# Wireless Sensor Technology for Data Centers

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## ABSTRACT

This paper describes the development and impacts of a new wireless sensor technology for data centers. Due to the critical nature of data processing equipment, and a lack of detailed real-time information on conditions within data centers, most facilities are over-cooled significantly to compensate for hot and cold spots within the building. This new wireless sensor technology will allow facility managers to evaluate and monitor real-time energy use within a data center, and benchmark their facility using an algorithm developed by DOE and LBNL (Green Grid Metrics: Describing Datacenter Power Efficiency Technical Committee White Paper, February, 2007). The result includes an energy efficiency report with specific recommendations for increasing energy efficiency and the corresponding GHG (Greenhouse Gas) reduction potential. The paper provides results of an application of this new technology by a utility at their data processing center.

The paper also illustrates an innovative approach taken by a publicly-owned utility for helping to achieve ambitious goals for increasing energy efficiency, and promoting environmentally sustainable local and global development. This utility has partnered with a wireless instrumentation company to promote development of this new technology. The utility implemented this technology at its own facilities to demonstrate data center energy savings potential. Since the technology is produced by a local company, future growth of this technology represents a significant potential source of clean sustainable local economic development, and a way for the utility to help achieve its community's goal of contributing to broader global environmental challenges.

## Background

The purpose of the demonstration project is to assess this new wireless sensor technology for data center environments. This study will baseline the energy use within this facility and provide an energy savings potential report to include the avoided carbon emissions potential SynapSense Wireless Green Data Center Solution (www.synapsense.com) was leased and installed in the Sacramento Municipal Utility District's (SMUD) data center with the intent to investigate the technology. Further investigation will include the application of this technology at three additional commercial data centers. With these projects, SMUD staff will be able to assess the capability of this wireless technology, study issues around energy benchmarking of data centers, and investigate continuous commissioning of data centers. Specific items include:

**Product Evaluation**

- Determining current energy costs
- Energy savings potential
- Ease of installation and maintenance of technology
- Cost-effectiveness
- Customer satisfaction
- Carbon emission reduction potential

**Energy Assessment**

- Energy issues associated with the data center and potential solutions
- Improvement of airflow by reducing supply and return air mixing
- Improving cooling efficiency
- Implementation of energy saving recommendations

**Continuous Commissioning**

- Continuous optimization of energy efficiency measures
- Balance data center IT (Information Technology) equipment load to the data center cooling capacity to increase space utilization and capacity

The SynapSense Wireless Green Data Center Solution extends visibility and instrumentation to data center infrastructure, including critical equipment, products, and facilities. The SynapSense solution provides data collection, monitoring, control, integration and analysis. SynapSense employs a wireless mesh network to monitor everything from specific equipment (such as power, vibration and utilization) to environmental conditions (such as ambient temperature, humidity, air pressure differential above and below the floor, and airflow). The SynapSense solution is used to baseline energy efficiency, identify and alert staff to environmental issues and manage operational improvement opportunities.

The energy used by the nation's servers and data centers is significant and growing. It is estimated that this sector consumed about 61 billion kilowatt-hours (kWh) in 2006 (1.5 percent of total U.S. electricity consumption) for a total electricity cost of about $4.5 billion (Greenberg et al. 2006). Data centers can be more than 40 times as energy intensive as conventional office buildings), meaning that large data centers more closely resemble industrial facilities than commercial buildings with respect to energy use.

Data center equipment generally exhibits high power intensities with all of the electric power converted to heat. A recent survey of power usage in more than 20 data centers found that a data center's IT equipment alone can use approximately 10 to almost 100 Watts per square foot of raised floor area (Greenberg et al. 2006, LBNL) with only about half the power entering the data center actually used by the IT equipment. The rest is expended for power conversions, backup power, and cooling. Peak power usage for data centers can range from tens of kilowatts (kWs) for a small facility, to tens of megawatts (MWs) for the largest data centers.

