2017 NSF IUCRC Biennial Meeting
ARLINGTON, VA• JULY 27, 2017

Multi-Site Centers
Student-centric Collaborative Experiences

Dereje Agonafer, Jenkins Garrett Professor
The National Science Foundation Center for Energy Smart Electronic Systems (ES2)

Outline

- Background & Motivation
- Infrastructures
- History of Working Relationships of Center Directors
- Managing Director
- Projects
- ES2 2016 – 2017 Projects – 21 projects – all led by students
- Sample Project
- ES2 Student collaboration on projects
- Monthly Project Meetings – led by students
- Quarterly Project Meetings – led by students

Outline - cont

- IAB Meeting – led by students
- Sample Project
- Student collaboration on projects example
- Students conference attendance
- Students internship
- Posters
- IAB Meetings
- Thesis Example
- Jobs - Recent PhD's graduates

Energy Usage in Typical Data Center

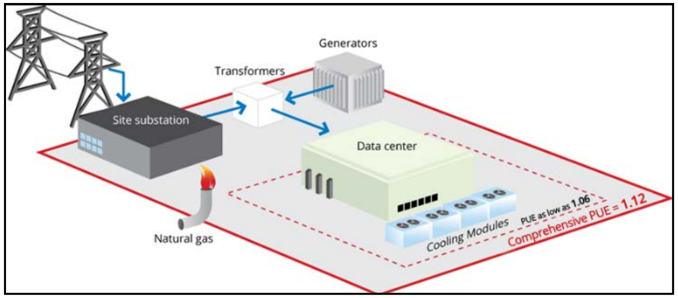
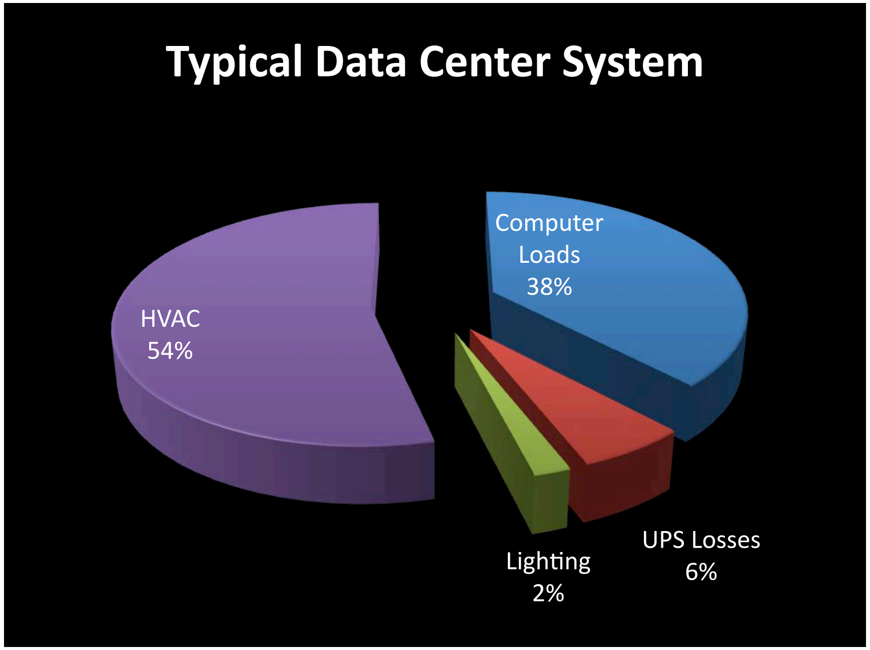


Figure 3: Typical Data Center Layout[1]

- Data centers are big consumers of electricity
- In 2014, 70 billion kWH electricity[3]
- 1.8% of total U.S. electricity consumption
- Cooling energy typically contributes 30-50% of Data Center overall energy consumption
- Environmental design criteria is important



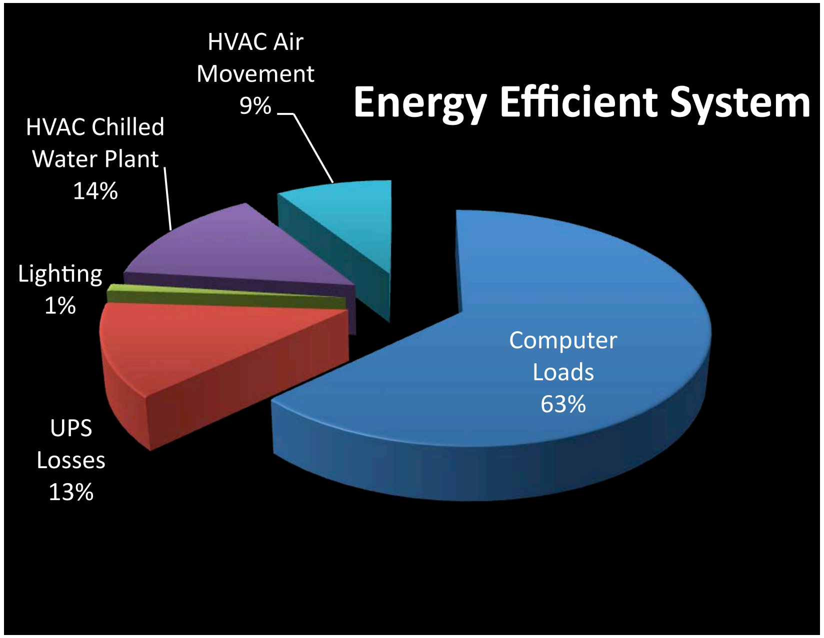


Figure 4: Electrical Consumption Distribution in two data centers[2]

