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Air Management in Small Data Centers

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After the original release of this report, LBNL undertook a demonstration study of two portable air management measurement tools, including one of those included in the report. The reader is encouraged to carefully read the demonstration study, which can be accessed from the Center of Expertise website at LBNL:

https://datacenters.lbl.gov/resources/demonstration-portable-air-management

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Disclaimer

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Executive Summary

Data centers are energy-intensive facilities. Air management in these facilities is imperative, not only for improving the energy efficiency, but also for managing the thermal environment. The end goal of air management is to save energy by suppling as little air as possible at as a high temperature as possible without adversely affecting the thermal environment.

This report focuses on improving air management in small data centers (<5,000 square feet [ft^2]) due to the great potential for energy savings. Recent industry intelligence shows that air management is not a standard practice in existing small (embedded) data centers. To be able to implement air management, key environmental parameters such as temperatures, airflow rates, and electrical power need to be monitored. The data collection process is therefore described in some detail within the report.

Access to simple, inexpensive tools for implementing and tracking air management is imperative. Many advanced monitoring systems are often too complex and expensive for small data centers. We looked at three portable measurement tools that can be brought into the data center for checking the thermal conditions. They have different technical sophistication and price points ($400 to $3,200), but they all have great potential for improving the energy efficiency of small data centers. A planned 2017 Lawrence Berkeley National Laboratory demonstration project will install and evaluate these tools.

We also reviewed more advanced stationary monitoring systems. Such Data Center Infrastructure Management (DCIM) products are slowly catching up to the needs of small data centers, and three development paths have crystalized. The report provides one product example for each type.

Some complete DCIM solutions are offered module-by-module. For example, power and environmental modules can be purchased if energy efficiency is the primary goal. This is a flexible solution if there ever is a need to expand into other modules. Entry-level DCIM solutions may not include all of the traditional DCIM modules and/or may have simplified modules. This is a less flexible solution if there ever is a need to increase the capabilities. Vendors are also developing simplified tools for power and environmental conditions. These tools (point solutions) are less complex and costly but do not provide the same expansion flexibility.

Due to a number of barriers in small data centers, including lack of expertise and money, it would help to provide utility incentives to customers for proven and rapidly deployable "packages" of air management measures that require no (or only marginal) customization. They would serve as a powerful economical alternative to labor-intensive, cost-ineffective customized solutions that address only one data center at a time. Such packages were developed in this study, with support from computer modeling.

Only a limited number of simulation tools are available to estimate energy savings from air management in data centers; we reviewed two: the Air Management Tool and the Airflow Management Calculator (AFM). The U.S. Department of Energy's (DOE) Air Management Tool was partially validated in 2010 with computational fluid dynamics (CFD) modeling with funds from Pacific Gas and Electric (PG&E). The AFM was developed by the Bonneville Power Administration (BPA) and Seattle City Light. The Air Management Tool is more focused on air management, whereas cooling systems are described in broad brush strokes. The AFM has taken quite the opposite approach. Since they are both spreadsheet tools, they potentially could be combined into a single powerful tool that could resolve each tool's shortcomings.

Only the Air Management Tool was deemed useful for studying the refrigeration equipment ("chiller") energy savings and fan energy savings from implementing the air management packages. Thus, for the simulations, we were limited by its capabilities. For example, it only allows input of a limited number of individual air management measures. It would benefit from having an interpolation routine added to its look-up tables. This would ensure that the output would change with even a small change in input. This modification was also suggested by PG&E's *Data Center Air Management Research* report (PG&E 2010).

We simulated a number of air management packages and calculated the relative energy savings. The modeling tool's capabilities and the energy savings trends were first demonstrated on a typical small data center. Then, six Small Data Center Air Management Upgrade Packages were crafted to work in small data centers, allowing replication with little or no customization.

Not surprisingly, the overall trend is that fan and chiller energy savings improve with more elaborate air management. However, the magnitude and characteristics of these savings vary considerably. The fan savings take us on a wild ride, whereas the chiller savings are steadily increasing more predictably.

The energy savings for the supply fans can be very large (70%–80%), whereas the savings for the chiller are significantly lower (15%–25%). Although the fan energy savings are higher than the chiller energy savings, the absolute savings may be on the same order, since the fan energy is generally considerably smaller than the chiller energy.

With constant air volume (CAV) computer room air conditioner (CRAC) units, their modularity can impact fan energy savings significantly. Reduced supply airflow requirements due to air management may not allow unit(s) to be shut off when only a few large units are used: therefore, no savings can be realized. The reduction is simply not high enough to allow CRAC unit(s) to be shut off. This is a common situation in many small data centers. Higher CRAC modularity (i.e., a larger number of smaller units) is favorable.

There is a drastic fan energy reduction associated with retrofitting CAV computer room air conditioner units with variable air volume (VAV) fans. One or several CAV units are shut off when the airflow demand is reduced, whereas VAV units are turned down equally on all units. The latter strategy is a much more efficient process since the fan energy is proportional to nearly the cube of the airflow. Simply turning units off may also pose operational risks associated with local overheating of IT equipment.

However, the energy savings between the three highest quality packages of the six is not great. This suggests that the cost effectiveness of driving air management too far is questionable in small data centers. This is especially true considering that the savings for the very highest-quality package requires an airflow reduction of more than 50%, which may not work in a retrofit situation.

The trend for chiller energy as a function of air management sophistication is a fairly steady increase in energy savings up to around 25%. The savings stem from the higher supply air temperatures “achievable” with better air management. However, many data centers are operated well below the achievable supply air temperatures for a number of reasons. If that is the case, additional savings are available.

One critical point is to be able to select the most appropriate air management package for the data center. The report outlines briefly the process to select the upgrade packages, calculate the energy savings, determine the cost of the packages, and establish the rebates. If an automatic method (“app”) could be devised to collect and process the necessary data, then the selection of the most appropriate package could be simplified significantly.

Finding and engaging small data centers is a huge challenge. An initiative to deal with this challenge could pay off big, and the benefits are valuable not only for the implementation of air management.

To further this work, the air management packages need to be scalable, and we need to know how well they work and how many data points were used to determine the savings, as well as other factors. The Small Data Center Air Management Upgrade Packages developed in this report are a first step in that direction. The next step is to demonstrate the packages in live data centers. Such a project is planned for in 2017.

1. Introduction

Data centers are among the most energy intensive facilities around. Good air management in data centers is not only imperative for energy efficiency but also for managing the thermal environment, which is a proxy for equipment reliability. Good air management is critical to achieving the right balance between energy savings and thermal conformance.

The principles of air management are simple enough: funnel the cold supply air directly to the heat-generating electronic equipment and then remove the hot exhaust air as effectively as possible, minimizing the opportunity for mixing of the supply air and the exhaust air. The goal of air management is to provide as little supply air as possible at as a high temperature as possible without adversely affecting the thermal equipment environment.

Unfortunately, air management is often badly misunderstood. Installing blanking panels or sealing the raised floor will not save energy per se. Such measures are rather examples of "enablers." These enablers will only allow energy savings when they are implemented in conjunction with two "activators." First, we need a way to reduce the supply air volume from the cooling system, which saves fan energy. Second, we need a way to increase the supply air temperature, which makes the refrigeration equipment ("chiller") work more efficiently.

Consequently, a holistic approach is needed for saving energy with air management. It would help to reward "packages" of air management measures with utility incentives or rebates; simply rewarding use of blanking panels or any other single air management measure will not be a cost effective investment. However, all packages must include a way to reduce the supply airflow rate and/or increase the supply air temperature.

There are a number of barriers to good air management in small data centers. For example, the 2013 Data Center Industry Survey by the Uptime Institute (2013) states that organizations need to have the expertise to implement air management effectively, which leaves out the bulk of small data centers. Furthermore, most small data centers do not have metering equipment, a monitoring system, or the expertise necessary to quantify their air management. Large data centers may invest in Data Center Infrastructure Management (DCIM) systems, but such systems are often too expensive and complex for small data centers, which benefit from having access to simple, inexpensive tools.

Judging from talks at data center conferences and articles in industry journals, it would appear that air management is common practice in data centers. Recent industry intelligence from the Uptime Institute (2013) and IDC (2015) shows that air management is, in fact, not a standard practice in small (embedded) data centers. This is an important detail, since utilities generally cannot provide financial incentives or rebates for measures that are considered "industry practice" (often considered as a penetration of >50%).

In this report, a *small data center* is defined as having less than 5,000 square feet (ft^2) (see Appendix A). Estimates from 2009 suggest that 72% of all servers in the United States are hosted in such data centers (see Appendix B). And, the strategic importance of small data centers has risen in the two past years (Emerson, 2016). That means that the energy-savings opportunity is highest in small data centers (as a group) since large data centers are more energy efficient and hosting fewer servers. Consequently, to achieve significant energy savings in data centers, these small facilities need to be targeted.

Again, simple and inexpensive solutions with clearly stated benefits are necessary to attract small data center owners and operators. The leading principle is that they are willing to compromise on accuracy to get things done. If we can move the needle from “unsatisfactory” to “good,” we have succeeded. We leave the “excellent” to the large data centers.

Finding out what works best, on average, with regard to air management would allow replication across many data centers without the need for customization. Small data centers need proven and rapidly deployable upgrade “packages” of air management measures. Therefore, the implementation mechanism of such packages is also an important aspect.

This report aims to empower Pacific Gas and Electric (PG&E) and its customers by developing air management packages that can be successfully implemented in small data centers, and thereby serve as a powerful economical alternative to labor-intensive, cost-ineffective customized solutions that address only one data center at a time. The packages may allow PG&E to develop a rebate program for air management based on deemed savings, which would further hasten the implementation.

2. Data of Importance

To be able to implement air management effectively, it is necessary to monitor key environmental parameters. Data of importance for evaluating air management include the following:

- IT equipment intake and exhaust temperatures
- IT equipment airflow rates
- Air handler supply and return air temperatures
- Air handler airflow rates
- IT equipment and electrical equipment power
- Total power (for power usage effectiveness [PUE] calculations).

The recommendations listed below are adopted from the DOE Data Center Air Management Tool: Data Collection Guide (DOE 2014b). Not all these general recommendations are directly applicable to small data centers as discussed throughout this report.

Data Collection of IT Equipment Intake Temperature and Temperature Rise

For air-cooled IT equipment, measuring the intake air temperatures are important because the equipment is designed to operate within a certain temperature range. The air at the equipment intake cools the electronics. A temperature that is too high may lead to compromised reliability and reduced longevity of the equipment. The intake temperature can be seen as a proxy for equipment reliability.

Measuring the temperature rise includes measuring the intake and exhaust temperatures. However, there is no industry standard on the methods, locations, or other factors for performing temperature measurements at the intakes and exhausts of IT equipment. Therefore, the following should be considered as a guideline only. Remember that the goal of the temperature probe count and probe location is to produce a clear picture of the temperature distribution at the IT equipment air intakes.

- The probe location must coincide (geometric center) with the actual equipment air intake or exhaust opening. Also, placing the temperature probe inches in front of the actual IT equipment intake opening rather than flush with the opening may well render an erroneous result, due to the presence of recirculation of hot exhaust air inside the rack. For example, the rack door is generally several inches in front of the IT equipment. The measured temperatures at the rack door could be several degrees cooler than the air that actually enters the IT equipment. They measure the room conditions around the rack rather than the equipment intake conditions.
- The optimal quantity and elevation of the temperature probes depends strongly on the contents of the IT rack. A rack often contains multiple pieces of IT equipment, each with its own intake and exhaust openings. Also, the temperature profiles along the front of the racks generally vary with elevation, due to recirculation above the equipment racks.
- It is not necessary to collect data for every IT rack. Measuring every other or every third rack is often adequate; even less on the exhaust side if the racks have similar design and function. The racks at the end of the equipment rows should be included since they may be exposed to higher temperatures due to recirculation around the end of the equipment rows. Some racks can often be disregarded because of marginal criticality and/or heat dissipation.
- For IT racks with many (20–40) evenly distributed intake and exhaust openings, six sensors per rack (three on the intake side and three on the exhaust side) is a reasonable compromise between accuracy and cost, especially when the ventilation openings have similar airflow and heat dissipation. Placing the sensors at three elevations (high, mid, and low) is usually adequate.
- For IT racks with multiple (4–10) intake or exhaust openings, six sensors per rack are again a sensible compromise. If a few openings dominate with regard to airflow and heat dissipation, place the sensors at those openings. If not, placing the sensors at three elevations (high, mid, and low) is usually adequate.
- For IT racks with discrete intake or exhaust openings, place the sensors at the geometric center of the actual intake and exhaust openings (flush to the openings). This is often the case for uninterruptible power supply (UPS) gear.

Data Collection of IT Equipment Airflow Rates

To understand whether the space is under- or over-ventilated, additional data must be collected. We need to know the airflow through the IT equipment and the supply airflow from the computer room air conditioner (CRAC) or computer room air handler (CRAH) units.

Measuring the airflow through IT equipment is complicated—at best. The following options provide more practical approaches:

- Airflow can easily be calculated if the power draw (see below) and the temperature difference between intake and exhaust (see above) are known.
- IT manufacturers' online calculators can generally be found on their websites. These tools are often very flexible, enabling a detailed analysis of equipment airflow.
- IT manufacturers' thermal reports per ASHRAE's (2015) *Thermal Guidelines for Data Processing Environments* are not common. If the report is available, however, it provides a quick way to estimate equipment airflow.
- Nominal airflow can be found in the equipment documentation. Since actual airflow can differ from nominal airflow, this is not the best choice. However, it may sometimes be the most practical option.

Data Collection of Air Handler Airflow Rates

The Pitot tube is a relatively inexpensive way to measure airflow in the field. A more sophisticated device such as a hot-wire anemometer can be used when better accuracy is required. Since the air velocity across the return opening (or duct) to the air handlers varies over the cross section, it is difficult to rely on information from a single probe location.

For temporary measurements, the airflow through an air handler can be accurately measured by using anemometers and the log-linear velocity traverse method across the return opening (or duct) (ASHRAE 2008). It measures the velocity in several different locations. By establishing a calibration curve, the average velocity can then be calculated from a single center point probe.

For a permanent installation, an airflow monitoring station measures the average air velocity, airflow, and temperature. The station is permanently installed in a duct and uses probes that are arranged in a grid to measure the average velocity.

Catalog airflow can be found in the air handler documentation. There is also a correlation between airflow and frequency for variable air volume (VAV) fans. Since actual airflow may differ from the nominal data, this is not the best option, but it may be the most practical option and sometimes the only option.

Data Collection of Air Handler Supply and Return Air Temperatures

Measuring the supply temperature from air handlers is generally an easy task with a calibrated, high-quality sensor. For raised-floor applications with down-flow CRAC/H units, placing a thermocouple probe in the airstream coming out of the unit under the raised floor should present few challenges. Thermocouples are easy to use and are relatively inexpensive, reliable, stable, and durable. Thermistors provide high accuracy but are generally more costly. Resistance temperature detectors are among the most accurate sensors; the drawback is an even higher cost.

Measuring the return temperature of air handlers is not as easy. For down-flow CRAC/H units, the temperature distribution across the return opening cannot be assumed to be uniform. Further complicating the matter is that the airflow cannot be assumed to be uniform. If the log-linear traverse method is used to determine the airflow, the average temperature can be calculated by measuring the temperature in the same locations. Before trying this, however, estimate the temperature variation across the opening by manual sampling. If the variation is small, use the center-point temperature.

Data Collection of IT Equipment Power, Electrical Equipment Power, and Building Power

In addition to the guidelines provided below, ASHRAE (2009) provides an overview in its *Real-Time Energy Consumption Measurements in Data Centers.* It is imperative that the person who conducts the power measurements understands the data collection techniques and the criticality of data centers.

- The inventory of the data center's equipment should include an estimate of the equipment power profile over time so that corrections can be made to one-time or short-term measurements. Another important factor that needs to be understood is redundant power feeds (both must be measured).
- Measurements of IT rack power (heat release) can produce most accurate results. The power input to the rack can be measured via voltage and current or preferably using a watt (power) meter, but it requires well-trained staff to do it safely and accurately, and it may be time consuming.
- Clamp-on current transformers (CTs) can be applied without breaking the electric circuit by placing the conductor to be measured through the CT. Current can be a stand-alone measurement or be combined with voltage (generally known) to compute power. Portable power meters are generally used for short-term measurements.
- Measurement of rack power may become tedious and time consuming due to the sheer number of IT equipment in many data centers. Based on the inventory, however, power measurements can be performed on one representative sample of many units of similar pieces of IT equipment. Another alternative, if total IT power is the goal, is to use portable power metering at a higher level in the distribution system.
- If there is a remote power management system with rack power distribution units (rPDUs), the task of determining rack power may be straightforward. The inventory should provide enough information for accurate mapping of the IT equipment with the rPDUs.
- In data centers, the IT equipment is generally powered from several power distribution units (PDUs), which often have meters to measure power draw. If this level of metering is sufficient, this may be the best option. The PDU meter accuracy is generally better than that of the rPDU.

