U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FEDERAL ENERGY MANAGEMENT PROGRAM

Wireless Sensors Improve Data Center Energy Efficiency

Technology Case-Study Bulletin: September 2010

Figure 1: Wireless temperature sensors at LBNL.

1 Introduction

As data center energy densities, measured in power-use per square foot, increase, energy savings for cooling can be realized by applying wireless sensor network (WSN) technology and using the gathered information to efficiently manage the data center. A wireless sensor technology system is a network of sending and receiving devices that provides the data center operator with a real-time tool to observe and manage space-conditioning energy. A wireless sensor array and receiving devices were installed in an older "legacy" data center at Lawrence Berkeley National Laboratory (LBNL) as part of a comprehensive energy efficiency retrofit. Numerous performance improvements were identified that contributed to cooling energy-use reduction. These improvements were facilitated by real-time feedback from the meshed sensor network that enhanced and verified floor-tile tuning, blanking-plate installations, and identification of redundant cooling units. This technical bulletin includes an overview of wireless sensor technology and the implementation experience and lessons-learned from the wireless network installation project at LBNL.

2 Wireless Sensor Technology Overview

In most buildings, space conditions are controlled and coordinated by a building automation system (BAS). A BAS can provide temperature visualization information with dashboard displays through a person-machine interface (PMI). However, in most data centers, space-conditioning is achieved with multiple, independently-operating cooling units located within the space. Unfortunately, these data centers do not have adequate automation systems or visualization tools to monitor or manage these cooling units efficiently.

In 2001, an emerging technology was demonstrated at University of California, Davis by Dr. Raju Pandey that "meshed" temperature sensors into a network using wireless Wi-Fi™ communication. The WSN had "self-organizing" nodes that established communication with gateway devices. The gateway devices received and processed data gathered from the mesh network. Through a user interface, the data center operator manipulated the data into information to help understand environmental conditions in the form of discrete points, trends, and other graphical representations. This technology was developed into a commercially available system that was deployed at LBNL.

A WSN can be useful for debugging hot-spots, benchmarking, capacity planning, and conditioning-system forensics including alerts and alarms. The non-invasive wireless system installation can measure and trend air or water temperature, humidity, air or water pressure, liquid volume flow, liquid presence, air particle count, electrical current, electrical power, and other data. Some WSN topologies can generate graphical representations of temperature profiles within the data center, called "heat maps." Further, some network system manufacturers promote that when integrated control over all cooling units in the data center is achieved, their system can "learn" to optimize cooling device operations to accommodate high server loads in specific rack locations.

2.1 Basic Operation

WSNs enable real-time decisions to operate a data center at peak efficiency. This real-time capability stems from the wireless sensor devices streaming data packets to gateway devices that relay the data to software for visual display and interpreted for operational adjustments. To attain beneficial operational adjustments, three basic issues need to be addressed when specifying and installing a WSN:

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Overall reliability

Overall reliability is a measure of data loss of the communication link between battery-powered sensors and the gateway device nodes. Accordingly, a good indication and measure of reliability is the signal strength of the wireless sensor at the gateway device. Signal strength depends greatly on wireless sensor location, which can interfere with uploading data from the sensor to the gateway. Interference can be caused by many situations including: physical barriers, such as steel beams; electrical noise from variable frequency drives; RF (radio frequency) noise from scientific apparatus; and other wireless devices using Wi-Fi (wireless fidelity) IEEE 802.11 standards in a wireless local area network (WLAN). It is recommended to perform a field test of sensor locations to ensure reliable operations.

Sensor battery life

A remote, wireless sensor device relies on an internal battery to send data to a gateway device. When installing a WSN, battery life must be considered during the configuration of the senor device. Sensor device battery life is primarily affected by the data reporting rate to a gateway device. The reporting rate is also referred to as the network latency, which is the response time that results in a data packet being sent to a gateway. Additional factors affecting battery life are the sensor's transmit power (selectable in some sensor types), the level of data encryption for security (usually set at 128-bit AES {Advanced Encryption Standard}), and idle-mode power consumption.