Source[1] : Google Data Center PUE estimation, 2008
Source[2]: Data Center Best Practices Guide, 2012
Source[3]: Lawrence Berkeley National Laboratory, United States Data Center Energy Usage Report, 2016

Infrastructure – built in Phase I

Panoramic view of one of the cold aisles in ES2 Data Center Laboratory at Binghamton University

Villanova Two-Phase Server Cooling Facility

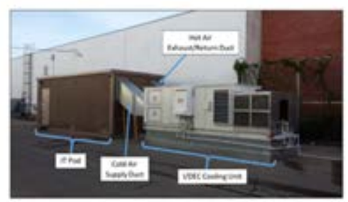
UTA ES2 Data Center Lab

UTA/Mestex Modular Data Center
Mestex, Dallas, TX

Facebook Opencompute Servers

Yahoo Servers

Cisco Liquid Cooled Servers



UTA's research modular data center facility in Dallas, Texas

UTA's research modular data center facility in Dallas, Texas

Villanova Organic Rankine Cycle Facility

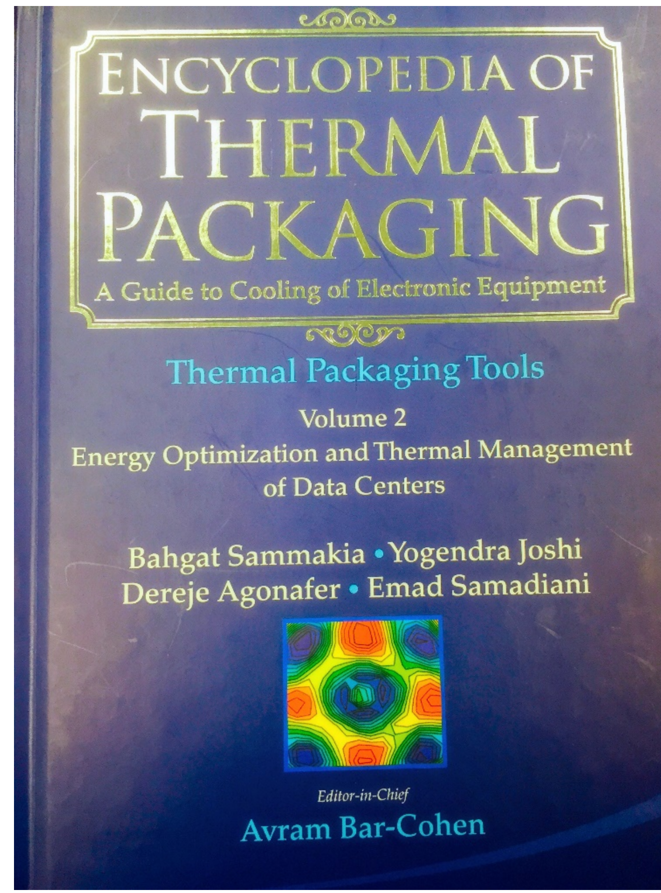
History of Working Relationships of Center Directors

Over 25 years of working relationship

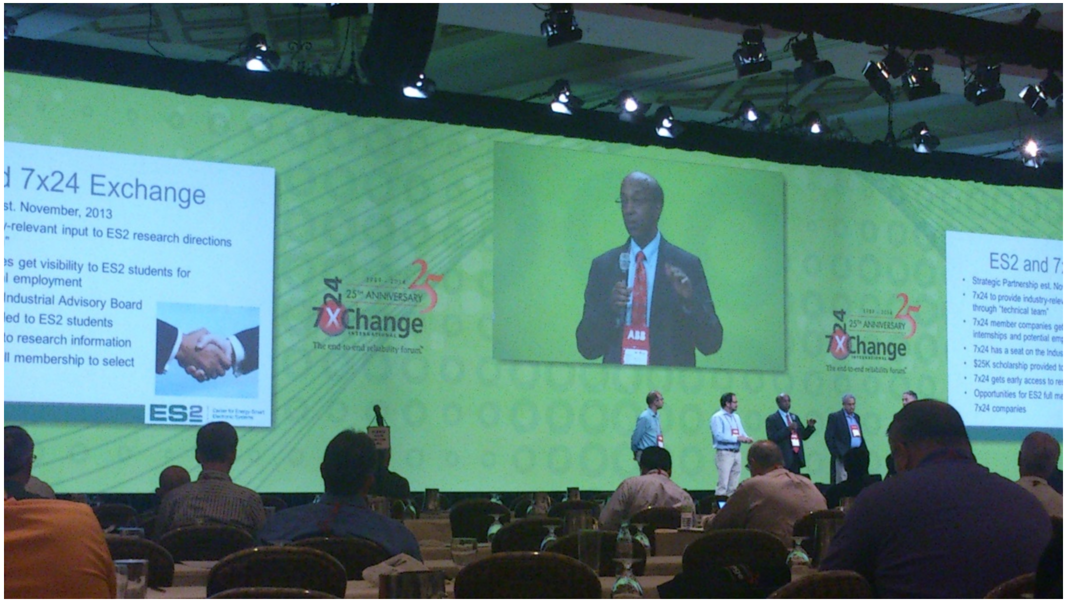
A Brief Overview of Recent Developments in Thermal Management in Data Centers

