Innovative Data Center Energy Efficiency Solutions

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A holistic Challenge: Energy & Thermal Management

- Energy / thermal management is relevant on all levels
- Various length and times scale and interdependencies are involved but also many analogies/similarities exist
- Truly holistic understanding is required to conquer the challenge
• The challenge is even bigger: Energy/thermal issues propagate all the way to the world climate

• Earth has an energy and thermal problem as well
Hotspots exist on all levels

Cooling hotspots cost (a lot of) energy and determine cooling energy efficiencies

...but opportunities for mitigation exist
(i.e., static, dynamic, spatial, temporal, spatial-temporal)
**Thermal Management and Hotspots**

**Microprocessor**  
~ 300 M transistors

**US Power Grid**  
~ 300 M customers

**Data Center**  
~ 1000 of servers

**Superstore / Airports**  
~ 1000 of customers
**Data Center Facts**

- DCs consume ~ 2 % of all US electricity
- **annual growth** (15 %) is non-sustainable
- DC power projected to be > 8 % of US power by 2020
- governments consider regulatory actions

- every DC is **different**, DCs are heterogeneous and **change** over time
- DCs are **not as efficient** as they should
- inefficiencies are caused by lack of **best practices**
- best practices are **hard to manage** because they are **hard to measure**
How to measure, model and manage data center energy efficiency?

- DC energy efficiency: PUE and beyond
- from a Mobile Measurement Technology (MMT 1.0)…
  - need for spatially dense data
  - a first solution
  - case study and results
- to a Measurement Management Technology (MMT 1.5)…
  - from a static to a dynamic solution
  - energy and thermal models
  - case study and results
PUE is widely used today: \[ \text{PUE} = \frac{\text{Total DC Power}}{\text{IT Power}} \]

- many PUE “claims” – but PUE metric can be problematic
  - weather-dependent, location dependent, application/tier dependent
  - non-linear, awards UPS consumption, power density dependent
  - PUE does not include IT performance
  - PUE metering is often not in place
  - PUE is often insufficient for “proving” and managing energy efficiency
**A more detailed Look – DC Energy Efficiency**

**Thermodynamic COP**

\[ \text{COP}^*_{\text{thermo}} \approx \frac{P_{RF}}{P_{\text{Chiller}}} \]

**Average Chiller COP** (throughout the year)

\[ \frac{1}{\text{COP}} \approx \frac{1}{\text{COP}_{\text{thermo}}} + \frac{1}{\text{COP}_{\text{trans}}} \]

**Transport COP**

\[ \text{COP}_{\text{trans}} \approx \frac{P_{RF}}{\sum_{i=1}^{\text{# of active ACUs}} P_{i}^{\text{ACU}}} \]

**THERMODYNAMIC PART OF COOLING:**

HOTSPOTS / HIGH INLET TEMPERATURES IMPACT CHILLER EFFICIENCY (~ 1.7 % per F)

**TRANSPORT PART OF COOLING:**

LOW ACU UTILIZATION IMPACTS ACU BLOWER CONSUMPTION (~ 5-8 kW/ACU)
**Visualizing, Measuring and Managing Data Center Best Practices**

**Mobile Measurement Technology**

- designed to optimize DC resources to reduce up to 15% of DC energy consumption
- scans, digitize rapidly physical environment (temperature, flow, pressure etc..) of DC
- cart tool comprises sensor network, where each sensor defines a virtual unit cell
- technology is based on interworking between measurements, models and DC management

![Diagram of temperature distribution and hot spot](image)
IBM Mobile Measurement Technology (MMT 1.0)

Solution Approach – Three Steps

1. Measure
   - Capture high resolution temperature data, air flow data, and infrastructure & layout data

2. Model
   - To identify improvement opportunities
     - model the data center and use optimization algorithms (“best practices rules”)

3. Manage “Best Practices”
   - Realize air transport energy savings
   - Realize thermodynamic energy savings
     - Achieve reduced energy consumption
     - Potential for deferring new investments
**MMT 1.0 @ Work – 3D Heat Maps**