Interoperability of gateway

The gateway device receives the data packets and processes them to provide information to the data center operator through an internet connection. The protocol for handling these data within the gateway can vary from one wireless sensor manufacturer to another. Therefore, interoperability of the protocol over a common, non-proprietary interface would allow future upgrades and installations that would include legacy installations. Gateways have numerous hardware output interfaces, such as digital I/Os, USB, RS-232, mechanical relays, that facilitate connection to existing (or expected) BASs. There are a multitude of software interfaces, such as TCP/IP over an Ethernet connection, that will provide real-time feedback to the data center operator. WSN vendors can also offer specialized interfaces that can enhance de-bugging cooling issues, plan cooling capacity expansions, and map cooling performance without compromising interoperability.

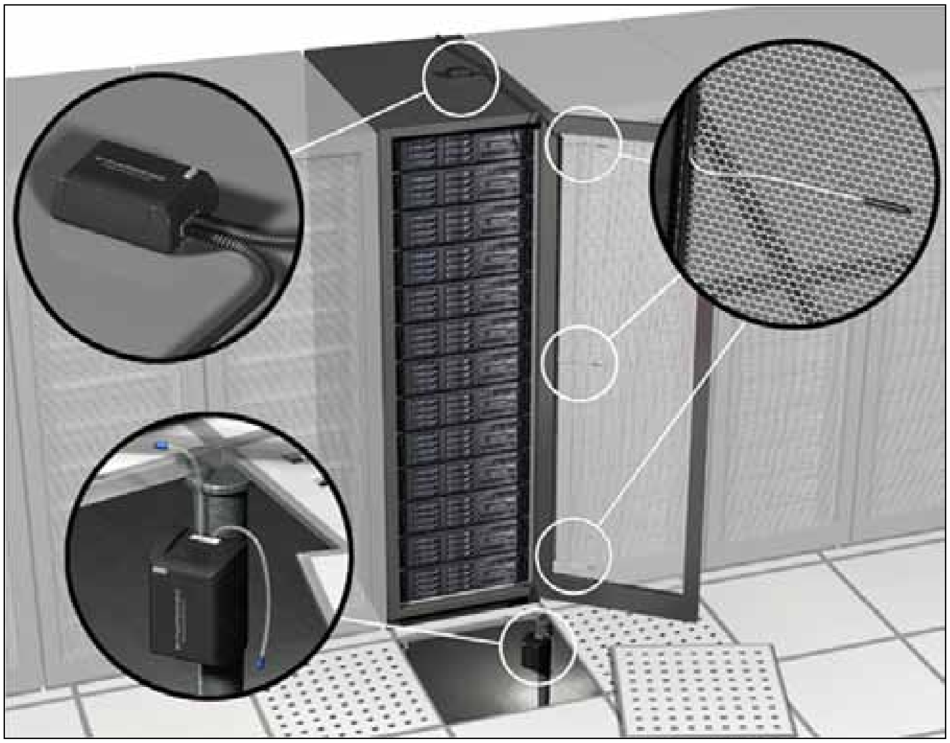

Figure 2: Wireless temperature sensors; top of rack, under-floor, server inlet. Courtesy: SynapSense Corp.

2.2 Technology Benefits

Many practical benefits can be realized by using a WSN. A brief list is provided:

- Cooling performance visualization through software.
- Humidification requirements.
- Floor-tile tuning.
- Hotspot identification.
- Historical data trending.
- Preventative Maintenance prediction.
- Multiple CRAC/CRAH unit operational control and coordination.
- Real-time Power Usage Effectiveness (PUE) calculation.

3 Implementation Experience at LBNL

At LBNL, the project included installing a WSN with approximately 800 monitored points including air temperature, relative humidity, under-floor air pressure, and electrical current and power. For the first time, the LBNL data center operators gained a detailed understanding of environmental conditions in the data center. Real-time and historical graphs and trends were available. The selected wireless sensor manufacturer installed the wireless sensors into a "meshed" network for increased reliability including:

- "Self-organizing" nodes.
- 802.15.4 (not 802.11) IEEE communication standard.
- Multi-hop node routing; relaying data to more than node to improve gateway communication.
- Non-invasive installation.

- 2 internal (one air temperature and one humidity) & 6 external sensors per node.

3.1 Energy Saving Improvements

With the WSN installation, operators of this LBNL data center achieved energy-efficiency by:

- Increasing data center setpoint temperature.
- Optimizing control coordination of CRAC units.
- Eliminating humidification systems, which can have unintended, simultaneous operations.
- Improving floor tile arrangements & server blanking.
- Installing hot-aisle or cold-aisle isolation systems.

