ES2 | Center for Energy-Smart Electronic Systems

The National Science Foundation Center for Energy Smart Electronic Systems (ES2) Research Activities at UTA

Dereje Agonafer

April 22, 2015

Maximizing Use of Efficient Air-Side Economization in Modular, Large Data Centers and Datacom Housing Units

PI: Dereje Agonafer (UTA)

UTA Students
Betsegaw Gebrehiwot, PhD
Abhishek S Guhe, MSc
Aniket R Kalambe, MSc
Digvijay Sawant, MSc
Dhanraj A Patil, MSc
Rajat Singh, MSc
Kanan D Pujara, MSc
Vishnu Sreeram, MSc
Suhas Sathyanarayan, MSc
Palak V Patel, MSc

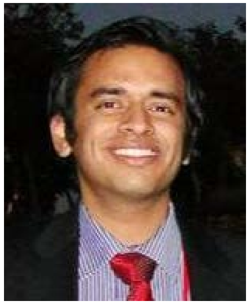
BU Student
Husam Alissa

Collaborator: Bahgat Sammakia (BU)

Mentors

David Mendo and Simpson Cumba	Comcast
Deepak Sivanandan, Mark Hendrix, and Tom Craft	CommScope
Veerendra Mulay	Facebook
Akhil Docca and Mark Seymour	Future Facilities
Saurabh Shrivastava and Yasin Makwana	Panduit
Naveen Kannan, James Hoverson, Jim Jagers, and Mike Kaler	Mestex
Robert Yurcik	Verizon Wireless

MAXIMIZING USE OF EFFICIENT AIR-SIDE ECONOMIZATION IN MODULAR, LARGE DATA CENTERS AND DATACOM HOUSING UNITS

						
Betsegaw	Suhas	Vishnu	Digvijay	Rajat	Dhanraj	Aniket
Gebrehiwot	Sathyanarayan	Sreeram	Sawant	Singh	Patil	Kalambe
PhD Student	MSc Student	MSc Student	MSc Student	MSc Student	MSc Student	MSc Student

				
Nikhil	Palak	Abhishek	Kanan	Adithya
Baviskar	Patel	Guhe	Pujara	Pothuri
MSc Student	MSc Student	MSc Student	MSc Student	MSc Student

Anantha	Sridhar	MSc Student
Nagaratnakar	Kotari	MSc Student
Dakshini	Musali	MSc Student

Strategic Goal/Project Description

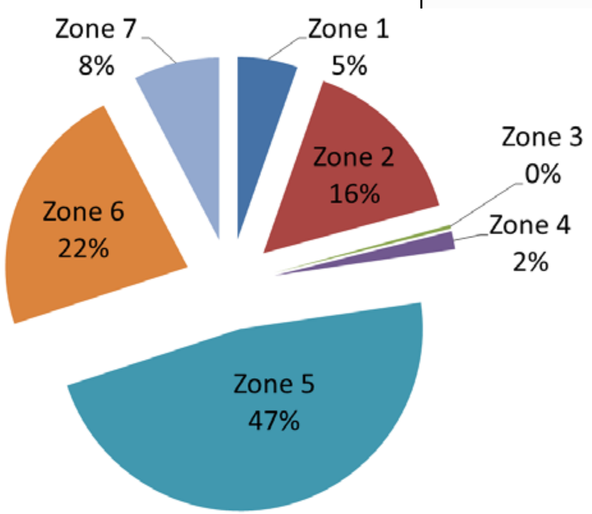
- This project is aimed at maximizing use of efficient air-side economization in modular, large data centers and Datacom housing units
- Determine percentage of a year a data center at a given location could use air-side economization with and without evaporative cooling systems.
- Improve control system
  - Integration of saturation effectiveness curves into the cooling system control algorithm
  - Control air mixing of cold ambient air with hot data center exhaust air
  - When to dump sump water: Control total dissolved solids (TDS) concentration in the sump water
- Minimize water usage of evaporative cooling systems
  - Study effect of total dissolved solids (TDS) concentration on life of cooling pads
  - Study life of cooling pads
  - Selection of cooling pads
- Provide best practices for using the above methods of cooling

Research Modular Data Center

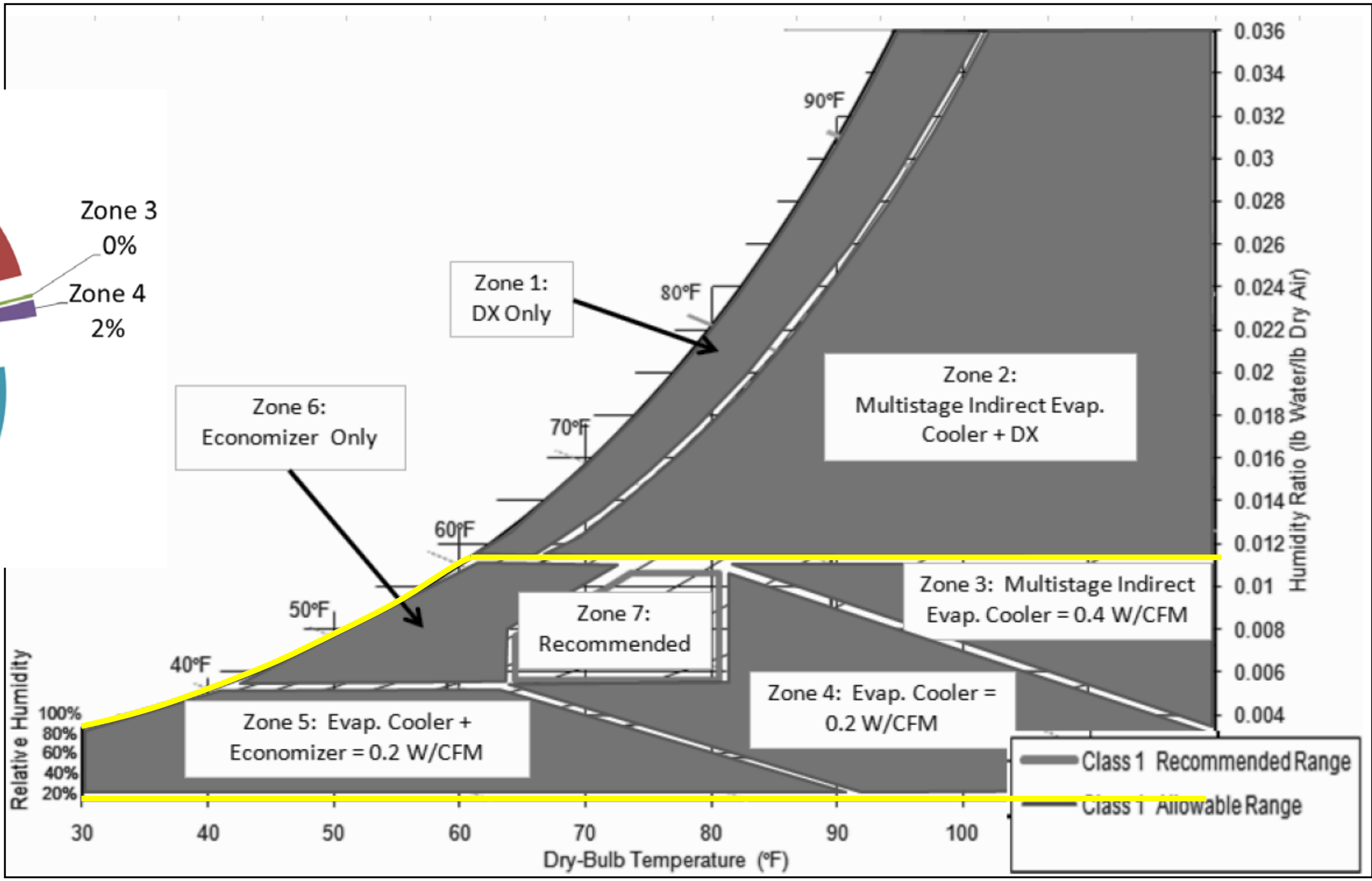
The research modular data center construction is completed.
Size 10ft x 12ft x 28ft

1 Year Chicago Weather Data (Recommended Range)

For Tier 1 Data Center



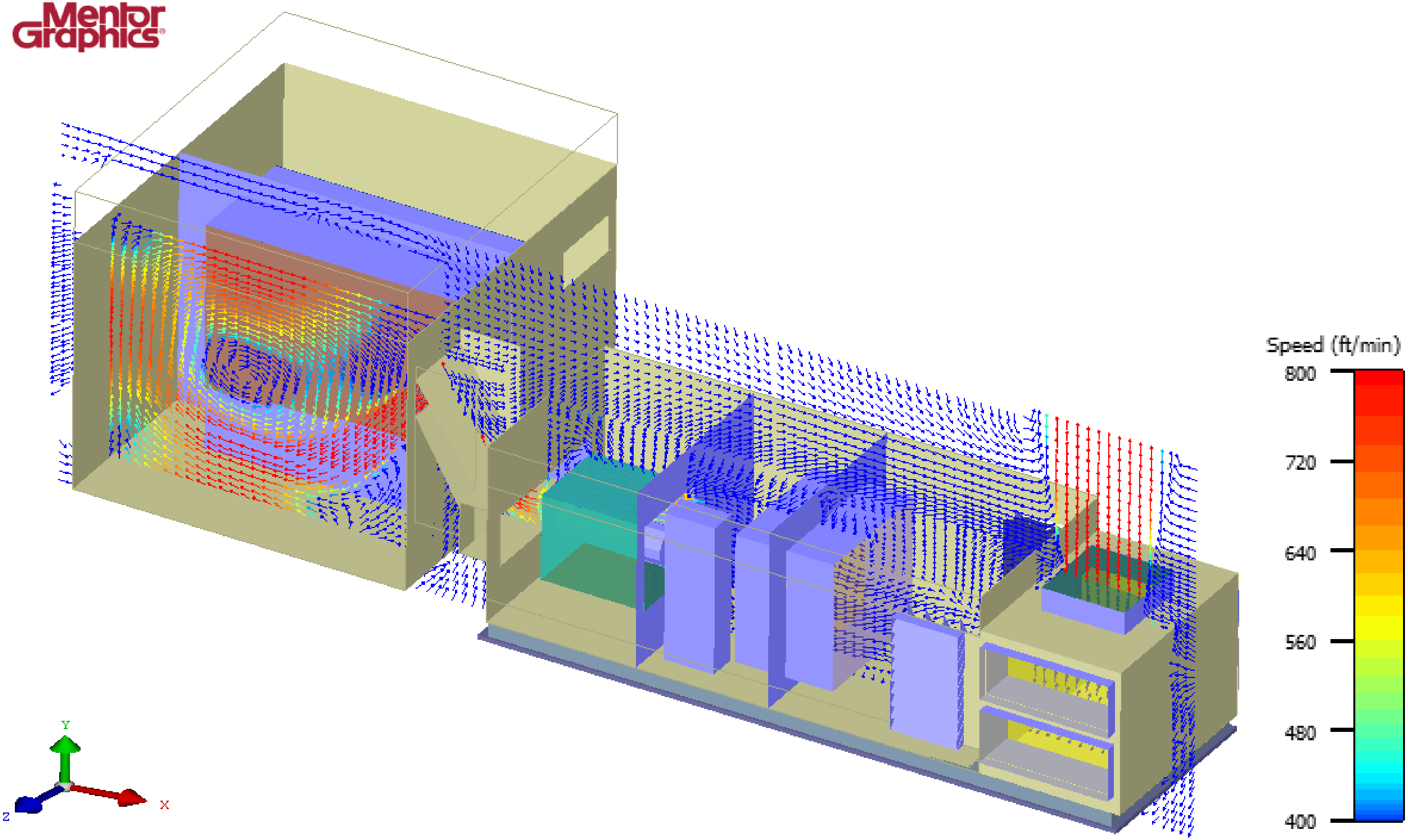
- A MATLAB code is written to make the above pie chart for the given weather data.



- For data centers with higher tier than 1, the number of hours air-side economizer plus evaporative cooling system can be used will be higher.

