American Recovery and Reinvestment Act
Public Interest Energy Research (PIER) Program

FINAL TECHNICAL PROJECT REPORT

Recovery Act: Federspiel Controls (now Vigilent) and State of California Department of General Services Data Center Energy Efficient Cooling Control Demonstration

Achieving Instant Energy Savings With Vigilent

Prepared for: U.S. Department of Energy
California Energy Commission

Prepared by: Vigilent Corporation

Vigilent™

SEPTEMBER 2011
DE-EE0002900
PIR-10-052

DOE PROJECT PERIOD
JANUARY 31, 2010 TO JUNE 30, 2011

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Contract Number: DE-EE0002900 and PIR-10-052

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ACKNOWLEDGEMENTS

This material is based upon work supported by the U S. Department of Energy within the Energy Efficient Information and Communication Technology Program, under Award No. DE-EE0002900 and California Energy Commission's Public Interest Energy Research (PIER) Program under contract No. PIR-10-052.

Special thanks are extended to

- Gideon Varga, Dibyajyoti Aichbhaumik, Darin Toronjo and Chad Sapp from the U.S. Department of Energy
- Kiel Pratt, Crystal Presley-Willis, Susanne Garfield and Adam Gottlieb from the California Energy Commission
- Jeff Henninger, John Munoz from the California Department of General Services
- Jon Russ Ray, Carl Boomgaarden, Adrian Farley and David Nahigian from the California Office of Technology Services
- Jim Durborough, Manuel Lujano, John Barrett, Susan Borgman from the California Franchise Tax Board

Additional thanks are extended to

- Ash Keval, Tim Garza and Sandy Cooney from the California Department of Water Resources
- John Hanafee, Nicole Winger, Bob Huggett, Janice Lumsden from the California Secretary of State
- Oscar Jarquin, Deborah Harris, Duncan McIntosh, and Ann Barsotti from the California Department of Transportation
- Samuele Yonan, Mark Hernandez, Jeff Nguyen, Eric Lamoureux, Joseph Martinez and Tom Jones from the California Department of General Services
- Damon Yates, Ben Williams, Mike Howland, Lore Levy from the California Employment Development Department

PREFACE

In 2010, the U.S. Department of Energy and California Energy Commission granted funds to Federspiel Controls. On May 10, 2011, within the period of performance for this project, Federspiel Controls changed its name to Vigilent™. The DOE and CEC project continues to be with Federspiel Controls. For this report and other marketing efforts related to this project, the Vigilent name is used.

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PREFACE: CALIFORNIA ENERGY COMMISSION

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

This is the final report for *Recovery Act: Federspiel Controls (now Vigilent) and State of California Department of General Services Data Center Energy Efficient Cooling Control Demonstration*, project number DE-EE0002900 and PIR-10-052 conducted by Vigilent Corporation. The information from this project contributes to PIER's Energy Efficiency Data Center Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

Eight State of California data centers were equipped with an intelligent energy management system to evaluate the effectiveness, energy savings, dollar savings and benefits that arise when powerful artificial intelligence-based technology measures, monitors and actively controls cooling operations. Control software, wireless sensors and mesh networks were used at all sites. Most sites used variable frequency drives as well. The system dynamically adjusts temperature and airflow on the fly by analyzing real-time demands, thermal behavior and historical data collected on site. Taking into account the chaotic interrelationships of hundreds to thousands of variables in a data center, the system optimizes the temperature distribution across a facility while also intelligently balancing loads, outputs, and airflow.

The overall project will provide a reduction in energy consumption of more than 2.3 million kWh each year, which translates to $240,000 saved and a reduction of 1.58 million pounds of carbon emissions. Across all sites, the cooling energy consumption was reduced by 41%. The average reduction in energy savings across all the sites that use VFDs is higher at 58%.

Before this case study, all eight data centers ran the cooling fans at 100% capacity all of the time. Because of the new technology, cooling fans run at the optimum fan speed maintaining stable air equilibrium while also expending the least amount of electricity. With lower fan speeds, the life of the capital investment made on cooling equipment improves, and the cooling capacity of the data center increases.

This case study depicts a rare technological feat: The same process and technology worked cost effectively in eight very different environments. The results show that savings were achieved in centers with diverse specifications for the sizes, ages and types of cooling equipment. The percentage of cooling energy reduction ranged from 19% to 78% while keeping temperatures substantially within the limits recommended by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) for data center facilities.

Keywords: California Energy Commission, U.S. Department of Energy, American Recovery and Reinvestment Act, data center, energy efficiency, computer room air conditioner, CRAC, energy management, controls, HVAC, wireless, Vigilent, Federspiel Controls, Cliff Federspiel, PUE, DCIE, data center cooling, greenhouse gas emissions

Please use the following citation for this report:

Federspiel, Clifford. Evers, Myah. (Vigilent Corporation). 2011. *Recovery Act: Federspiel Controls (now Vigilent) and State of California Department of General Services Data Center Energy Efficient Cooling Control Demonstration.* U.S. Department of Energy. California Energy Commission.

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EXECUTIVE SUMMARY

By installing intelligent, supervisory control and wireless mesh network sensing systems at eight State of California data centers, this project demonstrates that the results achieved with the 2009 PIER-sponsored pilot project[1] at the California Franchise Tax Board's Sacramento Data Center can be replicated under different conditions. The State of California data centers range in size from localized data centers (< 1000 square feet) up to enterprise data centers (40,000 square feet). While following American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) temperature ranges for inlet air to data center equipment, energy savings were produced by implementing intelligent energy management that measures, monitors and actively controls cooling units. In addition to testing the systems at data centers of different sizes, the project tested data center reliability with variations in cooling unit types, equipment ages, and data center layouts.

The same process and intelligent energy management system succeeded in saving energy at eight data centers of different sizes and types and the data center in the 2009 pilot project. The process and management system comprises remarkable technology that can be applied to data center environments worldwide.

Implementing automated control software based upon highly sophisticated artificial intelligence could save more than a billion kWh worldwide. Such large savings are attainable because few data centers currently use systems that actively control cooling on a dynamic real-time basis, use historical and predictive data, and understand how each cooling unit influences cooling throughout the data center.

Demonstration Sequence

After the final sites were selected, the technical tasks proceeded in the following order:

- Conduct a site audit and design hardware specifications for each site.
- Install wireless temperature sensors, power monitoring and IT equipment to support data collection to provide baseline energy-use data.
- Install and activate variable frequency drives (VFDs), which are connected to the computer room air-handling (CRAH) units to modulate fan operation. And, in the case of Gold Camp, install and retrofit the CRAHs with a switch to allow for manual or active controls.
- Install and commission automated software to provide temperature control.
- Measure and verify resulting energy savings.

[1] Bell, Geoffrey C., Cliff Federspiel. Sept. 2009. *Demonstration of Datacenter Automation Software and Hardware (DASH) at the California Franchise Tax Board California Energy Commission*. CEC-500-02-004, WA# 022.

Project Results

Over 2.3 million kilowatt hours in annual cooling energy savings resulted from the alterations to the eight data centers in this project, which equates to 1.58 million pounds[2] of greenhouse gases. This energy savings means the State of California's annual utility bill is reduced by $240,000.

Five of the eight sites achieved better reductions in energy savings than were predicted during the initial energy estimate. Table 1: kWh Savings at California State Data Centers shows the total average cooling energy savings across sites is 41%, which is the sum of the savings for all eight sites divided by the sum of the cooling energy consumption for all eight sites. When removing Gold Camp — an outlier because it has no VFDs — the data centers reduced cooling energy by a total of 58%.

Table 1: kWh Savings at California State Data Centers
(In descending order by square feet)

Site Name	Square Feet	Sensors	CRAHs	kWh Savings	Dollar Savings	Cooling Reduced
Gold Camp	40,000	495	23	484,174	$48,417	**19%**
Employment Development Department	12,500	63	5	433,049	$43,305	**54%**
Franchise Tax Board LA Data Center	12,000	126	15	697,045	$69,705	**78%**
Department of Water Resources	5,300	53	6	288,348	$28,835	**40%**
Caltrans 2nd Floor	4,000	44	4	149,555	$17,947	**64%**
Secretary of State	2,700	32	5	37,084	$3,708	**30%**
Ziggurat	2,500	41	4	84,134	$11,358	**50%**
Caltrans 9th Floor	667	31	3	140,135	$16,816	**64%**
Totals	**79,667**	**885**	**65**	**2,313,524**	**$240,091**	**Average 41%**

For more information on the kWh savings, see Appendix C: Baseline and Post-Install Comparisons

[2] To obtain greenhouse gases, or carbon emissions, kWh savings were multiplied by 0.681 based on eGRID2010 Version 1.1 Year 2007 Summary Tables. Criteria Pollutants. Page 2.

Conclusions

Enterprise data centers achieved significant savings by installing automated software along with sensors connected on a wireless mesh network. Whether data centers are small or large, the intelligent energy management system reduces cooling inefficiencies thus reducing operation costs. In an environment that has equipment with varying cooling performance, the intelligent energy management system helps divert cooling needs to more efficient CRAHs. The system works well with chilled-water (CHW) or direct expansion (DX) CRACs.

Recommendations

Data centers will be well served by taming the cooling environment with an intelligent energy management system capable of working on CHW and DX CRAHs. The ratio of sensors to CRAHs and server racks need not be excessive.

Data centers that are consolidating, expanding and generally in flux would be well served by an intelligent energy management system. As floor plans change, the ability to monitor temperature changes is just as important, if not more so, than during regular operations. More important than monitoring alone, intelligent management and significant energy savings can play a pivotal role in major data center improvements.

INTRODUCTION

In data centers, large amounts of energy are wasted. Data centers are typically overcooled as a result of inadequate temperature monitoring, overly conservative set points, constant-speed air-handling units and the placement of computer room air conditioners (CRACs) in relation to the server racks most in need of cooling. This case study at eight State of California data centers demonstrates the effectiveness of intelligent energy management systems, in which artificial intelligence dynamically controls the air distribution using wireless sensor networks. The intelligent energy management system creates airflow equilibrium and perpetuates stabilized temperatures within the data center, which creates energy savings and obviates the previously mentioned factors that generally lead to wasted energy.

In this case study, the intelligent energy management system and related alterations produced 2.3 million kWh in annual cooling energy savings at eight data centers of widely varying sizes, ages and types.

Artificial Intelligence Improves Cooling

The artificial intelligence driving the active, dynamic control of the cooling units uses data collected from temperature sensors that provide inlet air temperature feedback on the cold aisle data center racks. The system uses historical data to learn the relationships between the cooling equipment and the IT load. The system learns and adapts and determines how to weigh the vast data set that models real-time conditions of server inlet temperature status, historical models, and the relationships between each cooling unit.

Energy savings result from reaching airflow equilibrium within the data center. The equilibrium is reached when all CRAHs work together producing the optimum amount of cooling while expending the smallest amount of energy. Balanced loads that take into account how all the cooling units work together also eliminate unnecessary competition between units. Competition between units leads to overcooling and could cause CRAHs to switch to heating. Near constant temperatures can be achieved with active controls, and once the environment is at equilibrium, it takes less energy to maintain the temperature. At equilibrium, active dynamic controls are needed to constantly make adjustments given the changing conditions — changing IT loads, outside temperatures, and equipment moves.

Maintaining Regular Operations

A critical component of this system is to make implementation and ongoing control as unobtrusive as possible, allowing data center managers to continue operating with minimal impact. Implementation of the system causes little or no interruption to the data center. The system can operate without connecting to the data center's network, and no IT equipment is impacted. The wireless mesh network is easy to install. When server racks are moved in and out, the mesh network adapts easily and very few changes are needed.

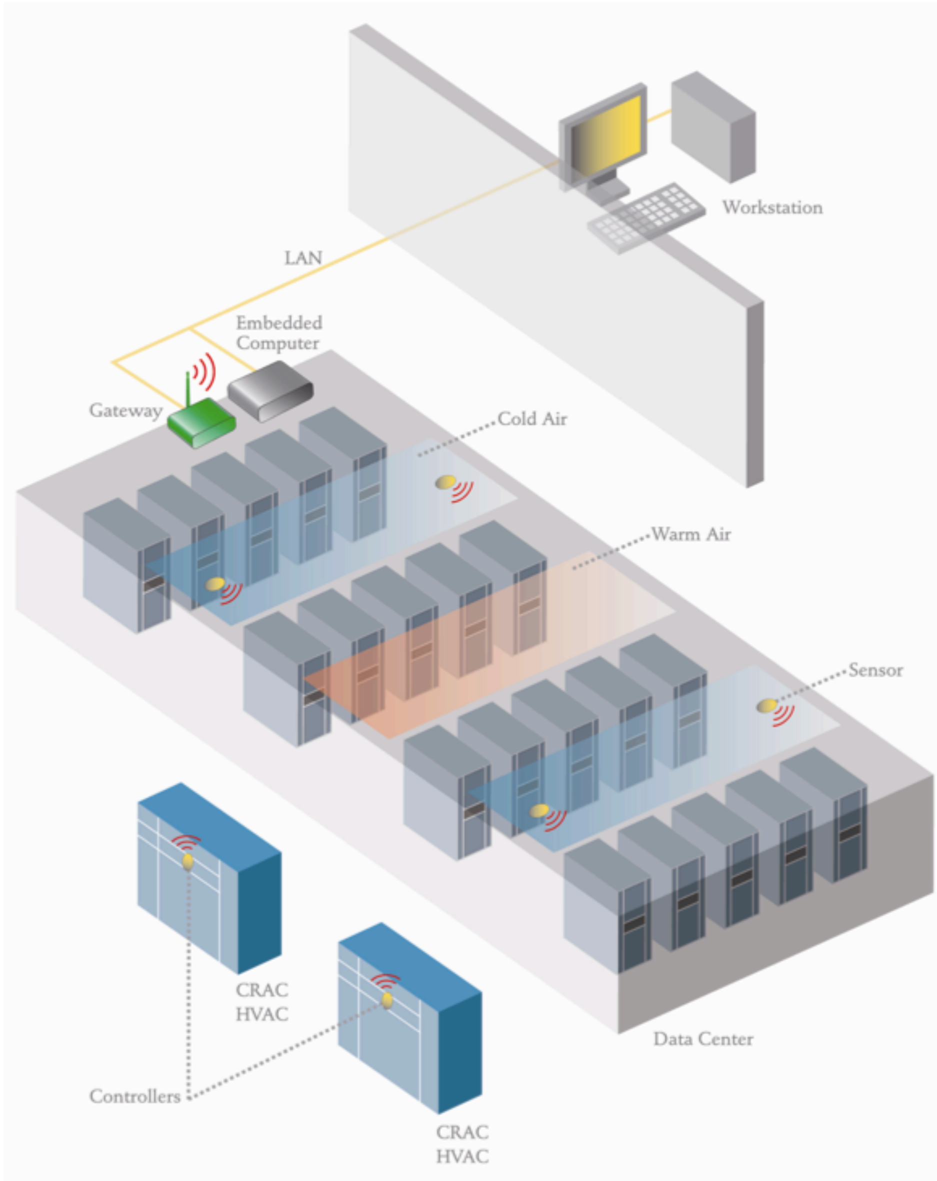
Measuring Savings

To demonstrate the energy savings before and after implementation, baseline measurements were taken before active controls were implemented. The post-install power consumption was measured versus the baseline period to determine energy savings. A Measurement and Verification Protocol was established to conform to industry standards and local utility requirements. (See Appendix B: Measurement and Verification Protocol.)

Monitoring Network

The diagram below demonstrates the components of the intelligent energy management system and how the wireless sensors and controls overlay on top of the existing infrastructure.

Figure 1: Data Center Architecture



During operation, the bi-directional wireless mesh network sends data from the temperature sensors to the gateway and then to the server running the artificial intelligence engine. The inlet temperatures are measured at two places on the rack — one on top and one on the bottom. Once every minute, the database receives the actual temperatures recorded by the sensors. All of the collected data is used for current system management. It is also stored for historical reporting and analytics.

Temperature sensors were installed to provide inlet air temperature feedback from the cold aisle server racks. The placement of sensors in cold aisles relates to ASHRAE, server design and capital needs. ASHRAE,[3] with agreement from manufacturers of IT equipment (servers, network equipment, and storage devices), has recommended operating temperature ranges for inlet air to data center IT equipment. These server inlet recommendations for temperature are: 64.4° F - 80.6° F. This standard relates only to the server inlet, which is in the cold aisle, because hot-aisle temperatures do not compromise the IT equipment, provided all servers are facing the correct direction. With sensors at two places on the rack, temperatures are recorded where it is most critical. Hot aisle temperatures do not need to be measured because the artificial intelligence engine is tuned to direct cool air to the areas where it is needed. This allows data centers to purchase less hardware, while maintaining all ASHRAE standards. The number of sensors used for any particular installation varies depending on the density of the server racks in the room. Control and power monitors (also known as modules) were also installed at each cooling unit.