- Some servers are able to measure and report power (ENERGY STAR 2008). Long term, users may wish to collect power data directly from the servers rather than from the rPDUs or PDUs.
- IT manufacturers' online calculation tools generally can be found on their websites. These tools are often very flexible, allowing detailed analysis of equipment power (heat release).
- IT manufacturers' thermal reports per ASHRAE (2015) are currently not common. If the report is available, however, it provides a quick way to estimate the power draw (heat release).
- Nameplate power rating can be found on the IT equipment and in the product documentation. However, the nameplate rating is for the purpose of electrical system design, not as an indicator of actual power draw. Depending on a number of factors, actual power draw can be 50% or less than the nameplate rating. Using nameplate power rating is strongly discouraged.
- For a UPS, the power dissipated as heat can be calculated by subtracting the OUT power from the IN power. Both power data are often accessible on the unit, though it is more common for output power to be available than input power.

3. Portable Monitoring Tools

Done correctly, air management can improve not only the data center's energy efficiency, but also its thermal environment, which is important for IT equipment reliability. The first step is to secure the thermal environment by using monitoring equipment and/or modeling tools. It is imperative to have access to simple and inexpensive tools/technologies, both hardware and software, for implementing and tracking air management.

Many advanced monitoring systems for air management are often too complex and expensive for small data centers. First, we will look at three simple and inexpensive portable measurement tools that can be used to check the thermal conditions. In Section 4, we will look at more complex stationary systems.

When effective monitoring is in place, various air management measures can be evaluated and tracked. To be able to effectively balance the energy efficiency with the thermal environment, it helps to have the portable tools (and the stationary systems) calculate and display the PUE.

Although stationary systems are preferred for long-term benefits, portable tools can also have great long-term effects since they can be brought in at any time. A small data center will typically not invest in a stationary system so portable tools may be the best option.

The three portable monitoring tools we reviewed are:

- Watchdog 15 (Geist),
- EMS 200 (Upsite Technologies), and
- Audit-Buddy (Purkay Labs).

These tools have different technical sophistication and price points, and we will cover the pros and cons of each. End users, consultants, or the Pacific Energy Center (PEC) lending tool library can own the tools.

All these portable tools have one potential drawback: the temperatures are measured outside the rack, well away from the actual air intakes of the electronic equipment. Temperatures measured this way will not include hot air recirculation inside the rack, if present. Consequently, the tools may not always accurately describe the actual IT equipment intake temperatures, but rather, describe the effectiveness of the room air distribution.

3.1 Watchdog 15 (Geist) www.geistglobal.com

The Geist Watchdog 15 has the capacity to enable data center managers to show that temperatures in the cold aisles are stable from one cabinet to the next and that raising the data center's overall temperature will not put equipment in danger.

Geist offers a number of options for monitoring temperature, humidity, and other environmental conditions in facilities such as data centers. The Geist Watchdog product line is designed to be a permanent solution for monitoring data center conditions, but due to the simple and compact design, it can be easily adapted into a portable data monitoring and collection tool. All parts used are standard off-the-shelf products.

Figure 3.1.1 below shows the tool's general setup. The end user is responsible for providing the utility cart, six-foot pole, laptop, and UPS. The Geist solution includes the Watchdog 15 self-contained environmental monitoring unit and a single GT3HD temperature sensor unit (Figure 3.1.2). The UPS unit would serve as the power supply for the Watchdog unit and laptop if desired. Alternatively, a 6-volt rechargeable battery could be used to power the system.

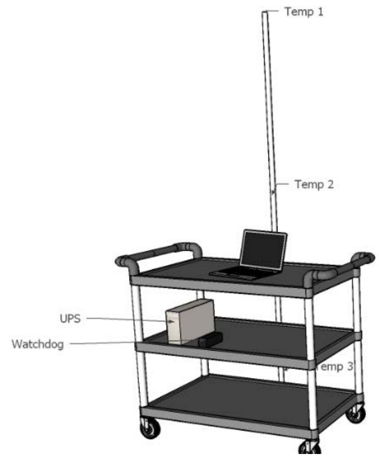


Figure 3.1.1: Geist Portable Tool Concept

Figure 3.1.2: Watchdog 15 and Sensor Unit

Once the components have been assembled, the utility cart is rolled from equipment rack to equipment rack to collect temperature readings at the top, middle, and bottom of the rack. Once in front of a rack the user refreshes the display screen until the temperature readings have settled. The estimated time is less than two minutes for temperature variations up to 5°F. At that point the user logs the readings and moves to the next selected rack. This process is repeated for every rack, every other rack, or potentially every third rack, depending on the coverage desired.

Figure 3.1.3 shows a screen shot of the web interface; one screen for each temperature sensor. The user can view both the live temperature readings as well as historic data on the line graph. A number of options are available to collect data from the Watchdog device, including SNMP, JSON, and via the device’s internal web interface. The method described above was a simple cut-and-paste method for collecting temperature data via the unit’s web interface. Automating the process of entering data from the unit onto a spreadsheet would be simple, and for a moderately sized data center could prove to be worthwhile.

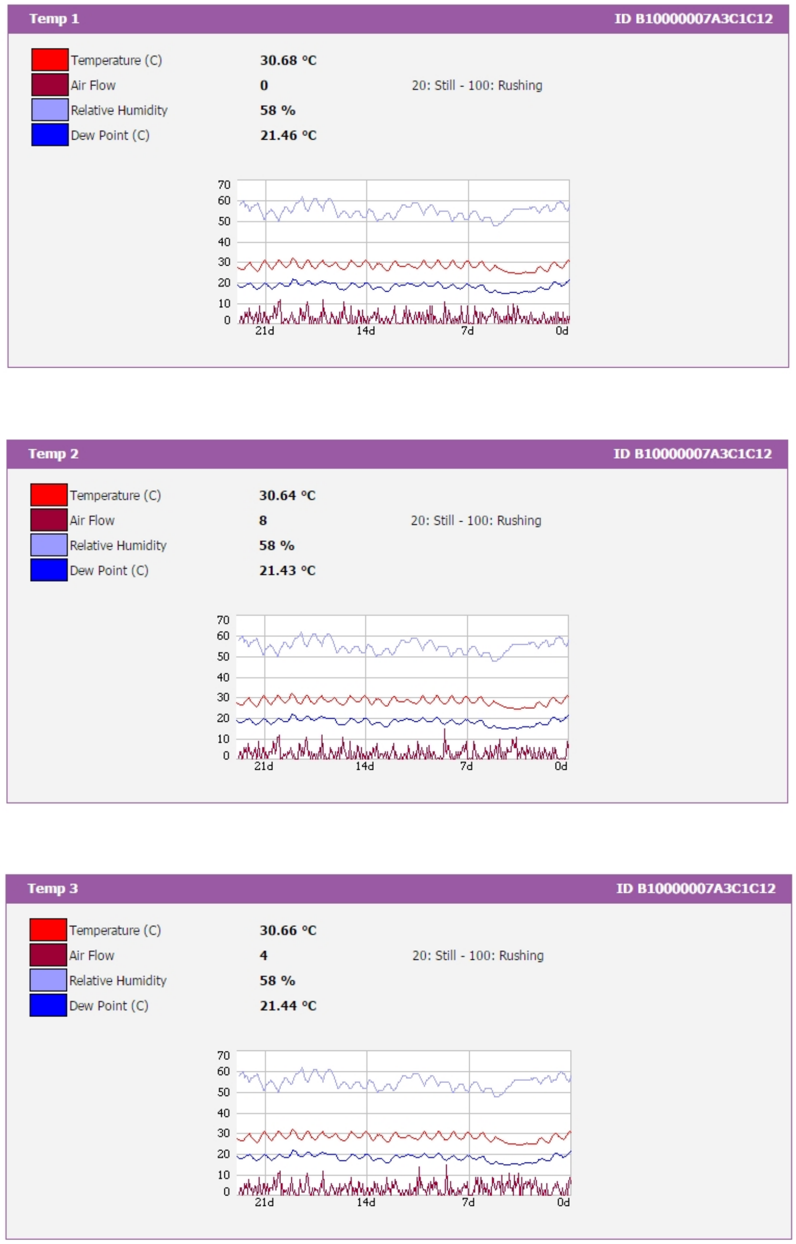


Figure 3.1.3: Data Collection View

3.2 AUDIT-BUDDY (Purkay Labs) www.purkaylabs.com

Purkay Labs' AUDIT-BUDDY may well be the first portable and standalone temperature- and humidity-monitoring tool explicitly developed for the data center market. It is battery operated and does not require a separate computer program to run or read data, nor does it need to be integrated into the facility infrastructure.

This tool is designed to enable a data center engineer with a limited budget to monitor the data center environment without having to install a complex monitoring system and the associated overhead of processing gigabytes of collected data.

The AUDIT-BUDDY can quickly survey the data center and give detailed time-stamped data to determine future corrective actions. It scans and suggests corrective actions using Microsoft Excel. There is no need to touch the servers or the CRAC settings. It is completely self-contained and can be used on demand and stored away when not needed.

The basic configuration consists of three independent temperature and humidity (TH1) units and an adjustable six-foot carbon fiber rod (Figure 3.2.1). The TH1 units may be placed anywhere on the rod, but the most likely scenario is one unit in the lower third, one in the middle third, and one in the upper third of the cabinet front, as recommended by ASHRAE. The weighted triangular base allows the rod and its three TH1 units to be safely placed as close as 1 inch (2.5 centimeters) from the perforated front of the server rack.

Figure 3.2.1: AUDIT-BUDDY Tool: Three Temperature/Humidity (TH1) Units Mounted on a Carbon Fiber Rod

The TH1 unit's fan draws air into the cavity where the temperature and humidity sensors are located. The sensors quickly complete the measurements and report the results. The temperature and humidity sensors use solid-state technology.

The operator can read the data directly on the TH1 unit screen or transfer it via USB flash drive (or direct PC connect) to a PC or MAC Excel Program. There is also a Wi-Fi version available. The vendor provides a free Excel macro that automates post-processing of data and generates reports, plots, and statistics.

The tool can capture both real-time and long-term scans of the data center's environmental conditions, with no need for infrastructure modifications or downtime. Specifically, the tool can be used in three basic ways:

1. **Spatial Scan.** The operator places the AUDIT-BUDDY in front of the first server rack in an equipment aisle, takes a 20-second QuickScan and moves the tool to the next server rack. The process is continued until measurements have been taken for every rack along every aisle in the area of interest. The data are then fed into the Contour Map Macro to generate a thermal contour map for each lineup. A data hall with 40 aisles will have 40 contour maps, representing the thermal state of the data center at the time of the readings. A single operator could complete the whole exercise in a couple of hours, depending on the size of the data center. It will point out zones with hot spots or zones that are overcooled.
2. **Temporal Scan.** The temperature contour plot in Figure 3.2.2 represents a snapshot in time, and does not account for any temperature and humidity changes over time. The operator could use the information from the QuickScans and the contour maps to isolate and focus on problem areas. This involves using the tool in the LongScan mode to confirm that the issue spotted is not a transient one. The tool is simply placed in front of the suspect rack and collects the temperature (and humidity) over a period of time, typically a day. The Base Excel macro will analyze the collected sample and indicate through trend graphs whether the problem is permanent or transient in nature.
3. **Delta-T Scan.** The data center can be made more energy efficient by measuring the extent of recirculation and bypass airflow for a particular equipment rack and correcting the root cause. The tool's Delta-T option provides a way to measure and generate metrics to indicate the degree of recirculation. This is achieved by placing one AUDIT-BUDDY tool at the front of the rack and one at the back of the rack of interest and collect LongScan data (typically a day). The collected data are processed using a Delta-T macro. The output indicates the degree of recirculation and bypass airflow. The macro also suggests corrective actions for the operator to implement.

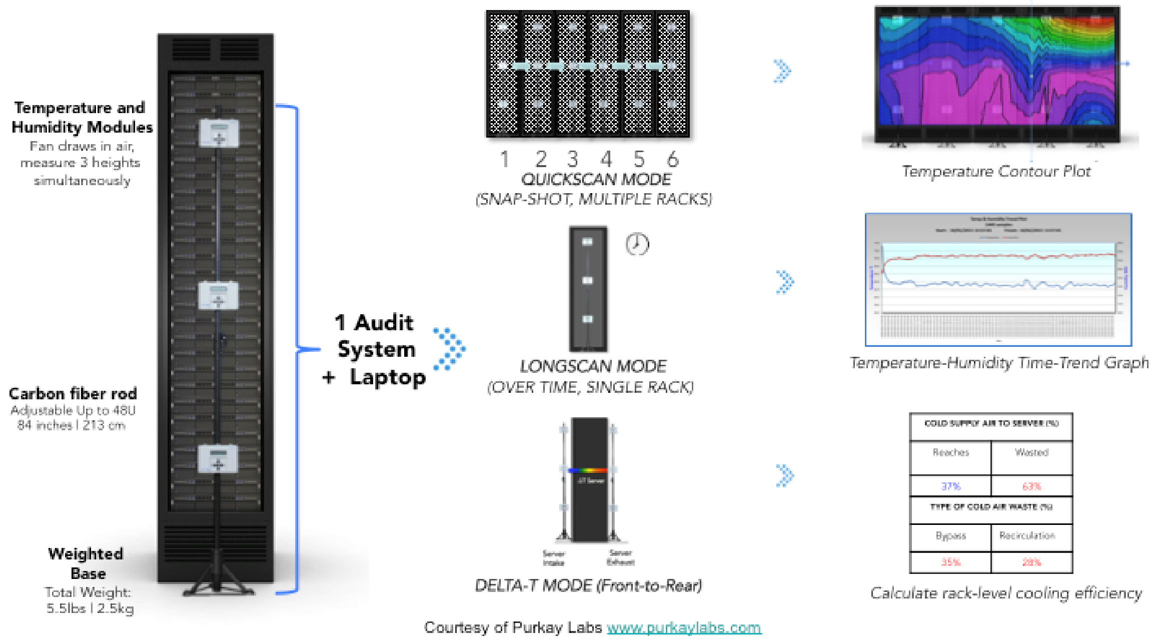


Figure 3.2.2: Summary of the Spatial Mode (QuickScan), Temporal Mode (LongScan), and Delta-T Mode

3.3 EMS 200 (Upsite Technologies) www.upsite.com

Upsite Technologies' Environmental Monitoring System EMS 200 was not designed to be portable, but its size and stand-alone, plug-and-play capabilities make it useful for portable applications. Its original purpose was for small data centers with high security. It is not a pre-packaged boxed tool.

The EMS 200 is a wired sensor network manager that allows for four sensor inputs, allowing the deployment of temperature sensors, temperature/humidity sensors, or any combination of the two. It has eight digital inputs that can monitor open/closed doors, motion sensors, fire alarms, gas detectors, airflow sensors, leak detectors, and summary alarms from critical equipment including UPS and generators. A digital input is either ON or OFF, and it cannot be used for a continuous signal. Figure 3.3.1 shows its four sensor ports (front) and eight digital inputs (rear).

The EMS 200 is simple to install and set up, with plug-and-play capability; the software and hardware guide the user through the process. Upsite Technologies' wired digital temperature sensor 200-TSR-001 (Figure 3.3.2) is recommended for use with the EMS 200. Modbus output enables simple integration to a Building Management System (BMS) or DCIM. It operates off USB power using an included adapter.

Figure 3.3.3 shows the tool's real-time web-based graphical dashboard. The top row of four gauges shows the temperatures for the four temperature (humidity) sensors. There are also multiple alarm notification configurations. The tool has integrated logging and trending. Once trending is enabled, a graph will appear at the bottom of the dashboard. The tool also allows the end user to download data points over a period of time into a CSV file. The user can then download the file into Excel to manipulate the data.

There is no wireless option for EMS 200 to avoid the long pre-made cables. However, the newer (2016) and larger EMS 300 (described later in this report) is wireless, targeting larger enterprise data centers.

Figure 3.3.1: EMS 200 Unit

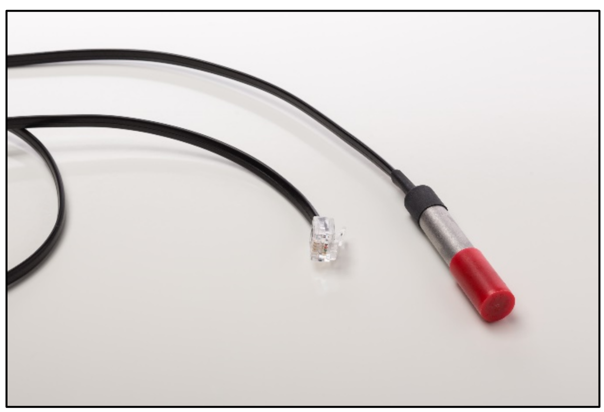


Figure 3.3.2: Temperature Sensor 200-TSR-001

Figure 3.3.3: EMS 200 Dashboard

3.4 Summary and Recommendations (Section 3)

Table 3.4.1 shows a summary of the three portable monitoring tools discussed above.