Ref. Weather data provided by Dr. Saurabh Shrivastava

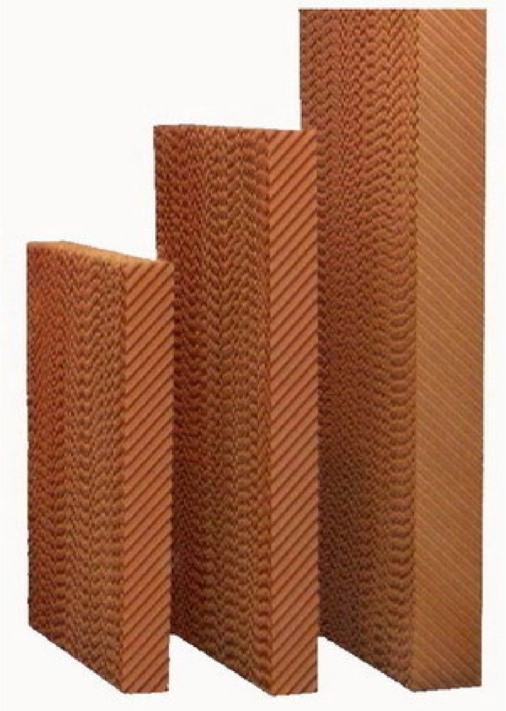
CFD Model of Modular Data Center



Cooling Pad Test Setup

Cooling pad test duct attached to an airflow bench

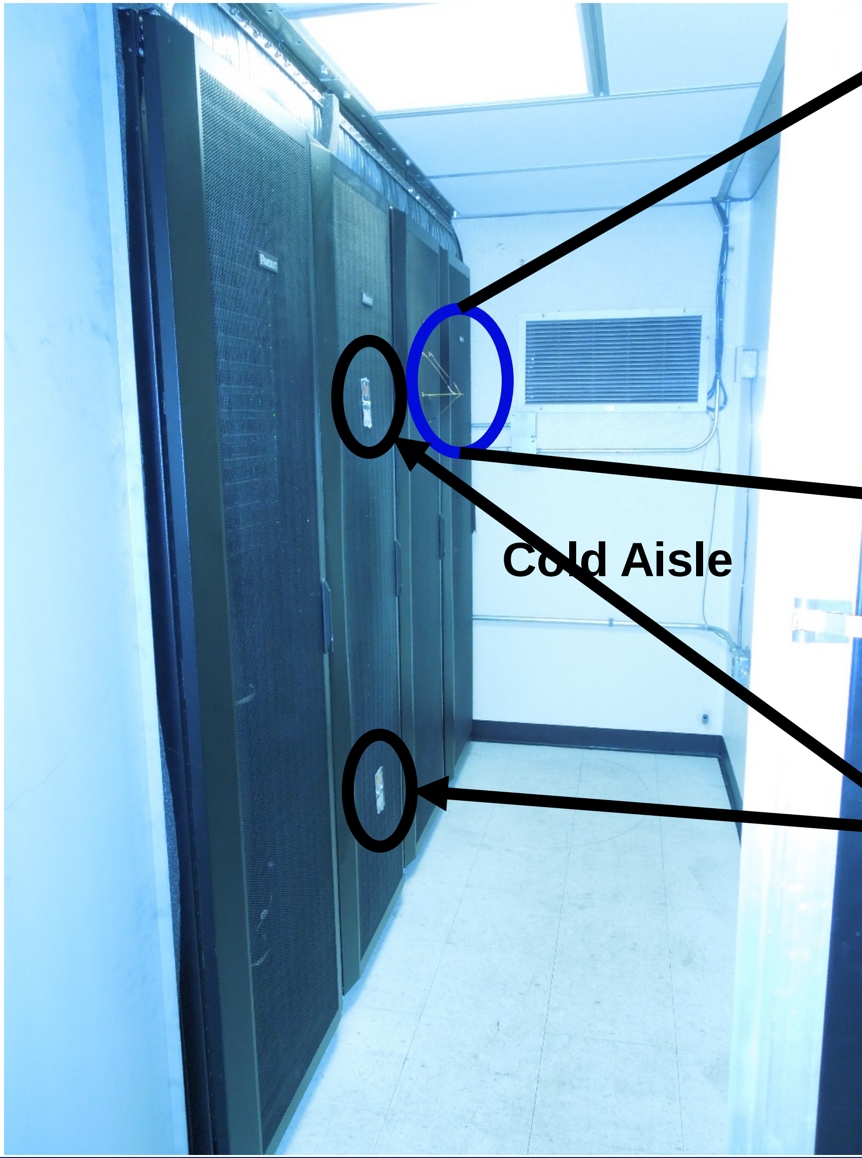
Cellulose Corrugated Paper*

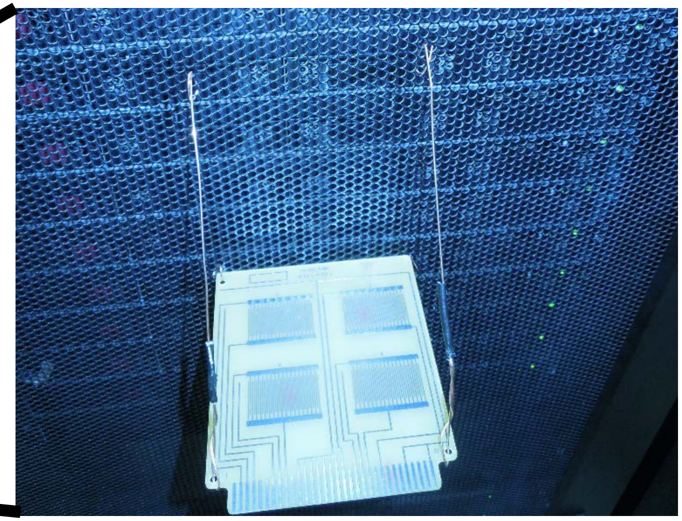


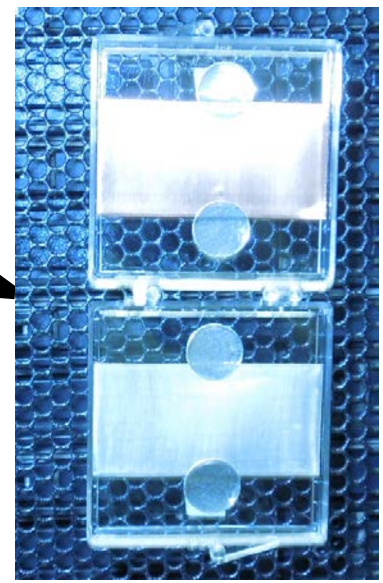
- Study:
  - Water utilization effectiveness (WUE) calculation
  - When to replenish and dump the sump water
  - Effect of total dissolved solids (TDS) concentration on life of cooling pads
  - When to replace cooling pads
  - Integration of saturation effectiveness curves into the cooling system control algorithm

*http://www.tradeindia.com/selloffer/3267080/Evaporative-Cooling-Pad-5090.html

Measuring Particulate and Gaseous Contaminants in Data Centers







Top figure: IBM donated comb for measuring particulate matter size and concentration

Left figure: IBM donated gaseous contaminant concentration measuring coupons (Ag & Cu)

Measuring Particulate and Gaseous Contaminants in Data Centers Impacts of Particulate and Gaseous Contamination on IT Equipment Where Air Side

Team Members

- Team Leads:
  - Jimil Shah, PhD Student
  - Oluwaseun Awe, PhD Student
- Masters Students:
  - Kanan Pujara
  - Tejeshkumar Bagul (Graduated in December 2014)

Contamination Study Plan

- Phase 1 (Completed):
  - The origin and concentration of gases
  - Classification of contaminants on the basis of corrosivity
  - Narrow down the list of contaminants
  - Concentrate on tackling the contaminants
- Phase 2 (In progress):
  - Dedicated to computational study.
  - Effects of contaminants on various data center equipment
- Phase 3 (In progress):
  - Primary Focus - Validation of CFD models with experiments
  - Effects of various contaminants under varying temperature and humidity conditions

John Fernandes
PhD (Dec 2014)

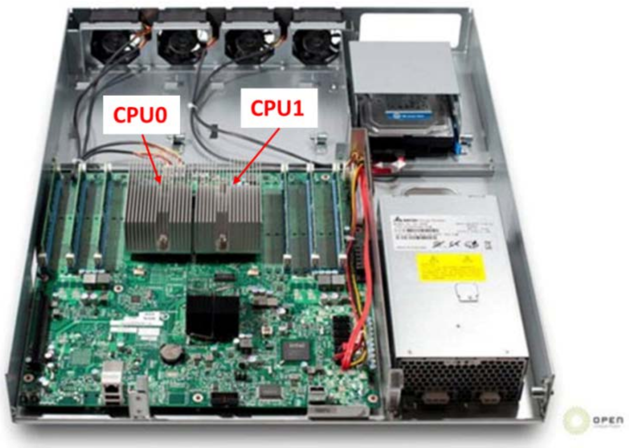
Rick Eiland
PhD (May 2015)

Shreyas Nagaraj
MSc (May 2014)

AIR COOLING OF SERVERS

Air Cooling of Servers

- Part I – Effect of RIT on server power consumption
  - Determine upper limit for energy-efficient operation
  - Effect on facility-level performance