The power monitors collect fan power and cooling energy of each cooling unit. The control module receives commands from the server to control the cooling unit. To modulate cooling, the cooling units at all of the sites except Gold Camp were converted to variable-speed operation with variable frequency drive (VFD) retrofits. At these sites the feedback is sent to the VFD, which then controls the rotational speed of the AC electric motor by altering the frequency of the electrical power supplied to the motor. At Gold Camp, however, the feedback sends a signal directly to the CRAH, to turn the CRAH off when appropriate.

The CRAH temperature data, which is taken at both the supply and return, is sent to the database once every minute. The open communication protocol of the cooling and power units in the data center allows the wireless supervisory control system to interface with the cooling unit controls.

Data center managers can access a control panel that displays all the parameters used for system control. Data Center managers can also make adjustments to set points.

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[3] ASHRAE, 2008, addendum to "2008 ASHRAE Environmental Guidelines for Datacom Equipment," Atlanta, GA.

BACKGROUND

Industry Impact

In 2010, data centers consumed roughly 2% of all the electricity used in the United States.[4] Data center electricity use is estimated to be growing 12% annually, "making it the fastest-growing end-use of electricity," according to a report from the Lawrence Berkeley National Laboratory.[5] Annual electricity cost for servers and data centers was expected to reach $7 billion by 2011.[6] These markets are not addressed by effective solutions. Most solutions to date have carried high price tags that typically cannot meet data center owners' ROI requirements. The data center market is a significant target of the technology shown in this case study.

This system provides energy savings, and in turn, helps add or maintain cooling capacity to existing facilities, which also provides longer lifespans of cooling equipment and delays the need to build more data centers.

Influence maps, which are not available from any other product, visually demonstrate the ability of the technology in this case study to depict the interaction between all cooling units. This is the only solution that gives the data center manager a mechanism to visually identify and record how a specific unit influences rack inlet temperatures. Further, the influence maps are continuously available, real-time, and based on current data.

Alternative Technologies

Companies producing servers and CRAHs have already begun adding temperature sensors to their new products, which can communicate with the building management system, leading to more and more analysis and initiatives to save energy. As new data centers continually improve because of these efforts, fewer industry resources are focused on retrofitting existing equipment and providing control. Existing data centers can house CRAHs that are over ten years old, and very few companies offer cost-effective efficiency enhancements.

A host of companies offer monitoring tools. However, these tools do not necessarily save energy. Ongoing active decision-making must be paired with monitoring. And while efficiency consultants can improve a data center's energy measurements for a specified period of time, once they leave, the efficient environment is often not maintained. Very few companies offer active controls that combine monitoring with alterations to the fan speed and operation of CRAHs. Few companies provide active controls for direct expansion (DX) and chilled water (CHW) units by modulating VFD speeds, which was used in seven of the eight sites. The technology showcased at Gold Camp, which turns CRAHs on and off, is unavailable from any other company or product.

No other company measures, visually graphs and bases control actions on each CRAH's ability to influence and affect cooling throughout the data center.

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[4] Jonathan Koomey. 2011. Growth in data center electricity use 2005 to 2010. Oakland, CA: Analytics Press. July 2011. http://www.analyticspress.com/datacenters.html.

[5] Coles, H.C., Taewon Han, Phillip N. Price, Ashok J. Gadgil, William F. Tschudi (Lawrence Berkeley National Laboratory). 2011. *Air-Side Economizer Cooling Is Safe for Most California Data Centers*. California Energy Commission. Publication number: CEC-500-2010-XXX.

[6] U.S Environmental Protection Agency. 2007. Report to Congress on Server and Data Center Energy Efficiency: Public Law 109-431.

Overview of Stakeholders

With eight data center installations, many organizations were stakeholders and supporters. Grants were received from the U.S. Department of Energy (DOE) and the California Energy Commission (CEC) Public Interest Energy Research (PIER) program. Additional funding came from the California Department of General Services (DGS) and California Office of Technology Services (OTech). Most of the data centers were located within DGS office buildings.

The eight data centers were:

- Office of Technology Services (OTech), Gold Camp, Rancho Cordova, California
- Employment Development Department (EDD), Sacramento, California
- Franchise Tax Board (FTB), Sacramento, California
- Department of Water Resources (WR), Sacramento, California
- Department of Transportation (Caltrans), District Seven, Second Floor, Los Angeles, Ca.
- Secretary of State (SOS), Sacramento, California
- Department of General Services, Ziggurat Building, Sacramento, California
- Department of Transportation (Caltrans), District Seven, Ninth Floor, Los Angeles, Ca.

Past Experience

This case study takes the approach used at the 2009 Franchise Tax Board project and replicates it at eight data centers. The 2009 Franchise Tax Board site was 10,000 square feet cooled by twelve computer room air-handling (CRAH) units that each have chilled water cooling. The study demonstrated improved air-distribution best practices, supervisory control driven by artificial intelligence and wireless sensor networks. The study took measurements as each practice was put into place, so that the incremental effects of each were measured. Three of the five significant results cited in the study are quoted here:[7]

> "1) Re-arranging floor tiles reduced and stabilized cold-aisle temperatures by improving air distribution, which resulted in a large reduction in chilled-water energy consumption. Re-arranging the floor tiles did not change the electrical consumption of the CRAHs or of the IT equipment, but it appears to have reduced the chilled water energy consumption for an equivalent of 44,496 kWh per year."
>
> "3) The control software increased the average cold-aisle temperature, while maintaining 97% of all temperature readings below the upper limit of the recommended range of ASHRAE. The control software eliminated 59.6% of the baseline fan energy (and 63% of the fan energy from the previous step). The control software eliminated 13.6% of the baseline chilled water consumption (and 18.3% of the chilled water consumption from the previous step)."

The ROI Analysis informed decisions made on this project, including the decision to eliminate hot aisle containment from the project. The 2009 case study that documented the previous energy efficiency implementations reduced 21% of the total data center's energy. When looking at the total cooling energy consumption, there was a reduction of 52% in cooling energy usage.

[7] Bell, Geoffrey C., Cliff Federspiel. Sept. 2009. *Demonstration of Datacenter Automation Software and Hardware (DASH) at the California Franchise Tax Board California Energy Commission*. CEC-500-02-004, WA# 022.

Table 2: 2009 Franchise Tax Board ROI Analysis

Measure	Cost	kWh/yr Saved	% Total Energy Saved	$ Saved
Rearrange tiles	$3,000	44,496	2.0%	$4,005
VFDs	$16,040	75,135	3.4%	$6,762
Control system	$56,824	339,603	15.2%	$30,564
Hot aisle containment	$58,193	16,005	0.7%	$1,440
Total	**$134,057**	**475,239**	**21.3%**	**$42,772**

Dr. Clifford Federspiel, Founder, President & CTO served as Principal Investigator for the 2009 project as well as this one. He is a leader and visionary in the field of energy management, having authored more than 50 papers on the topic. With a PhD from Massachusetts Institute of Technology and previous research experience at University of California at Berkeley, he has pioneered research in dynamic cooling systems and holds numerous patents in the field.

Project Objectives

The full project objectives were as follows:

- Demonstrate that the 2009 success at California's Franchise Tax Board Sacramento Data Center can be replicated across multiple State of California data centers.
- Prove performance at data centers as large as 40,000 square feet and as small as 1,000 square feet.
- Produce a 26% reduction in cooling energy consumption of which 15% comes from active controls.
- Reduce energy consumption by 4.7 million kWh.
- Demonstrate Data Center Infrastructure Efficiency (DCIE) at 0.8, or Power Usage Effectiveness (PUE) at 1.25.
- Implement intelligent, supervisory control and wireless mesh network and sensing at eight California data centers with varying cooling equipment, conditions, and data center layouts.
- Create 15 jobs. Of those 15 jobs, eight are for skilled trade, five for advanced technical or managerial positions and one is indirect or induced.
- Reduce greenhouse gas emissions.
- Leverage grant funds.
- Maintain temperatures within the limits recommended by ASHRAE.
- Implement data center best practices, which could include blanking panels, containment curtains, and raised floor changes.

Project Timeline

The high-level project timeline was determined by the timing of grant approvals and how long it took to identify and reach agreements with each data center. Both of these triggers took significantly longer than expected. Many of the data centers originally selected for the project were subject to an unexpected initiative to sell State of California buildings. This initiative resulted in delays and the project went from 12 identified sites to the final eight sites.

The project began January 2010 and ended June 30, 2011. Some technical transfer activities are still being conducted. More details on the technical transfer can be found in the section named Technology Transfer.

- **January 2010**
  - DOE project period begins.
- **February to October 2010**
  - Identify and agree upon matching funds and sites.
  - Audit sites and gather data.
  - Build systems.
  - Engage utilities for incentives.
- **November to December 2010**
  - CEC grant awarded.
  - Installation, training, and post-install measurements taken at the Water Resources and Secretary of State.
- **March 2011**
  - CEC kickoff meeting.
  - Install equipment and measure baseline data at EDD.
  - Installation, training, and post-install measurements taken at Ziggurat.
- **April to June 2011**
  - Technology transfer at Uptime Institute and Gartner IT Summit.
  - Installation, training, and post-install measurements taken at Gold Camp and both Caltrans sites.

Site Descriptions

The eight data centers vary in size and location. The smallest data center, the 9th floor of Caltrans, occupies part of a floor in a downtown Los Angeles high-rise. Gold Camp in Rancho Cordova near Sacramento, California, is California's largest data center and serves more than 500 state, county, federal, and local government entities. Gold Camp was the most sophisticated and up-to-date site, while the rest of the facilities worked with older equipment and technology.

All sites provide cooling using an under-floor air distribution system. Cooling is provided by chilled-water CRAH units. The Department of Water Resources has two DX units in addition to its CHW units. Prior to this project, the sites did not have any VFDs.

Table 3: California State Data Center Statistics

Site Name	Square Feet	Sensors	CRAHs	Racks	Avg. Utility Rate
Gold Camp	40,000	495	23	1,010	$0.10
Employment Development Department	12,500	63	5	77	$0.10
Franchise Tax Board	12,000	126	15	60	$0.10
Water Resources	5,300	53	6	75	$0.10
Caltrans 2nd Floor	4,000	44	4	105	$0.12
Secretary of State	2,700	32	5	29	$0.10
Ziggurat	2,500	41	4	70	$0.135
Caltrans 9th Floor	667	31	3	53	$0.12
Totals	**79,667**	**885**	**65**	**1,479**	

The table below shows the IT loads, as measured at the uninterrupted power supply (UPS) units and power distribution units (PDUs). The IT load indicates how much energy the servers and IT equipment use. Typically this number remains constant. Increases, such as those seen at Franchise Tax Board from 137 kW to 176 kW, indicate increasing IT usage.

See Appendix Table 16: Baseline and Post-Install Dates for more information on the time periods.

Table 4: Power Consumption

Site Name	Baseline IT Load (kw)	Post-Install IT Load (kw)	Square Feet
Gold Camp	529	705	40,000
EDD	200	203	12,500
FTB	137	176	12,000
WR	177	189	5,300
Caltrans 2nd Floor	Not available[8]	Not available	4,000
SOS	54	54	2,700
Ziggurat	76	77	2,500
Caltrans 9th Floor	Not available	Not available	667

[8] The Caltrans IT loads were not available or were not reliable.

Gold Camp

At 40,000 square feet, Gold Camp is the largest State of California data center. It is in the process of expanding from 23 CRAHs to 48 CRAHs and improving many of its systems.

Employment Development Department

With 12,500 square feet, EDD's data center is the second largest site. See below for more details on EDD.

Franchise Tax Board

Franchise Tax Board's data center is part of a larger room that includes printing equipment. Because of the printing process and presence of paper, humidity is a carefully monitored environmental factor. Humidity sensors were installed as part of this project, and they send data to the intelligent energy management system.

Department of Water Resources

The Department of Water Resources has a hybrid cooling system with four chilled-water (CHW) units and two direct expansion (DX) cooling units. The DX units were not retrofit with VFDs. Instead, the DX units were turned ON and OFF when the system determined that doing so would not create excess temperatures beyond the high-temperature set points.

Department of Transportation

The data centers are located in a Los Angeles high-rise. The LEED-certified building opened in September 2004. The smaller of the two Caltrans data centers takes up a small part of a larger office floor.

Secretary of State

The small Secretary of State data center has only five CRAHs. Its racks are grouped in four rows. Its IT load remained relatively constant from the baseline period to the post-install period.

Department of General Services

The Ziggurat data center in the Department of General Services building is separated from a much larger office floor. Ziggurat does not have backup generators typical of data centers. It has experienced unexpected power outages and outages resulting from planned maintenance. The power outages play a factor in the set points and procedures followed. The building is owned and operated by a separate commercial real estate company, which has staff monitoring the conditions of the data center. The data center is subject to both the policies of the State of California and the building operator.

Site Example: Employment Development Department

To better illustrate the type of information that is collected at every site, see the EDD figures below.

With 12,500 square feet, EDD's data center is the second largest site. As part of an older office building, it sits on a floor that was not initially designed for a data center. The floor plan is not optimized — one CRAH sits in a room that was previously walled off with glass, separated from the rest of the data center.

Figure 2: EDD Floor Plan

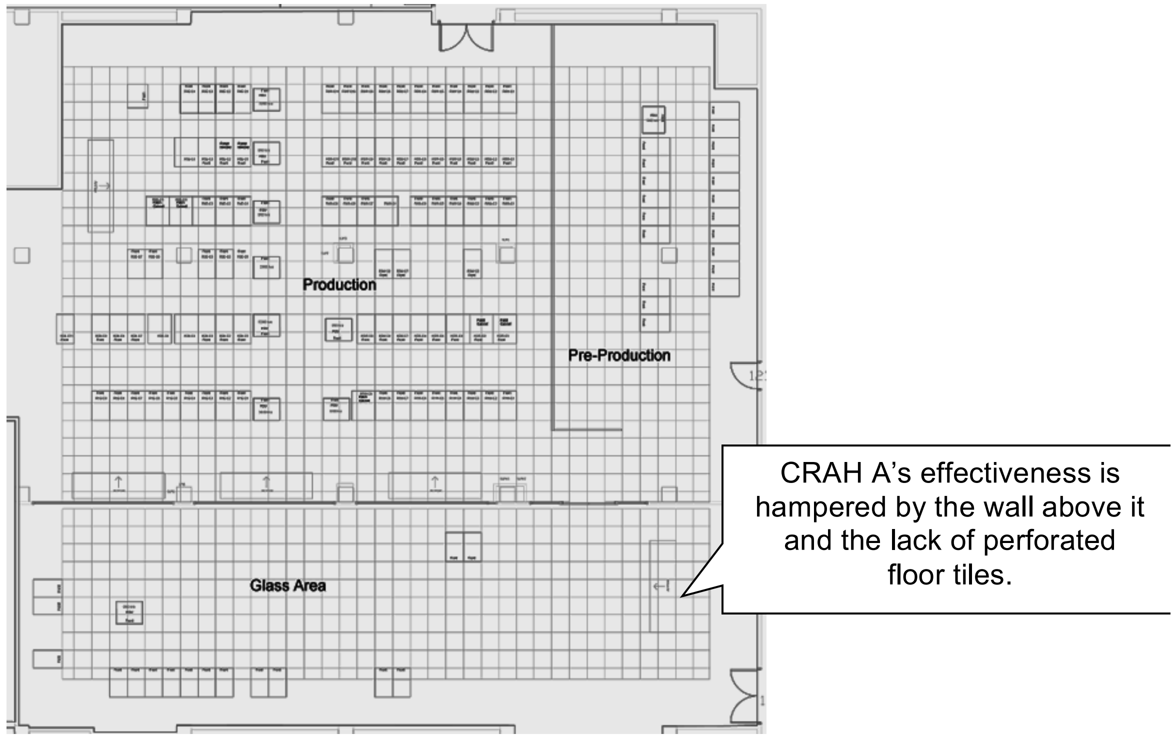
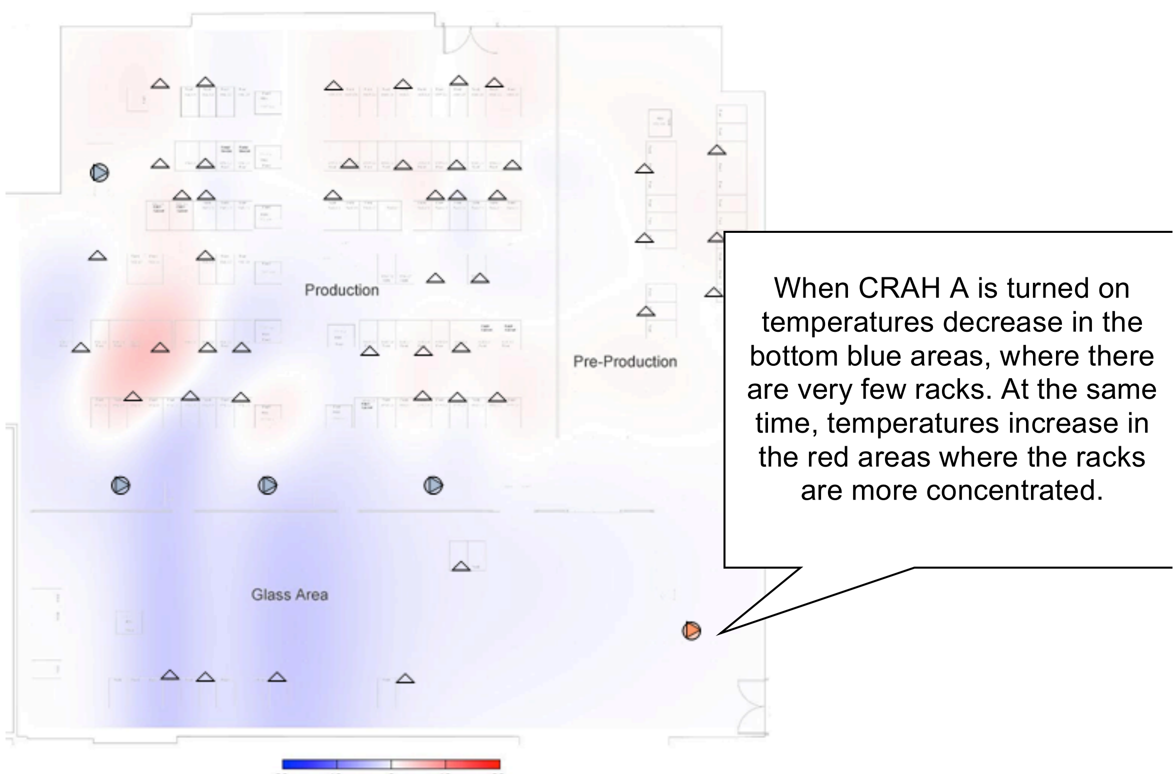


