HPC Data Center Cooling Design Considerations

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Data Center Efficiency

Today’s discussion will cover:

1) ASHRAE Activities
2) Fundamentals of the design of data centers
3) Typical Equipment involved in cooling Data Centers
4) Best Practices/Lessons Learned
5) Summit Design Overview
ASHRAE – TC9.9 Activities

• Meetings cover – Website, Handbook updates, Programs, Research (High Humidity, CFD, and DC Energy Modeling), Liaison Reports, and new/updated publications

• Subgroups for data center energy calculations
  – Data center zone/space, air flow, solution/simulation model
  – Prototype correlation based data center HVAC systems spreadsheet model based on Comnet
  – Prototype TC 4.7 secondary and primary toolkit spreadsheet model using callable Fortran from Excel
ASHRAE TC 9.9 – Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment

TC 9.9 is concerned with all aspects of mission critical facilities, technology spaces, and electronic equipment/systems. This includes data centers, computer rooms/closets, server rooms, raised floor environments, high-density loads, emergency network operations centers, telecom facilities, communications rooms/closets, and electronic equipment rooms/closets.
ASHRAE – 90.4 Approved/Published

• ASHRAE 90.4 – Energy Standard for Data Centers

• Data Center – a room or building, or portions thereof, including computer rooms being served by the data center systems, serving a total ITE load greater than 10 kW and 20 W/ft² (215 W/m²) of conditioned floor area.

• Performance Based
  – Mechanical and Electrical
  – Trade-off Method

• Compliance requires calculations at 100% and 50% of the design ITE load.

• Refers to 90.1 for envelope, lighting, service water heating, and equip. eff.
Data Center Efficiency

According to DOE

• How many data centers are in the U.S.?
  – ~3,000,000
  – ~1 for every 100 people
  – Spread all over the country

• What is a data center? – depends on who you ask…
  – A repository (closet, room, floor, or building) for the storage, management, and dissemination of data and information. Data centers house computing systems and associated components, such as telecommunications and storage systems.

• Why does it matter?
  – In 2014, U.S. data centers consumed ~70 billion kWh, or about 1.8% of total US electrical consumption. The number of data centers is growing and total energy use is expected to grow 4% from 2014-2020. (Source: Lawrence Berkley National Laboratory).
Data Center Cooling – Fundamentals

- Waste Heat
- Central Energy Plant 16%
- Environmental Control 5%
- IT Equipment 67%
- PDU 3%
- UPS 6%
- Low Voltage Electric Distribution and Lighting 3%
- Information Production (e.g. cat videos)
- Waste Heat to Environment
- Power IN
Data Centers and Mechanical Efficiency

- Measures of Efficiency
  - kW/ton, kW/cfm, etc.
- Technologies (Inherent Efficiencies)
  - Within the Data Center
    - Humidity Control
    - Air Cooling
      - Perimeter
      - In-row
      - Cabinet Based
      - Air Side Economizers
  - Liquid Cooling
  - Central Energy Plants
    - Air Cooled
    - Water Cooled
    - Water Side Economizers
Data Center Efficiency

What impacts efficiency in data centers?

• Electrical
  – Individual component/equipment efficiency
  – System efficiency

• Mechanical
  – Individual component/equipment efficiency
  – System efficiency
  • Controls

• IT
  – Individual component/equipment efficiency
  • Energy Star
  – System efficiency
  • Policy
  • Virtualization
  • Cloud

• Controls

• System efficiency
  • Energy Star
  • Policy
  • Virtualization
  • Cloud
Data Center Efficiency

Measures of Efficiency

• It’s how much do you have to put in compared to what you get out

• Power Usage Effectiveness (PUE) ratio of total data center energy consumed annually to the total IT energy consumed annually. Lower the better.

\[
PUE = \frac{E_{\text{FACILITY}} + E_{\text{IT}}}{E_{\text{IT}}}
\]

\( E_{\text{FACILITY}} = \) Energy consumed by the IT supporting systems annually

\( E_{\text{IT}} = \) Energy consumed by the IT equipment annually

2.0 Standard, 1.4 Good, 1.1 Better, 1.0 Best

\[1/PUE = \text{DCiE (Data Center Infrastructure Efficiency)}\]
Data Center Efficiency

