The CEETHERM Data Center Laboratory

A Platform for Transformative Research on Green Data Centers

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http://www.me.gatech.edu/CEETHERM/Purpose.html

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CEETHERM – Activities Overview

CEETHERM - Consortium for Energy Efficient Thermal Management.

Initiated in 2002 as part of the industry-academia joint initiative to develop techniques for efficient energy management of electronic equipments.

CEETHERM activities address the thermal issues of concern to a number of industries – Data centers, Telecommunications, Microprocessor thermal design, Power Electronics, Automotive, Aerospace, Compact energy systems.

Goals and Objectives

- ✓ Develop newer sustainable data centers with lower energy costs
- ✓ Waste heat recovery-reduce chiller power
- ✓ Liquid cooled rack development
- ✓ Thermally aware compute load allocation tools
- ✓ Compact CFD model development
- ✓ Green IT initiatives ⟶ Achieve a PUE of 1

Examples of current research at CEETHERM

Developing a Design Method for Open Air-cooled Data Centers

Adaptable & Continuous Improvement

Control Variables:

- CRAC Flow Rate
CRAC Supply Temperature
- Heat Load of Each Rack, Q_r *r=1, …, No. of racks*

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Thermal Model of Data Center

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Response:

- Maximum Rack Inlet Temperature, T_{max}, and its variation, ΔT_{max}
- CRAC Consumed Work, W_{crac}
- Chiller Consumed Work, $W_{Chiller}$

iterate

Goals:

- Energy Efficient & Reliable Design, $T_{max} + \Delta T_{max} = 32\ °C$
- Minimize Cooling Energy Consumption ($W_{crac}+W_{Chiller}$)
- Minimize Rack Inlet Temperature Variation, (ΔT_{max})

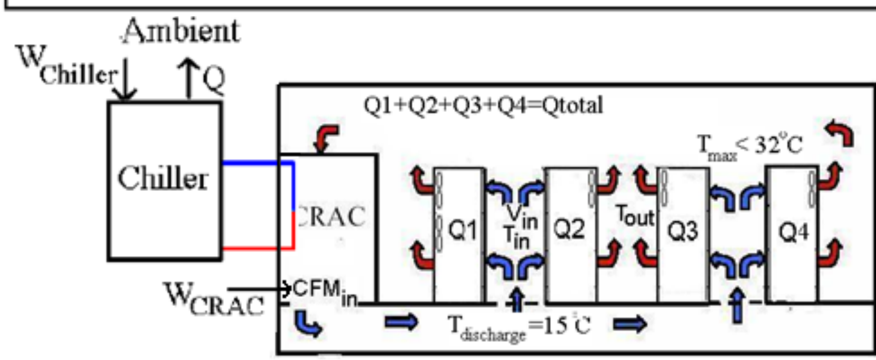
Constraint:

- Meet Total Data Center Power, $Q_{total}=sum(Q_r)$

Energy Efficiency

Robustness

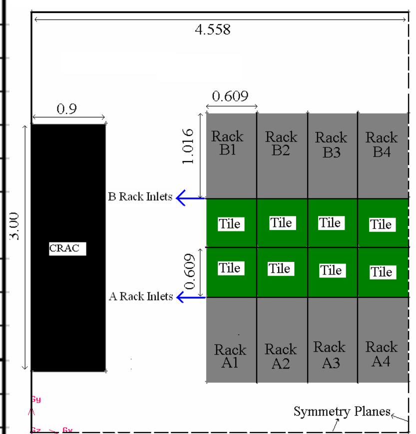
No Lifecycle Mismatch



Ref: "Samadiani, E., and Joshi, Y., 2009, "Multi-Parameter Model Reduction in Multi-Scale Convective Systems," Int. J. Heat Mass Transfer, in press."

Optimal CRAC flow Rate and Racks Heat Load Allocation Example

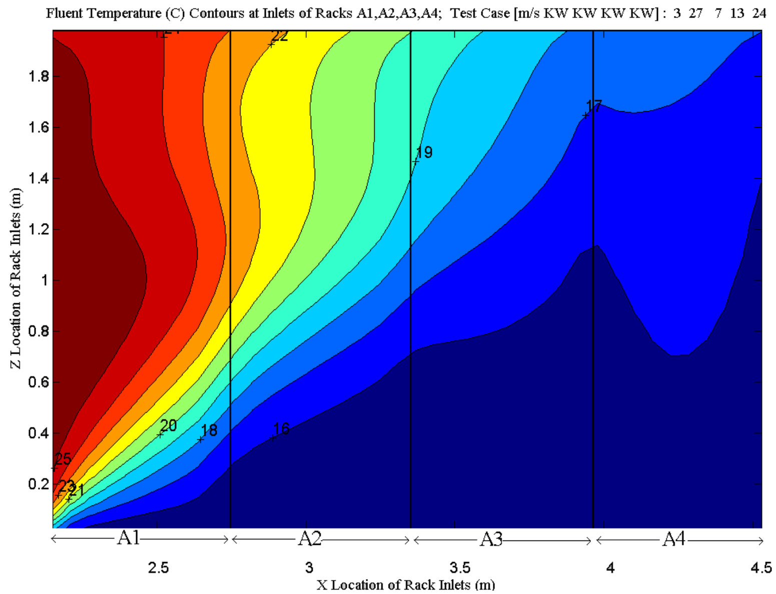
	Year#	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
	Data Center Utilization	10%	20%	30%	40%	50%	60%	70%	80%	90%
	Data Center Heat Load (kW)	24	48	72	96	120	144	168	192	216
Traditional/ Baseline Design	Vin (m/s)	0.76	1.51	2.27	3.03	3.79	4.54	5.30	6.06	6.82
	Q1 (kW)	2	8.4	4.8	7.5	14.8	9.9	4.8	25.7	27.3
	Q2 (kW)	6.1	5.1	3.4	13.5	11.7	15.1	29.7	23.2	28.5
	Q3 (kW)	2.8	7.1	2.1	18	14.8	17.7	28	29.7	22.8
	Q4 (kW)	1.1	3.4	25.7	9	18.7	29.3	21.5	17.4	29.4
	Tmax	27.74	26.08	34.41	26.32	28.06	31.85	39.09	33.19	35.56
	Supply Temp. (C)	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Wcrac (kW)	2.05	4.09	6.14	8.18	10.23	12.27	14.32	16.36	18.41
	Wchiller (kW)	12.00	24.00	36.00	48.00	60.00	72.00	84.00	96.00	108.00
	Wtotal (kW)	14.05	28.09	42.14	56.18	70.23	84.27	98.32	112.36	126.41
Adaptable Optimal Design	Vin (m/s)	1.12	1.93	3.00	3.00	3.71	3.24	3.39	9.40	9.38
	Q1 (kW)	8.35	12.9	3.8	9.5	2.725	11.1	9.3	11.9	18
	Q2 (kW)	1.05	4.5	29.8	29.9	15.625	29.9	29.7	24.7	30
	Q3 (kW)	1.55	3.3	1	2.3	29.925	13.9	26.9	29.9	30
	Q4 (kW)	1.05	3.3	1.4	6.3	11.725	17.1	18.1	29.5	30
	Tmax	21.48	21.90	21.29	23.33	23.72	26.55	27.14	27.40	29.69
	New Supply Temp. (C)	25.52	25.10	25.71	23.67	23.28	20.45	19.86	19.60	17.31
	Wcrac (kW)	3.03	5.22	8.10	8.10	10.01	8.74	9.16	25.38	25.33
	Wchiller (kW)	4.89	10.08	14.48	22.40	28.84	43.41	53.22	62.22	86.04
	Wtotal (kW)	7.92	15.30	22.58	30.50	38.85	52.15	62.39	87.60	111.37
	Energy Saving (%)	43.6	45.5	46.4	45.7	44.7	38.1	36.5	22.0	11.9



