



Center for Energy-Smart  
Electronic Systems

A National Science Foundation Industry/University Cooperative Research Center

## ES2 Funded Projects – 2016-2017

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### **Project 1: *Exergy Based Approaches for Holistic Design of Energy Efficient Data Centers***

**Project Description:** This project will enhance the design optimization and system simulation tool for data center cooling systems called the Villanova Thermodynamic Analysis of Systems (VTAS) by enhancing the existing transient framework through the addition of capacitance (i.e., equipment thermal mass) effects, and by initiating a library of validated, platform-independent component models. The inclusion of capacitance will enable the exploration of scenarios where the existing quasi-steady approximation for transient behavior is valid, and it will allow for the integration of advanced transient component models under development in other ES2 projects. The library will enable the integration of VTAS component models into other building simulation tools.

### **Project 2: *Energy Proportionality in Data Centers and Benchmarking: Synergistic Management of Workload, IT Equipment and Cooling System***

**Project Description:** Current and recent work on energy-aware scheduling at the server and rack levels, particularly for Linux platforms, does not exploit statically or dynamically determined job characteristics or the physical environmental conditions (such as temperatures near the vicinity of the servers/racks). The development of such job and temperature-conscious scheduling techniques at the server and rack level, are essential for the predictive and synergistic management of servers and the cooling system. This effort focuses on the development of such a scheduler, by extending an already developed scheduler to a multi-tiered version for scalability. The proposed scheduler is pro-active in nature, with overrides derived from temperature sensors located externally or in a smart rack.

### **Project 3: *Rapid Modeling Tools for Thermal Management of Modular Data Centers***

**Project Description:** Modular data centers (MDC) are portable systems that can be deployed anywhere computing and data capacity are needed. In addition to the multiple possible internal configurations, cooling air flow delivery requires special attention in a MDC due to the limited space. Computationally efficient models are needed for rapid design and evaluation of such systems, which we plan to pursue in this project. For the models, different options will be considered to achieve energy optimized cooling, such as rear door heat exchanger, air delivery with minimal hot air entrainment or cold air by-pass, free cooling, ground coupled heat exchangers, minimal expenditure on cooling air movement, and usage of hot exhaust air in room heating applications.





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#### **Project 4: *Direct and Indirect Evaporative Cooling for IT Pods***

**Project Description:** Information technology (IT) equipment in data centers need to be continuously cooled for reliable operation of the IT equipment. The required inlet air temperature and humidity ranges for the IT equipment are commonly given based on ASHRAE, NEBS, or ETSI specifications. If the outside air conditions fall within the temperature and humidity ranges specified in one or more of the above specifications, it could be used to cool IT equipment directly without any air conditioning. If outside air conditions fall outside acceptable ranges in the above specifications, one or more methods of conditioning outside air will be needed. One such method is mixing hot data center exhaust air with cold outside air. This method along with directly introducing outside air to IT equipment may be referred to as pure air-side economization. In this abstract, we propose study of two methods of air conditioning, direct and indirect evaporative cooling, for cooling outside air to meet one or more of the above specifications.

The goal of this study would be to provide best practices of using

1. Direct evaporative cooling, primarily using wet cooling pads, and
2. Indirect evaporative cooling coils for modular data centers

The study would provide energy saving analysis of using these cooling technologies, supported by computational fluid dynamics (CFD) models and actual experiment results.

#### ***Project 5 combined with project 7***

#### **Project 6: *Dynamic Cold Plates for Effective Cooling of Multi-Core High-End Chip Scale Packages***

**Project Description:** The need for energy-efficiency has coincided with continuing trends of increasing microprocessor power densities and non-uniform temperature distributions which pose a significant challenge to the cooling requirements of high power devices. Post-Pentium 3 era of microprocessors introduced non-uniform power distribution at the die, with varying power densities assigned to different functional units, which in turn gave rise to “hot spots”. Substantially large temperature differences, detrimental to performance and reliability, can be observed across the surface of high-end devices such as multi-core (planar) chip scale packages. Minimization of the thermal budget and in-turn cost of cooling has necessitated investigation of a dynamic approach, wherein cooling resources are allocated based on power distribution, as opposed to persistence with conventional static solutions.

This project will continue the efforts of Project 6 which has, to date, focused on cooling of relatively larger multi-chip modules (MCMs). However, since the majority of the industry is focused on chip scale packages, the proposed project aims to develop and test dynamic cold plates for localized cooling of such single-chip modules.