Purkay Labs' AUDIT-BUDDY is a turnkey, portable tool for monitoring temperature and humidity in data centers. It includes everything to make it portable except a laptop computer. Manuals and software are included to make data analysis easier, although it may require some learning and setup time. The real downside to this tool is the cost, which is approximately four to eight times the cost of the other two tools.

The Watchdog 15 and EMS 200 are off-the-shelf, wired products not explicitly intended to be assembled as portable systems. Although they are less expensive than the AUDIT-BUDDY, they need some extra equipment, such as sensor mounting, to become truly portable. They also require more work to get them to produce useful data. Only basic software is included for reporting and graphing the data in a generic fashion. Still, the simplicity may be an advantage for small data centers with limited resources and expertise.

Table 3.4.1: Summary of the Three Portable Monitoring Tools

Company	Product	Temperature Sensors	Wireless (Wi-Fi)	First Cost with Sensors ($)	Install Cost ($)	License Fee ($)
Geist	Watchdog 15	3	No	400[1]	Own Labor	No
Purkay Labs	AUDIT-BUDDY	3	No	3,200[2]	Own Labor	No
Upsite Tech.	EMS 200	3	No	800[3]	Own Labor	No

1. Watchdog 15: No power supply, laptop computer, or sensor-mounting device supplied.
2. AUDIT-BUDDY: Includes a complete system but no laptop computer. The wireless (Wi-Fi) version costs $7,000.
3. EMS 200: No laptop computer or sensor-mounting device is supplied.

A planned Lawrence Berkeley National Laboratory (LBNL) demonstration project will include installation and evaluation (for ease of use and accuracy) of a few commercially available portable tools such as those discussed above. Evaluation criteria for rating the portable tools may include the following:

- Existence and usefulness of user's manuals and other resources
- Features including software
- Accuracy
- Complexity
- Flexibility
- Support
- Portability
- Time to deploy
- Time to make sense of data
- Overall ease of use
- Connectivity, sensors to data acquisition to user's computer
- Costs
- Target data center size/type
- User experience

4. Stationary Monitoring Systems

The previous section focused on simple and inexpensive portable monitoring products. This section focuses on stationary monitoring systems already used successfully in larger data centers. Transferring such technologies to smaller data centers may not always be trivial. For example, some technologies may need to be repackaged and modified to fit into the small data center domain.

Many Data Center Infrastructure Management (DCIM) products provide "one pane of glass," meaning that a large number of subsystems can be reported on the same screen, providing a truly global view of the data center. In a small data center, this is generally not the preferred solution due to the inherent complexity and costs.

There are a number of DCIM vendors on the market, and organizations and the trade press have compiled several summaries of these companies. In "DCIM: The Big List", Bill Boyle (2016) profiled some of the main DCIM players. Gartner, Inc. also recently published "Magic Quadrant for Data Center Infrastructure Management Tools" (Gartner 2016).

While DCIM means different things to different people, it helps facilitate management, oversight, business, and compliance in data centers. These products are becoming increasingly popular in larger data centers. Although success stories are often in the press and advertisements, there are real concerns about the effectiveness of procuring and implementing DCIM in data centers (Uptime Institute 2015). DCIM products are often large, complicated, and costly, especially for small data centers. Here, "point solutions," which focus only on one, a couple, or a few of the modules available in a complete DCIM package, may be more practical.

Real benefits can be achieved with DCIM even if you do not deploy the full suite, and many organizations prefer to deploy DCIM on a module-by-module basis. Power monitoring, environmental monitoring, and asset management are the most common starting points. These capabilities not only help reduce energy costs but also resolve problems faster, reduce unexpected downtime, and speed asset deployment.

The following paragraphs present descriptions and recommendations on technologies used successfully in large data centers that also show significant promise in small data centers, with or without modifications. DCIM products are slowly catching up to the needs of small data centers, and three paths have crystalized:

- **Type 1: Part of Complete DCIM Solution.** Some DCIM solutions are offered module-by-module. For example, power and environmental modules can be purchased if energy efficiency is the primary goal. This is a flexible solution if there ever is a need for expanding into other modules.
- **Type 2: Entry-Level DCIM Solutions.** These solutions may not include all of the traditional DCIM modules and/or have simplified modules. This is a less flexible solution than Type 1 if there ever is a need to expand the capabilities.
- **Type 3: Point Solutions.** DCIM vendors are developing simplified tools for power and environmental conditions only. These tools (sometimes called "point solutions") are less

complex and costly than traditional DCIM products, but they do not provide the same expansion flexibility.

One typical offering will be discussed for each of these three product types. Please note that these products are being modified almost weekly, and the descriptions may not describe the very latest release. Numerous other vendors have similar products.

4.1 Type 1: Part of Complete DCIM Solution – Power IQ (Sunbird)

Sunbird handles Raritan's DCIM products. Sunbird's complete DCIM solution consists of two distinct products: (1) Power IQ, an active energy/environmental/power management, monitoring, and display product, featuring a dashboard capable of showing PUE and plotting environmental data on the ASHRAE psychrometric chart, and (2) DC Track, which tracks data center assets. Power IQ is the focus here.

Although Sunbird's DCIM solution is a full-blown DCIM product, Power IQ can be used stand-alone and thereby mimic a point solution. The DCIM solution includes Asset Management (DC Track), Capacity Management (DC Track), Change Management (DC Track), Energy Management (Power IQ), Environmental Management (Power IQ), and Power Management (Power IQ). The three last management modules make up Power IQ. Figure 4.1.1 shows an example of the customizable interface.

One challenge with adopting DCIM is controlling the costs and complexity of migrating the current system to DCIM. While a product covering all of the modules of a complete DCIM solution—Asset, Capacity, Change, Energy, Environment, and Power—might be the ultimate goal, it is not necessary to implement it all from day one to receive a positive return on investment (ROI). Implementing DCIM in phases can be cost effective, and might yield a quicker ROI. For example, just moving from environmental management spreadsheets to a DCIM environmental management module can both save energy and reduce IT equipment risks.

These types of products can be used for a phase-by-phase approach and be scaled down to become more attractive for small data centers. For example, we can drive energy efficiencies by using the Power and Energy Management and Environment Monitoring modules. They provide flexibility in their DCIM architecture to fit different needs but still have access to a large feature-rich DCIM system.

The cost for a software license for the Power IQ software depends on the number of nodes to be monitored. For example, the one-time fee is $2,595 for monitoring 20 nodes, but the cost for hardware, including sensors, is extra (from any vendor). Maintenance for a year costs an additional 18%, but software updates are free of charge. It is possible to either buy or subscribe to Power IQ. Sunbird also offers split licenses that can work for multiple small data centers.

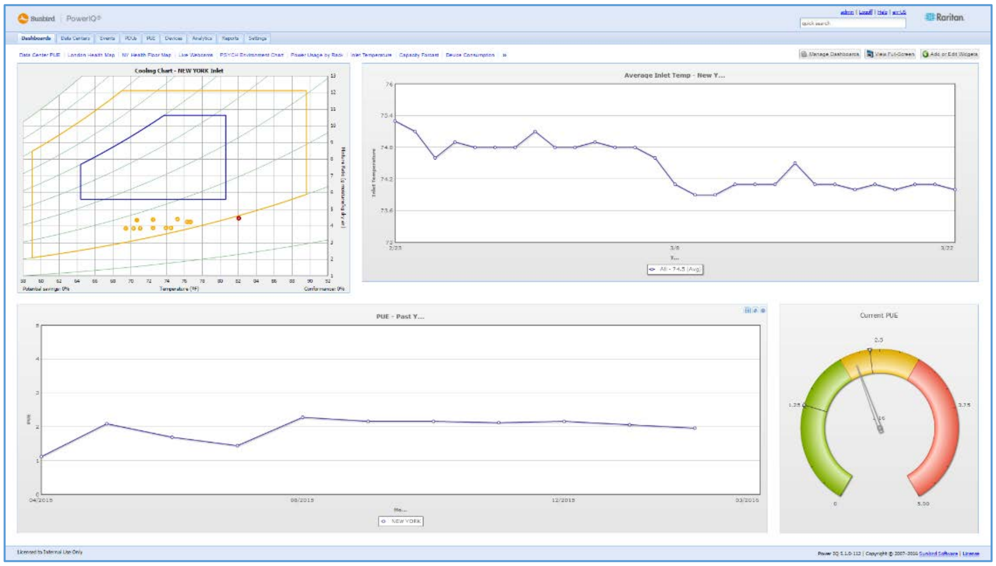


Figure 4.1.1: Custom Sunbird Screen with (clockwise from upper left) ASHRAE Cooling Chart, Average Intake Temperature, Current PUE (meter), and PUE over Time

4.2 Type 2: Entry-level DCIM solutions – Racknet (Geist)

Besides Geist's complete Environet DCIM solution, they offer a stand-alone, entry-level DCIM product called Racknet, which may be suitable for small data centers to consolidate rack-level, real-time power, and environmental information. The system can also monitor PDUs, UPS, and CRACs. However, Racknet does not monitor big devices such as chillers. It consolidates data center information on a dashboard and provides alarming, trending, and reporting. It is PUE-capable with suitable meters.

Racknet supports vendor-neutral SNMP devices. Specifically, a number of protocols are supported: device monitoring via SNMP (device auto-discovery) and Niagara protocols, device monitoring via Modbus IP, Modbus RTU, and BACnet—as well as API and BACnet output.

The system cost varies based on the number of devices (IP addresses) connected. Compared to complete DCIM systems, Racknet only takes a short time to learn. With some basic knowledge, the operator can "build" the system, and Geist's how-to-do videos help in this process. It has an auto-discovery feature that makes installation and adding devices fast and simple.

Racknet provides one comprehensive drag-and-drop, customizable view of all monitored equipment, with a combination of preconfigured and user defined graphics (Figure 4.2.1) on an unusual, hard-to-read black background. A number of views can be shown, including real-time PUE, temperature, humidity, and airflow; energy cost at rack and data center level; user-definable metrics; device status; and equipment location on the data center floor plan. It can monitor multiple local or remote locations. There are also user-definable high and low thresholds for both warning and critical alarms. Reports are fully user-configurable.

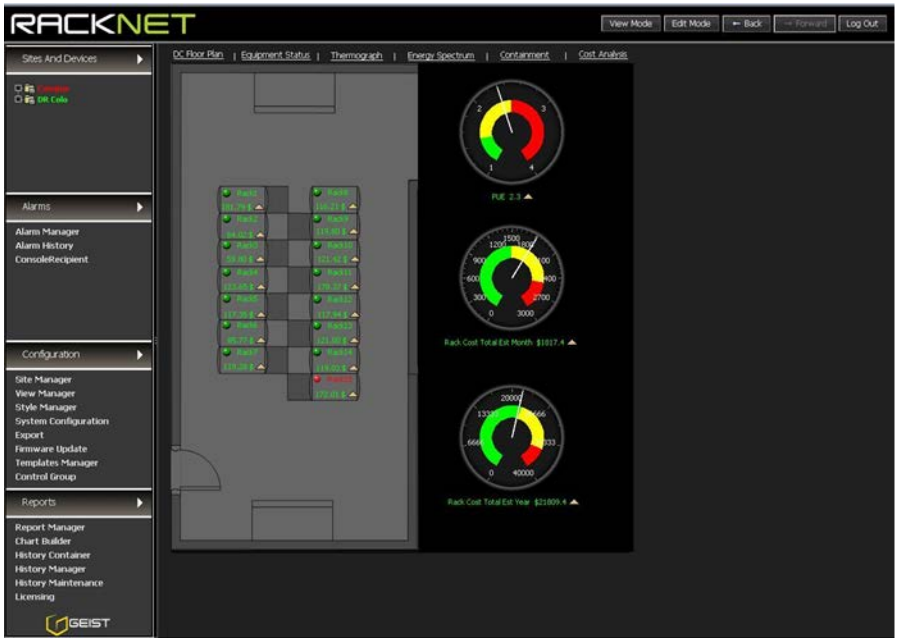


Figure 4.2.1: Typical Racknet Interface with Six Standard Tabs. Shown: Data Center Floor Plan View

This is a purchase-only system. There are several line items in a quote: (1) A software license to run the system is $3,300, which is a one-time fee (updates are free with software maintenance contract); (2) Environmental monitoring devices can monitor anywhere from 4 to 48 temperature sensors; they range from $200 to $600 per unit; and (3) The sensors range from $30 to $200 per piece, depending on what they sense (temperature/humidity/dew point/airflow). Both wired and wireless sensors are available. A complete wireless system with 20 temperature sensors is less than $10,000.

Delivery format includes software only or a 1U rack-mounted appliance. Services include free first-year priority support and limited lifetime software support. For-fee services include installation, configuration, and training, as well as turnkey design and configuration.

4.3 Type 3: Point Solutions – EMS 300 (Upsite Technologies)

Upsite Technologies offers a wireless environmental monitoring product called EMS 300 (Figure 4.3.1). This product is intended to be a cost-effective solution for data center operators to optimize cooling efficiency and prevent downtime. It tracks environmental conditions in real-time to help identify opportunities to improve the effectiveness of cooling and air management.

Figure 4.3.1: Upsite Technologies EMS 300 Gateway

The EMS 300 accepts up to 150 wireless sensor inputs, enabling users to deploy various temperature and humidity sensor configurations, along with four wired digital inputs (ON/OFF), which can be used to track open/closed doors, motion and airflow sensors, fire alarms, gas and liquid leaks, and summary alarms from critical equipment, including UPS and generator equipment.

The gateway is a sensor network manager that receives and aggregates signals from wireless sensors that can be displayed in a centralized, concise, and easy-to-access web interface (Figure 4.3.2). This interface provides a centralized view of the sensors, current readings, and trending, as well as a direct alarm notification to any smartphone or web browser. A number of battery operated wireless digital temperature and humidity sensors are part of the product lineup. The replaceable lithium battery lasts up to four years.

Since the EMS 300 can relay the gathered information to various facility monitoring systems, it streamlines communications and allows a variety of wireless equipment to communicate directly with a building management systems (BMS), network management systems (NMS), and DCIM. Newly added are four hardwired digital inputs and two hardwired relay outputs, which expands the device's capabilities and enables it to relay signals from traditional wired sensors and equipment.

While it can operate as a stand-alone device, the product can integrate into larger systems via SNMP or building management systems through BACnet. Modbus protocols can serve as a network repeater to convey alarm status information to a centralized location. Other protocols include TCP/IP, HTML, and TFTP. Two features that make it suitable for small data centers are easy and low-cost installation and stand-alone operation. Adding new sensors or relocating current ones are simplified with the auto-discovery mechanism that detects system modifications.

The cost for the EMS 300 Gateway alone is $1,595. Each wireless temperature sensor is $109, and each wireless temperature/humidity sensor is $190. A complete system with 20 wireless temperature sensors is $3,800. There is no annual licensing fee, only a one-time purchase cost with free software updates.

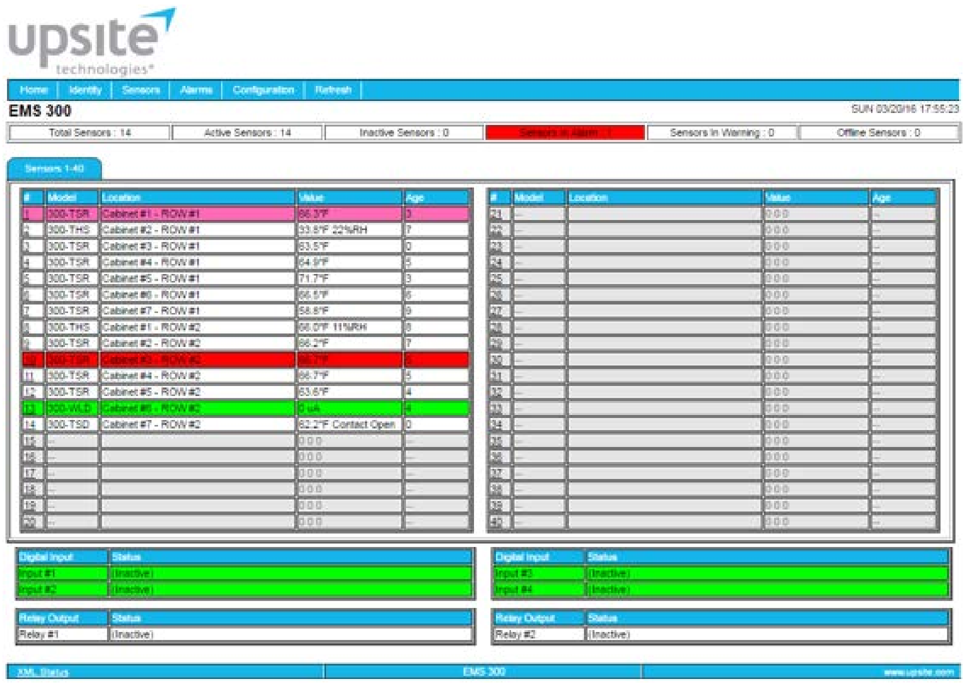


Figure 4.3.2: EMS 300 Web Dashboard

4.4 OpenDCIM

OpenDCIM is a free, web-based DCIM application in the public domain. The OpenDCIM Foundation, Inc., is a not-for-profit corporation formed to manage the project and cover any expenses related to hosting and publicizing OpenDCIM. The information below is based on the information provided on their home page (OpenDCIM 2016a).

