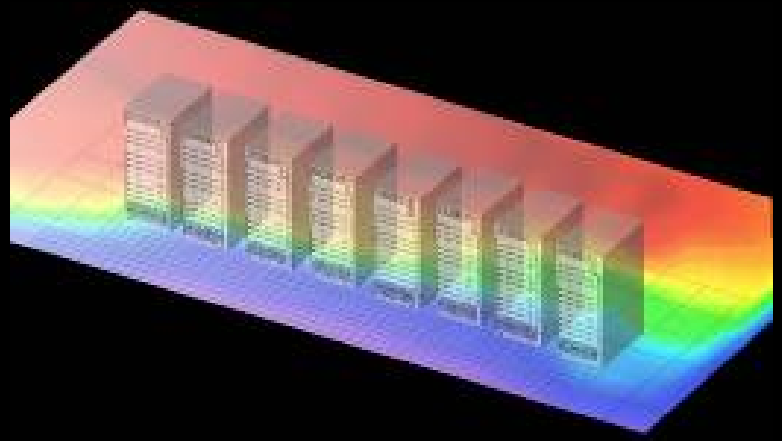
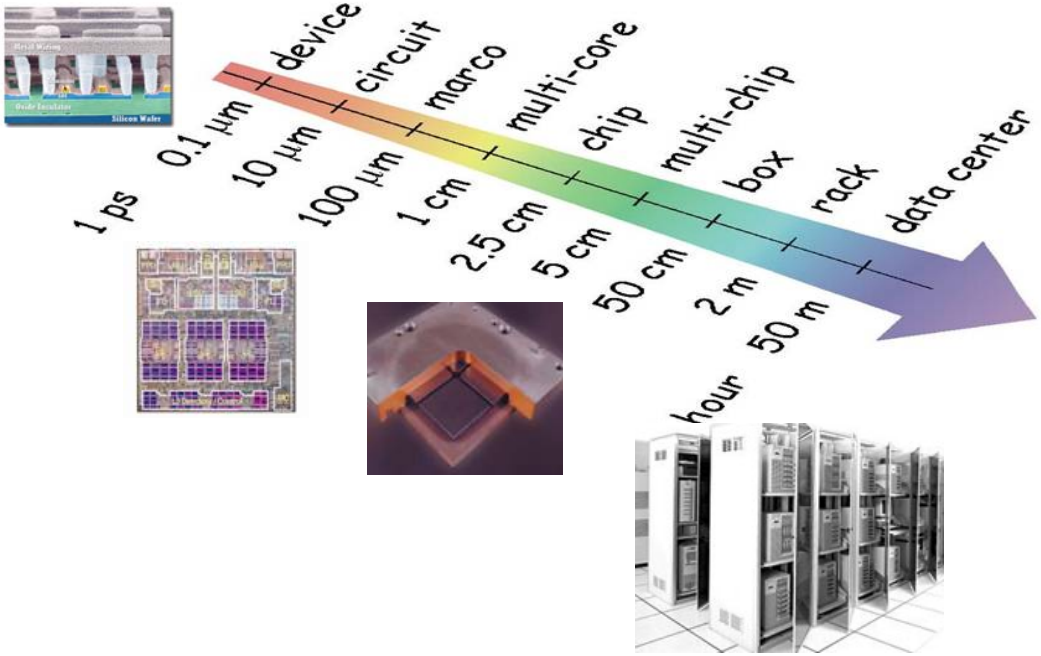
IBM Research

