Modeling Rack and Server Heat Capacity in a Physics Based Dynamic CFD Model of Data Centers

Sami Alkharabsheh, Bahgat Sammakia

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ES2 Center for Energy-Smart Electronic Systems

Binghamton University
State University of New York
Thomas J. Watson School of Engineering and Applied Science

ES2 Vision

To create electronic systems that are self sensing and regulating, and are optimized for energy efficiency at any desired performance level

Project Vision

Toward a full physics-based experimentally verified 3D computational fluid dynamics model for data centers

BINGHAMTON UNIVERSITY
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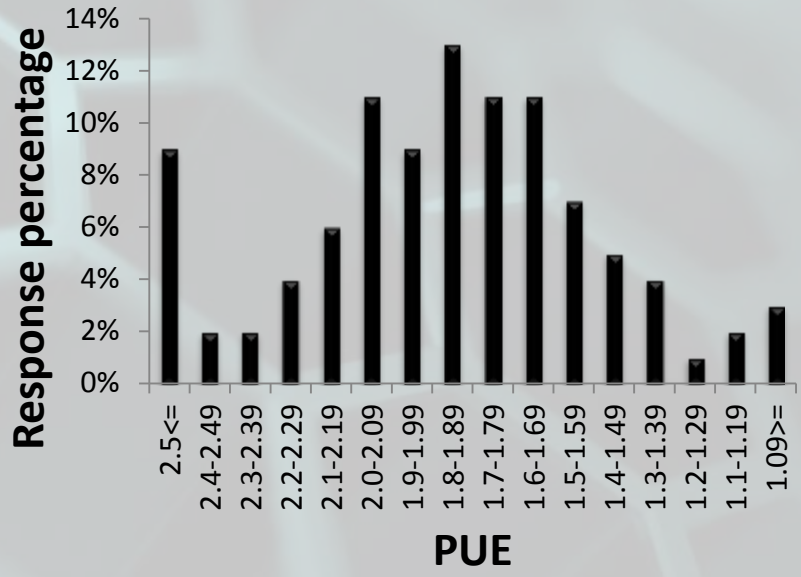
Outline

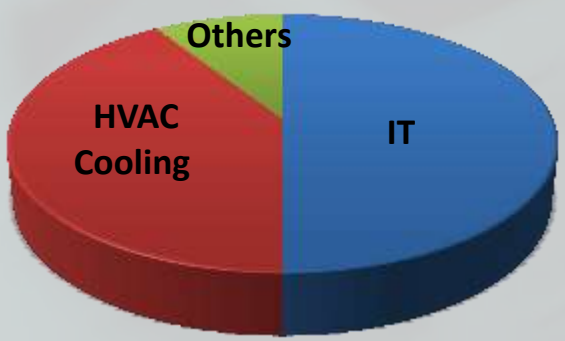
- Introduction
- Physics Based Steady State Baseline Model
  - CRAC model
  - Server model
  - Tile model
- Dynamic Model- Server Heat Capacity Effect
  - Server level model
  - Room level model
  - Case studies
- Conclusions and Future Work

Introduction

- **EPA (2007)**:1.5 % of total U.S. electricity consumption in 2006. (Total cost of $4.5 billion)
- **Datacenter Dynamics (2012) Global Census :** power requirements grew by 63% **globally** to 38 GW from 24 GW in 2011.
- **Uptime Institute 2012 Data Center Industry Survey:** PUE>1.8 for more than 55% of data centers



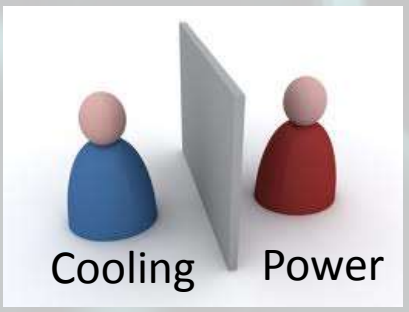
M. Stansberry and J. Kudritzki, "Uptime Institute 2012 Data Center Industry Survey," Uptime Institute, 2013.