Scott Miliken, computer facility manager at the Oak Ridge National Laboratory, introduced OpenDCIM five years ago. It is not a function-by-function replacement for commercial applications; therefore, it is not designed to compete with commercial DCIM products. Instead, OpenDCIM covers the majority of features needed by developers—as is often the case of open-source software. Anyone can take it, modify it, and share it with others, as long as they acknowledge where it came from.

OpenDCIM could be a good introduction to DCIM before committing to a larger system such as those discussed above. However, a small data center may not need more than OpenDCIM, since the requirements often are limited in scope. An article by David Chernicoff (2016) asks: Could Open Source Unlock DCIM?

Support is provided in a number of ways. A Wiki page provides a user’s manual (OpenDCIM 2016b), and users can search a YouTube channel called “OpenDCIM” for several videos on how to perform tasks in OpenDCIM.

The number one goal for OpenDCIM is to "eliminate the excuse for anybody to ever track their data center inventory using a spreadsheet or word processing document again. We've all been there in the past, which is what drove us developers to create this project."

OpenDCIM includes a number of useful features that help users track what is happening in the data center:

- Support for multiple data centers
- Provide complete physical inventory (asset management and tracking) of the data center
- Management of the three key elements of capacity management: space, power, and cooling
- Basic contact management and integration into existing business directory via UserID
- Fault tolerance tracking (run a power outage simulation to see what would be affected)
- Computation of center of gravity for each cabinet
- Template management for devices, with ability to override each device
- Optional tracking of cable connections within each cabinet, and for each switch device
- Archival functions for equipment sent to salvage/disposal
- Integration with intelligent power strips and UPS devices
- Open architecture built on a MySQL database for easy report building or export

4.5 Summary and Recommendations (Section 4)

Table 4.5.1 shows a summary of the stationary monitoring tools discussed above.

DCIM products are slowly catching up to the needs of small data centers, and three paths crystalized. One product example was given for each type.

- **Part of Complete DCIM Solution.** Some DCIM solutions are offered module-by-module. For example, power and environmental modules can be purchased if energy efficiency is the goal. This is a flexible solution if there ever is a need to expand into other modules.
- **Entry-Level DCIM Solutions.** These solutions may not include all of traditional DCIM modules and/or have simplified modules. This is a less flexible solution than the previous type should there ever be a need to expand the capabilities.
- **Point Solutions.** Vendors are developing simplified tools for power and environmental conditions. These more nimble tools (point solutions) are less complex and costly but do not provide the same expansion flexibility. A point solution may work well in small data centers.

For small data centers with limited budgets, it often can be beneficial to choose a product that is priced based on the number of connected nodes: The fewer nodes, the lower cost.

The free OpenDCIM could be a good introduction to DCIM before committing to a larger system such as the others discussed above. However, a small data center may not need more than the capabilities of OpenDCIM, since the requirements often are limited.

Table 4.5.1: Summary of Stationary Monitoring Systems

Company	Product	Type	Max # Temp Sensors	Wireless	First Cost ($)	Install Cost ($)	License Fee ($)
Sunbird	Power IQ	Part of a complete DCIM solution	>20,000 in use for single system today	Hardware not offered	Hardware not offered	$2,800[1]	$2,595 for 20 nodes[2] maintenance 18%/yr
Geist	Racknet	Entry-level DCIM solution	>5,000 in use for single system today	Yes	$4,780 Hardware with 20 sensors	$3,825[3]	$5,150[4] maintenance 15%/yr
Upsite Technol.	EMS 300	Point solution	150	Yes	$3,800 Hardware with 20 sensors	Own Labor[5]	None

[1] On-Site, One-Day Quick Start.

[2] One-time fee, free updates.

[3] Beyond initial training & programming of up to five devices.

[4] Free updates with software maintenance contract. Includes initial training and programming of up to five devices.

[5] Limited remote free technical support available.

5. Simulation Tools

Only a limited number of simulation tools are available for estimating energy savings from air management in data centers. We will look at two free, complementary tools: (1) the U.S. Department of Energy (DOE) Air Management Tool, which was partially validated with CFD modeling with funds from PG&E; and (2) the Airflow Management Calculator (AFM) developed by the Bonneville Power Administration (BPA) and Seattle City Light.

5.1 DOE Air Management Tool

The DOE Data Center Air Management Tool was developed to help accelerate the energy savings in data centers without affecting the thermal IT equipment environment. Based on user input, it provides air management recommendations and the potential for reducing the supply airflow rate and increasing the supply air temperature, which both affect energy use. Finally, it estimates the percent energy reduction, kilowatt-hour (kWh) reduction, and the associated energy-cost savings for supply fans and chillers.

This tool assumes that the data center is operated at sufficiently stable environmental conditions. For example, the air handlers may have variable air volume (VAV) fans, but they are assumed to be operating at a stable constant reduced airflow. Since the majority of conventional data centers have raised-floor cooling with hot and cold equipment aisles, this tool is intended mainly for such environments. Having a basic understanding of the physical data center environment makes this tool easier to understand and use.

The user fills in data and answers questions on four input Excel sheets (Steps 1–4). Each sheet includes basic guidance for entering the data correctly. The Excel sheets and cells are color coded to facilitate data tracking between sheets. Yellow cells indicate where to input data. All input cells have input-range checking to help avoid data-entry errors. The user's manual provides additional information.

Step 1: AHU Air-handling unit (AHU) data for calculating the return temperature index (RTI) metric, which plays an important role in understanding whether the data center is over-ventilated or under-ventilated.

Step 2: Equip Electronic equipment data for calculating the RTI metric. "Equipment" includes heat-generating electronic equipment (IT), as well as electric equipment such as PDU and UPS.

Step 3: RCI Equipment intake temperatures for calculating the rack cooling index (RCI) metric, which is a performance metric explicitly designed to gauge compliance with the thermal guidelines of ASHRAE and NEBS (Herrlin 2005).

Step 4: Main Input Main user input, including metrics from Steps 1–3. The main input includes air-management questions for current (existing architecture/controls) and target conditions (target architecture/controls).

Based on this user input, numerical output and recommended actions are given on two output Excel sheets (Steps 5 and 6).

Step 5: Main Results Main results, excluding energy results. Lists numerical output and recommended actions based on user input for realizing commissioned, retrofitted, or state-of-the-art conditions. Commissioned conditions involve tweaking the existing architecture/controls, whereas retrofitted conditions require upgrading to target architecture/controls.

Step 6: Energy Results Energy estimates for supply fans and chillers, including percent energy reduction, kWh reduction, and associated energy-cost savings. Bar charts show the savings for commissioned, retrofitted, or state-of-the-art conditions (Figure 5.1.1). By reading across the bars, the achievable (maximum) improvements for the three levels of measures can quickly be evaluated, as explained in the user's manual.

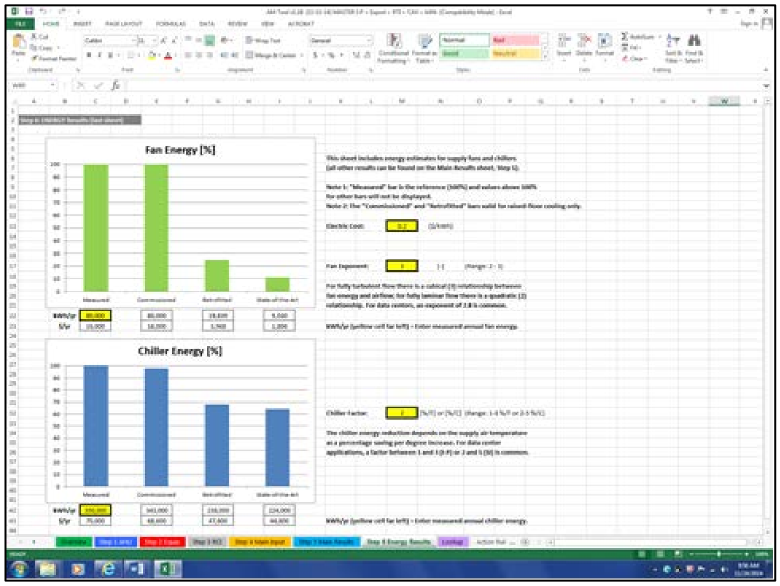


Figure 5.1.1: The Air Management Tool's Energy Results Sheet

The report, *Data Center Air Management Research* (PG&E 2010), includes several common air management measures applied to computational fluid dynamics (CFD) modeling to explore energy-saving potentials. Measured data were also included in an effort to verify the modeling. The results were intended to help improve the prediction of energy savings, as well as improve the DOE Air Management Tool.

The correlation between the CFD modeling results and the Air Management Tool estimates depends on the quality of the implemented air management. Most important, for high-quality air management, the modeled and the calculated results show similar trends. The report also points to areas where more work may be needed.

The Air Management Tool can be downloaded from DOE's Center of Expertise for Energy Efficiency in Data Centers website (DOE 2014a). The same website also has three complementary documents that facilitate the tool's use:

- The User's Manual provides information on how to use the tool.
- The Engineering Reference provides information on calculations, equations, and metrics.
- The Data Collection Guide provides information on how to collect the necessary input data.

Besides providing energy savings estimates and prioritizing different air management measures, the Air Management Tool can serve as an educational tool. As such, it is an integral part of the DOE Data Center Energy Practitioner (DCEP) training program (DCEP 2016).

The Air Management Tool also is part of the DOE Software Tool Suite (DOE 2014c), which includes an online Data Center Profiling Tool (DC Pro), a PUE Estimator, and an Excel-based

Electrical Tool. Lawrence Berkeley National Laboratory will develop a simplified version of the Air Management Tool in 2017. Called the Air Management Estimator, it will consist of just one input screen and one output screen, to provide a simple and very quick way of estimating the savings with various air management measures.

The Air Management Tool was produced with DOE funding. Lawrence Berkeley National Laboratory and ANCIS Incorporated jointly created the tool.

5.2 Airflow Management Calculator

The Airflow Management Calculator (AFM) estimates the annual energy consumption (kWh) and peak power demand (kW) of major energy consuming components (air handling units, fans, and chillers) of the heating, ventilation and air conditioning (HVAC) system from airflow reductions in small data centers. The tool includes system types that are commonly used to cool data centers with traditional air-cooled computer room environments. It does not include heat rejection subsystems such as cooling towers and dry coolers, and it does not cover airside economizers.

The user enters facility cooling load and HVAC system operating parameters. The calculator employs a calculation engine consisting of hourly climate data for a range of U.S. climate zones (TMY3 climate data), cooling load, and HVAC system power requirements (chiller, compressor, AHU fans) for that hour. Hourly data are then tabulated to develop an “Existing” (baseline) HVAC annual total energy usage (kWh) and peak power (kW) demand estimate. Partial PUE is also calculated.

The user proposes changes to the HVAC system and its operations (e.g., higher operating temperatures, fewer operating AHU’s, and reduced airflow rates) as a “Proposed” operating scenario. The proposed operating scenario is run through the same calculation engine as the existing scenario to create an annual potential energy savings (kWh) and peak power demand (kW) reduction estimate. Lastly, the “Implemented” operational scenario describes what was actually implemented. “Proposed” and “Implemented” HVAC annual total energy usage (kWh) and peak power (kW) demand are estimated based on staging air handlers on/off or adjusting the fan speed. Figure 5.2.1 shows a typical output example.

By entering information on operating temperature and airflow, the tool can estimate the annual energy consumption and peak power demand. Note, however, that the tool does not provide guidance in the process of realizing those conditions through “air management,” such as installation of blanking panels, sealing raised floors, or implementing hot/cold aisles.

The achievable delta-T (temperature drop) across the air handler(s), which in turn gives a corresponding airflow when the cooling load is known, can be entered on input. Three target options are available: Conservative (delta-T 18°F), moderate (delta-T 20°F), and aggressive (delta-T 24°F). The calculated airflow across the air handler(s) based on the entered information for existing, proposed, and implemented conditions is then compared with the airflow target. The tool calculates the excess airflow rate for the three conditions. This is meant to provide some general guidance on the degree of excess airflow.

This spreadsheet tool is not meant to be used for data center design or thermal management at the rack level. Small data centers are defined here as facilities populated with 50–750 kW of IT equipment load, deployed in racks with an average power density of 2–5 kW per rack. This energy savings estimate can then be used to estimate potential utility incentive funding.

The user of this versatile tool should have some degree of familiarity with the data center operating environment, requirements, and data center HVAC systems in order to generate a credible, achievable energy savings estimate. The tool and documentation (a user guide and technical reference) are available online (Airflow Management Calculator 2016).

The Airflow Management Calculator was produced with funding provided by The Bonneville Power Administration's (BPA) Emerging Technologies for Energy Efficiency Program and Seattle City Light's Conservation Resources Division. CLEAResult consulting under direction of Seattle City Light and Ted Brown created the tool. A PG&E airflow program was an "inspiration" for the current calculator. Trane Corporation and Emerson Network Power contributed HVAC system performance data. Performance data also came from DOE2/eQuest simulation tools.

Data Center Airflow/ Efficiency Project Summary *Ver 1.0 11/02/2015* **Date: 11/2/2015**

Company	SEACH
Facility Name	Admin Data Center
Address	123 Any Ave. NE
City, State Zip	Seattle, WA 98115
Contact	Mickey Mouse
Title	DC Ops Mgr.
Phone	206.555.1212
email	mickey@mouse.com

$	0.071	Avg. kWh Electricity Cost
$	1.92	Avg. kW Peak Demand Charge
$	0.20	per kWh Utility Incentive rate
$	-	per kW Demand reduction Incentive
	4,631,289	Annual Facility kWh
	6%	Implemented Saving % of Facility

	Energy Savings (kWh/yr)	Demand Savings (kW)	Utility Cost Savings ($)	Estimated Project Cost ($)	Estimated Incentive* ($)	Simple Payback After Incentive
Project Total - Proposed	283,557	23.2	$ 20,177.02	$ 89,178.00	$ 56,711.36	1.6
Project Total - Implemented	281,690	22.5	$ 20,043.19	$ 94,229.00	$ 56,337.97	1.9

** The Incentive Estimate contained in this calculator is for informational purposes only. It is NOT a formal offer of utility incentive funding*

203.0 kW Total Cooling Load | ***Proposed Project Implementation Date*** 11/2/2015 | ***Project Verification Date*** 11/3/2015

	EXISTING CONDITION	PROPOSED	IMPLEMENTED
Cooling Capacity			
Nominal Cap Ton / Nominal Ton	96	96	96
% of Norminal Cap	60.1%	60.1%	60.12%
Worst-case Ton	74	81	78
%Worst-case Cap	77.7%	71.0%	73.9%
Airflow Efficiency			
CFM / kW	242	161	151
Excess CFM %	**51%**	**0%**	**-6%**
Cooling Efficiency			
Annualized kW/ton	0.90	0.60	0.63
Economizing %	0%	63%	55%
Economizing Hours	0	5,535	4,818

Environmental Conditions

EXISTING CONDITION		PROPOSED		IMPLEMENTED	
62.1	Avg. Server Inlet Temp., °F (Estimated)	66.8	Target Server Inlet Temp., °F	62.0	Avg. Server Inlet Temp., °F
75	Avg. AHU Return Air Temp., °F	83	Avg. AHU Return Air Temp., °F	81	Avg. AHU Return Air Temp., °F
61	Avg. AHU Supply Air Temp., °F	66	Avg. AHU Supply Air Temp., °F	61	Avg. AHU Supply Air Temp., °F

Airflows

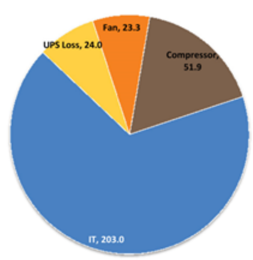
EXISTING CONDITION		PROPOSED		IMPLEMENTED	
49,200	Estimated CFM	32,600	Proposed CFM	30,600	Implemented CFM
160	Required CFM / kW	**34%**	**Planned Airflow Reduction**	**38%**	**Achieved Airflow Reduction**
5	CRAC Units "On"	5	CRAC Units "On"	5	CRAC Units "On"
100%	Avg, CRAC Fan Speed	75%	Avg, CRAC Fan Speed	70%	Avg, CRAC Fan Speed

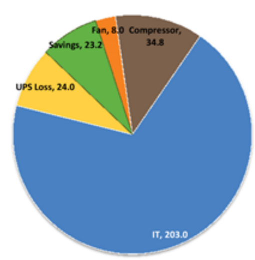
Cooling Energy Consumption

EXISTING CONDITION		PROPOSED		IMPLEMENTED	
203,949	Yrly. AHU Fan kWh	69,841	Yrly. AHU Fan kWh	57,346	Yrly. AHU Fan kWh
454,293	Yrly.Mechanical Cooling kWh	304,844	Yrly.Mechanical Cooling kWh	319,206	Yrly.Mechanical Cooling kWh
658,242	Total Cooling kWh	374,685	Total Cooling kWh	376,552	Total Cooling kWh
		283,557	Est. Annual kWh Savings	281,690	Achieved Ann. kWh Savings
		43%	**Reduction**	**43%**	**Reduction**

Energy Use Breakdown

Existing Condition	kW	Proposed	kW	Implemented	kW
HVAC		HVAC		HVAC	
Fan	23.3	Fan	8.0	Fan	6.5
Compressor	51.9	Compressor	34.8	Compressor	36.4
IT	203.0	IT	203.0	IT	203.0
UPS Loss	24.0	UPS Loss	24.0	UPS Loss	24.0
		Savings	23.2	Savings	22.5
PUE (Partial)	**1.49**	**PUE (Partial)**	**1.33**	**PUE (Partial)**	**1.33**





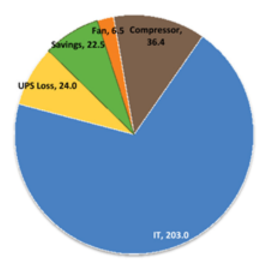


Figure 5.2.1: The Airflow Management Calculator's Airflow/Efficiency Project Summary

5.3 Summary and Recommendations (Section 5)

The two tools described above are quite complementary, as shown in Table 5.3.1 below. The Air Management Tool is more focused on the air management aspect, whereas cooling systems are handled in a more sketchy fashion. The AFM Tool has taken quite the opposite approach. Since they are both spreadsheet tools, they could potentially be combined into one single powerful tool, which could resolve each tool's shortcomings.