Innovative Data Center Energy Efficiency Solutions



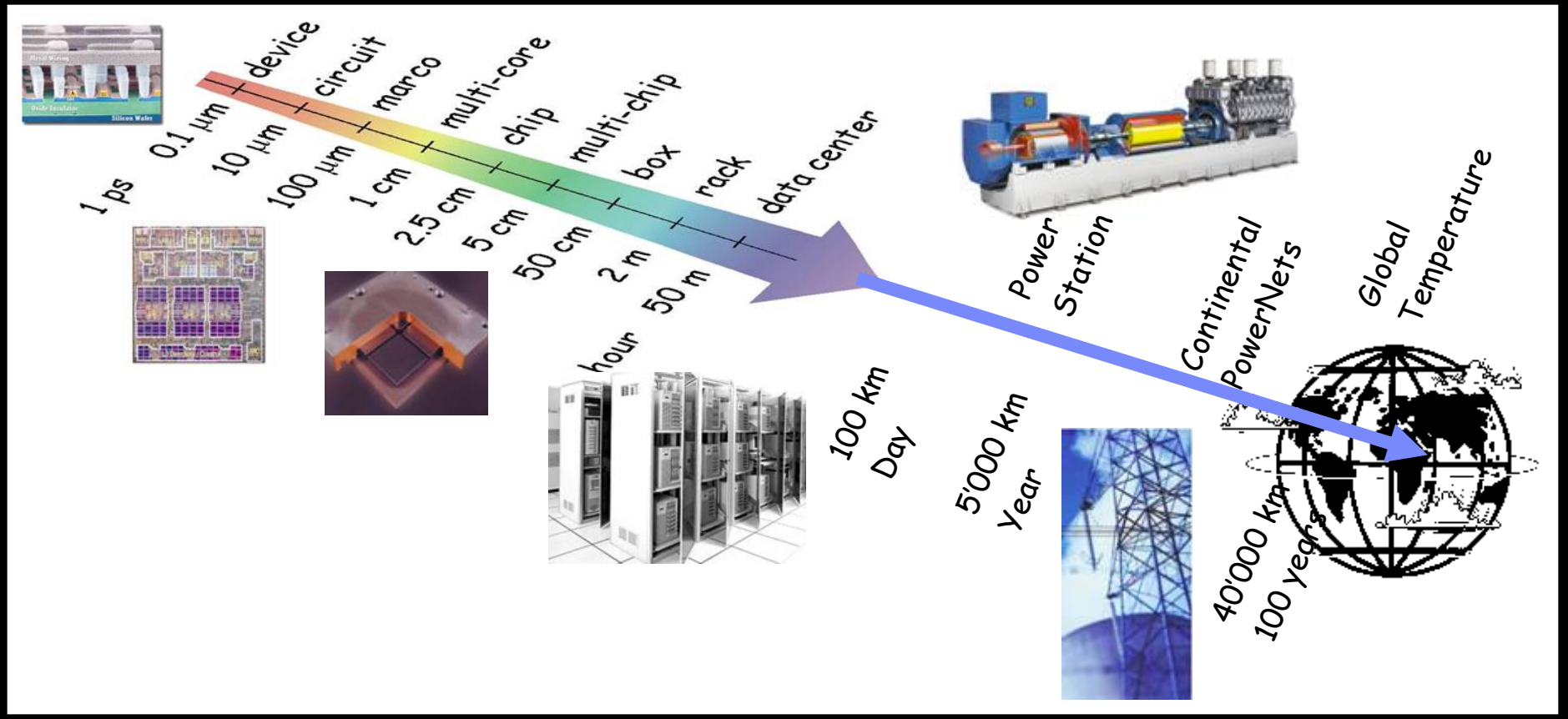
Dr. Hendrik F. Hamann
IBM T.J. Watson Research Center

A holistic Challenge: Energy & Thermal Management



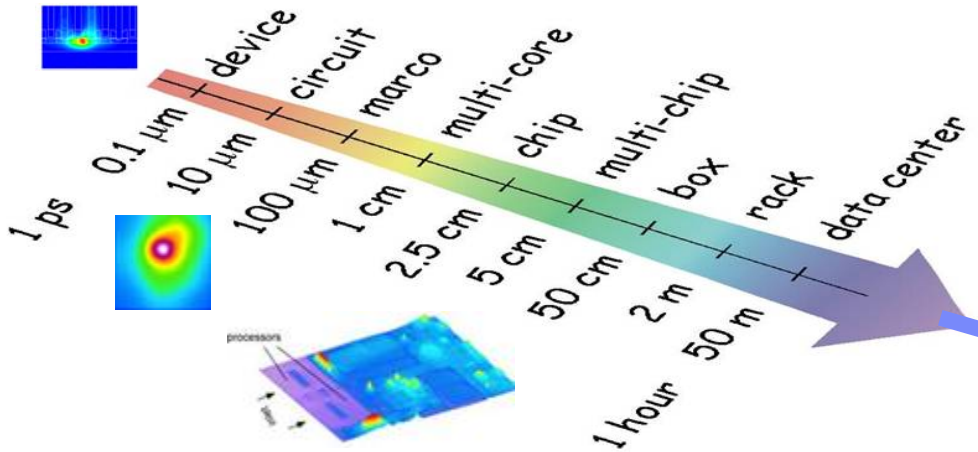
- Energy / thermal management is relevant on all levels
- Various length and times scale and interdependencies are involved but also many analogies/similarities exist
- Truly holistic understanding is required to conquer the challenge

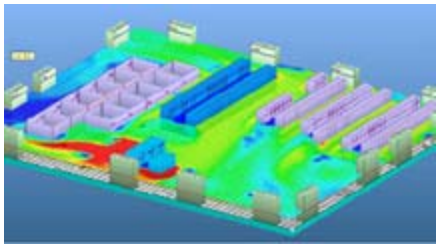
A broader Perspective

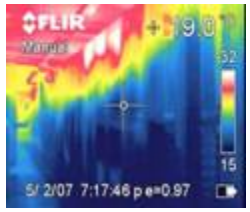


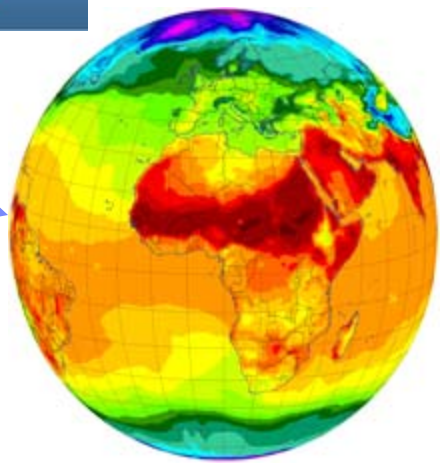
- The challenge is even bigger: Energy/thermal issues propagate all the way to the world climate
- Earth has an energy and thermal problem as well

