HVAC and Control System Design for Improved Energy Performance in Data Centers

Mark Hydeman, PE, Principal
Taylor Engineering, LLC
Alameda CA
mhydeman@taylor-engineering.com
www.taylor-engineering.com

Overview

- Present an overview of HVAC system design and controls issues designed to optimize energy performance
- Address current design options then a look at what is likely to emerge in the near future

Taylor Engineering, LLC 2

Agenda

- Set the stage: the potential for efficiency
- Thermal Environment
  - Humidity Controls
- Air Side Design
  - Rack Layout
  - Air-Side Economizers
  - Matching Airflow
- Cooling Plant
- Future
  - On board cooling
  - Data exchange with servers
- Resources

What matters

- **Reliability**
  - First cost
    - Operating costs

The challenge:
To achieve energy efficiency while maintaining reliability and low first cost.

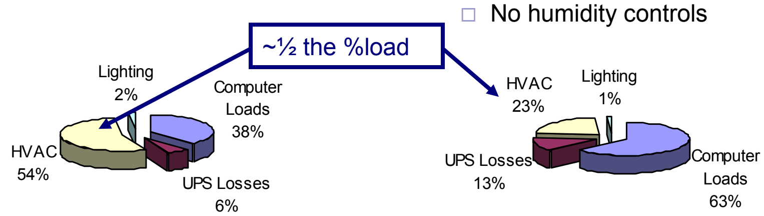
A case study of two designs

- Collocation facility in the Bay Area
- Side by side underfloor and overhead designs
- Motivation for the second design (overhead) was to reduce cost
- Case study was developed by Lawrence Berkeley National Laboratory (LBNL)
  - Data Centers 8.1 and 8.2
- Both sections at ~30% build-out during monitoring

Taylor Engineering, LLC 5

A tale of two designs: overview

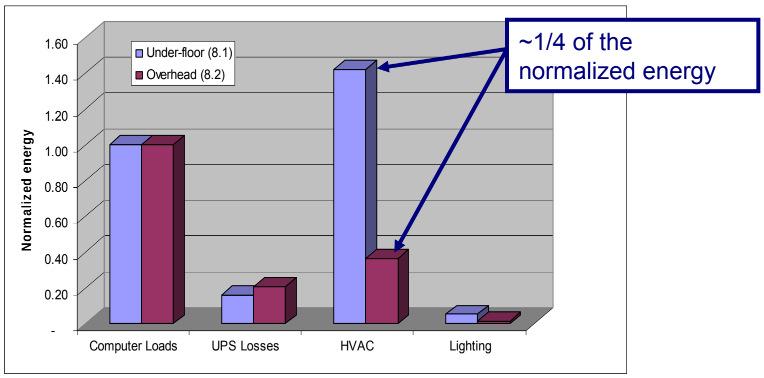
- **Underfloor Data Center (8.1)**
  - 26,200 ft2
  - 27 W/ft2 design
  - Traditional under-floor design with CRAC units
  - Air-cooled DX
  - Humidity controls (45%-55%)
- **Overhead Data Center (8.2)**
  - 73,000 ft2
  - 50 W/ft2 design
  - Overhead supply from central AHUs with CHW coils
  - Water-cooled plant
  - Air-side economizers
  - No humidity controls



Taylor Engineering, LLC 6

A tale of two designs: a closer look

Normalized efficiency metric: $\eta_{cooling} = \frac{kW_{cooling\_systems}}{kW_{servers}}$



Data normalized to computer loads

Taylor Engineering, LLC 7

A tale of two designs: results

- **Underfloor Data Center (8.1)**
  - Around 2x the HVAC installed cost ($/ft2)
  - Higher costs for raised floor as well
  - Around 4x the energy bills (when normalized to server load)
  - Acoustical problems
  - Higher maintenance costs
  - Lost floor space due to CRACs
- **Overhead Data Center (8.2)**
  - Preferred by the facility operators and data center personnel

Taylor Engineering, LLC 8

Two data centers: summary

- What made the difference?
  - Airside economizers
  - Overhead distribution
  - No humidity controls
  - Water-cooled chilled water system