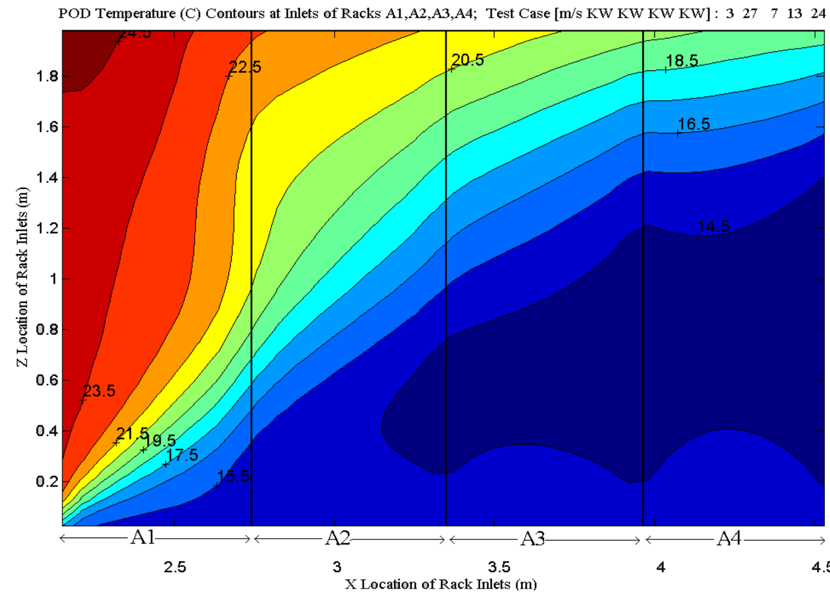
Ref: "Samadiani, E., and Joshi, Y., 2009, "Proper Orthogonal Decomposition for Reduced Order Thermal Modeling of Air Cooled Data Centers," ASME Journal of Heat Transfer, in press."

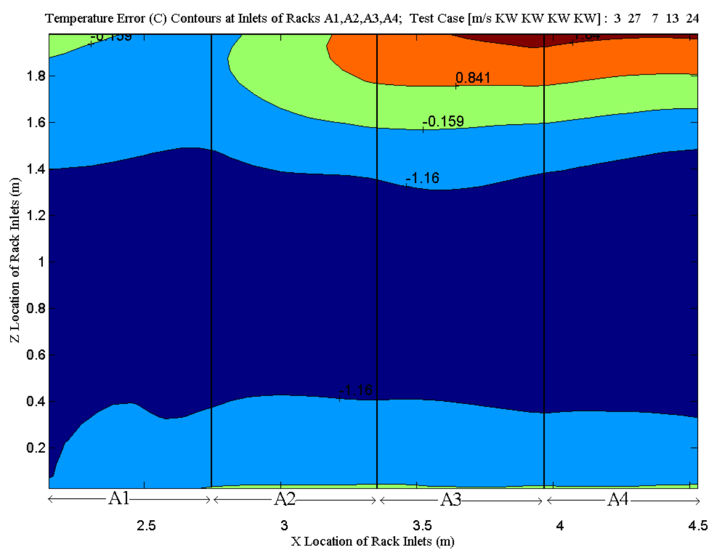
Sample results obtained using POD Method