Thermal Management and Hotspots





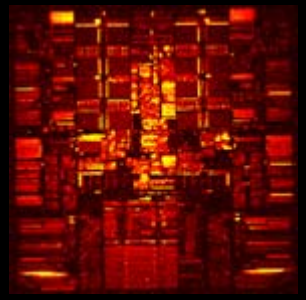




- Hotspots exist on all levels
- Cooling hotspots cost (a lot of) energy and determine cooling energy efficiencies
- …but opportunities for mitigation exist
  (i.e., static, dynamic, spatial, temporal, spatial-temporal)

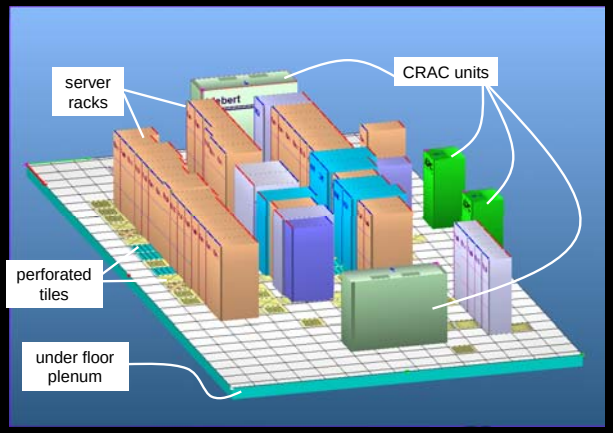
Thermal Management and Hotspots

Microprocessor
~ 300 M transistors



US Power Grid
~ 300 M customers

Data Center
~ 1000 of servers



Superstore / Airports
~ 1000 of customers

Data Center Facts

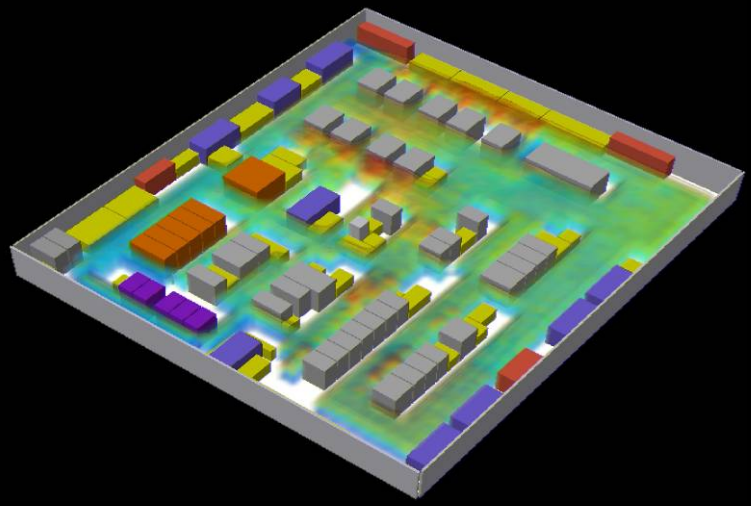
- DCs consume ~ **2 % of all US electricity**
- **annual growth** (15 %) is non-sustainable
- DC power projected to be > 8 % of US power by 2020
- governments consider **regulatory actions**