The data center operators immediately confirmed the positive results of these actions through the visualization software provided by the wireless system manufacturer. All of these improvements increased the cooling system capacity of LBNL's existing data center, which uses under-floor air distribution, and helped avoid the complexity and cost of installing new, additional cooling capacity.

3.2 Technology Results

The demonstrable results and benefits achieved at LBNL included:.

- Visualizing thermal performance: observing thermal profiles above and below floor in real time; heat mapping (Figure 3).
- Learning from sensors: instant feedback when installing blanking panels (Figure 4).
- Tuning floor-tile locations: balancing under-floor airflow to eliminate hot spots (Figure 5).
- Focusing on a single sensor: watching impact of floor tile opening (free hole area) (Figure 6).
- Verifying the impact of maintenance: trending data during maintenance (Figure 7).
- Determining the need for humidification: monitoring relative humidity and power consumption (Figure 8).
- Providing instant feedback: real-time information on data center anomalies (Figures 9 & 10).
- Real-time PUE calculation: calculates Total power consumption including thermal BTU monitoring and compares IT power consumption (reciprocal to Data Center Index of Efficiency, DCiE) at 15 minute intervals (Figure 11).

An example of each result is provided below.

3.2.1 Visualizing thermal performance

Heat map temperature profiles shown are at the top, middle, bottom level of server rack and below the subfloor at one instant in time. The real-time map, or an archive, is displayed by the wireless sensor system software as movie. A color legend is provided; note that map legend is in degrees Fahrenheit (Figure 3).