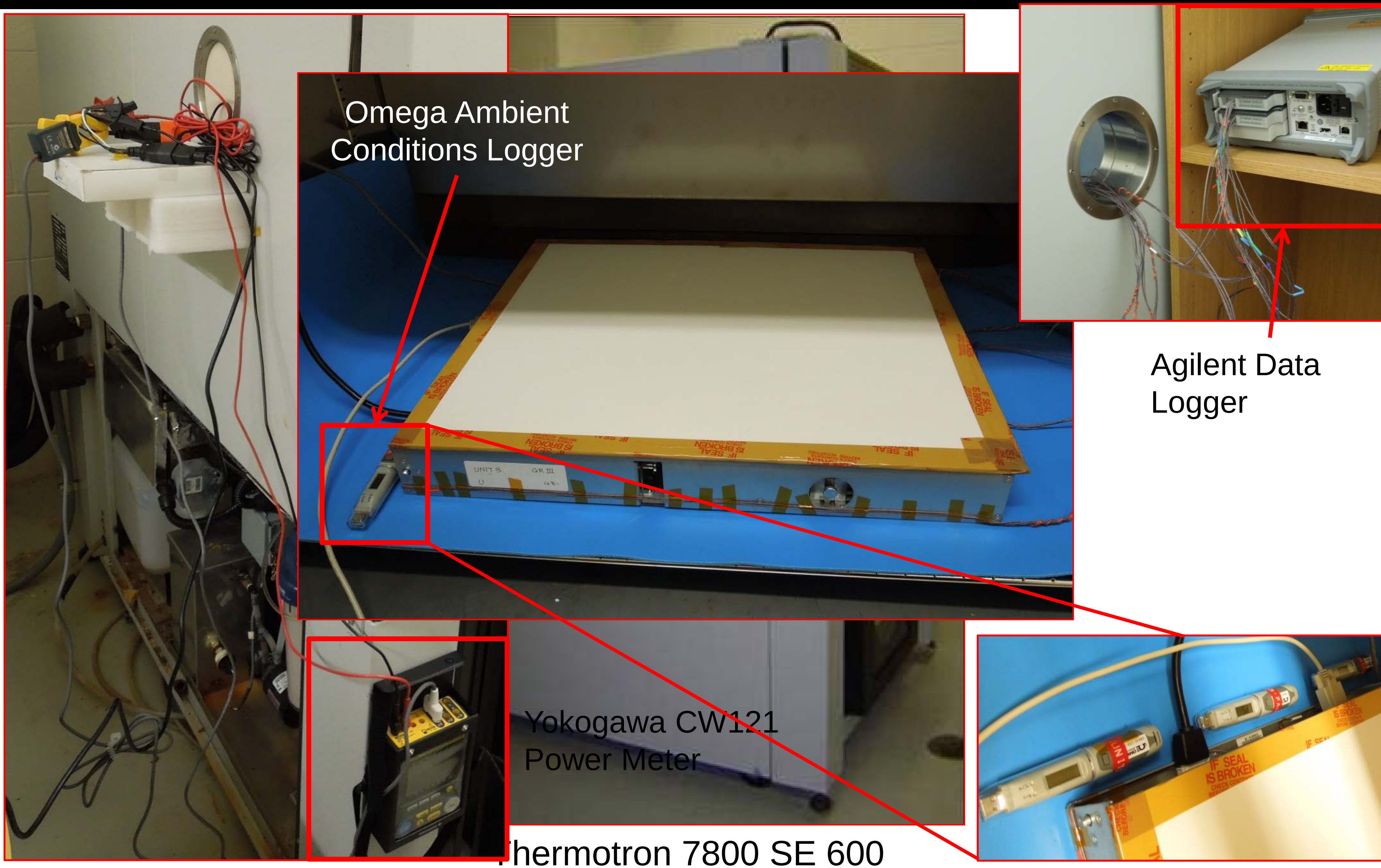


Intel Based
Open Compute Server

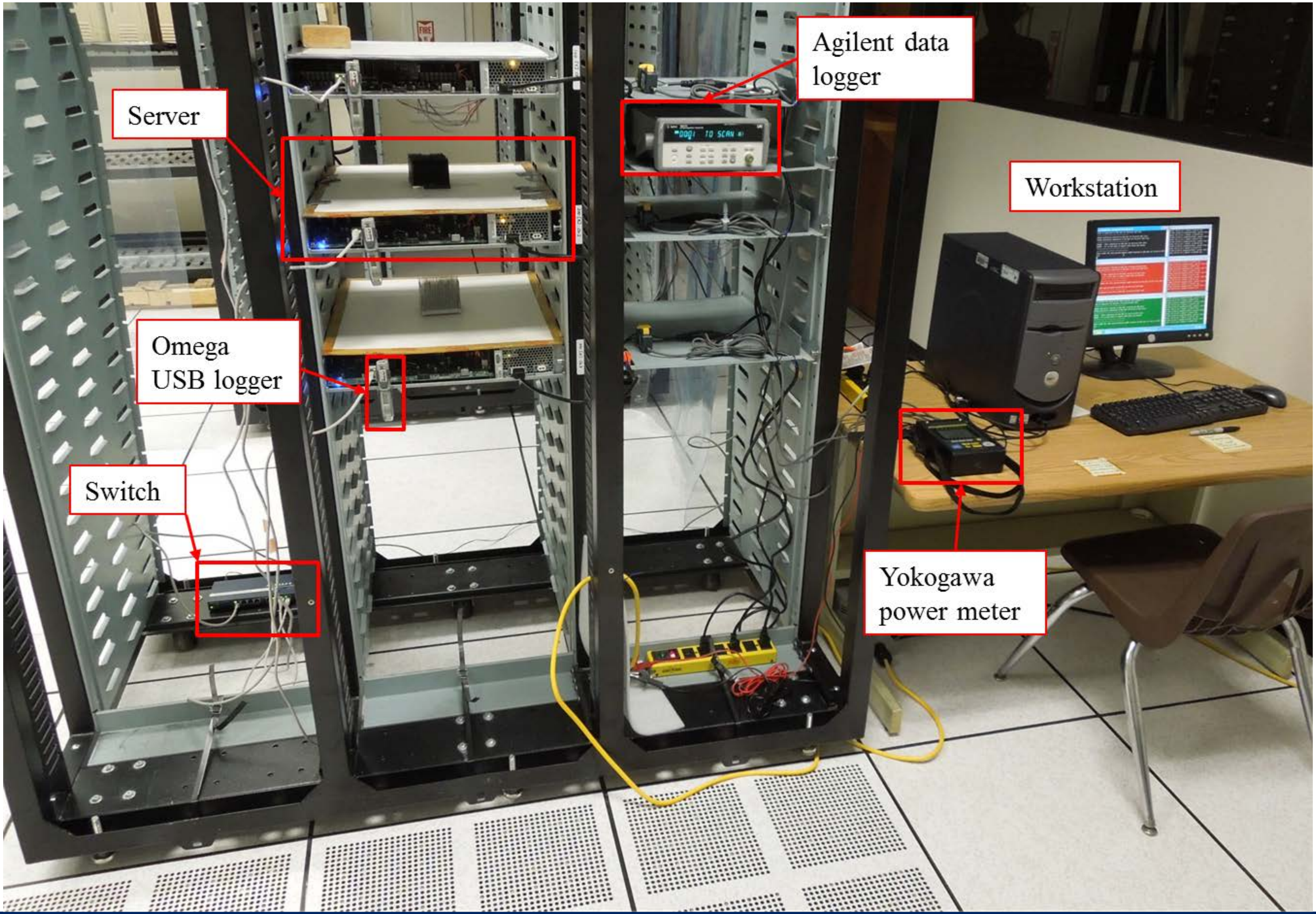
- Part II – Optimize fan control scheme
  - Determine temperature range for minimal server power consumption
  - Savings between original and modified setups

Note: RIT – Rack inlet temperature (°C)

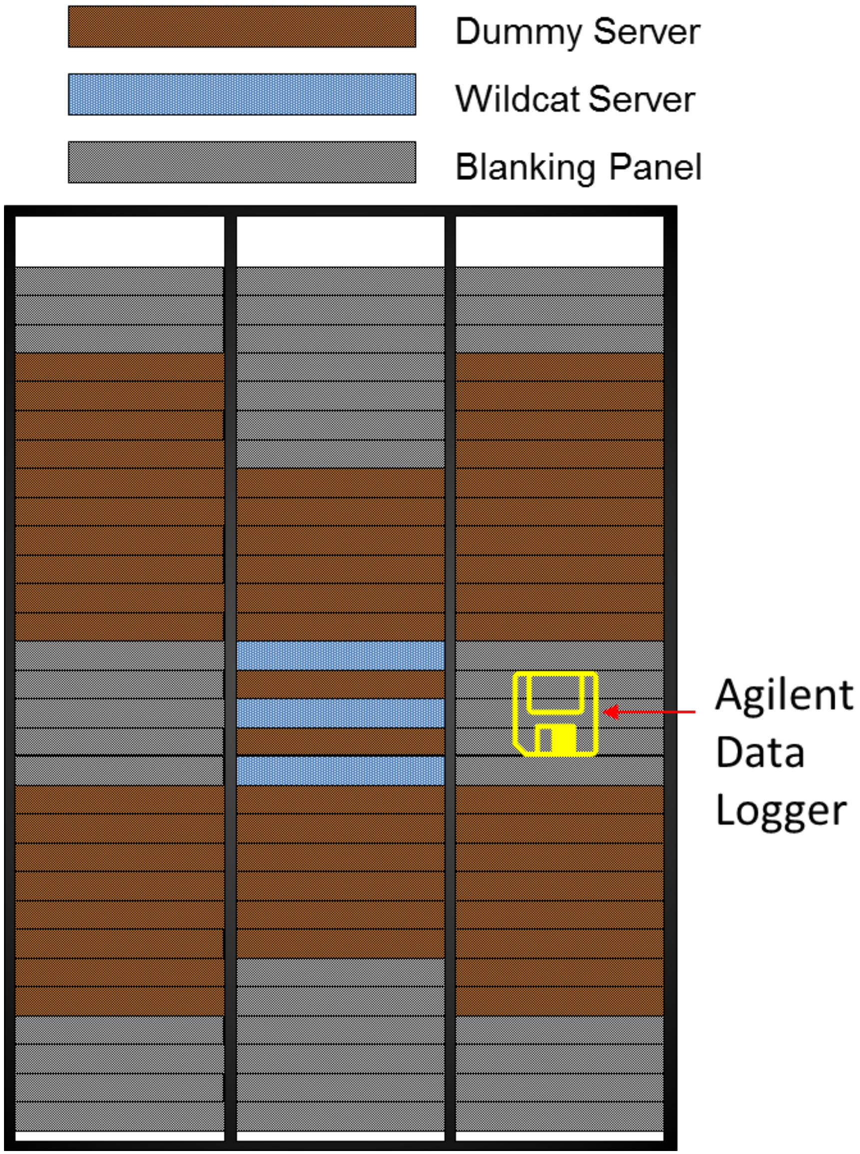
Part I – Single Server Test in Environmental Chamber



Several Servers Testing in a Data Center



Populating the Triplet



Bharath Nagendran
MSc (Dec 2013)

Shreyas Nagaraj
MSc (Dec 2014)

Rick Eiland
PhD (May 2015)

John Fernandes
PhD (Dec 2014)

CONSOLOIDATION OF RACK LEVEL FANS

Experimental Setup – Thermal Measurement

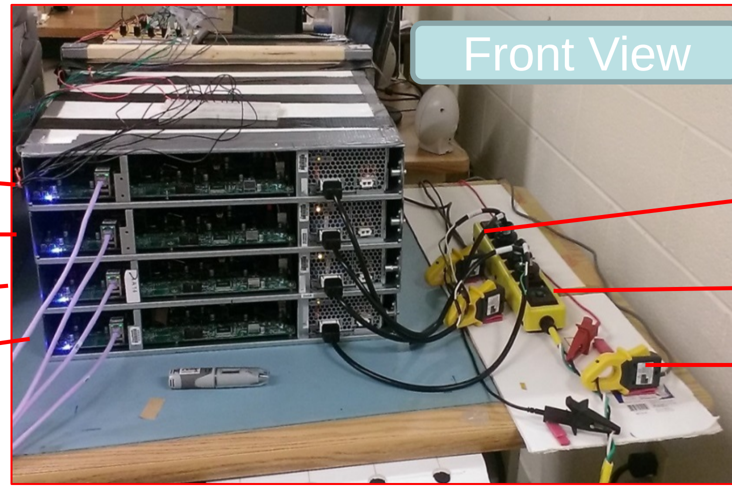
Server Numbers

40

30

20

10



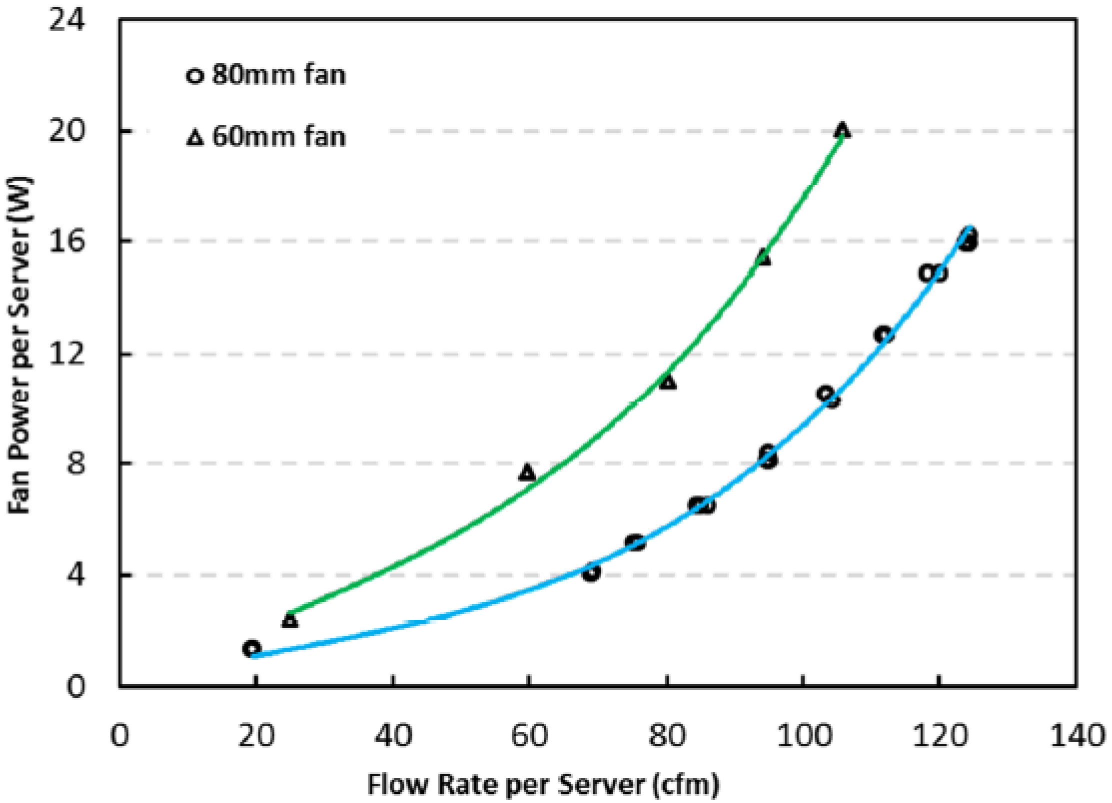
Channel 3 (40)

Channel 2 (20)

Overall

Predicted Savings

- The fan power saved is ***between 43% and 55%*** depending on the operating speed of the fans



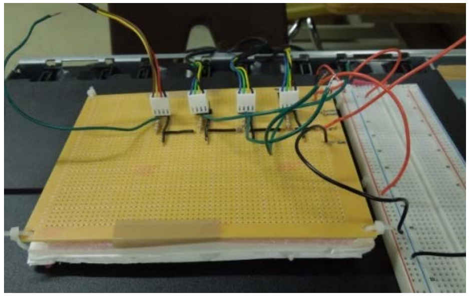
Comparison of fan power consumed per server at a given flow rate for the 60mm and 80mm fan cases

Fan Failure Study – Base line

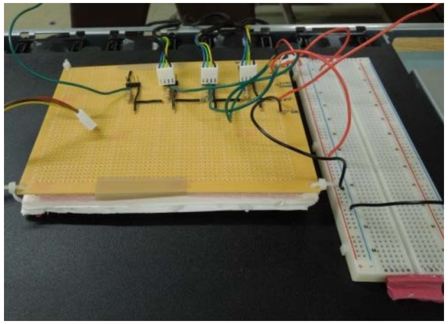
Impact of fan position in a failure scenario on die temperature

Test Setup

Fan Numbering Sequence



All fans in running condition



Fan 1 disconnected (Powered off)

Improving Cooling Efficiency of Servers by Replacing Smaller Chassis Enclosed Fans with Larger Rack-Mount Fans

Itherm 2014: Won Best Poster Award

Presented by:
Bharath Nagendran
University of Texas at Arlington

Thursday, May 29th, 2014
ITherm, Orlando, FL USA

Co-Authors:
Shreyas Nagaraj, UTA
John Fernandes, UTA
Richard Eiland, UTA
Dereje Agonafer, UTA
Veerendra Mulay, Facebook Inc.