The increasing demand for Information Technology and the geometric growth of digital storage can lead to a situation in which companies are forced to build new data centers, not because they are running out of floor space, but because they need power and cooling beyond what can be provided in their existing data centers. This situation has driven much of the recent interest in energy-efficiency improvements for data centers. If the power consumed (and resulting heat generated) in data centers can be reduced through energy-efficiency measures, the existing infrastructure can continue to meet cooling and power needs, and costly investments in new data centers can be deferred. (Andrew Fanara, et al. 2007)

A major barrier to improved energy efficiency is the difficulty of collecting data on the energy consumption of individual components of data centers, as well as the lack of data collection for data centers overall. Better energy data collection would not only help to quantify the energy load of data center operations, thus highlighting the importance of energy-efficiency improvements and facilitating right-sizing of equipment to match the energy load, but it would also allow data center managers and facility managers to monitor and evaluate the energy savings and corresponding GHG reductions resulting from specific energy-efficiency improvements using a common tool. Data center managers and facility managers are taking enormous risk with critical business infrastructure without the benefit of monitoring and are hesitant to make changes without this type of technology.

## Approach

SMUD and SynapSense initiated an assessment of SMUD's data center. The assessment evaluated the SynapSense wireless mesh sensor network's ability to characterize resiliency metrics in the data center. The metrics were used to collect data to provide empirical measures of hot and cool air mixing, thermal imbalances, cooling system efficiencies and adherence to thermal standards such as those prescribed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (Thermal Guidelines for Data Processing Environments, ASHRAE 2004). The assessment also established baseline energy utilization and identified energy savings opportunities in the data center.

After installation and for a period of four weeks of data collection, SynapSense gathered the information necessary to provide a comprehensive analysis including thermal inefficiencies, operating risk profiles and energy savings opportunities. SynapSense recommended operational and physical changes that, if implemented, will turn these opportunities into actual savings. SMUD personnel and SynapSense reviewed the potential energy saving recommendations, evaluated the ROI and determined their implementation strategy to achieve the energy savings and maintain the ongoing visibility for operational efficiency.

### Deployment Plan and Timeline

Phase I – Preparation: A team from SynapSense visited the data center to perform a site survey and assess installation requirements including node placement, special hardware requirements, network configuration, gateway placement, etc. This team generated an installation plan and sensor layout using an actual data center schematic.

Phase II – Installation: A team from SynapSense visited the data center to install agreed upon sensory equipment, establish the SynapSense Wireless Network and make certain the system is fully functional and logging sense points. The installation of the 79 nodes with 400 sensing points took fours hours to install but this time would vary for other data centers based on the their size and any special installation requirements. During the installation a data center representative was trained to use the Data Center Console.

Phase III – Consultation: SynapSense provided onsite support and answered questions, and reviewed system performance.

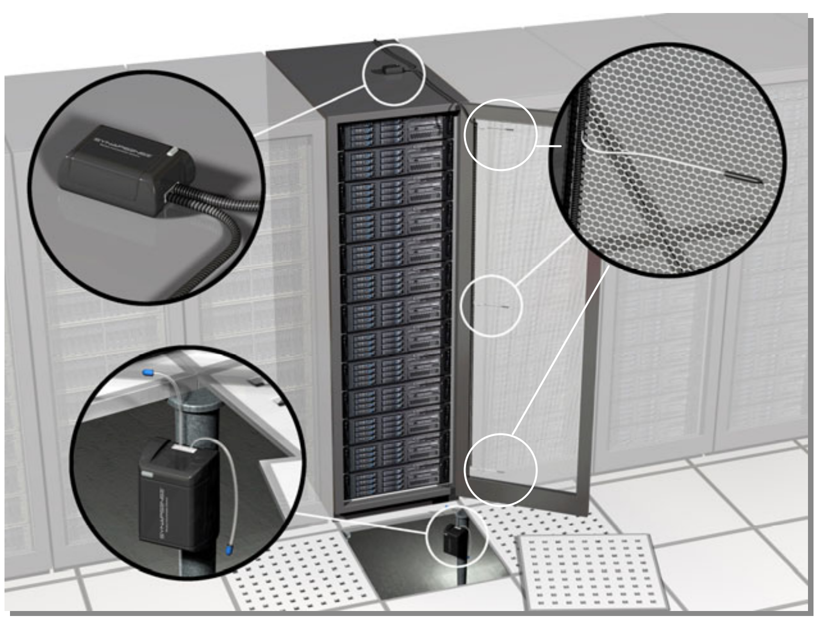
Phase IV – Data Collection & Analysis: The SynapSense console collected sensor point information over a period of four weeks. This information was analyzed and a summary report was generated with potential energy savings and recommendations. This analysis was presented and reviewed with SMUD Energy Efficiency Planner and staff, information technology executives, and facilities management.