Measures of Efficiency

• It’s how much do you have to put in compared to what you get out

• kW/ton – commonly used in cooling plants

Plant Eff. = \frac{kW_{\text{CONSUMED}}}{\text{tons of cooling}}

kW = Power consumed by the facility

Tons = Rate at which heat is removed from the system
Data Center Efficiency

- Measurements taken while a 6600 ton chiller plant had a HPC IT load of ~8.1MW (2300 tons or 35% load). Chiller Plant efficiency = 0.75kW/ton

- For a “typical” data center
Data Center Efficiency

Figure 3: Google includes servers, storage, and networking equipment as IT equipment power. We consider everything else overhead power.

Equation for PUE for our data centers

$$PUE = \frac{ESIS + EITS + ETX + EHV + ELV + EF}{EITS - ECRAC - EUPS - ELV + ENet1}$$
Monitoring & Metering Strategy

System PUE Dashboard
Data Center Cooling

Final Heat Rejection
- Dry Cooler
- Air Cooled
- Evaporatively Cooled
- Water Cooled w/ HX
- Water Cooled Direct

Central Energy Plant
- Refrigerant DX
- Chiller
- Economizer
- Heat Exchanger
  - Can be integrated with chiller for partial use.

Distributor of Cooling
- CRAC
- CRAH
- Central AHU
- Liquid Cooling
- CDU W/ RDHx

Distribution Method
- Raised Floor
- Over Head
- In Row
- In Rack
- On Board

Water to Outside Air (Cooling Tower)
- Refrigerant to Water (Chiller Condenser)

Air to Water (CRAH)

Circuitry to Air and/or Liquid (Rack)

NEED TO SPECIFY HOW THE HEAT GETS FROM THE CIRCUITRY TO THE ENVIRONMENT PROVIDE EQUIPMENT SPECIFICATIONS
Data Center Efficiency – Air Management

General Air Side Cooling Design Using Facility Fans

- Make air flow management a priority from the beginning and make it visible, so it is more likely to be maintained. Keep the supply and return air paths separate!
- Use premium efficiency motors with variable frequency drives (VFDs) or electronically commutated (EC) direct drive fans
- Use filters with low pressure drop
- Minimize pressure drop in the air distribution
- Minimize air flow volume and length of air flow path to the IT equipment and back to the air handler
Data Center Efficiency - Perimeter

- Automatic backflow damper with fail closed position (if redundancy allows)
- Include VFD
- Control air flow based on underfloor pressure or rack inlet temperatures
- Return air from the highest point possible above the CRAH/CRAC
- Run the fewest number of CRAHs/CRACs possible at minimum VFD speed needed
- Locate down flow air handlers at the ends of hot aisle if possible
- Avoid installing down flow air handlers too close to cold aisles
- Maintain clearances around the air handlers to allow proper maintenance
Data Center Efficiency – In-Row Coolers

- Require EC Fans
- Control air flow based on CAC pressure or rack inlet temperatures
- Control supply air temperature on an individual unit basis
- Run the fewest number of IRCs possible at minimum EC fan speed needed
- Locate throughout the row for best air flow distribution
- Avoid installing IRCs too close to the ends of the aisles
- Calibrate sensors periodically
## Data Center Efficiency – Air Flow Management – Air Distribution

### CRU Return Temperatures Study - Before and After Installing Top Hats

<table>
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<th>CRU</th>
<th>Before</th>
<th>After Top Hats</th>
<th>Difference</th>
</tr>
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<td>64.4</td>
<td>68.3</td>
<td>3.9</td>
</tr>
<tr>
<td>CRU 2</td>
<td>65.7</td>
<td>70.1</td>
<td>4.4</td>
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<td>73.8</td>
<td>76.2</td>
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<td>CRU 38</td>
<td>65.4</td>
<td>70.7</td>
<td>5.3</td>
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<tr>
<td>CRU 21**</td>
<td>67.3</td>
<td>71.9</td>
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<tr>
<td>CRU 20</td>
<td>72.7</td>
<td>71.9</td>
<td>-0.8</td>
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<tr>
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<td>66.6</td>
<td>75.2</td>
<td>8.5</td>
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<tr>
<td>Average</td>
<td>68.0</td>
<td>72.1</td>
<td>4.4</td>
</tr>
</tbody>
</table>
Data Center Efficiency – Air Flow Management – Hot/Cold Aisle Containment