John Fernandes
PhD (Dec 2014)

Manasa Sahini
PhD (May 2016)

Divya Mani
MSc (Dec 2014)

Ruturaj Kokate
MSc (May 2015)

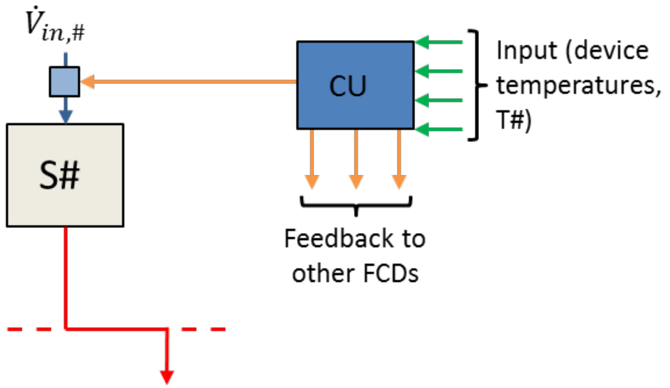
DYNAMIC COLD PLATE

Overview

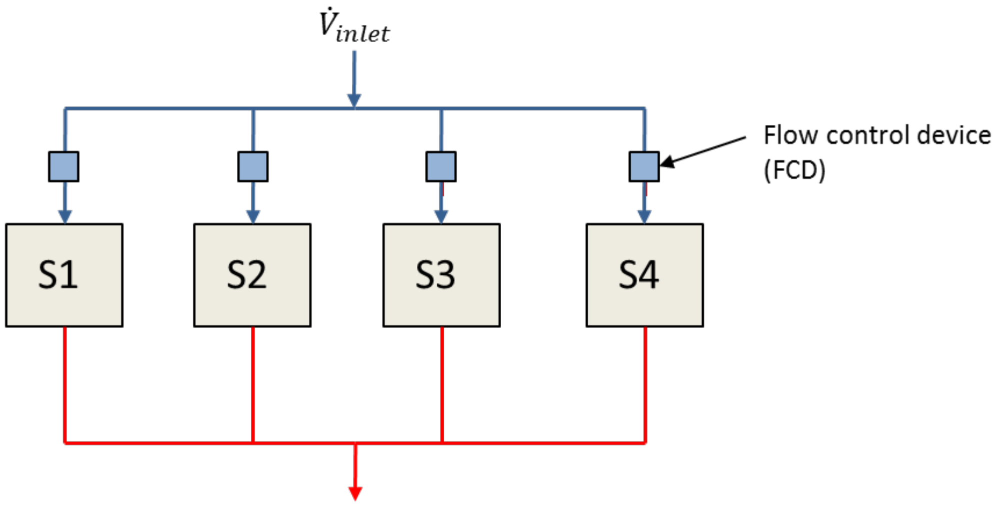
- *Objective*
  - Energy-efficient liquid cooling of high power modules
- *Approach*
  - Propose concept of '*dynamic cold plate*'
  - Design solution for high power MCM
  - Evaluate performance with extensive CFD analysis
  - Requirements of experimental testing
    - Preview test matrix

Concept

(a) Sectioned dynamic cold plate



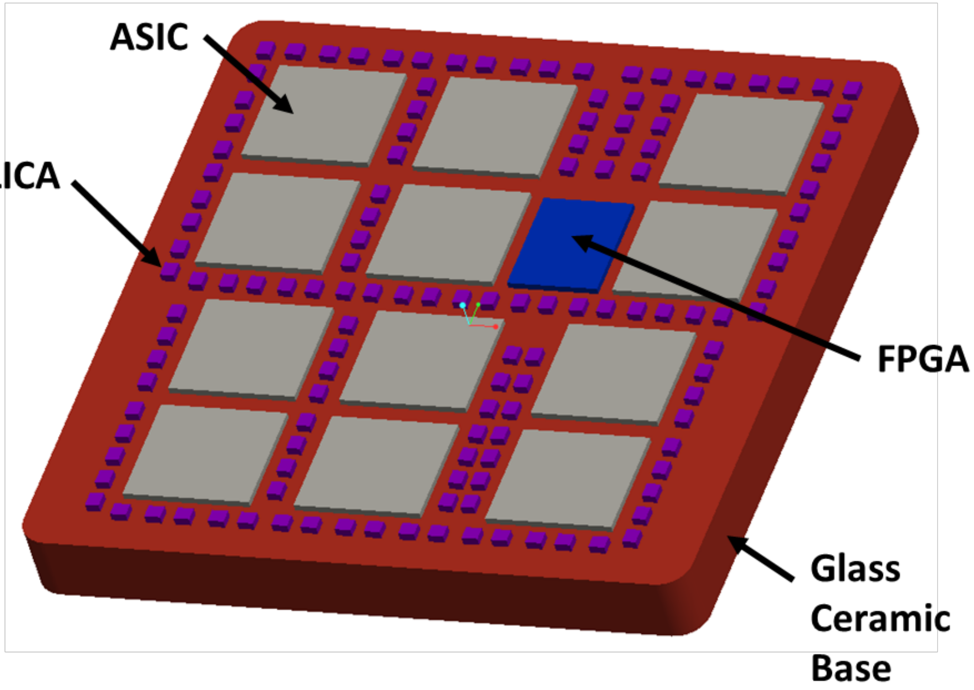
(c) Control strategy (unit) operating single section



(b) Parallel flow distribution: Simplified layout and instrumentation

Reference Platform

- MCM serves as basis for design of solution
  - Power dissipation of 485W over 78mm × 78mm
- Provided by Endicott Interconnect Technologies



Dimensions (in mm)
ASICs – 14.71 × 13.31 × 0.8
FPGA – 10.5 × 12.7 × 0.8

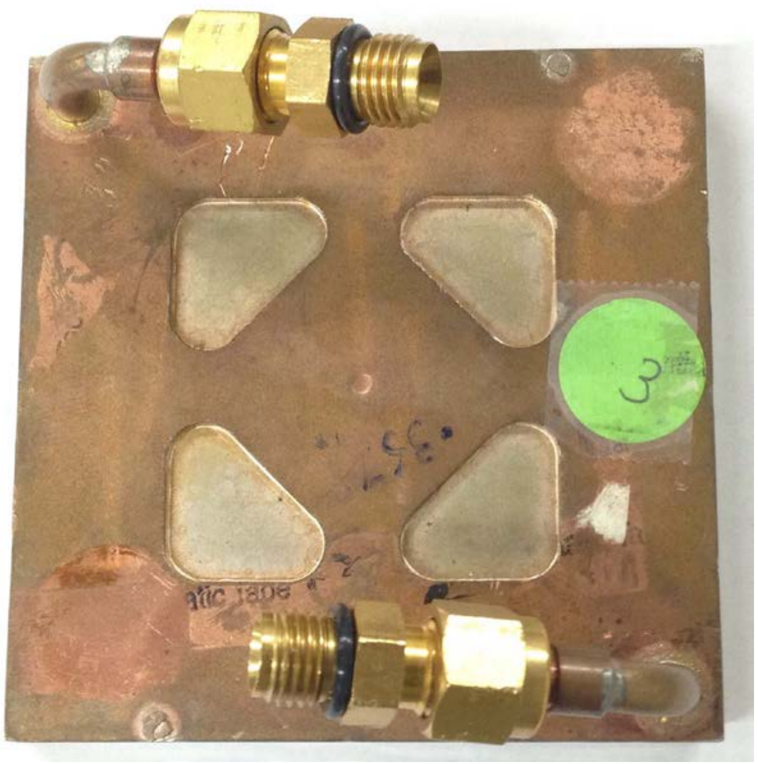
Details of MCM components

Component	Quantity	Power (W)
Base	1	-
ASIC	12	40
FPGA	1	5
LICA	137	-

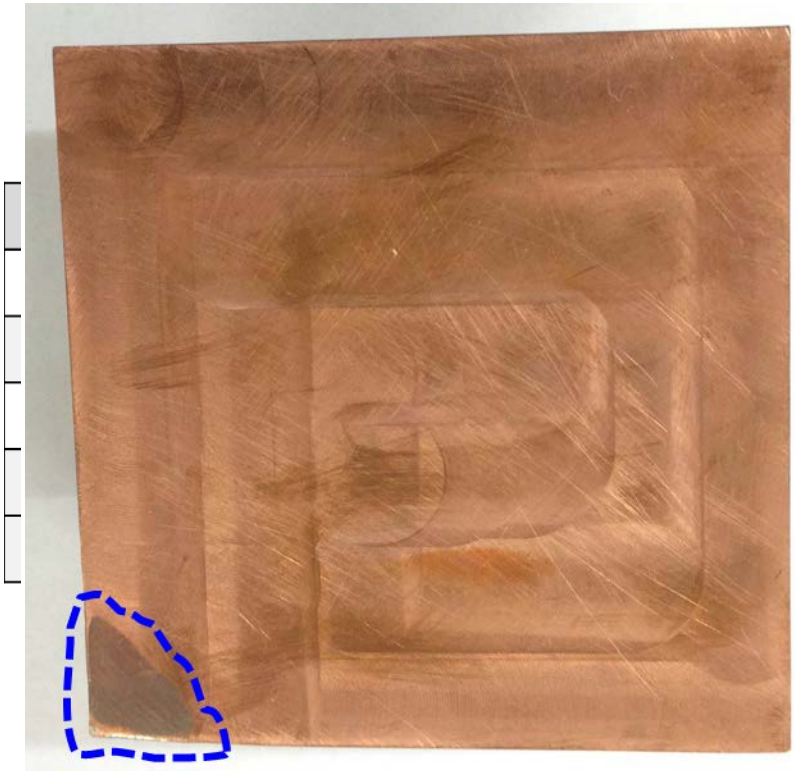
Note: MCM – Multi-chip module; TTV – Thermal test vehicle

Original Cold Plate

- Brazed copper body
- Prevent detrimental performance of TIM
  - Base is milled to 0.002” planarity