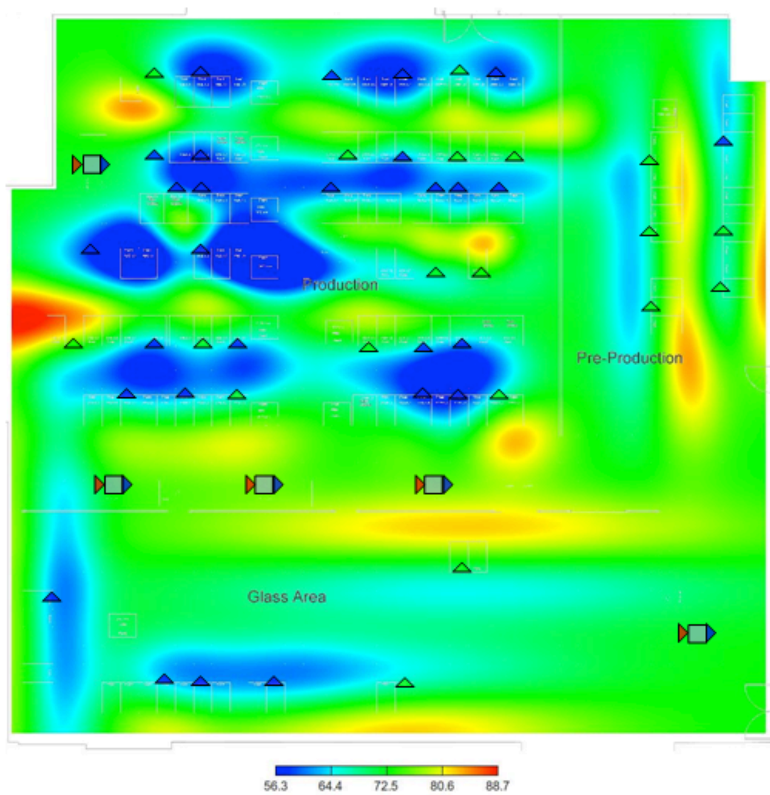
Figure 3: EDD Influence Map Before Go-Live



The separate room on the bottom of the map had no air-cooling coming up from the floor tiles. Temporary storage in that room disrupted airflow and caused suboptimal conditions. Pipe under the floor blocked full air distribution and created hot spots. In order to combat those hot spots, a great deal of cold air was needed.

The cold spots shown in the thermal map, Figure 3: EDD Thermal Map Before Go-Live, illustrate the conditions of the data center prior to the activation of dynamic controls.

Figure 4: EDD Thermal Map Before Go-Live (March 2011)



PROJECT APPROACH

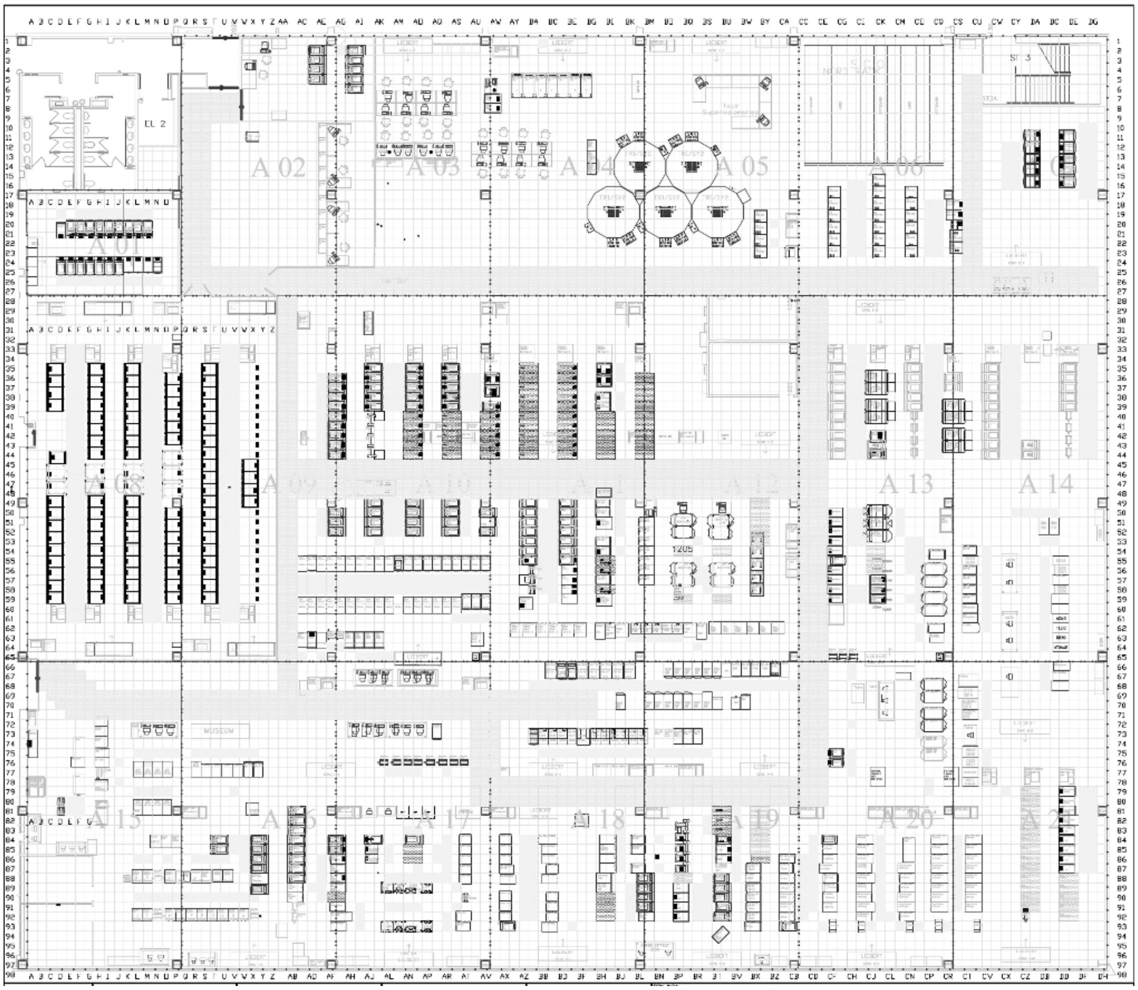
Technical tasks began in November 2010 at Secretary of State and the Department of Water Resources. In June 2011, the final technical tasks were completed at the two Department of Transportation data centers. While many tasks at the various data centers were performed simultaneously, the activities at each data center proceeded in the following order:

Task 1. Identify and agree upon site requirements.
Task 2. Apply for utility incentives.
Task 3. Site audit and information gathering. Determine system hardware requirements.

In this phase, floor plans are procured. A project manager walks the floor, asks about known problem hot spots, evaluates hot and cold aisles, and determines where to place hardware.

In Figure 4: Floor Plan Gold Camp, a variety of equipment and staff desks were present within the data center. Circles at the top of the floor plan represent the old IT equipment, which had tape backups. As part of its planned expansion, the tape-related equipment was moved out in the spring of 2011. Almost the entire top third of the floor plan was completely reconfigured by project end.

Figure 5: Floor Plan Gold Camp (Jan. 2011)

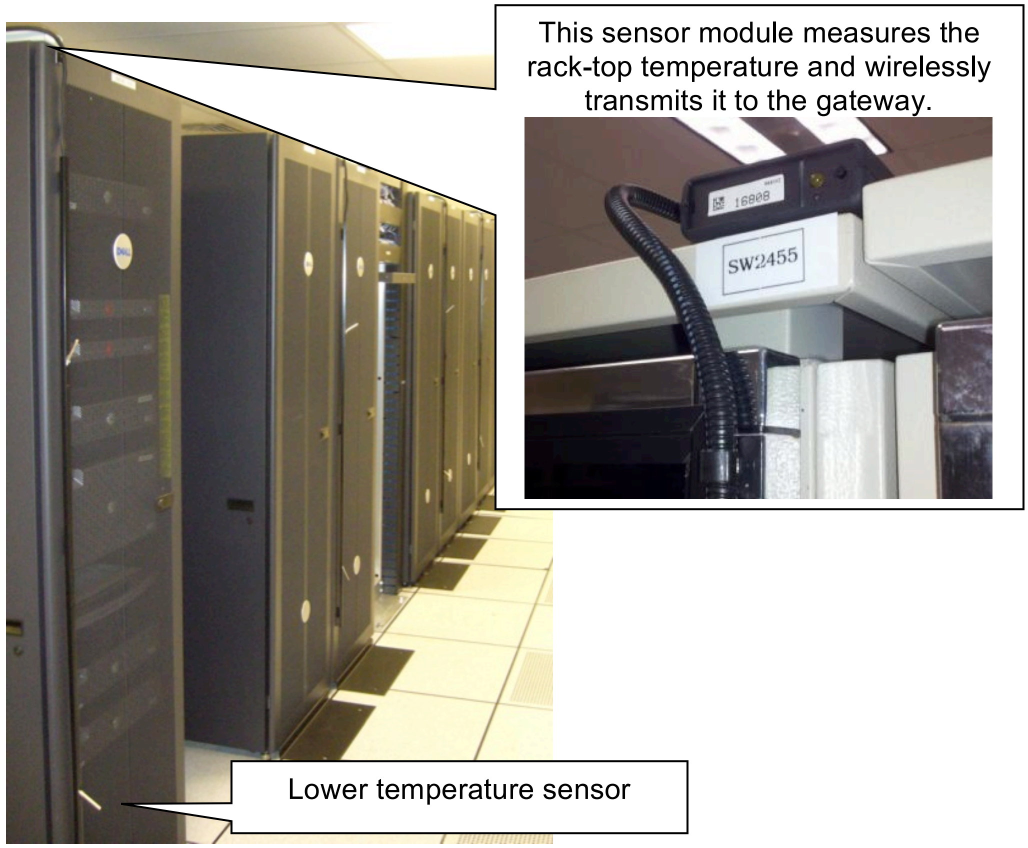


Task 4. Build and commission intelligent, energy management system, which includes building the wireless mesh network and configuring the server with the software application.

Task 5. Install hardware and software to audit site and collect data before active controls go live.

For all eight sites, a total of 885 wireless sensors were installed. See Table 3: California State Data Center Statistics for a breakdown of sensors by site. In many cases, project managers worked with data center managers to identify and remediate hot spots. Recommendations for floor tile rearrangements were made along with other recommendations like pointing out inconsistencies in cold- and hot-aisle arrangements.

Figure 6: Temperature Sensors

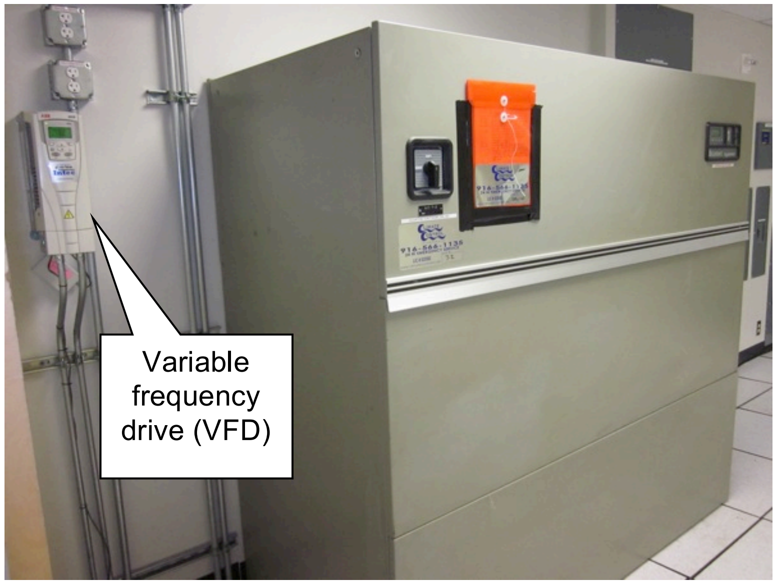


Task 6. Work with third parties to install and activate VFDs.

At Gold Camp, there were no VFDs. There, switches were installed on the CRAC to allow for manual or automatic ON/OFF control.

Task 7. Record baseline metrics.

Figure 7: VFD Installed Next to CRAH



The thermal map is a key tool to help data center managers adjust the airflow of the data center. By seeing hot spots and cold spots, the data center manager can take actions. The intelligent energy system actively controls the actions of the CRAHs, but the managers can adjust set points, configure perforated floor tiles and perform other physical modifications using the thermal map. An example of the thermal map is shown in Figure 7: Gold Camp Thermal Map Before Active Controls Fully Live.

In the thermal map, the location of each CRAH is indicated with 

Each sensor is indicated with 

The background of the thermal map shows the temperatures indicated in the scale at the bottom of the map.