Taylor Engineering, LLC 9

The quest for efficiency

Taylor Engineering, LLC 10

Design conditions at the zone

Table 2.1
Class 1, Class 2 and NEBS Design Conditions

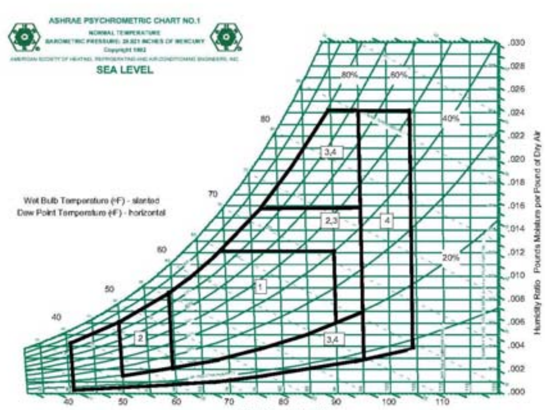
Condition	Class 1 / Class 2		NEBS	
	Allowable Level	Recommended Level	Allowable Level	Recommended Level
Temperature control range	59°F – 90°F[a,f] (Class 1) 50°F – 95°F[a,f] (Class 2)	68°F – 77°F[a]	41°F – 104°F[c,f]	65°F – 80°F[d]
Maximum temperature rate of change	9°F. per hour[a]		2.9°F/min.[d]	
Relative humidity control range	20% - 80% 63°F. Max Dewpoint[a] (Class 1) 70°F. Max Dewpoint[a] (Class 2)	40% - 55%[a]	5% to 85% 82°F Max Dewpoint[c]	Max 55%[e]
Filtration quality	65%, min. 30%[b] (MERV 11, min. MERV 8)[b]			

[a] These conditions are inlet conditions recommended in the ASHRAE Publication *Thermal Guidelines for Data Processing Environments* (ASHRAE, 2004).
[b] 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.
[c] Telecordia 2002 GR-63-CORE
[d] Telecordia 2001 GR-3028-CORE
[e] Generally accepted telecom practice. Telecom central offices are not generally humidified, but grounding of personnel is common practice to reduce ESD.
[f] Refer to Figure 2.2 for temperature derating with altitude

From ASHRAE's Design Considerations for Data and Communications Equipment Centers

Taylor Engineering, LLC 11

Design conditions at the zone



From ASHRAE's Thermal Guidelines for Data Processing Environments

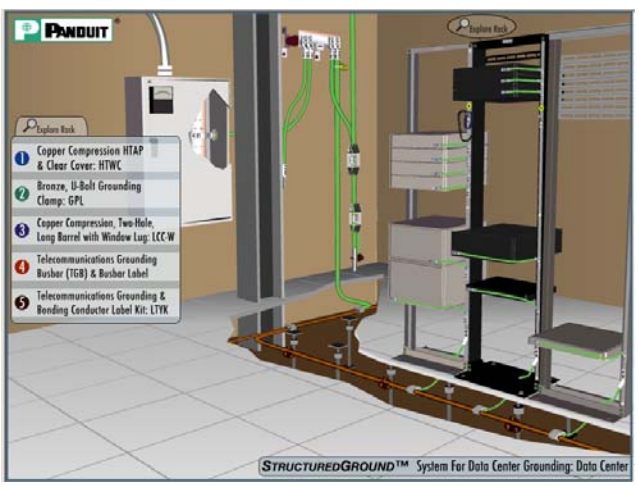
Taylor Engineering, LLC 12

Lower humidity limit

- Mitigate electrostatic discharge (ESD)
  - Can be addressed with procedures (personnel grounding and ESD flooring)
  - Telecom industry has no lower limit
  - Servers tested for ESD resistance
  - Grounding always works, humidification relies on controls, humidifiers and might not work in the hot aisles (due to high ΔT)
  - 3 out of the 11 data centers that LBNL benchmarked had no humidity controls or the controls were disabled
  - ASHRAE Technical Committee 9.9 is planning some research on ESD issues
- And for some physical media (tape storage, printing and bursting)
  - Old technology not found in most data centers