Top View



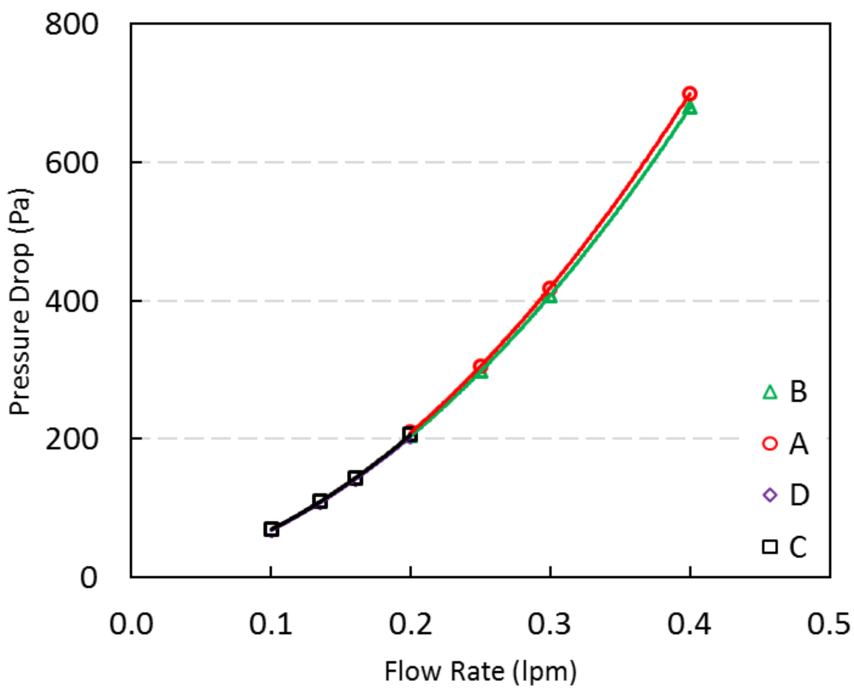
Bottom View

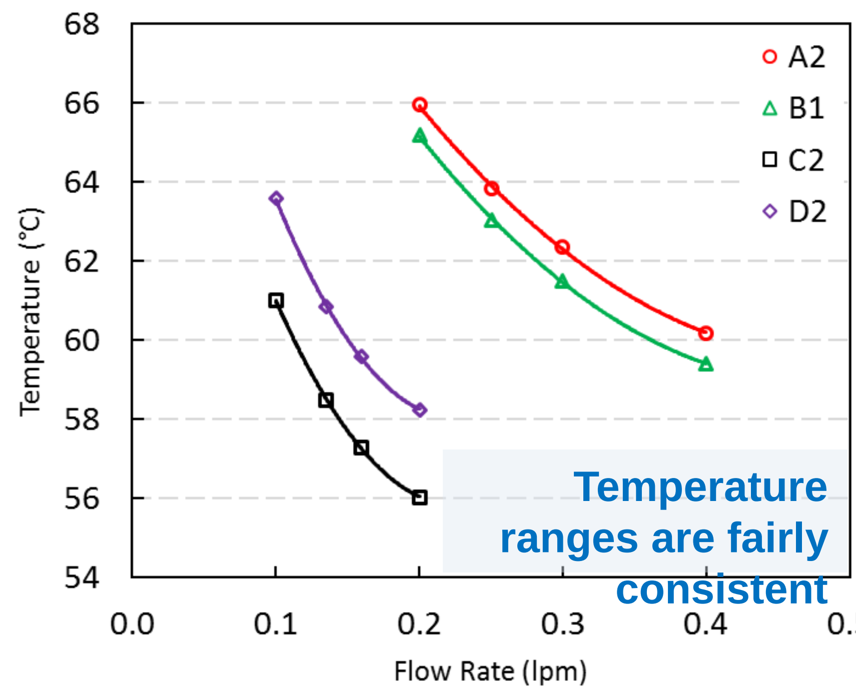
Thermal Performance

Electronics, MEMS and Nanoelectronics Systems Packaging Center

- Original cold plate
  - P_{pump} of 0.575W at flow rate of 2lpm
- Proposed design
  - P_{pump} of 0.05W at 2lpm
  - *Expect savings in either flow power or device temperatures*

Q_{total} (lpm)	P_{pump} ($\times 10^{-3}$ W)
0.60	1.61
0.77	3.00
0.92	4.88
1.20	10.56



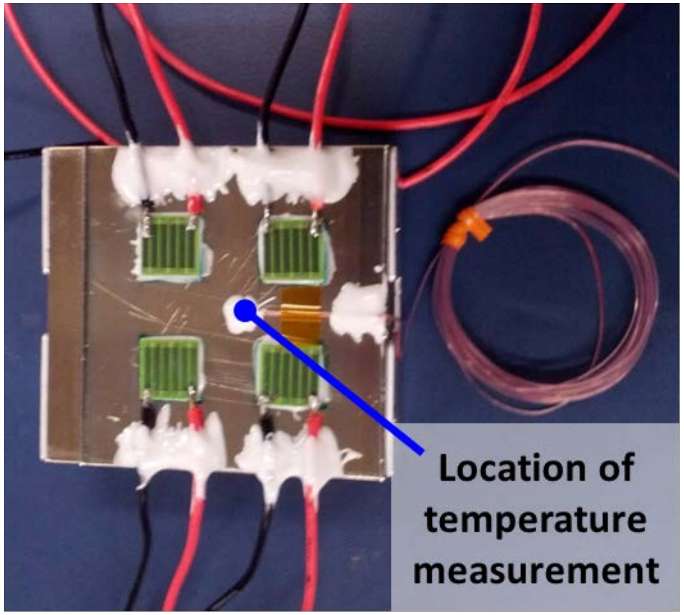


Temperature ranges are fairly consistent

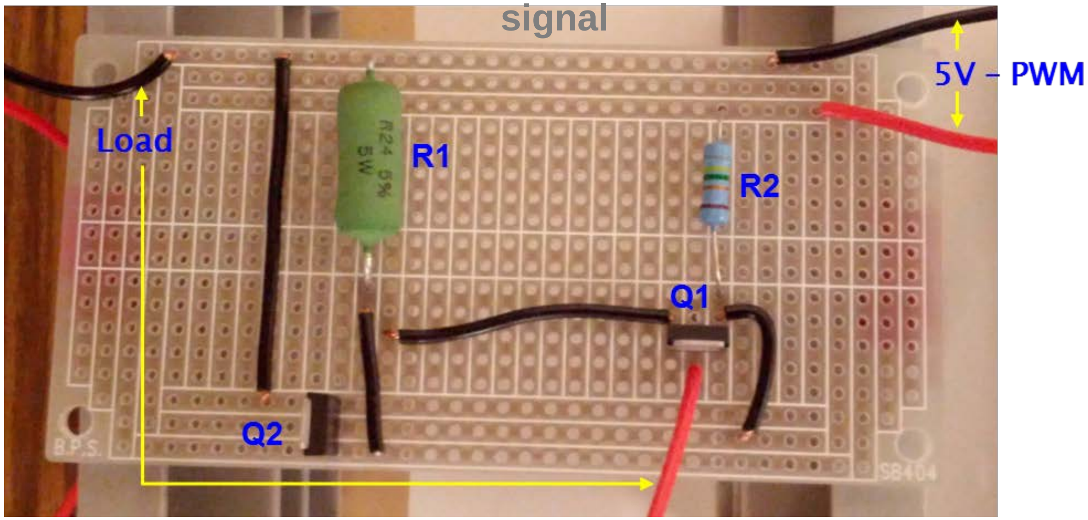
Initial Study

- Implement a simple setup that can
  - Power and control resistive heaters
  - Control cooling based on measured temperature
  - Automate the entire procedure

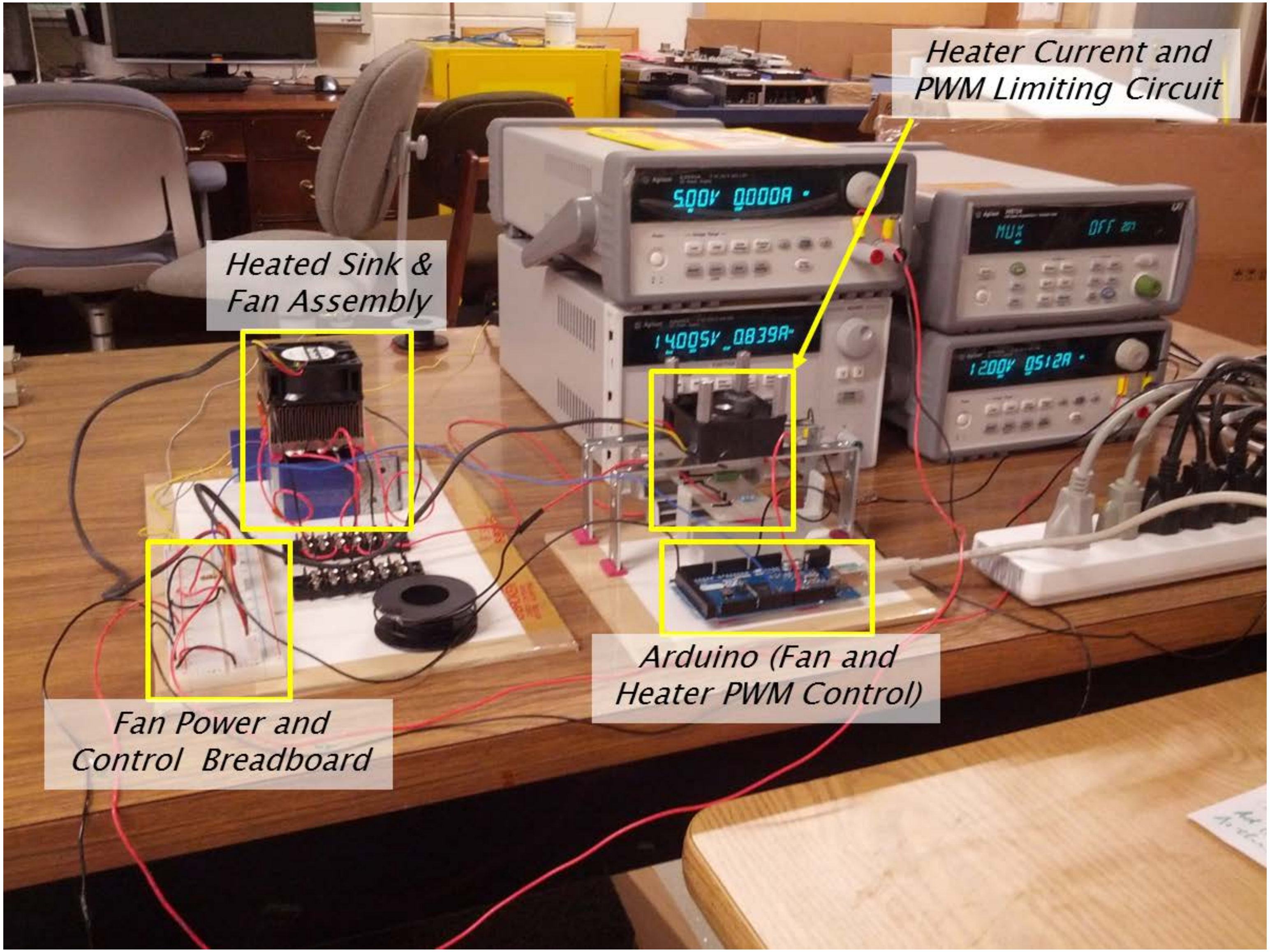
Four thick film heaters epoxied to heat sink base