Sami Alkharabsheh, John Fernandes, Betsegaw Gebrehiwot, Dereje Agonafer, Kanad Ghose, Alfonso Ortega, Yogendra Joshi and Bahgat Sammakia *J. Electron. Packag* 137(4), 040801 (Sep 10, 2015) (19 pages)

IAB Meeting, UTA 2016 (alum Suma Kuravi)



History of Working Relationships of Center Directors – SemiTherm 2017



Discussion: led by Bahgat Sammakia, BU
Panelist:
Dereje Agonafer, UTA
Kanad Ghose, BU
Yogendra Joshi, Georgia Tech
Al Ortega, Villanova

2017 Thermi Award
Presented to Chandrakant Patel
Chief Engineer and Senior Fellow of HP Inc.

Presenters
Dereje Agonafer, UTA (Nominator)
Dr. Veerendra Mulay, General Chair
Facebook

Managing Director of ES2

- Andrea Palmeri serves as the Managing Director of ES2. In my opinion, she is critical to the functioning of the center and Phase II would not have happened without her leadership. As a Managing Director, Andrea is responsible for all of the Center’s operations, including
  - proposal coordination,
  - business development,
  - marketing, website,
  - Center communications,
  - development of policies and procedures,
  - NSF reporting, and
  - serving as the liaison between the university partners and industry members.

Projects

- ES2 2016 – 2017 Projects – 21 projects – all led by students
- Sample Project
- ES2 Student collaboration on projects
- Monthly Project Meetings – led by students
- Quarterly Project Meetings – led by students
- IAB Meeting – led by students

ES2 2016-2017 Projects

ES2 2016-2017 Projects, PIs and Mentors

Project	Project Name	PI	Site	Mentors
1	Exergy-based Approaches for Holistic Design of Energy Efficient Data Centers	Wemhoff, Ortega	VU	Dave Mendo, Comcast; Jim Jagers, Mestex; Andrew Calder, Mahmoud Ibrahim, Elsa Madrigal, Bharath Muralidharan, Panduit; Mark Seymour, Kourosh Nemati, Future Facilities; Russ Tipton, Vertiv
2	Energy Proportionality in Data Centers and Benchmarking: Synergistic Management of Workload, Servers and Cooling System (combines former projects 2&8)	Ghose	BU	Mark Seymour, Dave King, Kourosh Nemati, Future Facilities; Shane Case, Bloomberg; Mahmoud Ibrahim, Panduit; Russ Tipton, Vertiv; Gamal Refai-Ahmed, Xilinx
3	Rapid Modeling Tools for Thermal Management of Modular Data Centers (project completed)	Joshi	GT	project completed
4	Direct and Indirect Evaporative Cooling for IT Pods (Phase II)	Agonafer	UTA	Tom Craft, CommScope; Jim Jagers, Mestex; Bharath Muralidharan, Mahmoud Ibrahim, Panduit; Mark Seymour, Kourosh Nemati, Future Facilities, Mike Kaler - Mestex; Russ Tipton, Vertiv
6	Dynamic Cold Plates for Effective Cooling of Multi-Core High-End Chip Scale Packages (Phase II)	Agonafer	UTA	Steven Schon, QuantaCool; Mahmoud Ibrahim, Andrew Calder, Panduit ; Chris Aldham, Mark Seymour, Kourosh Nemati, Future Facilities; Russ Tipton, Andrew Cole, Vertiv
7	Models and Metrics for Dynamic Air and Hybrid Liquid Cooled Data Centers Based on Computational and Experimental Approaches – Phase II	Ortega, Sammakia, Bowling,	VU, BU, UTA	Vidhya Shankar, Dave Mendo, Simpson Cumba, Commcast; Tom Craft, CommScope; Mahmoud Ibrahim, Panduit; Mark Seymour, Mark Fenton, Kourosh Nemati, Future Facilities; Russ Tipton, Vertiv; Bill, Skinner, Joe Citarella, Bloomberg; Gamal Refai-Ahmed, Xilinx
9	High Bandwidth Integrated Parallel Optical Communication Links for Power Efficient, Cost Effective Data Center Interconnects, Phase II	Ghose	BU	Doug Butler, Corning; Mahmoud Ibrahim, Panduit; Mark Seymour, Kourosh Nemati, Future Facilities
10	Impacts of Particulate and Gaseous Contamination on IT Equipment Where Air-Side Economizers are Implemented, Phase II	Agonafer	UTA	Tom Craft, CommScope; Bharath Muralidharan, Camelia Mititelu, Mahmoud Ibrahim, Panduit; Mike Kaler, Jim Jagers - Mestex; Gamal Refai-Ahmed, Xilinx; Russ Tipton, Vertiv; Mark Seymour, Kourosh Nemati, Future Facilities
11	Two-Phase Cooling Coupled with Waste Heat Energy Capture for Data Center Environments – Fleischer/Jones (follow on to project 11)	Fleischer/Jones	VU	Steven Schon, QuantaCool; Mark Seymour, Kourosh Nemati, Future Facilities; Russ Tipton, Vertiv; Camelia Mititelu, Mahmoud Ibrahim, Panduit; Tom Craft, CommScope