Phase V – Final Review: Follow-on meetings with a SMUD Energy Specialist were held to assess the performance of the demonstration project and review recommendations. Next steps include the consideration of energy efficiency rebates and performance incentives.

**Data Center Profile and Installation**

The SynapSense Wireless Green Data Center Solution installed at SMUD included 79 wireless SynapSense devices with approximately 400 sensing points. The data center was typical of those within SMUD's service area at 5,000 square feet with a combination of servers, storage, and network equipment co-located within the facility. Prior to this project, significant work was underway to improve energy efficiency within the data center but without monitoring and instrumentation it was difficult to validate or assess the impacts of those measures implemented or those under consideration. The following briefly describes the location of the sensors at different racks and CRACs (computer room air-conditioners):

- 10 CRAC supply & return air temperature and supply air relative humidity sensors
- 200 air temperature sensors at the top, middle and bottom of representative racks
- 100 humidity sensors
- 37 hot aisle temperature sensors at the top of racks
- 6 sub-plenum pressure differential sensors



**Monitoring & Consultation**

The SynapSense wireless sensor network devices sampled data center environmental conditions every five minutes. During the testing period (between November 1 and November 21, 2007), the SynapSense Wireless Green Data Center Solution collected nearly 90,000 vital signs a day or about 1,800,000 measurements for the duration of the test period.

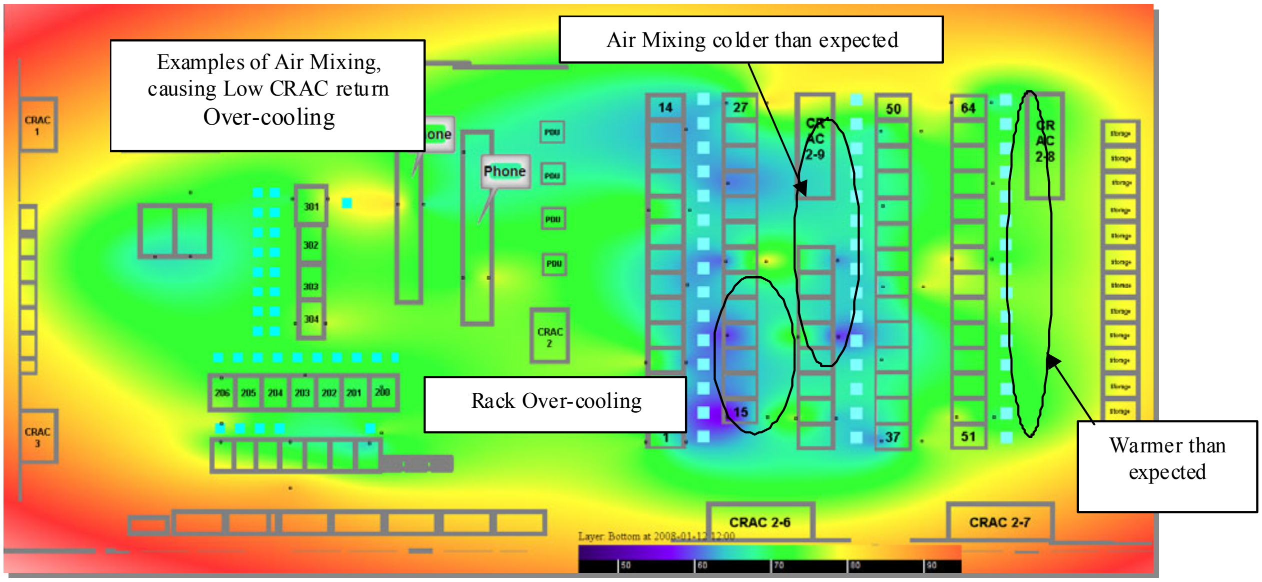
Sensors were placed to monitor CRAC supply & return air temperature and supply relative air humidity. Server rack inlet air temperature was measured at the top, middle and bottom of the racks (see above illustration). Top of the rack hot aisle sensors and sensors to measure the difference between the room and sub-floor pressure were also installed. The SynapSense Wireless Green Data Center Solution enabled development of a base-line energy assessment, energy metrics and recommendations for improvements for the SMUD data center to achieve additional energy savings.