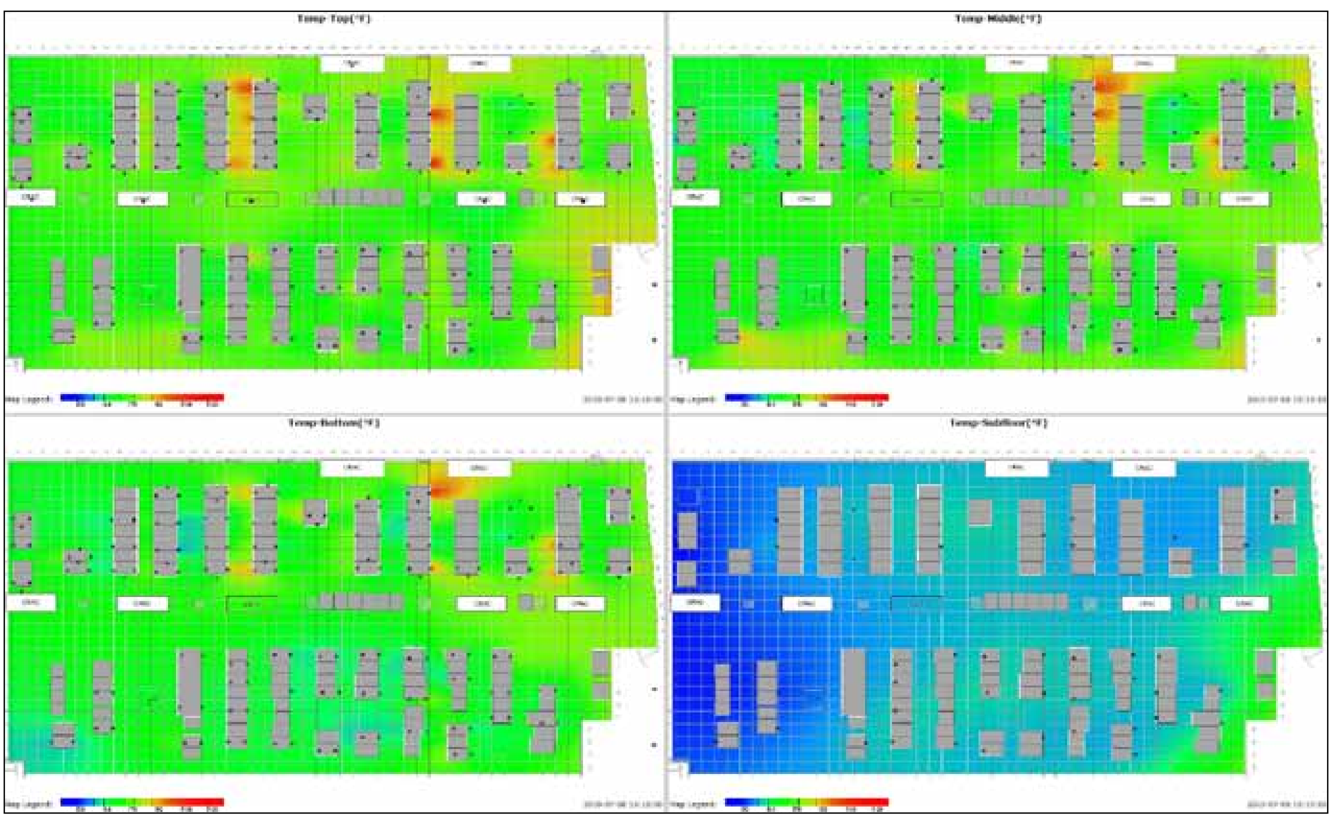

Figure 3: Data Center Heat Map from wireless sensors. Courtesy: SynapSense Corp.

Map Legend: 50 64 78 92 106 120

3.2.2 Learning from the sensors

Rack blanking panels can significantly affect server air inlet temperature. When a blanking panel is not installed, warm air exiting from the server can short-circuit back to the front of the server rack. Consequently, the server air inlet temperature will be increase due to the mixing of the short-circuited airflow. Figure 4 shows the result of adding one 12" blanking panel to the middle of a rack to eliminate the short-circuit pathway. Without monitoring and visualization, this process becomes guesswork.

3.2.3 Tuning floor-tile location

Optimizing airflow from a data center under-floor air distribution system is quite difficult. Tile opening size and placement need to be arranged so that airflow is delivered to server hot spots in the data center. However, this result is not always achieved by increasing the number of outlet tiles, or opening them, in the hot spot area. Rather, this result is preferably achieved by removing or closing outlet tiles in areas that are overcooled. When outlet tiles are removed or closed, there will be a resulting increase in under-floor pressure and a decrease in rack-top temperatures (Figure 5). Note that outlet tiles should always be removed from hot-aisles, where the servers discharge heated air, and be replaced with solid tiles.

At LBNL, under-floor air pressures were increased with floor-tile tuning and a major airflow management retrofit, which included redirection of overhead cold air supply under the floor (see airflow management Technical Case Study Bulletin). These efforts resulted in an under-floor air pressure increase that ranged from 300 to 900 percent. The wireless system enabled trending and verification of the improvements throughout the retrofit project.

3.2.4 Focusing on a single sensor

Positioning floor tiles can be an iterative process. Therefore, monitoring single server inlet air temperature sensor of the wireless sensor system can expedite this process. Also, by using a laptop within data center while adjusting tiles, the monitoring capability provided instant feedback for when the inlet temperature was too cold, too hot, and eventually, just right (Figure 6).

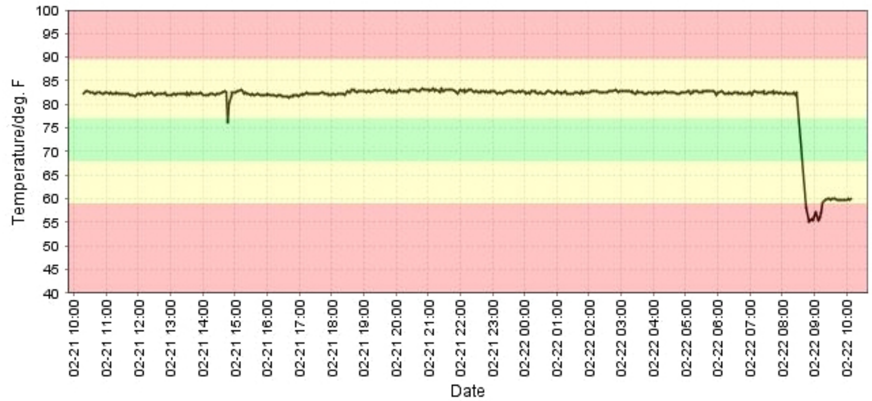

Figure 4: Learning from sensors; server air inlet temp. Courtesy: SynapSense Corp.