M. Iyengar and R. Schmidt, "Energy Consumption of Information Technology Data Centers", 2010.

Nature of Problem

- In real time, cooling is difficult to control due to long lag times
- Complexity of transport in data centers
- Overprovisioning is commonly used for safe operation

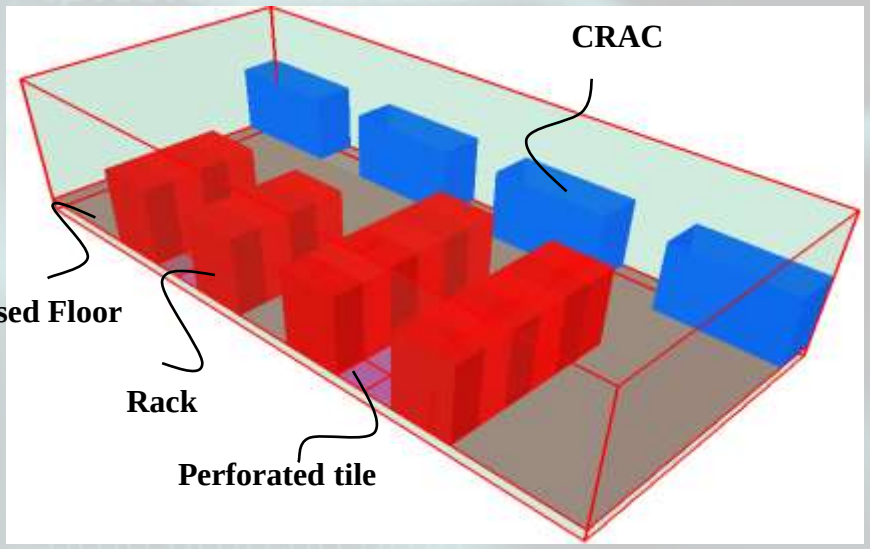


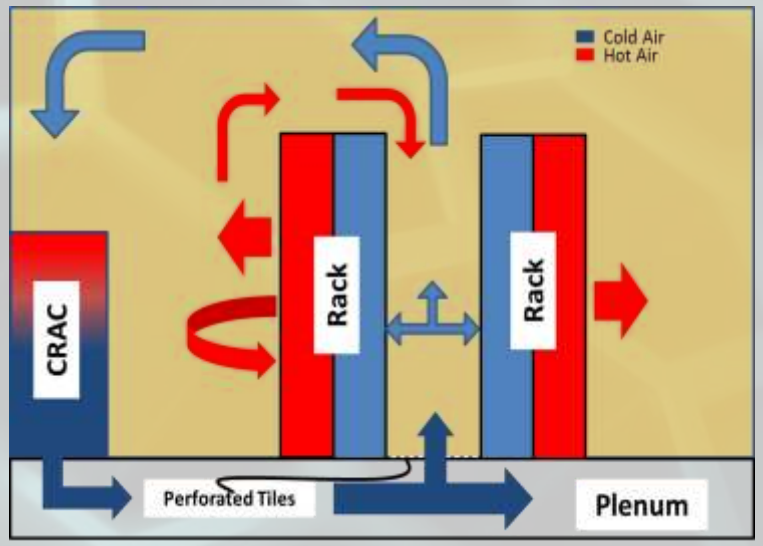
Solutions for improving the energy efficiency in data centers have been isolated

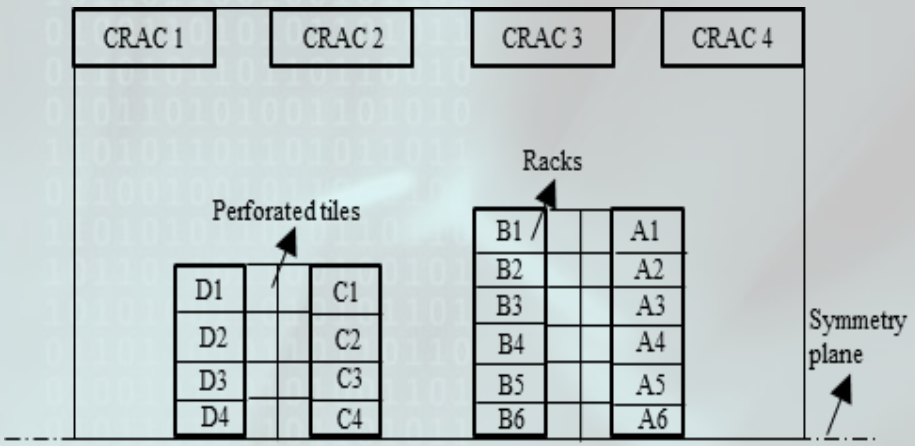
System-level and holistic solutions are a MUST

- Performance is not proportional to power
- Server overprovisioning is a common practice