Current control circuit – Modulate heat power with PWM signal



Simple Control Setup

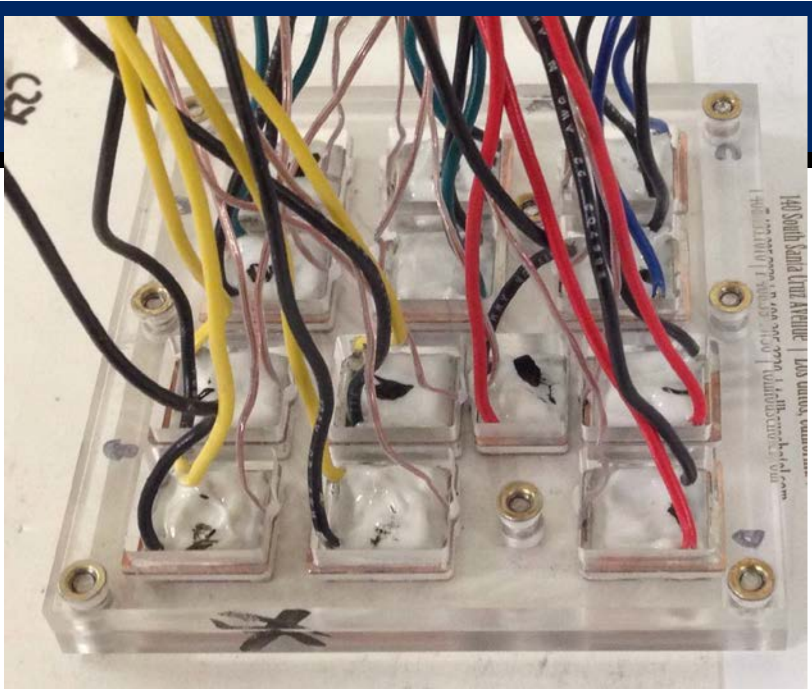


Electronics, MEMS and Nanoelectronics Systems Packaging Center

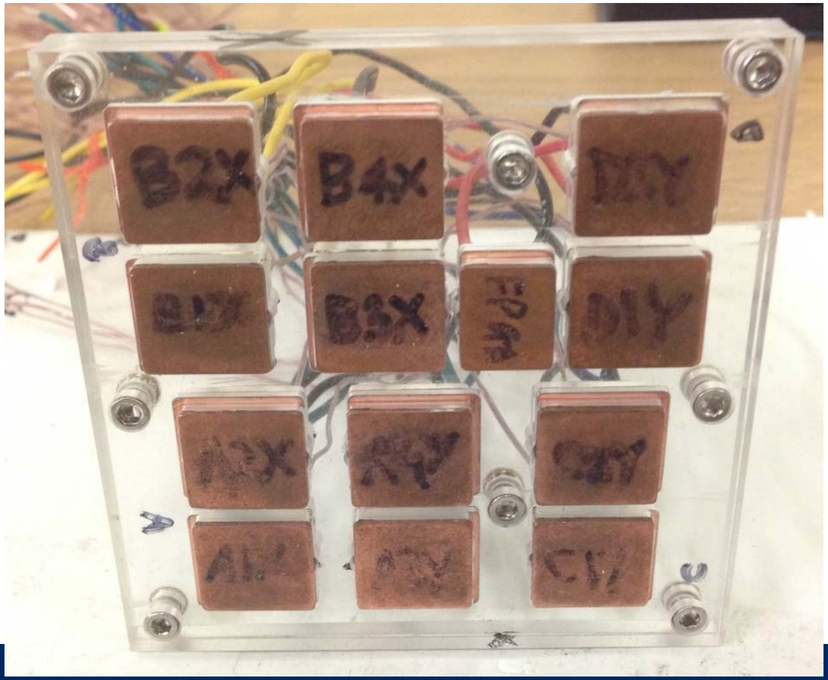
MCM TTV

- Heaters, leads and thermocouples have been installed

Block	Resistance (Ohms)			
	Run 1	Run 2	Run 3	Avg.
A1X	10.06	10.07	10.06	*10.06*
A2X	10.06	10.07	10.08	*10.07*
A3Y	10.06	10.08	10.07	*10.07*
A4Y	10.07	10.06	10.06	*10.06*
B1X	9.91	9.90	9.91	*9.91*
B2X	9.93	9.91	9.90	*9.91*
B3X	9.96	9.97	9.97	*9.97*
B4X	9.90	9.90	9.89	*9.90*
C1Y	10.02	10.03	10.02	*10.02*
C2Y	10.03	10.02	10.03	*10.03*
D1Y	9.83	9.81	9.81	*9.82*
D2Y	9.99	9.99	10.00	*9.99*
FPGA	25.40	25.39	25.38	*25.39*



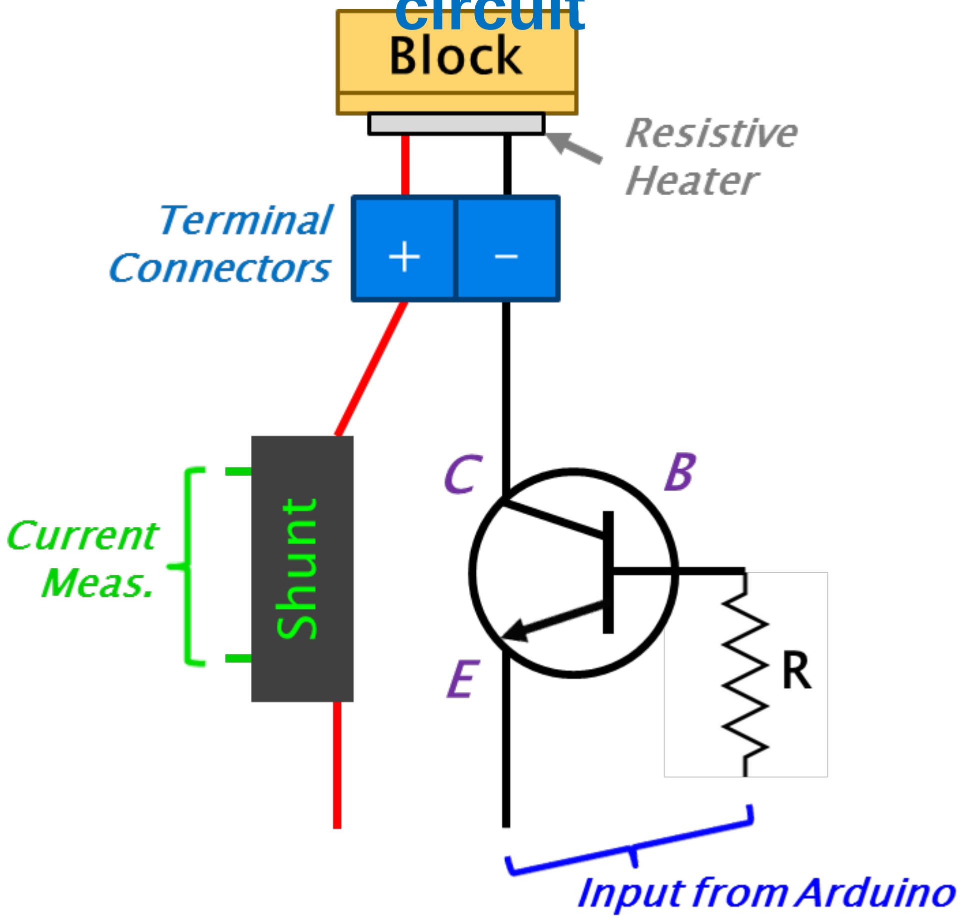
Bottom View



Top View

Control Circuit

Simplified depiction of single circuit



Conclusions

- Concept of dynamic cold plate was previewed
- Solution was designed for reference MCM platform
- Evaluation of cold plate by CFD analysis
  - Distribution through parallel fins in a section was made fairly uniform
  - Expect sizeable savings in either flow power or device temperature
- Preparation for experimental testing
  - MCM TTV and control circuits
  - Test setup and outline
- Future work
  - Determine available savings through experimental testing of both solutions

Evaluating Liquid Cooling at the Rack

Presented by:
John Fernandes
University of Texas at Arlington

Wednesday, Oct. 29th, 2014
IMAPS – ATW on Thermal Management
Los Gatos, CA

Co-Authors:
Manasa Sahini, UTA
Dereje Agonafer, UTA
Veerendra Mulay, Facebook Inc.
Jacob Na, Facebook Inc.
Pat McGinn, CoolIT Systems Inc.
Michael Soares, CoolIT Systems Inc.
Cam Turner, CoolIT Systems Inc.

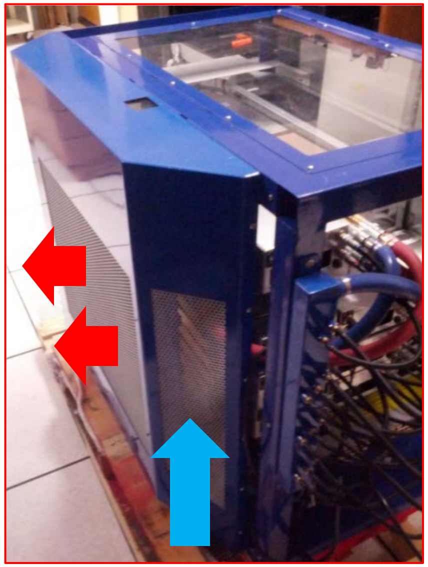
Rack at a Glance

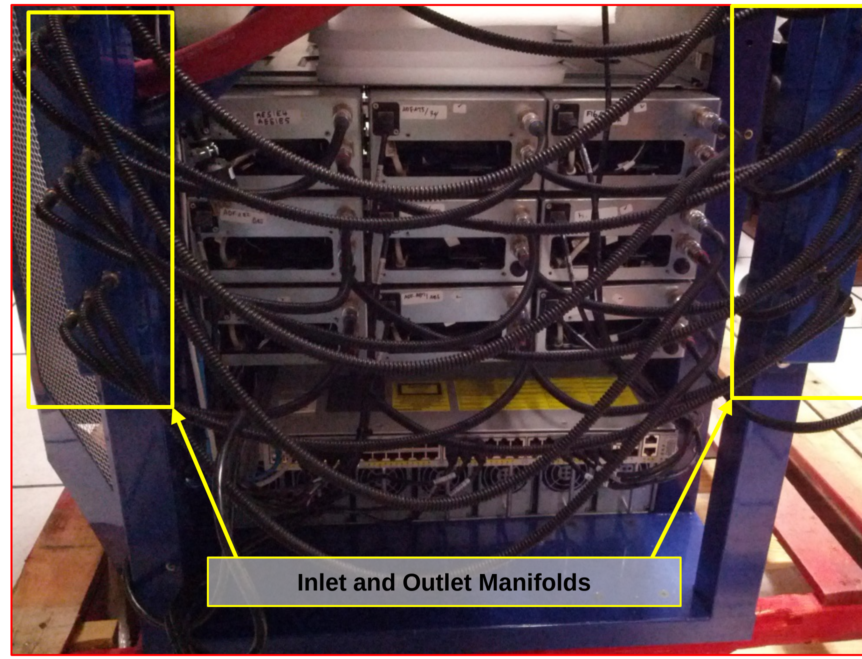
- IT equipment installed in the short rack
  - Up to 11 servers (in 4 shelves)
  - One network switch
  - Fully populated power shelf

Cooling Configuration

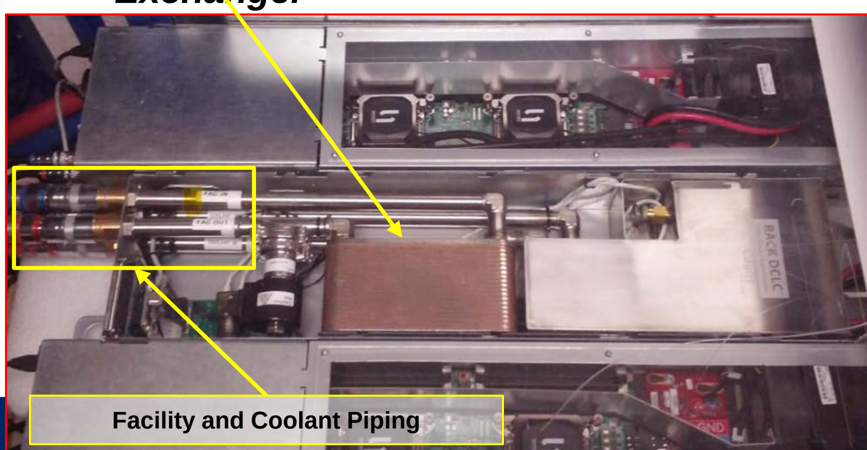
- Equipped with two heat exchangers
  - In series, exhaust heat from servers to the environment