ES2 2016-2017 Projects (cont)

13	Transient Thermal Response and Control of Data Centers	Joshi/Yoda	GT	Mark Seymour, Dave King, Mark Fenton, Kourosh Nemati, Future Facilities; Mahmoud Ibrahim, Tom Peddle, Panduit; Gamal Refai-Ahmed, Xilinx; Russ Tipton, Vertiv
14	Experimental and Analytical Studies on Transport in Fully and Partially Enclosed Cold Aisles in Air Cooled Data Centers	Sammakia	BU	Mahmoud Ibrahim, Panduit; Mark Seymour, Dave King, Kourosh Nemati, Future Facilities; Russ Tipton, Vertiv; Veerendra Mulay, Facebook; Gamal Refai-Ahmed, Xilinx
15	Warm Water Cooling in Data Centers Including Water Storage Systems	Fleischer/Chiarot/ Sammakia/	VU, BU	Tom Craft, CommScope; Mark Seymour, Kourosh Nemati, Future Facilities; Mahmoud Ibrahim, Panduit; Steve Schon, QuantaCool; Gamal Refai-Ahmed, Xilinx; Russ Tipton, Arash Golafshan Vertiv; Vadim Gektin, Huawei
16	An In-Depth Understanding of Oil Immersion Cooling strategies for Data Centers	Agonafer	UTA	Mark Seymour, Kourosh Nemati, Future Facilities; Tom Craft, CommScope; Veerendra Mulay, Facebook; Mahmoud Ibrahim, Panduit; Russ Tipton, Vertiv; Herb Zien, Harsh Patel, Rick Tufty and David Roe, LiquidCool Solutions
17	Data Center Temperature Monitor Analysis System	Jabade	VIT	Chetan Khare, Logicare; Mark Seymour, Future Facilities
18	Investigations on FCMA Soft Starter-Based Compressor Employed in Refrigeration System for Data Center Cooling	Sant	VIT	Sanjay Bhade, Innovative Technomics; Mark Seymour, Future Facilities
19	Thermal Analysis of Data Center Using Hybrid (Air and Water) Cooling	Chaudhari	VIT	Vikas Kumar, CDAC; Mark Seymour, Future Facilities
20	Environmental Acclimation of IT Equipment	Agonafer	UTA	Jim Jagers, Mestex; Mahmoud Ibrahim, Andrew Calder, Panduit; Gamal Refai-Ahmed, Xilinx; Mark Seymour, Kourosh Nemati, Future Facilities

Project 4: Maximizing Use of Efficient Air-Side Economization in Modular, Large Data Centers and Datacom Housing Units

***Area of expertise*: Thermal transport and fluid dynamics modeling, experimental measurements of heat transfer and fluid flow**

PI: Dereje Agonafer (UTA)

UTA Students

Dr. Betsegaw Gebrehiwot (Intel)
Dr. Manasa Sahini (Intel)
Vishnu Sreeram
Suhas Sathyanarayan
Digvijay Sawant

BU Student

Dr. Husam Alissa (Microsoft)

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
Richard Craig and Robert Yurcik	Verizon Wireless

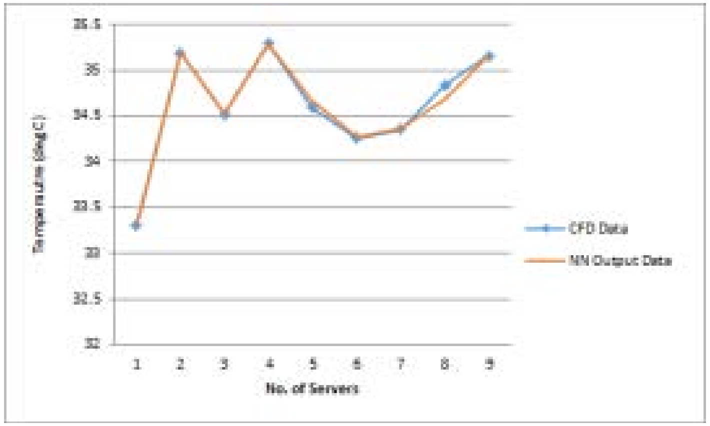
ES2 Student collaboration on projects, Example 1

- Data Center Lab with raised- floor hot aisle containment configuration.
  - CRAC Units equipped with Variable Speed Drives
  - SynapSense Wireless sensors to monitor temperature, humidity and static pressure
  - Remote connection that facilitates data logging from all servers for experimental analysis
- Collaboration with ES2 students in Binghamton University
  - Interdisciplinary collaboration (CS, ME etc.) between ES2 graduate students
  - Access to research facilities and laboratories for all ES2 research projects

