



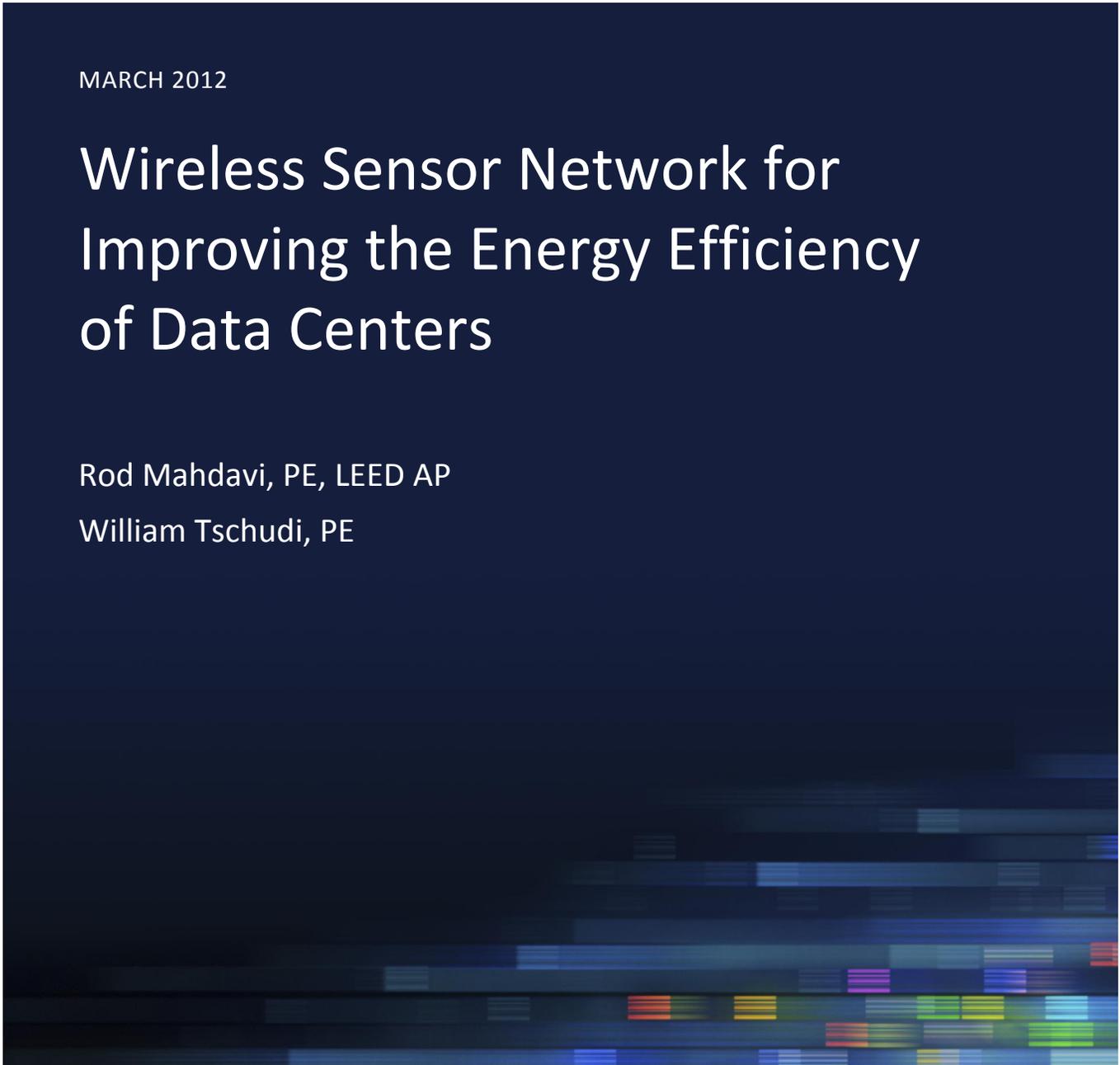
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Wireless Sensor Network for Improving the Energy Efficiency of Data Centers

Rod Mahdavi, PE, LEED AP

William Tschudi, PE





The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

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Contributors:

United States Department of Agriculture (USDA): Jamie Boyle, Ron Jones, Diego Maldando, Greg Massey, and Steve Venegoni

United States General Services Administration (GSA): Chris Cockrill, Zach Hawks, Mike Lowell, and Kevin Powell

SynapSense: Patricia Nealon and Ray Pfeifer

Lawrence Berkeley National Laboratory (LBNL): Rod Mahdavi, Dale Sartor, Bill Tschudi, Mark Wilson

For more information contact:

Kevin Powell
Program Manager
Green Proving Ground
Office of the Commissioner
Public Buildings Service

U.S. General Services Administration
555 Battery Street, Room 518
San Francisco, CA 94111-2312
Email: kevin.powell@gsa.gov

Table of Contents

	<i>Page</i>
I. Executive Summary.....	1
II. Background	2
A. Introduction	2
B. Data Center Monitoring	3
III. Purpose	3
IV. Technology Description and Research Plan.....	4
A. Wireless Sensor Technology	4
B. Study Design.....	4
V. Assessment	5
A. Facility Description.....	5
B. Wireless Technology Specification.....	5
C. Technology Deployment	6
D. Technology Application.....	6
VI. Measured Results	7
A. Data Center Environmental Findings	7
B. Thermal Monitoring	8
C. Air Management and Air Distribution Metrics.....	8
D. Rack Cooling Index (RCI ^{TM/SM}):.....	8
E. Return Temperature Index (RTI ^{TM/SM}):	9
F. Data Center Temperature Analysis Using Thermal Maps	10
G. Relative Humidity Analysis and Map.....	13
H. Sub-Floor Pressure Analysis and Imaging Map	14
I. Rack Cooling	15
J. Data Center Air Handler Operational Behavior	17
K. Implementation of the Recommended Measures.....	18
VII. Summary Findings and Conclusions	28
A. Overall Technology Assessment at Demonstration Facility	29
B. Best Practices	29
C. Market Potential within the GSA Portfolio	32
D. Installation and Commissioning at Demonstration Facility	32
E. User Acceptance.....	33
F. Barriers and Enablers to Adoption.....	33

VIII. Appendix A - Assessment Kit Specification 34

I. Executive Summary

Data centers occupy less than 2% of the federally owned portfolio under the jurisdiction, custody or control of the U.S. General Services Administration (GSA), but represent nearly 5% of the agency's overall energy budget. Assuming that energy use in GSA's data centers tracks with industry averages, GSA can anticipate that data center energy use will grow at an annual rate of 15%, a doubling of energy use every five years.¹ In fact, energy is the single largest operating expense for most data centers. Improving the energy performance of data center systems supports progress toward meeting federally mandated greenhouse gas emission-reduction goals, while reducing operating and energy costs and allowing for greater flexibility in future expansion by eliminating the need to provide additional power and cooling.

Studies sponsored by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) have shown that energy use can be reduced by 25% through implementation of best practices and commercially available technologies. The present study evaluated the effectiveness of a strategy to cost-effectively improve the efficiency of data center cooling, which is the single largest non-IT load. The technology that was evaluated consists of a network of wireless sensors—including branch circuit power monitors, temperature sensors, humidity sensors, and pressure sensors, along with an integrated software product to help analyze the collected data. The technology itself does not save energy; however, its information collection and analysis features enable users to understand operating conditions and identify problem areas. In addition, data obtained by this technology can be input into assessment tools that can identify additional best practice measures. Energy savings result from the implementation of the best practices.

The study was conducted to validate the premise that providing data center operators with detailed, real-time measurement of environmental parameters and power consumption enables them to establish baseline performance, discover areas of sub-optimal performance, and identify concrete opportunities for improvement. Real-time measured performance data was collected in a demonstration facility at the U.S. Department of Agriculture's (USDA) National Information Technology Center (NITC) Data Center in St. Louis, Missouri, to validate the effectiveness of these improvements, enable further fine-tuning of systems, verify savings, and report results. Wireless sensor technology was selected because, in contrast to wired sensor technology, it can deliver the data in a cost-effective, facility-friendly way.²

After wireless sensor technology was deployed at the demonstration facility, implementation of the identified efficiency measures was used to reduce the data center's cooling load by 48%, reducing total data center power usage by 17%. This represented an annual savings of 657 megawatt-hours (MWh). There was also a corresponding reduction in the data center's Power Usage Effectiveness (PUE), from 1.83 to 1.51. The data center's carbon footprint was reduced by 542 metric tons annually.

The implications for broader deployment of this technology by tenant agencies in space managed by the GSA are significant. The GSA provides its tenants with space for more than 1,400 data centers.³ Although the technology was deployed only at a single demonstration facility, the actual results track closely with expected results. The evaluation team is therefore confident that similar performance improvements can be

¹ U.S. Environmental Protection Agency. 2007. *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431*. ENERGY STAR Program. August 2, 2007.

² Because of its high cost (\$1,000–\$1,500 an installed node), no comparably dense network of wired sensors is feasible.

³ According to GSA's STAR database for Automated Data Processing (ADP) space, as of October 2011.

achieved by deploying similar technology across all data centers within the GSA portfolio. The team projects the potential energy savings identified in Table 1 if such deployment by GSA’s tenants are achieved:

	PUE	Watts/ Square Foot IT Load	Utility Cost (\$/kWh)	Annual Energy Savings (kWh)	Annual Cost Savings (\$)	Carbon Savings (metric tons)
Baseline	1.94	69	0.11	n/a	n/a	n/a
Projected Results Using Real-time Monitoring ⁴	1.51	69	0.11	557,000,000	61,000,000	532,000

Table 1. Projected Savings for the Entire GSA Portfolio⁵

The study also confirmed the cost effectiveness of this technology. Even though energy costs at the demonstration facility (\$0.045/kWh) were among the lowest in GSA’s portfolio, simple payback at the study location was calculated to be 3.4 years, based on a \$101,000 cost (vendor provided hardware, software, and labor).

The most significant barrier posed by this technology was the multiple interruptions of facility power required to safely connect power monitoring equipment at the demonstration facility. The evaluation team, working with SynapSense Corporation, the vendor that provided the technology, addressed this issue by developing an assessment kit capable of capturing the most important information and efficiently deploying the technology without facility power interruptions. The evaluation team recommends that this type of technology be used in facilities that wish to achieve energy savings using non-intrusive/non-interruptive equipment. This technology supports a rapid assessment to identify energy efficiency measures, one of which would likely be to install a full wireless monitoring system.

In summary, the study validates the effectiveness of a dense network of wireless sensors to provide a reliable, facility-friendly, cost-effective source of real-time information that enables data center operators to achieve 10% or greater improvements in overall data center efficiency. Dissemination of these findings should encourage the adoption of this technology throughout GSA and the data center industry.

II. Background

A. Introduction

As the nation’s single largest energy user and a significant energy consumer in many areas of the country, the federal government is keenly aware of the need not only to use energy efficiently, but also to invest in energy-reduction measures that make good business sense while not interrupting operations. Recognizing the pervasiveness of this problem, multiple mandates direct the Federal government to improve data center efficiency.⁶

⁴ This savings projection assumes an average 17% reduction in total data center energy use.

⁵ Average numbers for the GSA portfolio according to GSA’s Office of Innovative Technology, as of October 2011.

⁶ Energy Independence and Security Act; Executive Orders 13514 and 13423; Energy Policy Act of 2005; Title 10 Code of Federal Regulations 433.

To identify the energy-efficiency opportunities in data centers, and to stimulate the adoption of measures that address them, DOE developed an energy assessment process, along with assessment tools to help data center stakeholders identify energy-efficiency measures. The DOE's Federal Energy Management Program (FEMP) and GSA are promoting the use of energy assessments to discover efficiency opportunities that can lead to dramatically improved energy performance while maintaining or improving data center reliability.

B. Data Center Monitoring

Performing accurate assessments and benchmarking, however, requires knowledge of the data center's operation, monitoring of multiple environmental parameters (such as temperature, dew point, and pressure in the data center at many locations and elevations), and metering of electrical power, from the electrical sub-station to its end use. To monitor so many parameters through a conventional wired monitoring system is expensive and logistically difficult. The cost of such hard-wired systems ranges from \$1,000 to \$1,500 per sensor node, and this rarely yields a feasible payback. Recent advances in wireless technology, however, enable wireless sensor networks to achieve equivalent performance at a projected cost of \$100 to \$150 per node.⁷ Moreover, wireless systems eliminate the key logistical barrier of placing additional wiring in overcrowded racks. Because they are easily expandable and relocatable, wireless systems also provide flexibility to grow and adapt as a data center evolves over time. There are multiple vendors selling wired and wireless monitoring and control systems for data centers, and there is certainly a market for these systems.

III. Purpose

With input from industry, the DOE Industrial Technologies Program's⁸ (DOE ITP) Save Energy Now initiative developed a suite of assessment tools (DC Pro Software Tool Suite), that is useful for assessing data center energy use and identifying potential energy-efficiency measures. These tools, when used with the recommended assessment process, are most effective if implemented with monitored real-time data.⁹ The high cost and logistical constraints of deploying a wired sensor network, however, provided a significant barrier to capturing such data. Through an Interagency Agreement between GSA and DOE, Lawrence Berkeley National Laboratory (LBNL) worked with SynapSense to demonstrate that a wireless sensor network could be installed rapidly and at low cost, to facilitate delivery of the projected savings.

The Green Proving Ground (GPG) program, under direction of the Public Building Service's Office of the Chief Greening Officer, was created to evaluate precisely such innovative technologies. The goal of this GPG technology evaluation was to learn whether such a wireless sensor network could provide the real-time power monitoring and thermal mapping of the data center needed to visualize problems, identify solutions, and optimize the facility's air flow management. It also sought to document that energy could be saved in a cost-effective, facilities-friendly way.

⁷ Hard-wired cost estimate is based on experience of LBNL engineers. Projected wireless sensor cost estimate is based on discussions with vendors.

⁸ The DOE Industrial Technologies Program is now the DOE Advanced Manufacturing Office (AMO).

⁹ The DOE assessment resources are available from the following DOE websites: Assessment Protocol (http://www1.eere.energy.gov/industry/datacenters/pdfs/data_center_assessment_process.pdf); Metering Protocol (http://www1.eere.energy.gov/femp/pdfs/hpc_metering_protocol.pdf); Data Collection Protocol (<http://www1.eere.energy.gov/femp/pdfs/datacollectionprotocol.pdf>).