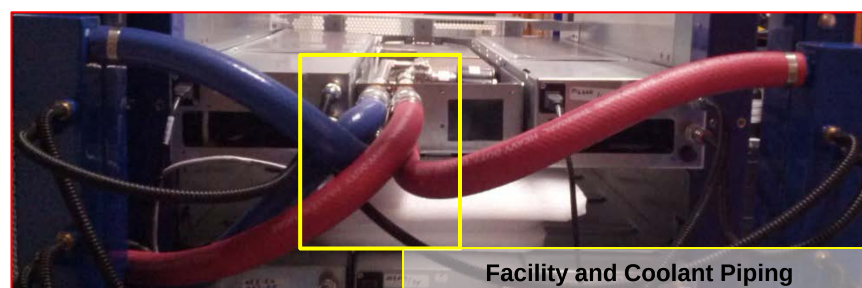
Sidecar Liquid to Air Heat Exchanger





Liquid to Liquid Plate Heat Exchanger





PERFORMANCE OF A HIGH DENSITY MINERAL OIL IMMERSION COOLED SERVER SYSTEM

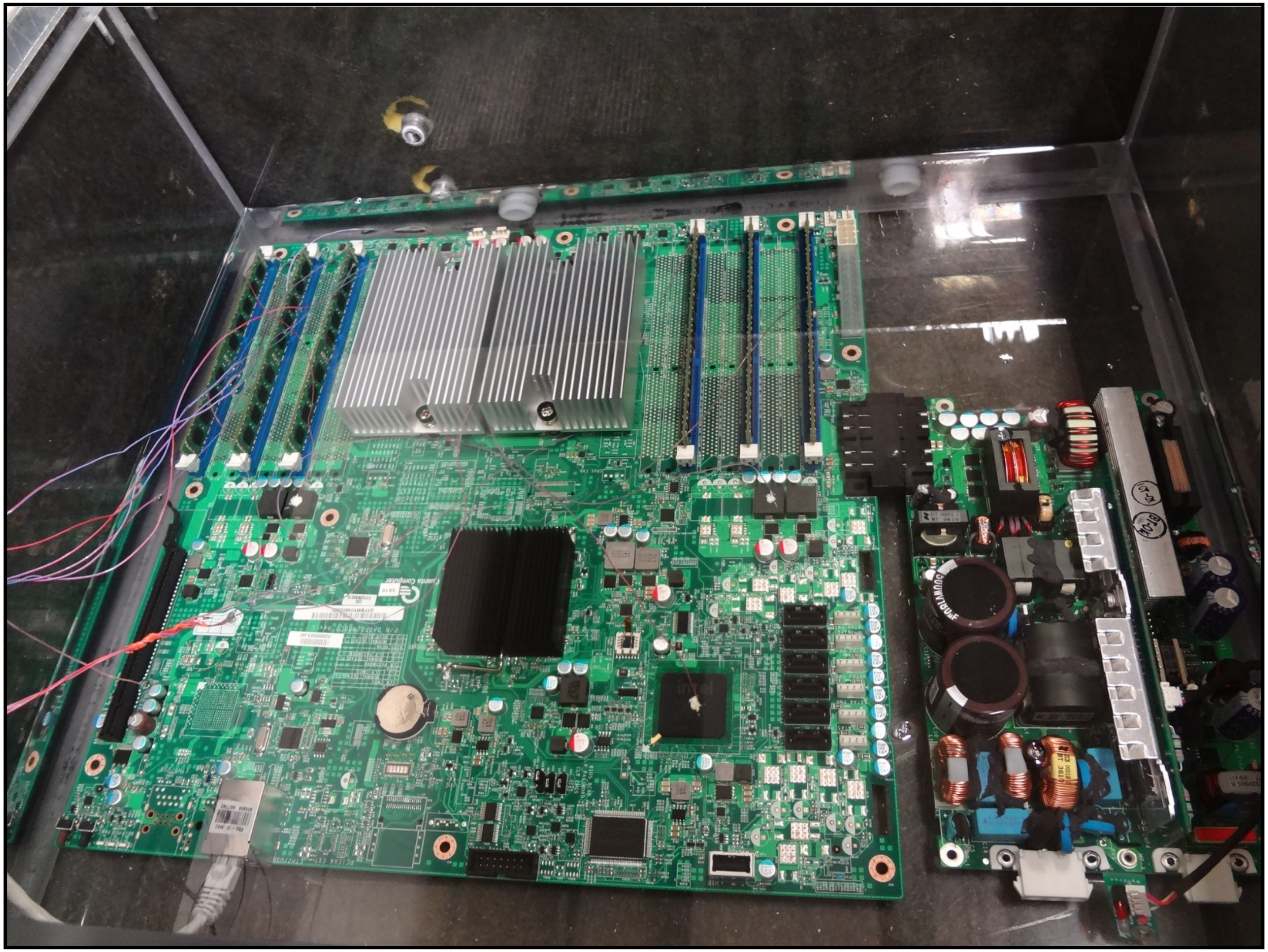
Rick Eiland
PhD Student
May 2015

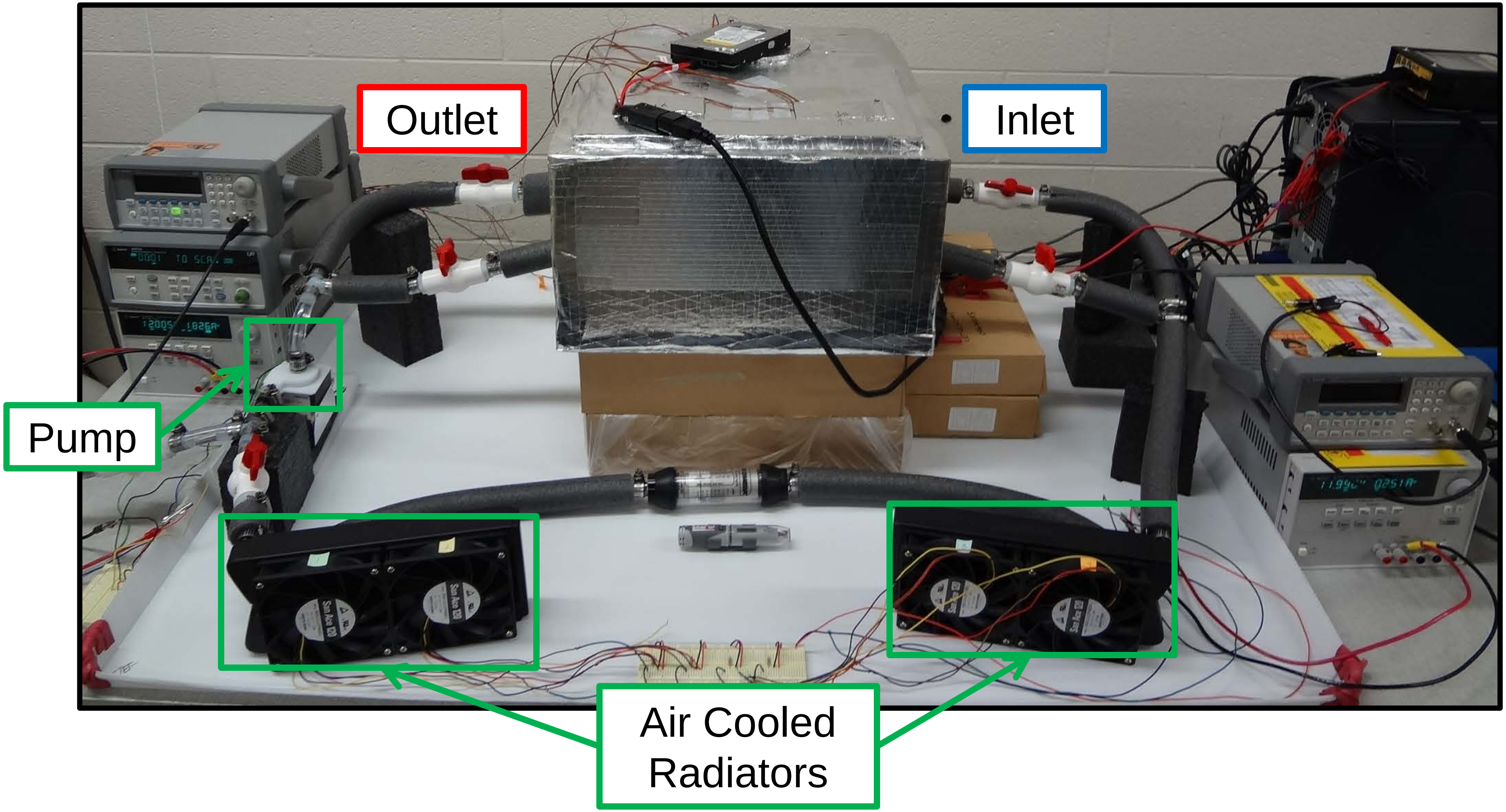
Data Center Fluids

Fluid	Density (kg/m^3)	Specific Heat (J/kg·K)	Thermal Conductivity (W/m·K)	Dynamic Viscosity (kg/m·s)	Relative Heat Capacitance
Air[1]	1.21	1005	0.026	0.0182	1
Water[2]	997	4180	0.610	0.89	3440
HFE 7200[3]	1430	1220	0.070	0.61	1440
Mineral Oil[4]	849	1670	0.130	13.6	1170

1 – Air Properties, Engineering Toolbox, http://www.engineeringtoolbox.com/air-properties-d_156.html
2 – M. Ellsworth, "Comparing Liquid Coolants from Both a Thermal and Hydraulic Perspective" Electronics Cooling, 2006.
3 – Data Sheet, 3M™ Novec™ 7200 Engineered Fluid, http://solutions.3m.com/
4 – Crystal Plus 70T MSDS, STE Oil, http://www.steoil.com/msds-tech-data

Server Under Study




Outlet
Inlet
Pump
Air Cooled Radiators

Measurements

- Total server power
- Cooling power
  - Pump & Radiator Fans
- Tank inlet temperature & Flow rate
- Component temperatures
  - **CPU**, memory, voltage regulators, and chipsets

Steady State Conditions

- Constant synthetic computational load applied using the '*lookbusy*' program
  - 75% of CPU resources utilizes
  - 20% of memory resources allocated
  - Represents near peak power consumptions
  - Ideal workload in data center

- Steady state data collected over at least hour long period

System Efficiency

- Partial Power Usage Effectiveness (pPUE)

$$pPUE = \frac{IT + Cooling\ Energy}{IT\ Energy}$$

- Experimental system can be representative of a “complete” data center system rejecting heat to 25°C ambient

pPUE Values Achieved

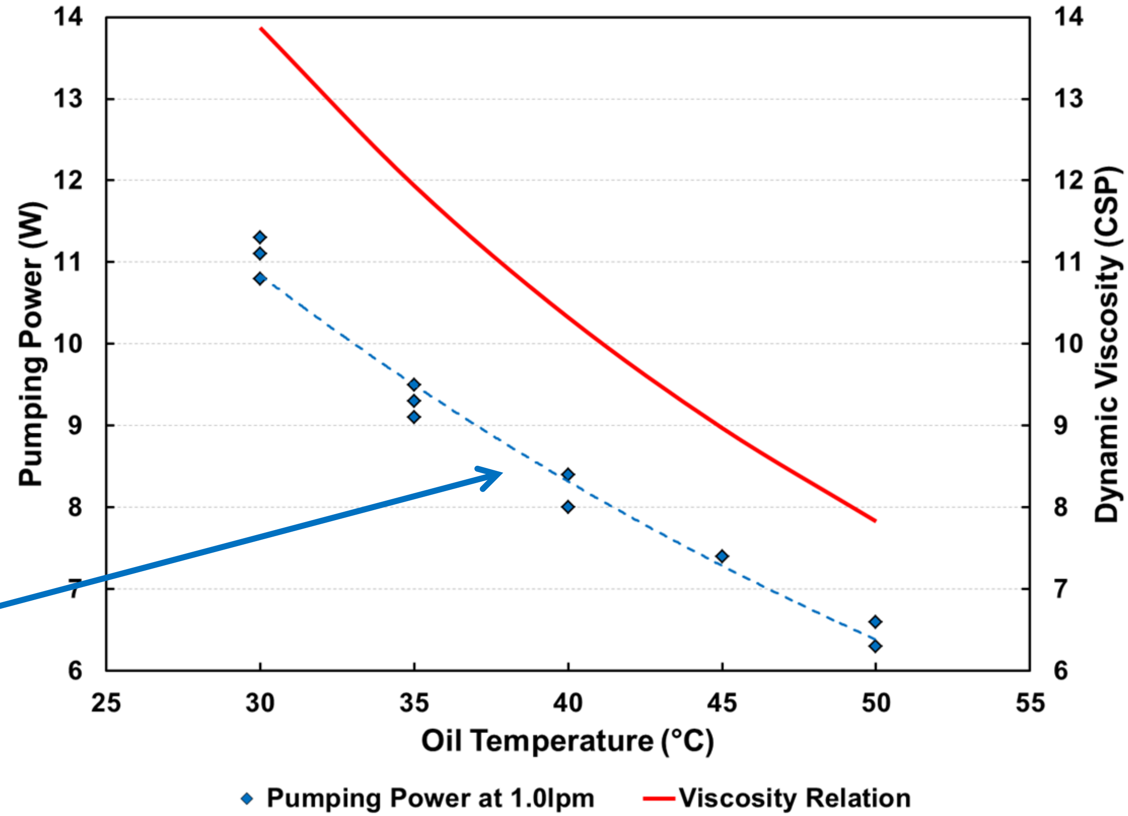
		Oil Inlet Temperature (°C)				
		30	35	40	45	50
Flow Rate (lpm)	0.5	1.055	1.041	1.036	1.030	1.027
	1.0	1.086	1.051	1.058	1.039	1.035
	1.5	1.124	1.068	1.079	1.053	1.046
	2.0	1.170	1.088	1.102	1.072	1.059
	2.5	-	-	1.129	1.095	1.075

Equivalent COP ranging from 5.88 – 33.33

Oil Temperature-Viscosity

- Viscosity relationship predicted by ASTM standards for transformer oil (mineral oil):
  - $\mu = C_1 * Exp\left[\frac{2797.3}{(T+273.2)}\right]$
- $\mu \propto \frac{1}{Re} \propto f \propto \Delta p$
- $P_{pump} = \Delta p * \bar{V}$

