

# Demonstration: Portable Air Management Measurement Tools

February 23, 2018

This work sponsored by FEMP



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## EXECUTIVE SUMMARY

Air management is critical in energy intensive data centers, not only for improving the energy efficiency but also for managing the thermal environment for the IT equipment. The goal of air management is to supply air to all rack inlets within the desired temperature and humidity thresholds with the minimum fan and cooling energy consumption. Air management is key in data centers since it is a prerequisite for many other energy-saving measures.

This report focuses on improving air management in small data centers due to the great potential for energy savings across the data center industry. To be able to implement air management, key environmental parameters such as IT equipment intake temperatures need to be monitored. Since manufacturers design their products to operate within certain temperature ranges measured at the air intake, it is crucial that, for air cooled equipment, the cooling infrastructure is set to provide the designed temperature at the equipment intake.

This demonstration involves two inexpensive, portable measurement tools for assessing air management in small data centers on a limited, temporary basis. Access to simple, inexpensive tools for implementing and tracking air management is imperative in such environments. Besides evaluating the accuracy of the temperature measurements, this report also includes an in-depth evaluation of the ease of use of the tools.

A cold equipment aisle in a production data center at Lawrence Berkeley National Laboratory in Berkeley, California was used as the demonstration location. The two portable air management measurement tools demonstrated were Packet Power RDP (E302/E306/E312) (\$500/700/800) and Purkay Audit-Buddy (\$3200). These tools have different technical characteristics/price points, and they have two different technical approaches.

Packet Power RDP (E302/E306/E312) is a wireless tool not originally intended as a portable system, but due to the simple and compact design it can easily be adapted into a portable tool. The system was found to be very easy to use in quickly gathering highly accurate data on rack air inlet temperatures. It is an inexpensive, pocket-sized system that does not need extra equipment besides a laptop and an Ethernet cable to be useful. The simplicity of use is an advantage for small data centers with limited resources and expertise. It can also be inexpensively expanded to include additional sensors and graphing capabilities. No major shortcomings were noted. In addition, the probes can readily be used for measuring CRAC supply and return temperatures as well as other temperatures. This tool may be viewed as “representative” of a family of tools from different vendors. Similar tools from two other vendors are described in some detail but not demonstrated.

Purkay Labs Audit-Buddy is a portable tool for monitoring temperature (and humidity) in data centers. One unique and potentially problematic feature of this tool is its built-in temperature probe and fan-aided air sampling. The system includes “everything” except a computer. Manuals and software make data analysis uncomplicated, although it may require some learning and set-up time. The system was relatively easy to use in quickly gathering and downloading data. However, a number of shortcomings were noted that makes it more difficult, slower, and less accurate to use. Most significantly, self-heating of the internal temperature probe was observed, which resulted in compromised accuracy. There is a need to manage and control this self-heating. In addition, the system did not allow the preferred

placement of the sampling site on the rack door, introducing another temperature inaccuracy. A potential additional downside to this tool is the cost, especially if multiple systems are desirable.

Lawrence Berkeley National Laboratory has developed Excel software that can be used to quickly and easily plot the intake temperatures as well as calculate the Rack Cooling Index (RCI) metric, which is a measure of the conformance with any selected equipment intake temperature specification such as those from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) or Telcordia Technologies (NEBS). The software could be especially useful for portable systems with no graphing capabilities but also for more advanced systems without the capability of calculating the RCI metric.

## **INTRODUCTION**

Data centers are energy-intensive facilities. Good 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 supplying as little air as possible at as a high temperature as possible without adversely affecting the desired thermal environment.

This demonstration project focuses on improving air management in small data centers (<5,000 sf) due to the great potential for energy savings across the data center industry, where small data centers account for nearly half of all data center energy consumption. Recent industry intelligence shows that air management is not a standard practice in existing small data centers. To be able to implement air management, key environmental parameters, principally IT equipment intake temperatures, need to be monitored. Many larger data centers also suffer from poor monitoring and air management.

This demonstration involved two inexpensive, portable measurement tools for assessing air management in small data centers on a limited and temporary basis. Access to simple, inexpensive tools for implementing and tracking air management is imperative in such environments. Many advanced, or even basic but permanent, monitoring systems are often too complex and expensive for small data centers.