- Detailed 3D heat maps (<40 mins scan time)
- 30,000 thermal readings
- 3,000 humidity readings
- 200 air flow sensors

**MMT – Scans:**
Thermal measurements at different heights (1 ft increments in z)
**MMT 1.0 @ Work – Energy Savings**

Case Study: DC Area = 20k sqf; Temp. Meas. = 200,000; Airflow Meas. = 1,200; Power density ~ 75 W / sqf

**Thermo Savings**

*BEFORE*

**AFTER**

**Transport Savings**

*BEFORE*

**AFTER**

**Increase Chiller Set-Point**

**Increase ACU Utilization**

Thermo Savings: 4 F = 20 kW

Thermo Savings: 34% = 120 kW

Increase Chiller Set-Point: 7 F = 37 kW

Increase ACU Utilization: 34% = 120 kW
Typical Energy Savings

- saved 177 kW with measurement / metrics driven best practices implementation
- developed 6 tier metric to drive best practices implementation with minimal investments
- typical 1-2 Month turnaround to realize savings
- Improved DC COP 2.39 to 3.44
  - $\text{COP}_{\text{thermo}}$ from 4.5 to 5.1
  - $\text{COP}_{\text{trans}}$ from 5.3 to 9.8

<table>
<thead>
<tr>
<th>Finding / Metrics</th>
<th>Key Action / Solution</th>
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<tbody>
<tr>
<td>Horizontal hotspots (HH)</td>
<td>change tile layout &amp; deploy high throughput tiles</td>
</tr>
<tr>
<td>Vertical hotspots (VH)</td>
<td>snorkels / fillers</td>
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<tr>
<td>Non-targeted air flow</td>
<td>close leaks / cable cutouts</td>
</tr>
<tr>
<td>Plenum temperatures</td>
<td>service ACUs supply side / increase ACU utilization</td>
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<tr>
<td>ACU utilization</td>
<td>turn under-utilized ACUs off</td>
</tr>
<tr>
<td>ACU flow</td>
<td>remove blockage</td>
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Case Study:  DC Area = 20k sqf; Temp. Meas. = 200,000; Airflow Meas. = 1,200; Power density ~ 75 W / sqf
**MMT 1.0 - Status**

- MMT service provided to more than 30 DCs (different sizes, power densities, locations etc.)
- Repeatedly identified energy savings of > 10% of IT power (to date more than 35 M kW hours)
- MMT has delayed major DC upgrades / capital investments
- MMT is being deployed in all IBM’s strategic DCs in NA (saving target of more than 17 M kW hours)
- MMT 1.0 is a service offering in 3 GEOs (NA, EMEA, AP,...)
**MMT 1.5 - From a static to a dynamic Solution**

- DC can change over time
  - IT power levels can change (e.g., 10-15% during a day)
  - cooling conditions change etc..
  - new racks / new servers / re-arrangement of tiles etc..
- MMT 1.0 is “sparse” in time but “dense” in space
- Real-time sensor are “sparse” in space but dense in time
- MMT 1.5 provides high time & spatial resolution combining
  - MMT 1.0 for **base model** generation, sensor placement etc..
  - real-time sensors for creating **dynamic models**

Animation of 3D heat map over 24 hours
Evolution from MMT 1.0 to MMT 1.5

Mass Transport Equation: \( \nabla^2 \varphi = 0 \)

Energy/Thermal Equation:
\[
\rho c_p \nabla \cdot \nabla T + \nabla \cdot (k \nabla T) + h_{\text{Racks}} = 0
\]
Summary

• MMT 1.0 has repeatedly shown energy efficiency improvements by more than 10%
  http://www.youtube.com/watch?v=feF7vFj4Deo

• MMT is being extended to an active energy management energy solution by combining MMT models with real-time sensor data (MMT 1.5)

• MMT leverages different models based on data availability, and application