- 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**

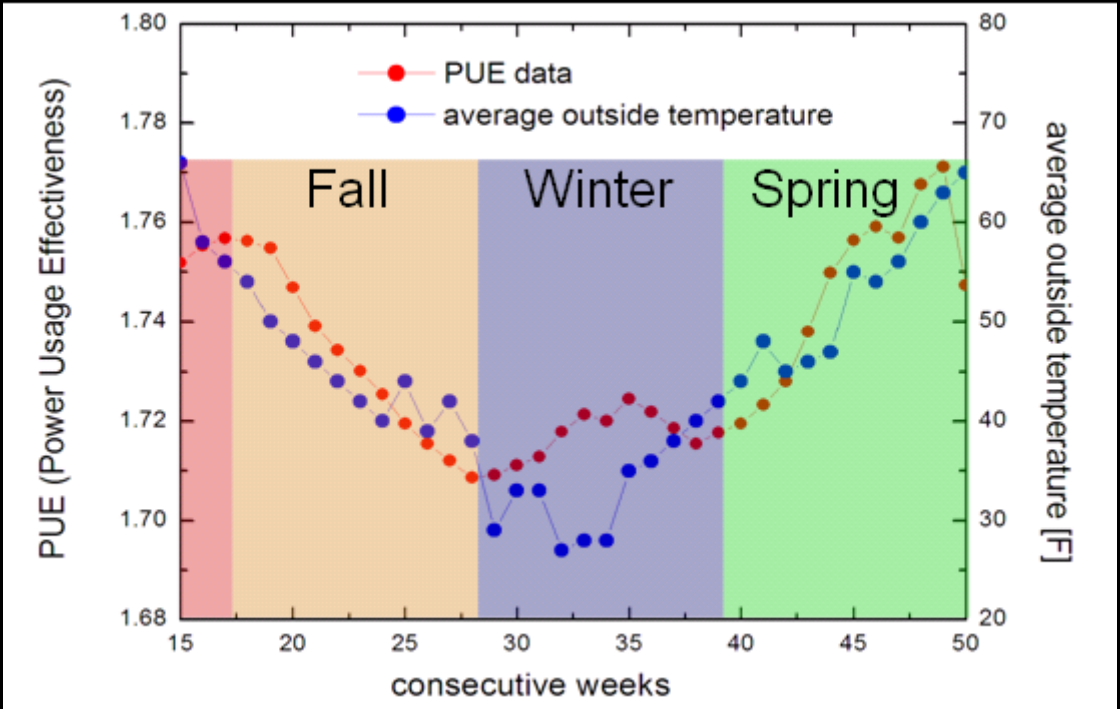
Content

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



Data Center Energy Efficiency – PUE Metric

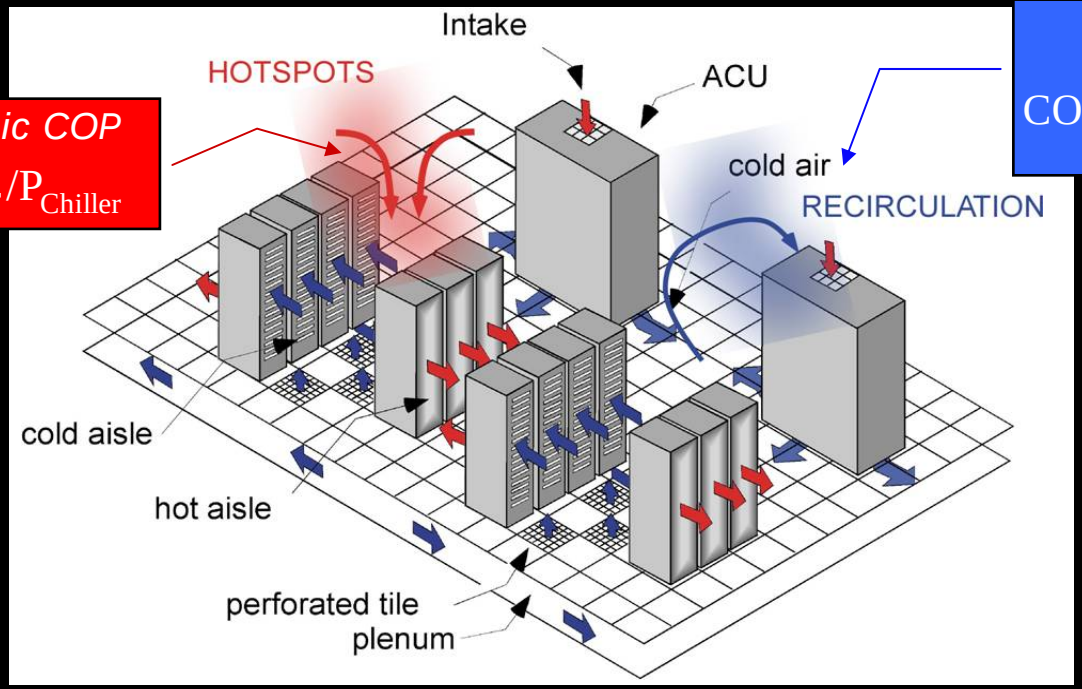


- PUE is widely used today: PUE = Total DC Power / IT Power
- many PUE "claims" – but PUE metric can be problematic
  - weather-dependent, location dependent, application/tier dependent
  - non-linear, awards UPS consumption, power density dependent
  - PUE does not include IT performance
  - PUE metering is often not in place
  - PUE is often insufficient for "proving" and managing energy efficiency

A more detailed Look – DC Energy Efficiency

Thermodynamic COP

$$COP^{*}_{thermo} \approx P_{RF}/P_{Chiller}$$



Transport COP

$$COP_{trans} \approx P_{RF} / \sum_{i=1}^{\#\text{ of active ACUs}} P^{i}_{ACU}$$

Average Chiller COP
(throughout the year)