In a scoping study completed in 2016, "Air Management in Small Data Centers" (PG&E, 2016), three portable measurement tools were evaluated 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 the potential for finding opportunities to improve the energy efficiency of small data centers. This demonstration evaluated the accuracy, ease of use, and cost of one of those tools plus a fourth that was not included in the earlier scoping study.

## **ABOUT THE ASSESSMENT**

### **Scope of Demonstration**

This demonstration, besides evaluating the accuracy of the temperature measurements, included installation and ease-of-use evaluation of two commercially available tools. Evaluation criteria for rating the tools included the following items:

- Packaging
- Existence and usefulness of user manuals and other instructional resources
- Features including software
- Time to deploy
- Connectivity
- Portability
- Time to make sense of data
- Accuracy/uniformity of temperature measurements
- Complexity
- Flexibility
- Support
- Costs
- Overall user experience.

### **Assessment Procedure**

- Note size and weight of received package.
- Open package and inventory contents.
- Assemble sensors to data logger, stand, etc. Note difficulty and time to assemble.
- Review user manuals and other resources and assess their usefulness.
- Note whether the sensors measure humidity

#### A. Test Installation at a Convenient Location

- Connect measurement tool to laptop. Note level of difficulty and whether reviewer needed to contact vendor for help.
- Connect to Internet (if intended to be used with Internet). Note level of difficulty and whether need for contacting vendor for help.
- Mount sensors and turn on system and gather a few sets of sample data. Note difficulty, features. Note also whether need for contacting vendor for help.
- Assess whether the data is in a useful form or does it need post-processing? How long does it take to make sense of the information? Is there software built into the system to help the user interpret and analyze the data?
- Assess portability of the system. How easy is it to transport to a site, set it up, move it from rack to rack, and put away when the survey is completed?
- Note complexity and flexibility of the entire system.
- Test sensor temperature precision by placing the sensors near each other and record the temperatures.
- Test sensor temperature accuracy by comparing with a temperature reference.

#### B. Data Center Measurements in LBNL 50B-1275

- Repeat the sequence under Test Installation above in the data center (except for the two last bullets).
- Can the sensors be put at the actual IT inlets inside the perforated rack door? And, can they readily be used for IT exhaust temperatures?
- Can the sensors readily be used for CRAC/CRAH return and supply temperatures?
- Assess the support provided by the vendor. How is technical support provided?
- Provide price list from vendor for as-tested and any other configuration available

- Assess the overall user experience based on the above.

### **Selected Portable Air Management Measurement Tools**

When implemented 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 safeguard 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 to save energy.

Many monitoring systems for air management are too complex and expensive for small data centers. In "Air Management in Small Data Centers" (PG&E, 2016), three simple and inexpensive portable measurement tools that can be used to check the thermal conditions were evaluated. That report was the precursor for this demonstration project.

Although stationary systems are preferred for long-term monitoring and benefits, portable tools can also have great long-term effects since they can be brought in repeatedly over time. Since stationary systems are often too expensive in small data centers, portable tools may be the only option to create a baseline and identify opportunities for improvements in air management and energy efficiency.

Two portable air management measurement tools were reviewed in this demonstration:

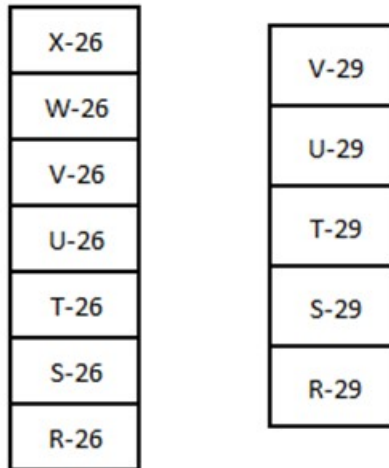
- Packet Power Rapid Deployment Pack - RDP (E302/E306/E312)
- PurkayLabs Audit-Buddy.

These tools have different technical characteristics and price points. The pros and cons of each are discussed together with the evaluation.

Two other tools were considered for this demonstration project: Geist Watchdog 15 and Upsite EMS 200. However, both tools were withdrawn from this demonstration by the vendors before testing had started. Nevertheless, a brief description of both tools are included later in this report, since they have much in common with the Packet Power tool.