IV. Technology Description and Research Plan

A. Wireless Sensor Technology

The wireless sensor technology installed and evaluated as part of this project consists of sensor nodes, gateways, routers, server platforms, and software applications. Specifically, this wireless sensor technology enables data center operators to:

- Establish baseline energy utilization and identify improvement opportunities using the DC Pro Software Tool Suite.
- Monitor and validate energy-saving measures following the implementation of improvements.
- Measure real-time energy end use and calculate PUE with accurate power measurements.
- Interpret temperature, humidity, and subfloor pressure differential data from hundreds of sensor nodes using intuitive live-imaging maps.
- Measure power (and use it to calculate energy) and incorporate other sources of data, such as building automation system (BAS) data.
- Monitor environmental conditions to help ensure that they stay within ranges recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and provide alerts if the ranges are exceeded.

B. Study Design

The wireless sensor technology that was evaluated consists of hardware and software that collects and analyzes data that can be used to help identify efficiency improvements in data centers, including those that are already considered energy efficient. To measure and validate performance claims for this technology, the study team identified a well-designed and well-managed data center for this demonstration project. The location selected, the USDA's National Information Technology Center Data Center in St. Louis, Missouri, had a baseline PUE of 1.83 (Figure 1). It utilizes traditional computer room air conditioning (CRAC) units and has a highly motivated, engaged, and knowledgeable facility operator.

The NITC facility is a Tier 3 data center located at the GSA Goodfellow Federal Complex. The data center is in a general-purpose office building that houses a number of USDA departments, including a local USDA Office of the Chief Information Officer (OCIO) data center. The facility includes two raised-floor rooms separated by under-floor barriers. To accommodate future expansion of the NITC data center, the OCIO designed and constructed an expansion data-center room adjacent to the existing data center space.

While the scope of the energy assessment was the entire NITC data center facility, including the newly constructed expansion space, the wireless sensor network deployment was limited to one room of the data center facility (demo room).

The demonstration consisted of deploying a self-configuring, multi-path network (mesh network)¹⁰ of wireless sensors that provide real-time measurement of server inlet temperature and sub-floor pressure differential. Analytics based on mapping of the sensor data helped identify improvements for more energy-efficient cooling of the IT equipment. The total average electrical demand for the NITC data center during

¹⁰ A wireless mesh network (WMN) is a communications network made up of nodes organized in a mesh topology. A mesh network is reliable and offers redundancy. When one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more intermediate nodes.

the 11-day baseline period (June 14–24, 2010) was 434.6 kilowatts (kW), which equates to an annualized energy use of 3.81 gigawatt-hours per year (GWh/yr). During the baseline period, approximately 55% of the total energy use was for the IT equipment.

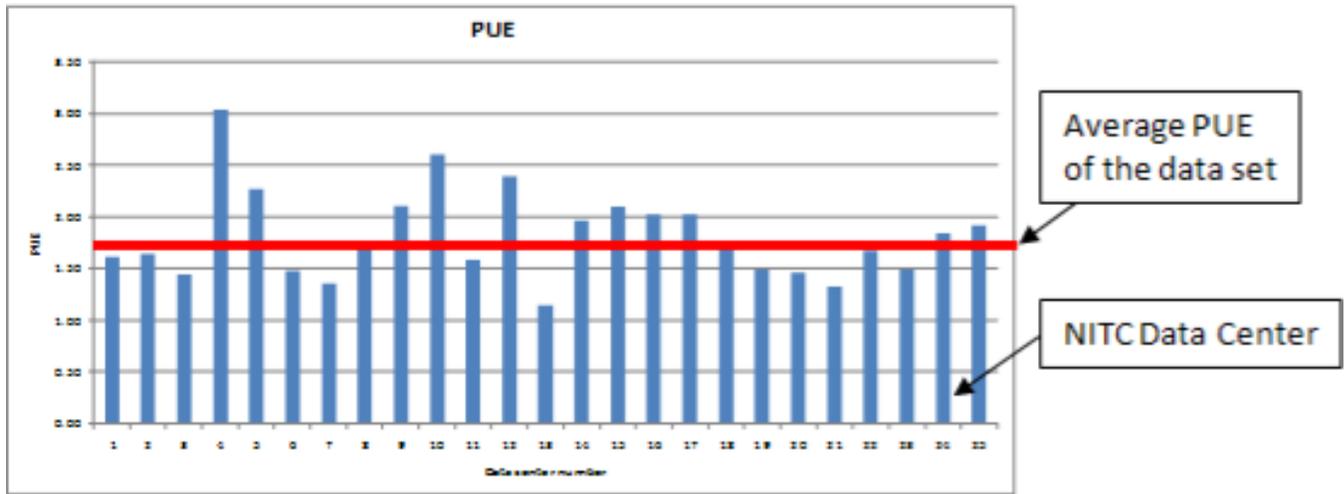


Figure 1. NITC Data Center Power Utilization Effectiveness (PUE) (Center Number 24) Compared to Other Data Centers Benchmarked by LBNL

V. Assessment

A. Facility Description

The NITC data center facility has 18,600 square feet (sf) of raised floor area with approximately 13,050 sf (70%) currently built out. Cooling for the three raised floor rooms that comprise the NITC data center is provided by eight down-flow CRAC units in the data center demo room; four CRAC units in the expansion room (two units were previously shut off); and two CRAC units in the TELCO/Tape Storage room.

These glycol-cooled CRAC units provide cooling and humidification for the data center raised floor and are equipped with dual direct-expansion (DX) compressors, glycol condensers, electric reheat coils, and infrared humidifiers. These units also provide cooling for the uninterruptible power supply (UPS) units that are located on the data center raised floor. Each CRAC has an associated glycol circulation pump located in a mechanical penthouse on the roof to supply their cooling.

B. Wireless Technology Specification

Working with the wireless vendor, SynapSense, LBNL identified standard specification requirements for such sensor networks. Requirements included the following:

- The wireless system should be robust and reliable for use in industrial environments, which typically have a large amount of radio frequency (RF) noise. In data centers, this noise is created by servers, UPS inverters, and building systems, as well as other wireless communications, such as Wi-Fi and mobile phones, all of which create interference that can significantly degrade network performance.
- Time, frequency, and physical diversity should be incorporated to assure reliability, scalability, power source flexibility, and ease of use.
- A “manager” (gateway) should coordinate routing, aggregate packets, collect network statistics, and handle all data transfers. There should be a wireless connection between the manager and its mesh network, and a hard-wired connection to the server.

- The sensor nodes should be ultra low-power wireless transceivers that transfer data to and from integrated sensors or controllers, and use an on-board radio to send the packets to neighboring nodes to eliminate operational interference.
- For security, the wireless sensor, router, and gateway devices should not support any IP-based protocols.
- Data latency should be minimized to achieve data reliability of the wireless network at least on the order of 99.999%.
- The wireless network should be able to accommodate feedback (i.e., data flow from upstream and back).
- Environmental monitoring should provide real-time visualization of air distribution and mixing.

Although there are a number of additional parameters that can be monitored with the wireless sensors (e.g., particulates), only temperature, humidity, pressure differential, and electrical power are included for energy assessments in most data center applications.

A graphic summary of a typical system is shown in Figure 2.

C. Technology Deployment

A total of 588 environmental sensors were installed throughout the demo room: 16 temperature and 16 humidity sensors were installed in the CRAC units, and 420 temperature sensors were located at the top, middle, and bottom of computer racks measuring air intake and exhaust conditions at the IT equipment. Additional sub-floor reference temperatures were monitored at selected racks. Sixty humidity/temperature sensors were located at the top of selected racks. Eighteen pressure sensors were located throughout the demo room. In addition, eleven power meters were installed strategically on main power distribution panels. The balance of the system included routers and a gateway that was connected to a server.

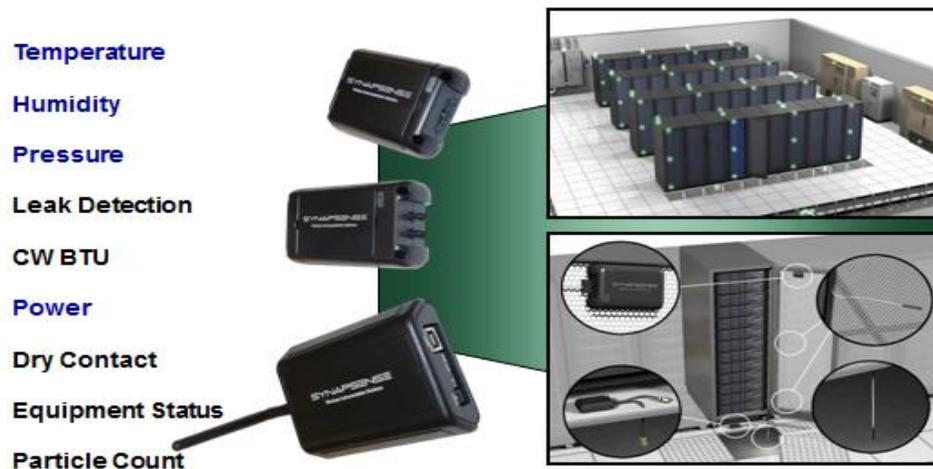


Figure 2. Typical Monitoring Solutions

D. Technology Application

After the network was fully commissioned, data were gathered and analyzed by a qualified assessor. Results were used to create an accurate understanding of the data center operation, and the measured data were input into the DC Pro Software Tool Suite. The output from the assessment tools provided recommendations

on specific potential energy savings opportunities. With the measured data and the output from the DC Pro Software Tool Suite, the assessor was able to identify high-value energy-efficiency measures. As measures were implemented, the improvement in PUE was readily determined by the wireless monitoring system.

Broadly, energy-efficiency measures fell into two categories:

- *Airflow Distribution Optimization*
 - Changing all remaining IT alignment to conform with a hot aisle/cold aisle configuration
 - Installing missing blanking plates in the IT equipment racks
 - Turning off and covering three CRAC units to reduce by-pass air
 - Rebalancing the perforated floor tiles using the rack inlet air temperature sensors to match the IT equipment air flow and cooling demand
- *Cooling Efficiency Measures*
 - Raising CRAC return air temperature set points from 64°F–68°F to 72°F, $\pm 3^\circ\text{F}$, to increase the sensible cooling capacity of the units and decrease the over-cooling occurring in the room
 - Lowering CRAC return relative humidity (RH) set points from 46% RH to 30% RH, $\pm 5\%$ RH
 - Turning off CRAC dehumidification and reheat modes to eliminate simultaneous humidification and dehumidification

After each trial, the wireless monitoring system immediately showed the impact of the changes, providing encouragement for additional trials.

VI. Measured Results

A. Data Center Environmental Findings

The initial field assessment of the NITC data center demo room revealed several energy-efficiency design and operational best practices already in place. These are highlighted below:

- IT equipment racks were, for the most part, installed in hot aisle/cold aisle orientation.
- The majority of cable penetrations under equipment racks were sealed, as were power and cabling penetrations in the sub-floor barriers between adjacent data center rooms.

In addition to visual observation of the data center, findings were based on analysis of the data collected during the baseline monitoring period. The SynapSense software, which provides historical analysis capabilities as well as console navigation and data center alarms and alerts, was used to complete the assessment. Much of the analysis presented in this report, including the graphical images, was provided by SynapSense and is included with its consent.

The analysis included the following:

- Analysis of key data center air management and air mixing metrics.
- Analysis of thermal and relative humidity pressure conditions. The aggregation of real-time data enabled the evaluation team to produce thermal maps that visually captured the environmental state of the data center at a given date and time. These maps helped quickly identify possible problem areas in specific locations of the data center.

- Analysis of temperature, RH, and dew point (DP) conditions at individual rack levels. The rack level analysis showed thermal, RH, and dew point conditions over time and helped to identify overcooling, overheating, and air mixing conditions in specific racks or aisles.
- Analysis of temperature, RH, dew point, and fan/humidification energy were used to identify cooling efficiency of the individual cooling systems.

B. Thermal Monitoring

Temperature sensors were installed on selected racks, to provide temperature readings for identifying hot spots, to measure the level of overcooling, and to quantify the level of recirculation and by-pass air mixing occurring in the data center.

During the baseline period, the central cooling systems were being operated to control supply air temperature to maintain rack inlet air temperature within the ASHRAE-recommended guidelines. The ASHRAE 2011 ranges¹¹ are shown in Table 2:

ASHRAE 2011 Recommended Ranges	
Low-End Temperature	18°C (64.4°F)
High-End Temperature	27°C (80.6°F)
Low-End Moisture	5.5°C DP (41.9°F)
High-End Moisture	15.0°C DP (59.0°F)

Table 2. 2011 ASHRAE Recommended Environmental Ranges

C. Air Management and Air Distribution Metrics

Server intake and exhaust temperatures were continuously monitored on 60 selected racks in the data center, representing over 180 server intakes. In addition, return and supply air temperatures were continuously monitored on the data center CRAC air handling units, as were the sub-floor air temperatures being delivered to the perforated floor tiles.

The goal was to establish an understanding of the air management performance and to identify any issues, such as potential hot spots. From these temperature measurements, the following indices were calculated every 30 minutes during the baseline period.

D. Rack Cooling Index (RCI^{TM/SM}):¹²

Rack Cooling Index (RCI) is a dimensionless measure of how effectively equipment is cooled within a given intake temperature specification (e.g., ASHRAE, Network Equipment Building System [NEBS]). It provides a measure of the conditions at the high (HI) end and at the low (LO) end of the specified temperature range. $RCI_{HI}^{TM/SM} = 100\%$ means that no intake temperature is above the maximum recommended, and $RCI_{LO}^{TM/SM} = 100\%$ means that no intake temperature is below the minimum recommended.

¹¹ ASHRAE. 2011. ASHRAE TC 9.9 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance Whitepaper prepared by ASHRAE Technical Committee (TC) 9.9 Mission Critical Facilities, Technology Spaces, and Electronic Equipment. (<http://tc99.ashraetcs.org/documents/ASHRAE%20Whitepaper%20-%202011%20Thermal%20Guidelines%20for%20Data%20Processing%20Environments.pdf>)

¹² Rack Cooling Index (RCI), Rack Moisture Index (RMI), and Return Temperature Index (RTI) are trademarks and service marks of ANCIS Incorporated (www.ancis.us).