Data Center COP

$$1/COP \approx 1/COP_{thermo} + 1/COP_{trans}$$

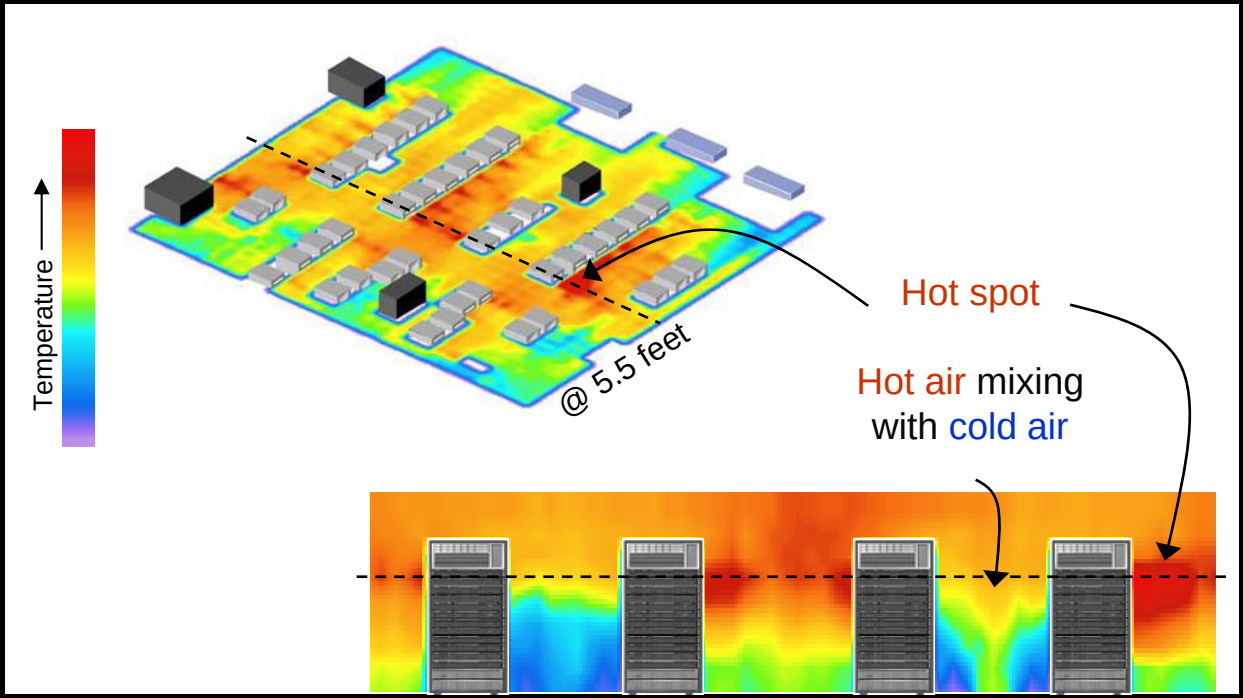
THERMODYNAMIC PART OF COOLING:
HOTSPOTS / HIGH INLET TEMPERATURES IMPACT CHILLER EFFICIENCY (~ 1.7 % per F)

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



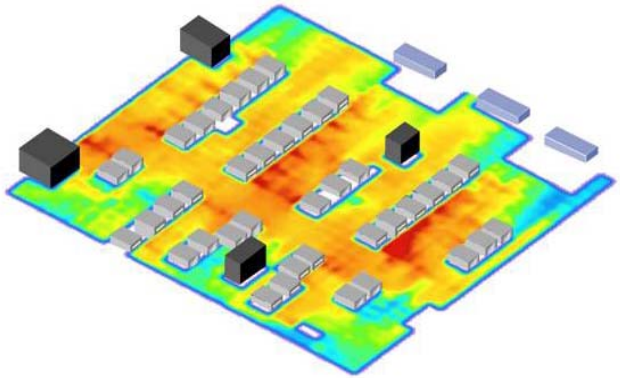
IBM Mobile Measurement Technology (MMT 1.0)

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*")

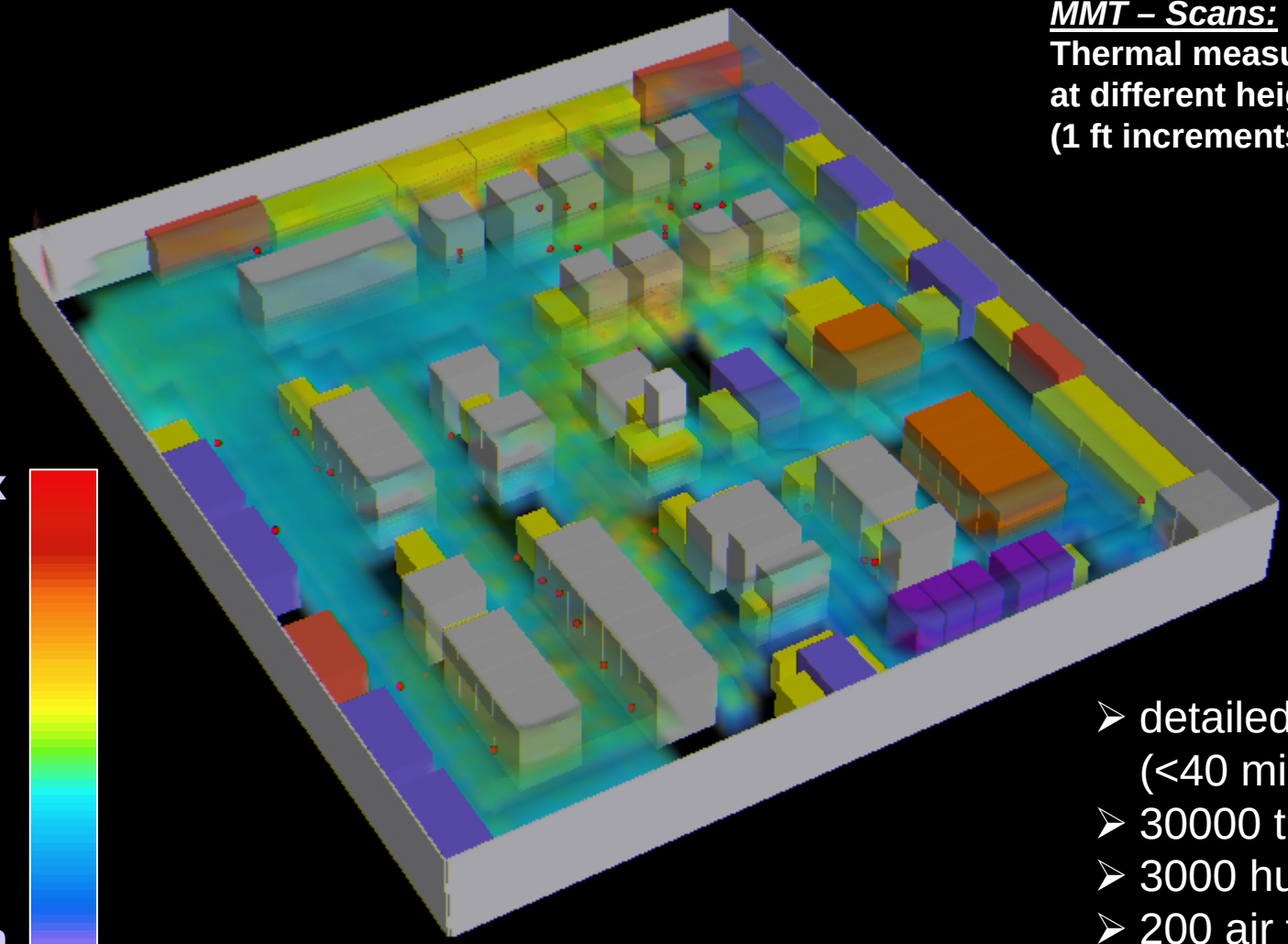
3 Manage "*Best Practices*"