### **Test Aisle at LBNL Data Center**

The data center is located on the LBNL campus in Berkeley, California. Figures 1 and 2 show the selected cold equipment aisle for this demonstration project. The hot aisles are partially enclosed with strip curtains. The cold aisle is monitored by a stationary Data Center Infrastructure Management (DCIM) system. The racks are labeled R-29 through V-29 (five racks) on one side and R-26 through X-26 (seven racks) on the other. The racks in the 29 row are individually wider than those in the 26 row. Therefore, the 7-rack row is only about 30" longer than the 5-rack one. The stationary wireless sensors are mounted at three elevations on the inside surface of the perforated front door of every other rack.



**Figure 1. Plan view of selected cold aisle in the LBNL data center.**



**Figure 2. Aisle Layout. Rack R-26 is in the left foreground; R-29 is in the right foreground.**

### **Data Collection Process for Equipment Temperatures**

In order to implement air management effectively, it is necessary to measure key environmental parameters. The important data points 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 the Power Utilization Effectiveness [PUE] calculations).

Since the IT inlet temperature is the most important parameter, the focus in this demonstration is on those temperatures. The recommendations listed below are adopted from the DOE Data Center Air Management Tool: Data Collection Guide (DOE 2014).

For air-cooled IT equipment, measuring the intake air temperature is important, because the equipment is designed to operate within a certain intake 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, while a temperature that is too low typically results in higher energy consumption and utility costs than necessary.

There is no industry standard on the methods, locations, or other factors for performing temperature measurements at the air intakes of IT equipment. Therefore, the following bullets should be considered as a guideline only. Remember that the goal of the temperature monitoring system is to produce a clear picture of the temperature distribution at the IT equipment.

- The probe (sensor) location should preferably coincide (geometric center) with the actual equipment air intake opening. Also, placing the temperature probe inches in front of the actual IT equipment intake opening rather than flush with the opening may render an erroneous result, due to the presence of recirculation of hot exhaust air inside the equipment 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 entering the IT equipment. See also section Sensitivity of Sensor Placement on page 28.
- The optimal quantity and elevation of the temperature probes depends strongly on the contents of the IT racks and the aisle temperature profile. Most racks contain multiple pieces of IT equipment, each with its own intake opening(s). The temperature at the front of the racks generally vary with elevation, due to recirculation above, beneath, and/or around the equipment racks.
- It is not necessary to collect intake temperature data for every rack. Measuring every other or every third rack is usually adequate 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 may be excluded because of the marginal criticality of their contents.
- For IT racks with many (20–40 or more) evenly distributed intake and exhaust openings, three sensors per rack on the intake 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, evenly distributed vertically and centered horizontally within equal rectangular areas on the rack face) is usually recommended. This is the protocol adopted in this demonstration.

- For IT racks with multiple (4–10) intake openings, three sensors per rack is again a sensible compromise. If a few openings dominate with regard to airflow and heat dissipation, place the sensors at those openings.
- For IT racks with discrete intake openings, place the sensors at the geometric center of the actual intake openings (flush to the openings – if possible). This is often the case for uninterruptible power supply (UPS) gear.

**Table 1. Demonstration measurement protocol for intake temperatures.**

What to measure	Measuring equipment	Measuring Technique	Recording interval
IT equipment air intake temperatures	Two portable tools evaluated in this report	<ul style="list-style-type: none"> <li>• Move each tool from rack to rack to record intake temperatures at high, middle, and low locations along the rack face.</li> <li>• Position the sensors:               <ol style="list-style-type: none"> <li>1) as close to the door as possible</li> <li>2) at three levels (center point of each of three equally sized areas of the rack front).</li> </ol> </li> </ul>	Once at each rack location until steady reading.

## ASSESSMENT RESULTS

Sequentially, both monitoring tools will now be described followed by its evaluation.

### Packet Power RDP (E302/E306/E312) [www.packetpower.com](http://www.packetpower.com)

Packet Power offers a number of options for monitoring temperature and humidity in data centers. Their products are mainly designed for permanent installations, but due to the very compact form factor, they can be adapted into portable data monitoring and collection tools. All products in this assessment are off-the-shelf.