Using ASHRAE Class 1 temperature specification, “poor” conditions are $\leq 90\%$; whereas, “good” conditions are $\geq 96\%$. The $RCI^{TM/SM}$ assumes the ASHRAE Class 1 recommended intake temperature. The Rack Cooling Index for the demo room is shown in Table 3. The data indicated that the data center was being overcooled, as the $RCI_{LO}^{TM/SM}$ index was between poor ($< 90\%$) and good (above 96%).

E. Return Temperature Index ($RTI^{TM/SM}$):

The Return Temperature Index ($RTI^{TM/SM}$) is a dimensionless measure of the actual utilization of the available temperature differential in the equipment room, as well as a measure of the level of by-pass air or recirculation air in the data center. One hundred percent is generally the target; $> 100\% \rightarrow$ recirculation air; $< 100\% \rightarrow$ by-pass air. For this assessment, the evaluation team used the air management assessment tool in the DC Pro Software Tool Suite to calculate the $RTI^{TM/SM}$ for the NITC data center, using the real-time data collected by the wireless sensor network system during the baseline period.

The $RTI^{TM/SM}$ value of 44% indicated that the demo room was currently being oversupplied with cooling air that was by-passing the IT equipment and mixing with the hot discharge air before it returned to the air handling systems, thereby lowering their cooling efficiency and capacity. The associated 100/ RTI metric was more intuitive: it indicated that with nine operating CRACs in the NITC data center, 2.3 times more cooling air was being delivered than was needed by the IT equipment.

The Return Temperature Index for the NITC data center is included, along with the Rack Cooling Index (HI, LO), in the table of air management metrics produced by the air management assessment tool (Table 3, below):

Metric		Definition	Measured	Unit
ΔT_{AHU}		Typical (airflow weighted) AHU temperature drop	7.9	F
ΔT_{Equip}		Typical (airflow weighted) equipment temperature rise	18.0	F
V_{AHU}		Total AHU airflow	128250	cfm
V_{Equip}		Total equipment airflow	56427	cfm
RTI		Return Temperature Index: $\Delta T_{AHU} / \Delta T_{Equip} = V_{Equip} / V_{AHU} (x100)$	44	%
RCI(HI)	Alt. 1*	Rack Cooling Index: Measure of absence of over-temperatures	99.0	%
RCI(LO)	Alt. 1*	Rack Cooling Index: Measure of absence of under-temperatures	96.0	%
IAT max	Alt. 2*	Typical (not extreme) max IT equipment intake temperature	85.4	F
IAT min	Alt. 2*	Typical (not extreme) min IT equipment intake temperature	61.7	F
SAT		Typical (airflow weighted) AHU supply air temperature	63	F
ΔSAT		Maximum difference between AHU supply air temperatures	11.1	F

Table 3. NITC Data Center $RCI^{TM/SM}$ and $RTI^{TM/SM}$

Figure 3 shows the average top rack intake and exhaust temperatures across the entire NITC data center floor, which illustrates the low temperature rise across the equipment racks:

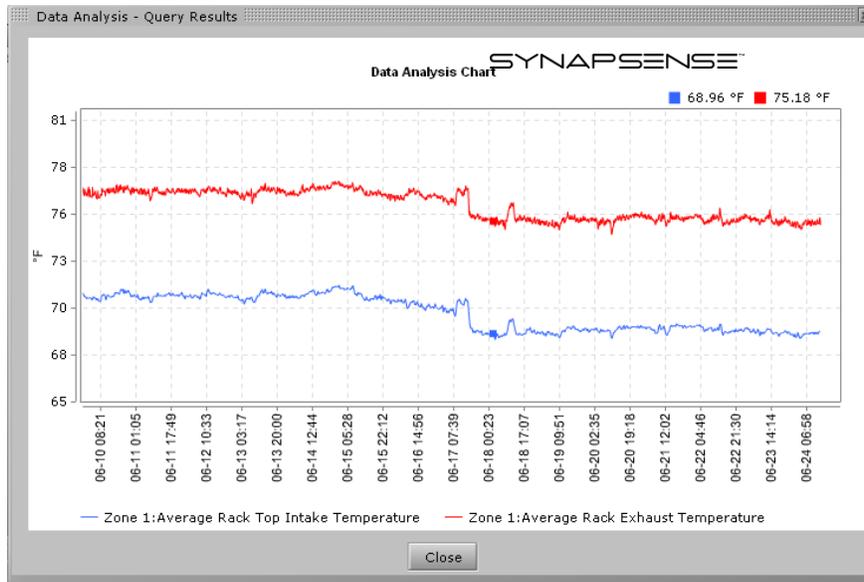


Figure 3. NITC Average Rack Intake-Exhaust Temperatures

F. Data Center Temperature Analysis Using Thermal Maps

The SynapSense software creates images of temperature, humidity, and pressure maps of the data center, using actual measured data. Thermal maps were constructed from the measured temperature data that continuously collected real-time data from the 480 rack sensors. The thermal maps displayed regions that were within the desired target inlet air temperature range of 72°F–78°F (green), overcooled regions that were below the recommended ASHRAE range (blue), regions with some level of air mixing (yellow), and regions that had temperatures higher than the recommended range (red).

The imaging application provided four levels of thermal maps in the demo room. Maps illustrate conditions at the top, middle, and bottom of the racks and in the sub-floor. Data were refreshed every five minutes on a continuous basis. They identified areas with the highest degree of air mixing among the racks in the data center and the respective hot and cold spots. Figures 4 through 7 show representative maps for each of the four levels in the demo room during the baseline period.

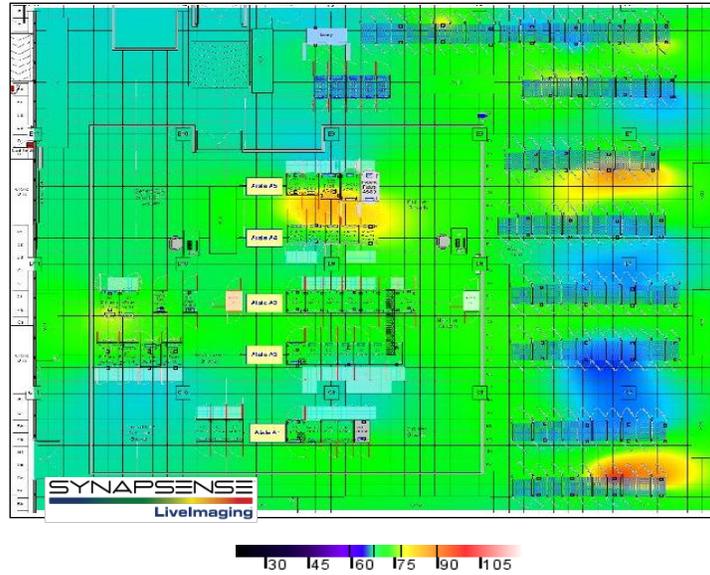


Figure 4. NITC Data Center Thermal Map at the Top of the Racks

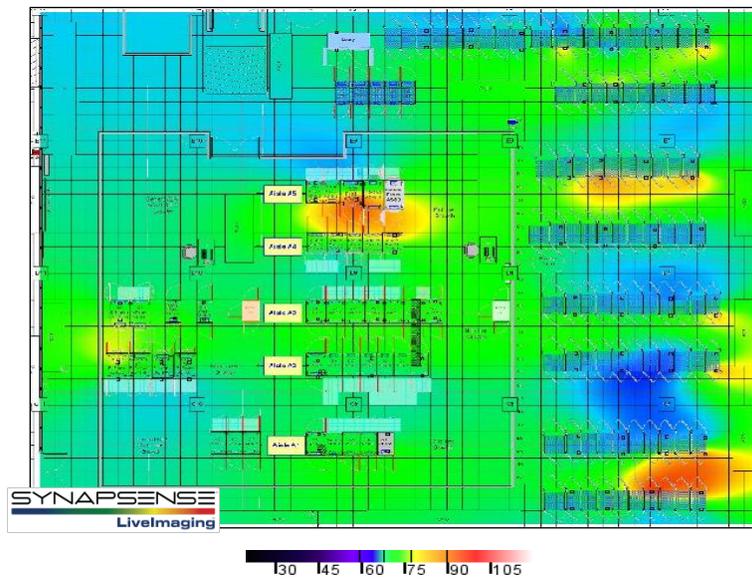


Figure 5. NITC Data Center Thermal Map at the Middle of the Racks

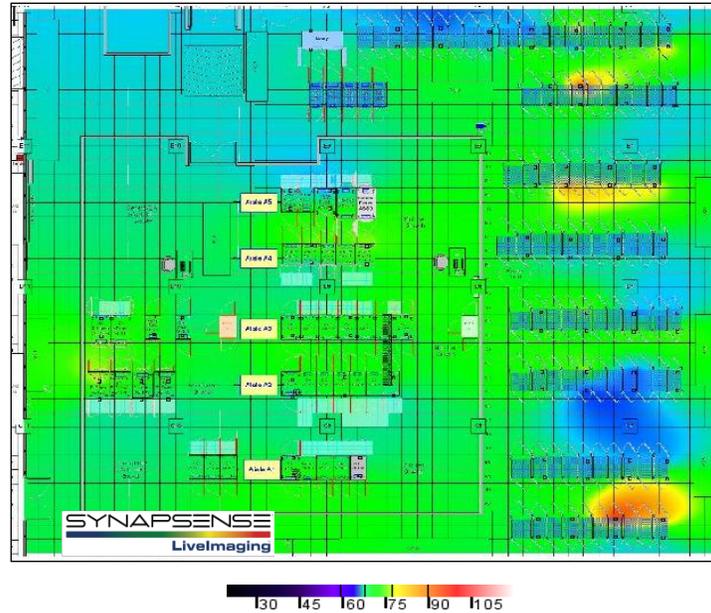


Figure 6. NITC Data Center Thermal Map at the Bottom of the Racks

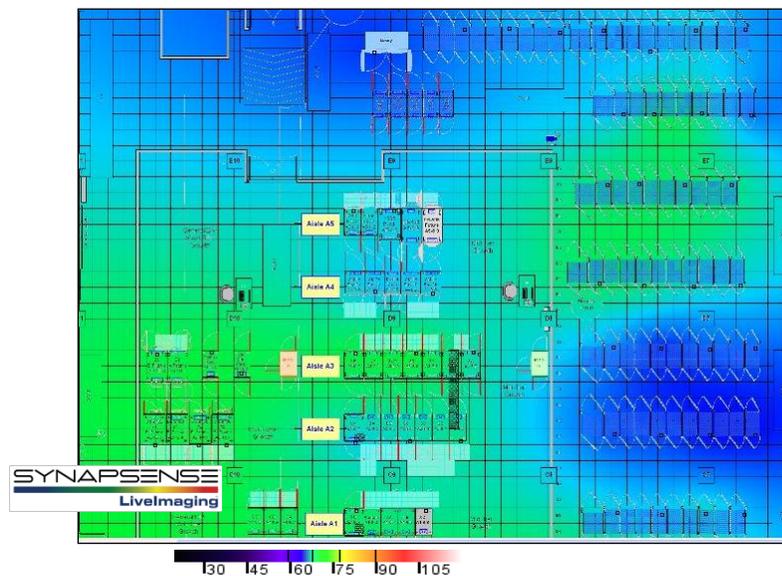


Figure 7. NITC Data Center Thermal Map in the Sub-Floor Under the Racks

Analysis of the data, including the thermal imaging, enabled the evaluation team to determine that the root cause of overcooling was the high volume of air and the low supply air temperature delivered to the racks by the CRAC units. Similarly, using the collected data, the evaluation team determined that hot discharge air from the IT equipment was recirculating back through the racks due to the absence of blanking plates, thereby increasing server inlet air temperatures above the desired range. In addition, a high level of stratification was observed to be occurring in front of many of the data center racks, with the bottom of the racks having the lowest temperatures.

The evaluation team therefore recommended that the data center operator remove the excess perforated floor tiles to significantly decrease the overcooling in the data center and to raise the inlet air temperature to the IT equipment to within the ASHRAE recommended range.

Due to the low supply air temperatures delivered to the data center, the hot aisles were cooler than desired. This led the evaluation team to pursue a deeper analysis of rack cooling effectiveness to further improve the operating environment of the IT equipment and the energy efficiency of the data center.

G. Relative Humidity Analysis and Map

Eighty humidity sensors were placed throughout the data center on each monitored rack at the top of the cold inlet air side of the rack. The imaging system was used to construct a relative humidity map of the data center. The RH map captured a snapshot of the specific RH values at the different sensing points in the data center. The RH map in Figure 8 shows the humidity levels in the data center during the baseline period.

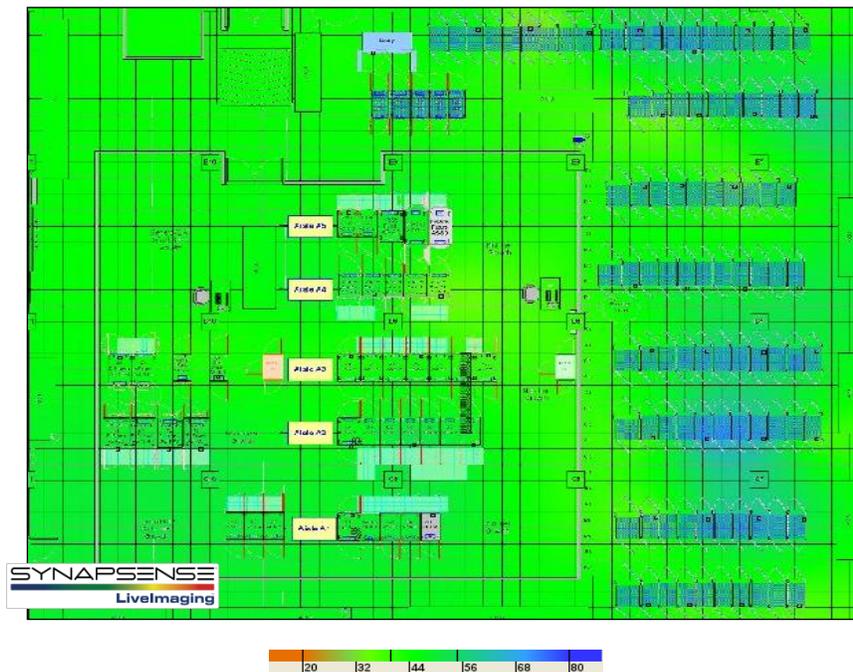


Figure 8. NITC Relative Humidity Map

During the baseline period, the relative humidity measured at the top of racks was fairly consistent across the data center, except for the rows that were being significantly overcooled. The evaluation team therefore recommended resolving the overcooling and recirculation air issues to provide a more uniform relative humidity level across the entire data center floor.