Monitoring data indicated that the cooling systems currently installed in the data center are sufficient for existing load and up to 58 kW of new server or storage capacity. The SynapSense network identified over ten areas of overcooling in the data center which could be improved with better airflow management through installation of blanking plates, sealing of cable penetrations and rebalancing of floor tile using SynapSense sub-floor pressure monitoring. These improvements, plus 24x7 environmental monitoring could enable SMUD to turn off up to two CRAC units and raise each of the CRAC unit's supply air temperature set points which will increase the CRAC cooling capacity.

| Calculated Max Cooling Capacity - (tons) | |
|---|---|
| 39,700 | Total Supply Air CFM |
| 61.5 | Cooling Tons vs. 45.0 Cooling Load-tons |
| 33.8 | Fan Load (kW) |
| **216.4** | **Total Cooling Capacity in kW** |

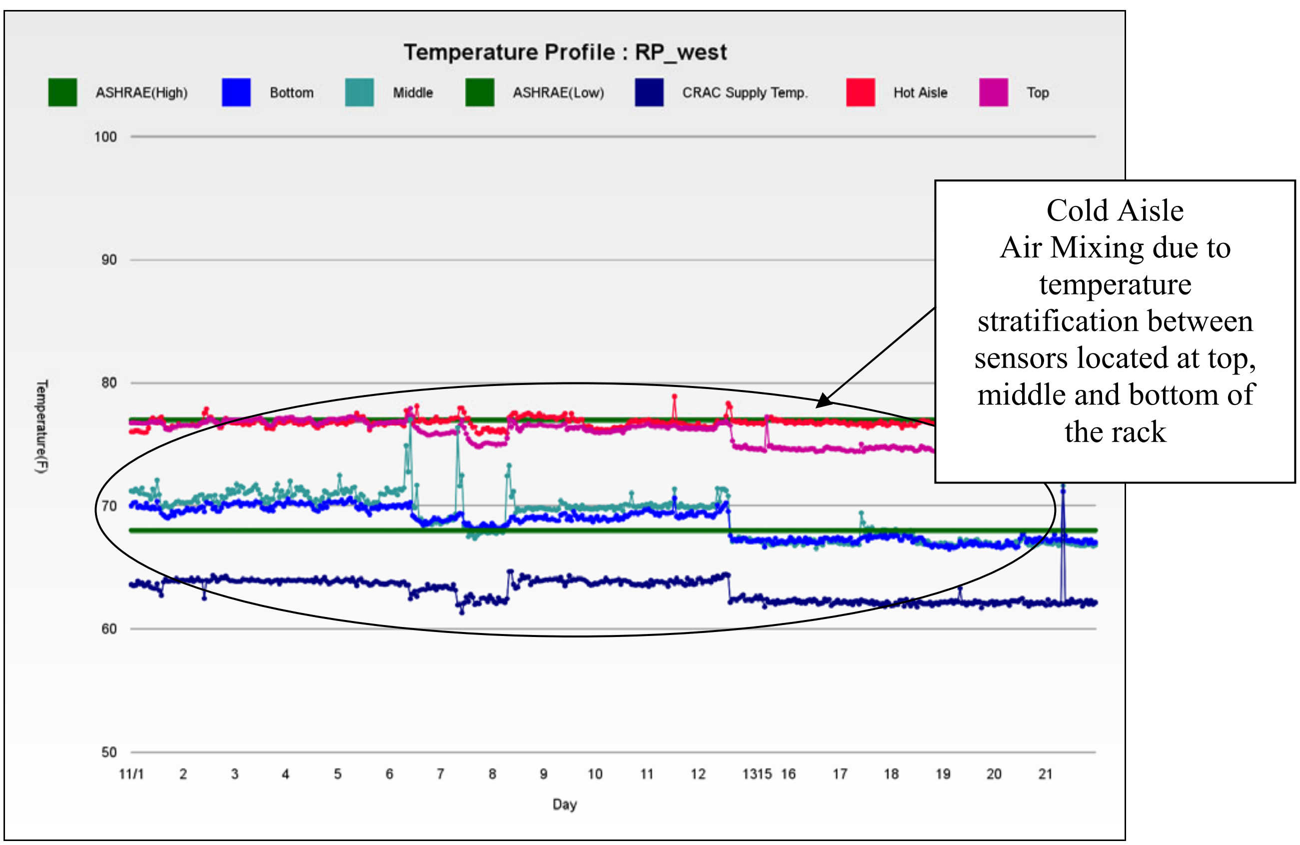
**Total Cooling Capacity Formula = Total Cooling Capacity Installed x Conversion Factor for Tons to kW (3.517)**

Air mixing is shown in the LiveImaging™ thermal map below. Leaks in floors, missing blanking plates, misplaced tiles, top and side air swirls, and holes cause the hot air to leak into the cold aisles and vice versa. In cold aisles, this has the impact of increasing the overall average temperature. This reduces the overall effectiveness of the cooling systems as the cold air is being used to cool the air from the hot aisle. Also, this makes the racks susceptible to over-heating.