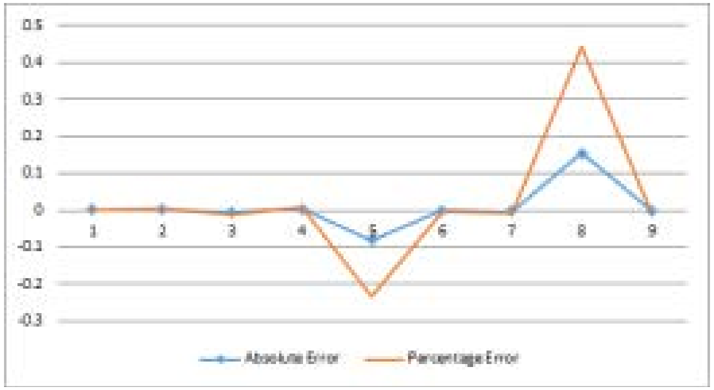
Data Center Lab at UTA

ES2 Student collaboration on projects, Example 2

- Artificial Neural Network applications in data center control systems
- A neural network developed and trained with CFD data modelling the BU data center lab.
- ANN technique successful in predicting the output of the data center in both steady state and transient cases.



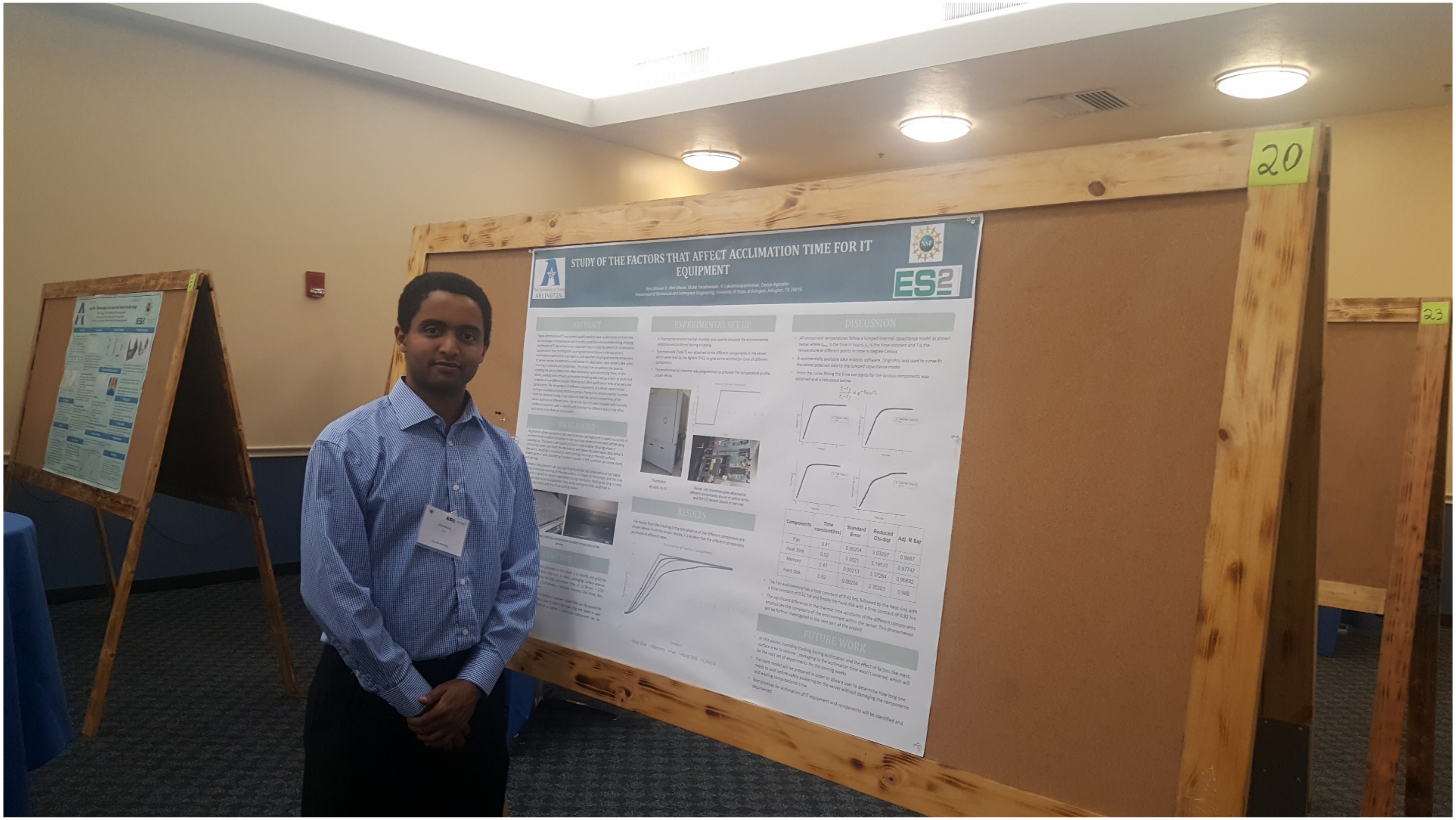
Prediction of server temperature using Neural Network



Output error when compared to CFD data

[Source: Neural network modeling in model-based control of a data center]

Presentation of Project 20 at IAB Meeting Villanova, 2017
Abel Misrak, PhD student (accepted internship at Tesla)