Since the ASHRAE IT equipment moisture guidelines are based upon dew point versus relative humidity, which varies with rack inlet air temperature, the system calculated rack inlet air dew point using the top dry-bulb (db) temperature and RH sensor internal to the wireless node mounted at the top of each monitored rack.

Figure 9 shows a graph of the average rack dew point, as well as the average supply air dew point temperature from the CRAC units. During the baseline period, the CRACs in the demo room were enabled for humidification and dehumidification control with return RH set points from 46%–50%, \pm 5%–13% RH.

As Figure 9 indicates, the demo room operated within the recommended ASHRAE dew point range of 41.9°F–49.0°F at the inlet of the IT equipment. However, because the CRAC’s return air temperatures were different, several of the units fought each other to maintain their return air RH set points.

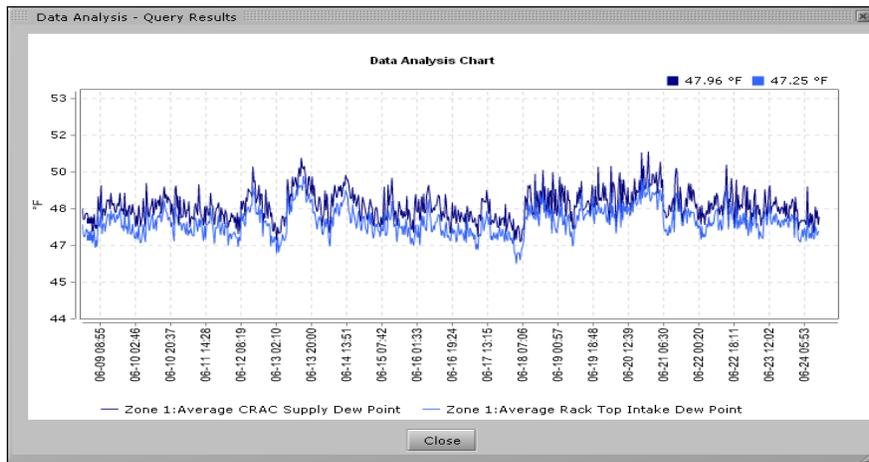


Figure 9. NITC Supply Air and Rack Dew Point Temperature

H. Sub-Floor Pressure Analysis and Imaging Map

Sixteen pressure sensors were placed throughout the data center to measure the sub-floor to room differential pressure in the cold aisles in the demo room. The imaging system was used to construct a sub-floor pressure map of the data center that shows the variations in the pressure values across the entire data center floor. See Figure 10.

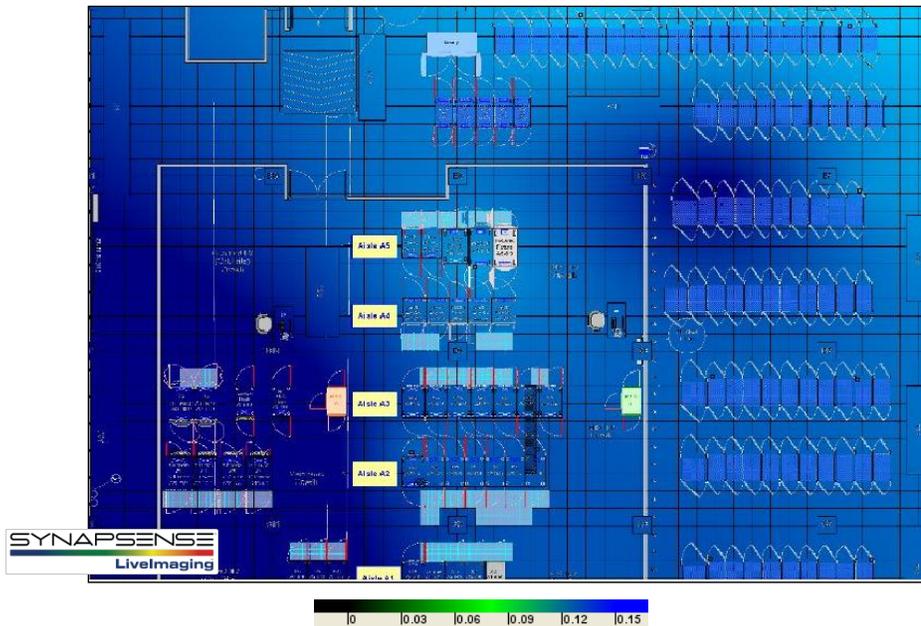


Figure 10. NITC Sub-Floor Pressure Map

During the baseline period, the sub-floor pressure differential measured in the demo room was from 0.06–0.13 inches of water, which is significantly above the desired range of 0.03–0.05 inches of water, which

provides the best energy balance between air volume and CRAC fan energy. Figure 11 is a representative graph showing sub-floor pressure in the NITC data center.



Figure 11. NITC Sub-Floor Pressure

The evaluation team determined that the root cause for the variation in the sub-floor pressure across the raised floor in the data center was the uneven provisioning of perforated floor tiles. In addition, the team determined that the over-pressurization was caused by running more CRAC units than necessary, based upon the cooling air flow demand in the data center. Resolution of these air flow management issues resulted in a more uniform and energy-efficient pressure differential level across the entire data center floor.

I. Rack Cooling

ASHRAE provides a temperature control range with a recommended lower level for server inlet temperatures, due to the concern that if the equipment is too cold, thermal shock damage may occur during a cooling outage that causes >9.0°F rise in temperature per hour.

For this reason, overcooling the data center can lead to increased risk of IT equipment malfunction, in addition to inefficient use of cooling energy. During the baseline period, the environmental data collected by the wireless system indicated that generally the data center was overcooled, with the majority of the racks operated below the ASHRAE-recommended range.

However, even with this degree of overcooling there were still a few hot spots, causing several of the racks to experience inlet air temperatures above the recommended temperature range. The risk of IT equipment malfunction is increased with sustained operation above or below the ASHRAE-recommended operating temperature range.

Figures 12–15 are graphs of the selected IT equipment racks that were being overcooled in the demo room.

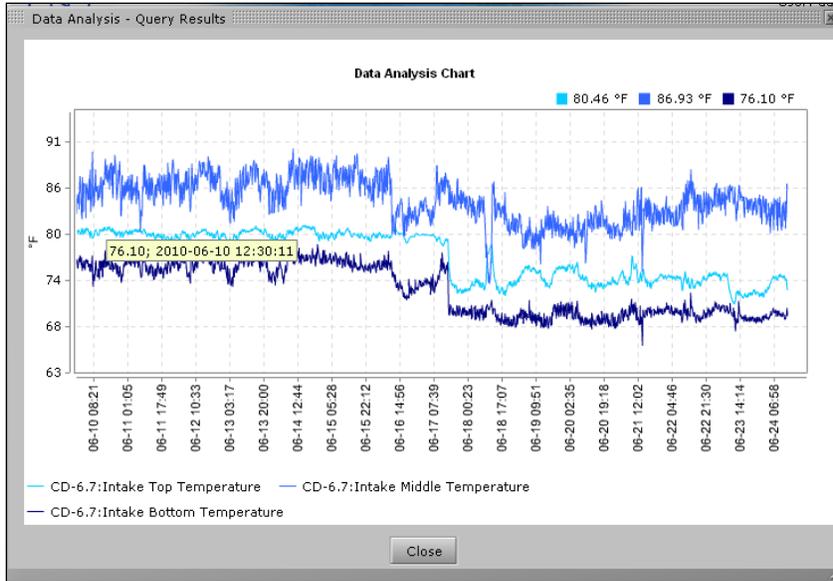


Figure 12. NITC Sample Rack 1

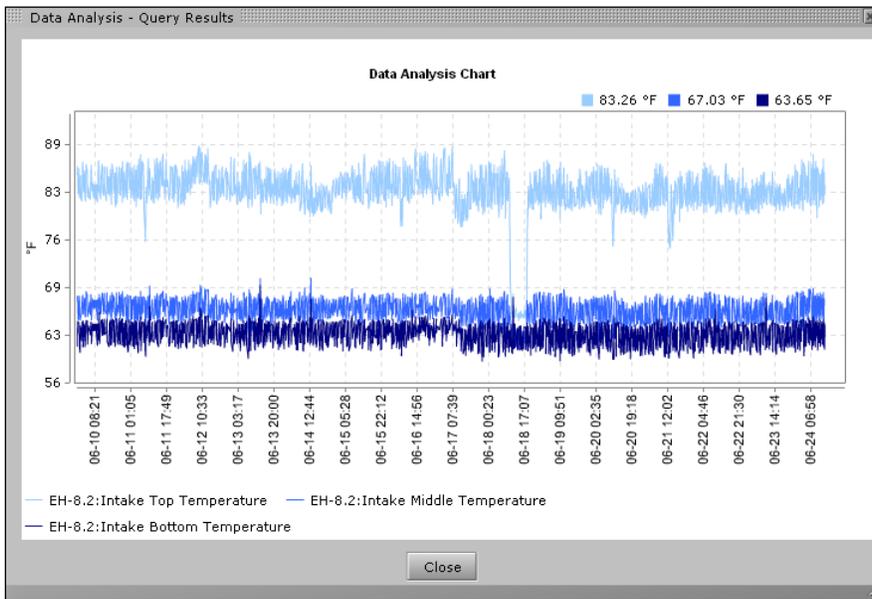


Figure 13. NITC Sample Rack 2

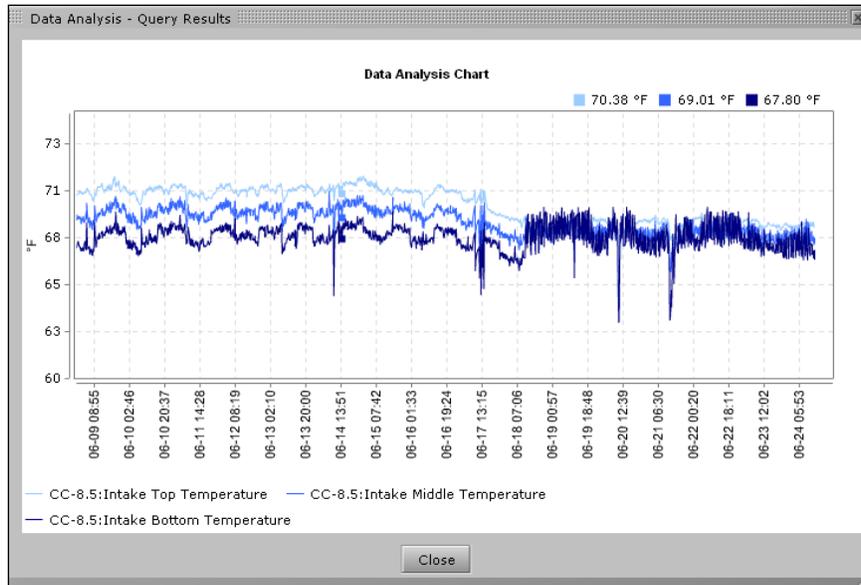


Figure 14. NITC Sample Rack 3

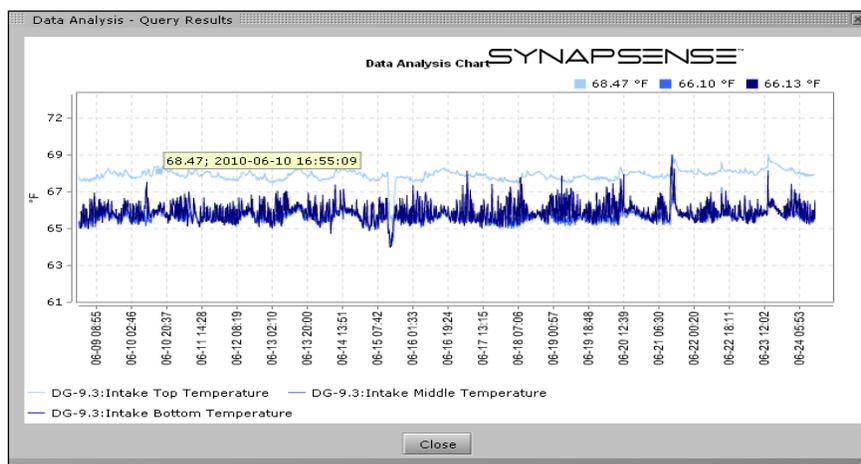


Figure 15. NITC Sample Rack 4

It was determined that the largest contributor to overcooling in the NITC data center was the low supply air temperature delivered to the data center. In addition, analysis of the top, middle, and bottom rack inlet air sensors indicated that a high level of stratification was occurring in front of many of the data center racks.

J. Data Center Air Handler Operational Behavior

SynapSense wireless sensors were installed on the CRAC units in the demo room to monitor supply and return air temperature, relative humidity, and dew point temperature to measure the data center's operational and cooling efficiency.

These sensors were used to evaluate each cooling unit's environmental operating conditions to quantify the degree of by-pass air in the NITC data center. By-pass air occurred when cooling air delivered to the intakes of the IT equipment by-passed the equipment racks and mixed with the IT equipment hot exhaust air before

it returned to the CRAC cooling unit, significantly lowering the return air temperature. This resulted in under-utilization of the cooling systems cooling capacity.

During the baseline period, the average return air temperature of the demo room (Figure 16) was 71.4°F, which indicates a high degree of by-pass air in the data center. This sensor data was also used to calculate cooling air loss, which represents the percentage of wasted cooling air flow and wasted fan energy. During the baseline period, approximately 60% of the fan energy was being wasted due to the low average delta T of 7.9°F.