Example of LiveImaging™ Thermal Map of Anonymous Data Center (to protect SMUD Data Center identity)

The graphs below show representative charts of selected racks with high levels of mixing in the cold aisles:



A temperature sensor was also installed on the top of each rack for correlation with the rack inlet air temperature sensors and the CRAC supply air temperature to quantify the degree of hot air infiltration into the cold aisle for each rack and row of racks. SynapSense has developed a metric, called Cold Supply Infiltration, or CSI index, that provides a measure of air mixing in aisles, zones and the entire data center. The CSI value indicates the degree to which the rise in the cold aisle inlet air is due to the temperature rise across the servers mixing with the inlet air, prior to the air entering the servers.

The CSI index at time t is calculated by the following equation:

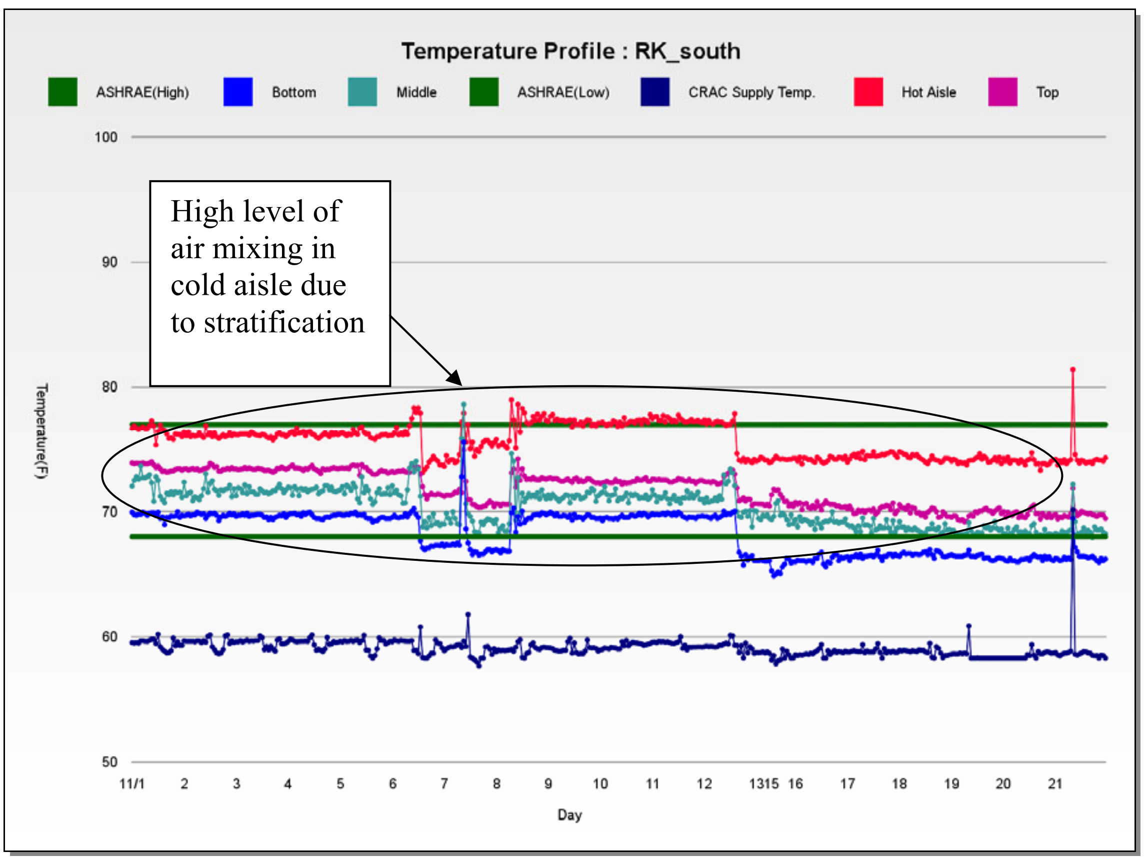
$$CSI(t) = \frac{T_{top}(t) - T_{ref}(t)}{T_{hot}(t) - T_{ref}(t)}$$