Fluent Temp. Contours (°C) Obtained in 2 hours **



POD Temp. Contours (°C) Obtained in 4 seconds **





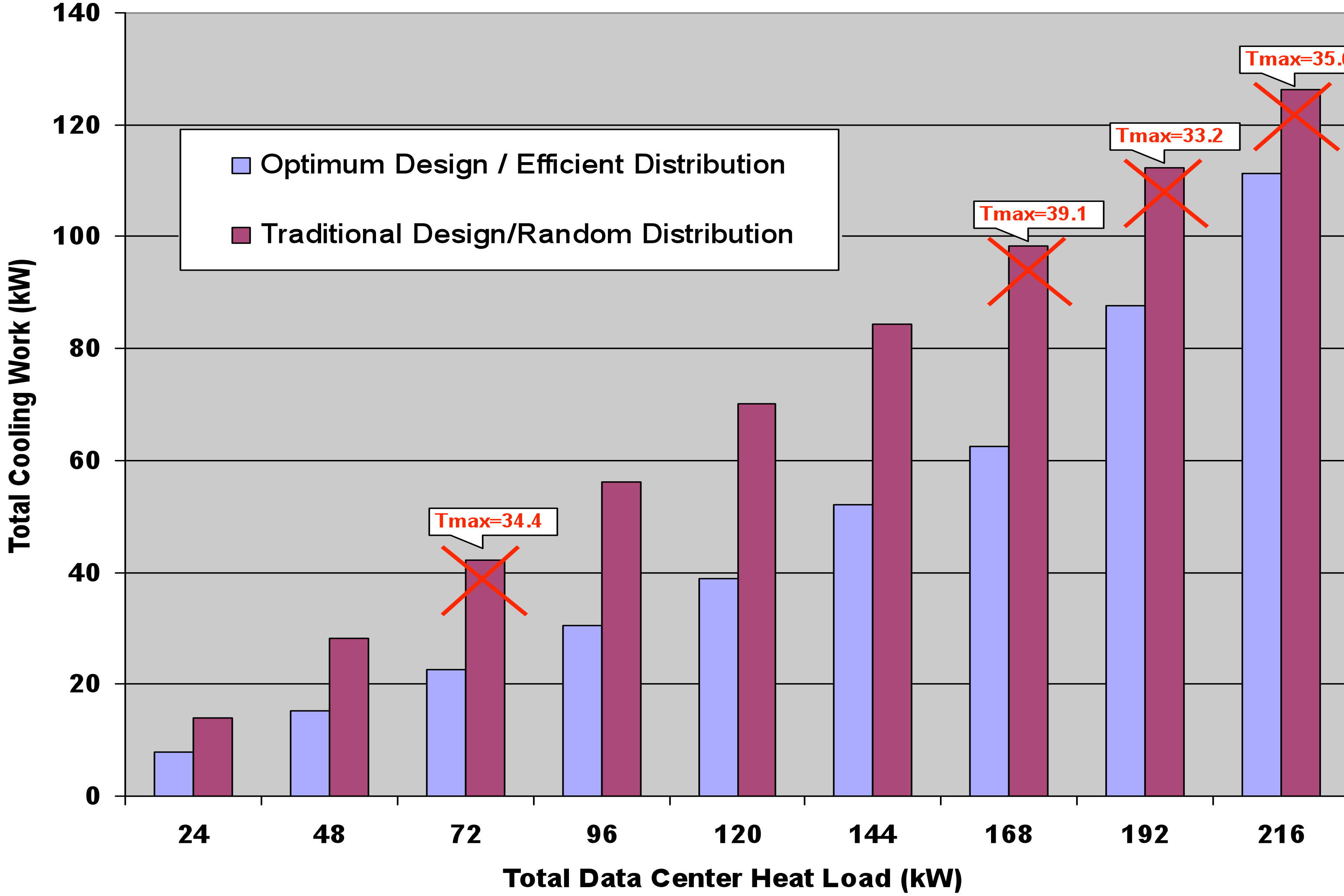
Time Needed for POD:

1-Observation Generation: 25*2 =50 hours

2- POD Temperature Generation: 4 Seconds with Avg. Error at Racks Insides & Inlets of 1.4 °C

** All computations were performed on desktop computer with Xeon™ CPU, 2.8-GHz and 2.75 GB of RAM.

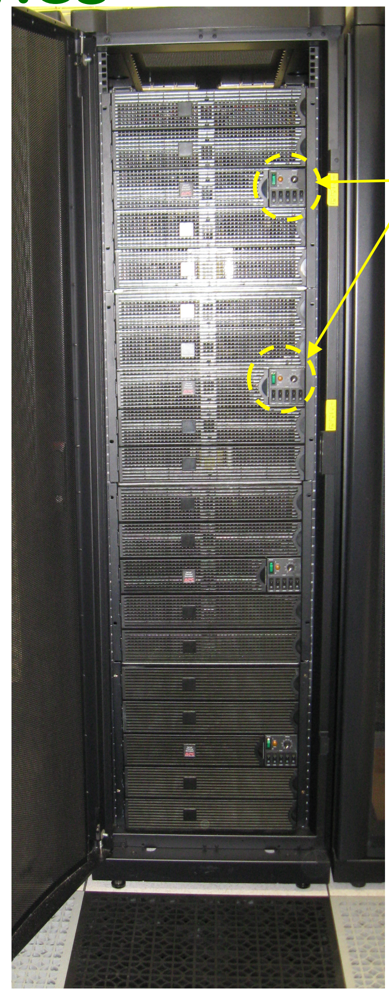
Energy Saving by POD-Based Design Approach



Ref: "Samadiani, E., Joshi, Y., Allen, J.K., and Mistree, F., 2009, "Adaptable Robust Design of Multi-scale Convective Systems Applied to Energy Efficient Data Centers," Numerical Heat Transfer, Part A: Applications, (accepted) "