IAB Meeting – April 29 - 30, 2015, Steel ORCA, NJ

Experimental Setup for Dynamic Liquid-Cooled MCM (Project 6)

R. Kokate (Google), J. Fernandes (Facebook), M. Sahini (Intel) and D. Agonafer

Department of Mechanical & Aerospace Engineering, University of Texas at Arlington, Arlington, TX - 76019

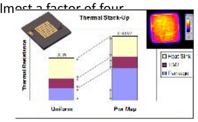
Abstract

Continuing trends of increasing microprocessor power densities and non-uniform temperature distributions pose a significant challenge to the cooling requirements of a data center environment. With a view to minimizing energy consumption of cooling infrastructure, the objective is to design a dynamic, energy-efficient and practical cooling solution for high-power equipment. A multi-chip module (MCM) is chosen as the platform to base the design of such a liquid-cooled solution.

Determining practical application of the dynamic cold plate necessitates experimental testing. In the absence of a MCM thermal test vehicle (TTV), an assembly consisting of copper blocks embedded with thick-film heaters installed in a plastic substrate will serve to simulate a functioning module. Operation of the mock-MCM and control of pumps will be previewed through a representative, but simplified, air-cooling setup. Results show great promise for application to the TTV and suggested control schemes are discussed.

Background/Need of Study

- The International Technology Roadmap for Semiconductors (2010) predicts
  - Power density of high performance processors to more than double by 2024
  - Allowable junction temperature to decrease from 90°C to 70°C
  - Total thermal resistance will need to decrease by almost a factor of four
- Non-uniform power distribution at the die
  - Need to cool for maximum chip temperature
- Energy efficiency of servers
  - High efficiency near maximum utilization only
  - Cooling accounts for 30% of overall power (S. Pelly, 2009)



Source: R. Mahajan, *Proc. IEEE*, August 2006

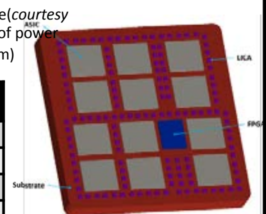
Goals

- Develop an extendable, dynamic and practical cold plate for energy-efficient thermal management of high power devices
- Introduce controls and instrumentation to create a smarter solution with targeted delivery of cooling resources based on local heat dissipation
- Optimize cooling infrastructure to reduce energy consumption and boost the overall system efficiency

Platform

- Agreed-upon benchmark device platform for investigation
- High-power MCM layout as reference(*courtesy of Endicott Interconnect*)Around 500W of power dissipation in a 78mm x 78mm (60 sq.cm) footprint

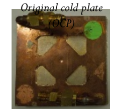
Component	Quantity	Power
Substrate	1	-
ASIC	12	40W
FPGA	1	5W
LIGA	137	-



Preparing for Experimental Testing

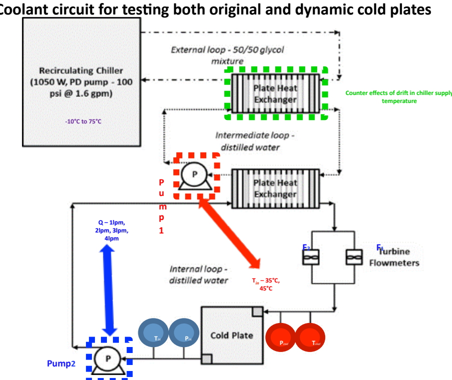
- **Objectives**
  - Compare performance of original and dynamic solutions
    - Critical measurements
      - Pumping power (P_p)
      - Component temperatures
      - Component power dissipation
  - MCM TTV is subjected to different loading schemes
    - Uniform power distribution
    - Non-uniform power distribution
      - Including dynamic loading
  - Cool for the highest temperature across all devices
    - OCP – Run tests at different flow rates
    - DCP – Set target temperature in dead-band control scheme

Original cold plate



Dynamic cold plate

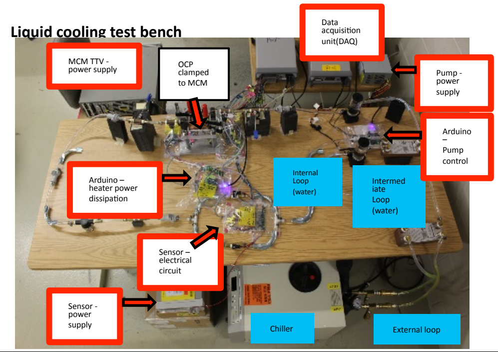
- **Coolant circuit for testing both original and dynamic cold plates**



- **Test matrix**
  - While testing both OCP and DCP solutions
    - MCM TTV is subjected to different loads
      - Uniform loading (5 cases)
        - Idling: ASICs and FPGA each dissipate 5W
        - Higher loads: ASICs each dissipate 10, 20, 30 and 40W
          - FPGA power dissipation is always 5W
      - Non-uniform loading (12 cases)
        - Each block is set to dissipate 40W in isolation
          - Remaining blocks are set to idling power (5W)
  - While testing OCP
    - Maximum permissible device temperature is 85°C
    - Different chiller supply temperatures: 35°C and 45°C
      - *Investigating warm water cooling is a priority*
    - Chiller bypass loop is modulated to deliver specific flow rates to the cold plate
      - Different flow rates considered: 1lpm, 2lpm, 3lpm and 4lpm
      - All 17 loading cases tested at each flow rate
    - Results: Device temperatures vs. pumping power