Bench Mark Numerical Model





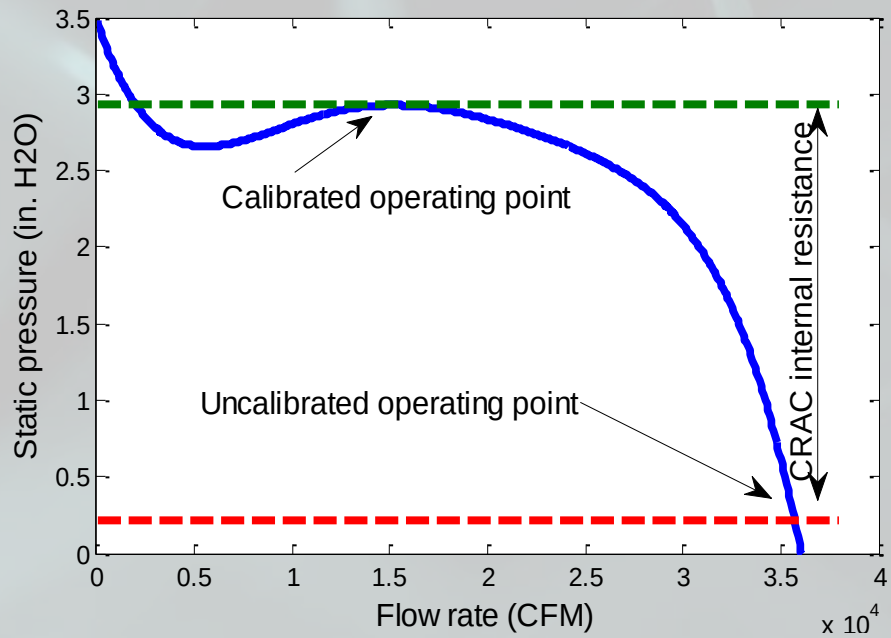


Parameter	Value
Room size	6.05 m x 13.42 m x 3.65 m
Plenum depth	0.6 m
Tile perforation ratio	50%
Perforated tiles area	0.61 m x 0.61 m
CRAC fan speed	100%

CRAC Model

- Based on manufacturer data
- Liebert 114D CW
- Operating fan curve is obtained from the manufacturer, Liebert Consulting
- The CRAC model is calibrated such that the flow rate can be predicted accurately at different operating pressures