#### **Project 7: *Models and Metrics for Dynamic Air and Hybrid Liquid Cooled Data Centers Based on Computational and Experimental Approaches***

**Project Description:** In a truly holistic design of an energy efficient data center, the server IT load allocation and the server cooling system will be synergistically controlled so that cooling can be provided on demand. In order to





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enable simulated and true real-time control strategies, accurate predictive models of the cooling system components such as heat exchangers are required, as well as fast and accurate control system strategies for optimal response of cooling systems to IT load that can vary in location and time within a data center. The goals of this project are to acquire research quality experimental data on the steady and dynamic performance of air and hybrid air-liquid cooling systems in order to validate computational models that will enable system level studies. The studies will assess energy efficiency of hybrid systems compared to conventional systems and will develop strategies for controlling dynamic air and hybrid air-liquid cooled systems.

### ***Project 8 combined with project 2***

### ***Project 9: High Bandwidth Integrated Parallel Optical Communication Links for Power Efficient, Cost Effective Data Center Interconnects***

**Project Description:** Emerging optical fiber based interconnection technologies that permit optical transceivers supporting multiple concurrent channels that are co-located or integrated into protocol adapters appear to be an attractive and superior alternative to overcoming the many limitations of multi-Gigabit, copper link-based Ethernet in a very cost-effective manner. The goal of this effort is to quantitatively evaluate the many benefits of such optical fiber based technologies in servers and data centers, vis-à-vis performance and power dissipation. A successful conclusion of this 18-month effort will bring out the clear performance, energy savings and cost advantages of multichannel optical interconnections based on the use of integrated optical transceivers at several levels within a data center

### ***Project 10: Impacts of Particulate and Gaseous Contamination on IT Equipment Where Air-Side Economizers are Used***

**Project Description:** When air-side economizers are used for data center cooling, there are typically contaminants that are introduced from the outside air. This project will investigate the contaminants affecting corrosion in data centers, incorporate the data center design in the CFD analysis for better understanding of the corrosion source and test and optimize a real time model similar to that of a CFD model to get the mechanism of the corrosion and the behavior of corrosion propagation.

### ***Project 11: Two-Phase Cooling Coupled with Waste Heat Energy Capture for Data Center Environments***

**Project Description:** In-rack liquid cooling for data center electronics is being increasingly recognized as a way to remove the high heat load of advanced electronics in an efficient and compact manner. Liquid cooling options are being considered by many, however this project allows IAB members to look beyond the immediate benefits of single phase liquid cooling to evaluate and understand the even greater potential of two-phase cooling. This project will evaluate the use of device level cooling through microchannel evaporative cold plates in both two-phase pumped and thermosyphon loops using a refrigerant as working fluid in a data center environment. Recognizing that the use of a two phase cooling system enables higher coolant operating temperature, the system will be coupled to a waste heat recovery test bed for energy recovery evaluation.

### ***Project 12: Investigation of Air Flow through Perforated Floor Tiles***





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**Project Description:** Our previous investigations have shown that perforated tile geometry significantly affects the downstream flow field development and cooling air delivery to adjacent racks. Direct geometrical resolution of the perforated tile is the most accurate method to model air flow through it, though resulting in larger computational effort. In this project we propose to directly resolve the tile geometrical structure of some of the commercially available tiles and devise effective strategies, and establish modeling guidelines to deal with complex tiles features. We will also experimentally investigate the thermal and flowfield (tile and aisle level) for air delivery through commercially available floor tiles. The experiments will also serve as a basis for validation of the developed CFD models.

### **Project 13: *Transient Thermal Response and Control of Data Centers***

**Project Description:** Data centers have dynamic thermal environments because of continuously changing computational (hence thermal) loads on the servers. An efficient thermal management scheme is required to closely follow the local and global cooling requirements and supply optimal cooling resources. Such a scheme is expected to have built in transient response and control characteristics of the data center. Presently, most of the data center thermal control is limited to preset supply (or return) air temperatures from the computer room air conditioning (CRAC) units, without having any information on other critical parameters, such as server inlet air or, more importantly, the chip temperatures, which we propose to investigate in this project.