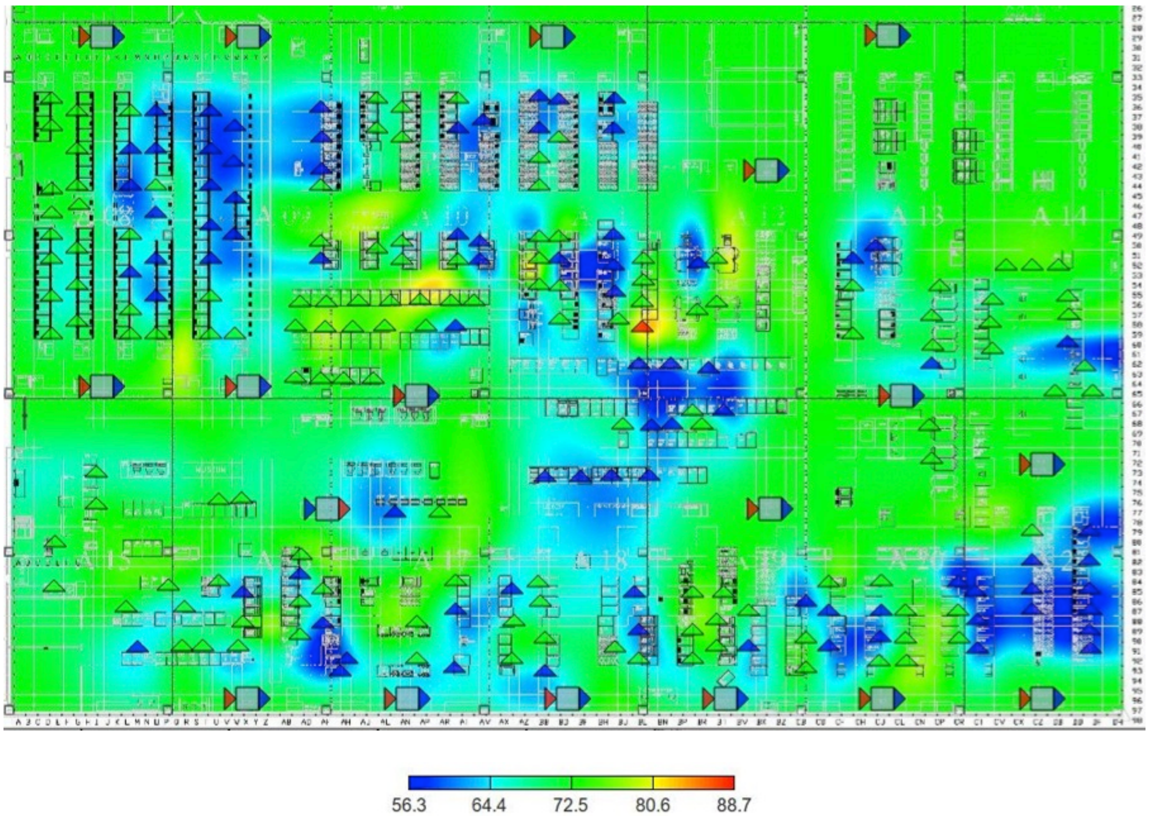
Sensors are color-coded based on the sensor's temperature reading. If the sensor is green, it indicates the temperature is within the lower and upper set points. If the sensor is red, it indicates the temperature is above the upper set point. Blue indicates the sensor is below the lower set point.

These colors (blue, green, and red) make it easy to determine the reported status of the system set points that are configured in the system. The color-coding also provides assistance with identification and remediation of data center floor hot spots. Should the need arise, the system administrator can override the system's active controls.

When the system is at equilibrium there will typically be a small number of red sensors indicating temperatures above the set point. The color of the sensor triangles depends on the sensor's temperature reading in relation to the set points, whereas the background color indicates the temperature.

The thermal map shown below depicts how cold the top of the rack at Gold Camp had been prior to dynamic control activation. Only three very small spots appear close to 80° F. Since this map illustrates the temperatures at the top of the rack, warmer temperatures are expected.

Figure 8: Gold Camp Thermal Map Before Active Controls Fully Live (Feb. 2011)

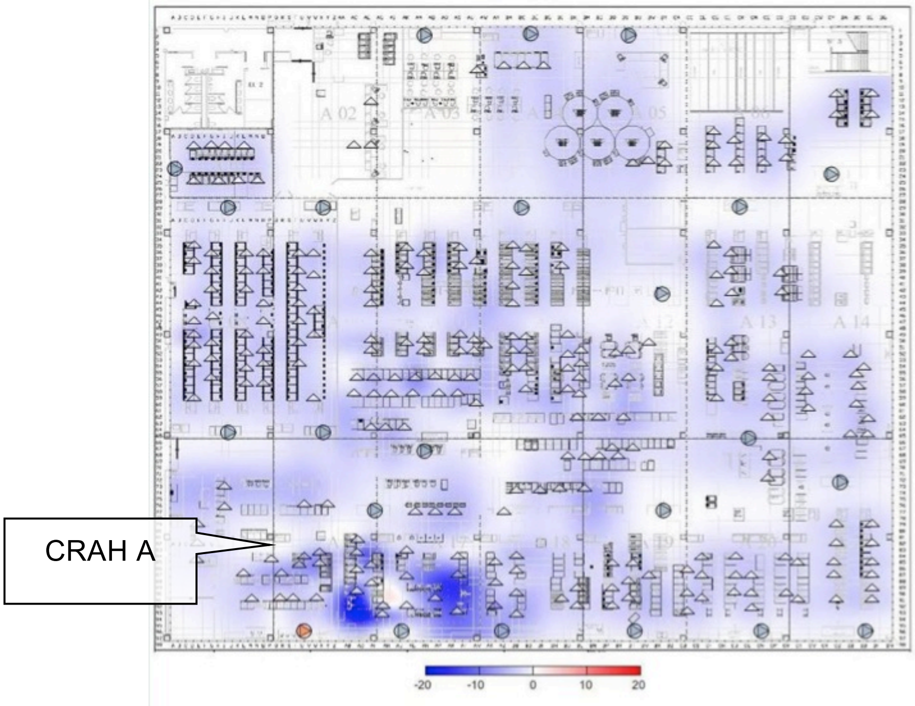


Task 8. Install and go live with active controls. Test systems, and train data center employees.

Task 9. Once the system is live, influence maps provide insight into how the CRAHs affect the rack inlet temperatures on the data center floor.

In the figure below, CRAH A influences cooling in the blue areas. CRAH A has a strong local cooling effect, and a weaker cooling effect throughout a large portion of the data floor.

Figure 9: Post-Install Gold Camp Influence Map CRAH A



The next figure shows that by turning CRAH B on, increased cooling is provided to the blue areas, but temperatures rise in the red areas. CRAH B affects temperatures less than CRAH A does. This type of chart can help a data center manager determine the location(s) of the most redundantly cooled areas of the data center. Additionally, the manager gets a better sense of the AI control strategy and how it decides which CRAHs are more or less effective. Managers also use these maps to determine maintenance schedules that cause less impact to temperatures and reduce truck rolls.

Figure 10: Post-Install Gold Camp Influence Map CRAH B

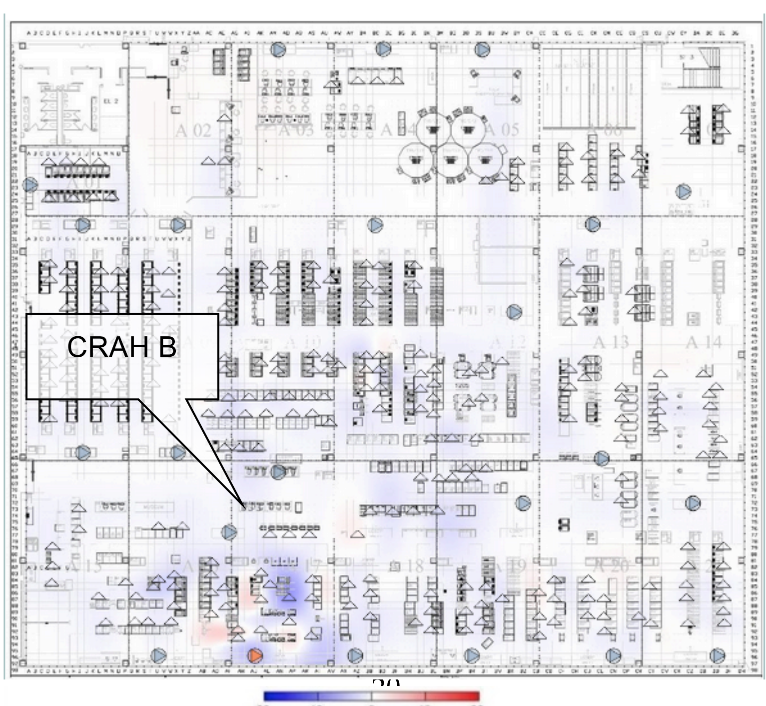


Figure 11: Post-Install Gold Camp Influence Map CRAH C

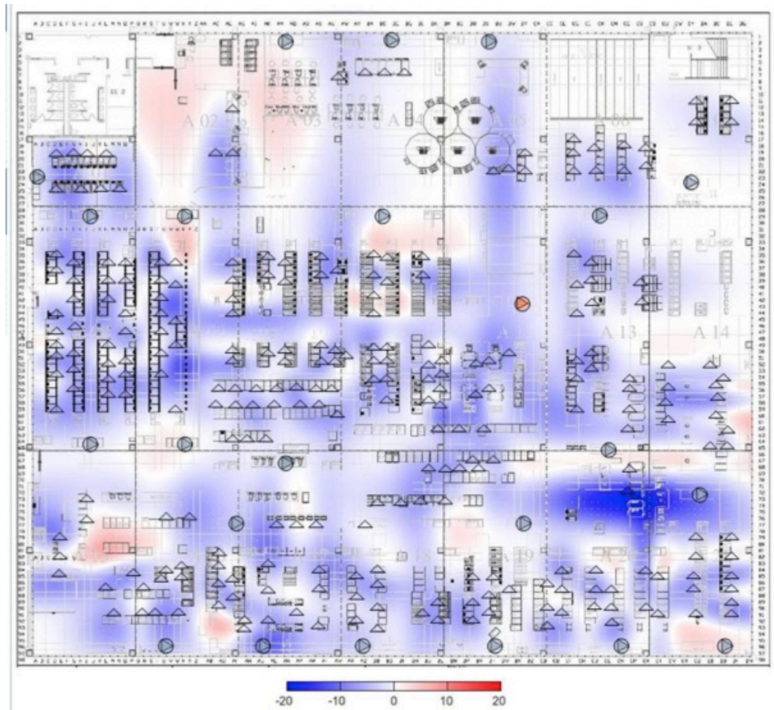
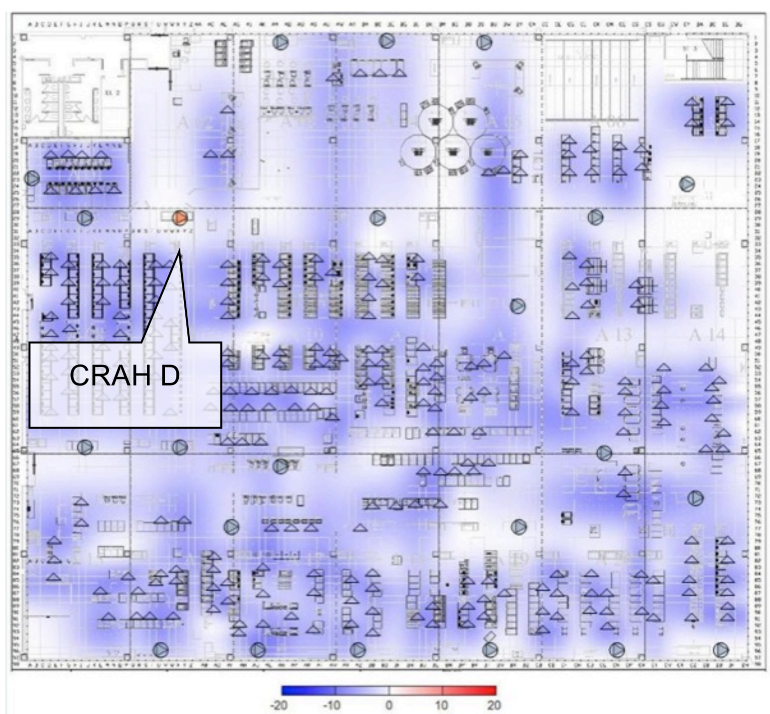
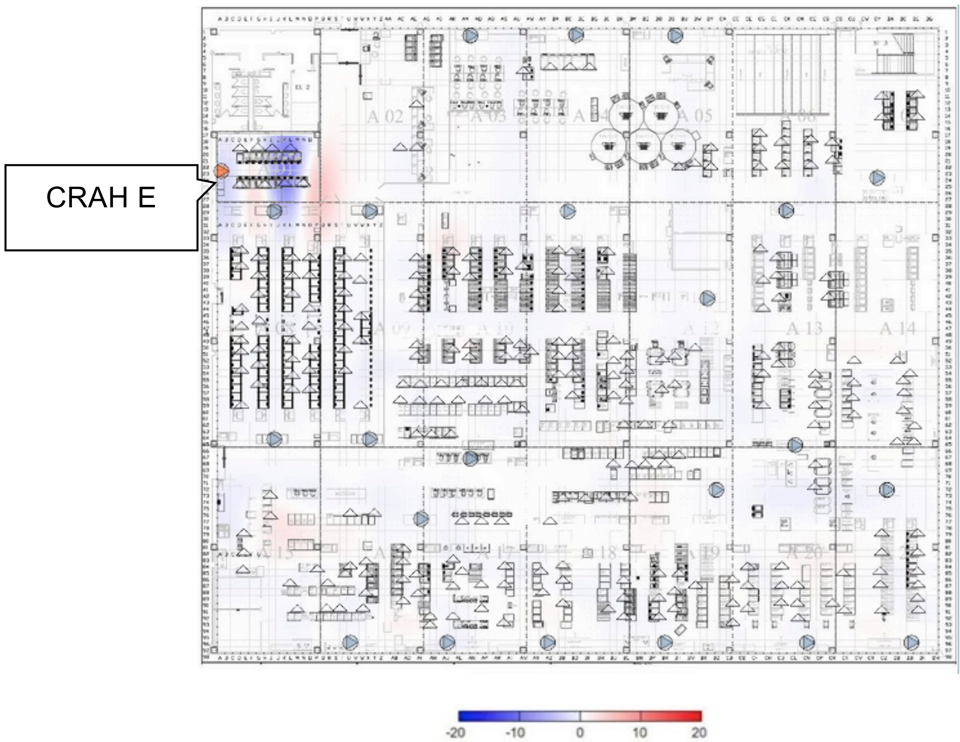


Figure 12: Post-Install Gold Camp Influence Map CRAH D



Even through CRAH D and CRAH E are relatively close to each other, their influence maps are significantly different. CRAH E's influence is much more localized.

Figure 13: Post-Install Gold Camp Influence Map CRAH E

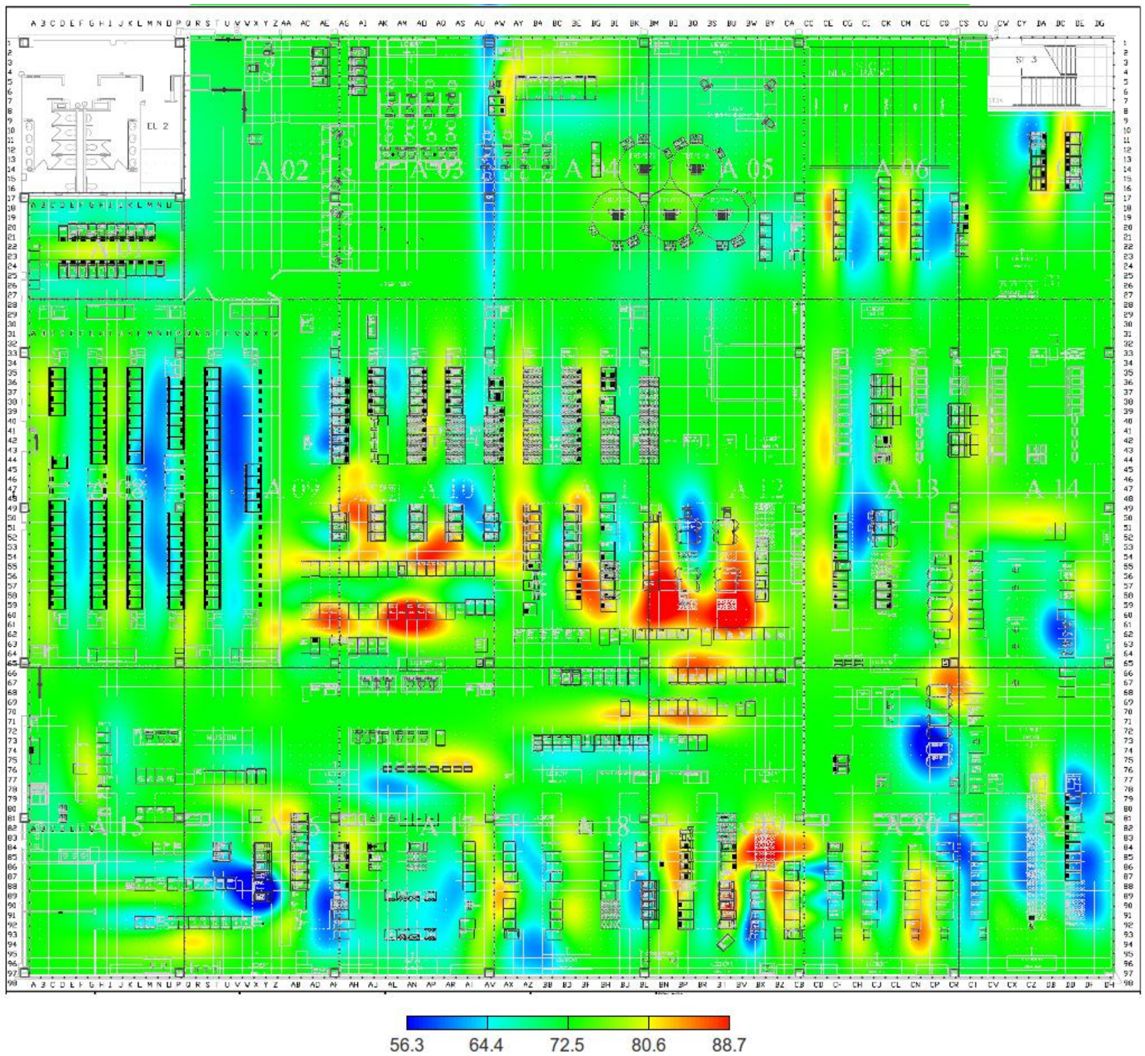


Task 10. Measure and validate control and energy savings.