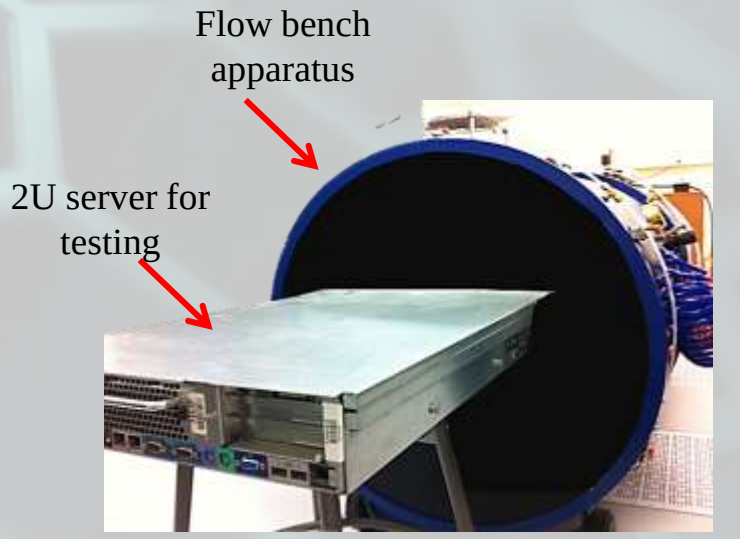
Emersonnetworkpower.com

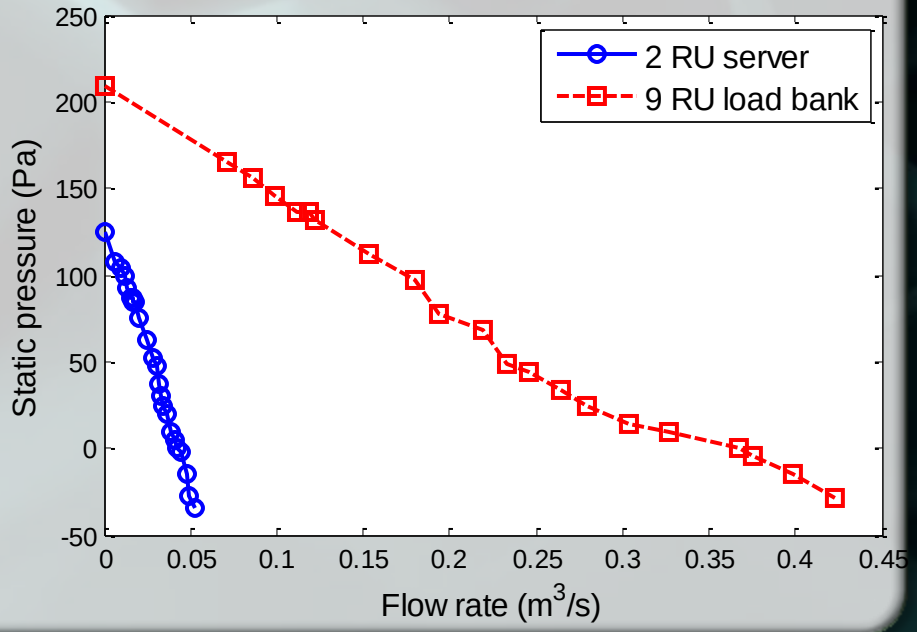


* Alkharabsheh et al. “Utilizing Practical Fan Curves in CFD Modeling of Data Centers,” SEMITHERM2013.

Server Model

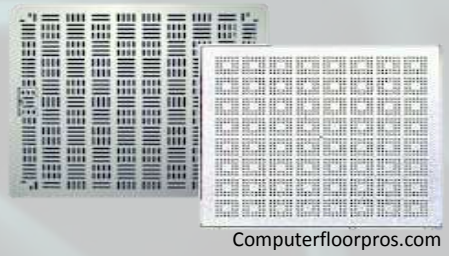
- A standard testing procedure following the AMCA 210-99 guidelines are used to measure the pressure fan curves
- 9 RU server simulators (load banks) and a 2 RU commercial server are tested
- The measured fan curves include the internal resistance of the server
- The measured fan curve can be imbedded directly into the CFD

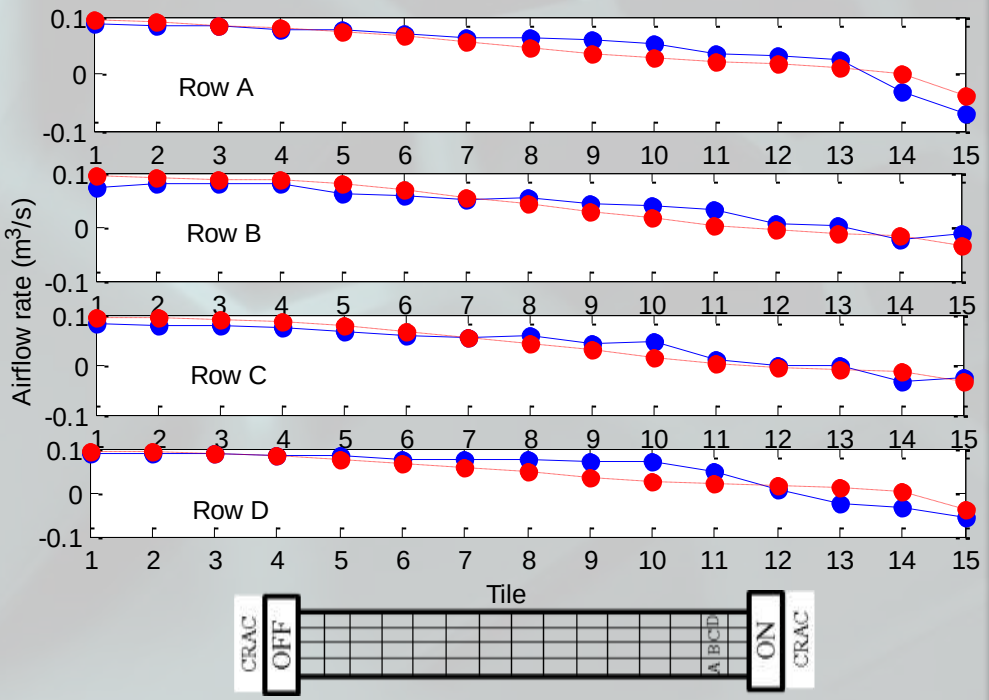




Tile Model

- The CFD tile model is validated using experimental data in Schmidt et al.*
- The CFD tile model is modified to compensate for the momentum loss in the CFD flow resistance model
- The CFD tile model is able to capture the tile flow distribution and can be used in room level simulations