- 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



MMT – Scans:
Thermal measurements at different heights (1 ft increments in z)

max

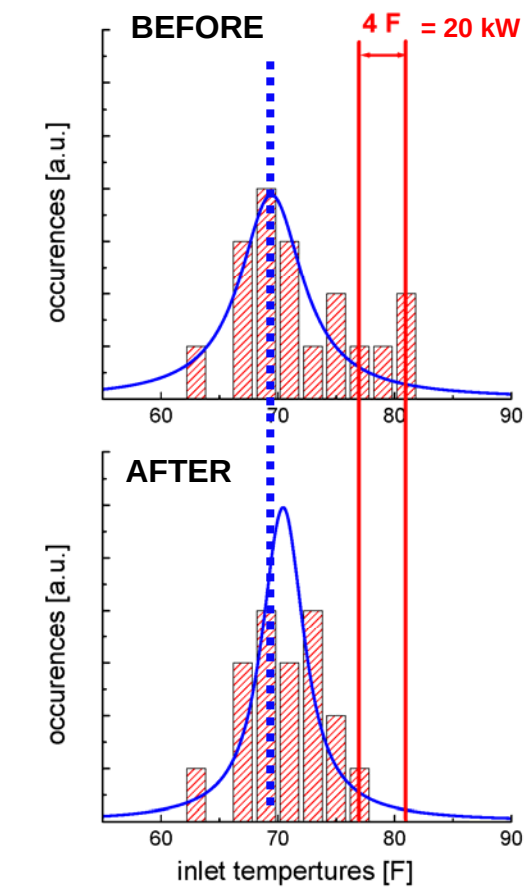
min

- detailed 3D heat maps (<40 mins scan time)
- 30000 thermal readings
- 3000 humidity readings
- 200 air flow sensor