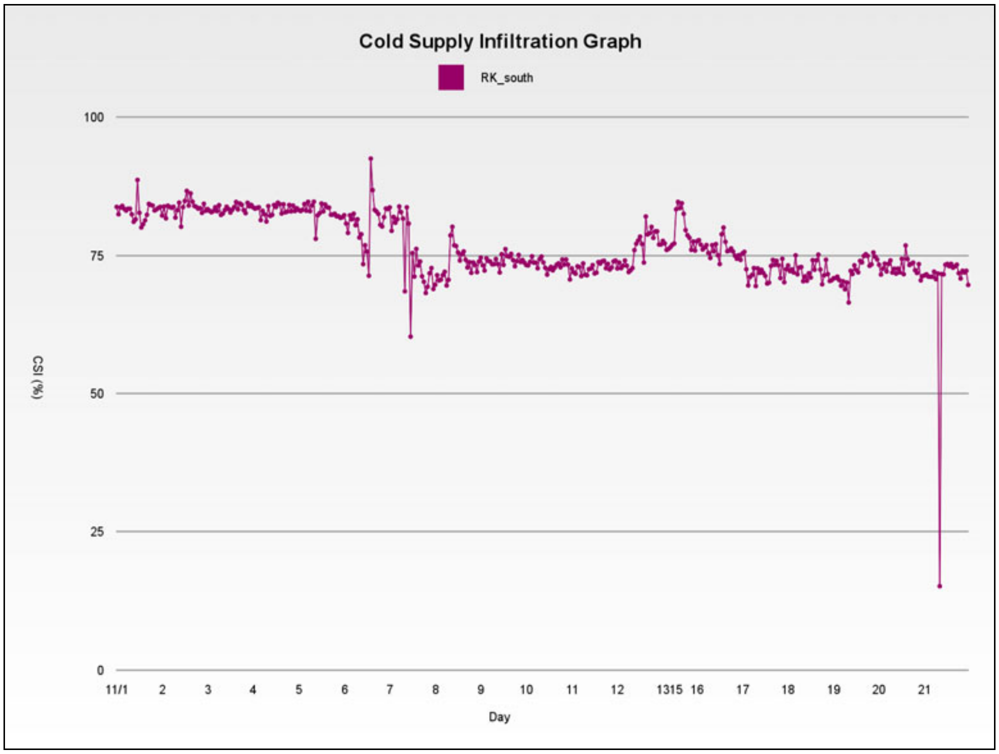
$T_{top}$ = Temperature top is server inlet temperature

$T_{ref}$ = Temperature reference is CRAC supply temperature

$T_{hot}$ = Temperature hot is server discharge temperature

The charts below show an example of thermal distribution and the corresponding CSI index for rack RK South. The CSI index shows that more than 50% of the total heat is gained within the aisle itself, indicating high level of air mixing.






To enable comparing the energy efficiency of the data centers being evaluated with common metrics, SynapSense calculated the SMUD data center's Power Utilization Effectiveness ratio or PUE ratio. We also calculated the Department of Energy's (DOE) Data Center Infrastructure Efficiency Ratio, or DCIE which is the inverse of the PUE. Where data was accessible, such as reading the IT load from the Power Distribution Units, it was used in the calculation of these metrics. Where data was not available, such as for Chilled Water Plant kW per ton or lighting watts/sf, SynapSense used engineering estimates to calculate these metrics.

**Power Utilization Effectiveness Ratio (PUE)**

$$PUE = \frac{TotalPower}{TotalITPower}$$

**SMUD Data Center Power Utilization Effectiveness (PUE) = 1.7**
(Lower is better on a scale of 1.0 to 3.0 per DOE formula)

The ratio of total data center energy use to total IT equipment energy use, including servers, storage devices and network equipment, is often referred to as the "power usage effectiveness" (PUE ratio). In the August, 2007 EPA study (Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431;U.S. Environmental Protection Agency ENERGY STAR Program) on energy use by datacenters, a PUE ratio of 2.0 was assumed to be the average value across all U.S. data centers; based a sampling of data centers by Lawrence Berkeley National Labs, however the PUE ratio can vary widely across individual data centers depending upon infrastructure equipment configurations and efficiencies, time of year and local climate. Going forward, SMUD will continue to monitor PUE over a full calendar year.