Preparing for Experimental Testing

- While testing DCP
  - Different chiller supply temperatures: 15°C, 25°C, 35°C and 45°C
    - *Investigating warm water cooling is a priority*
  - Results of OCP testing used to determine target device temperature
    - Setup control scheme to achieve selected temperature
  - Results: Device temperatures vs. total flow rate
- Determine pumping power for each section by
  - Measuring impedance curve for each section
  - Use flow rate to determine pressure drop at operating point
- **Liquid cooling test bench**



Future Work

- Experimental Testing
  - Establish reference points by testing performance of original cooling solution
  - Determine improvement over baseline with employment of dynamic solution

Acknowledgements

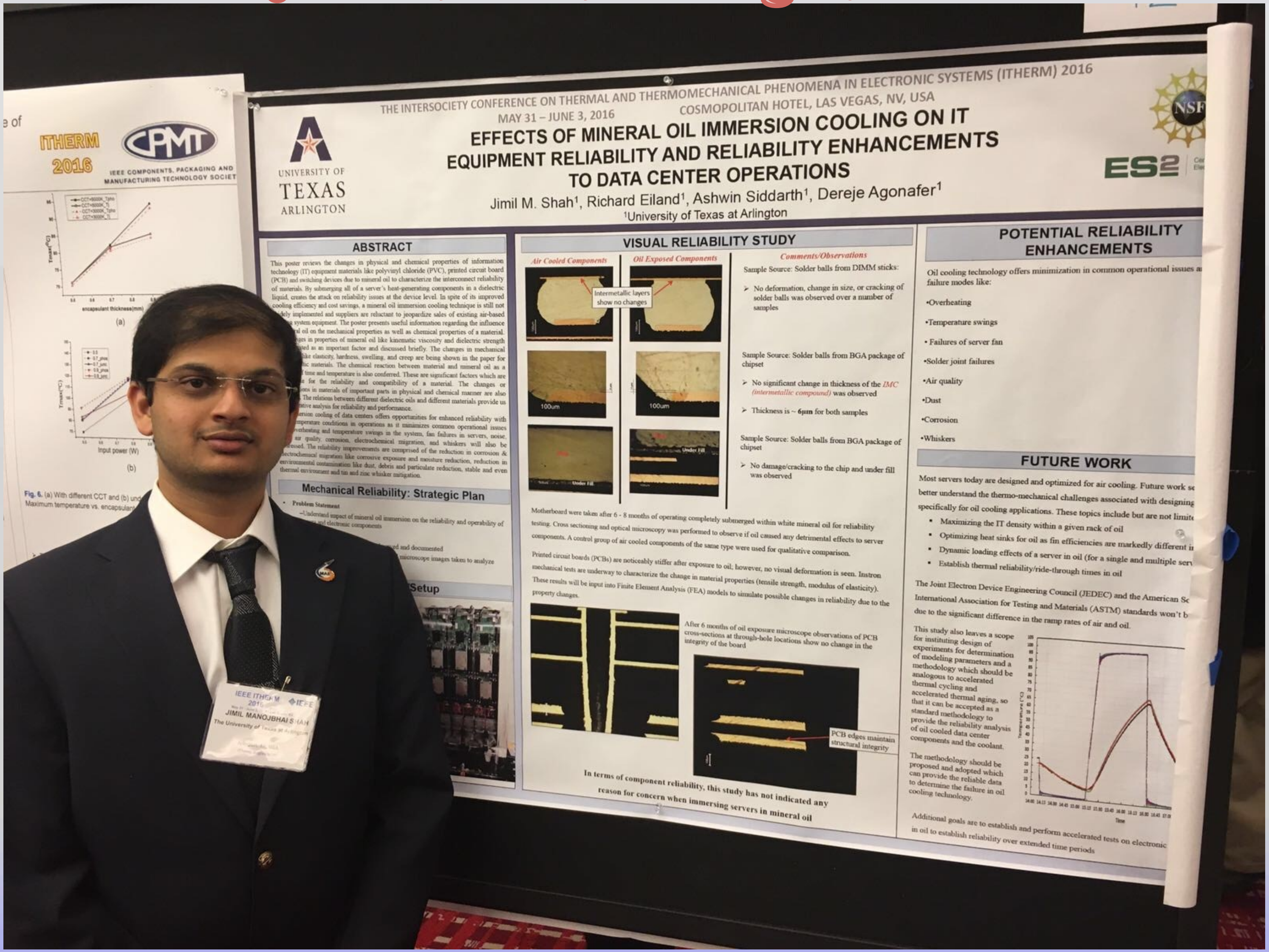
- Thanks to the industry mentors for their continuous input and support

Mentor	Affiliation
Peter Beucher	Wolverine / MicroC[illegible]
Sy-Jenq L[illegible]	[illegible]lverine / MicroC[illegible]
Scott H[illegible]d	[illegible]lverine / Micro[illegible]l
Mark [illegible]our	Future Faciliti[illegible]
Chr[illegible]dham	Future Facili[illegible]
St[illegible] Schon	QuantaC[illegible]
[illegible]a Shankar	IBM
[illegible]nson Chan	Endi[illegible]ott Inte[illegible]nnect
[illegible]sin Makwana	[illegible]
Pat McGinn	Cool[illegible]ms