**ORNL CACS - Cold Aisle Containment System**

- Polargy Drop-away Containment Panels
- Network Cable Tray
- IRC
- Smoke Detection
- Chilled Water Supply
- Chilled Water Return
- Leak Detection
- Individual Cabinet Power and Monitoring

**PolarFlex™ 42U Blanking Panels**

**PolarBlock™ Air Separation Skirts and Barriers**
Data Center Efficiency – Air Flow Management – Floor Penetrations
Data Center Efficiency – Air Flow Management – Active Tiles
Data Center Efficiency – Air Flow Management Metrics

• Airflow efficiency - Air Handler Fan Power (W)/Total Air Flow (cfm)
  – 1.25W/cfm Standard
  – 0.75W/cfm Good
  – 0.5W/cfm Better

• Return Temperature Index (RTI)
  – RTI is a measure of the efficiency of air flow in the data center. The results of this calculation show how much improvement the air flow system can have. The desired result is 90%-110%. An RTI value of less than 100% indicates that the some of the supply air is by-passing the racks, and a value greater than 100% indicates that there is recirculation of air from the hot aisle.

\[
RTI = \left( \frac{\text{Return}_{AT} - \text{Supply}_{AT}}{\text{Outlet}_{RT} - \text{Inlet}_{RT}} \right)
\]

Where

Return\(_{AT}\) . . . = CRAH Return Air Temperature
Supply\(_{AT}\) . . . = CRAH Supply Air Temperature
Outlet\(_{RT}\) . . . = Rack Outlet Mean Temperature
Inlet\(_{RT}\) . . . . = Rack Inlet Mean Temperature
Data Center Efficiency – Air Flow Management Metrics

• Rack Cooling Index (RCI)
  - The RCI is a measure of compliance with ASHRAE/NEBS temperature specifications. RCI_{HI} = 100%: no temperature above max recommended, RCI_{LO} = 100%: no temperature above max recommended. Below 90% is poor in this index.

\[
RCl_{HI} = \left[ 1 - \frac{\text{Average Over Temp}}{\text{Max Allowed Over Temp}} \right] \times 100(\%)
\]

Where
Max Allowed Over Temp = 32°C or 89.6°F
Max Recommended = 27°C or 80.6°F
Average Over Temp = Average Temp – Max recommended

\[
RCl_{LOW} = \left[ 1 - \frac{\text{Average Under Temp}}{\text{Min Allowed Under Temp}} \right] \times 100(\%)
\]

Where
Min Allowed Under Temp = 15°C or 59.0°F
Min Recommended = 18°C or 64.4°F
Average Under Temp = Min Recommended – Average Temp
**Energy Efficiency Best Practices**

**Water Cooled Computing**
- Trend is towards elevated chilled water temps (dedicated systems?)
- Water side economizers
- Possible to eliminate or reduce chiller use in some climates
- Lake or seawater cooling

**In Row Cooling**
- Reduces floor space requirements
- Allows for increased rack density
- 30-40% more efficient than perimeter cooling

**Air Flow Management**
- Hot/cold isle containment
- Blanking panels in racks
- Seal raised floor openings
Energy Efficiency Best Practices

Variable Frequency Drives (VFDs)
• Utilized on chillers, towers, pumps
• Significant partial load savings
• Allows for higher chilled water temps
• Sensitive to power quality events, may require UPS power

Transformers near loads
• Reduces line loses
• Climate controlled electrical rooms improve reliability and maintainability
• Reduces copper costs for distribution to loads

Metering
• Recommend metering power, chilled water, potable water usage on per system and data center total basis
• Allows for metrics (PUE) and measuring impact of efficiency upgrades
• Useful in determining available capacity for future systems
Energy Efficiency Best Practices

High Efficiency UPS

- Energy Efficient UPS Mode
- Allows for higher energy efficiency to load
- Long Battery life
Data Center Efficiency

Best Practice Features in the Data Center

• Dew Point Control with supervisor control preventing simultaneous dehumidification and humidification. Have dedicated system for controlling humidity if possible.