## Final Review & Findings

SynapSense humidity sensors on each rack could allow SMUD to widen the minimum and maximum acceptable RH% resulting in additional energy savings. The expected result for SMUD is an additional 13% energy savings representing over 300,160 kWh saving annually, 22% reclaim of current space and 9% of additional energy availability for data center growth. Based upon the estimated 300,160 kWh annual savings and SMUD's 580 lbs/$CO_2$ intensity per MWh, SMUD can reduce power emissions generation carbon footprint by 174,093 lbs of $CO_2$ (Bartholomew, Obadiah, Sacramento Municipal Utility District Renewables Project Manager).

In addition to the increase in the RH% within the acceptable range, the overall findings and recommendations of the assessment are summarized below:

- The cooling systems currently installed in the data center are sufficient for the existing load and could accommodate ~58 kW of new server or storage capacity.
- The cooling optimization opportunities in the data center are the result of airflow management issues that can be addressed by the following proposed measures:
  - Installation of blanking plates where there are no servers
  - Rigorous sealing of the cable penetrations in the raised floor
  - Rebalance of the perforated floor tile using the SynapSense sub-floor pressure sensors and rack temperature sensors for feedback
  - Tighter alignment of zonal cooling based upon localized thermal imbalances
- Turn off one to two CRAC units and raise each of the CRACs supply air temperature set points eight to nine degrees, which will provide significant energy cost savings through reduced power consumption, while maintaining adequate cooling to the current server equipment in the room. Increasing CRAC supply air temperature will increase the CRAC cooling capacity and provide the opportunity to increase chilled water supply temperature which will result in additional chiller cooling energy savings.

There are clear operational and financial benefits for SMUD to get on the path to a Green Data Center. Specifically, there are a number of opportunities to improve the energy efficiency and overall operation of the SMUD data center without significant capital outlay. SMUD can improve airflow loss from 50% to 21% by better managing the data center airflow. This would require completing the hot aisle/cold aisle equipment configuration and containment, replacing additional perforated tiles, sealing raised floor cable penetrations and installing any remaining blanking plates where necessary. This in conjunction with increasing the CRAC supply air temperature from 59 to 68 degrees and turning off one to two CRAC units will improve overall energy efficiency by 13%. The resulting cost savings (see ROI below) for this first step on the path to the Green Data Center is projected to be ~ $27,659. Continued monitoring by the SynapSense Wireless Green Data Center Solution will enable SMUD management to make these changes with confidence and realize the energy savings potential.

The site assessment findings suggest that while there is air conditioning (cooling capacity) to spare, the airflow in the SMUD data center must be improved in order to meet the data processing needs of the next few years if more high density servers are part of the growth plan. If these steps are taken, using the SynapSense Wireless Sensor Network, SMUD can continue to make changes to the data center, including turning off one of the CRAC units.

The table below summarizes the energy savings possible by implementing these measures and the projected return on investment for the SynapSense wireless sensor solution installed in the SMUD data center.

**SMUD ROI Analysis**

**Energy Savings Calculations**

| | | | |
|---|---|---|---|
| IT Load | | 156.0 | kW |
| Cooling System Infrastructure | | 73.3 | kW |
| IT Load Loss | | 36.0 | kW |
| Lighting Load | | 2.4 | kW |
| Total Load | | 267.6 | kW |
| Watts/SF | | 53.2 | |
| PUE - Before | | 1.7 | |
| PUE - After | | 1.5 | |
| DCiE - Before | | 58% | |
| DCiE - After | | 67% | |
| Total Energy Usage | | 2,344,592 | kWh |
| Annual Savings | 13% | 300,160 | kWh |
| Price per kWh | | $ 0.09 | |
| Annual Energy Savings ($) | | $ 27,659 | |
| Total Solution Cost less POC Costs | | $ 31,842 | |
| ROI (Yrs to Payback) | | 1.2 | |
| Utility Incentive | $ 0.14 | $ 42,022 | |
| Incentive Cap - 30% of Project Cost | | $ 9,553 | |
| Price After Incentive | | $ 22,289 | |
| ROI - After Incentive (Yrs to Payback) | | 0.8 | |
| Data Center Sq Ft | | 2,932 | SF |
| CO2 Emissions Reduction | | 174,093 | Lbs |
| Based upon SMUD conversion factor (.58 lbs/kWh) | | | |