Experimental activities

3-D PIV system



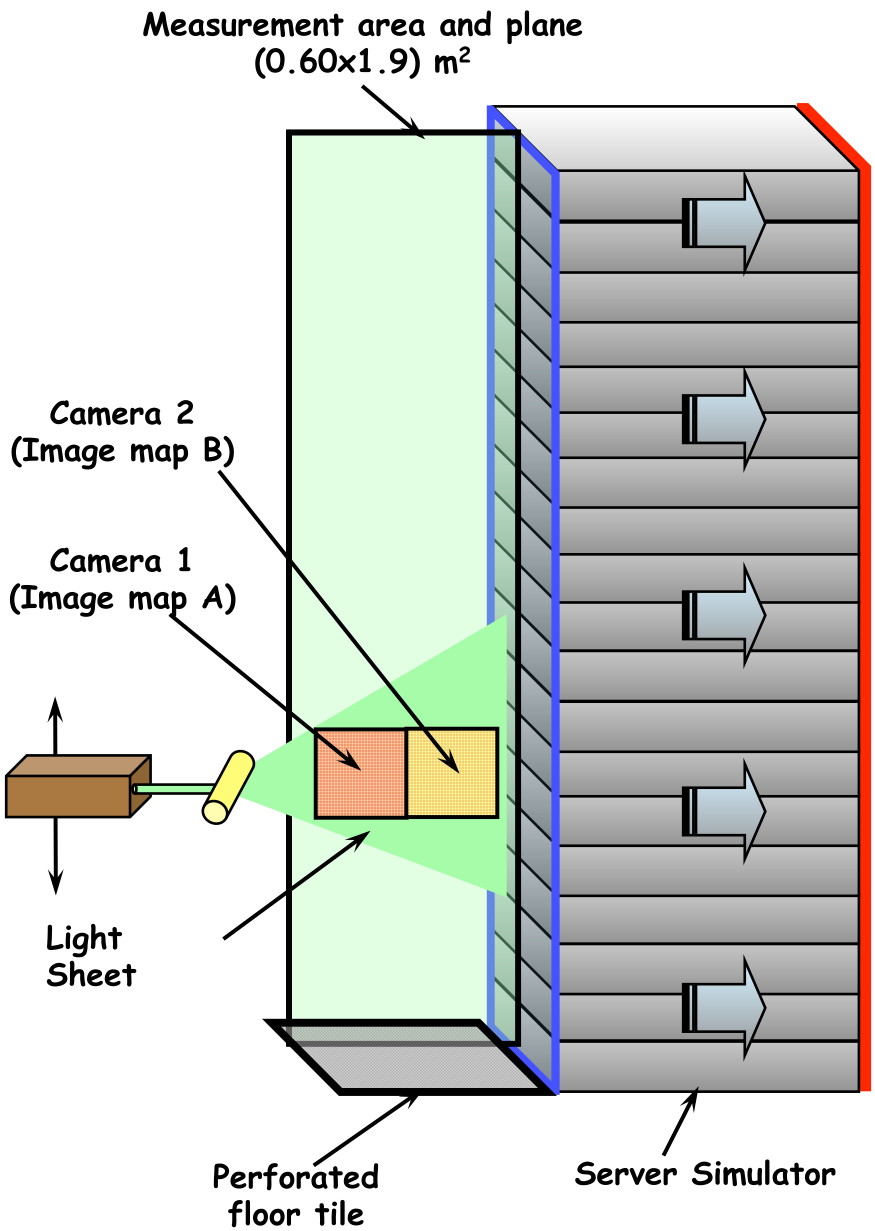
Fan speed and Heat setting dials

Server Simulator

Perforated floor tiles with dampers

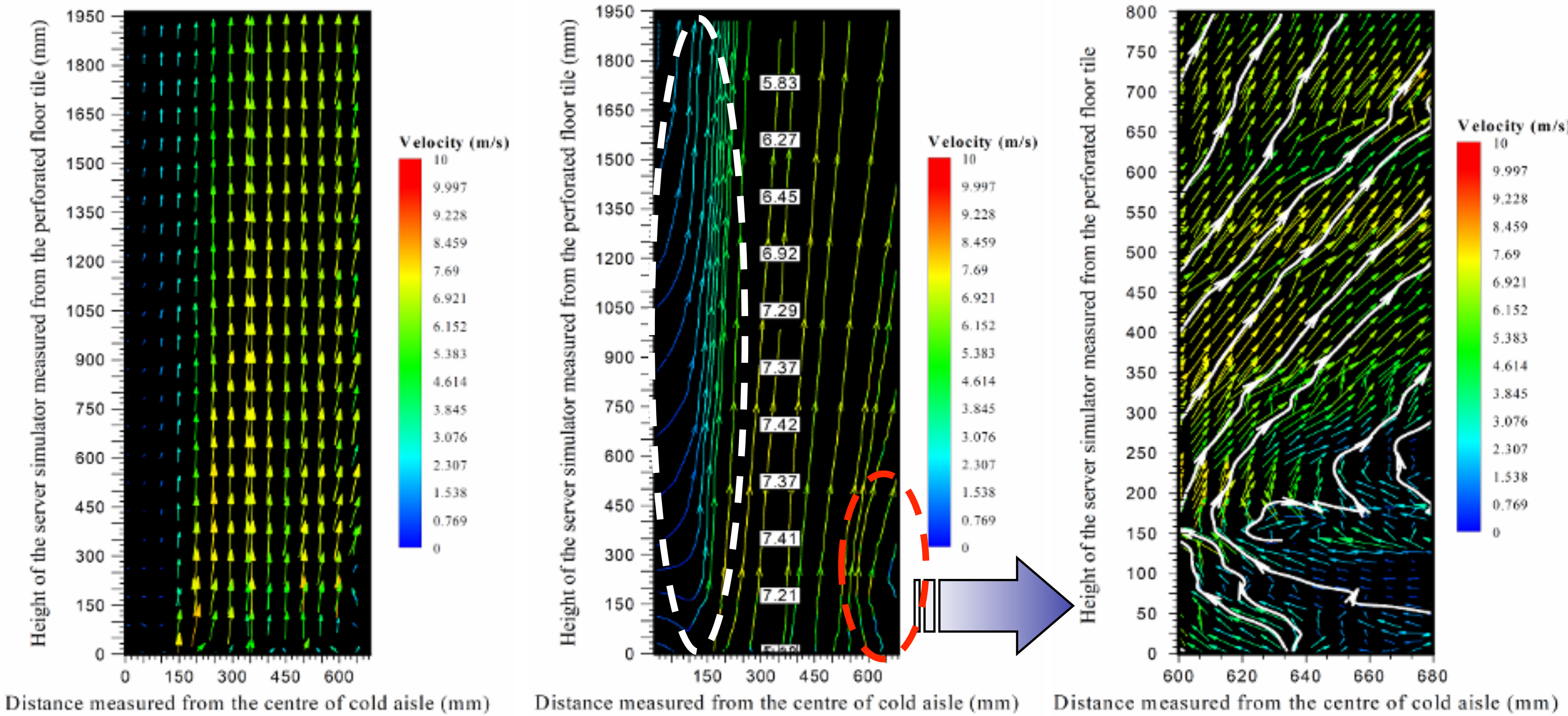
- 3-D Stereoscopic PIV (Particle Image Velocimetry system for room level air flow mapping.
- 25kW Server Simulator with adjustable fan and heater settings to simulate a variety of heat loads.
- Perforated tiles with adjustable dampers to control air discharge rate.