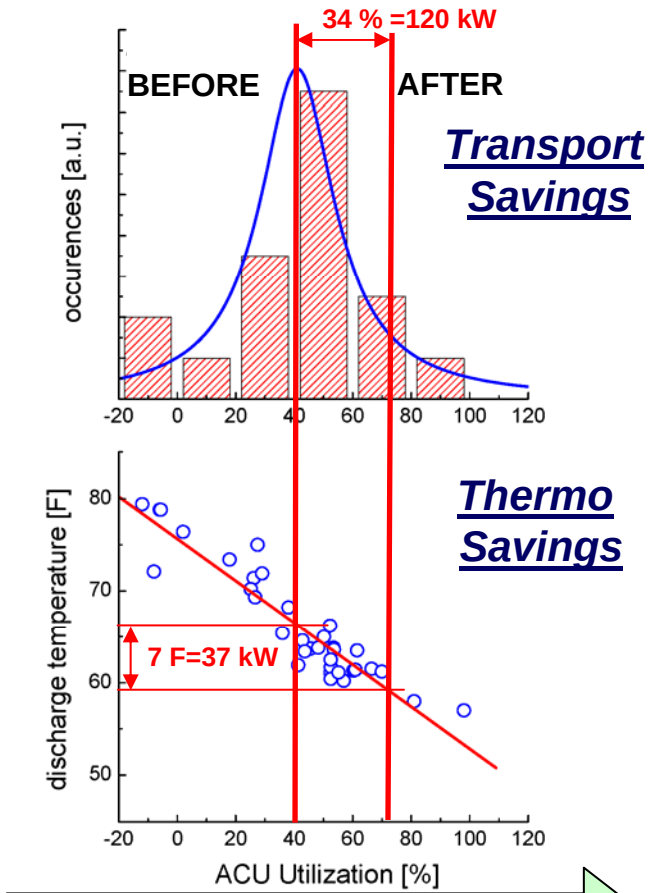
MMT 1.0 @ Work – Energy Savings

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

Thermo Savings



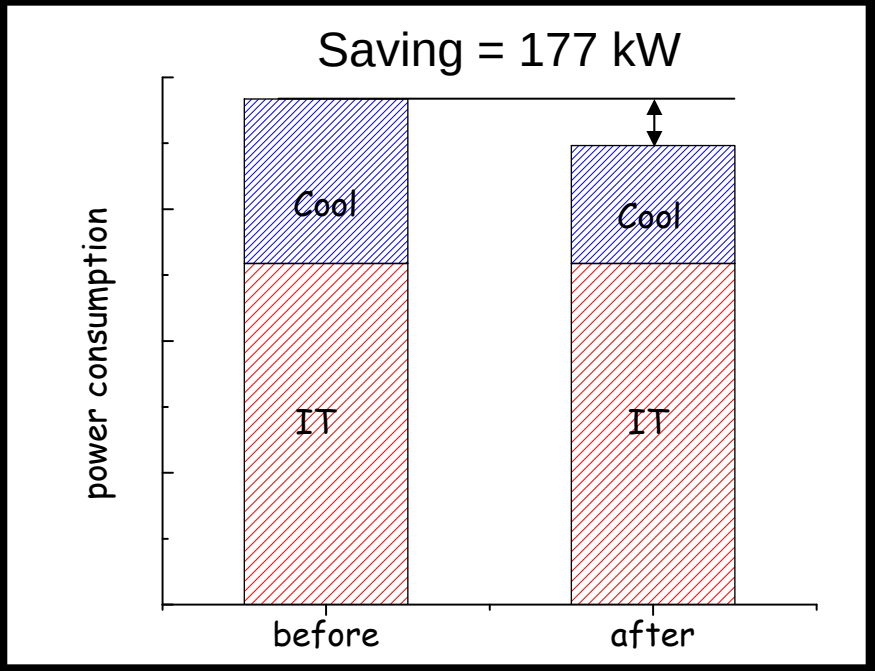
Increase Chiller Set-Point



Increase ACU Utilization

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
  - COP_{thermo} from 4.5 to 5.1
  - COP_{trans} from 5.3 to 9.8

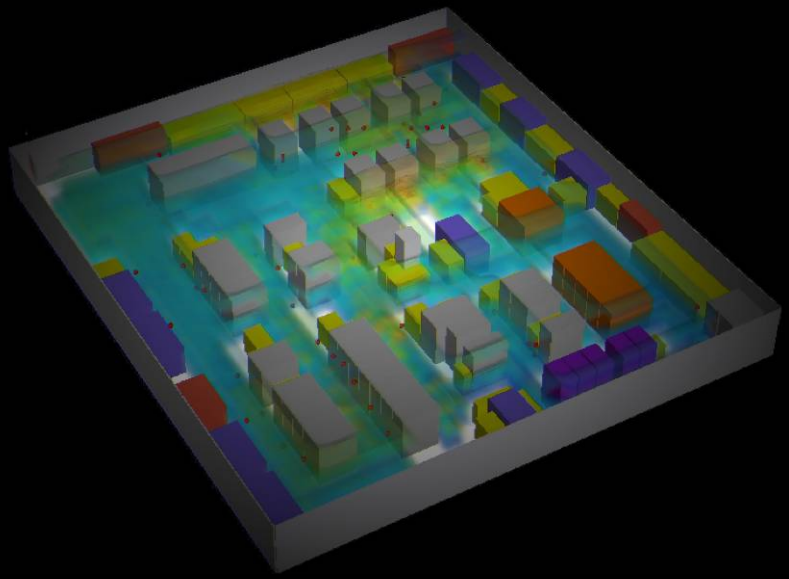


Finding / Metrics	Key Action / Solution	
Horizontal hotspots (HH)	**change tile layout & deploy high throughput tiles**	**thermo**
Vertical hotspots (VH)	**snorkels / fillers**	
Non-targeted air flow	**close leaks / cable cutouts**	
Plenum temperatures	**service ACUs supply side / increase ACU utilization**	**transport**
ACU utilization	**turn under-utilized ACUs off**	
ACU flow	**remove blockage**	