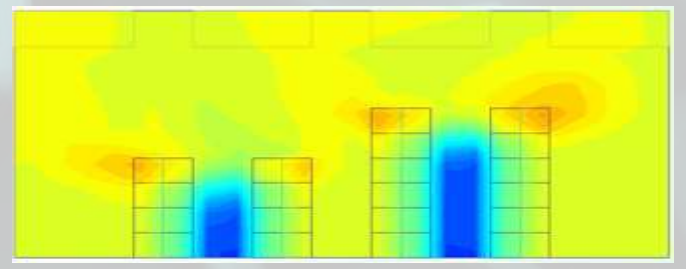


Solid line: experimental data, Dashed line: CFD results

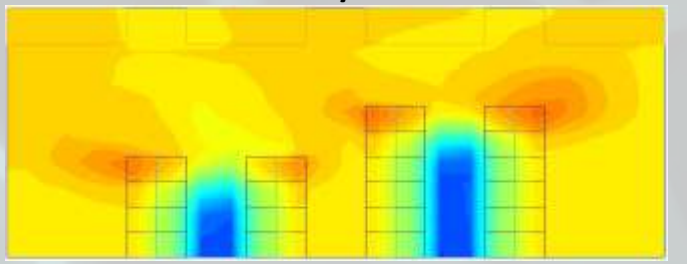
*Experimental data: Schmidt et al, "Measurements and Predictions of The Flow Distribution Through Perforated Tiles in Raised-Floor Data Center," InterPACK2001

Steady State Room Level Simulations

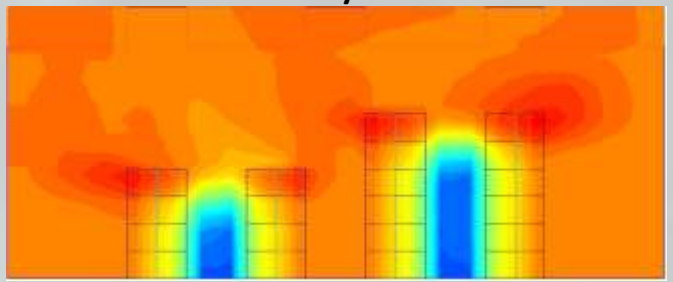
- In addition to affecting the power dissipation, the servers power scenario also the airflow pattern by operating
- The room can be underprovisioned/ overprovisioned based on the servers power level
- Several parametric studies can be conducted using this model



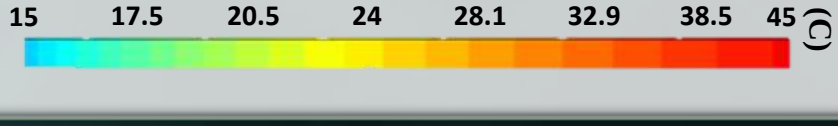
15 kW/ rack



20 kW/ rack



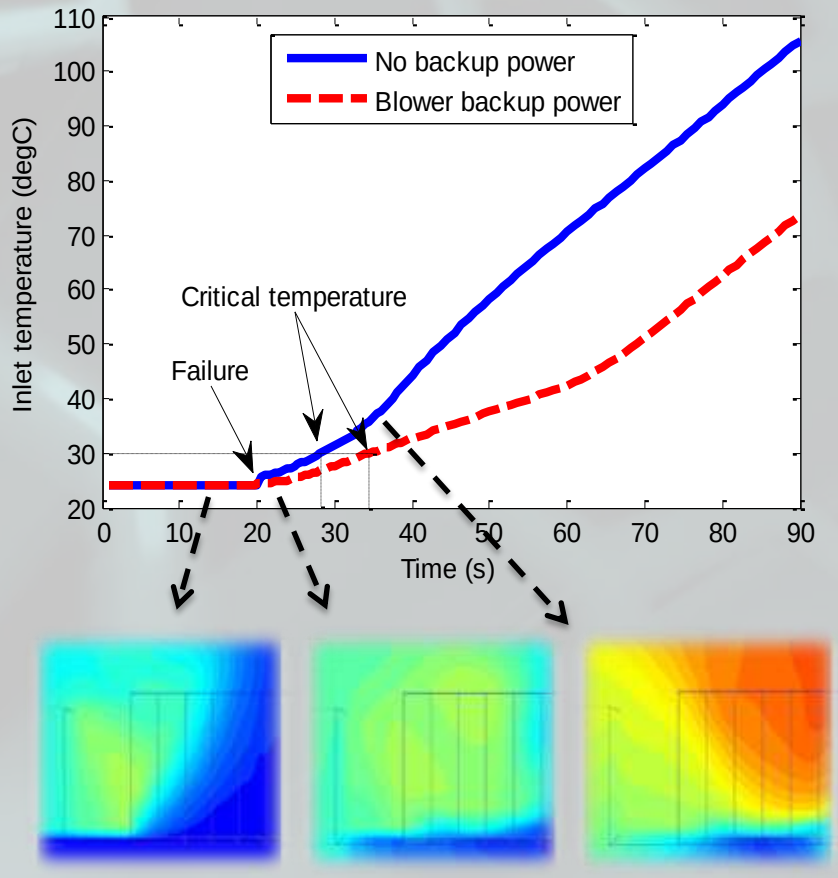
32 kW/ rack



* Alkharabsheh et al. “Numerical Steady State and Dynamic Study in a Data Center Using Calibrated Fan Curves for CRACs and Servers,” InterPACK2013