Details of the PIV Measurements



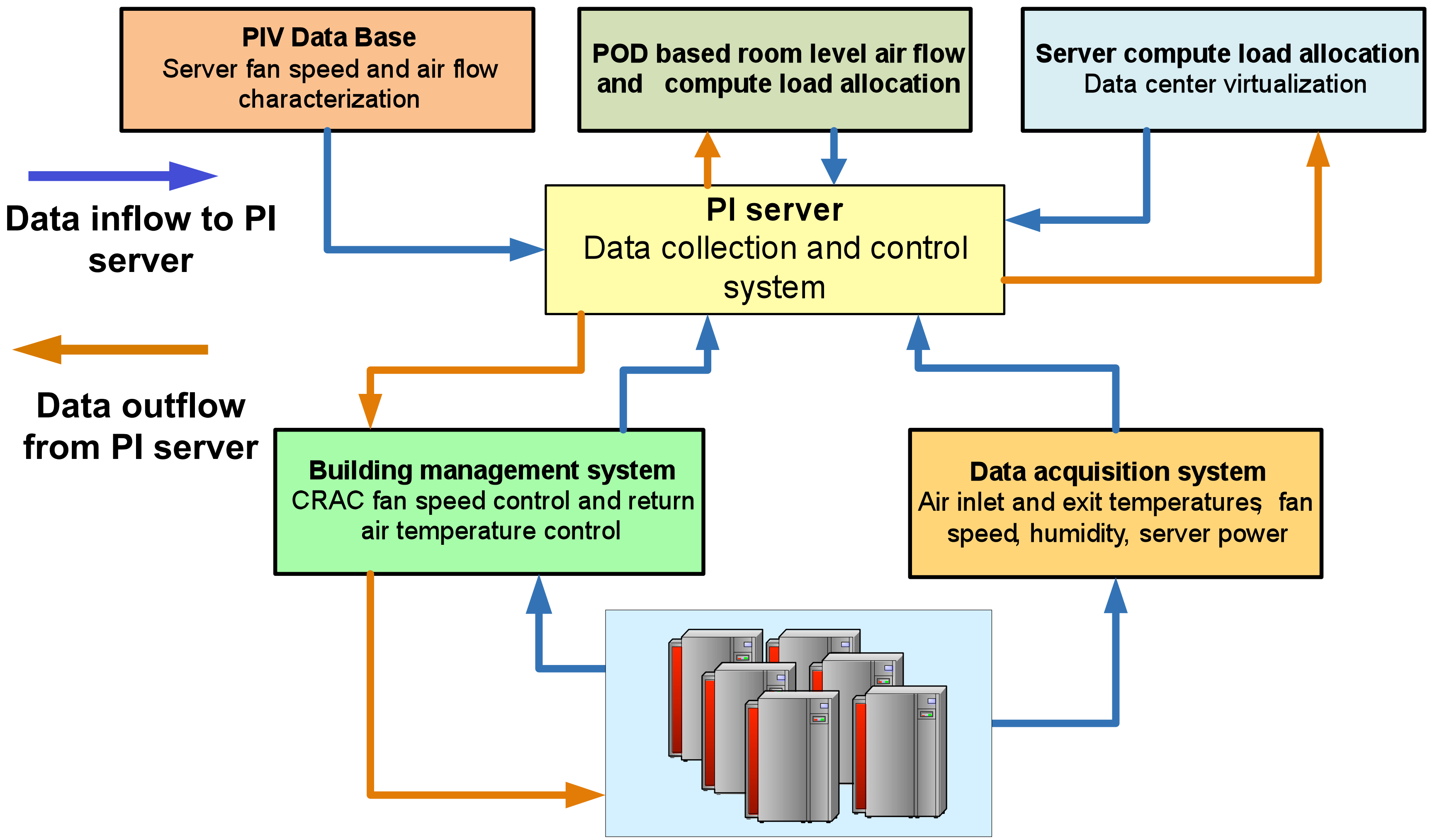
- Pulsed Argon Laser 200mJ power density @ 532nm wavelength - 200 Hz mounted on a **traverse**
- The flow is seeded with a **water based fog droplets** ~1μm
- **2 image maps** in succession from **2 cameras** in intervals of **800 μs**
- Each location consists of **80 image map pairs** and **24 such locations** are captured to get a one complete flow
- Each experiment is **repeated twice** and a statistical average consisting of **80 image maps** is taken to get the mean velocity component
- The **24 vector maps are stitched** to get a complete picture of the flow
- Adaptive correlation along with a moving average filter is used to get the velocity vector map from the raw image data

Sample case study: Perforated Tile Air Flow Rate = 1.224 m^3/s (2594 CFM)



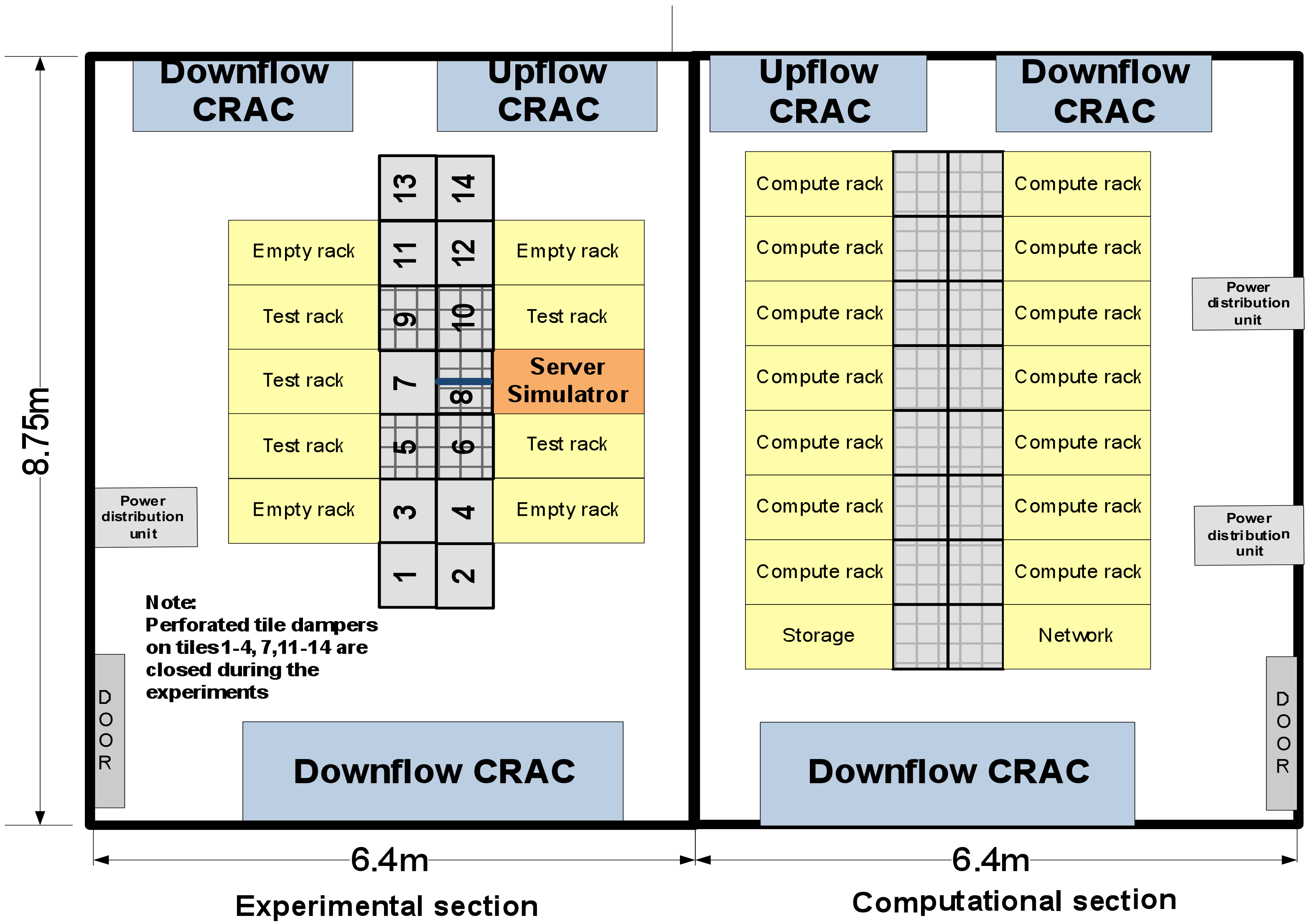
- ✓ Inlet velocities ~O(5.83 (top)-7.5 (tile surface) m/s
- ✓ Bottom servers up to the height of 500 mm from the floor do not receive cool air
- ✓ Air entrainment velocity in the cold aisle ~ 1.8m/s severely disrupts the air distribution to the opposite rack
- ✓ Reversed flow in the servers located in the bottom of the rack (v~2.5 m/s) up to a height of ~ 400 mm can lead to thermal failure of the servers placed in the bottom of the rack