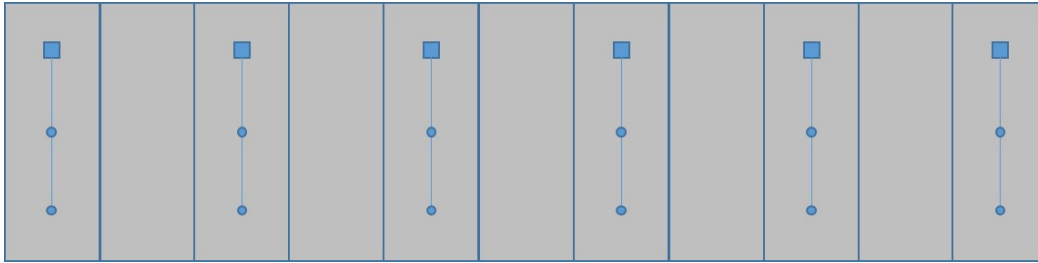
Figures 3 and 4 show general setup (six-string configuration) and the components for the portable tool, respectively. Each “string” of the system includes a small environmental monitor (E302) with a built-in single temperature/humidity point, two external temperature probes, and an Ethernet gateway.

Additionally, other equipment is required to use these Packet Power products: an Ethernet cable for connecting the Ethernet Gateway with either a laptop to view the data locally or with a Network Router to view the data remotely. None of this equipment (cable, laptop, or router) is included.

The cables from the two exterior epoxy-coated thermistors are connected directly to the battery powered E302, which in turn communicates wirelessly (2.4 GHz) with the plug-and-play Ethernet Gateway. The Gateway has its own power supply, which requires access to a standard AC wall receptacle.

The Gateway, in turn, communicates via an Ethernet cable either directly with a laptop or with a Network Router. Both connection options allow control via an Ethernet Gateway Console (free website).

Data can also be analyzed with another (licensed – nominal yearly fee) application called EMX Energy Monitoring Portal, which can be viewed with an internet connected computer (anywhere).



**Figure 3: Packet Power: Setup for an 11-rack lineup with three probes on every other rack.**

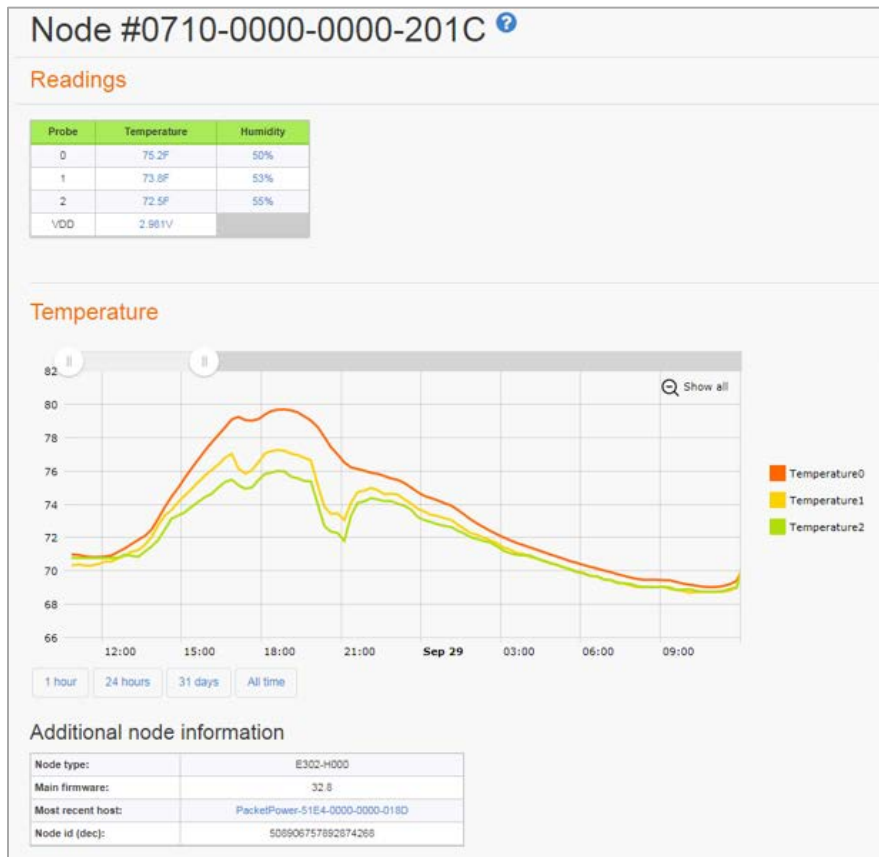


**Figure 4: Packet Power: Portable measurement tool components, power supply not pictured (From left to right: Environmental monitor (E302), two exterior probes, Ethernet Gateway-4).**

For a six-string configuration, an entire row of equipment racks can often be measured at one time, which significantly speeds up the measurements. Rarely is it needed to have probes on every single rack (see Figure 3 above). Once the strings are in place (by magnets), the user waits until the temperature readings have settled. Another advantage of having multiple strings rather than just one is that they can be left in place for, say, a 24-hour reading and still cover an entire rack lineup. The Packet Power system allows economical multiple-string configurations.