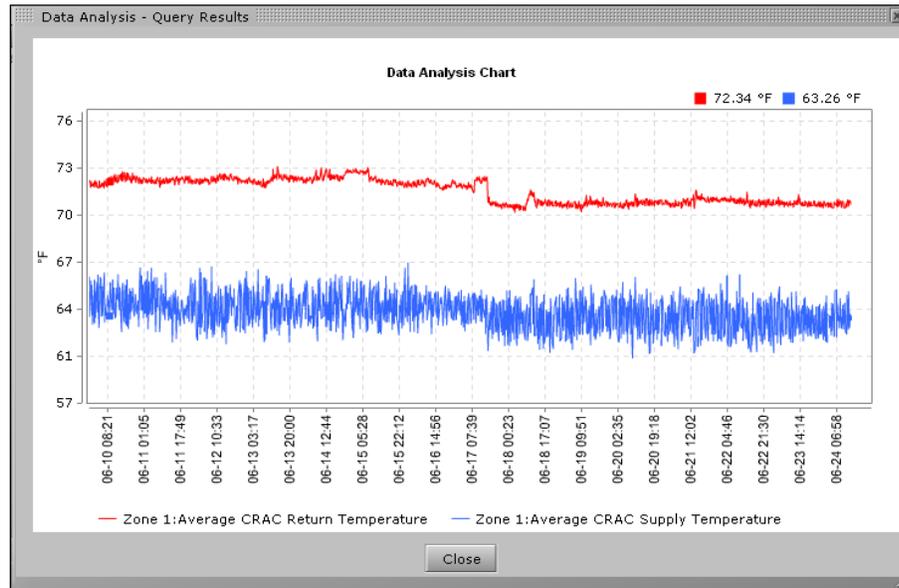


Figure 16. NITC CRAC Average Supply and Return Temperatures

K. Implementation of the Recommended Measures

Following approval by USDA management to proceed with the recommended changes to the data center, the evaluation team continued with the implementation phase of the project, which was successfully completed in less than a day.

First, the evaluation team reviewed the electrical single-line drawings to confirm which CRAC units were fed by which electrical system. The team then tested various options of which three CRAC units to turn off, using wireless sub-floor pressure data to determine which combination provided the most even floor pressure.

After testing several options, the evaluation team turned off three CRAC units and covered them so that the cold air would not leak back into the data center from the pressurized raised floor.

The team then proceeded to raise the return air temperature set points and lower the return air relative humidity set points to the recommended settings before turning off the dehumidification and reheat modes on the CRACs.

The team used the inlet air temperature wireless sensors to rebalance the cooling by readjusting the quantity and location of the perforated floor tiles in the cold aisles to match the IT cooling demand of the racks.

As anticipated, there were too many perforated tiles deployed in the data center. When the team finished the optimization process, it had removed approximately 45 perforated floor tiles and replaced them with solid tiles.

The evaluation team waited approximately thirty minutes to let the demo room adjust to the changes, then reviewed the thermal images and historical rack-inlet air-temperature trend charts to see if any hot spots had developed after it rebalanced the air flow in the room.

The team identified four racks that had top inlet air temperatures greater than the ASHRAE-recommended range and one rack above the allowable range. Visual inspection confirmed that: two racks had missing blanking plates and were being affected by recirculation air; one rack had recently been decommissioned and was empty with no blanking plates installed; and the top third of two racks had no equipment at all.

Since the OCIO did not have any blanking plates or high-flow tiles in inventory at this site, the evaluation team temporarily blanked off the recirculation air and added two perforated floor tiles in the cold aisle to mitigate the problem. The team recommended that the OCIO permanently address this problem by installing the missing blanking plates on several racks in the row and replacing the two low-flow perforated floor tiles with a high-flow tile. The team also relocated the wireless node on the decommissioned empty rack to the adjacent rack.

Over the next two hours, the team reviewed the real-time and historical rack temperature data and the cooling performance of the remaining operating CRACs in the data center. It determined that one unit's return air temperature stayed just below the new return air temperature set point of 72°F. To be assured that CRAC 2 would retain cooling control and just not recirculate return air back under the raised floor or short-cycle into and out of cooling, the team adjusted the return air set point on CRAC 2 to 70°F, ± 2 °F.

This adjustment enabled CRAC 2 to continuously remain in control, and the team agreed that the data center was being cooled within the desired inlet air temperature range.

Post-Measures Environmental Conditions

After completing the recommended air flow optimization and cooling efficiency measures, the evaluation team requested the OCIO to provide a copy of the database containing the monitored data, so that it could complete the post-measures analysis and the final assessment report.

The following summary of the changes in the demo room's environmental conditions, the associated changes in the data center's thermal metrics, and the energy savings resulting from implementing the recommended air flow optimization and cooling efficiency measures is based on the real-time environmental and energy monitoring data provided by a one-month post-measures baseline period.

Rack Cooling Index (RCI^{TM/SM})¹³

The Rack Cooling Index for the demo room, after the implementation of the recommended energy-efficiency measures, is shown in Figure 17 below. The data indicated that the data center was no longer being overcooled, as the RCI^{TM/SM} index increased from an average of 93% (which was poor) to >96% (which is good).

The evaluation team recommended installing the missing blanking plates because once the excessive air flow mixing was reduced, the hot aisle temperatures were significantly higher, and recirculation air could lead to undesirable equipment operating conditions.

This is the reason why RCI_{HI}^{TM/SM} decreased from 100% after implementation of the recommended energy-efficiency measures. Installation of the remaining blanking plates should rectify this problem.

¹³ Rack Cooling Index (RCI), Rack Moisture Index (RMI), and Return Temperature Index (RTI) are trademarks and service marks of ANCIS Incorporated (www.ancis.us).

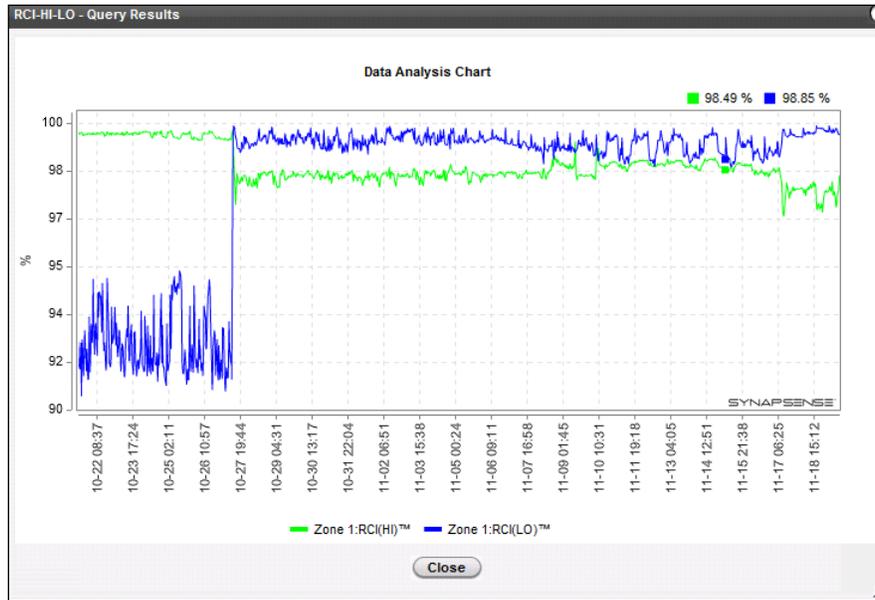


Figure 17. Post-Measures Demo Room RCI

Data Center Thermal Map: Report

The thermal imaging maps created after implementing the recommend air flow optimization and energy-efficiency measures (figures 18–22) provide visual confirmation that it is possible to improve the environmental operating conditions in a data center while reducing cooling costs.

Due to the low supply air temperatures provided by CRACs in the data center, both the cold and hot aisles were cooler than desired during the baseline (or pre-optimization) period.

Lowering the raised floor pressure by turning off three CRACs, raising the return air temperature set points on the CRACs that remained in operation, and rebalancing the quantity and location of perforated floor tiles in the cold aisles significantly reduced the overcooling condition in the data center. Cold aisle temperatures were then more even across the data center, and the IT equipment inlet air temperature was closer to the high end of the ASHRAE-recommended range.

Similarly, rebalancing the raised floor reduced the high level of by-pass air that existed during the baseline period and resulted in hot aisle temperatures closer to the discharge temperature of the IT equipment.

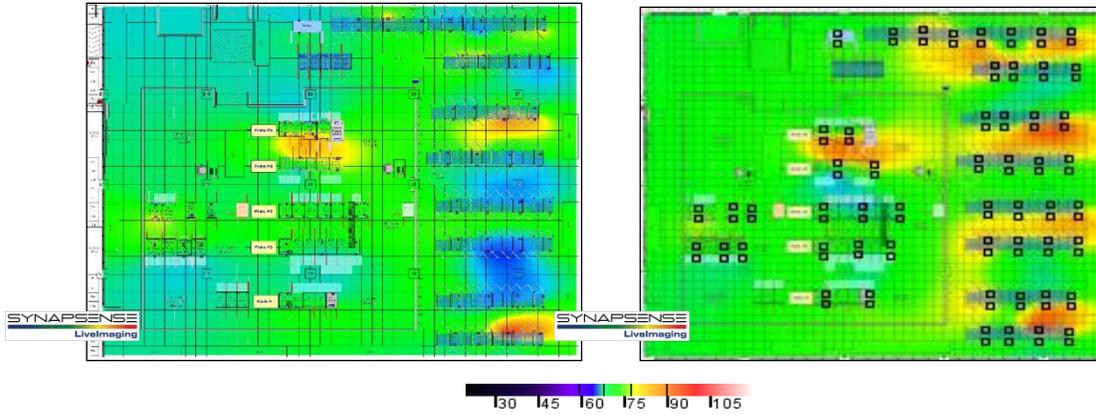


Figure 18. NITC Data Center Thermal Map at Top of Racks during the Baseline (image on left) and Post-Optimization (image on right) Periods

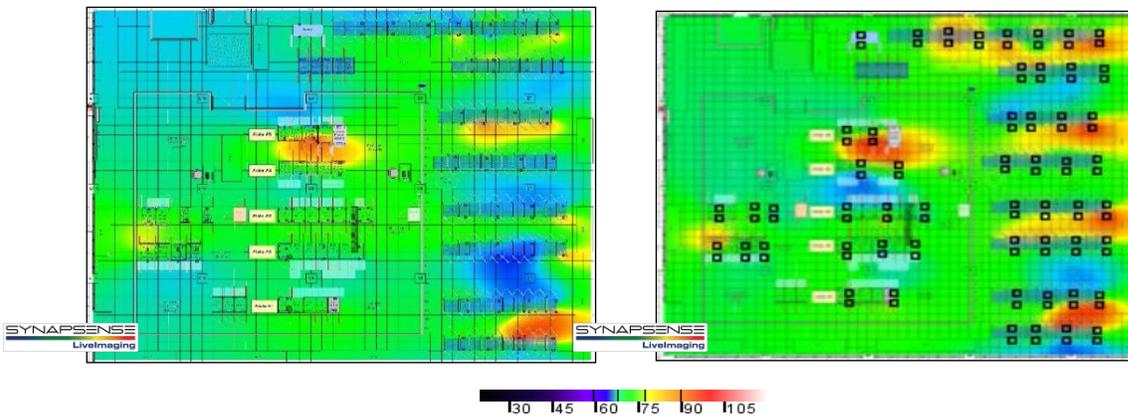


Figure 19. NITC Data Center Thermal Map at Middle of Rack during the Baseline (image on left) and Post-Optimization (image on right) Periods

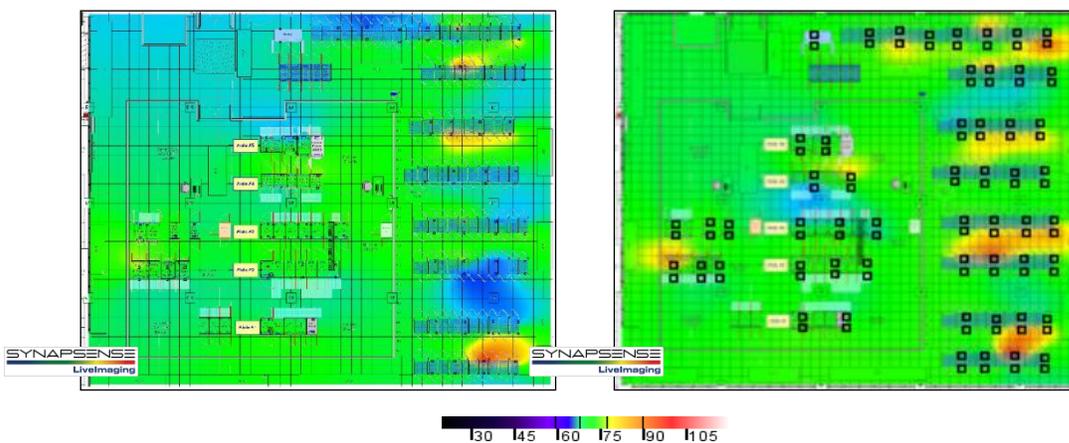


Figure 20. NITC Data Center Thermal Map at Bottom of Racks during the Baseline (image on left) and Post-Optimization (image on right) Periods

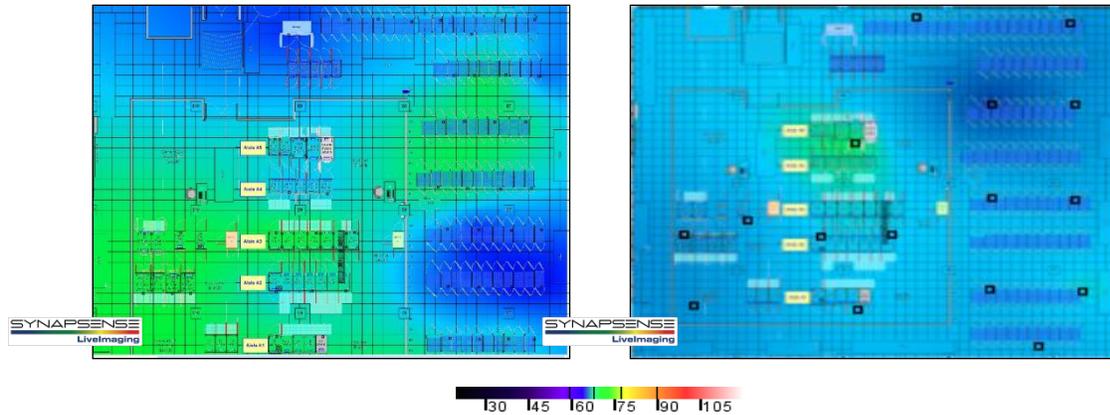


Figure 21. NITC Data Center Thermal Map of Subfloor during the Baseline (image on left) and Post-Optimization (image on right) Periods

Relative Humidity Analysis and Livelmaging™ Map

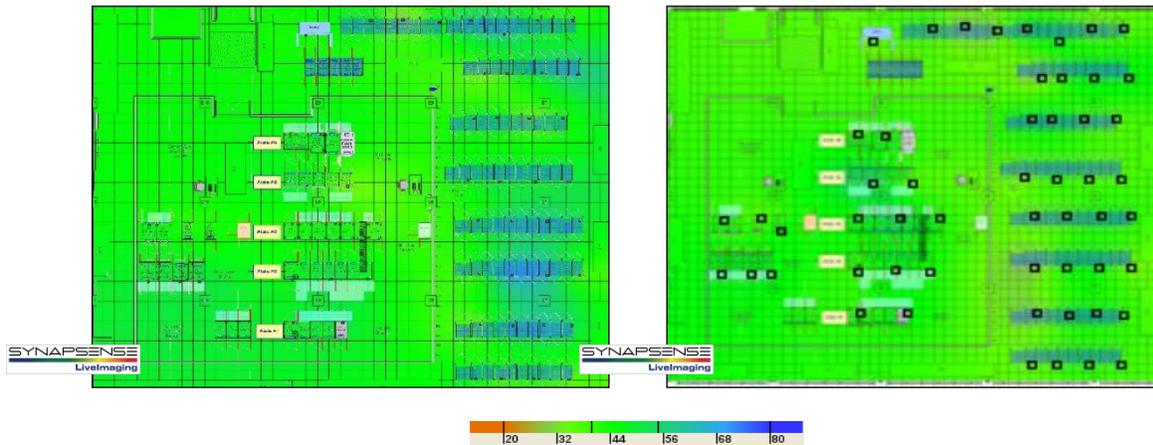


Figure 22. NITC Data Center Map of Relative Humidity during the Baseline (image on left) and Post-Optimization (image on right) Periods

The post-optimization relative humidity map (Figure 22) illustrates that lowering the CRACs return relative humidity set points and turning off their dehumidification and reheat modes resulted in more-even relative humidity across the data center. And even though optimization reduced CRAC energy use, it did not have an adverse impact on the NITC data center dew point. Figure 23 shows the average rack dew point, as well as the average supply air dew point temperature from the CRACs, during the baseline and post-optimization period.