Taylor Engineering, LLC 13

ESD control: floor grounding



Taylor Engineering, LLC 14

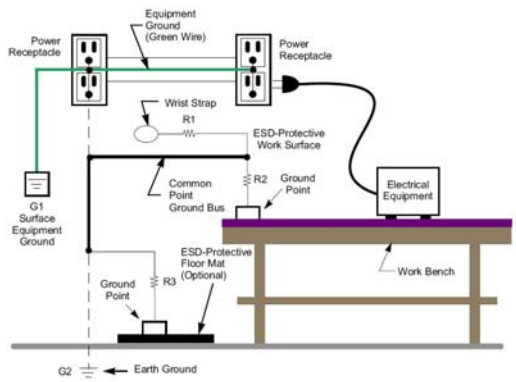
ESD control: personnel grounding

Telecom practice is to leave wrist strap attached to cabinet

Wrist strap

Foot strap

Workplace



Images from Zilog Whitepaper, Preventing Electrostatic Discharge

Taylor Engineering, LLC 15

Upper humidity limit

- Upper humidity limit for data equipment is typically very high or simply non-condensing
- Condensation is only a problem with cold surfaces – data center equipment is always hot
- Cooling coils will maintain a low dew-point naturally without active humidity controls
- Hygroscopic dust can be addressed with filtration
- Hence, typically no need for active upper humidity controls and reheat – waste of money and energy
  - In humid climates pre-conditioning of outdoor air may be needed

Taylor Engineering, LLC 16

Humidity control issues

- Cost of humidity controls
  - First cost of equipment
  - Energy cost of running humidifiers
- Presence of water in data center (make-up water)
- Accuracy and drift of sensors (see Iowa Energy Center study in references)
- Coordination of controls among CRAC units
- Reduces effectiveness of air-side economizers
- Increased fan capacity and energy costs to move air at higher discharge air temperatures

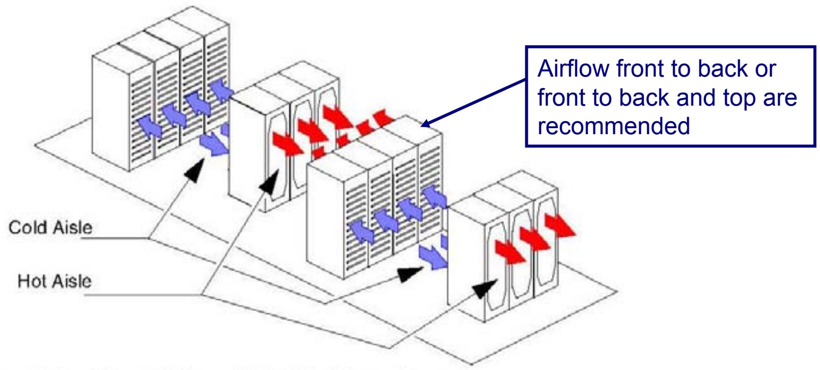
Humidity control recommendations

- Avoid humidification if possible, use telecom procedures
  - If installed, consider adiabatic humidifiers (ultrasonic or direct evaporative cooler)
- Never install reheat coils; the cooling coils will handle the dehumidification naturally
- If installed
  - Humidify/dehumidify centrally, e.g. on make-up air unit
  - Or coordinate the humidity controls across CRAC units to ensure all in same mode
  - Use high quality humidity sensors

Air side design overview

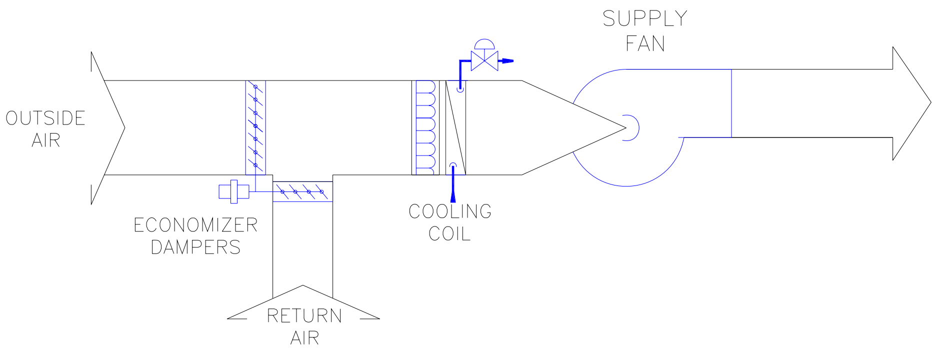
- Data center layout
- Economizers
- Airflow configurations and issues
  - Constant airflow systems
  - Variable airflow systems
- Thermal report form