After the active controls were turned on, ten days of temperature data were collected and used for energy savings analysis. A measurement and verification (M&V) procedure was negotiated with the local utility. In all cases, sensible cooling energy was measured using airside temperature measurements at each CRAH, the speed of the fan, and the manufacturer's rated airflow for the unit at full fan speed. Latent cooling heat transfer was not measured.

Figure 13: Gold Camp Thermal Map illustrates the temperature at Gold Camp after the intelligent energy management system was live. The data center is cooling and hot aisles clearly shown in red. This is in sharp contrast to Figure 7, the thermal map before the system went live. At the end of the installation at Gold Camp, seven out of the 23 racks were turned off.

Figure 14: Gold Camp Thermal Map After Active Controls Live (Feb. 2011)



In Figure 14 below more than four months after Gold Camp went live, temperatures were higher than they were in February 2011. Unlike the February map, the racks in the bottom third of the data center appear significantly warmer.

Figure 15: Gold Camp Thermal Map Top of Rack (July 2011)

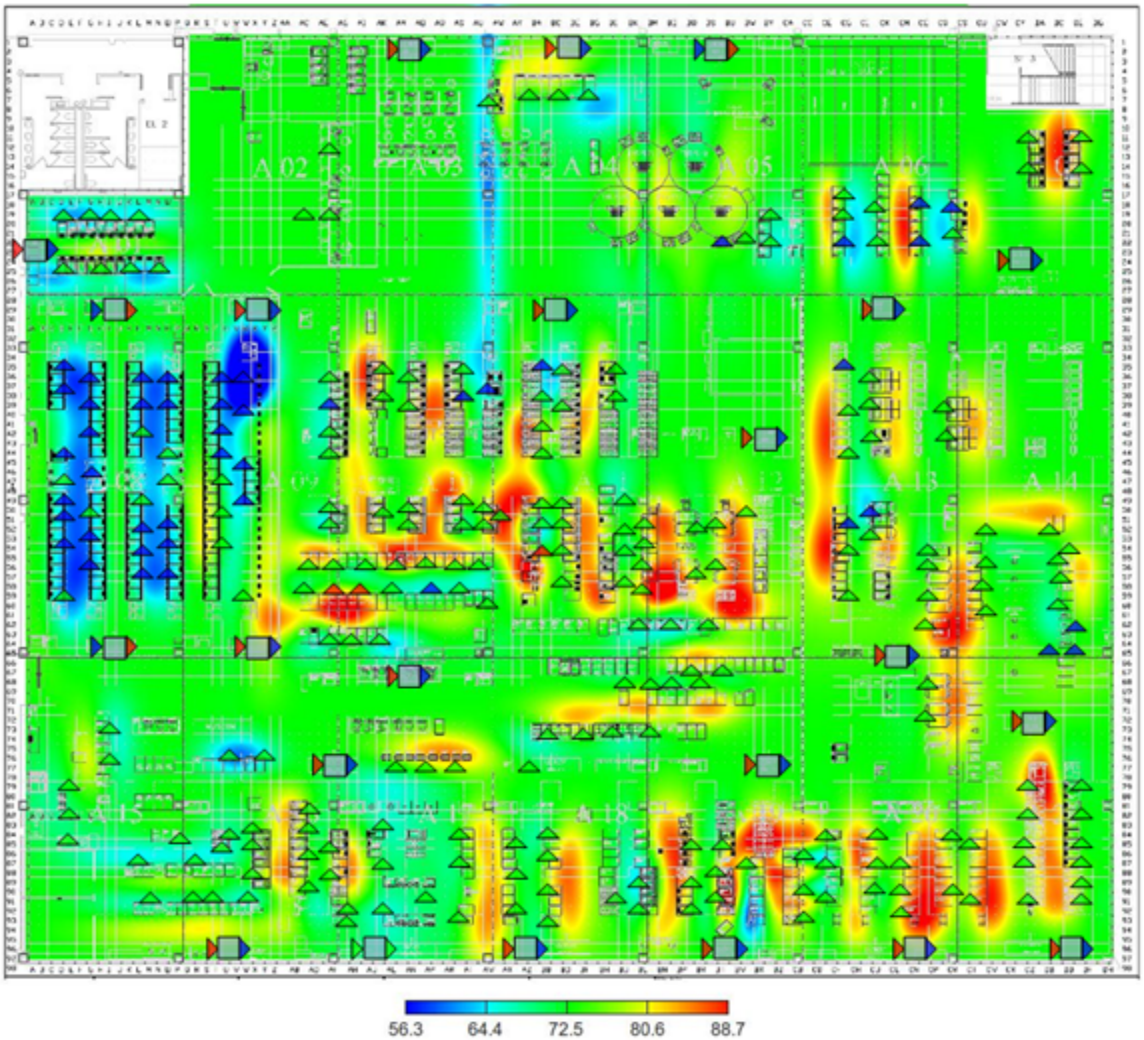
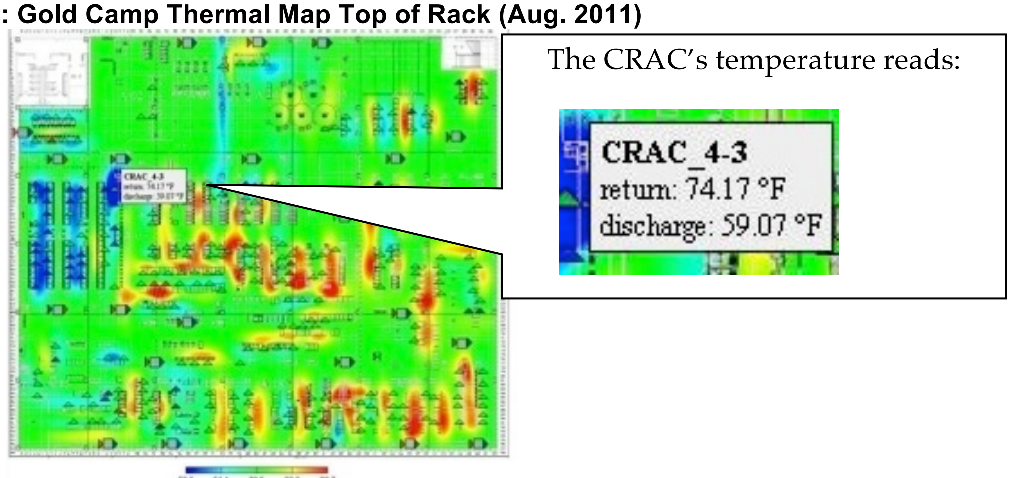


Figure 16: Gold Camp Thermal Map Top of Rack (Aug. 2011)



PROJECT RESULTS

This section describes the impact of the demonstrations at each of the eight sites in terms of thermal performance, mesh network performance, and energy performance.

Temperature Changes

To a large extent, the cold aisle temperatures in the eight data centers remained below the upper ASHRAE recommended limit. Increasing the cold aisle temperatures while still in the ASHRAE limits allows for an increase in chiller efficiency producing energy savings. Adjusting the upper cold aisle set points for most of the sites in this project would yield higher energy savings without increasing risk. For various reasons, policies at the data centers required conservative, cool set points.

ASHRAE's recommended upper limit for server intake is 80.6° F, and across all the sites, the average temperature was 70.6° F at the top of the rack. In the 2009 Franchise Tax Board study, the temperature at the data center was raised about eight degrees Fahrenheit, which subsequently increased chiller savings. At the eight data centers the average rack bottom temperature actually decreased by less than one degree Fahrenheit, and the average rack top temperature increased by less than three degrees Fahrenheit. These minor temperature changes meant that savings were left on the table.

Table 5: Average Temperatures

Site Name	Baseline at Rack Top	Post-Install at Rack Top	Baseline at Rack Bottom	Post-Install at Rack Bottom
Gold Camp	67.8	72.1	63	63.1
EDD	65.7	71.0	62.7	60.1
FTB	70.2	69.9	68.9	66.1
WR	57.3	66.0	56.9	60.7
Caltrans 2nd Floor	75.3	76.4	64.4	67.8
SOS	67.5	70.6	59.7	59.3
Ziggurat	72.7	71.7	67.4	64
Caltrans 9th Floor	67	67.0	66.3	65.0
Average	**67.9**	**70.6**	**63.7**	**63.3**

Since all sites had constant-volume fans prior to this case study, fan speed had been 100%. As fan speeds decline, made possible by the newly installed VFDs and the intelligent energy management system, more energy was saved. Significant savings come when VFDs are coupled with intelligent energy management systems, since VFDs alone cannot create constant equilibriums. The post-install fan speed in Table 6 was determined using the same baseline and post-install time periods as for energy savings.

Gold Camp did not install VFDs. Instead, CRAHs were turned off in order to attain equilibrium. As mentioned earlier, the day after active controls went live, seven out of 23 CRAHs were turned off (30%). Using a 45-day monitoring period from April 1 to May 13, 2011, on average 36% of the CRAHs were turned off.

Gold Camp chose not to install VFDs for two main reasons, which were cost effectiveness and an improvement process already underway. All the CRAHs at Gold Camp are slated for replacement with cooling units that have variable speed fans. In the long term, adding VFDs to Gold Camp would add redundant technology. Generally at a data center of Gold Camp's size and existing technology, it is more cost effective to turn the CRAH off rather than use VFDs. The energy savings for VFDs in the short term would not have justified their cost. When Gold Camp's new CRAHs are all in place, the intelligent energy management system could be reconfigured to take advantage of the variable speed fans. The cost-benefit analysis of the upgrade would need to be weighed against the energy savings at that time.

Table 6: Post-Install Average Fan Speeds

Site Name	Average Fan Speed
Gold Camp	Not applicable[9]
EDD	49.5%
FTB	49.8%
WR	56.2%
Caltrans 2nd Floor	45.7%
SOS	49.7%
Ziggurat	39.5%
Caltrans 9th Floor	49.7%

Mesh Network Reliability

The intelligent energy management system is built on an industrial-grade wireless mesh network. Built around Time-Synchronized Mesh Protocol™ (TSMP™), the technology combines time diversity, frequency diversity and path diversity to assure reliability, scalability, power source flexibility and ease-of-use.

The following statistics are based upon measurements for each wireless mote. Data reliability measures the percentage of expected data packets that were actually received by the gateway. Latency measures the average time (in milliseconds) required for a data packet to travel from

[9] Gold Camp did not install VFDs.

the originating mote to the gateway. Path stability measures mote-to-mote transmissions, and it indicates the percentage of data packets that successfully reach their destination.

Table 7: Mesh Network Statistics

Site Name	Reliability (%)	Latency (Milliseconds)	Path Stability (%)
Gold Camp	100.00	4.71	92.99
EDD	99.49	4.51	97.01
FTB	99.19	2.22	95.44
WR	100.00	3.77	95.37
Caltrans 2nd Floor	99.99	2.11	96.04
SOS	100.00	1.84	97.56
Ziggurat	99.99	1.86	92.27
Caltrans 9th Floor	100.00	4.95	96.45

Accomplishments

Result 1: Demonstrate that the 2009 success at Franchise Tax Board Sacramento Data Center can be replicated across multiple State of California data centers. Prove performance at data centers with 1,000- 40,000 square feet.

With annual cooling energy savings reductions at 2.3 million kWh, this case study proved that every data center can save energy with intelligent energy management savings. The smallest data center with only 667 square feet and 3 CRAHs was able to reduce annual cooling energy by 140,135 kWh. [10]

[10] To compute energy savings in kW, the sensor modules convert the CRAHs' energy consumption in Amps to kW assuming 475 volts and a power factor of 85%. To get kWh per year we multiply average kW by the number of operating hours in a year, which is 8,760.

Table 8: Energy Savings

Site Name	Energy Savings (kWh)	Fan Baseline kW	Fan Post-Install kW	Cooling Baseline Tons	Cooling Post Tons	Baseline total kW	Post-Install total kW
Gold Camp	484,174	143.73	94.15	364.39	350.14	289.48	234.21
Employment Development Department	433,049	46.08	14.69	112.78	67.67	91.19	41.76
Franchise Tax Board	697,045	67.79	15.53	86.59	18.30	102.42	22.85
Department of Water Resources	288,348	64.29	28.33	43.32	50.92	81.62	48.70
Caltrans 2nd Floor	149,555	16.09	2.84	12.50	8.00	26.72	9.64
Secretary of State	37,084	5.41	1.09	21.44	21.65	13.99	9.75
Ziggurat	84,134	13.82	6.90	13.28	6.57	19.13	9.53
Caltrans 9th Floor	140,135	14.17	2.26	12.57	7.77	24.86	8.86
Totals	**2,313,524**	**371.38**	**165.79**	**666.86**	**531.02**	**649.41**	**385.30**

Table 9: Cooling kWh Saved Per Square Foot

Site Name	Cooling kWh Saved Per Square Foot
Gold Camp	12.10
Employment Development Department	34.64
Franchise Tax Board	58.09
Department of Water Resources	54.41
Caltrans 2nd Floor	37.41
Secretary of State	13.73
Ziggurat	33.65
Caltrans 9th Floor	210.10
Average Without Caltrans 9th Floor Outlier	34.86

Result 2: Produce a 26% reduction in cooling energy consumption of which 15% comes from active controls.

Originally the project was going to include best practices like containing the hot-aisle. Containment did not take place. Other best practice activities, like moving floor tiles, were measured at the same time as the effect of active controls. All sites achieved over 15% reduced cooling energy usage as a result of active controls. Franchise Tax Board reduced cooling energy usage by more than 75%. The average cooling energy reduction at all sites was 41%.

Table 10: Percentage of Cooling Energy Reduced

Site Name	% Cooling Energy Reduction	Square Feet	Dollar Savings
Gold Camp	19%	40,000	$48,417
Employment Development Department	54%	12,500	$43,305
Franchise Tax Board	78%	12,000	$69,705
Department of Water Resources	40%	5,300	$28,835
Caltrans 2nd Floor	64%	4,000	$17,947
Secretary of State	30%	2,700	$3,708
Ziggurat	50%	2,500	$11,358
Caltrans 9th Floor	64%	667	$16,816
Totals	**Average 41%**	**79,667**	**$240,091**

Result 3: Reduce energy by 4.7 million kWh.

The 4.7 million kWh energy reduction objective was not met, instead the project achieved an annual reduction of 2.3 million kWh.

Several factors affected the ability to reach the 4.7 million kWh. The main factors are the following:

- The objective was based on savings at the 2009 Franchise Tax Board data center, with the expectation that higher savings could be achieved given the lessons learned in 2009.
- Not all planned savings measures were implemented.
- Five sites were removed from the original scope when Gold Camp was added.
- Existing site policies limited the ability to increase cold aisle temperatures, which would have saved additional energy through increased chiller efficiency. See Table 5: Average Temperatures.
- VFDs were not installed at Gold Camp.
- A portion of Gold Camp that was significantly inefficient was inaccessible for improvements.

- Other limitations at Gold Camp, including strict policies and being a colocation, were not factored into the original savings estimate.

Result 4: Demonstrate Data Center Infrastructure Efficiency (DCIE) at 0.8 and PUE of 1.25.

DCIE is defined as the IT equipment power divided by the total site power consumption. Most of the sites are located in facilities where non-cooling power consumption cannot easily be measured.