As Figure 23 indicates, the demo room still operated within the recommended ASHRAE dew point range of 41.9°F–49.0°F at the inlet of the IT equipment without using any dehumidification or reheat energy.

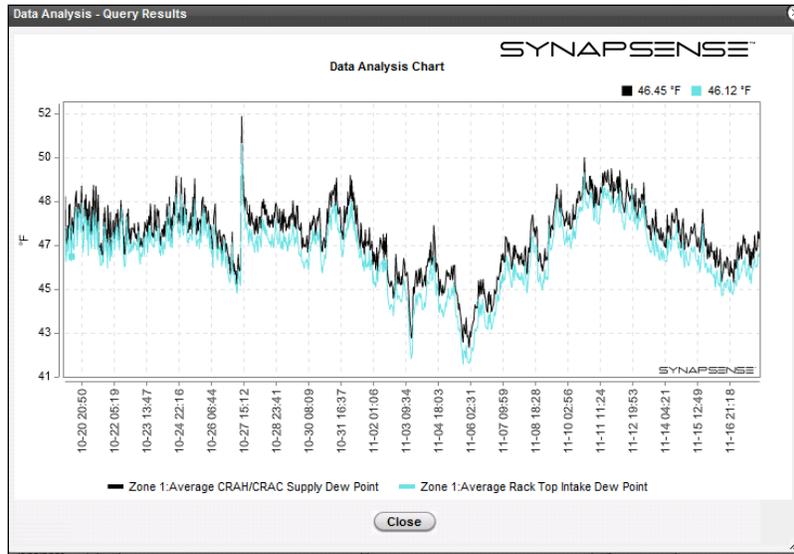


Figure 23. Post-Measures Demo Room Average CRAC Supply Dew Point and Rack Dew Point

Two improvements were achieved by turning off the three CRACs: (1) a reduction in the rack by-pass air, and (2) a lower CRAC air loss ratio (which is a measure of wasted fan energy due to by-pass air mixing with the hot discharge air from the IT equipment and lowering the CRAC return air temperature).

Figure 24 shows the average rack by-pass air and the average CRAC air loss ratio after the three CRACs were turned off during the post-measures baseline period. The graph illustrates the positive effect of turning off three CRACs in the NITC data center.

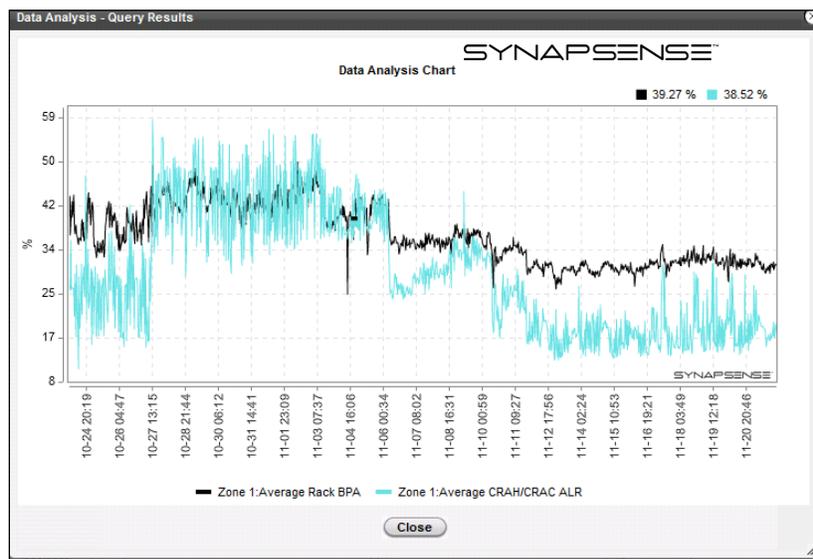


Figure 24. Post-Measures NITC Average Rack BPA and CRAC ALR

The evaluation team turned off three CRACs and rebalanced the raised floor to provide a more uniform and energy-efficient pressure-differential level across the data center floor. The pressure map created after implementing these measures (Figure 25) showed that this strategy was successful.

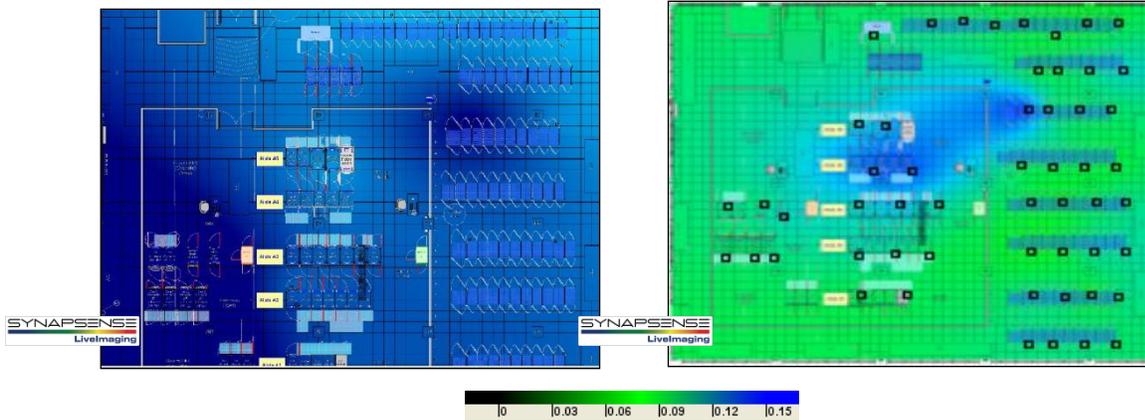


Figure 25. NITC Sub-Floor Pressure Map during the Baseline (image on left) and Post-Optimization (image on right) Periods

Figures 26 and 27 illustrate the positive effect of turning off the three CRACs, which resulted in a lower and more balanced sub-floor pressure.

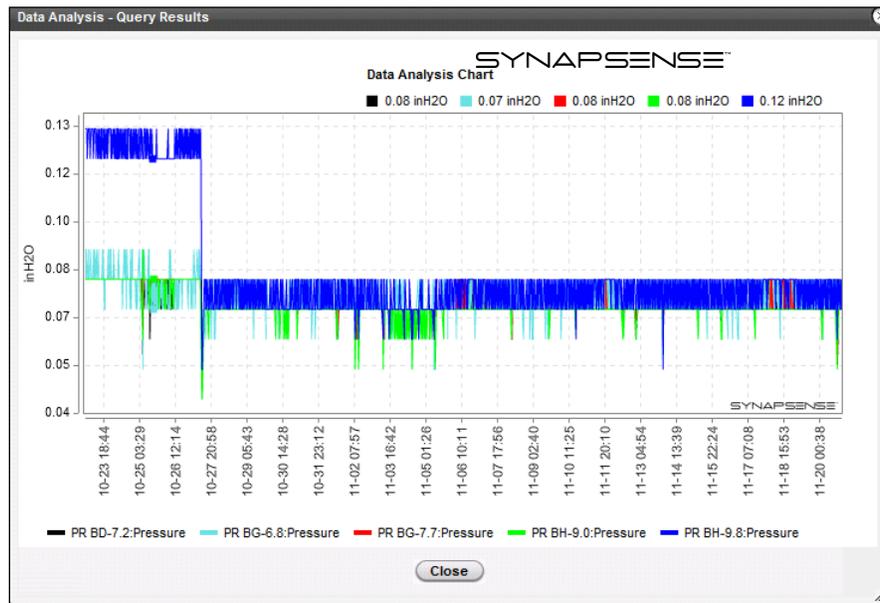


Figure 26. Post-Measures NITC Row B Sub-Floor Pressure

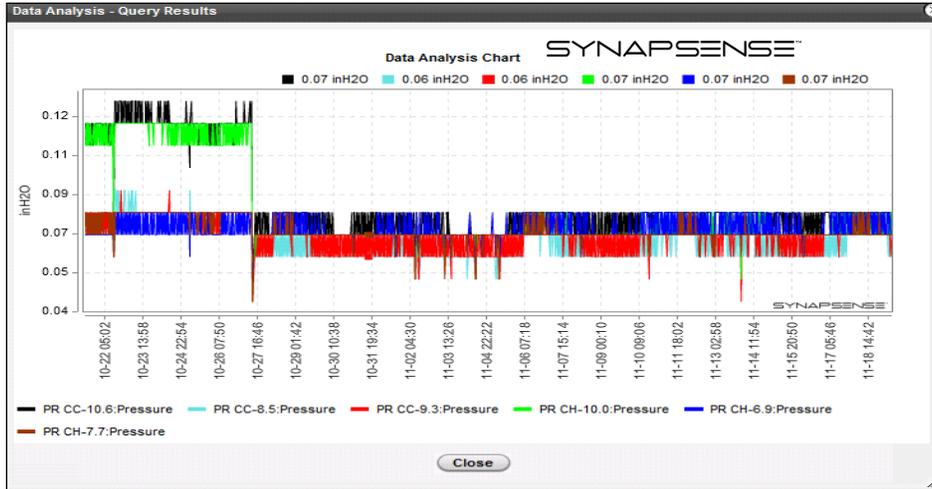


Figure 27. Post-Measures NITC Row C Sub-Floor Pressure

Prior to implementing the recommended air flow optimization and cooling efficiency measures, the sensor data indicated that the data center was being overcooled, with the majority of the racks operating below the ASHRAE-recommended range. Figures 28–31 are graphs of the top rack inlet air temperature for several racks and rows of racks following implementation of the efficiency measures. The graphs illustrate that the rack inlet air temperatures were within the target range of 72°F–79°F.