Only the Air Management Tool was deemed useful for studying the energy impact from implementing packages of air management measures. Consequently, for the modeling part, we were limited by its capabilities. For example, it only allows input for certain air management measures, and the look-up tables are based on limited data (expert experience and CFD modeling).

Table 5.3.1: Summary of Simulation Tools

Developer	Product	Pros	Cons	Cost
U.S. DOE, LBNL, and ANCIS Incorporated	Air Management Tool	Multiple Air Management Measures and IT Thermal Conformance	Lack of HVAC System Data and Yearly Calculations	Free
BPA, Seattle City Light, and CLEAResult	Airflow Management Calculator (AFM)	HVAC System Data and Hourly Calculations	Lack of Air Management Measures and IT Thermal Conformance	Free

6. Air Management Measures

Ten primary individual input air management measures used in the Air Management Tool impact the energy estimates. Each measure will be described below in general terms, since they will be used in the modeling in Section 7. This does not mean that no other air management measures are available on the market.

Enabling and realizing energy savings in data centers is a two-step process: First, physically arrange the space to promote separation of hot and cold air. This can be accomplished by a number of measures as described below. These measures by themselves do not save energy but rather *enable* the savings. Second, to *realize* the savings, at least one of two additional things must happen: (1) Increase the supply air temperature (producing higher chiller efficiency and economizer utilization), and/or (2) decrease the supply airflow rate (resulting in lower fan operating costs). The modeling in Section 7 will look at both of these factors.

1. *Recommended IT Equipment Intake Temperature Range (statement of reliability)*

   The temperature of the air drawn into the air-cooled equipment defines the thermal equipment environment—the temperature the electronics depend on for reliable cooling and operation. ASHRAE's *Thermal Guidelines for Data Processing Environments* (ASHRAE 2015) is frequently referenced for environmental specifications in data centers.

   The purpose of the Recommended (and Allowable) environmental range is to give guidance to data center operators on maintaining high reliability while operating their data centers energy efficiently. The Recommended range is a statement of reliability. This is the preferred facility operation; most intake temperatures should be within this range (65°F–80°F). Adopting the ASHRAE environmental criteria (Figure 6.1) provides opportunities to reduce energy use.

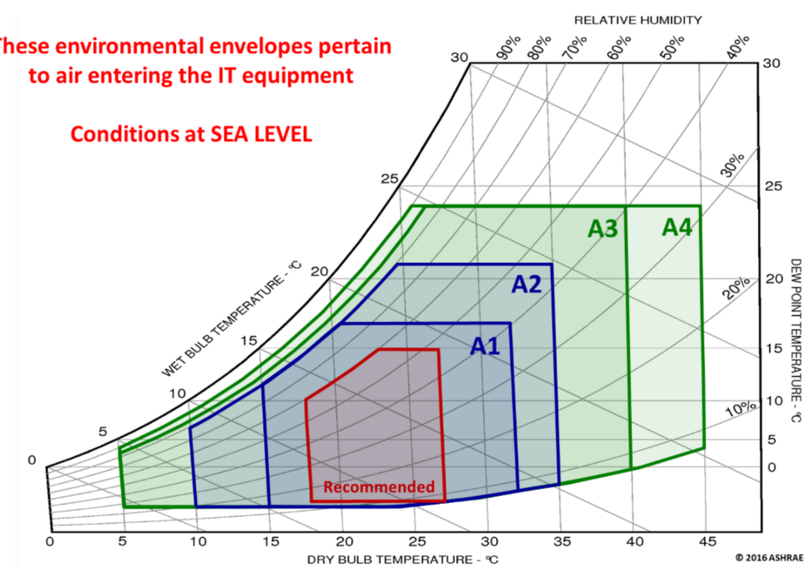


Figure 6.1: ASHRAE Recommended and Allowable Environmental Envelopes (ASHRAE 2015)

2. *Allowable IT Equipment Intake Temperature Range (statement of functionality)*

   The Allowable range is a statement of functionality; no intake temperatures should be outside this range. ASHRAE specifies four allowable ranges for data centers: A1–A4. A1 is often considered the default range (59°F–90°F). The Recommended range is the same for all four Allowable ranges.

3. *Aisle Containment*

A number of aisle containment systems exist, both with regard to where the containment is installed (hot aisle or cold aisle) and the “flexibility” of the containment (curtains or rigid sheets).

The primary types of air containment systems are cold-aisle containment (Figure 6.2) and hot-aisle containment. There are benefits and drawbacks of both. The key benefit they share is that they effectively promote the separation of hot and cold air, which may boost energy efficiencies. Any leakage between the contained space and the surrounding space may negatively affect system performance.

For a cold-aisle containment system, the equipment intake air temperatures are close to the supply air temperature. On the negative side, this system results in elevated room temperatures outside the containment, which may expose staff to uncomfortable conditions. For a hot-aisle containment system, on the other hand, the hot equipment exhaust is isolated from the rest of the room, which becomes a room with a temperature close to the supply air temperature.

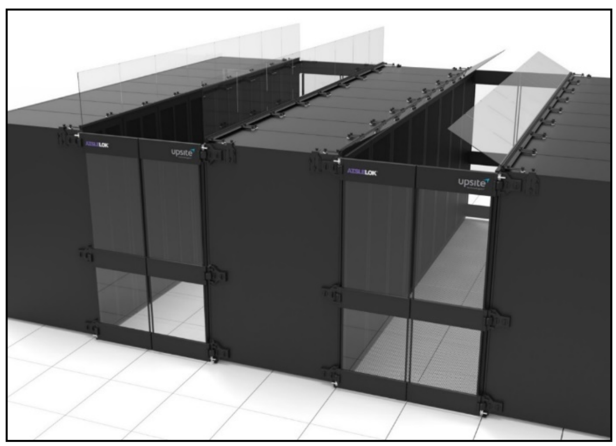


Figure 6.2: Rigid Cold-Aisle Containment (Upsite Technologies)

4. *Blanking Panels in Equipment Racks*

Any opening between the cold aisle and the hot aisle will degrade the separation of hot and cold air. Leakage may occur between racks, above racks, around racks, under racks, in empty spaces in racks, and between equipment and vertical rails inside racks (in-rack recirculation).

Blanking panels are used to seal such openings (Figure 6.3). Broken equipment rows should be filled with empty racks with blanking panels from top to bottom. Blanking panels come in various heights and widths to fit almost any application, and they come in snap-on or screw-in types.

Managing blanking panels and unbroken equipment rows is important in hot and cold aisle environments in general, and in contained environments in particular. Both recirculation of hot exhaust air and bypass of cold supply air degrade the benefits of the hot and cold aisle configuration.

Figure 6.3: Example of Two Blanking Panels (Upsite Technologies)

5. *Floor Leakage*

A large fraction of the air from the air handlers is often lost through leaks in the raised floor. Such leakage can cause bypass air that does not contribute to cooling the electronic equipment and also contributes to additional fan energy. Even the chiller energy usually goes up due to depressed return air temperatures. Figure 6.4 shows a grommet that reduces the leakage at cable openings in the raised floor. The cables will enter the data center space though the "brushes."

Figure 6.4: Example of Grommet (Upsite Technologies)

6. *Perforated Floor Tile Placement*

Perforated floor tiles should only be placed in the cold aisles, and they should approximately match the airflow need of the IT equipment. The hot aisles are supposed to be hot, and perforated tiles should not be placed in those areas. Perforated tiles in the hot aisles result in bypass air.

7. *EC-Class (equipment ventilation protocol)*

   The Equipment Cooling (EC) Class refers to the way the IT equipment is ventilated. Today, nearly all IT equipment conforms to the front-to-rear protocol. Cold air enters at the front of the rack and hot exhaust air leaves at the rear of the rack. This protocol is preferred since it supports the cold and hot aisle configuration.

8. *Controls Sophistication*

   Temperature control: Monitors the return air temperatures (common), the supply air temperatures (less common, better), the rack intake temperatures (even better), or the IT intake temperatures (ideal) to manage the CRAC supply temperature to save chiller energy while maintaining IT equipment thermal requirements.

   Pressure control: Monitors the raised-floor pressure to control VAV fans and deliver only required airflow volumes to the data center, to save fan energy.

9. *AHU Modularity/Distribution*

   From an air management perspective, a larger number of smaller CRAC units are better than a smaller number of larger units. This is especially true if they have CAV fans. Turning off a large unit may have hard-to-predict consequences for the airflow distribution.

10. *Cable/Pipe Management in Supply Air Path*

    Cable congestion in raised-floor plenums can sharply reduce the total airflow, as well as degrade the airflow distribution through the perforated floor tiles (Figure 6.5).

Figure 6.5: Poor (left) and Good (right) Cable Management (ANCIS Incorporated)

7. Air Management Packages

The “Basic Air Management Levels” (defined in Section 7.1) will demonstrate the capabilities of the Air Management Tool, whereas the subsequent “Small Data Center Air Management Packages” (defined in Section 7.2) will be crafted to work in small data centers, allowing replication with little or no customization.

A number of individual air management measures were discussed in the previous section. The interaction between individual measures can be strong; some measures will not result in savings without other measures. Therefore, it makes sense to reward “packages” of air management measures with financial utility incentives rather than rewarding individual measures that may or may not result in energy savings.

Installing blanking panels or sealing the raised floor will not save energy per se. These measures are examples of “enablers” that only achieve energy savings when they are implemented in conjunction with two “activators.” First, we need a way to adjust the supply air volume from the cooling system, (which saves fan energy), and second, we need a way to increase the supply air temperature (which makes the chillers and economizers work more efficiently).

Simulation tools can provide an estimate of potential fan and chiller energy savings by implementing a certain combination (package) of air management measures. As discussed in Section 5, the DOE Air Management Tool was used as the simulation tool.

The energy modeling results can help develop “deemed savings” for the air-management packages. Deemed savings are much more cost effective in small data centers, compared with measuring and evaluating one data center at a time. However, the packages need to be scalable and we need to know how well they work on average, the number of data points used to determine the energy savings, and other factors. The packages proposed in this report could be a first step in that direction. Section 8 provides a roadmap for determining the deemed energy savings and utility rebates.

7.1 Basic Air Management Levels

The Basic Air Management Levels will demonstrate the capabilities of the Air Management Tool, likely range of energy savings, and energy savings trends.

Defining the Basic Air Management Levels

The selected four basic levels will closely follow the different quality/implementation levels used in the Air Management Tool: L (Low), M (Mid), and H (High). Each of the levels uses ten individual air management measures. We will start with the less sophisticated air management level and move towards the most sophisticated.

- Level L (Reference)
- Level M1 (with CAV fans): Low first cost, low savings
- Level M2 (with VAV fans): Intermediate first cost, medium savings
- Level H: High first cost, large savings

Table 7.1.1 shows the level of quality/implementation for each of the ten air management measures for the four Basic Air Management levels. The Air Management Tool's Measure 1 (Recommended Range) is assumed to be the same (65°F–80°F) for all four levels, and Measure 2 is not applicable (N/A) since the Allowable Range is not involved in the energy calculations.

Table 7.1.2 shows what "L", "M", and "H" levels stand for with regard to each individual air management measure in Table 7.1.1. The level descriptions are taken directly from the Air Management Tool. It is assumed here that an "L" data center has an "L" across most measures and that an "H" data center has an "H" across all measures. Of course, this may not be true for a specific data center.

Measure 7 has been assigned "H" since nearly all of today's electronic equipment adheres to the preferred front-to-rear cooling airflow scheme, which supports hot and cold aisles.

Measure 8 has only two values—"L" and "H"—where L = CAV (constant air volume fans) and H = VAV (variable air volume fans). To reduce the airflow, select CAV unit(s) can be shut off, whereas with VAV units, all units are turned down.

Measure 9 uses two models: one with two CRACs (assigned L) and one with three CRACs (assigned M). It is not likely with a change from two to three CRACs for Levels L, M1, and M2.

Table 7.1.1: Basic Air Management Levels

(Not necessarily designed for small data centers)

AM Measure (AM Tool)	L (Reference)	M1	M2	H
1: Recommended Range[1]	65°F–80°F	65°F–80°F	65°F–80°F	65°F–80°F
2: Allowable Range[2]	N/A	N/A	N/A	N/A
3: Aisle Containment	L	M	M	H
4: Blanking Panels	L	M	M	H
5: Floor Leakage	L	M	M	H
6: Tile Placement	L	M	M	H
7: EC-Class	H	H	H	H
8: CAV/VAV (CRAC)	L (CAV)	L (CAV)	H (VAV)	H (VAV)
9: CRAC Modularity	L (2) or M (3)	L (2) or M (3)	L (2) or M (3)	L (2) or M (3)
10: Cable Management	L	M	M	H

[1] The ASHRAE Recommended range is used throughout.

[2] The ASHRAE Allowable range does not enter the energy calculations.

Note that the Air Management Tool does not allow input for the location of the temperature sensors for the control system. It assumes the ideal location; namely, at the electronic equipment intakes. The commonly used location at the air return is much less accurate, and the level of accuracy depends on the calibration with the intake temperatures. Return Air Temperature sensing may require post-processing (discussed in Section 8).

Table 7.1.2: Description of Each Level of Air Management

AM Measure (AM Tool)	Level (AM Tool)	Typical Implementation
3: **Aisle Containment**: Level of containment	Low: None Mid: Partial High: Full	Low: No containment. Mid: doors to (cold) aisles, rigid or curtains. High: full containment, doors to and lid over (cold) aisles or direct rack exhaust to return plenum.
4: **Blanking Panels:** Open area of total front rack area	Low: 10%–30% Mid: 5%–10% High: 0%–5%	Low: No or only marginal use of blanking panels. Mid: Fair use of blanking panels in racks, possibly under and between racks. High: Extensive use of blanking panels in, between, and under racks.
5: **Floor Leakage**: Floor leakage of total supply airflow	Low: 35%–65% Mid: 15%–35% High: 5%–15%	Low: Marginal use of grommets and seals. Mid: Major leakage paths sealed. High: Extensive effort to limit all floor leakage.
6: **Tile Placement**: Perforated tiles outside the cold equipment aisles	Low: 15%–25% Mid: 5%–15% High: 0%–5%	Low: Large number of tiles outside cold aisles. Mid: About one in ten tiles outside cold aisles. High: Nearly no tiles outside cold aisles.
7: **EC-Class**: Airflow protocols other than front-to-rear	High: 0%–5%	Low: N/A Mid: N/A High: Nearly no IT racks ventilated other than front-to-rear
8: **CAV/VAV CRAC**: Level of air volume adjustments	Low: CAV (constant) High: VAV (variable)	Low: Constant Air Volume fans. Mid: N/A High: Variable Air Volume fans.
9: **CRAC Modularity**: Number of racks served by each CRAC	Low: 40%–80% Mid: 20%–40% High: 10%–20%	See previous column.
10: **Cable Management**: Blockage of total cavity volume	Low: 25%–35% Mid: 15%–25% High: 5%–15%	Low: Unbundled cabling with a large number of cables, including retired. Mid: Mixture of bundled and unbundled cables. High: Bundled cabling with only active cables.