For a single-string configuration, the string of probes needs to be moved from equipment rack to equipment rack to collect temperature readings for an entire equipment lineup. Once in front of a rack, the user waits until the temperature readings have settled or converged. The estimated time is less than 3 minutes (see spot test below). At that point, the user manually 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 and accuracy desired.

Figure 5 shows an example screen shot of the web interface for the EMX Monitoring Portal. The user can view both the current temperature readings as well as historic data on a line graph. The data can also be exported to Microsoft Excel for further analysis. Third party interfaces can be used with Modbus TCP/IP and SNMP protocols. The Packet Power system comes with a rich set of online manuals. However, they are designed for stationary installations, and therefore do not describe the exact method of moving the probes around the data center.



**Figure 5: Packet Power: EMX data collection view from one node (string of 3 probes), 24-hour reading.**

## Unpacking

The system, in a single-string configuration, arrived in a small, light 7”x7”x10” shipping box with a packing list. The shipping box included two inner, smaller boxes.

The first inner box included an E302 Environmental Monitor (with one internal sensor, ports for two external probes, and a factory-installed battery) with two external probes. A number of short cable straps were also included. The second inner box included the Ethernet Gateway-4 with its power supply. See Figure 4 above for pictures of the key system components.

No installation instructions were found in the box. Manuals should be included in the box or, at minimum, a link to support information. However, Packet Power sent separately (via email) a two-page “Ethernet Gateway V4 Quick Start Guide” and a five-page “Quick Deployment Guide”. The second document has links to more information about the Gateway-4 and the EMX system.

As described above, attach the Environmental Monitor with an included magnet to the front perforated equipment rack door at the top probe location and then let the other two probes hang down for measuring at the mid and bottom probe locations.

## Test Installation (single-string configuration)

The installation was started by setting up the Ethernet Gateway by following the instructions in the “Ethernet Gateway V4 Quick Start Guide” with additional data center focused support from the “Wireless Environmental Monitoring Guide”. The Gateway guide has eight (8) distinct steps. The instructions are not entirely stand-alone, especially not for a technology challenged person. A bit more of a descriptive text would help. Nevertheless, steps 1-7 were fairly simple. The assessment laptop, connected to the same network as the Gateway, found both the Gateway and Environmental Monitor (E302). What users see on their computer screens is called the “Ethernet Gateway Console”. The Console is accessed by entering the IP address of the Gateway (shown on the blue display on the Gateway) into a standard web browser.

However, initially, there was no access to the temperature data. This was resolved by changing the web browser from Explorer to Chrome. There were no references to this issue in the product documentation. However, the Packet Power Service Team quickly provided the technical assistance.

Step 8 in the Quick Start Guide is not necessary for the Ethernet Gateway Console to work. This step is intended for exporting data. The Gateway can make monitoring data accessible (export) via three formats: The EMX Monitoring Portal and third party interfaces: Modbus TCP/IP and SNMP. The Ethernet Gateway Console, on the other hand, has direct access to the Ethernet Gateway. To avoid confusion, this relationship could be better described in the manuals.

The Console only reports current data and only in a simplified fashion (table and dials; see Figure 6). If data across time is of interest (graphed), the EMX Monitoring Portal needs to be activated. When the system was received, EMX was not enabled (this feature requires a license). A license was requested and received the same day. Plugging in the received license credentials at <http://emx.packetpower.com> allowed a login to EMX. To get the data feed working, it was necessary to go back to Step 8 in the “Ethernet Gateway V4 Quick Start Guide” and to select “Cloud EMX” for both the Data Feed and the Support Feed. After reboot, the temperature data showed up on the EMX interface. By clicking on the Monitoring Node of interest, graphed data is displayed (but only after significant delay) and the data can be exported to Excel for further analysis. Also, under Analyze on the top menu on the EMX screen, rack details can be selected, though this last feature did not prove terribly useful. The EMX landing page and the graph across time was most useful.

The graph, however, should be updated more frequently than every 15 minutes. Every 30 seconds would be more appropriate to better capture the time to reach steady state after a temperature change. In addition, the time zone must be end user adjustable and all temperatures should be in degrees F as default. Temperature data is now reported in degrees C.