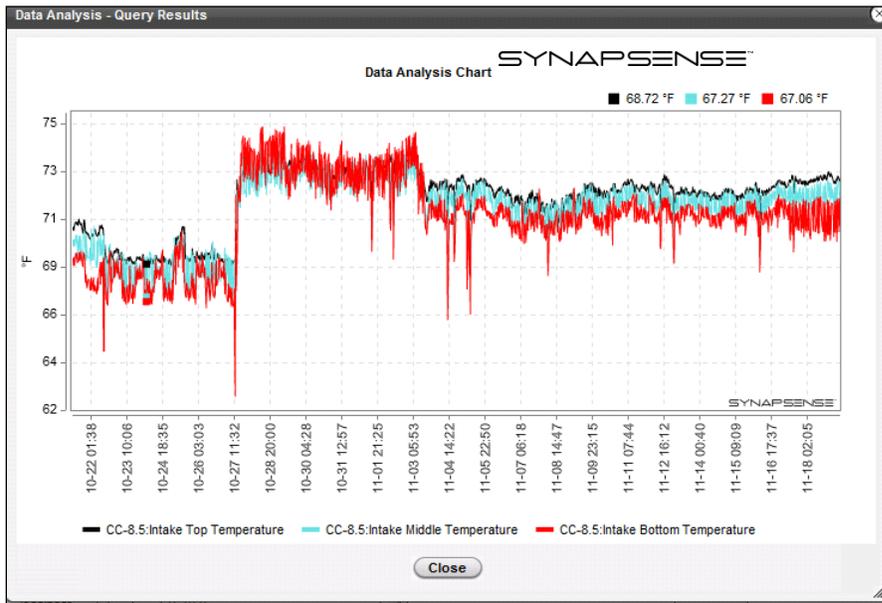


Figure 28. Post-Measures NITC Sample Rack 3 Inlet Air Temperatures

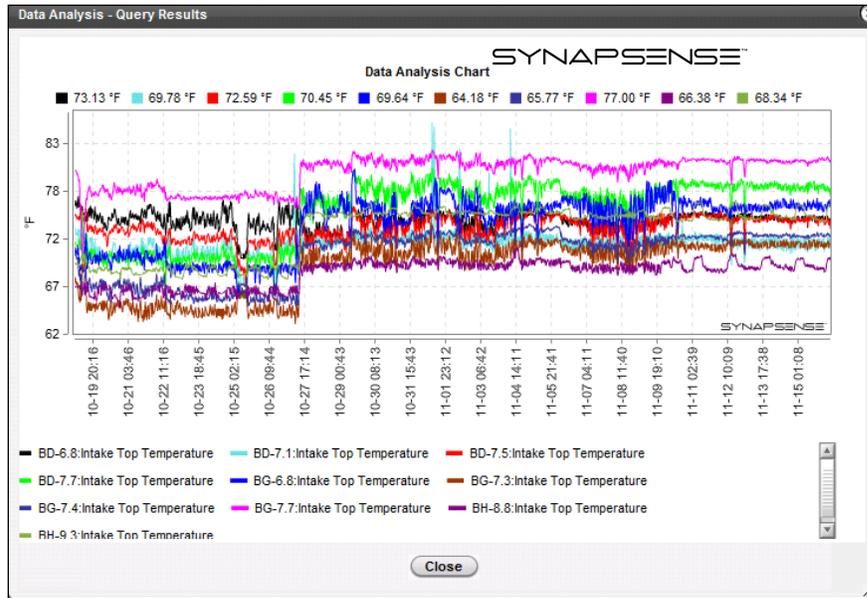


Figure 29. Post-Measures NITC Row B Top Inlet Air Temperatures

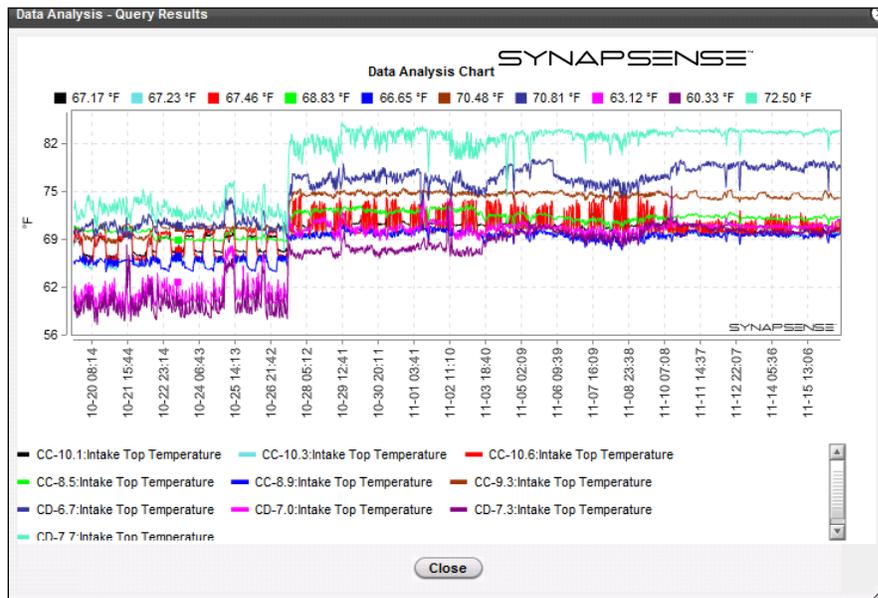


Figure 30. Post-Measures NITC Row C Top Inlet Air Temperatures

Visual inspection after implementation of the air flow optimization of the demo room confirmed that the one rack, CD-7.7 (shown in Figure 30) did not have any equipment mounted in the top third of the rack.

During the baseline period, the average return air temperature was 71.4°F, and approximately 60% of the fan energy was being wasted, due to the low CRAC delta T of 7.9°F. Figure 31 shows the CRAC supply and return air temperatures following the completion of the recommended air flow measures.

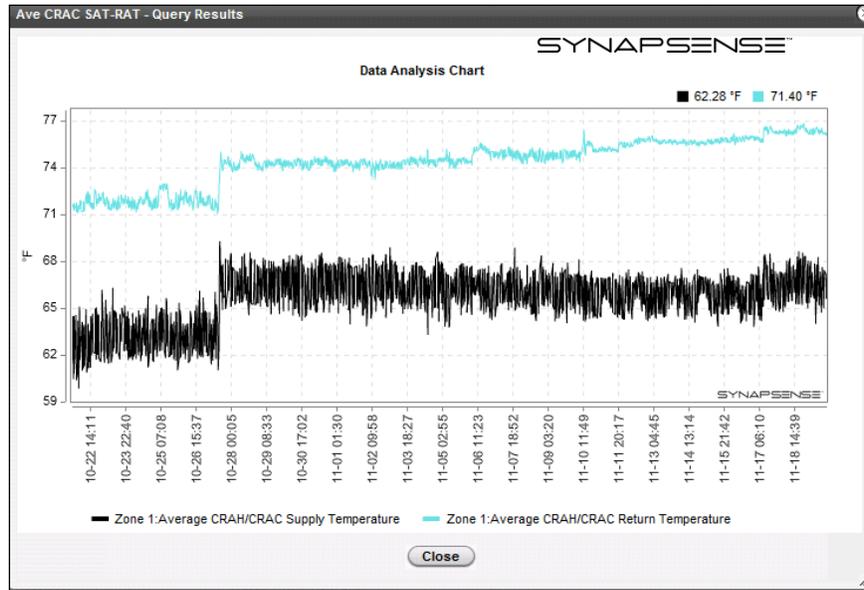


Figure 31. Post-Measures NITC CRAC Supply and Return Temperatures

NITC Demonstration Room Data Center Energy End Use

Table 4 shows the electrical end use breakdown associated with the NITC data center.

NITC Demo Room	Initial Average Load (kW)	Post Assessment Average Load (kW)	Post-Measures kW Change
IT Load	238.0	238.0	0.0
Bldg Trans/UPS Loss	30.0	29.1	-0.9
Lighting Load	6.2	6.2	0
Fans	63.1	42.1	-21.0
Refrigeration/Hum	93.0	39.9	-53.1
Generator Heaters	4.3	4.3	0
TOTAL	434.6	359.6	-75

Table 4. Summary of Post-Measures NITC Data Center Power

The average return air temperature following implementation of the efficiency measures increased to 76.2°F, and the average CRAC delta T increased by 33%, to 10.5°F. The CRAC cooling and humidification energy decreased as a result of turning off three units and disabling dehumidification and reheat. Total cooling energy decreased 75 kW, representing a 48% decrease in cooling energy. The cooling power savings resulted from a 57% reduction in refrigeration/humidification power and a 33% reduction in fan power.

For the data center demo room, the result was a reduction in PUE from 1.83 to 1.51, based on a 17% reduction in total data center power. This represented a 657 megawatt-hour savings annually. These measures also resulted in approximately \$29,900 in annual energy cost savings, based on current local utility rates, and a carbon footprint reduction of 542 metric tons.

Figures 32 and 33 show the baseline energy breakdown for the NITC data center and the same breakdown after implementation of the air flow remediation and cooling efficiency measures.

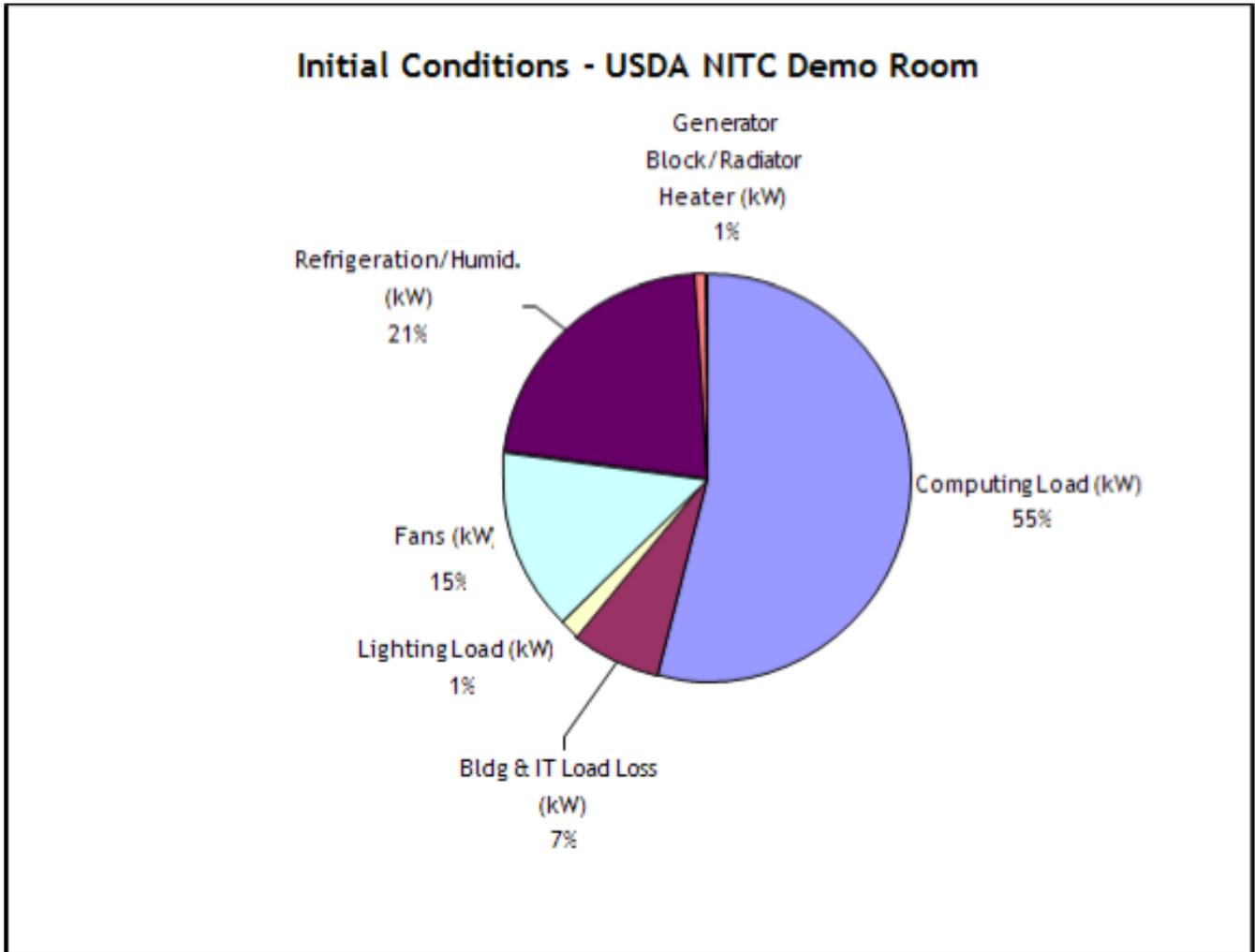


Figure 32. Baseline NITC Data Center Energy Use Breakdown

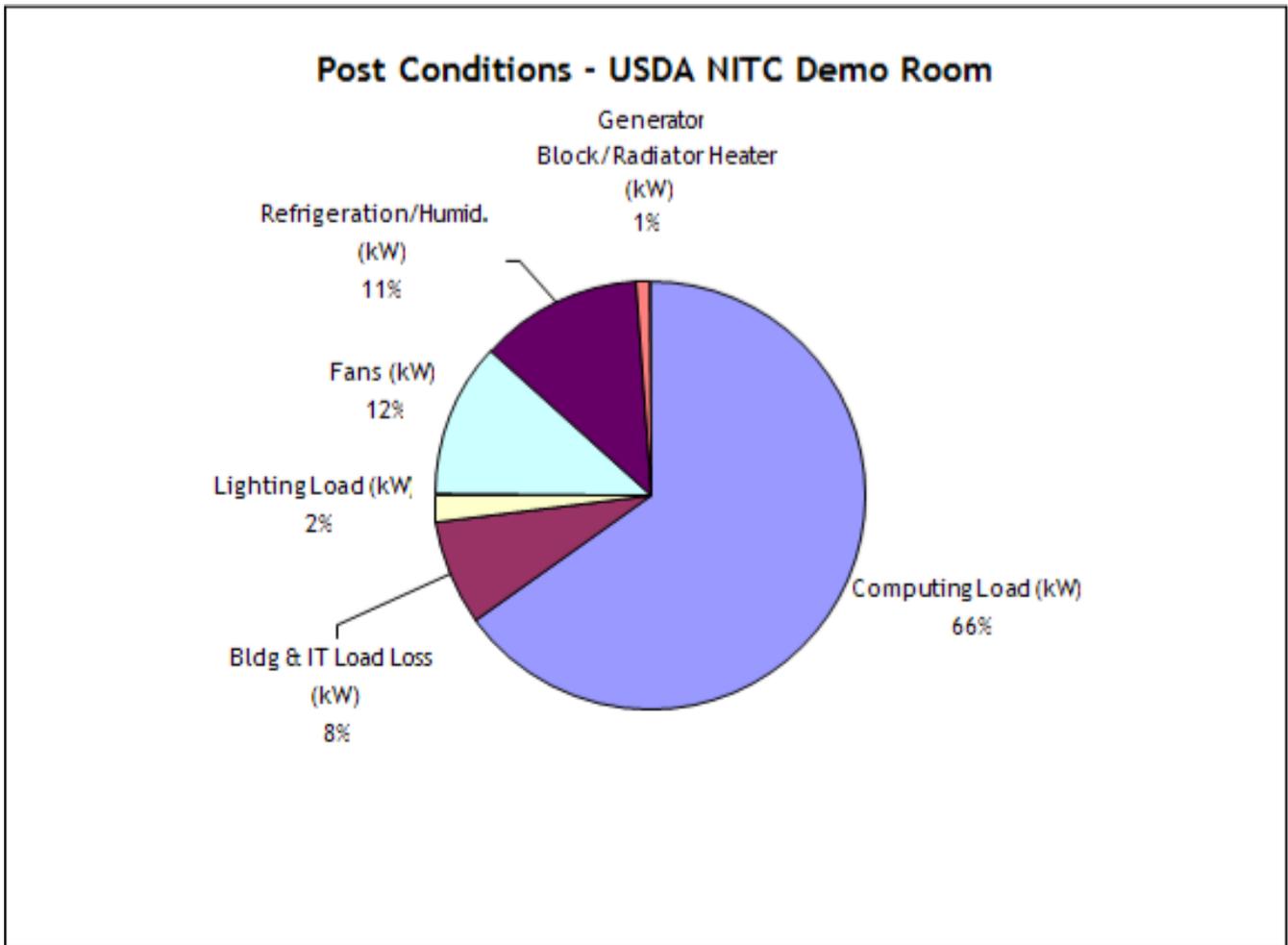


Figure 33. Post-Optimization NITC Data Center Energy Use Breakdown

VII. Summary Findings and Conclusions

A. Overall Technology Assessment at Demonstration Facility

This study confirmed that data center operators and analysts can accurately baseline their facility’s energy performance using a mesh network of sensors to measure environmental parameters and electrical power. It also demonstrated that analysts can input this data into energy assessment software (in this case, the DOE DC Pro Software Tool Suite) to quickly identify energy-efficiency opportunities, even at a data center that is relatively efficient, well operated, and well designed.