Defining the Data Center Used for Modeling

For the simulations, the reference data center was chosen to coincide with the poor (L) air management quality/implementation level in the Air Management Tool, since most small data centers are not well maintained.

We used two DX-CRAC modularity: Two 30-ton CRACs or three 20-ton CRACs. Besides this difference, the data centers were identical.

Common Data Center Description:

Area: 2,000 ft^2 (45 ft x 45 ft)

Total IT racks: 60

Equipment rows: 4

Supply air path: Raised floor

IT Equipment Data:

Power: 82 kW

Temperature rise: 25°F (mainly modern equipment)

Airflow: 10,364 cubic feet per minute (cfm)

DX-CRAC (common in small data centers) Modularity:

2 x 30 ton (2 x 105.6 kW) CRAC; maximum CRAC capacity/IT load = 211,000/82,000 = 2.57

13,000 cfm (x2); CRAC maximum airflow/IT flow = 26,000/10,364 = 2.51

One redundant unit, but two running (with reduced cooling), providing 82 kW (23 ton) cooling.

Fans can either be CAV (ON/OFF) or VAV (modulating).

3 x 20 ton (3 x 70.4 kW) CRAC; maximum CRAC capacity/IT load = 211,000/82,000 = 2.57

8,667 cfm (3); CRAC maximum airflow/IT flow = 26,000/10,364 = 2.51

One redundant unit, but three running (with reduced cooling), providing 82 kW (23 ton) cooling.

Fans can either be CAV (ON/OFF) or VAV (modulating).

Please note again that throughout this report “chiller” means refrigeration equipment.

Modeling Assumptions

For the fan modeling with the Air Management Tool, the “Fan Exponent” for VAV operation was set to 2.8 rather than 3.0, to account for non-ideal conditions. Ideally, the fan energy is proportional to the cube of the airflow. This exponent is the reason that the percentage fan energy savings from air management measures can be very high. The Air Management Tool allows the user to set this parameter to any value between 2.0 and 3.0.

Furthermore, the “Chiller Factor” in the Air Management Tool was set to 2% chiller energy savings per degree F increase in supply air temperature. The tool allows the user to set this parameter to any value between 1% and 3%.

Modeling Results

Next, Figures 7.1.1–7.1.4 show the relative energy savings for fans and chillers, respectively, for each of the four Basic Air Management Levels compared to the reference level. The look-up tables in the Air Management Tool determine the “achievable” airflow rates and supply air temperatures for levels L, M1, M2, and H.

Comparing Figures 7.1.1–7.1.4, the overall trend shows that both fan and chiller energy savings improve with more elaborate air management. The percentage energy savings for fans can be very large (70%–80%), whereas the percentage savings for the chiller energy is significantly lower (15%–25%). Although the percentage fan energy savings are higher than the chiller energy savings, the absolute savings are often of the same magnitude. This stems from the fact that the fan uses less energy than the chiller does (Figure 7.1.)

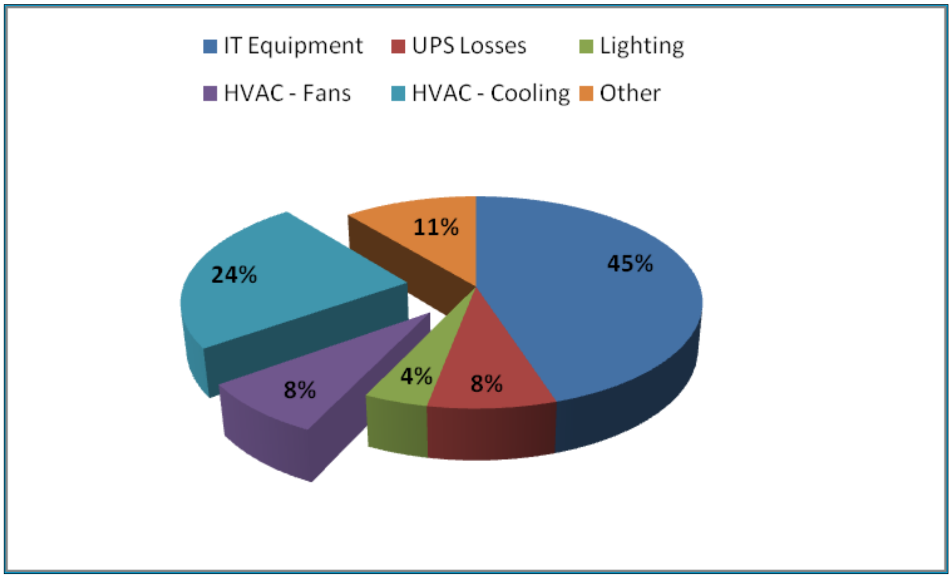
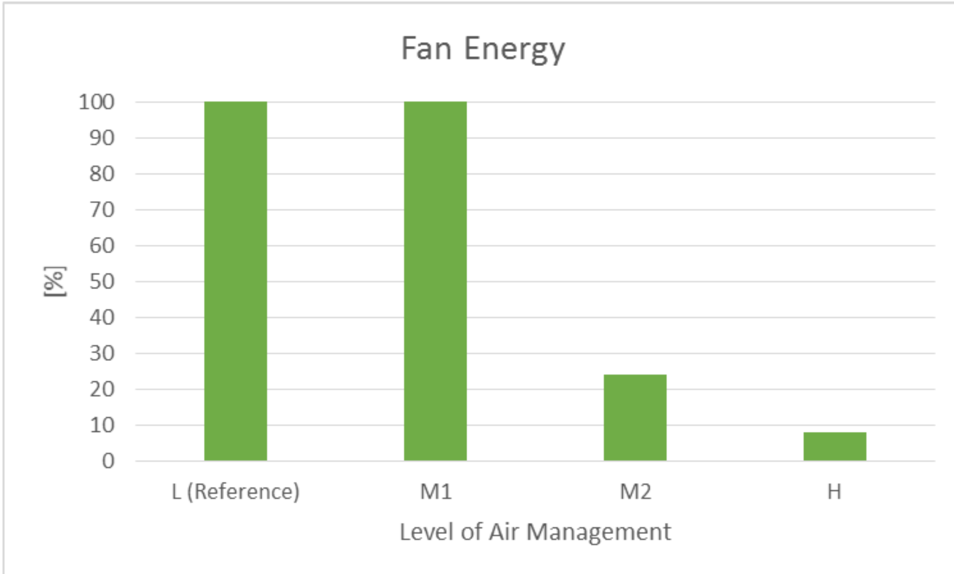


Figure 7.1 "Typical" Power Allocation in Data Centers (LBNL)

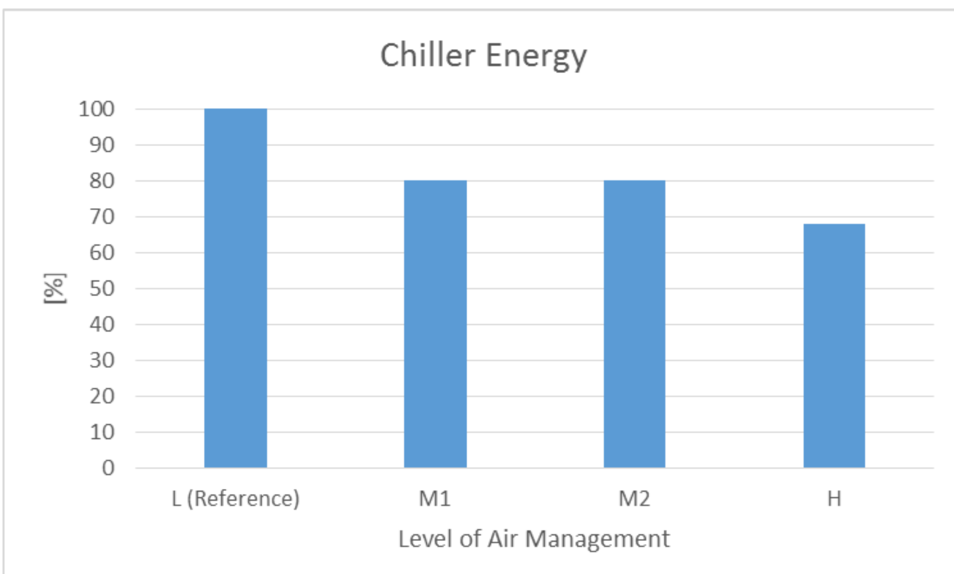
EPRI (2013) reported that in retrofit situations, the airflow across a DX-CRAC can be safely reduced to 60%, but not much lower than 50%. This limitation has to do with the risk of condensate freeze up on the cooling coil. Consequently, although the calculations may indicate very steep airflow reductions, they may not be recommended. Note that a 50% airflow reduction represents an energy reduction of 86%.

With constant air volume CRACs, their modularity can have a significant impact on fan energy savings. See Basic Air Management Level M1 in figures 7.1.1 and 7.1.3. Figure 7.1.1 shows a data center with two equally sized CRACs. The reduced airflow requirement does not allow one unit to be shut off. Figure 7.1.3 shows the same data center with three equally sized CRACs (with the same total capacity). In this case, one unit can be shut off, and the fan savings are 33%. The cooling capacity of the two remaining units is more than enough, and having the third fan off also reduces the overall cooling load.



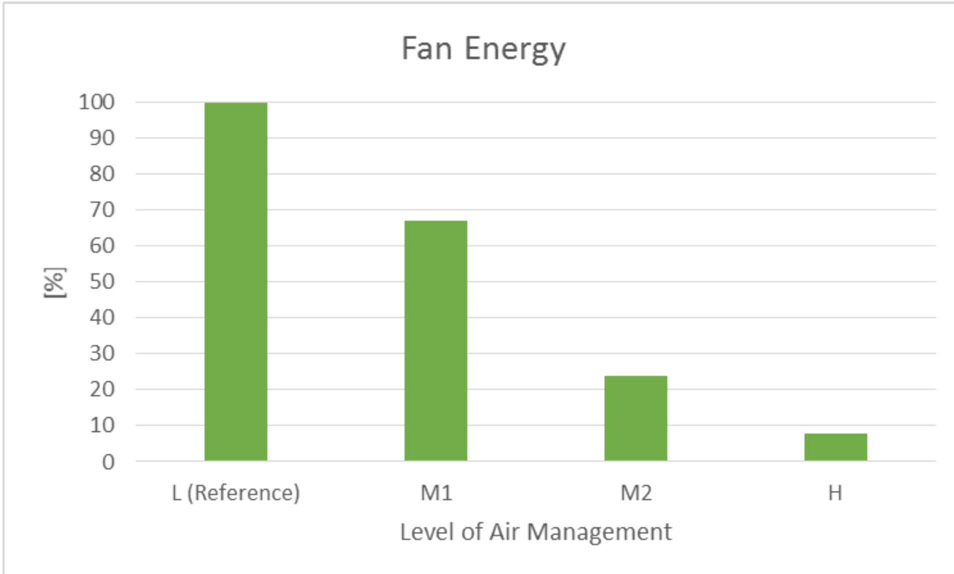
CRAC Flow/IT Flow: 2.51 2.51 1.50 1.00

Figure 7.1.1: Configuration 2 x 30-ton CRAC Units: Fan Energy



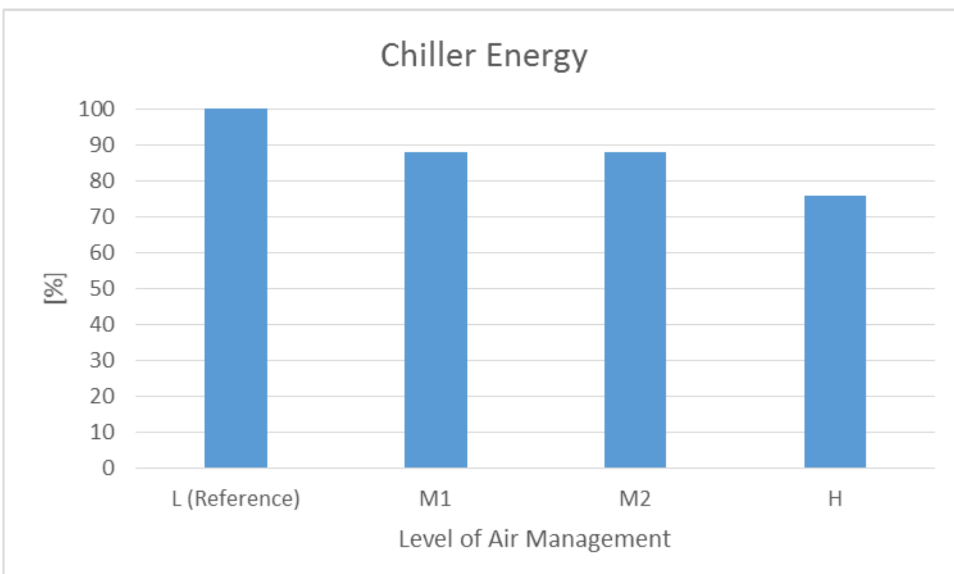
SAT (°F): 62 72 72 78

Figure 7.1.2: Configuration 2 x 30-ton CRAC Units: Chiller Energy



CRAC Flow/IT Flow: 2.51 1.67 1.50 1.00

Figure 7.1.3: Configuration 3 x 20-ton CRAC Units: Fan Energy



SAT (°F): 66 72 72 78

Figure 7.1.4: Configuration 3 x 20-ton CRAC Units: Chiller Energy

The difference in fan energy savings between Basic Air Management Level M1 (CAV) and M2 (VAV) is due to the way the fans are controlled. In the case of constant air volume CRACs, units are shut off when the airflow demand is reduced. In the case of variable air volume CRACs, the flow rate is instead reduced on all units. The latter is a much more efficient way to operate, since the fan energy is proportional to (nearly) the cube of the airflow. Figure 7.1.3 shows that it would not be desirable to turn off one of the three CRACs and use VAV capability on the remaining two units.

Turning off select CRACs not only reduces energy savings compared with turning down all CRACs, there also may be operational risks with turning equipment off. The raised floor plenum is seldom a constant-pressure plenum; the pressure in the floor varies throughout the cavity. Turning a CRAC unit off can have unpredictable results on the airflow distribution entering the data center space, which, in turn, may affect the intake air temperatures to the IT equipment. Backdraft can also occur in CRACs that are off.

The Air Management Tool takes into account the level of CRAC modularity for the achievable supply airflow and supply air temperature. For the Basic Air Management Level L, Figures 7.1.2 and 7.1.4 show that the achievable supply air temperature is higher for the data center with three CRAC units (66°F) compared to the data center with only two units (62°F). In this example, the higher CRAC modularity allows the supply temperature to be increased from 62°F to 66°F.

A higher supply temperature translates into improved chiller efficiency. Please note that this means that the 100% bar for the Basic Air Management Level L in Figure 7.1.2 represents a higher chiller energy than the corresponding 100% bar in Figure 7.1.4.

Keep in mind that the Air Management Tool uses look-up tables for fetching airflow rates and supply air temperatures. The look-up tables are quite course, so an input change may not change the output (the results). The input change needs to be large enough to force a cell change in the look-up tables.

Because of the course look-up tables, do not overanalyze the individual results in these figures; focus instead on the overall energy trends. In Section 7.2, manual interpolation between the cells improved the “continuity” of the results.

7.2 Small Data Center Air Management Upgrade Packages

Section 7.1 covered energy savings driven by four Basic Air Management Levels, which closely followed the different quality/implementation levels used in the Air Management Tool: L (Low), M (Mid), and H (High). However, since the Air Management Tool was not specifically developed for small data centers, these overall levels may not be the best choices for those centers.

In this section, we will discuss five data center upgrade packages (P1–P5), plus a reference case especially suitable for small data centers for upgrade purposes. We used the same methodology discussed in the previous section to estimate the potential relative energy savings, except that we refined the output from the Air Management Tool by using manual interpolation between the cells in the look-up tables, as well as the classifications of CRAC Modularity (9 in Table 7.2.1).

Pacific Gas and Electric (PG&E) could potentially provide financial rebates for deploying the upgrade packages, rather than for individual air management measures. The packages could then be considered "products" by PG&E, and as such could qualify for financial rebates.