Before contacting the Service Team to resolve issues, it is recommended to take a look at the additional information at [www.packetpower.com/support](http://www.packetpower.com/support) Under Getting Started, select Support Content Home Page. Reading the sections Ethernet Gateways and Packet Power Communications Protocol are especially recommended to better grasp how the different components communicate.

Precision. To test the precision (uniformity of readings) of the probes, two external probes were placed so they almost touched the E302 unit’s faceplate. Ten measurements were performed. The maximum temperature deviation between the probes was 0.6°F, the internal probe always reported the highest temperature (see Table 2), maybe due to some self-heating from the electronics inside E302.

An artifact was noted in the temperature reporting. The external sensors kept a suspiciously constant temperature (down to 1/100 °F) for the first eight measurements, and then suddenly “jumped” to a new value. Since the jump is small, this should have only a marginal practical significance.

Accuracy. A calibrated thermometer was also used to check the accuracy (deviation from a reference) of the probes. The deviation from the calibrated thermometer was well within  $\pm 0.4^\circ\text{F}$ . The technical specifications for RDP (E302/E306/E312) state a temperature accuracy of  $\pm 1.8^\circ\text{F}$ .

Speed. A spot test was performed to evaluate the time for the external probes to converge into a new temperature. On average, it took 2-3 minutes to converge within  $0.5^\circ\text{F}$  of the new temperature after a  $5^\circ\text{F}$  temperature change in the room, which is acceptable for this application. The built-in temperature sensor in the E302 unit, on the other hand, had a much more problematic (long) time constant. See the next section for recommendations to rectify this shortcoming.

**Table 2. Temperature precision and accuracy test of three Packet Power probes (°F).**

Measurement	Calibrated Sensor °F	Internal Sensor	External #1	External #2	Max - Min	Max. Deviation from Calibrated
1	73.44	73.67	73.15	73.15	0.52	0.29
2	73.44	73.69	73.15	73.15	0.54	0.29
3	73.45	73.67	73.15	73.15	0.52	0.30
4	73.45	73.69	73.15	73.15	0.54	0.30
5	73.47	73.71	73.15	73.15	0.56	0.32
6	73.49	73.72	73.15	73.15	0.57	0.34
7	73.51	73.72	73.15	73.15	0.57	0.36
8	73.54	73.74	73.15	73.15	0.59	0.39
9	73.56	73.78	73.15	73.35	0.63	0.41
10	73.60	73.80	73.35	73.35	0.45	0.25

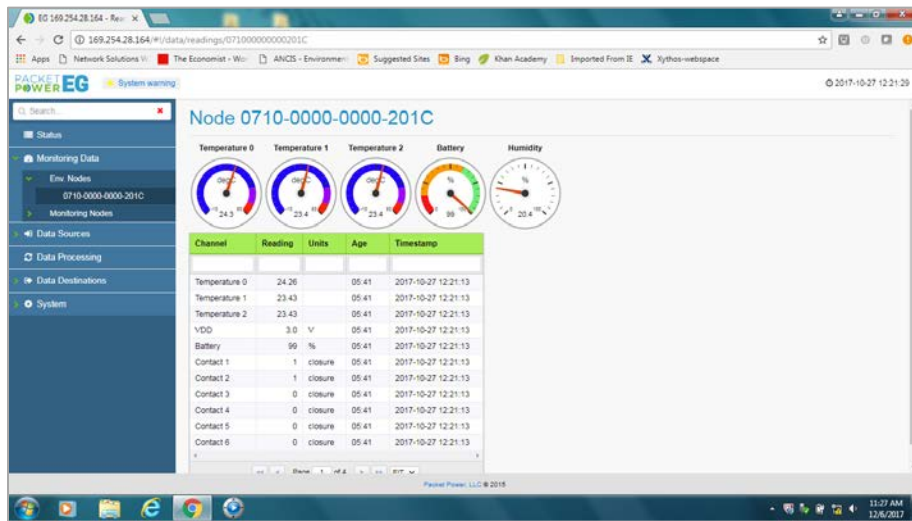
### **Data Center Measurements (one-string configuration)**

The purpose of this exercise was to test the user experience (ease of use) with the Packet Power system when moving down an aisle from rack to rack. As noted above, a cold aisle with racks on both sides (see Figures 1 and 2) was selected. The racks are R-29 through V-29 (five racks) on the right side and R-26 through X-26 (seven racks) on the left side. A sequence of measurements was performed on R29, T29, V29, X26, V26, T26, and R26.