A modified DCIE is reported below, which is the IT equipment power divided by the cooling equipment power plus IT equipment power. [11] This does not include the power usage for the facility, lighting, plug loads and HVAC systems for comfort cooling. Every building varied, some had large amounts of office space close to the data center, and some had larger distances to the chilled water plant. To avoid capturing additional loads, such as other office HVAC equipment, and to create apples-to-apples comparisons without varying distances to the chilled water plant, facility power was not included in the DCIE and PUE calculations. When looking at Table 10: Data Center Infrastructure Efficiency and Power Usage Effectiveness look at the relative change of the values.

The average post-install DCIE was 0.82,[12] which is an improvement over the baseline DCIE at 0.70. The largest DCIE improvement was seen at Franchise Tax Board. Ziggurat and the Franchise Tax Board have the best DCIE of all the data centers.

The inverse of DCIE is Power Usage Effectiveness (PUE). In this report, the PUE is defined as the cooling equipment power plus the IT equipment power divided by the IT equipment power. A PUE of 1 is ideal and means that no energy is being used for cooling.

[11] The IT equipment power, also known as the IT load, was measured at the line side of the uninterruptible power supply (UPS) when there was a UPS at the site. If there were no UPS, IT load was measured at the line side of the PDU. By measuring this way, in facilities with or without a UPS, the IT power consumption includes the losses in the power distribution system.

[12] DCIE and PUE figures are based on water-to-wire cooling efficiency of 0.85 kilowatts per ton for the two Los Angeles Caltrans data centers and 0.4 kilowatts per ton for all other sites. Sacramento Municipal Utility District (SMUD) recommended 0.40 kilowatts per ton based on its experience with DGS chiller plants. Latent cooling heat transfer was not measured during the baseline or post-install period.

Table 11: Data Center Infrastructure Efficiency (DCIE) and Power Usage Effectiveness (PUE)

Site Name	Baseline DCIE	Post-Install DCIE	Baseline PUE	Post-Install PUE
Gold Camp	0.65	0.67	1.55	1.48
Employment Development Department	0.69	0.83	1.46	1.21
Franchise Tax Board	0.57	0.89	1.75	1.13
Department of Water Resources	0.68	0.79	1.46	1.26
Caltrans 2nd Floor	Not available[13]	Not available	Not available	Not available
Secretary of State	0.79	0.85	1.26	1.18
Ziggurat	0.80	0.89	1.25	1.12
Caltrans 9th Floor	Not available	Not available	Not available	Not available
Average	**0.70**	**0.82**	**1.46**	**1.23**

Changes to the IT load affect the DCIE. Note that the IT load significantly changed at Gold Camp, Franchise Tax Board, Caltrans 2nd Floor and Caltrans 9th Floor. See the figure below.

[13] The Caltrans IT loads were not available or were not reliable.

Table 12: Cooling Power and IT Power Load

Site Name	Baseline Total Cooling Power (kW)	Post-Install Total Cooling Power (kW)	Baseline IT Equipment Power Load (kW)	Post-Install IT Equipment Power Load (kW)
Gold Camp	289.48	234.21	529.00	485.00
Employment Development Department	91.19	41.76	200.00	203.20
Franchise Tax Board	102.42	22.85	137.00	176.00
Department of Water Resources	81.62	48.70	177.00	188.50
Caltrans 2nd Floor	26.72	9.64	Not available[14]	Not available
Secretary of State	13.99	9.75	54.00	53.70
Ziggurat	19.13	9.53	76.00	77.00
Caltrans 9th Floor	24.86	8.86	Not available	Not available

Result 5: Create 15 jobs. Of those 15 jobs, eight are for skilled trade, 5 for advanced technical or managerial positions and 1 is indirect or induced.

Eleven jobs were created as a result of this project. Two companies directly benefited from this project and increased their workforce. Vigilent Corporation added four highly skilled positions, which were full-time advanced technical or managerial positions. Vigilent also added one part-time position. UMAI, which manufactures Vigilent hardware, added six full-time employees to its staff as a result of Vigilent orders. At UMAI, one manager was hired and two of the employees were skilled tradesmen. Three of the UMAI employees hired were semi-skilled.

All of these jobs are located in California.

Result 6: Reduce greenhouse gas emissions.

Annually, 1.58[15] million pounds of greenhouse gas emissions were reduced as a result of this project. The site with the largest amount of reduced greenhouse gas emissions was Franchise Tax Board with an annual reduction of 474,688 pounds.

Result 7: Leverage grant funds.

The DOE grant of $584,079 made up less than 50% of the total project cost because of matching funds received from the CEC, DGS, OTech, Federspiel Controls Inc. and various suppliers. The CEC grant of $250,000 made up 21% of the total project cost.

[14] The Caltrans IT loads were not available or were not reliable.

[15] To obtain greenhouse gases, or carbon emissions, kWh savings were multiplied by 0.681 based on eGRID2010 Version 1.1 Year 2007 Summary Tables. Criteria Pollutants. Page 2.

Result 8: Maintain temperatures within the limits recommended by ASHRAE.

ASHRAE[16], with agreement from manufacturers of IT equipment (servers, network equipment, and storage devices), has recommended operating temperature ranges for inlet air to data center IT equipment. These server inlet recommendations for temperature are: 64.4° F - 80.6° F.

Most of the server inlet temperatures remained within the ASHRAE recommended range. During the post-install measurement period, temperatures at the bottom of the rack at all sites averaged lower than 64° F. Six sites had average temperatures in the mid to low 60s. The average temperature at Secretary of State was 59.3° F.

Even though less fan power was used during the post-install period, the server inlet temperatures fell at five sites.

Result 9: Implement data center best practices, which could include blanking panels, containment curtains, and raised floor changes.

Given the impact of the long site identification and approval process, some data center best practices were not implemented, though, variable frequency drives (VFDs) were installed at seven sites. Variable frequency drives retrofit cooling units from constant volume to variable volume. As fan speeds decrease, energy is saved. The relationship between fan speed and energy savings is not linear; therefore, as fan speeds decrease, the increase in energy savings grows. Gold Camp and the DX units at the Department of Water Resources did not get VFDs for reasons already mentioned.

Containment of hot aisles did not take place. Though time was a large factor, the main consideration was the return on investment coupled with the characteristics of many of the data centers. In Table 2, that shows the return on investment analysis of the 2009 Franchise Tax Board Project, hot-aisle containment made up 43% of the project cost yet produced less than one percent of the energy savings achieved.[17] Hot-aisle containment did not make sense at several of the sites because of their features. Gold Camp, for example, is in a state of flux because of its expansion and improvement plans. Containment works much better in a data center that does not anticipate floor-plan changes. Several of the smaller data centers were not likely to see much benefit given their design and conditions. Containment should be a very low priority at EDD, for example, where mixing hot and cold air is less of an issue than floor-tile arrangements.

During site audits and implementation, project managers identified areas that would benefit from rearranging floor tiles and using blanking panels to optimize airflow through the server racks. Several data center managers made floor-tile changes, however, few added blanking panels to their racks because of cost, time and labor constraints.

Additionally, using blanking panels and changing floor tiles will benefit the data centers more now that they have thermal maps from the intelligent energy management system. Managers can make improvements at any time and see energy savings. The thermal maps, which data center managers can access at any time, help decision makers determine where floor-tile changes could alleviate hotter areas. These maps also identify areas that do not require perforated floor tiles, where temperatures could go up. Perforated floor tiles, while needed in cool aisles, can waste cooling capacity and energy if in inappropriate areas.

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[16] ASHRAE, 2008, addendum to "2008 ASHRAE Environmental Guidelines for Datacom Equipment," Atlanta, GA.

[17] Bell, Geoffrey C., Cliff Federspiel. September 2009. *Demonstration of Datacenter Automation Software and Hardware (DASH) at the California Franchise Tax Board California Energy Commission.* CEC-500-02-004, WA# 022. Table 1, Page 15.

Gold Camp Results

The measures taken at Gold Camp resulted in a cooling energy reduction of 484,174 kWh. This was accomplished by turning off 36% of the CRAHs at Gold Camp on average. Various policies and standards at Gold Camp did not allow for additional adjustments to set points and floor tiles. If standards at Gold Camp became less conservative, more energy savings could be achieved.

One area where restrictions resulted in overcooling was the caged area in the upper left quadrant of the data center. The caged area has a limited amount of highly critical IT equipment, and the whole area has perforated floor tiles. Optimization could not take place in this large cage because the area is controlled by another agency that insisted on preserving the floor tile arrangement.

Employment Development Department Results

After installation, the fan speed was reduced 50% at all CRAHs, with one exception. Changes to the floor tiles helped alleviate the hot spots that were generated primarily because of pipes blocking air distribution under the floors. Cooling energy consumption was reduced by 54%, which provides $43,305 in projected annual savings and 433,049 kWh.

The VFDs and AI-driven controls will result in less wear and tear on the cooling infrastructure. More importantly, in an environment with older equipment, the intelligent energy management system will alert operators to hot spots and machinery that is running badly and in need of repair or replacement.

EDD does remain a cold data center with temperatures in the low 70s even at the top of the racks. Like many of the data centers, various policies prevented further alterations to the temperature set points. Additional savings, however, could be achieved if the chilled water temperatures and the rack set points increased.

Major improvements were made to the organization in the data center. Stored boxes had blocked perforated tiles, and some cool aisles were blocked. Before installation, boxes were sometimes placed up to the back of the cabinets, which pushed hot air back into the cold aisles.

Franchise Tax Board Results

Fan speeds dropped immediately from 100% to 50%. Fan speeds could probably go even lower if permitted. One factor in the energy savings was eliminating the previous cross fighting between CRAHs. There were CRAHs that were simultaneously humidifying and dehumidifying. The system was able to identify these competing units so that their humidity control settings could be adjusted to mitigate the fighting.

California Benefits

Annually 2.3 million kWh are saved in California because of cooling energy reductions in the case study's eight data centers. This saves ratepayers $240,000 annually and reduces greenhouse gas emissions by 1.58 million pounds. The data center industry in California can now tour eight data centers equipped with intelligent energy management systems. This is a rare opportunity for the high-security data center industry, which is often closed off. Several industry leaders with data centers in California have toured Gold Camp and Franchise Tax Board between May and September 2011. Six of the sites are located in the Sacramento general area, and because this area is an increasingly popular home for data centers, it is a convenient place for tours.

The State of California has aggressive energy reduction goals, and this case study illustrates another successful tool to make the goals a reality. Further, the state has an initiative to consolidate IT equipment in data centers that meet the state's Tier 3 standards, and this technology will aid data centers in attaining Tier 3 status.

Two companies created 11 jobs in California because of this project and its grants.

Many non-energy benefits are produced at the eight California data centers. Monitoring, alerts and several maps provide data center managers more tools than they had before. Cooling capacity increased, helping to reduce the need for more cooling units and potentially for more data centers. Because fan speeds decreased and some units in Gold Camp were turned off, wear and tear on machinery will be lessened, improving the machinery's lifetime and maintenance needs.

Cost Summary

The total project cost is projected at $1,208,417,[18] which includes technology transfer activities and auditing activities to comply with federal regulations. The total project budget was $1,168,271. The contributions of funding partners are as follows.

Table 13: Project Cost by Funding Partners

Source	Cost Share
U.S. Department of Energy	$584,079
California Energy Commission PIER Program	$250,000
California Department of General Services and Office of Technology Services	$50,000
Federspiel Controls, Inc.	$205,399
Suppliers Cost Match and Utility Incentives[19]	$118,939
Total Project Cost	**$1,208,417**

Three budget categories had cost overruns. Travel exceeded its budget by approximately $6,000. Two sites were in downtown Los Angeles, and more travel was required than expected because of some problematic CRAH motors and additional time spent supervising the third-party VFD installer. There were multiple walk-throughs in Los Angeles and Sacramento to find and receive bids from California-certified small businesses that could do VFD installations. This was a requirement of the agreement with California Department of General Services.

Supplies exceeded its budget by approximately $20,000; however, it was compensated by lower personnel costs.

The "Other Direct Costs" category was also higher than expected because the required audit could not be done for the budgeted amount and, because the technology transfer activities increased in scope. The original technology transfer budget only contained personnel costs, and other direct costs were necessary to fulfill the full requirements of the California Energy Commission and Department of Energy grant.

[18] Auditing activities continue, therefore, final costs are projections.

[19] Some utility incentives have not been fully processed. If incentives are lower than projected, the Federspiel Controls, Inc. cost portion will increase.

California Energy Commission Funding

The CEC funding was spent on the following tasks:

- Administration related to the kickoff meeting and quarterly progress reports.
- Materials and resource acquisition and installation.
- Installing active control functionality.
- Measuring and validating energy savings.
- Training data center managers.
- Technology transfer, including the industry meetings at the Uptime Institute and Gartner IT Infrastructure, Operations & Management Summit.

Technology Transfer Summary

On the afternoon of May 11, 2011, Dr. Clifford Federspiel, PhD, PE, Founder & CTO presented "Achieving Instant Energy Savings While Improving Uptime" at the Uptime Institute Symposium in Santa Clara, California. Leaders in data center energy efficiency attended the talk and heard about project results related to three of the data centers in this case study. In mid-June, the IT and data center industry heard about project results at the Gartner IT Infrastructure, Operations & Management Summit in Orlando, Florida.

As of the writing of this report, there has not been a press release publicizing the results of this project. In early June, the press release was drafted and the approval process began at the end of the month. Approval was received from seven data centers, their public affairs departments and the various funding parties, however, there was an unexpected delay with two high-level State of California officials. As a result of this delay, no materials have yet been posted to the Internet since they would dilute the press release's power and potentially jeopardize the last high-level approval.

Once final approval is received, in addition to posting the press release on the Internet, several case studies will also be developed and published on the Vigilent site.

Lessons Learned

Cooling energy savings result from the reduction in fan speeds and from changing the heat transfer rate to the under-floor slab and walls of the data center. At Secretary of State and the Department of Water Resources, chilled-water monitoring proved very difficult and unreliable. The flow meters did not work reliably, and support from the manufacturer of the flow measurement devices was unattainable. Measuring the fan speed and the air-side temperature difference can be done reliably no matter what type of air-handling unit is used, so chiller energy analysis was performed based on air-side measurements of sensible heat transfer.

BENEFITS ASSESSMENT

This project demonstrates a significant leap in data center innovation — the ability to control the cooling actions and settings of CRACs and CRAHs with or without variable frequency drives. Older air-handling equipment of all sorts achieves the ability to behave like newer equipment with intelligent and newer technology, with a far less capital-intensive investment. No retrofitting takes place, and the system does not need to touch the data center's IT equipment or network. The eight State of California data centers provide environments with both chilled water and DX and a wide variety of other characteristics that are similar to those found in the marketplace. Though some data centers use systems to actively control cooling, most rely on technology for power monitoring only. Monitoring power supplies gives data centers better understanding of what happens, but the significant savings seen here are born from active, dynamic controls. Annually, implementing intelligent automated control software in data centers worldwide could save more than a billion kWh.

Overall, this project produced an annual energy reduction of 2.3 million kWh, saving California taxpayers a projected $240,000. Besides energy savings and lower utility bills, the project extends the life of the capital investment made in cooling infrastructure. Previously the cooling infrastructure would have been utilized at 100% capacity on a 24/7 basis. Now, the cooling infrastructure will have balanced loads that modulate depending on real-time conditions. The infrastructure, as a result, will be utilized only when it is necessary and can be turned down or off. Less wear and tear, additional cooling capacity and the ability to defer capital expenses on new data center build-outs all contribute to long-term savings.

COMMERCIALIZATION

Commercialization has already begun. For example, the same technology presented in this case study enabled Verizon to reduce energy consumption by 55 million kWh annually at 24 of its U.S. data centers. Akamai reduced its carbon footprint by 170,000 pounds of greenhouse gas emissions by installing Vigilent systems in its 5,700 square foot data center.

NTT Facilities, Inc., entered a long-term strategic relationship with Vigilent. As a partner, NTT will distribute Vigilent systems to data centers worldwide. A pilot project took place in San Jose at a data center of approximately 10,000 square feet. Within two days of deployment, 9 of the 14 CRACs were automatically turned off to dynamically match capacity with the cooling load.

ACCOMPLISHMENTS

This case study describes a demonstration project meant to prove the effectiveness of the intelligent energy management system, which was designed and patented prior to this project. As such, technology transfer is important but patents were not part of the project objectives.

The results of this project will be reflected on the Vigilent Web site, the CEC site, and on the OSTI web site. Several publications have been contacted regarding Vigilent products, and they will be updated to help promote this report and the press release, once they are made public. Once the press release is public, Vigilent will pursue awards and publicity based on the project results.