Upon implementation of energy-saving measures at the demonstration facility where the technology was evaluated, project team, including facilities staff, was able to reduce cooling energy by 48%, leading to an overall reduction of data center energy use of 17%. Use of wireless technology enabled this network to be cost-effectively deployed in a facility-friendly way. At the demonstration facility, the return on the \$101,000 investment (ROI) was 29%, with a simple payback of 3.4 years.

B. Best Practices

The evaluation team identified the following best practices that are likely to be broadly applicable to achieving improved energy efficiency in typical or even well-managed data centers, based on the study

results. The identification of these best practices can be made easier by using a wireless monitoring system to monitor conditions and create temperature, humidity, and pressure maps that enable operators and analysts to visualize and identify the specific system issues that are causing inefficient operations.

Best Practice: Air Management

It is a challenge to provide air with optimal environmental conditions to cool IT equipment. To optimize air management, it is necessary to minimize mixing of cool or hot airstreams. Mixing can occur via by-pass of cool air around IT equipment (e.g., short-circuiting of cool air) where it is then mixed with the returning hot air, and via recirculation of hot air back to IT equipment, causing higher intake temperatures than desired. Poor air management results in inefficient air delivery to the IT equipment, under-utilization of the cooling system's capacity, and inefficient energy use. Several strategies can be used to avoid or mitigate these issues:

- Configure IT equipment in hot aisles and cold aisles. A hot aisle/cold aisle configuration results in more energy-efficient operation by allowing higher and more uniform temperatures at the inlet to the IT equipment and a higher return temperature to the CRAC.
- Use the monitoring system to quantify and pinpoint air mixing in the data center. Temperature maps can be used to determine the locations of air by-pass and recirculation. Check for stratification in front of the racks, and identify and eliminate hot spots that cause IT equipment to experience inlet air temperatures above the recommended temperature range.
- Use blanking plates in IT equipment racks to reduce mixing of hot air from the rear of the IT equipment with its inlet air. Many times, blanking plates are inadvertently omitted as racks are being populated or equipment removed. This simple fix can quickly improve air management.
- Use wireless temperature sensors at the inlet of IT equipment to identify problem areas (hot spots). Then rebalance the cooling airflow by adjusting the quantity and location of the perforated floor tiles to match the IT cooling demand of the racks. Perforated tiles should never be placed in the hot aisles, since the only environmental conditions that are important are at the intake to the IT equipment. Replace unneeded perforated tiles with solid tiles.
- Ensure that low-flow and high-flow perforated floor tiles are each positioned appropriately. High flow perforated tiles tend to allow the underfloor area to depressurize, resulting in a situation where the cool air does not have enough velocity to reach the top of the racks. Using pressure imaging maps to visualize the pressure under the raised floor will help users identify areas of low pressure and these maps can be used to help identify where high-flow perforated tiles are counter-productive.
- Seal cable penetrations under equipment racks, as well as power and cabling penetrations in sub-floor barriers between data center rooms. Openings under equipment racks or through floors for cabling or other penetrations allow air stream mixing, which leads to inefficient operation through excessive airflow (fan energy) and poor CRAC unit performance.

Best Practice: Optimize Cooling

Data centers are often overcooled due to a lack of understanding of conditions appropriate for IT equipment, or to compensate for poor air management where there is mixing of hot and cool air streams. The following best practices will help in optimizing data center air cooling:

- Operate IT equipment within ASHRAE-recommended or allowable limits, to optimize energy efficiency and ensure reliability. ASHRAE-recommended inlet air temperatures are between 64°F and 80°F. Make sure that a low supply air temperature is not contributing to overcooling.
- Check the air temperatures at the inlets to the IT equipment using the wireless visualization maps. The air temperature at the warmest inlets to the IT equipment should preferably be at the upper end of the ASHRAE recommended range (80°F).
- Adjust CRAC unit set points using the real-time visualization feature provided by the wireless sensing system to safely increase temperatures. Note that many CRAC systems control the temperature of the return air to the CRAC, but by using the wireless sensor maps it is easy to see the effect of changes on the supply air to the IT equipment inlets. The sensible cooling capacity of the CRAC units increases with higher return temperatures. This effectively provides more cooling capacity for each unit, which may enable operators to turn off additional CRAC units.
- Turn off unneeded CRAC units. As improvements are made to air management and supply and return temperatures are increased, the number of required CRAC units will likely decrease. The wireless monitoring system can provide data to both safely increase the supply temperature and to see the resultant effect on return air temperature to the CRACs.

Best Practice: Humidity Control

Humidity control in data centers is problematic. Although ASHRAE Guidelines indicate that humidity ranges can be very broad, many data centers attempt to tightly control humidity. In addition, humidity sensors are notoriously inaccurate, which leads to a situation where the individual CRAC units “fight” each other by humidifying and dehumidifying simultaneously. Since absolute humidity does not change as air is heated or cooled around the data center, ASHRAE focuses on dew point control rather than relative humidity control, since relative humidity will vary around the center. To avoid humidity control conflicts and energy waste, consider the following strategies:

- Turn off CRAC dehumidification and reheat modes to eliminate simultaneous humidification and dehumidification. Disabling humidity control usually has little impact on humidity levels.
- Lower CRAC RH set points to 30% or below. Lowering CRAC return RH set points and turning off their dehumidification and reheat modes can result large energy savings. The wireless humidity sensors and visualization maps can provide assurance that humidity levels are in the desired ranges while making these adjustments.

Best Practice: Optimizing Sub-Floor Pressure

Raised floor systems in data centers rely on relatively high pressure under the floor to force the air through perforated tiles to deliver it to the IT equipment. In practice, however, due to obstructions under the floor, the nature of the floor openings, and other factors, the air pressure is not consistent throughout the data center. This has made placement of perforated tiles a trial-and-error practice. By using a wireless sensing system that provides visualization of the underfloor air pressure, operators can better predict where tiles should be placed, and immediately see the impact of any changes in tile type or location. This supports the following best practices:

- Using the pressure maps, identify variations in sub-floor pressure across the room, and reposition perforated floor tiles to attain a more even pressure. An optimal pressure range of between 0.03 and 0.05 inches of water supplies the best energy balance between air volumes supplied to the IT equipment and CRAC fan energy.

- Using the pressure maps and the IT equipment temperature maps for real-time feedback, rebalance the floor by relocating perforated floor tiles to match the IT equipment air flow and cooling needs.
- Turn off unnecessary CRAC units in high-pressure areas to attain a more uniform and energy-efficient pressure differential across the entire floor. Cover them so that the cold air will not leak into the data center from the pressurized raised floor. Use the wireless monitoring system to visualize the effects of turning off the CRAC units on the under-floor air pressure and to assure that the IT equipment receives the right environmental conditions.

C. Market Potential within the GSA Portfolio

Any energy-intensive building could benefit from more detailed energy and thermal monitoring. Data centers are the most pervasive, energy-intensive use in GSA's portfolio. Applying the findings from the evaluation of the demonstration facility to all tenant-operated data centers in the GSA portfolio yields the following potential reductions: applying a 17% overall reduction in overall data center energy use at a typical federal data center with a 69 watts-per-square-foot (W/sf) IT load and a PUE of 1.94 (average for all of GSA's data centers) will result in annual savings of \$21.50/sf (assuming \$.11/kWh).¹⁴ The PUE for this example was reduced to 1.51.

There are more than 1,400 data centers operated by tenant agencies in space leased from GSA. The total area of this space, excluding server closets with area less than 500 sf, is 3.6 million square feet. Assuming that 80% of the total area is the actual computing space ("white space" determined by deducting administration, storage, and electrical/mechanical areas), and assuming 69 W/sf of IT equipment load in the white space, the total IT power load administered by GSA is estimated at 200 megawatts, and the total power load including infrastructure is estimated at 385 megawatts. After implementation of these types of energy-efficiency measures in these data centers, assuming the 17% energy use reduction, 557 million kWh in total annual energy use could be saved. The corresponding annual cost savings would be \$61 million and the carbon emission reduction would be 532,000 metric tons.

To realize these savings, the evaluation team recommends that agencies not currently collecting performance data acquire and deploy wireless sensor technology to help identify efficiency opportunities and collect the performance data needed to develop improvement plans for their data centers, as they are mandated to do under the Federal Data Center Consolidation Initiative.

D. Installation and Commissioning at Demonstration Facility

The installation of the environmental sensors was non-intrusive and non-interrupting to data center operations; however, this was not the case for power meters. The shutdowns required to install power meters in electrical panels interrupted the data center operations and delayed the assessment until appropriate shutdowns could be scheduled for IT equipment refresh, maintenance, and other modifications. Consequently, a long time was required to install the meters, and this increased cost.

Once the network of environmental sensors and power meters was successfully deployed and integrated, the evaluation team identified opportunities for improved operation, and the facility implemented the resulting energy-efficiency measures. With every measure implemented, the team immediately mapped the impact, to show the success or failure of each action toward optimizing air distribution and meeting other energy-efficiency goals. While installing temperature sensors in front and back of the servers, the evaluation team was careful not to disturb access to the servers by the IT staff.

¹⁴ Average numbers for the GSA portfolio according to GSA's Office of Innovative Technology, as of October 2011.

E. User Acceptance

Installation of the power meters were scheduled to coincide with typical maintenance downtime, which delayed the project, but accommodated the critical nature of the facility. There were no major impacts on the reliability of the IT or infrastructure equipment because of the assessment activity.

The USDA, which operates the facility, has a firewall policy that does not allow USDA managers, the installation contractor, or energy consultants to view the monitoring system's real-time information outside of the data center. The USDA nonetheless reported that they find the technology valuable, and would deploy it again, because it helped on-site staff further observe the opportunities for changes that would enable energy savings and to understand the effect of recommended measures.

F. Barriers and Enablers to Adoption

Potential interruption in operation of critical building systems is a barrier to use of this technology, since multiple shutdowns are required to install power meters. In the demonstration facility, for example, this delayed the assessment process and added cost.

To improve applicability of the technology, the evaluation team worked with SynapSense, the vendor of the technology evaluated, to develop an assessment kit that does not require major shutdowns but still provides most of the benefit. Although assessments typically recommend a permanent and more robust monitoring system, use of a wireless sensor technology assessment kit delivers many of the initial benefits of such a permanently installed system by providing a similar granular view of key data center operating parameters, while not interrupting facility operation. If this limited monitoring illustrates the benefits of an ongoing real-time monitoring, then the data center operator can pursue installation of a full system as part of other planned maintenance or retrofits at a later date. A sample specification for such an assessment kit is described in greater detail in Appendix A.

VIII. Appendix A - Assessment Kit Specification

Data center operations can be disrupted when conducting a complete energy assessment where power meters are used to accurately determine electrical losses and end use. As observed in the USDA assessment and other similar assessments, the need to shut down electrical equipment to install power meters can delay the assessment until an appropriate shutdown can be scheduled for an IT equipment refresh, maintenance, or other modifications to the center. It also increases the cost of the assessment. This experience led to the creation of a portable assessment kit that is not intrusive to data center operation.

Use of a temporary wireless mesh assessment kit can speed the assessment process and overcome the issue of installing power meters on “live” equipment, while providing much of the key information needed for a successful assessment at a lower cost. In using this approach, power is determined in other ways in lieu of metering. Existing power metering information is used where available, and power use is determined by various means for the remainder. IT equipment load is typically determined through a UPS readout or other power distribution unit displays. Chiller plant loads can be determined based on a kilowatt-per-ton estimation. Electrical distribution power loss through UPS systems or power distribution unit transformers can often be determined by a direct readout or through manufacturer performance curves. Estimates of lighting loads can be determined through fixture count or typical watts per square foot, and standby generator block heater electrical use can be estimated using manufacturer specifications.

The assessment kit supports a rapid assessment to identify energy-efficiency measures, one of which would likely be to install a full wireless monitoring system to achieve the optimization results outlined in this case study. The kit can be used for retro-commissioning, enabling visualization of problem areas, resulting in immediate savings when the issues are corrected. It also provides the owner/operator a glimpse of the long-term benefits of real-time energy and environmental monitoring. The assessment kit includes temperature, relative humidity, and pressure sensors, as well as power meters that can be installed on a representative CRAC which, due to its redundancy, can usually be shut down (providing site policies permit such installations).

Subsequent to the USDA facility evaluation, Lawrence Berkeley National Laboratory has successfully employed the assessment kit in several other data centers where the data obtained through the monitoring system has been useful in identifying efficiency opportunities and enabling the site staff to visualize data center conditions.

Below are images courtesy of SynapSense Corporation representative of the sensors and gateway included in such an assessment kit:

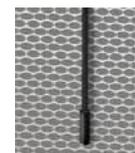
Thermal Node:

Temp/Humidity/Dew Point, 6 external sensors

Can be connected. Wireless communication with Gateway.



External Temperature Sensor:





Pressure Node:

Differential air pressure using two filtered heads, one under and one above raised floor. Connects to the unit with hoses.



Gateway Node:

Ethernet connectivity to server; 120v power supported

Gateway communicates wirelessly with temperature/humidity nodes on racks, CRAC, and pressure nodes. Connects to server via Ethernet.

Although the wireless system installation is relatively easy, an assessment plan should be developed to determine the monitoring locations. This plan will vary, based on the size of the center, equipment type, diversity, redundancy, layout, and other site-specific factors. During assessments of other data centers, the assessment kit was further evaluated; based on this experience, additional changes were made to the kit.

The assessment kit is designed to acquire the monitored data required for a detailed energy assessment baseline of the data centers. Focusing on environmental parameters, the assessment kit allows easy comparison to industry-recognized thermal guidelines, i.e., ASHRAE-recommended values. By monitoring conditions at the inlets to the IT equipment, air distribution problems can be uncovered. Ultimately, the goal is to supply all of the IT equipment with cooling that meets the ASHRAE’s TC9.9-recommended limits for Mission Critical Facilities, Technology Spaces, and Electronic Equipment, as shown below:

At IT Equipment Intake	Recommended	Allowable
Temperature, Data Centers	65°–80°F	59°–0°F
Humidity, Data Centers	42°F DP–60% RH or 59°F DP	20%–80% RH and 63°F DP

Table A- 1. Environmental Ranges (as adapted from ASHRAE thermal guidelines, 2011)