| | | | | |
|---|---|---|---|---|
| | | BHP | kW | CRAH Fans kW |
| CRAHs (Total) | | 45.3 | 33.8 | 33.8 |
| | CFM | Ave ?T | CRAH Tons (Total) | |
| Cooling Tons | 39,700 | 14.0 | 50.0 | |
| | Cooling Tons | Chiller Efficiency | Chiller kW | |
| Chiller Tons | 50.0 | 0.8 | 39.5 | |
| Total Cooling kW | | 73.278 | | |
| | | Before | After | kW Savings |
| Excess Air Flow Loss | | 50% | 21% | |
| Air Flow Loss Reduction | | | 29% | |
| CRAH Fan Load kW Savings | | 33.8 | 4.8 | 28.9 |
| Average CRAH SAT | | 59.0 | 68.0 | |
| Chiller kW Savings | | | | 5.3 |
| Total kW Savings | | | | 34.3 |
| kWh Savings (Annual) | | 300,160 | | |
| % kWh Savings | | 13% | | |
| SF Reclaim | | 644 | | |
| % SF Reclaim | | 22% | | |
| Reclaim: Additional IT Availability | | 9% | | |

**Formulas:**

| | | | |
|---|---|---|---|
| PUE - Before | Total Power/IT Power | CRAH Fans kW | Fan BHP x .7457 |
| DCiE - Before | IT Power/Total Power | CRAH Cooling Tons | (CFM x Delta T x 1.08)/12000 |
| | | Chiller Tons | CRAH Cooling Tons x Chiller kW/ton |
| SF Reclaim | Total Savings kW x 1000/ Watts SF | Total Cooling kW | CRAH Fans kW + Chiller kW |
| % SF Reclaim | Reclaim SF/ Data Center SF | Excess Air Flow Loss | (Average Server Delta T - CRAH Delta T)/Ave Server Delta T |
| Reclaim: Additional IT Availability | | Air Flow Loss Reduction | Air Flow Loss Before - Air Flow Loss After |
| | (DCiE After - DCiE Before) | CRAH Fan Load kW Savings | (m x Air Flow Loss Reduction x CRAH Fan Load Before) |
| | Ave ?T= Return air temp-supply air temp | Where m = Factor for calculating power savings based upon air flow change | |
| | | Chiller Load kW Savings | # of degrees increase in CRAH SAT x 1.5% chiller power savings/degree |
| | | Total kW Savings | Fan kW savings + Chiller kW savings |
| | | kWh Savings | Total kW savings x 8760 hours/year |

# Future Steps

## SMUD Site Implementation

Although SMUD initially leased the SynapSense sensors and technology for a short term/test case, the SMUD facility and IT personnel have agreed to purchase the technology for the SMUD data center and leave it deployed. While SynapSense has proven its value through the expected energy efficiency/commissioning aspect of the tool, the technology has filled a major void in the controls component of the SMUD data center. Prior to this technology, there were two levels of temperature sensors in the data center. First, the HVAC system is controlled by return air sensors. These sensors were monitored by facilities staff through the building Energy Management System. As long as the return air temperature stayed low, facilities personnel had no sense if there were hot spots in the room or unique cooling issues. Secondly, the temperature of the racks and servers were monitored by the IT staff. They could identify if a particular server or rack was too hot, with no knowledge of the status of the air-conditioning system. This SynapSense system allows SMUD facility and IT personnel to bridge these two systems and capture information on the data center as a whole.

Finally, SMUD will benefit by pursuing aggressive strategies to achieve a Green Data Center at their own facility. SynapSense plans to partner with SMUD in each phase of their improvement efforts, as they move toward attaining a Green Data Center. This initial step of benchmarking and improving both data center resiliency and energy efficiency is now underway. Future efficiencies can be realized in partnering with SynapSense to move toward adaptive cooling and containment and eventually to power management.

**SMUD Customer Test Sites**

SMUD is working with SynapSense to implement their technology at three customer sites as a further test of the technology. These three sites have been identified and represent typical data center customers for SMUD. These sites are:

- a collocation center with state of the art equipment
- a smaller data center for a large insurance company with a mixed environment
- a data center for a large technology company which has the latest technology

SMUD will continue to review and analyze the results from these three test sites to determine the appropriate incentive level and structure to encourage the adoption of Wireless Sensor Technology for Data Centers within the SMUD Service Territory. In addition, by offering incentives to customers for improving energy efficiency by supporting emerging technologies, such as the Wireless Instrumentation, SMUD can provide tremendous value to their customer/owners.

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