Defining the Small Data Center Air Management Upgrade Packages

The Small Data Center Air Management Upgrade Packages were especially crafted to work in small data centers, allowing cost-effective hands-on replication across many small data centers with little or no customization. Still, for the purpose of modeling, we needed to stay within the capabilities of the Air Management Tool as demonstrated in the previous section.

Table 7.2.1 outlines the Small Data Center Air Management Upgrade Packages in a similar fashion to Table 7.1.1 for the Basic Air Management Levels. The sophistication level of air management increases when moving from the left towards the right in the table. Package 5 represents a state-of-the art package.

Table 7.2.1: Small Data Center Air Management Upgrade Packages

(Designed to be suitable for small data centers)

AM Measure (AM Tool)	Reference	P1	P2	P3	P4	P5
1: Recommended Range[1]	65°F–80°F	65°F–80°F	65°F–80°F	65°F–80°F	65°F–80°F	65°F–80°F
2: Allowable Range[2]	N/A	N/A	N/A	N/A	N/A	N/A
3: Aisle Containment	L	L	L	M	M	H
4: Blanking Panels	L	M	M	M	H	H
5: Floor Leakage	L	M	M	M	M	H
6: Tile Placement	L	M	H	H	H	H
7: EC-Class	H	H	H	H	H	H
8: CAV/VAV (CRAC)	L (CAV)	L (CAV)	H (VAV)	L (CAV)	H (VAV)	H (VAV)
9: CRAC Modularity	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)
10: Cable Management	L	L	L	L	M	M

[1] The ASHRAE Recommended Range is used throughout.
[2] The ASHRAE Allowable Range does not enter the energy calculations.

Please refer to Table 7.1.2 for the description of each individual level (L, M, and H) of air management. The principle is that inexpensive measures are introduced first. An effective measure is one that is easy and inexpensive to implement and is a good "enabler" for energy savings (e.g., to place perforated floor tiles in the cold aisles only). In Table 7.2.1, this measure is indeed phased in the quickest, starting with package P1. Full aisle containment, on the other hand, only appears in the most sophisticated package (P5). This measure can be expensive, and it also requires other measures to be in place first to secure the support for hot and cold aisles.

Modeling Assumptions

Once again, the Air Management Tool's "Fan Exponent" for VAV operation is set to 2.8 rather than 3.0, to account for non-ideal conditions. Also, the "Chiller Factor" is set to 2% chiller energy savings per degree F increase in supply air temperature.

Modeling Results

Figures 7.2.1–7.2.4 show the relative (%) energy savings for fans and chillers, respectively, for five of the Small Data Center Air Management Upgrade Packages, as compared with a reference package. The Reference package is a low-quality data center with regard to air management with mostly "L" in Table 7.2.1. Supply airflows, supply air temperatures, and percentage savings are those predicted as achievable (maximum) by the Air Management Tool.

The modeling shows the percentage savings achievable for fan energy and for chiller energy, respectively, for each package with a reference that represents a low quality data center; however, a specific data center considered for upgrade may not necessarily be of this poor quality. In that situation, Section 8 lays out a methodology to match the data center with one of the packages before the savings are estimated.

Keep in mind that all bars in Figures 7.2.1–7.2.4 refer to the same data center with an approximate 2.5 ratio between air handler capacity (airflow and cooling) and IT equipment demand. This ratio is fairly typical. The changes between the packages only deal with air management per Table 7.2.1. Note that the packages are listed in order of increasing savings.

The overall trend is that both fan and chiller energy savings improve with more elaborate air management. However, the magnitude and characteristics of these savings are quite different. The fan savings takes us on a wild ride, requiring some analysis, whereas the chiller savings are more limited but more predictable.

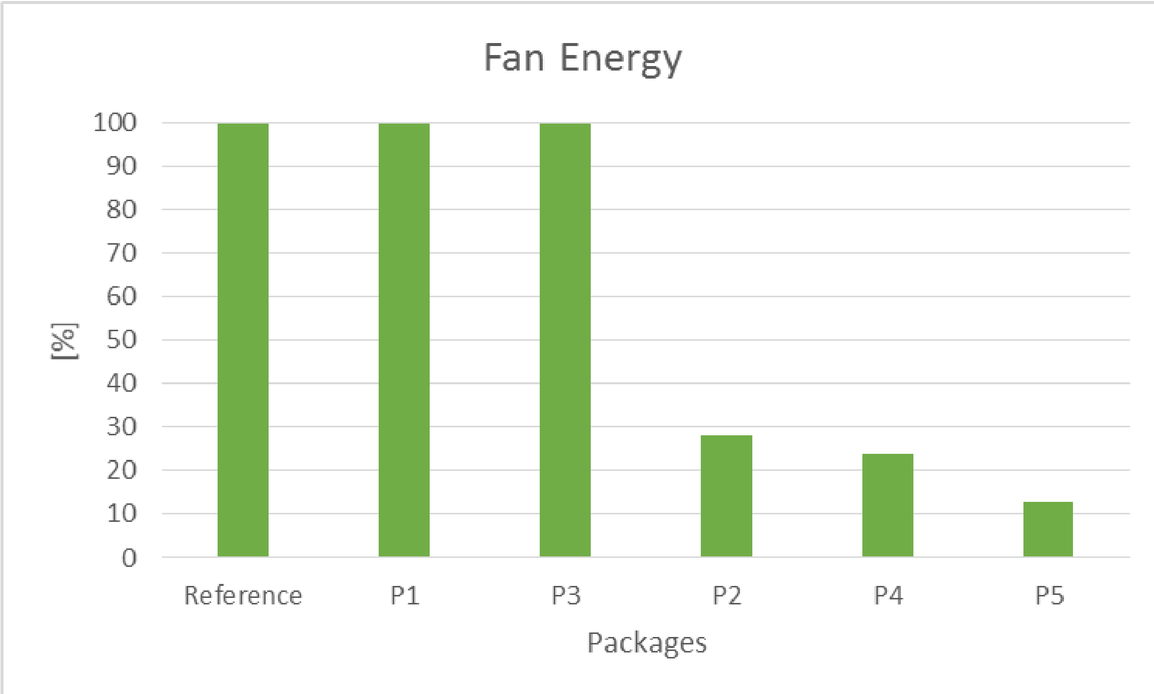
Figure 7.2.1 shows the energy reduction of fan energy as a function of air management sophistication. The first three bars represent constant air volume CRAC units, whereas the last three bars represent variable air volume CRAC units. Clearly, there is a significant energy reduction associated with using variable air volume CRAC units. However, the savings between the three VAV packages is not large. This suggests that the cost effectiveness of driving air management to the P5 package may be questionable. This is especially true when considering that the savings for Package P5 requires an airflow reduction of more than 50% (which may not be desirable).

It should also be noted that the first three bars are at 100%, meaning that no savings are realized. This is because the airflow demand is not reduced enough to allow one of the two CRAC units to be shut off, which is a common situation in many small data centers. Later we will look at how the same data center, but with three CRAC units, will support savings.

Figure 7.2.2 shows the energy reduction of chiller energy as a function of air management sophistication. The trend here is a fairly steady decrease in energy with an increase in air management sophistication. The achievable (maximum) supply air temperatures (SAT) are shown under the figure. With an increase in SAT, the chiller efficiency increases (in this case with 2% for each degree increase in SAT).

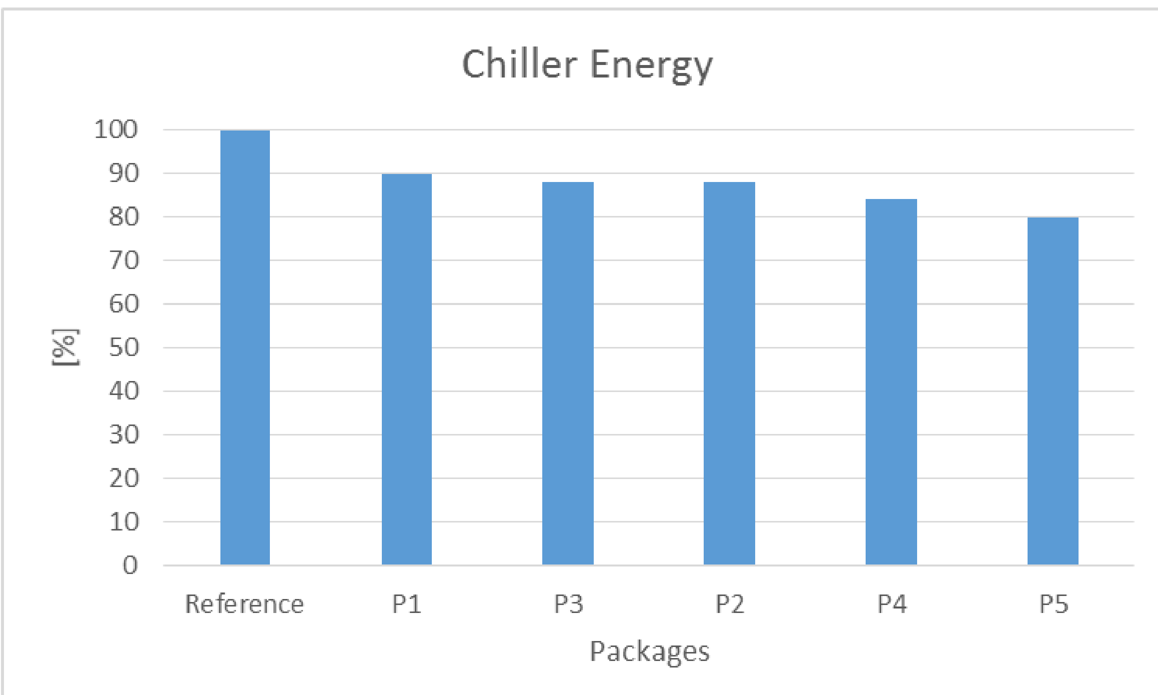
Keep in mind that many data centers are operated well below the achievable temperatures given in Figure 7.2.2 for a number of reasons. If that is the case, those savings need to be added. Say that we are currently running a 60°F supply air temperature with the Reference package; the savings associated with moving towards the achievable temperature of 64°F would be (64 - 60) x 2%/°F = 8%. The same logic can be applied to all the packages.

Figures 7.2.3 and 7.2.4 show the savings with the same data center but with three (now smaller) CRAC units. The largest change is for the fan energy with CAV CRAC units (the first three bars in Figure 7.2.3). In this case, one of the three CRAC units can be shut off and save one-third of the fan energy. The CRAC unit modularity does play an important role. Again, upgrading to variable air volume CRAC units drastically reduces the energy consumption (the last three bars).



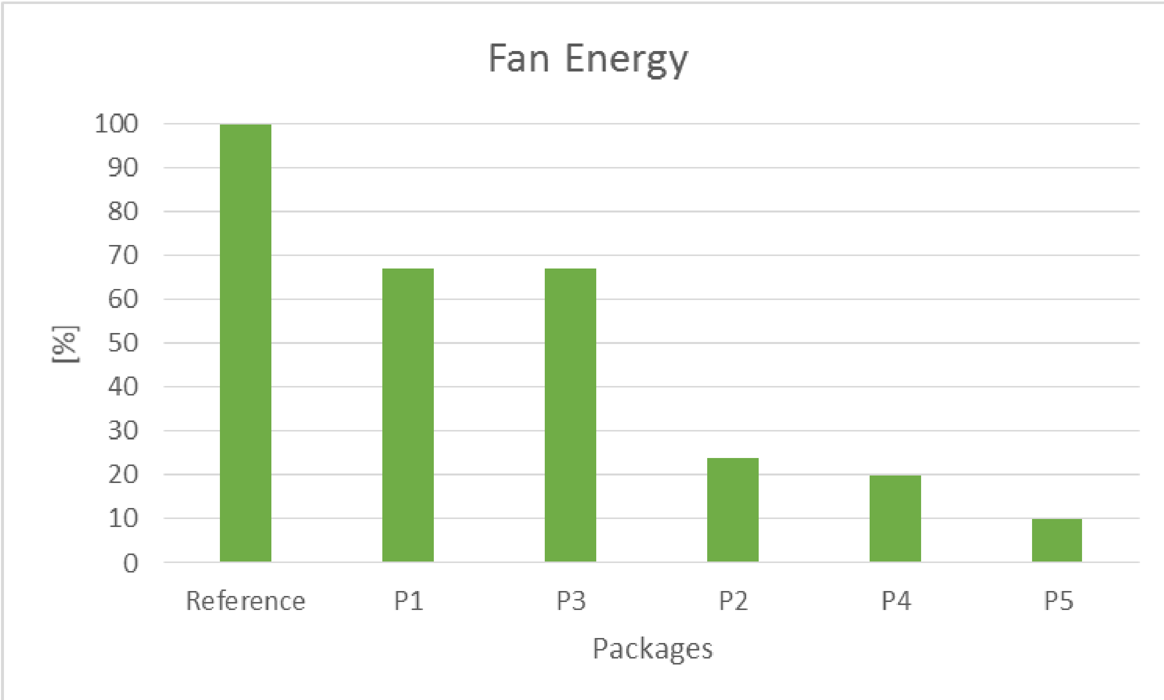
CRAC Flow/IT Flow: 2.51 2.51 2.51 1.60 1.50 1.20

Figure 7.2.1: Configuration 2 x 30-ton CRAC Units: Fan Energy



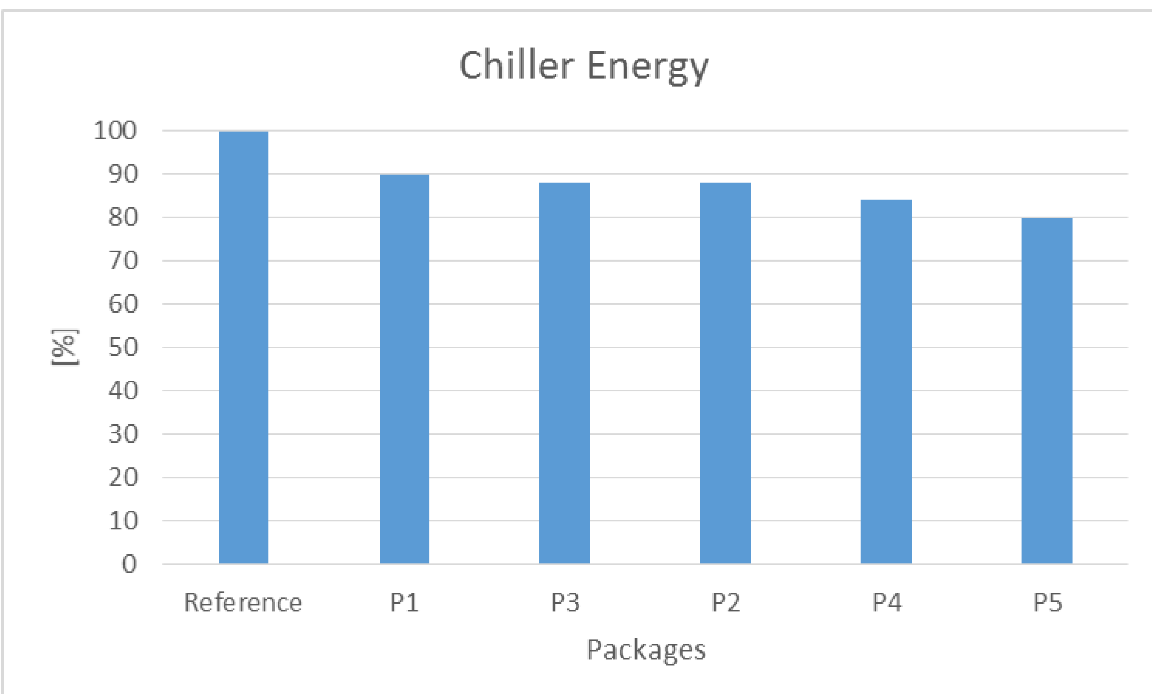
SAT (°F): 64 69 70 70 72 74

Figure 7.2.2: Configuration 2 x 30-ton CRAC Units: Chiller Energy



CRAC Flow/IT Flow: 2.51 1.67 1.67 1.50 1.40 1.10

Figure 7.2.3: Configuration 3 x 20-ton CRAC Units: Fan Energy



SAT (°F): 66 71 72 72 74 76

Figure 7.2.4: Configuration 3 x 20-ton CRAC Units: Chiller Energy

7.3 Summary and Recommendations (Section 7)

As expected, the trend is that both fan and chiller energy savings improve with more elaborate air management. However, the magnitude and characteristics of these savings are quite different. The fan savings increase abruptly (with the introduction of VAV fans) whereas the chiller savings increase steadily.

The energy savings for fans can be great (70%–80%), whereas the percentage savings for the chiller energy is significantly lower (20%). Although the percentage fan energy savings are higher than the chiller energy savings, the absolute savings may be on the same order, since the energy used by the fan is considerably less than that used by the chiller.

