architecture allows the highest supply temperature (near the upper end of the recommended intake temperature range) since mixing of hot and cold air is minimized. In contrast, the supply temperature in open architectures is often dictated by the hottest intake temperature.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EC.A.4</strong></td>
<td>Place temperature/humidity sensors so they mimic the IT equipment intake conditions</td>
<td>IT equipment manufacturers design their products to operate reliably within a given range of intake temperature and humidity. The temperature and humidity limits imposed on the cooling system that serves the data center are intended to match or exceed the IT equipment specifications. However, the temperature and humidity sensors are often integral to the cooling equipment and are not located at the IT equipment intakes. The condition of the air supplied by the cooling system is often significantly different by the time it reaches the IT equipment intakes. It is usually not practical to provide sensors at the intake of every piece of IT equipment, but a few representative locations can be selected. Adjusting the cooling system sensor location in order to provide the air condition that is needed at the IT equipment intake often results in more efficient operation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EC.A.5</strong></td>
<td>Recalibrate temperature and humidity sensors</td>
<td>Temperature sensors generally have good accuracy when they are properly calibrated (+/- a fraction of a degree), but they tend to drift out of adjustment over time. In contrast, even the best humidity sensors are intrinsically not very precise (+/- 5% RH is typically the best accuracy that can be achieved at reasonable cost). Humidity sensors also drift out of calibration. To ensure good cooling system performance, all temperature and humidity sensors used by the control system should be treated as maintenance items and recalibrated at least once a year. Twice a year is better to begin with. After a regular calibration program has been in effect for a while, you can gauge how rapidly your sensors drift and how frequent the calibrations should be. Calibrations can be performed in-house with the proper equipment, or by a third-party service.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EC.A.6</strong></td>
<td>Network the CRAC/CRAH controls</td>
<td>CRAC/CRAH units are typically self-contained, complete with an on-board control system and air temperature and humidity sensors. The sensors may not be calibrated to begin with, or they may drift out of adjustment over time. In a data center with many CRACs/CRAHs it is not unusual to find some units humidifying while others are simultaneously dehumidifying. There may also be significant differences in supply air temperatures. Both of these situations waste energy. Controlling all the CRACs/CRAHs from a common set of sensors avoids this.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EC.A.8</strong></td>
<td>Consider disabling or eliminating humidification controls or reducing the humidification setpoint</td>
<td>Tightly controlled humidity can be very costly in data centers since humidification and dehumidification are involved. A wider humidity range allows significant utilization of free cooling in most climate zones by utilizing effective air-side economizers. In addition, open-water systems are high-maintenance items.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EC.A.9</strong></td>
<td>Consider disabling or eliminating dehumidification controls or reducing the dehumidification setpoint</td>
<td>Most modern IT equipment is designed to operate reliably when the intake air humidity is between 20% and 80% RH. However, 55% RH is a typical upper level in many existing data centers. Maintaining this relatively low upper limit comes at an energy cost. Raising the limit can save energy, particularly if the cooling system has an airside economizer. In some climates it is possible to maintain an acceptable upper limit without ever needed to actively dehumidify. In this case, consider disabling or removing the dehumidification controls entirely.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EC.A.10</strong></td>
<td>Change the type of humidifier</td>
<td>Most humidifiers are heat-based; i.e., they supply steam to the air stream by boiling water. Electricity or natural gas are common fuel sources. The heat of the steam becomes an added load on the cooling system. An evaporative humidifier uses much less energy. Instead of boiling water, it introduces a very fine mist of water droplets to the air stream. When set up properly the droplets quickly evaporate, leaving no moisture on nearby surfaces. This has an added cooling benefit, as the droplets absorb heat from the air as they evaporate.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>