Simple Dynamic Model

- The thermal capacity of the equipment is not taken into account
- Complete CRAC failure simulated at 20 seconds
- Supporting the CRAC blower with backup power provides the room with extra cooling and time that can be utilized in increasing the reliability of operation

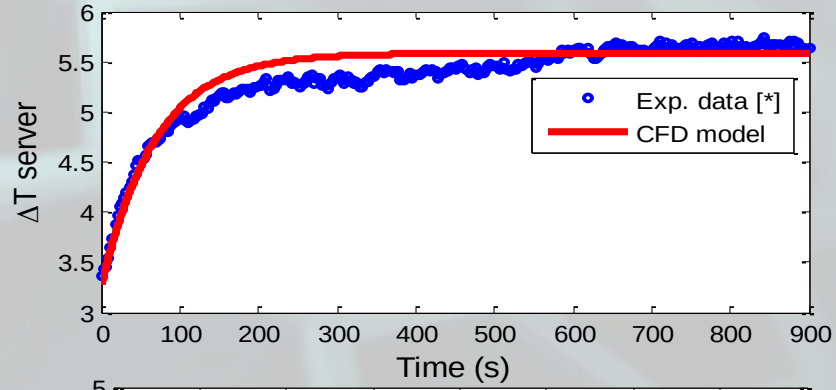


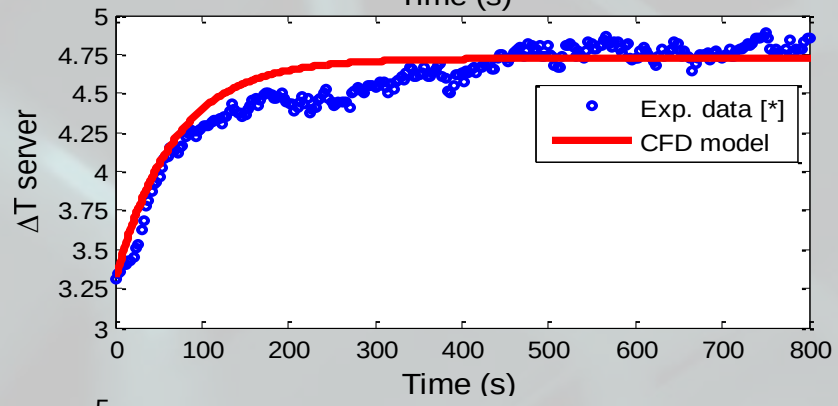
Unused plenum cold air

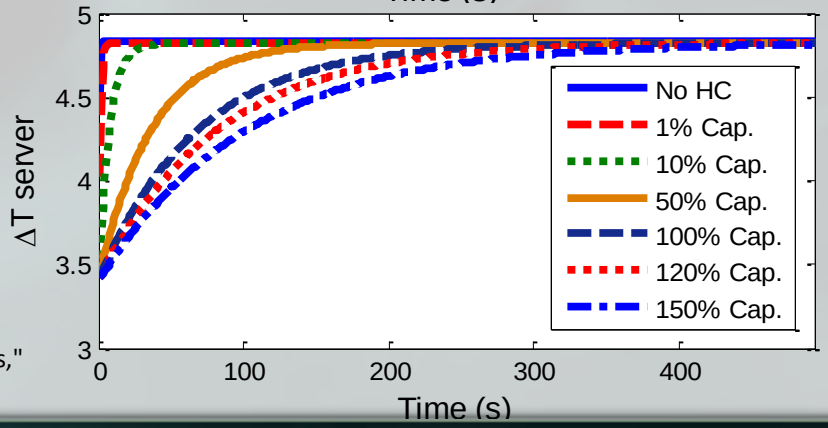
* Alkharabsheh et al. "Numerical Steady State and Dynamic Study in a Data Center Using Calibrated Fan Curves for CRACs and Servers," InterPACK2013

Server Heat Capacity

- The server level CFD model is developed based on the lumped mass approximation
- Experimental data is used to calibrate and validate the server level CFD model
- An increase in the rate of change in temperature is observed at low values of heat capacity until instantaneous change in temperature is noticed when server heat capacity is completely neglected