Compute Load Based Virtual Data Center Center Thermal Management Scheme

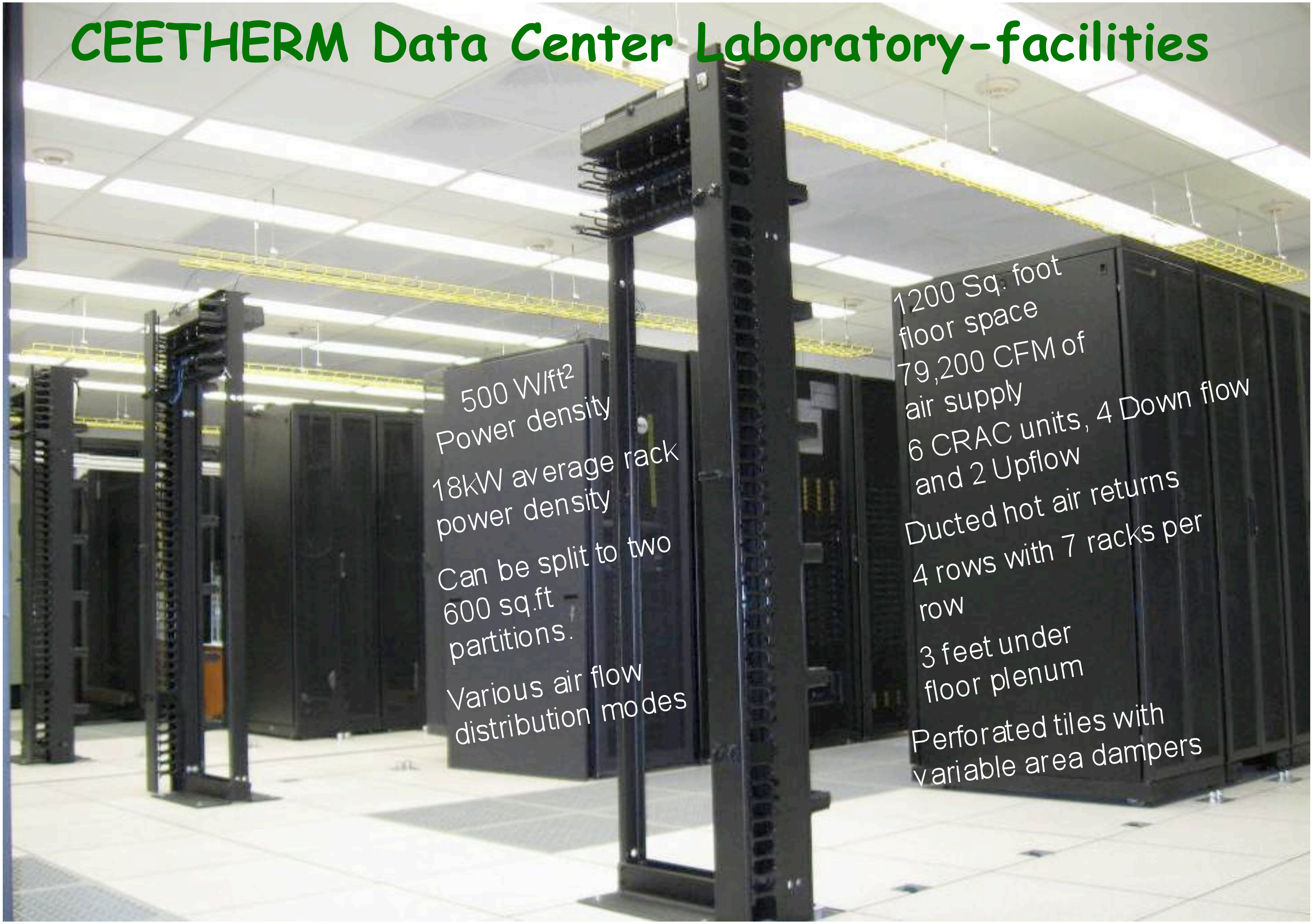


CEETHERM Data Center
Experimental facilities

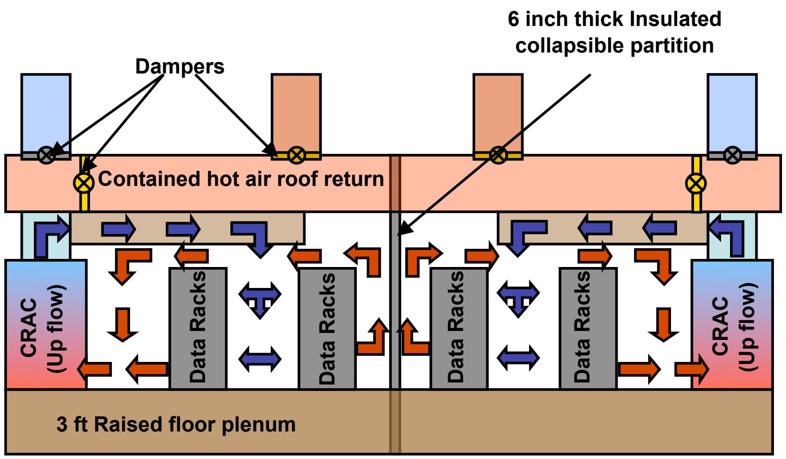
CEETHERM Data Center Layout



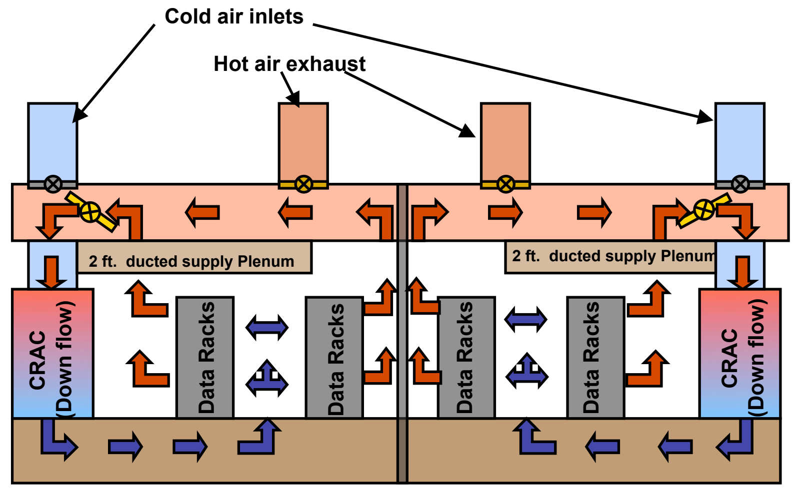
CEETHERM Data Center Laboratory-facilities



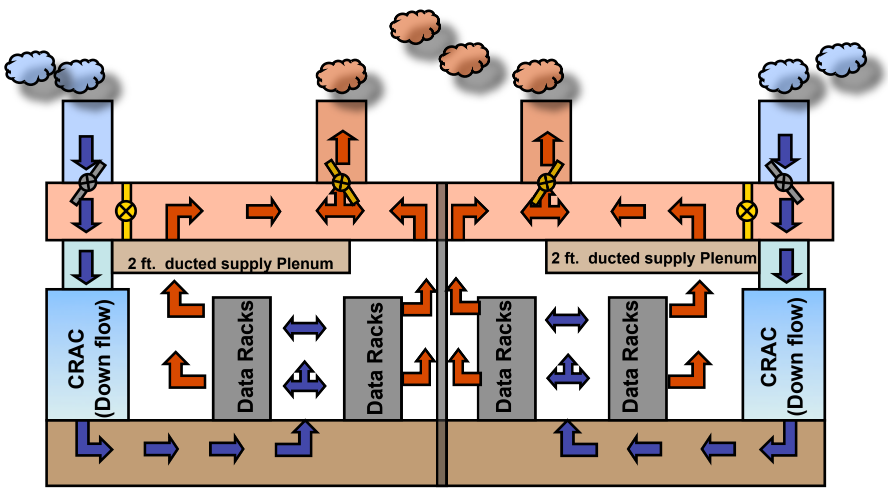
CEETHERM data center- air distribution system



Over head cold air supply and hot air room return



Under floor cold air supply and contained hot air ceiling return

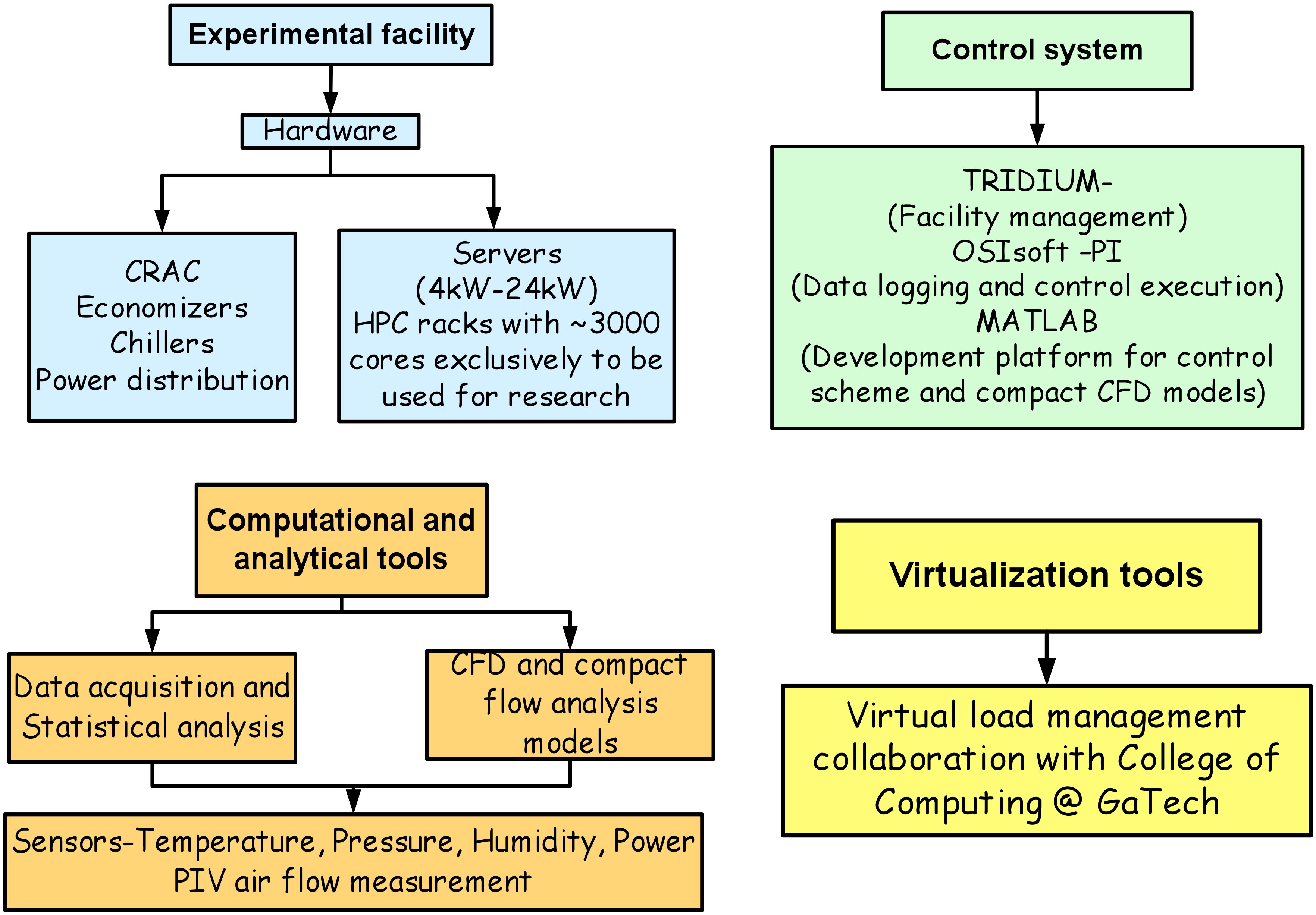


Air economizer mode operation with under floor cold air supply

Outside air economizer operation

- ✓ Building monitoring system (BMS) monitors data center space temperature humidity and pressure.
- ✓ BMS performs psychometric calculations.
- ✓ BMS monitors outside air temperature and quality.
- ✓ Regulated dampers openings for hot and cold air inlet and exit
- ✓ Positive data centre space pressure to prevent influx of outside air.
- ✓ The down flow CRAC units distribute the cold air.
- ✓ Electrostatic filters control air quality
- ✓ Independent economizer operations for both the partitions.