Data center layout



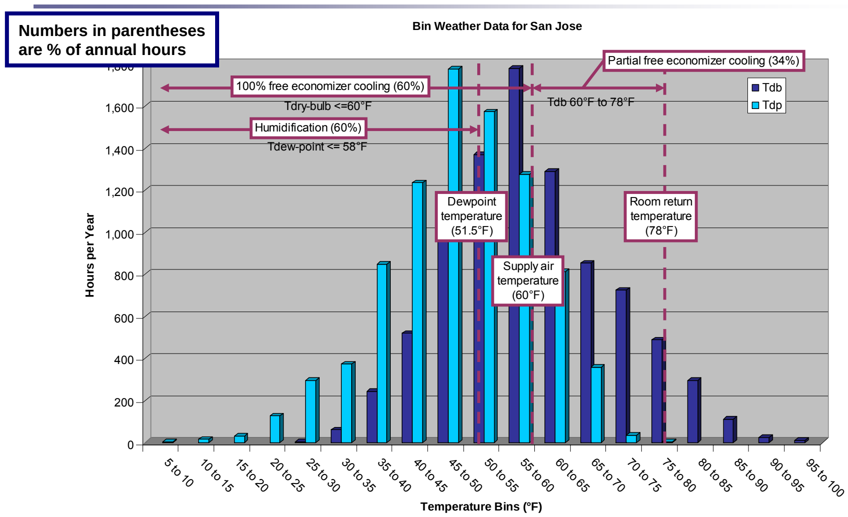
From ASHRAE's Thermal Guidelines for Data Processing Environments

Air-side economizer



Taylor Engineering, LLC 21

Economizer performance



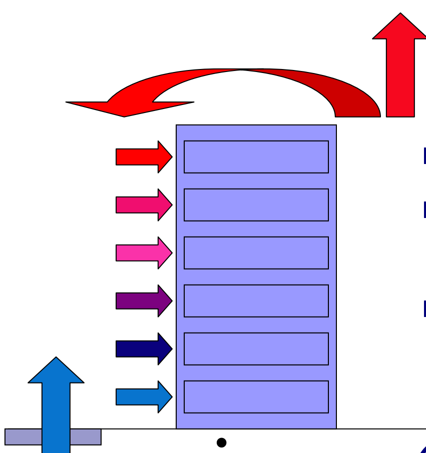
Taylor Engineering, LLC 22

Airflow design disjoint

- IT departments select servers and racks
- Engineers size the fans and cooling capacity
- What's missing in this picture?

Taylor Engineering, LLC 23

Airflow coordination with constant volume server fans

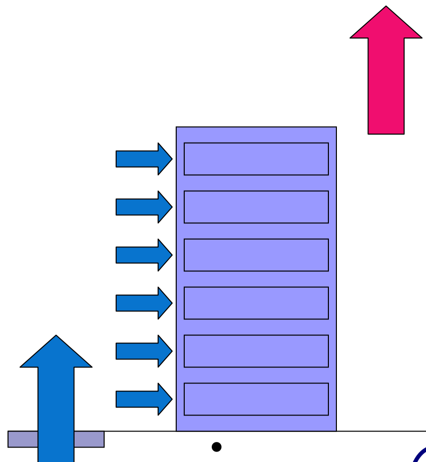


- Hot spots
- Higher hot aisle temperature
- Possible equipment failure or degradation

$$\dot{V}_{HVAC\_Supply} < \sum \dot{V}_{Servers}$$

Taylor Engineering, LLC 24

Airflow coordination with constant volume server fans

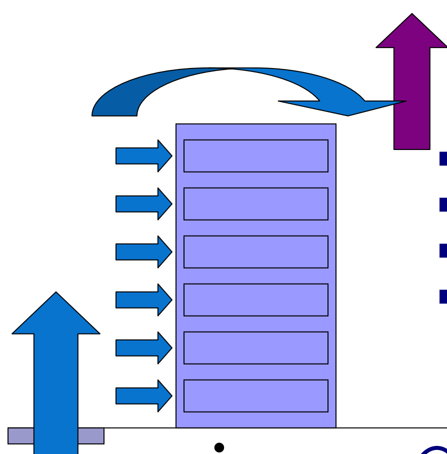


- Least fan energy
- Fewer hot spots
- Best performance
- Will limit densities that can be served by underfloor