Since an internet connection could not easily be installed in the selected Federal government operated data center, other solutions were considered. It is not a good assumption that data centers have an available Ethernet connection point or are willing to install one considering the fact that this is supposed to be a temporary system.

The first thought was to take the internet connection out of the picture by connecting the Gateway-4 directly to the laptop with the standard Ethernet cable. The resulting fully contained system also helps address security concerns in many data centers. The potential drawback to this approach is that it only allows access to the simplified “Ethernet Gateway Console” and not to the more advanced EMX Monitoring Portal. This turned out not to be such a big loss, since the data presentation in the EMX system is recorded only every 15 minutes, which is too long an interval for this application. On the other hand, the Ethernet Gateway Console reports about every 30 seconds.

To select the Ethernet cable connection on the laptop, the wireless capabilities of the computer were simply disabled. No adjustment of the Gateway-4 settings were necessary besides a reboot (using its “joystick” and display). Wait for the blue screen on Gateway-4 to show the automatically assigned IP number. Use a Google browser, and enter this IP address in the search field (again Explorer will not work). At this time, the Ethernet Gateway Console should open up on the laptop. From the left side tabs, select Monitoring Nodes and then Environmental Nodes where the data is reported from the three sensors (see Figure 6). The data is updated every 30 seconds (with its associated time stamp).



**Figure 6: Packet Power: Ethernet Gateway Console data collection view from one node (string), instantaneous reading. Temperature readings are in degrees C.**

Since the built-in sensor in the E302 unit itself is too slow for this application, using the sister unit E306 (see Figure 7), which allows a maximum of six exterior sensors (but no interior), is a better choice. By using three exterior sensors, the E306 unit makes the entire system faster and more useful. E306 requires a 5 V DC source. A universal 100-260V AC power supply is included with the E306 device and provides the required 5VDC. Since the power supply requires access to a standard AC wall receptacle, a better option is to use a small USB battery pack (power bank) with a readily available USB-to-Barrel Jack output cable for connecting power to the E306.



**Figure 7: Packet Power: Portable measurement tool components, power supplies not pictured (From left to right: Environmental monitor (E306), exterior probes, Ethernet Gateway).**

The E306 unit has other benefits. It has a local display with the temperatures (see Figure 7), which would allow removing the Gateway-4 as well. One drawback of using the local display option is that the temperature readings may be affected by the person taking the readings. This was noticed during the assessment measurements.

Such a system would be the true bare-bones, pocket-sized system. The readings have to be manually recorded with either configuration. Section “Free and Easy-to-Use Graphing and Metric Tool” describes an open domain software for recording and analyzing the data. Since the system is supposed to be used on a temporary basis with limited measurement points, this seems to be a fair compromise. The bare-bones system can also be used by almost anyone, which is appropriate for small data centers. The “manual” could probably fit on a single page of paper.

An upgraded option is to use the sister unit E312 (not pictured) which is battery powered (or use the same AC power supply as for E306). It allows a maximum of twelve exterior sensors (but no interior). Since no exterior power pack is required, the system becomes fully portable. However, this unit does not come with a local display with the temperatures. In any case, this demonstration proceeded with the E302 unit and the Gateway.

In assembling the system, the E302 unit was attached on the perforated equipment rack door at the top location per ASHRAE (the unit has a magnet on the back). The two external probe cables simply hang down along the door. The cables were spooled so that the right lengths were achieved to match the middle and bottom locations for the probes per ASHRAE (see Figure 8).

The vertical positions of the probes were: 13.1”, 39.3”, and 65.5” above the floor. The vertical probe positions were not changed when moving down the aisle from rack to rack. If all racks are approximately the same height, and more or less filled with the same amount and type of equipment, this procedure is the recommended one.





**Figure 8: Packet Power: System installed on equipment rack. The blue/white box on the upper part of the rack door is the E302 unit. The two external probes are hanging down along the door (at arrows).**

Following a similar process as outlined above, the Gateway was connected to the assessment laptop to be able to use the Ethernet Gateway Console for displaying the temperatures (see Figure 9).