Research tools



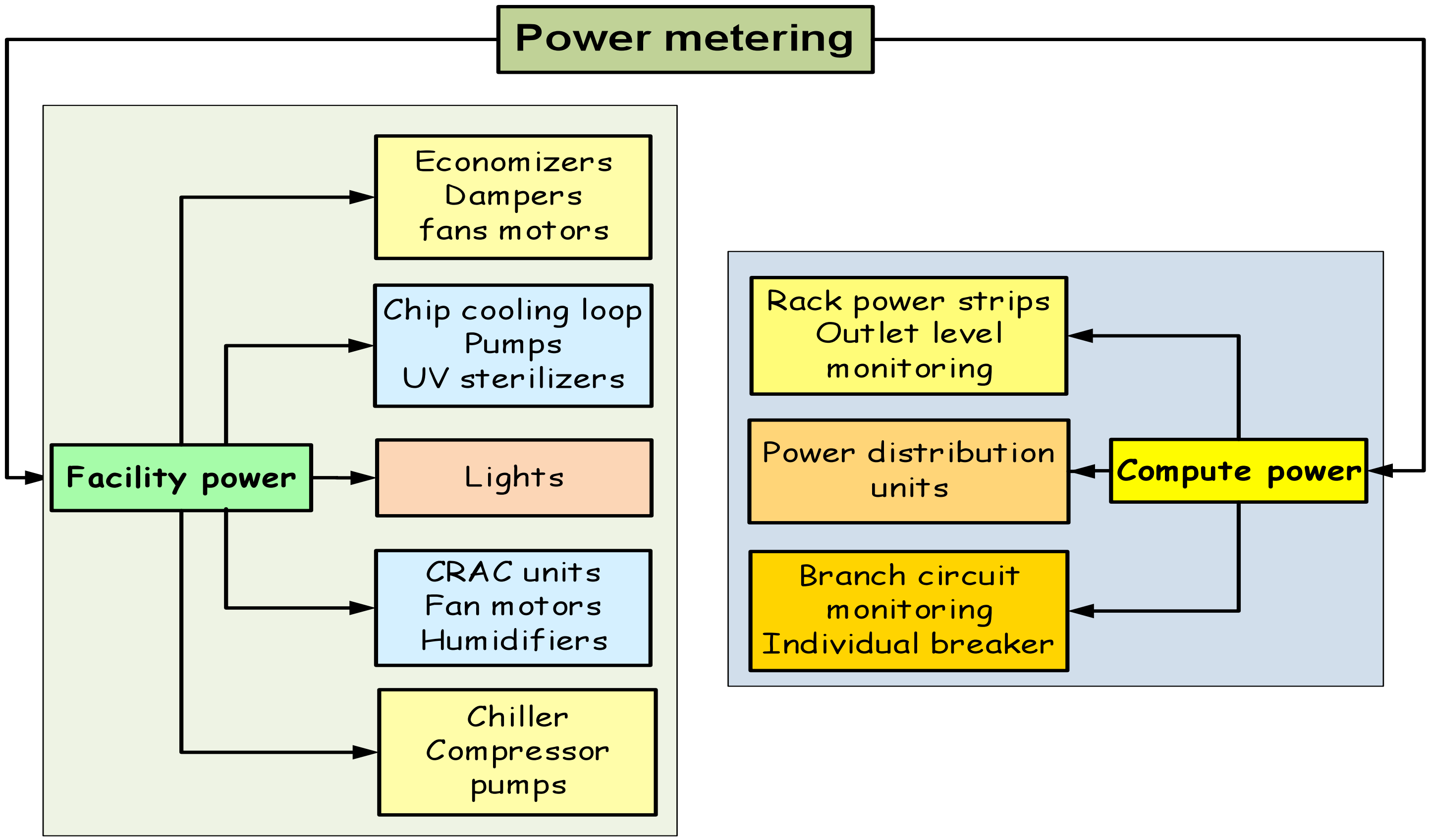
Data acquisition

- ✓ 800 Temperature monitoring points distributed in room to measure space temperature (under progress)
- ✓ 70 temperature probes measure server inlet and outlet air temperatures at various heights in the rack
- ✓ 8 humidity sensors in the rack
- ✓ BTU meters for chip cooling loop, CRAC's and chiller
- ✓ Air exit and return temperature for each of the CRAC units
- ✓ Chilled water flow for all the CRAC units
- ✓ VFD fan speed control

All the data is continuously being measured (7/24)

Power metering

- ✓ Power metering at all levels right from incoming grid to individual server

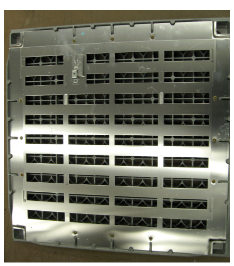


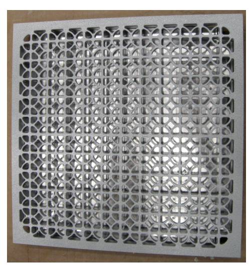
- ✓ The power meters are instrument grade certified with an accuracy of ± 0.5% accuracy
- ✓ Outlet level management for turning off unutilized servers
- ✓ Measure Current, Voltage, power factor, supply line frequency to compute kW, kW-hr and runtime of each unit
- ✓ Ability to quantify distribution losses

Photographs of the facility

3 ft. Plenum with dedicated chip cooling loop for liquid cooling and rear door heat exchangers

High flow perforated tiles with dampers





Chip cooling loop

24kW HPC racks are fitted with rear door heat exchangers
BMS monitors and maintains the chilled water temp> Dew point temp

180 gallon expansion tank

Dedicated Chip cooling loop →

Power Distribution units

All the Power Distribution units are equipped with branch circuit monitoring devices

Server level monitoring

Remote switching with
Outlet level monitoring

HPC racks

840 node/3360 core IBM BladeCenter cluster.

Each node has two dual-core AMD Opteron processors, 4GB ram, and two 73GB hard drives.


Thank You
Georgia Institute of Technology