• Aisle containment – CAC, HAC for row or perimeter based cooling

• Floor penetration seals – grommets, brushes

• Pressurization air – conditioned and filtered

• Install vapor barrier around the data center

• Turn off reheat (part of dehumidification process)

• Control supply air temperature
Data Center Efficiency

Best Practice Features in the Data Center

• Maximize supply and return temperatures at air handlers
• Maximize allowable ranges of environmental conditions
• Calibrate Sensors
• Economize!

To the right – ASHRAE TC 9.9
Inlet Conditions
Data Center Efficiency – Air Flow Management – Air Distribution
Data Center Efficiency – Floor Openings

- Electrical PDUs and RDUs
- CRAHs/CRACs
- Perforated Tiles
- Column Wraps
- IT Equipment
- Cooling Distribution Units
- Switch Board Primary Conduit(s)
- Any penetration to/from data center, especially under the floor (high pressure area for perimeter cooling)
Data Center Efficiency – Air-Side Econo

Good if you are away from the coast, have clean air and the real-estate for the filters, duct, and air handlers.

Usage depends on air supply temperatures and geographic location

Yahoo “Chicken Coops”

PUE = 1.1
Data Center Efficiency – Air Cooled Chiller Plants

Generally small data centers.

Digital Scroll Compressors and pumped refrigerant technologies with economizers are bringing kW/ton more toward water cooled centrifugal plant efficiencies.

kW/ton – 0.95-1.2

Image - ASHRAE
Data Center Efficiency – Rack Level

- Must have separate air filtration system for balance of the data center space.
- Must have separate humidity control system if rack coolers can’t handle condensate (and cooling fluid temperatures must remain about dew point).
- Rack coolers are best if designed for sensible cooling only (no wet coils) with supply temperatures as low as an economizer can do while being above the dew point temperature in the space.
- Require EC fans if not rear door heat exchangers
Data Center Efficiency

Liquid Cooling – Allows higher cooling temperatures

Remember why water is better than air?

Higher heat capacity per unit volume

Higher pumping efficiency

Higher rate of heat transfer

Most of the time you still have heat to remove on the air side

HP

ASE
Data Center Efficiency

Liquid Cooling – Immersion

Geek.com (above)

GRC (right)

3M - https://www.youtube.com/watch?v=a6ErbZtpL88
Data Center Efficiency – Water Cooled Chiller Plants

Best Practices in the CEP

- VFDs on chilled water, condenser water pumps, and cooling tower fans
- VFDs on centrifugal chillers
- Premium Efficiency Motors
- Optimized controls
  - Utilize turn down on cooling towers
  - Coolest condenser water temperature – run towers in parallel
  - Head pressure control on chillers
  - Base load constant speed chillers and trim with VFD chiller if chiller plant is mixed
- Water side economize
- Supply highest chilled water supply temperature possible
- Water cooled is more efficient than air cooled systems
Data Center Cooling – Water-side Econo

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Refrigerant to Water (Chiller Evaporator)

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Data Center Efficiency – Water-Side Econo
Data Center Efficiency – Water-Side Econo

Cooling Summit
Summit - Expected Cooling Source

• Variables
  - System Size (changes the slope of CHW demand)
  - Cabinet Load (changes the overall load)
  - Cabinet Cooling Supply Temperature (shifts the demand line left/right)
  - Approach Temperatures of HXs and Cooling Towers (shifts the demand line left/right)
  - Outside Air Wet Bulb Temperature
Data Center Efficiency - Resources

DOE FEMP

• DC Pro 3 Profiling Tool for Data Centers Software

• Data Center Air Management Tool

• https://datacenters.lbl.gov/technologies
Data Center Efficiency

• Resources


• Vendor sites have great information about general data center related topics

• Webinars!

• [https://datacenters.lbl.gov/](https://datacenters.lbl.gov/)


• [http://www.thegreengrid.org/](http://www.thegreengrid.org/)

• [http://www.datacenterknowledge.com](http://www.datacenterknowledge.com)


• [https://uptimeinstitute.com/](https://uptimeinstitute.com/)


• LBNL Data Center Energy and Water Usage Report 2016
HPC Data Center Cooling Design Considerations

Questions & Discussion