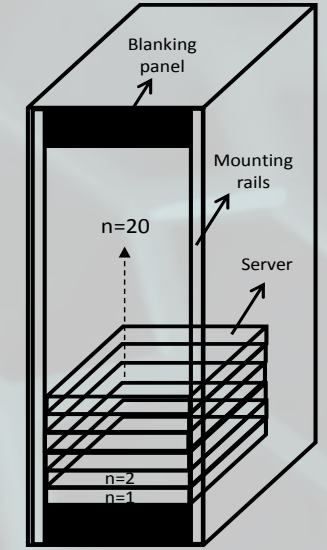




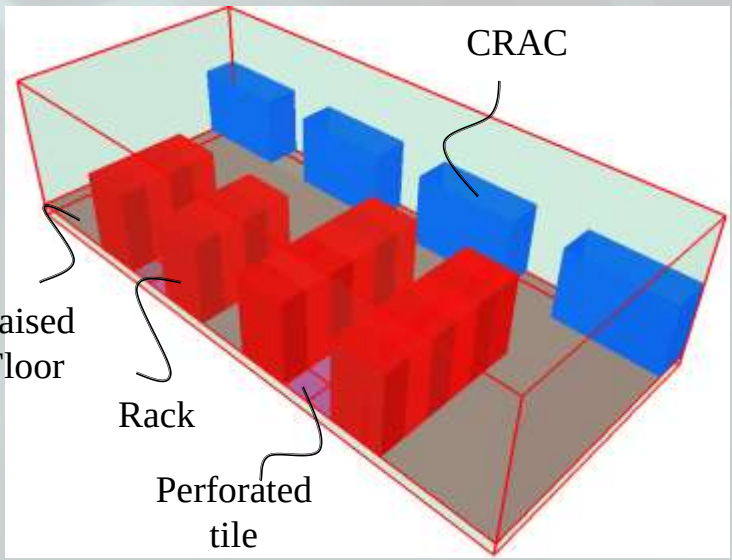
*Ibrahim et al., "Thermal Mass Characterization of a Server at Different Fan Speeds," ITHERM2012.

Room Level Model

- The detailed rack model is capable of hosting the server model, blanking panels, leakage through the mounting rails, and internal supports
- Each server consists of an experimentally characterized fan curve and thermally calibrated heated mass
- Each rack is populated with twenty of the 2 RU servers