$$\dot{V}_{HVAC\_Supply} \approx \sum \dot{V}_{Servers}$$

Taylor Engineering, LLC 25

Airflow coordination with constant volume server fans



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

$$\dot{V}_{HVAC\_Supply} > \sum \dot{V}_{Servers}$$

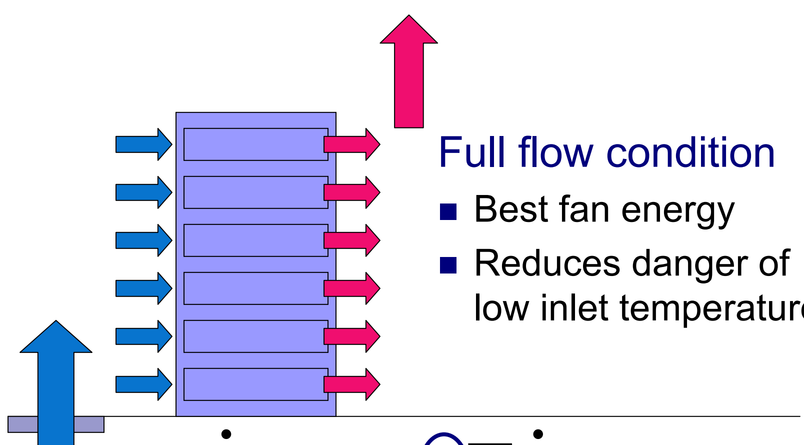
Taylor Engineering, LLC 26

Airflow coordination with constant volume server fans

- Note most of these observations apply to overhead and underfloor distribution
- With constant volume fans on the servers you can only be right at one condition of server loading!
- The solution is to employ variable speed server fans…

Taylor Engineering, LLC 27

Airflow coordination with variable volume server fans



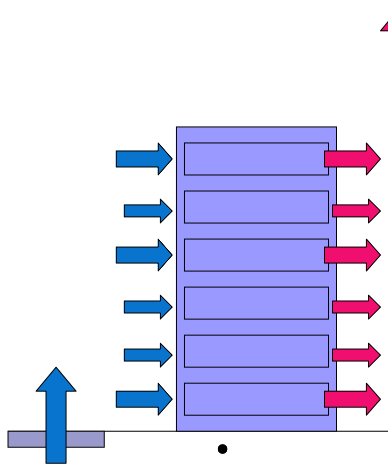
Full flow condition

- Best fan energy
- Reduces danger of low inlet temperatures

$$\dot{V}_{HVAC\_Supply} \approx \sum \dot{V}_{Servers}$$

Taylor Engineering, LLC 28

Airflow coordination with variable volume server fans



Partial flow condition

- Supply controlled to maintain ΔP underfloor or temperatures on rack inlets
- Could be reset by server temperatures or fans (future)

$$\dot{V}_{HVAC\_Supply} \approx \sum \dot{V}_{Servers}$$

Taylor Engineering, LLC 29

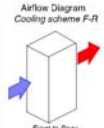
Thermal report

XYZ Co. Model abc Server: Representative Configurations

	Condition								
	Voltage 110 Volts								
	Typical Heat Release	Airflow[a], Nominal		Airflow, Maximum at 35°C		Weight		Overall System Dimensions[b] (W × D × H)	
Description	watts	cfm	(m^3/h)	cfm	(m^3/h)	lbs	kg	in.	mm
Minimum Configuration	1765	400	680	600	1020	896	406	30 × 40 × 72	762 × 1016 × 1828
Full Configuration	10740	750	1275	1125	1913	1528	693	61 × 40 × 72	1549 × 1016 × 1828
Typical Configuration	5040	555	943	833	1415	1040	472	30 × 40 × 72	762 × 1016 × 1828

ASHRAE Class: 1, 2, 3

Airflow Diagram
Cooling scheme F-R



Minimum Configuration	1 CPU-A, 1 GB, 2 I/O
Full Configuration	8 CPU-B, 16 GB, 64 I/O (2 GB cards, 2 frames)
Typical Configuration	4 CPU-A, 8 GB, 32 I/O (2 GB cards, 1 frame)

a. The airflow values are for an air density of 1.2 kg/m^3 (0.075 lb/ft^3). 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 40 in. (1016 mm) in the rear.

From ASHRAE's Thermal Guidelines for Data Processing Environments

Taylor Engineering, LLC 30

Best practices

- Arrange racks in hot aisle/cold aisle configuration
- Provide server thermal reports to engineers
- Provide temperature controlled variable airflow fans at servers
- Provide variable airflow fans for AC unit supply
  - Also consider using air handlers rather than CRACs for improved fan energy usage
- Connect temperature sensors at racks to reset supply air and airflow setpoints
- Configuration of overhead or underfloor
  - Overhead provides better temperature control at rack inlets
  - Overhead usually has cost advantages