ITherm/ECTC 2014
June , 2014, Orlando, Fl
John Fernandes won “Best Poster Award (1/83)”

Poster Presentation at ITherm/ECTC 2016

June 2, 2016, Las Vegas, NV



REU & REV & UG

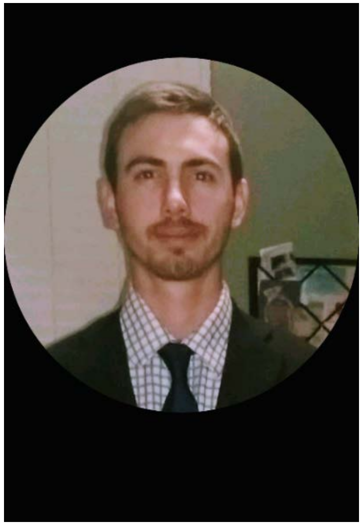
Nicholas C Ricciardelli

USMC-R SGT (2007-2015)

Iraq (OIF) 2009

Mali/Djibouti (OEF) 2012

Under-Graduate Research Assistant on Project #6 – Dynamic Cold Plates for Effective Cooling of Multi-Core High-End Chip Scale Packages



Lieutenant Alex Priesser

Dan Furman

Attending IAB Meeting at Georgia Tech, Apr 2015
Kanan Pujara won Best Poster Award

Attending IMAPS Meeting in Las Gatos, Oct 2015
5 Students Poster Awards

Attending ITherm/ECTC 2016, June 2, 2016, Las Vegas, NV

IUCRC Meeting at University of Texas at Arlington, October 2012

E3S Center for Energy-Efficient Electronic Systems

IUCRC Meeting at Georgia Tech, 2013

E3S Center for Energy-Efficient Electronic Systems

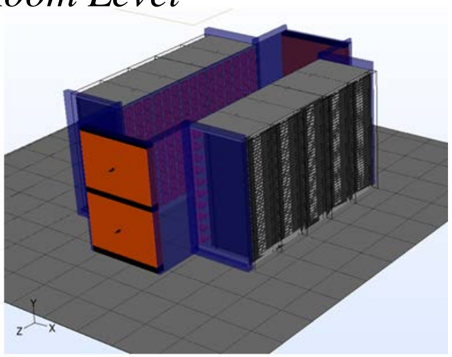
IUCRC Meeting at UTA, Visiting Cowboys Stadium

E3S Center for Energy-Efficient Electronic Systems

Dissertation Defense Exam

Experimental and Computational Study of Multi-level Cooling Systems at Elevated Coolant Temperatures in Data Centers

Room Level



Manasa Sahini

PhD Candidate

Mechanical Engineering

University of Texas at Arlington

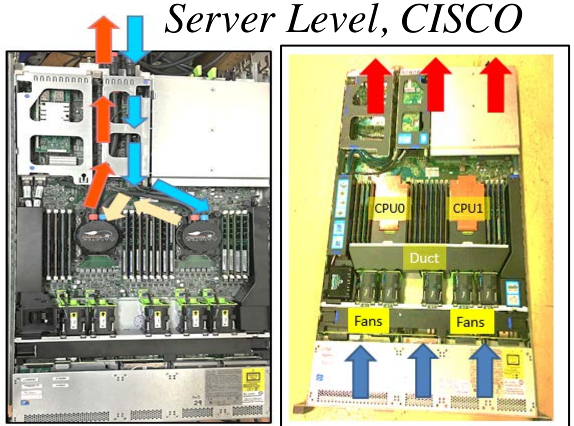
Supervising Professor

Dereje Agonafer

Rack Level, Facebook CoolIT

Facebook Winterfell OC

Server Level, CISCO



7x24 Exchange, June 2017

Jimil Shah presenting

Jobs - Recent ES2 PhD's graduates

Student Name	University	Graduation (date)	Internship (list company, denote IAB members)
Fahad Mirza	UTA	2014	Global Foundries
Saeed Ghalambor	UTA	2014	Faculty, Sichuan University – Pittsburgh Institute, Chengdu, China
Tianyi Gao	BU	2015	Baidu
Zhihang Zang	BU	2015	Faculty member in China
Anjali Chauhan	BU	2015	Microsoft
John Fernandes	UTA	2015	Facebook
Rick Eiland	UTA	2015	Dell
Marianna Vallejo	UTA	2015	CH2M
Furat Afran	BU	2016	NVIDIA
Husam Alissa	BU	2016	Microsoft
Kourosh Nemati	BU	2016	Future Facilities
Betsegaw Gebrehiwot	UTA	2016	Intel
Jeff Luttrell	UTA	2016	UTA Faculty
Oluwaseun Awe	UTA	2016	Business Owner
A Sakib	UTA	2016	NXP Semiconductors
Tyler Stachecki	BU	ABD	Bloomberg
Marcelo del Valle	VU	2016	Comcast
Manasa Sahini	UTA	2017	Intel

Thank you!