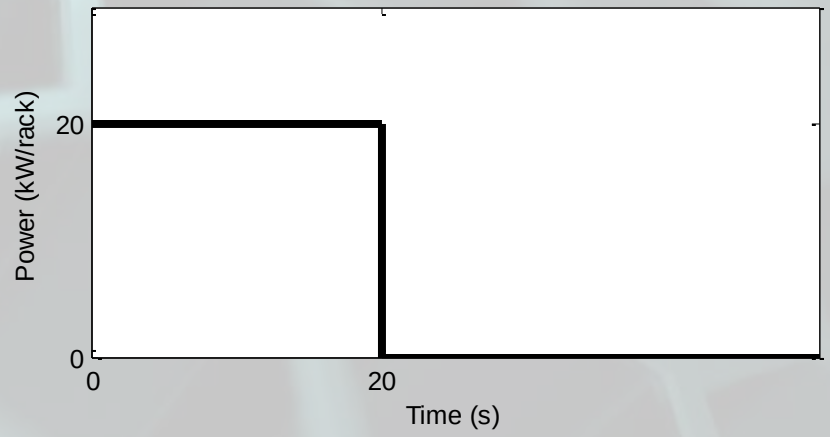


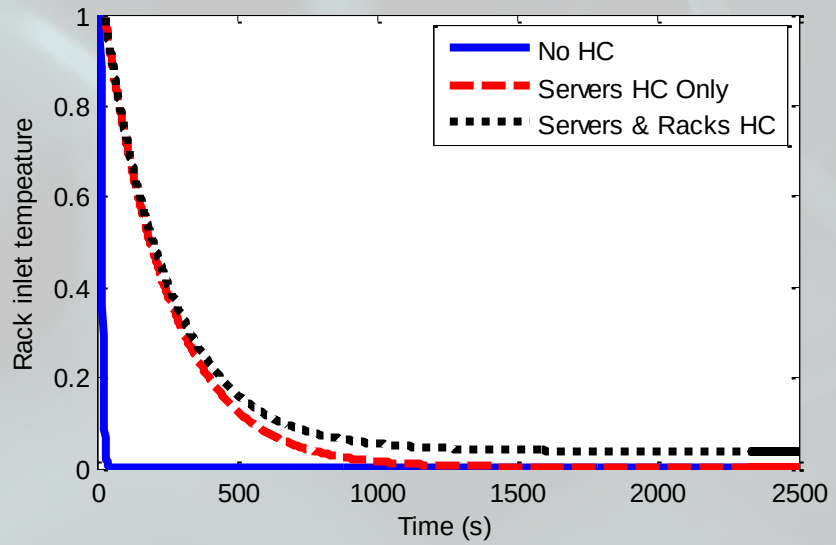
Detailed rack model



Case I: Servers Shutdown

- It is assumed that all the servers inside the modular data center are shutdown at time 20 seconds
- Three different room level models are compared in this transient analysis
- Including the servers heat capacity is crucial in dynamic modeling. However, the heat capacity of the rack chassis can be neglected without affecting the accuracy of the results and reducing the computational time

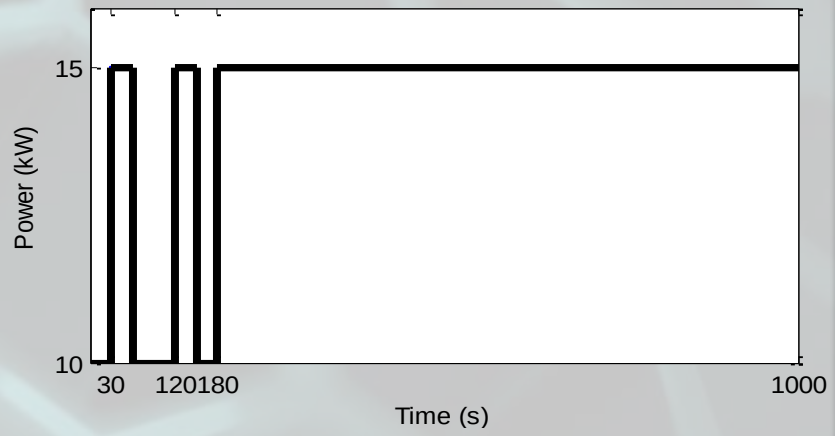


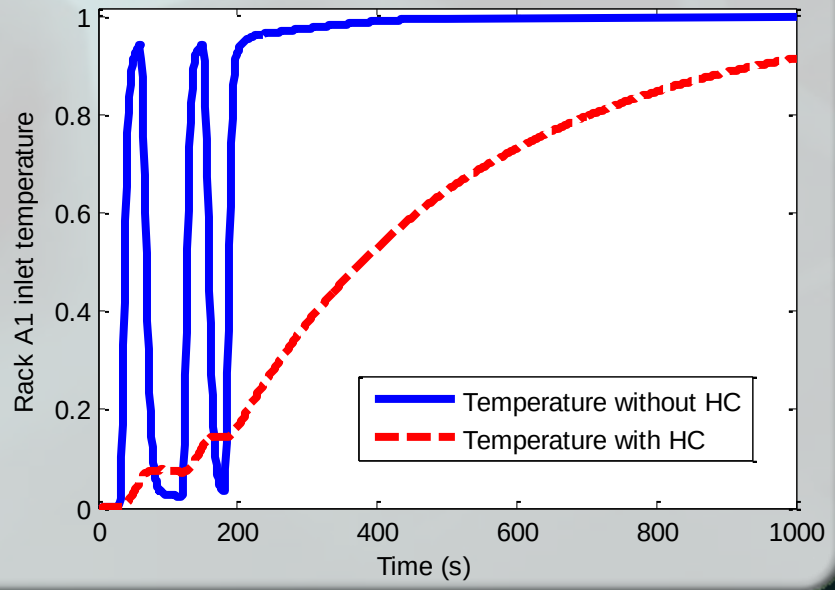


Where: $\hat{T} = \frac{T - T_{ss}}{T_o - T_{ss}}$

Case II: Server Power Short Pulses

- Fluctuations in the dissipated power is simulated in the form of 30 second pulses
- The temperature increases immediately in the model if we ignore the heat capacity
- The heat capacity damps down the effect of short duration power fluctuations on the inlet temperatures





Conclusions and Future Work

- Experimentally validated models of different data center components are developed
- A steady state and dynamic, physics based, room level CFD model for a bench mark data center is developed
- It is found that the heat capacity of the servers affects the rate of change in temperature significantly
- The effect of rack frames heat capacity is found to be small and can be neglected in room level simulations
- Future work will include adding cooling unit heat capacity

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