With constant air volume CRAC units, their modularity can affect fan savings significantly. Reduced airflow needs may not allow one unit to be shut off when only a few large units are used, meaning that no savings can be realized. This is because the airflow demand is not reduced enough to allow one of the two units to be shut off; a common situation in many small data centers. More but smaller CRAC units are favorable.

Upgrading from constant air volume CRAC units to variable air volume units can reduce fan energy use drastically. Using VAV units is much more efficient, since the fan energy is proportional to nearly the cube of the airflow. Turning CAV units off may also pose operational risks, in the form of local overheating of IT equipment.

The savings between the three high-quality packages with variable air volume CRAC units is not large. This suggests that the cost effectiveness of driving air management too far may be questionable. This is especially true when considering that the savings for the very highest-quality packages require an airflow reduction of more than 50%, which may not be desirable.

The energy reduction trend for chiller energy as a function of air management sophistication is a fairly steady increase in energy savings up to around 20%. The savings stem from the higher supply air temperatures allowable with better air management. Many data centers are operated well below the achievable supply air temperatures for a number of reasons. If that is the case, additional savings are readily available.

8. Roadmap

Although somewhat out of this study's scope, this section discusses briefly how potentially the energy savings and utility rebates could be determined. It also addresses some candidates for selecting upgrade packages and installing them.

8.1 Determine Energy Savings and Utility Rebates

At this point it is necessary to determine the energy savings on which to base the utility rebates. The overall process could proceed along the steps described below.

Step 1: Determine the Achievable (Maximum) Percentage Energy Savings for Upgrade Packages

Table 7.2.1 (Small Data Center Air Management Upgrade Packages) descriptions allow the Air Management Tool to calculate achievable or maximum percentage chiller and fan energy savings for each upgrade package compared to a reference package, assuming either CAV or VAV fans and intake air temperature sensing. The achievable energy savings are those determined at maximum supply airflow and supply air temperature changes.

Actual percentage savings may be less, since it may not be desirable to reduce the supply airflow or increase the supply temperature to the maximum levels. Step 3 below makes a correction for this situation, including return air temperature sensing. The savings may also be larger should the data center currently be operated with low supply air temperatures and/or high supply airflows compared to those shown in Figures 7.2.1–7.2.4. Step 2 addresses this case when actual data are available.

Step 2: Match the Data Center with one Package and Select the Target Package

One critical point for a particular data center is to select an appropriate air management upgrade package. This requires an assessment of the current data center conditions by visual inspection and some measurements.

- Visually inspect the data center with regard to the level of air management for each measure and then fit the data to one of the Small Data Center Air Management Upgrade Packages in Table 7.2.1.
- This will be the Matched upgrade package (see blue column in Table 8.1.1), with its predicted achievable supply airflow and supply air temperature (figures 7.2.1–7.2.4).
- If the actual supply airflow and supply air temperature are known, however, that data should instead be used, since they are generally better. The airflows and temperatures can be measured with one of the tools discussed in sections 3 and 4. A visual inspection is still required to determine the current implementation of air management.

In addition, an air management "score" could be assigned to the data center, as well as to each upgrade package. Such a score may help in the process of matching the data center with an upgrade package. This has not been done in this report.

When the package with the closest match to the data center has been identified, a desirable Target package (see green column in Table 8.1.1) can be selected. Keep in mind that the supply airflow and supply air temperature for the Target package is a prediction made by the Air Management Tool for achievable conditions. The question now becomes, how much energy could be saved by moving from the Matched package to the Target package. From here on, all energy calculations are performed on the packages where the matched package represents the current data center conditions.

If an automatic method (an "app") could be devised to collect and process these data, then the selection of the most appropriate Matched package and Target package for a particular data center could be significantly simplified, as well as removed from the decision of an individual.

Knowing the supply airflow and supply air temperature for the Matched data center (determined by one of the two methods described above) and for the Target data center (determined in Figures 7.2.1–7.2.4) enables us to calculate the percentage savings. The fan savings can be calculated by the near cubical relationship between energy and airflow, and the chiller savings can be calculated by assuming 2% energy savings per degree F increase of the supply temperature.

Table 8.1.1: Example Selection of Matched and Target Air Management Packages

AM Measure (AM Tool)	Reference	P1	P2 **Matched**	P3	P4 **Target**	P5
1: Recommended Range[1]	65°F–80°F	65°F–80°F	65°F–80°F	65°F–80°F	65°F–80°F	65°F–80°F
2: Allowable Range[2]	N/A	N/A	N/A	N/A	N/A	N/A
3: Aisle Containment	L	L	**L**	M	**M**	H
4: Blanking Panels	L	M	**M**	M	**H**	H
5: Floor Leakage	L	M	M	M	M	H
6: Tile Placement	L	M	H	H	H	H
7: EC-Class	H	H	H	H	H	H
8: CAV/VAV (CRAC)	L (CAV)	L (CAV)	H (VAV)	L (CAV)	H (VAV)	H (VAV)
9: CRAC Modularity	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)	M (2) or H (3)
10: Cable Management	L	L	**L**	L	**M**	M

[1] The ASHRAE Recommended Range is used throughout.

[2] The ASHRAE Allowable Range does not enter the energy calculations.

Table 8.1.1 can now be used to evaluate what air management measures need to be upgraded and to what degree. Measure 3 (aisle containment) goes from "L" (matched - blue column) to "M" (target - green column). Table 7.1.2 is used to figure out what this actually means. "L" means no containment, whereas "M" means doors to cold or hot aisles. Measure 4 (blanking panels) goes from "M" to "H," and measure 10 (cable management) goes from "L" to "M." All other measures are unchanged.

Step 3: Decrease Energy Savings for Matched and Target Packages based on Limitations

The achievable (maximum) percentage energy savings determined in Step 1 may not be fully realizable. Actual savings may be less than achievable, since it may not be possible or even desirable to reduce the airflow or increase the supply air temperature to their maximum extent.

Such a correction needs to be made for both the Matched package and the Target package. Typically, the decrease of the energy savings for the Matched data center is larger than for the Target package, since the latter package is more optimized. At other times, the corrections for the Matched package and the Target package may cancel out.

- Supply fan control
  - CAV control: If a CRAC unit cannot be shut off, no fan energy savings will be possible.
  - VAV control: If fan speed can only be partially reduced, fan energy savings will decrease—sometimes significantly—due to the near cubical relationship between power and airflow rate.

- Supply air temperature control
  - If supply air temperature can only be increased partially, the chiller energy savings will decrease.
  - If return air temperature sensing is used (most common) rather than the assumed intake air temperature sensing, the supply air temperature may need to be reduced a degree or two as a safety factor, since return air sensing is less accurate. The level of accuracy depends on the calibration with the intake air temperatures. Again, the chiller energy savings will decrease.

Note that from a thermal management perspective, there is no risk involved in limiting the airflow control and/or the supply air temperature control, since the thermal conditions would improve either way.

Step 4: Determine the Absolute Energy Savings – Rebates Based on Savings

The fourth and last step is to determine the absolute (not percentage) energy savings associated with upgrading from the Matched package to the Target package. Estimating these energy savings requires that an energy baseline be established for the Matched package.

The energy baseline could be determined in a number of ways. One potential method would first measure the actual IT electrical draw (UPS output) and assume a PUE to arrive at the infrastructure energy. Then, by estimating the energy fraction for chillers and fans, respectively, two baselines could be established: One for chiller energy and one for fan energy.

When the baselines are known, the Target package chiller energy and fan energy can be calculated based on the percentage savings established in Step 3. The absolute energy savings in kilowatt-hours would then simply be the energy for the Matched package minus the energy for the Target package. Again, there will be two separate energy calculations, one for chillers and one for supply fans.

The associated utility rebates would need to be developed by the utilities. Besides considering the energy savings, the cost for installation/products and service life need to be included. The two latter items are out of scope for this report, but they need to be addressed before awarding rebates.

If a package is highly profitable before rebates, there is no need for a utility rebate. If a package is highly non-profitable, there is no hope that a utility rebate could change the equation. However, between these extremes, a utility rebate could make the package attractive and thereby save energy.

The method described here will not always provide accurate estimates of the energy savings for a particular data center. However, we believe that it does provide a reasonable estimate of the collective energy savings, which, from a utility perspective, is the most important yardstick.

8.2 Installation of the Upgrade Packages

When the most appropriate package has been selected, it needs to be installed. Potential candidates for helping with the installation could include the following:

- **Data center owners/operators.** This option may not always be the best for small data centers since the expertise may not exist in-house. However, if the small data center belongs to a larger organization with multiple data centers this option may well be the best.

- **Vendors.** A number of vendors specialize in air management. They may, however, have a conflict of interest, since they most likely prefer using their own products rather than competitors' (perhaps objectively better) products.

- **Third parties.** This category includes consultants specialized in air management but not directly tied to a manufacturer or vendor. Working with consultants often increases the chances for unbiased recommendations and product selections.

- **Utilities.** If a utility provides incentives or rebates for the upgrade packages, they may themselves provide the installation support to ensure that the packages are installed to their liking.

These candidates potentially could also help the data center select an appropriate upgrade package in Step 2 of Section 8.1, and also calculate the energy savings and rebates.

9. Summary Recommendations

Portable Monitoring Tools

Purkay Labs' AUDIT-BUDDY is a turnkey solution developed specifically as a small portable temperature/humidity monitoring system for data centers. It comes with everything to make it portable except for a laptop computer. The downside is the cost, which is around four to eight times the cost of similar tools from Geist and Upsite Technologies.

The Geist and Upsite Technologies tools are off-the-shelf, wired products not explicitly intended to be configured as a portable system. Although they are more attractively priced, they need extra equipment and work to become truly portable and useful. However, their simplicity may turn into an advantage for small data centers with limited resources.

Stationary Monitoring Systems

Besides portable tools, there are advanced stationary solutions. Such DCIM products are slowly catching up to the needs of small data centers.

- Some complete DCIM solutions are offered module-by-module. For example, power and environmental modules can be purchased if energy efficiency is the primary goal. This is a flexible solution if there ever is a need to expand into other modules.
- Entry-level DCIM solutions may not include all of traditional DCIM modules and/or have simplified modules. This solution is less flexible if there is ever a need to expand the product's capabilities.
- Vendors are developing simplified tools for power and environmental conditions. These more nimble "point solutions" are less complex and costly but do not provide the same expansion flexibility. A point solution may work well in a small data center.

The free OpenDCIM could be a good introduction to DCIM before committing to a larger system. However, a small data center may not need more than the capabilities of OpenDCIM, since the center's requirements often are limited in scope.

Simulation Tools

Two simulation tools were reviewed for estimating energy savings from air management in data centers: The U.S. Department of Energy's Air Management Tool, which was partially validated with CFD modeling with funds from PG&E, and the Airflow Management Calculator (AFM), developed by the Bonneville Power Administration (BPA) and Seattle City Light. The former simulation tool was used for the calculations in this report.

- Air Management Tool update: The Air Management Tool would benefit from having an interpolation routine added to the look-up tables. This would ensure that the output would change with any change on input. This update was also suggested by the Data Center Air Management Research report (PG&E 2010).

- Tool Merger: The Air Management Tool is more focused on air management, whereas cooling systems are described fairly simplistically. The AFM Tool has taken quite the opposite approach. This raises the question of whether it could be useful to merge the two complementary models and thereby resolve each tool's shortcomings.

Demonstration Project

Lawrence Berkeley National Laboratory may launch a demonstration project in 2017 to help refine the upgrade packages and the energy savings estimates presented in this report. This project would evaluate the energy savings in a few live data centers. Through cost-sharing with electric utilities, LBNL would scope the work, design a measurement and verification (M&V) plan, oversee the implementation of the M&V plan, perform the evaluation, and author the report.

- CRAC Modularity: With constant air volume CRAC units, their modularity can affect fan energy savings significantly. Reduced airflow needs may not allow units to be shut off when only a few large units are used, meaning that no savings can be realized. It is favorable to have more, but smaller, CRAC units. Turning off CAV units may also pose thermal risks for the IT equipment.

- Variable Air Volume CRAC Units: There is a drastic fan energy reduction associated with upgrading from constant air volume CRAC units to variable air volume units. The latter is a much more efficient process, since the fan energy is proportional to nearly the cube of the airflow. Energy savings as high as 70%–80% are possible.

- Level of Air Management: The results suggest that the cost effectiveness of driving air management too far is questionable. This is especially true considering that the savings for the very highest-quality air management packages require an airflow reduction of more than 50%, which may not be desirable in a retrofit situation.

- Low Supply Temperatures: The energy reduction for chiller energy as a function of air management sophistication is a fairly steady increase in energy savings up to around 25%. The savings stem from the higher supply air temperatures allowable with better air management. However, many data centers are operated well below the achievable supply air temperatures for a number of reasons. If that is the case, additional savings are readily available.

Roadmap Refinements

The roadmap for determining energy savings and utility rebates needs to be refined. The energy savings will help establish utility rebates. The process and candidates for assisting with the onsite matching of the data center with an upgrade package, selecting the target upgrade package, calculating the energy savings, determining the cost of the package, establishing rebates, and installation also need refinement.

- Develop an App: One critical point for a particular data center is to be able to select the most appropriate Target air management package. This would require an assessment of the current conditions by visual inspection or measurements. If an automatic method (an "app") could be devised to collect and process these data, then the selection could be greatly simplified. Such a product potentially could be launched as a utility service.

- Finding Reliable Cost Estimates for Air Management Measures: The energy savings need to be compared with the cost and life of the upgrade; not only product costs, but also installation costs. The Small Data Center Air Management Upgrade Packages are crafted to work in small data centers, allowing cost-effective replication across many small data centers with little or no customization.

- Finding the Small Data Centers: Finding and engaging the small data centers are a huge challenge. An initiative to deal with this challenge could pay off big, and the benefits are not only beneficial for the implementation of air management.

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Appendix A: Classification of Data Centers (Mini to Mega) Based on Size

This table suggests that small data centers are those below 5,000 square feet (ft^2).

	# of Racks	ft^2	m^2
Mega	≥ 9,001	≥ 225,001	≥ 22,501
Massive	3,001–9,000	75,001–225,000	7,501–22,500
Large	801–3,000	20,001–75,000	2,001–7,500
Medium	201–800	5,001–20,000	501–2,000
Small	1 –200	251–5,000	26–500
Mini	1–10	1–250	1–25

Source: Data Center Standards, Data Center Size and Density, Version 3.0, AFCOM, October 1, 2014.

Appendix B: Fraction of Servers Installed in Small Data Centers

This table suggests that 72% of all servers in the United States are in data centers of 5,000 ft^2.

<table>
<tr><th>Data Center Type</th><th>Description</th><th>Square Footage</th><th>Facilities (2009 U.S. estimation)</th><th>Total Servers (2009 U.S. estimation)</th><th>Average Servers per Location</th></tr>
<tr><td>Utility Scale</td><td>Generally measured by the size of the facility's total load (in MW), or the amount of power available to the IT equipment. Usually larger than 10 MW, and commonly built with 40 MW load. This category includes most retail and wholesale co-location data centers.*</td><td>>100,000</td><td rowspan="2">7,006</td><td rowspan="2">3,604,678</td><td rowspan="2">515</td></tr>
<tr><td>Enterprise</td><td>Typically operated by large corporations and institutions. Generally occupy spaces in the low tens of thousands of square feet (10,000 square feet can support approximately 1 MW of IT equipment load, with almost another 1 MW needed for cooling and power delivery systems).</td><td>>5,000</td></tr>
<tr><td>Localized</td><td>These facilities may serve only the local, specific needs of a call center or office operation (for example), with general, large-scale IT services provided by a data center in another location.</td><td>500-5,000</td><td>73,987</td><td>3,977,187</td><td>54</td></tr>
<tr><td>Server Room**</td><td>These data centers often do not have dedicated cooling or power delivery systems or climate conditioning equipment.</td><td>200-499</td><td>1,170,399</td><td>3,057,834</td><td>3</td></tr>
<tr><td>Server Closet**</td><td>Smallest-scale data center.</td><td><200</td><td>1,345,741</td><td>2,135,538</td><td>2</td></tr>
</table>

Source: Bailey, Michelle et al. IDC Special Study. *Data Center of the Future.* Filing Information: April 2006, IDC #06C4799.

* Retail and co-location data centers provide rental space to multiple tenants and are only responsible for managing their tenants' IT equipment. Wholesale co-location providers develop new data centers, which then lease these facilities on a long-term basis to single tenants who take over the responsibility of operating and maintaining the entire facility, including the cooling and power delivery systems. *Seattle City Light* is starting to see more interest from co-location providers.[6]

** Server rooms and server closets are not considered data centers in the ENERGY STAR Buildings Program.

Source: U.S. Environmental Protection Agency. 2012. "Understanding and Designing Energy-Efficiency Programs for Data Centers." U.S. Environmental Protection Agency. 14 pp.