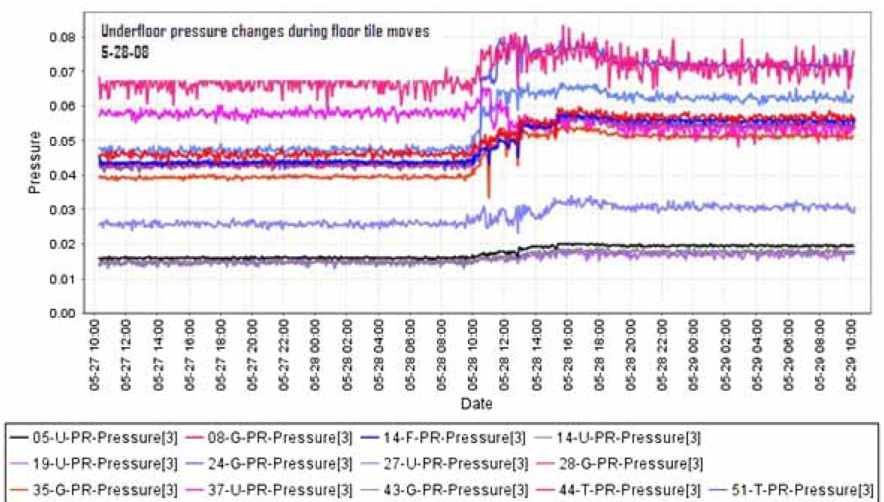

Figure 5: Under-floor pressure improvement from floor-tile tuning. Courtesy: SynapSense Corp.

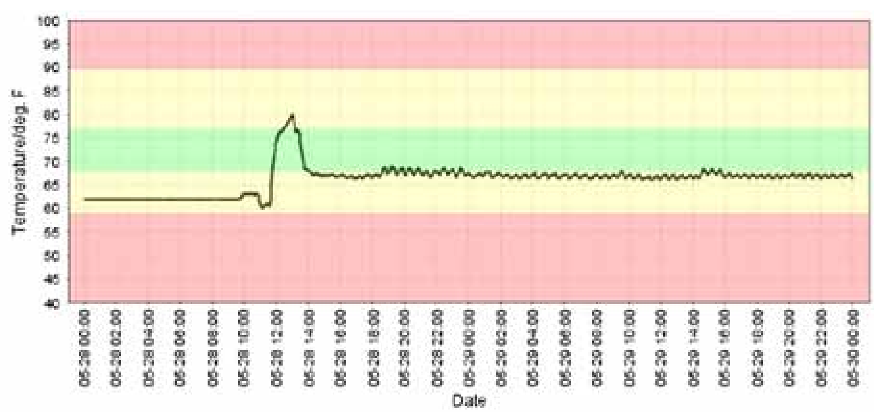

Figure 6: Results from observing one sensor during floor-tile tuning. Courtesy: SynapSense Corp.

3.2.5 Verifying the impact of maintenance

Maintenance service was performed on the CRAC units in the data center after the wireless sensor system was installed. The real-time feedback capability of the wireless system enabled data center operators to learn about the cooling characteristics of each individual CRAC unit. They were able to identify each CRAC unit's relative contribution to cooling the data center. This was achieved by monitoring both under-floor pressure and known hot-spot temperatures as each CRAC unit was turned off, in turn, for service (Figure 7). Notably, many CRAC units were not performing to expectations due to slipping fan belts. An additional benefit from monitoring during maintenance was knowledge gained regarding the redundancy characteristics of the CRAC units in the data center.

3.2.6 Determining the need for humidification

The ability to eliminate humidification by CRAC units in a data center can result in large energy savings. However, without monitoring, operators cannot determine the impact of turning off CRAC unit humidity control. The wireless sensor system enabled the data center operators to monitor relative humidity in real-time. Accordingly, disabling the humidification system in the CRAC units allowed the operators to observe the effect. Turning off humidification resulted in a negligible reduction in humidity, but an impressive 28 percent drop in CRAC unit energy use (Figure 8).

3.2.7 Providing instant feedback

LBNL data center operators have realized surprising benefits from the instant feedback capabilities of the WSN. Combined with a commitment to regularly review the wireless network data, an ongoing monitoring-based commissioning (MBCx) process has become part of the data center operators daily routine. An example of a successful MBCx effort lead to an interesting discovery. An unusual temperature rise was observed from a particular set of server-inlet temperature sensors (Figure 9).