### **Project 14: *Experimental and Analytical Studies on Transport in Fully and Partially Enclosed Cold Aisles in Air Cooled Data Centers***

**Project Description:** The use of containment configurations have become common to minimize mixing of hot and cold air in data centers, resulting in considerable savings in energy needed to cool the data center. However the adoption of containment changes the way in which the IT equipment behaves against increased impedance inside the area of containment. Furthermore CAC/HAC solutions change the relationship between the IT equipment, perforated tiles and airflow delivered by the CRAHs to be directly in series. Meanwhile, within the area of containment itself, the IT equipment develops a parallel relationship between one another, meaning that they will compete for the cold airflow supply coming from the tiles possibly resulting in under-provisioning for some servers and general mal-distribution. The purpose of this project is to conduct a wide range of numerical and experimental investigations that will address detailed containment schemes and characterize main air flow path components in the data center, such as tiles and IT equipment of interest.

### **Project 15: *Warm Water Cooling in Data Centers Including Water Storage Systems***

**Project Description:** Liquid-based cooling solutions for IT equipment are slowly coming into utilization as an alternative to conventional chilled air cooling systems for data centers. Liquid cooling offers a number of advantages for improving energy efficiency. In particular, warm water direct liquid cooling systems (DLCS) that utilize available water at environmental temperatures (“warm water”) have considerable potential in this regard. The





heat dissipated by server components like CPUs and DRAM chips is removed by circulating the warm water through attached cold plates. With proper design and implementation, DLCS can be a cost-effective alternative to many existing data center cooling technologies. These systems are an ideal way to take advantage of available environmental cooling, but they provide significant energy efficiency improvements in chiller based cooling as well. There are two interdependent specific aims of this research project: First, to optimize heat exchanger designs including the assembly and reliability of cold plates, and next, to develop thermal storage systems to enable reduction or elimination of chiller-based cooling.

### **Project 16: *An In-Depth Understanding of Oil Immersion Cooling Strategies for Data Centers***

**Project Description:** Complete immersion of servers in electrically nonconductive oil has recently become a promising technique for minimizing cooling energy consumption in data centers. Liquid cooling in general offers significant advantages over traditional air cooling approaches due to the higher heat capacities of fluids. Although a lower heat capacity than water, oil cooling has advantages over other liquid cooling strategies by not requiring complex infrastructure (piping, pumps, valves, etc.) within individual servers. However, a lack of sufficient published data and long term reliability documentation on oil cooling makes most data center operators hesitant to apply these approaches to their mission critical facilities. Initial testing and data collected at UTA on a single server immersed in oil show that it is possible to use high temperature (~45°C), low flow rate oil to cool a server, requiring minimal cooling energy. The purpose of this project is to explore and develop a deeper understanding of the concept of submersion cooling of information technology equipment (ITE). The goals of this proposal can be broken down into two primary areas:

1. The cooling efficiency of oil immersed ITE
2. The operational efficiency (overall life cycle of oil, reliability of components, and serviceability) of an oil cooled data center

### **Project 17: *Data Center Temperature Monitor Analysis System***

**Project Description:** The purpose of this project is to conceptualize, design, develop and test a wireless, decentralized, real time, environmental parameter measurement system of the rack and servers housed therein. Research, analytical and experimental function will be implemented to measure temperature, humidity, pressure and velocity, to verify accuracy and repeatability of measurement, and to estimate Power Vs performance conclusion. A feasibility verification of sensor size and power will be done, as well as a system prototype demonstration in an operational environment.

### **Project 18: *Investigations on FCMA Soft-Starter Based Compressor Employed in Refrigeration System for Data Center Cooling***

**Project Description:** This project will investigate the effect of FCMA soft-starter on a refrigeration compressor used for data center cooling. A Case study is being conducted on a 1200 TR refrigeration plant using centrifugal compressor at Tata Communications Data center located in Pune, India. The objectives are to study the effect of FCMA soft-starter on electrical energy consumption, to optimize the size of Transformer (Electrical side), to



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investigate with screw compressor, to and to develop an energy efficient refrigeration system for data center cooling.

**Project 19: *Thermal and Flow Analysis of Data Center Using Hybrid Cooling (Air and Water)***

**Project Description:** The objectives of this project are to carry out a CFD modeling of a high end server and a data center server rack to enhance its thermal characteristics using hybrid cooling.

**Project 20: *Environmental Acclimation of IT Equipment***

**Project Description:** IT equipment is designed to operate in specified environmental conditions, however, the equipment is often shipped in conditions that leave it well outside the operating specifications at delivery. This issue is more critical in cold weather shipping, as moisture forms on the cold surfaces upon delivery. Powering up a moist system can damage the equipment. The purpose of this project is to understand the factors that influence the acclimation time of the IT equipment, and to develop a transient model to predict the wait time before powering on to avoid damaging the equipment.