CONCLUSIONS

This demonstration project exhibits how intelligent energy management systems, which integrate artificial intelligence and dynamic controls, can be used effectively to improve energy use in data centers. This project resulted in the annual reduction of 2.3 million kWh of cooling energy, the annual elimination of 1.58 million pounds of greenhouse gases, and the creation of eleven jobs in California. The total average cooling energy consumption was reduced by 41% across all sites, and at the seven sites with VFDs, the average cooling savings reduction was 52%.

The eight data centers ranged from 667 square feet to 40,000 square feet. The systems and active controls were installed and maintained temperatures within the ASHRAE server inlet recommendations. The system monitored temperatures, controlled VFDs and CRAHs, and brought fan speeds down to an average range of 40% to 50%, thereby increasing cooling capacity. The one site without VFDs, Gold Camp, reduced annual cooling energy by 484,174 kWh during an improvement and expansion phase. Gold Camp benefited from using software that worked during the transition and will continue during normal operations.

Overall, this case study shows that significant energy savings can be replicated with the same process and intelligent energy management system, across large and small data centers, those with new equipment and old equipment, and those with chilled water and direct expansion. As IT loads continue to expand at the eight data centers, the facilities are better equipped to maintain energy and dollar savings.

APPENDIX A:
List of Acronyms

AHU: Air-handling unit. This is the entire system that makes up an HVAC unit. An AHU may have multiple fans.

AI: Artificial intelligence

ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers

CHW: Chilled water

COP: Coefficient of Performance

CRAC: Computer room air conditioner. A standalone device sitting on the data center floor that provides cool air to the room via a fan. CRAC units have a direct expansion (DX) refrigeration cycle built into the unit. Multiple local compressors and self-contained refrigerant act as the cooling agent.

CRAH: Computer room air handler. A standalone device sitting on the data center floor that provides cool air to the room via a fan. CRAH units use chilled water as the cooling agent that is supplied from a central chilled water plant in the facility.

DCIE: Data Center Infrastructure Efficiency

DX: Direct expansion. (See CRAC above)

HVAC: Heating, ventilation, and air conditioning

M&V: Measurement and verification

kW: Kilowatt

KWh: Kilowatt-hour

PDU: Power distribution unit

PUE: Power usage effectiveness

UPS: Uninterruptible power supply

VFD: Variable frequency drives. This is a system for controlling the rotational speed of an alternating current (AC) electric motor. The VFD controls the frequency of the electrical power supplied to the motor.

APPENDIX B: Measurement and Verification Protocol

The following protocol was established with the Sacramento Municipal Utility District to conform to industry standards and local utility requirements. It is included in full here:

Energy savings measurement and verification shall be performed using methods described in the 2007 International Performance Measurement and Verification Protocol (IPMVP). In most cases, measurement and verification shall follow either IPMVP Option A: Retrofit Isolation with Key Parameter Measurement or IPMVP Option B: Retrofit Isolation with All Parameter Measurement. Options A and B isolate the affected equipment, establishing a baseline for the affected equipment itself and comparing actual consumption of each affected item of equipment to its baseline. The baseline may be statistically controlled for exogenous variables such as weather, time of day, IT load, etc. The difference between the two is that Option A uses proxies for power or energy consumption, while Option B uses sub-metering of the affected items of equipment. IPMVP Option C uses whole-building energy analysis, with the baseline statistically controlled for variables such as weather, time of day, IT load, etc.

The Parties shall agree on the appropriate Option for each site and affected load. In the event that sub-metering does not exist and there is no acceptable proxy that would enable the use of Option A, Customer install sub-metering so that Option B can be used.

Examples of how to apply IPMVP methods to fans, electric chillers (when the chiller primarily serves the data center), and chilled water (when a secondary loop off a chiller plant serves a smaller data room) are described below: IPMVP methods shall be applied to DX CRAC units similarly to cycling fans.

CRAC/AHU Fan Energy Consumption

All fans serving a common space shall be monitored, and their loads aggregated to avoid inadvertent shifting of load to unmonitored equipment. The coincident peak load shall be recorded (the peak simultaneous load of all fans), and shall not be recorded as the combined peak of each fan irrespective of time.

Fans currently supplied with variable frequency drives shall be monitored for a 24h period prior to modification to determine kWavg, kWpeak. 15-minute interval data shall be recorded for this period.

Constant speed fans that cycle on/off shall be monitored for a 24h period prior to modification to determine kWavg, kWpeak. 15-minute interval data shall be recorded for this period.

Fans not subject to cycling or VFD control only require spot check with current probe. Nameplate data is not acceptable.

Option A

For fans with variable-speed controls, fan speed is an acceptable proxy for fan power. Fan power shall be correlated with fan speed using the following equation:

$kW = kW_{100} (F_0 + (1-F_0) S^3)$

where kW is the fan power in kilo-watts. kW_{100} shall be determined by the customer, Supplier, or a third party on a one-time basis using a temporary power meter for each fan by measuring its electrical power at 100% speed (Name plate data is not acceptable). S is the fractional speed measured as a percent of full speed. F_0 shall be determined by the customer, Supplier, or a third party on a one-time basis using a temporary power meter by measuring the fan electrical power at a fractional speed less than seventy percent (70%) using the following equation:

$F_0=(kW/\ kW_{100} - S^3)/(1 - S^3)$ - Affinity Law Correction

If the data center has more than two variable-speed fans of the same make, model, and capacity, then the average values of kW_{100} and F_0 shall be used for all like units.

For fans with on-off controls, fan power when on shall be determined by the customer, Supplier, or a third party on a one-time basis using a temporary power meter. If there are more than two (2) fans in the data center of the same make, model and capacity, then the average power from two units shall be used as the power consumption of all like units.

Option B

For fans with variable-speed drives that have on-board power monitoring capabilities, the on-board meter in the variable speed drive shall be an acceptable meter for measuring savings. An alternative acceptable meter for measuring savings could be installed at each fan motor or at a panel that feeds more than one (1) fan motor as long as the panel only supplies affected fan motors.

If the electric power meter has an accumulation function, then that function shall be used to determine average electrical power consumption over an interval of time by dividing the accumulated energy consumption by the time interval. If the electric power meter does not have an accumulation function, then average fan power consumption over an interval shall be determined by polling a power reading periodically and averaging the polled readings over the time interval.

Fan energy savings over an interval for variable speed fans shall be determined by subtracting the baseline power consumption from the average computed power over the interval and then multiplying the difference times the time interval as follows:

Savings = $(kW_b - \text{average}(kW))\ T$

where kW_b is the baseline power consumption. The baseline power consumption shall be determined as the power consumption at the time of initiating the Order. For fans being retrofit with variable speed drives, new fans, or on-off operated fans, kW_b shall be the same as kW_{100}.

Dedicated electric chillers with chilled water reset

Note: Chillers that serve both data center and office loads will be required to use the “secondary chilled water loop” methodology below.

For chillers that have their chilled water set point reset based on a signal from the Supplier’s system, savings shall be determined by correlating the percent reduction in power consumption of the chiller with the chilled water set point. The baseline shall be the referenced to the chilled water set point at the time that the work order is issued.

Option A

An acceptable power measurement proxy is the chiller current (Amps) consumption reported by the chiller. Chiller current shall be converted to power using the following equation:

kW = Volts * Amps * sqrt(3) * PF

where Volts is the line voltage supplied to the chiller (typically 460-480) and PF is the power factor of the electric motor (assumed 0.85).

Option B

Option B includes the use of an external submeter dedicated to the chiller, or a chiller with on-board metering that can report power consumption directly.

Savings shall be determined by measuring chiller power at three (3) or more chilled water set points and correlating percent power change with the chilled water set point. If the chilled water pumps have VFDs, then the kW feedback from the VFDs shall also be recorded and combined with the chiller (compressor) power.

The following table shows an example correlation. The first column of the table is the chilled water set point. The second column is the chiller power. The third column is the percent savings relative to the baseline condition, which is 46 deg F. The power savings equal the Percent Savings multiplied by the chiller power consumption. For the example below, the power savings are computed as follows:

Power Savings = (0.0002 * $ChWSP^2$ – 0.0035 * ChWSP – 0.02198) * kW

Energy savings over an interval are computed as the average Power Savings over the interval multiplied by the time interval. For the example below, the energy savings over an interval, T, are as follows:

kWh savings = average(Power Savings) * T

Power Savings shall be computed periodically and stored along with values of kW and Chilled Water Set point.

Table 14: Measurement and Verification Table

degF	kW	pct
60	532	21.4%
55	570	13.3%
50	615.6	4.9%
48	630.8	2.4%
46	**646**	**0.0%**

Peak kW savings shall also be recorded.

APPENDIX C: Baseline and Post-Install Comparisons

The dollar savings projections are annual savings based on multiplying the site kWh savings by the average utility rate that applies to that data center. The two Caltrans sites are in the Los Angeles Department of Water and Power (LADWP) utility area with an average $0.12 rate. The DGS Ziggurat building is supplied by Pacific Gas & Electric (PG&E), where they informed us there is an average rate of $0.135. All of the other buildings are within the Sacramento Municipal Utility District (SMUD) and they informed us electricity has a $0.10 average rate.

For the Sacramento sites in this project, we followed a SMUD recommendation for the conversion from kW to tons. This is based on their recommendation that chilled water plants that have been built more recently (for example the last five to ten years), and which have the most efficient equipment, use a conversion factor of 0.4 kW/ton. The two Caltrans sites in Los Angeles used a conversion factor of 0.85 kW/ton.

Table 15: Baseline and Post-Install Dates

Site Name	Baseline Dates	Post-Install Dates
Gold Camp	2/17/11	4/23/2011 - 5/2/2011
EDD	3/26/11	4/1/2011 - 4/10/2011
FTB	2/16/2011 - 2/17/2011	6/2/2011 - 6/14/2011
WR	11/10/10	11/20/2010 - 11/30/2010
Caltrans 2nd Floor	4/20/2011 - 4/26/2011	8/10/2011 - 8/20/2011
SOS	12/10/10	12/12/2010 - 12/23/2010
Ziggurat	2/8/2011 - 2/11/2011	8/15/2011 – 8/26/2011
Caltrans 9th Floor	5/22/11	5/27/2011 - 6/10/2011

APPENDIX D:
Thermal Maps

Figure 16: Gold Camp Thermal Map on Before Active Controls Fully Live (Feb. 2011)

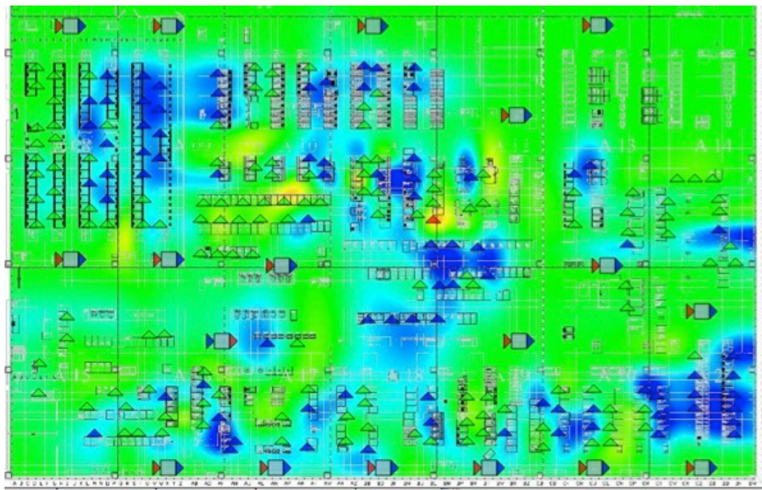

Figure 17: Office of Technology Services Gold Camp Thermal Top (July 2011)

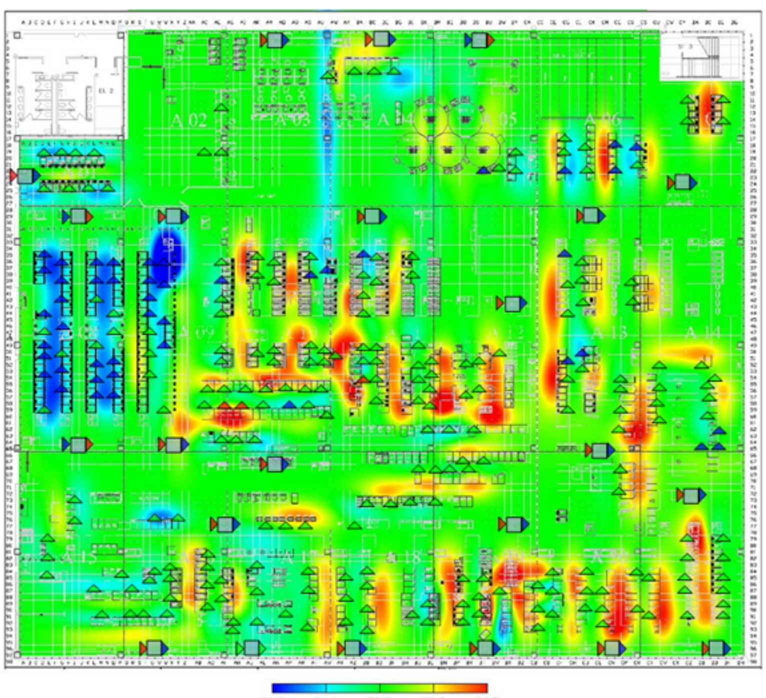

Figure 18: EDD Thermal Map of Top of Racks Before Go-Live (March 2011)

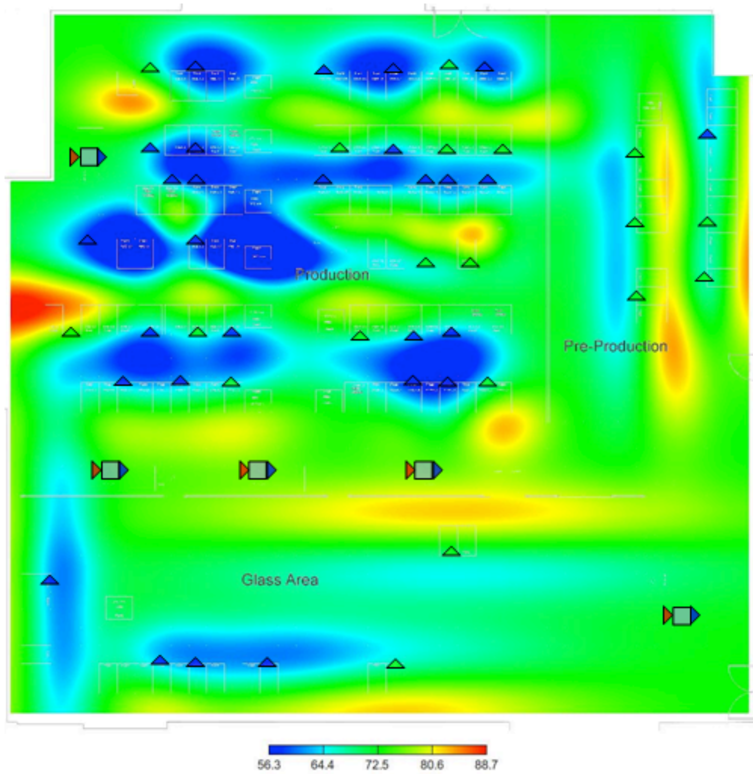

Figure 19: EDD Thermal Map of Top of Racks After Go-Live (March 2011)

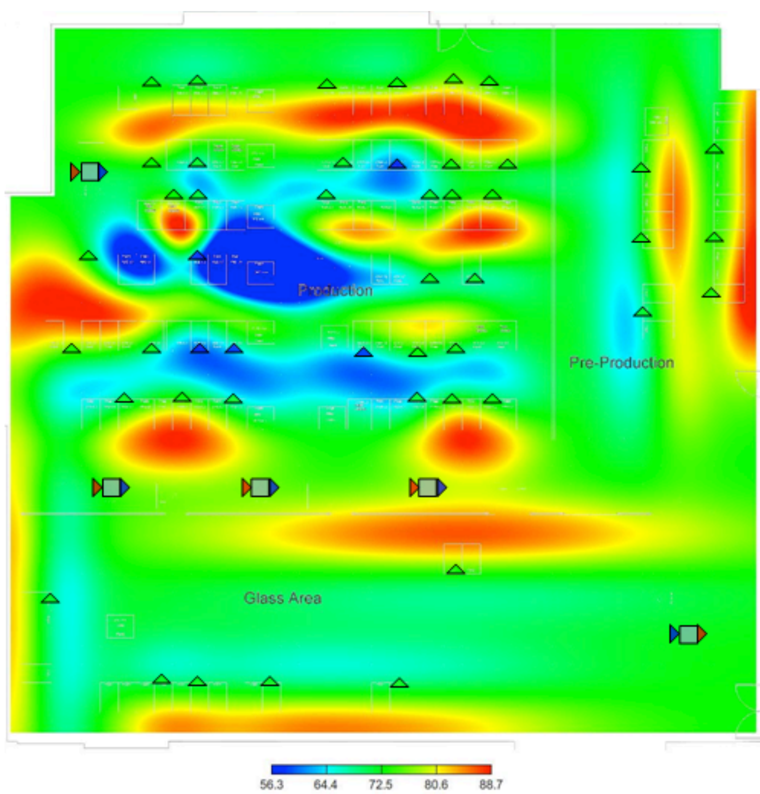

Figure 20: EDD Thermal Map of Top of Racks (Aug 2011)