~40% drop in pumping power from 30°C to 50°C



Comments – Thermal Performance

- A single Open-Compute server was characterized for its thermal performance in mineral oil

- Suitable oil inlet temperatures up to 45°C may be used for service in oil immersion cooled data centers
  - Short excursions into 50°C inlet temperature may be acceptable

- pPUE values ranging from 1.027 – 1.170 were achieved

Current Experimental Setup

- Three Open Compute V3 servers oriented vertically
- Includes*:
  - (6) Intel Xeon E5-2670
  - (48) 8GB DIMMs ➔ 384GB RAM total
- Roughly 1kW IT load in 2U (OpenU) form factor

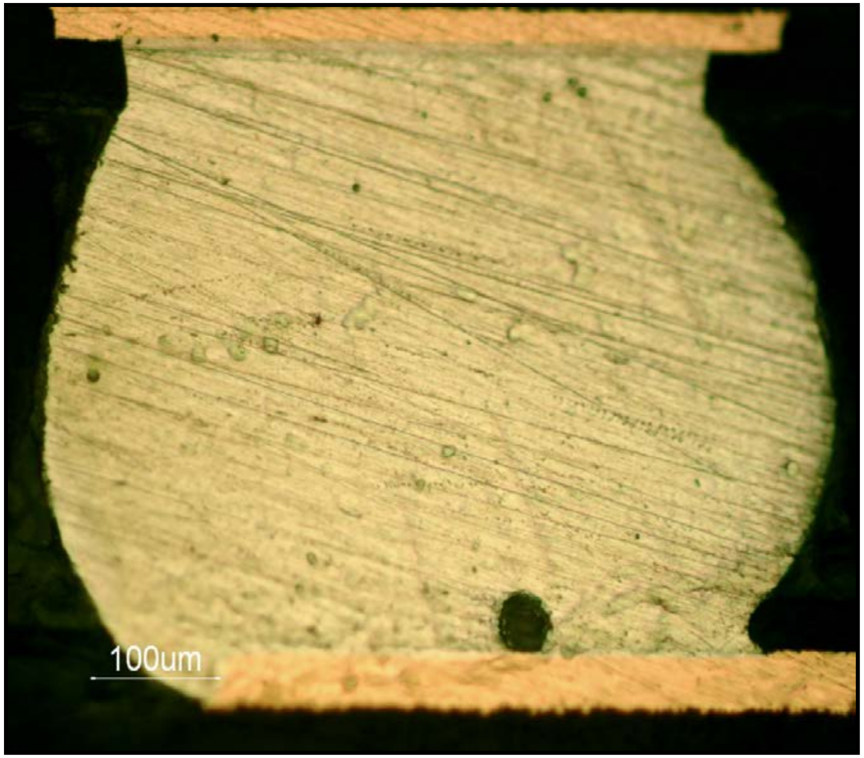
Rick Eiland
PhD Student
May 2015

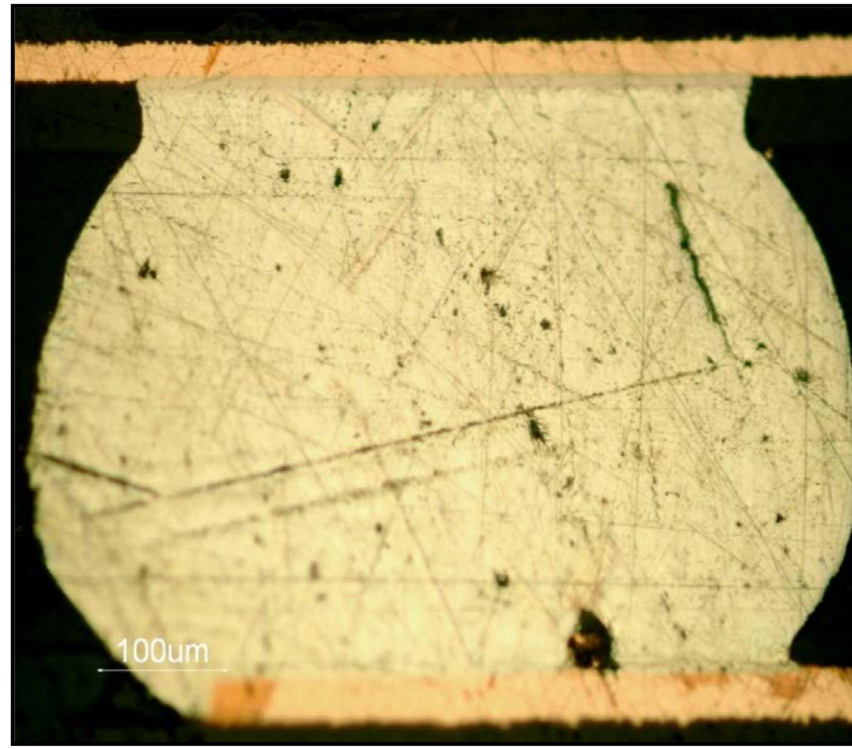
Gowtham Pedapudi
MSc
May 2015

Fahad Mirza
PhD
Dec 2014

OIL IMMERSION RELIABILITY

Solder Balls





- No cracks or failure at solder balls were observed
- No bulging seen in oil cooled servers

Evaluating Heat Sink Performance in an Immersion-Cooled Server System

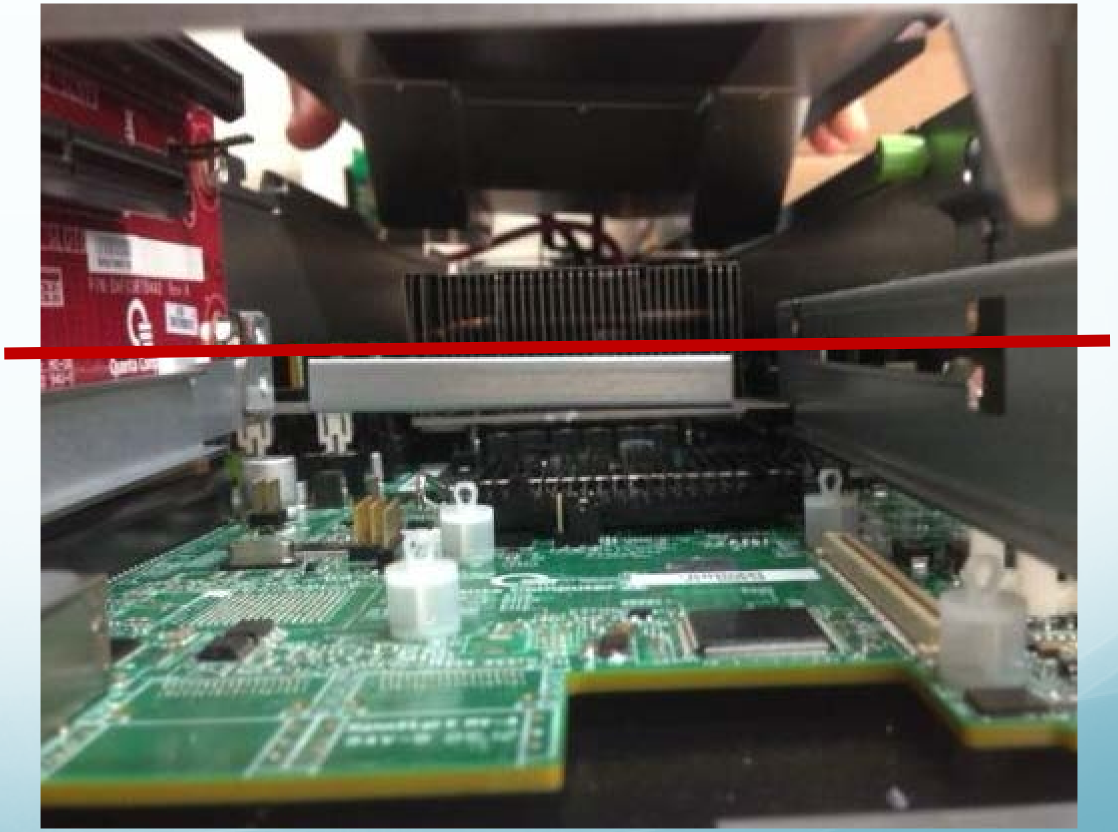
Trevor McWilliams
M.S. Mechanical Engineering

Advisor : Dr. Dereje Agonafer

July 24, 2014

Conclusions

- Server Heat sinks can be dropped to a 1U height in immersion cooling!



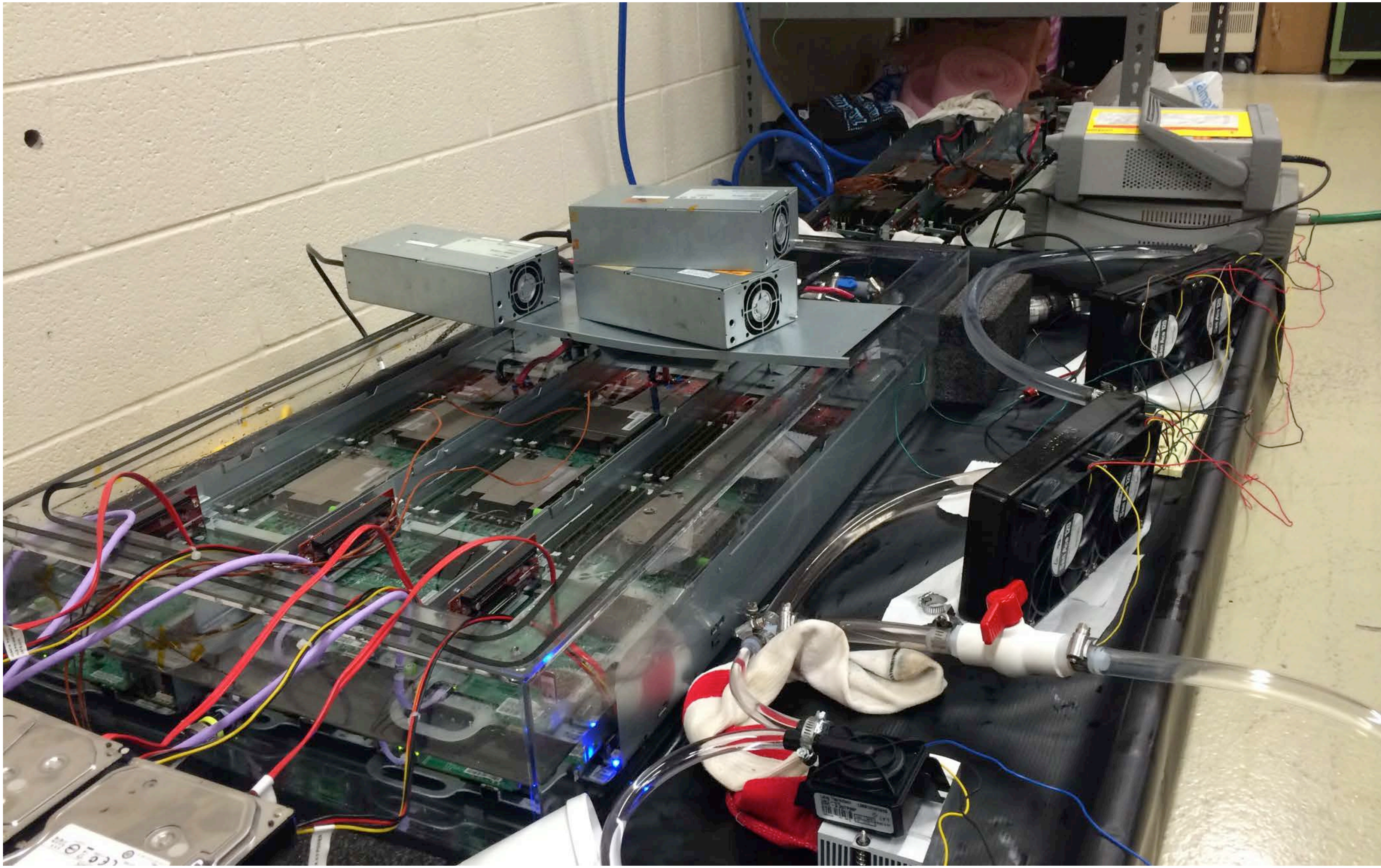
Performance study of Thermal Interface Material in Generation-3 Intel Server MotherBoard

Gowtham Pedapudi
M.S. Mechanical Engineering

Advisor : Dr. Dereje Agonafer

July 28, 2014

Immersed Server Set-up



Thank You !