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

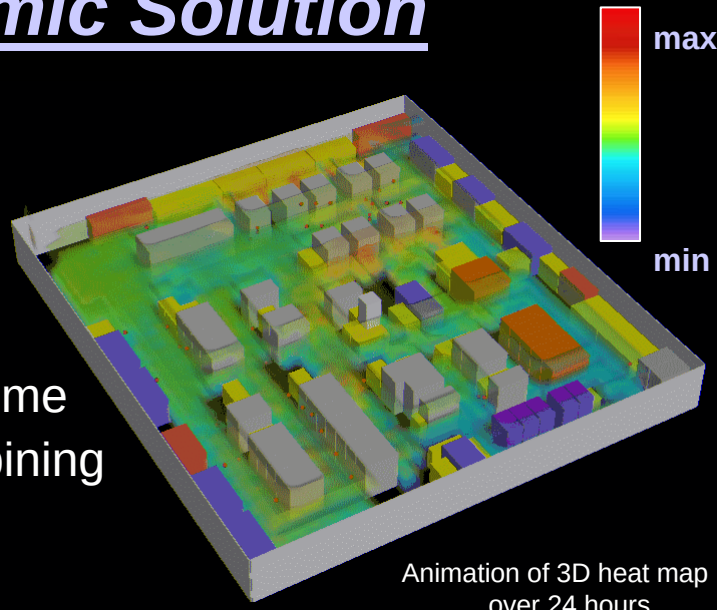
MMT 1.0 - Status

- 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

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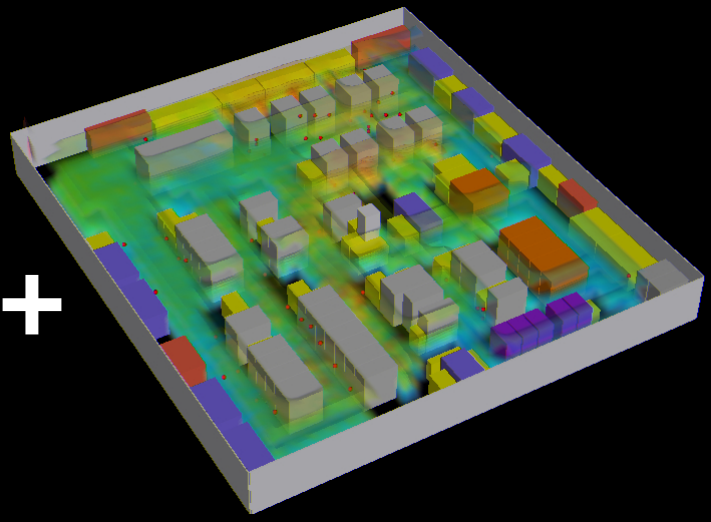

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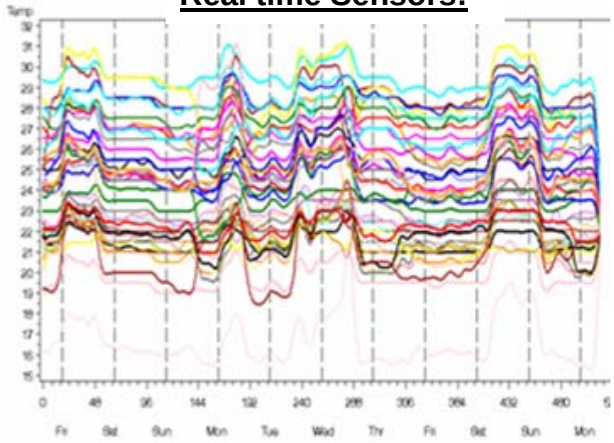
Real time Sensors:

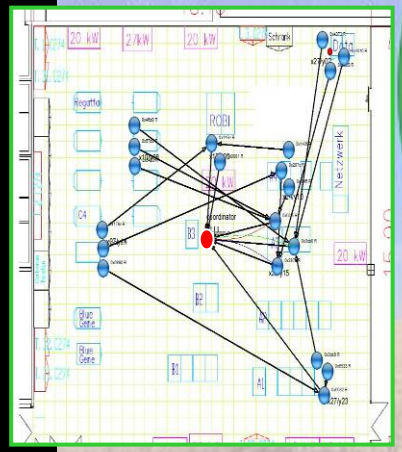


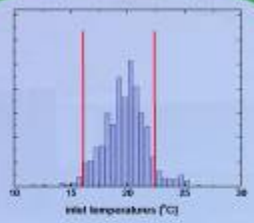
MMT 1.5 – Measurement & Management Technology

Evolution from MMT 1.0 to MMT 1.5

MMT 1.0: Dense in Space

MMT 1.5: Dense in Time





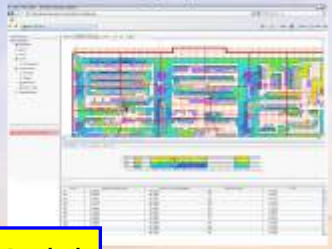
Measurements

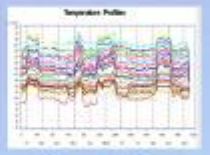
MMT 1.0: Detailed Report

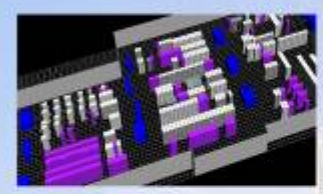
Management

MMT 1.5: DC Management Solution

Measurement Management Technology (MMT 1.5)







MMT 1.0: Detailed Base DC Model

Modeling

MMT 1.5: Dynamic DC Model

Mass Transport Equation: $\nabla^2 \varphi = 0$

Energy/Thermal Equation:

$$\rho c_p \vec{v} \cdot \nabla T + \nabla \cdot (k \nabla T) + h_{Racks} = 0$$

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