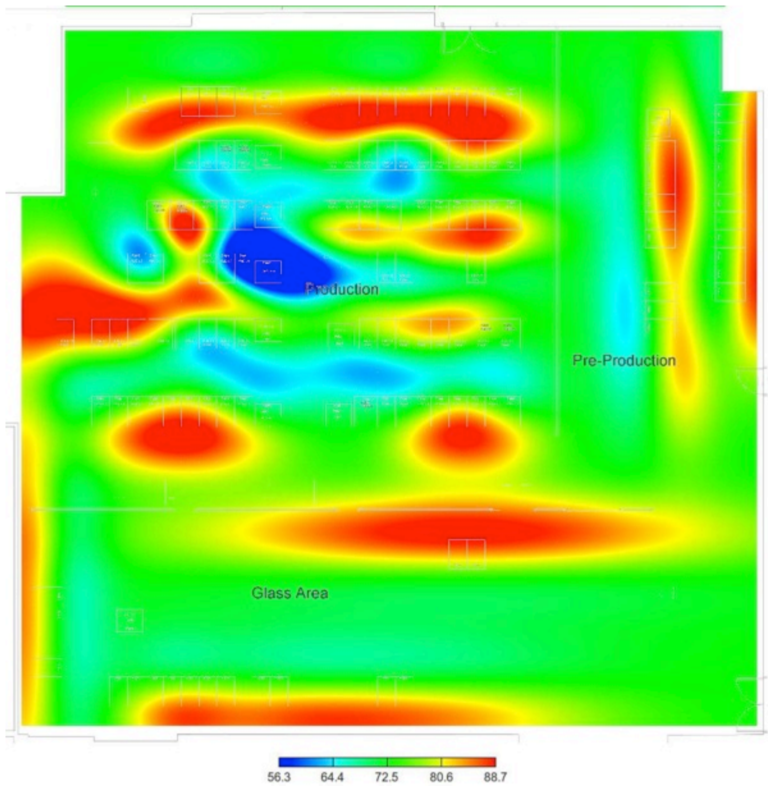

Figure 21: EDD Thermal Map of Bottom of Racks (Aug 2011)

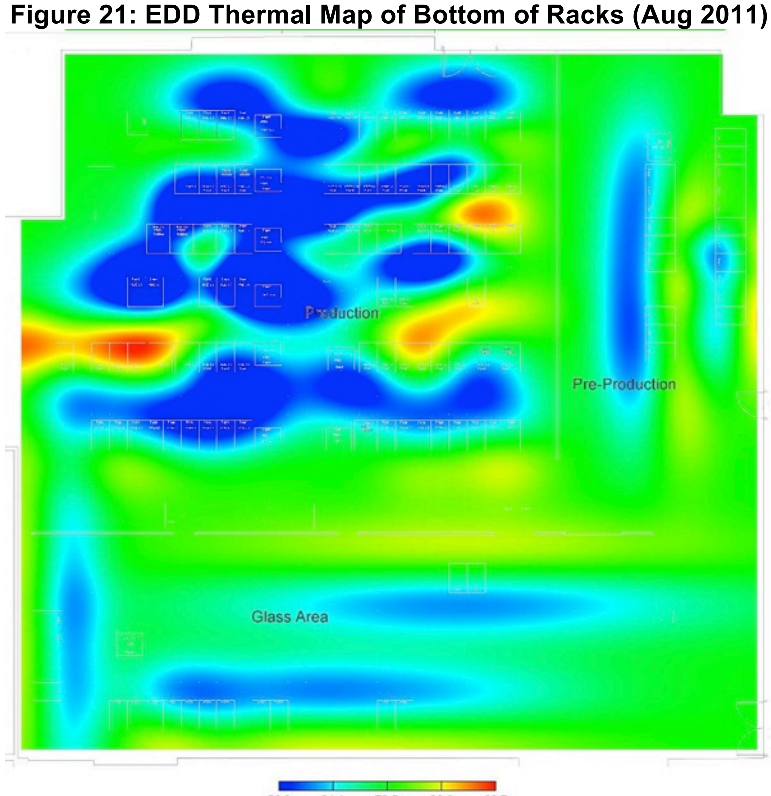

Figure 22 Franchise Tax Board Thermal Map for Top of Rack (Aug. 2011)

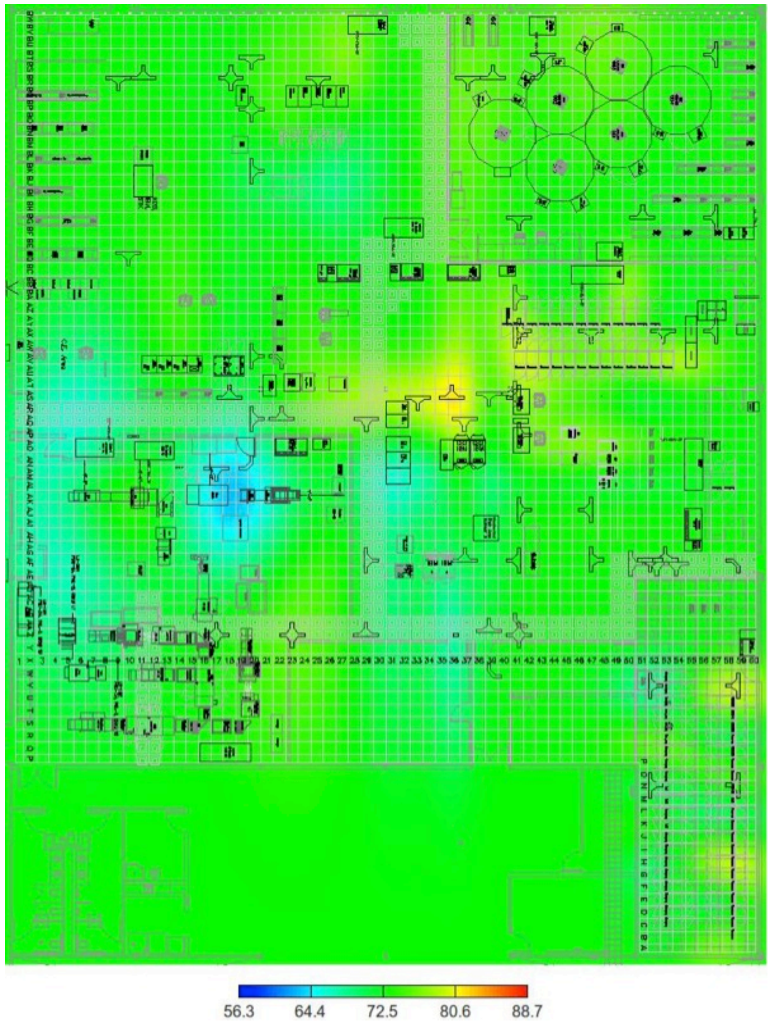

Figure 23: Franchise Tax Board Thermal Map for Bottom of Rack (Aug. 2011)

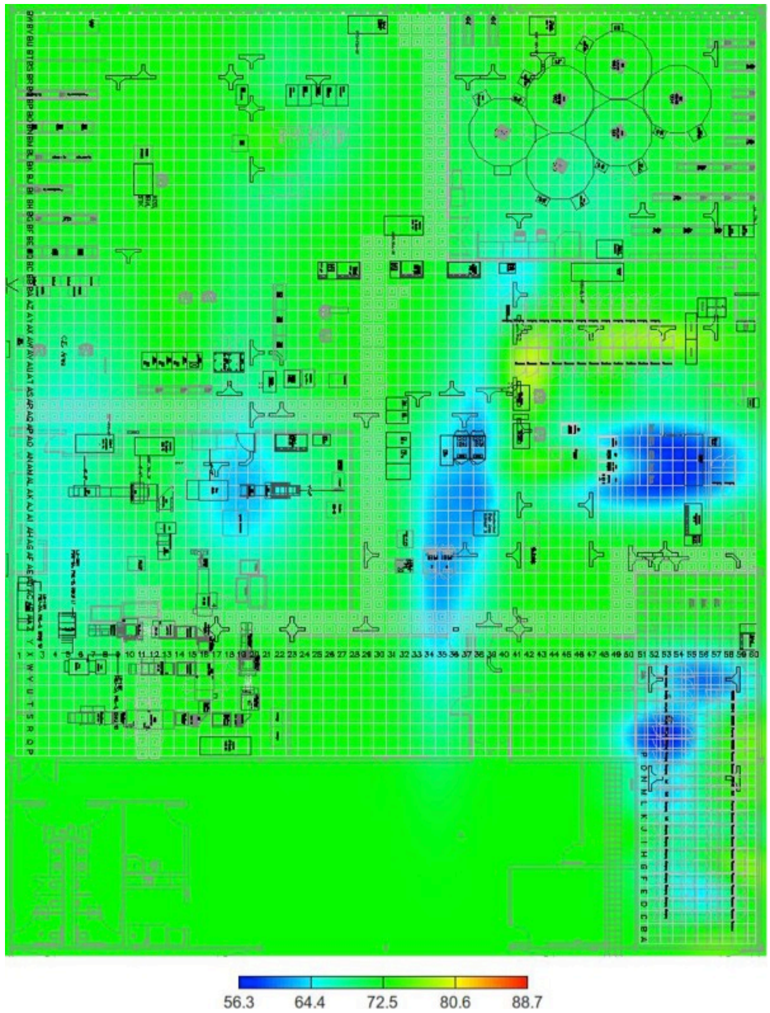

Figure 24: Department of Water Resources Thermal Map for Top of Rack (Aug. 2011)

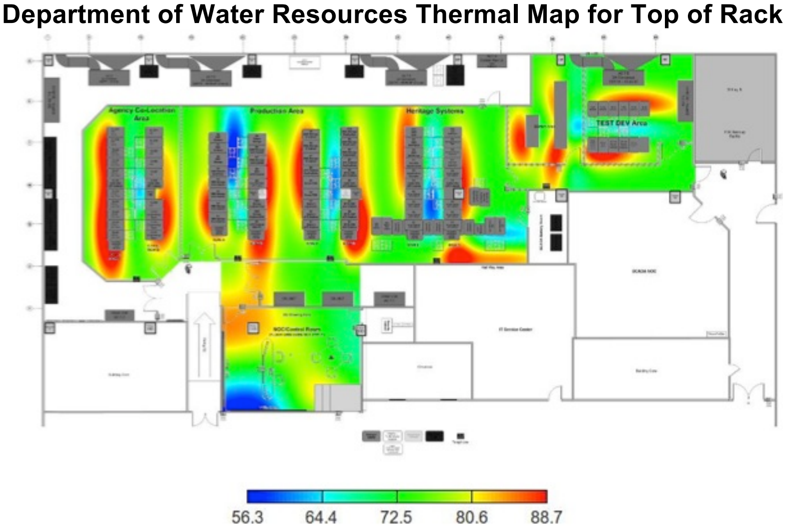

Figure 25: Caltrans Second Floor for Top of Rack (Aug. 2011)

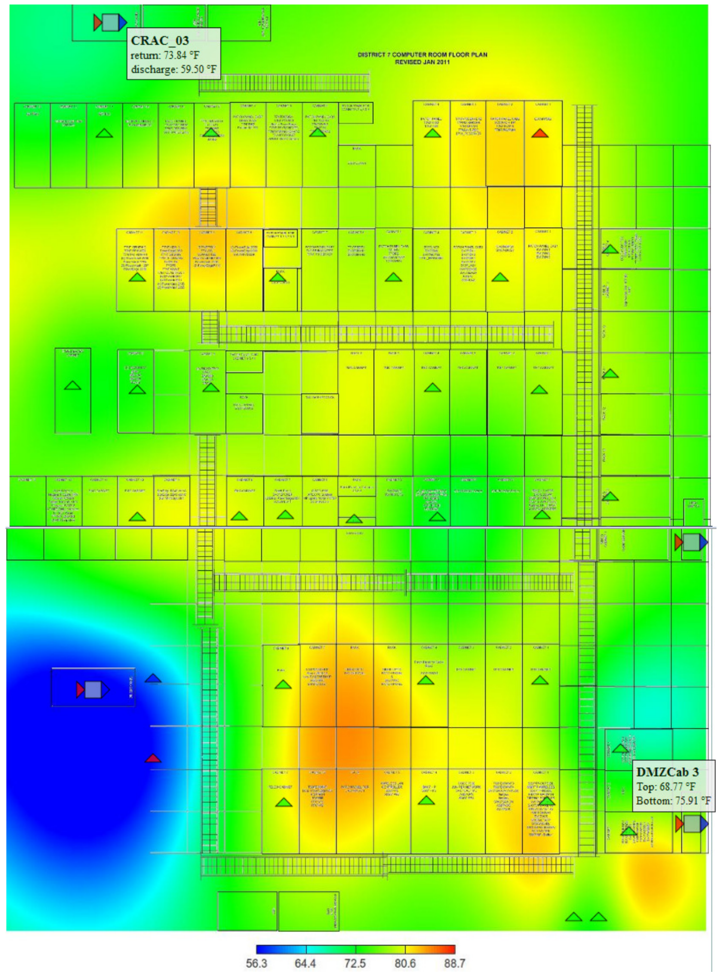

Figure 26: Secretary of State Thermal Map for Top of Rack (Aug. 2011)

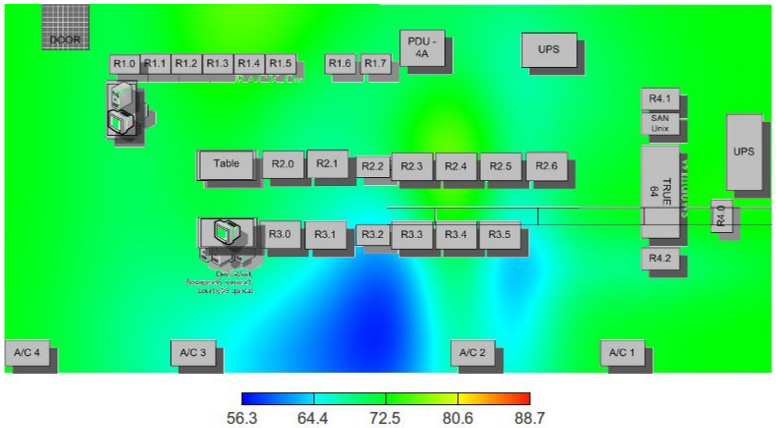

Figure 27: Secretary of State Thermal Map for Bottom of Rack (Aug. 2011)

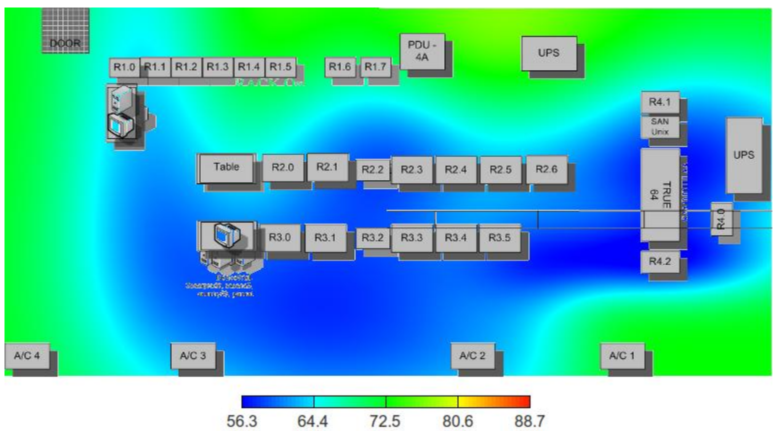

Figure 28: Caltrans Ninth Floor Thermal_Map for Top of Rack (Aug. 2011)