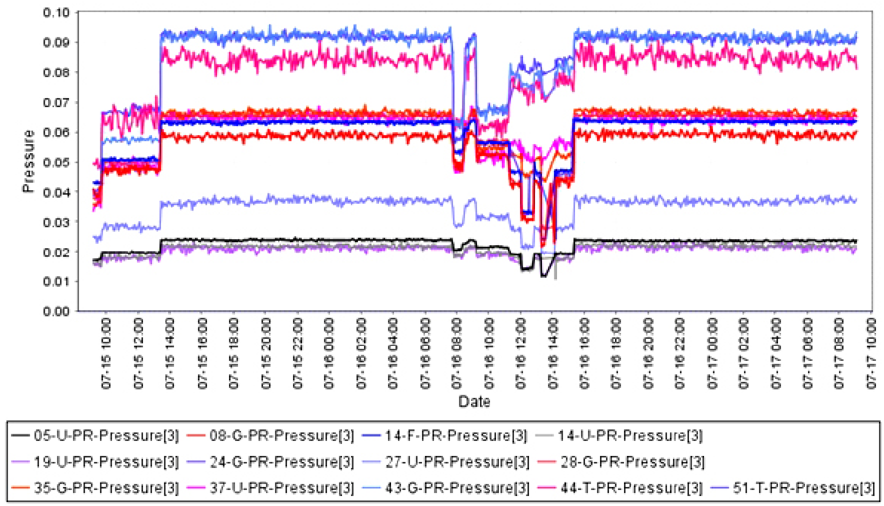

Figure 7: Verify the impact of CRAC maintenance by observing under-floor pressure. Courtesy: SynapSense Corp.

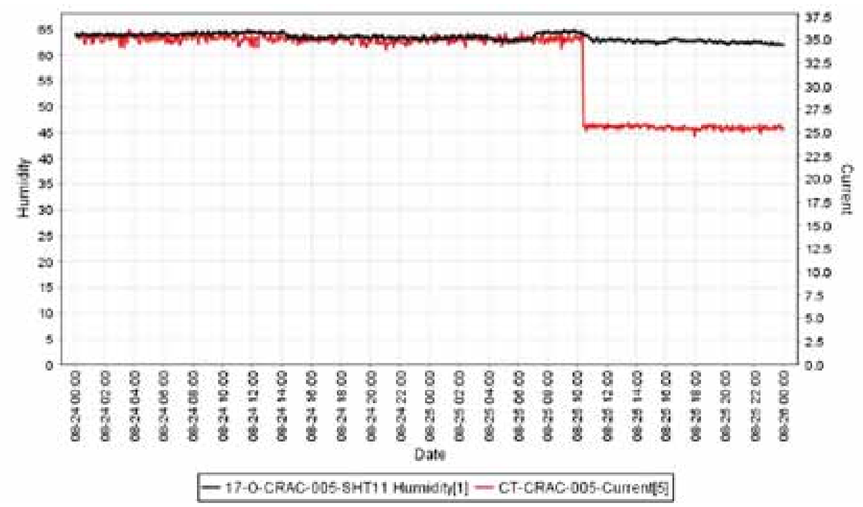

Figure 8: Measuring relative humidity and electrical power. Courtesy: SynapSense Corp.

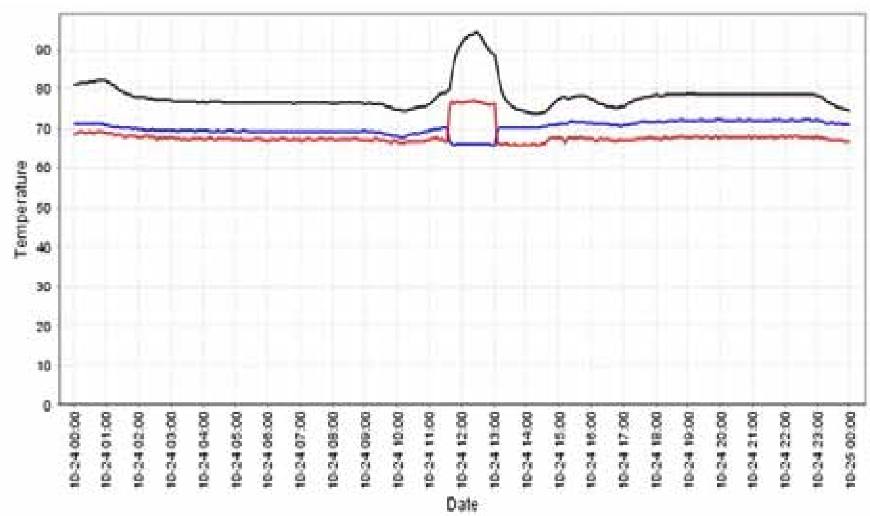

Figure 9: Unusual temperature profile observed. Courtesy: SynapSense Corp.