Taylor Engineering, LLC 31

Plant Issues

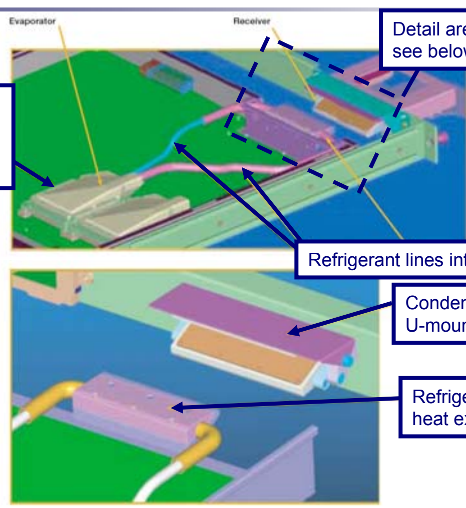
- Refer to CoolTools™ design guide for optimization of chilled water plants
- Best Energy Efficiency practices
  - Water cooled where possible
    - Requires on-site water storage, however
  - Evaporative precoolers on air-cooled equipment
  - Variable speed high efficiency chillers
  - Variable speed/flow with 2-way valves
  - Oversized propeller cooling towers with VSDs
  - Use CoolTools™ LCC chart for sizing of pipes

Taylor Engineering, LLC 32

Future

- Liquid cooling
  - Chilled water
  - Condenser water and refrigerant heat pipes
- Integration of server temperature sensors with EMCS (using IP)
- Lower energy servers

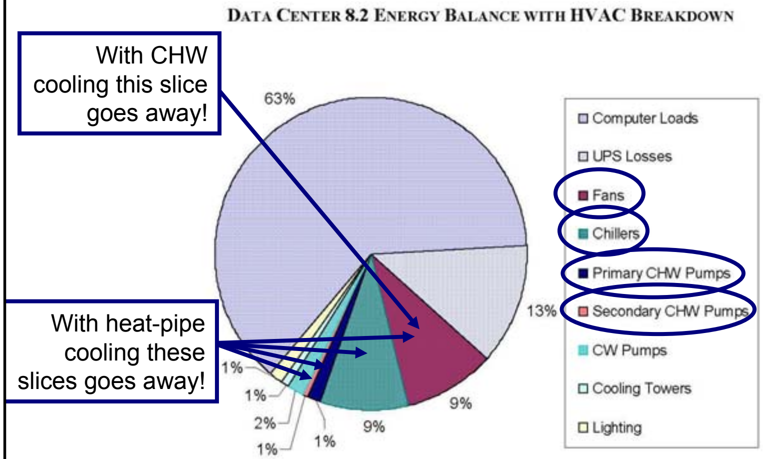
On-Board Cooling with Heat Pipes



From Intel Developer Update Magazine, March 2002.

High-density Architecture Meets Electrical and Thermal Challenges

Liquid cooling potential



From LBNL report, Data Center Energy Benchmarking Study, Facility 8

Taylor Engineering, LLC 35

Resources

- Upcoming PG&E Pacific Energy Center Seminar
  - Energy-Efficient HVAC Design and Control for High Density Data Centers
  - Mark Hydeman, Peter Rumsey and Dr. Magnus Herrlin
  - April 6th, 9am-4:30pm
  - 851 Howard Street (between 4th and 5th Streets), San Francisco
  - http://www.pge.com/pec

Taylor Engineering, LLC 36

Resources

- ASHRAE (http:\\www.ashrae.org)
  - Technical Committee (TC) 9.9 Mission Critical Facilities http://tc99.ashraetcs.org/
  - Design Considerations for Datacom Equipment Centers
  - Datacom Equipment Power Trends and Cooling Applications
  - Thermal Guidelines for Data Processing Environments
  - Additional Guidelines in Development (1/2006)
    - TCO and Energy Efficiency
    - High Density Data Centers
    - Liquid Cooling

Taylor Engineering, LLC 37

Resources

- LBNL High Performance Buildings for High-Tech Industries (http://hightech.lbl.gov/datacenters.html)
- PG&E CoolTools™ Chilled Water Plant Design Guide (send email to Marlene Vogelsang at mxv6@pge.com)
- EDR High Performance Datacenters, A Design Guidelines Sourcebook (http://www.energydesignresources.com)
- Electrostatic Discharge Association (http://www.esda.org/)
- Uptime Institute (http://www.upsite.com/TUIpages/tuihome.html)
- Iowa Energy Center research report on humidity sensors (http://www.buildingcontrols.org/publications.html#other)

Taylor Engineering, LLC 38

The end

Taylor Engineering, LLC 39