Figure 10: Cause for unusual temperature profile discovered.

Upon inspection, it was discovered that a service cart was left in front of the server rack that obstructed cold-aisle air flow, causing the unusual rise in temperature (Figure 10).

3.2.8 Real-time PUE calculation

Working closely with the wireless sensor company, outside engineering consultants, and LBNL internal scientific, IT, and facilities personnel, the data center operators had sufficient sensing and monitoring instrumentation installed to track their total energy use compared to the center's IT energy use. This comparison, known as the power usage effectiveness or PUE, is a metric used to determine relative data center performance. Thirty wireless energy-meter nodes facilitated the real-time gathering of these data, while only five Modbus™ — and one SNMP (simple network management protocol) — hardwired meters were required. In Figure 11, it can be seen that the LBNL data center was operating at a PUE of 1.49, which means that 67 percent of the electrical energy being consumed was for IT server operation, while the remaining 33 percent was for HVAC, lighting, and other infrastructure.

Figure 11: Calculated Real-time PUE. Courtesy: SynapSense Corp.

4 Lessons Learned

The energy-efficiency project at LBNL provided lessons-learned that may be relevant to other WSN installations. One anticipated result was that excess cooling capacity would be recovered within the data center. The newly found capacity required coordinating CRAC unit cooler operation. The newly installed wireless sensor system became an integral part of coordinating and optimizing CRAC unit operation. Additional lessons were learned that are summarized below.

4.1 Maintain Airflow Devices

Regular preventative maintenance, inspection, and tune-ups are highly effective in reducing energy waste in data centers. A sizeable increase in airflow was verified with the wireless sensor system from basic maintenance. In particular, CRAC fan belts were found to be loose and slipping by LBNL facilities personnel. During these maintenance procedures, redundant capacity cooling units were identified with the aid of the wireless sensor system. These CRAC units were turned off for later use as backup units.

4.2 Manage Energy with Metering

The LBNL energy-efficiency project clearly validated the old energy-use axiom that generally states that you cannot manage energy without monitoring energy. Essential metering and monitoring is provided by the wireless sensor system. The system installation resulted in reliable energy consumption data and trend information that contribute to the persistence of data center performance over time.

4.3 Supervise Performance with EMCS

An energy monitoring and control system (EMCS), or other building monitoring system, should be used in conjunction with a wireless sensor system. Prior to installing energy efficiency retrofits, the wireless system augments gathering air temperatures and developing trend information. Afterwards it ensures persistence of the retrofits. At LBNL, the newly-found cooling capacity required coordinating existing CRAC unit operation to allow shutdown of redundant CRAC units. This was achieved by manual control of the existing CRAC units; no centralized control system was available.

In addition, standard CRAC return-air control methods, which are beyond the scope of this bulletin, can present a challenging situation.

4.4 Optimize Rack Cooling Effectiveness

Data center operators should consider the following items to maximize rack cooling effectiveness:

- Match under-floor airflow to IT equipment needs.
- Locate higher density racks near CRAC units and verify airflow effectiveness.
- Locate severs to minimize vertical and horizontal empty space in racks.
- Consolidate cable penetrations to reduce leaks.
- Load racks bottom first in under-floor distribution systems.
- Use blanking plates and panels.
- Eliminate floor openings in hot aisles.
- Establish hot and cold airstream isolation.

Energy Savings Achieved at LBNL with improved control and monitoring:

1. Increased server inlet air temperature setpoint by ~10F = ~330,000 kWh/year
2. Turned off one CRAC unit = ~ 165,00 kWh/year
3. Turned off humidification devices = ~148,000 kWh/year

Total estimated savings = ~643,000 kWh/year

WSN Cost at LBNL

Demonstration project cost for mix of thermal, pressure, and gateways estimated at $70 per point
Approximately 800 points were installed

Total estimated cost = $56,000

Simple Payback at LBNL: Estimated at $0.06/kWh = 1.5 years

5 References

Hydeman, M. "Lawrence Berkeley National Laboratory (LBNL) Case Study of Building 50B, Room 1275 Data Center from 2007 to 2009." Taylor Engineering, LLC. December 2009.

6 Acknowledgements

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