**Figure 9: Packet Power: Gateway-4 (middle shelf – detail at right) and laptop. Gateway-4 connects wirelessly to E302. Laptop shows the Ethernet Gateway Console with temperature data.**

The time stamp on the Console was observed, and a temperature reading was made after 2-3 minutes. After the temperatures were noted, the probes were moved to the next rack. The process was repeated for the entire equipment aisle. Even this seemingly short time constant (time to stabilize) may be considered tedious if many racks were to be measured. The thick epoxy coating on the probes could possibly be made thinner, which would make the sensors stabilize faster.

The magnet holding the E302 unit could be stronger. It had a tendency to slip down a bit when attached to the perforated rack fronts. A stronger magnet can be specified. With the assessment setup, the bottom temperature sensor moved slightly back and forth due to the strong inflow of air from the perforated floor tile. However, neither effect impacted the measurements.

## Summary and Conclusions

Packet Power RDP (E302/E306/E312) is a wireless tool not originally intended as a portable system, but due to the simple and compact design it can easily be adapted into a portable tool. The system was found to be very easy to use in quickly gathering very accurate data on rack air inlet temperatures. It is an inexpensive, pocket-sized system that does not need extra equipment besides a laptop and an Ethernet cable to be functional. The simplicity of use is an advantage for small data centers with limited resources and expertise. It can also be inexpensively expanded to include additional sensors and graphing capabilities. No major shortcomings were noted. In addition, the probes can readily be used for measuring CRAC supply and return temperatures as well as other temperatures.

## Similar Tools

The following two tools are similar (technology and cost) to the demonstrated Packet Power tool, which may be viewed as a “representative” of a family of tools from different vendors. These tools are not pre-packaged (boxed) tools and only basic software is included for reporting/graphing the data. The simplicity and low cost are advantages for small data centers with limited resources and expertise.

**Geist** ([www.geistglobal.com](http://www.geistglobal.com)) offers a number of options for monitoring temperature and other environmental conditions in facilities such as data centers. The Watchdog product line is designed to be a permanent or temporary solution for monitoring data center conditions, but due to the simple and compact design, it can be adapted into a portable data monitoring and collection tool.

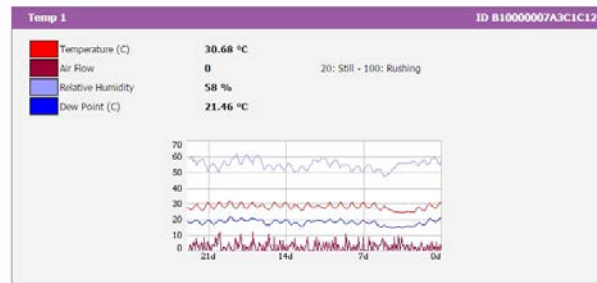
The Geist solution includes the entry-level Watchdog 15 self-contained environmental monitoring unit and a single GT3HD temperature sensor unit (Figure 10) for monitoring small spaces. However, the unit is capable of monitoring up to a maximum of 13 temperature sensors. The end user is responsible for providing a laptop and a 6 V DC power source.



**Figure 10: Geist: Watchdog 15 and sensor unit with two probes.**

Once the components have been assembled, the measurement procedure is identical to that of the Packet Power system. The system is moved 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 waits until the temperature readings have settled. The estimated time is less than three minutes for temperature variations up to 5°F. At that point the user logs the readings manually and moves to the next selected equipment rack.

Data is stored on the units and can be graphed using the onboard web GUI or alternatively exported in a CSV format. Figure 11 shows a screen shot of the web interface; one screen for each temperature sensor. The user can view both the real-time temperature readings as well as historic data on the line graph. A number of options are available to collect data from the device, including SNMP, JSON, and via the device's internal web interface. The manual method described above is a simple cut-and-paste method for collecting temperature data via the unit's web interface.



**Figure 11: Geist: Data collection view**

**Upsite Technologies** ([www.upsite.com](http://www.upsite.com)) also offers a number of options for monitoring temperature conditions in data centers. Its Environmental Monitoring Systems EMS 200 and EMS 300 were not designed specifically to be portable, but their size and stand-alone, plug-and-play capabilities make them useful for portable applications. Both units can be wired directly to a laptop via their Ethernet ports.

The EMS 200 is a wired sensor network manager that allows four temperature sensor inputs. In addition, it has eight digital inputs (not user in this application). Figure 12 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. It operates off USB power using an included adapter.

EMS 200 has a real-time, web-based graphical dashboard. Four gauges show the temperatures for the four temperature sensors, and there are multiple alarm notification configurations. The tool has integrated logging and trending. The tool also allows the end user to download data into a CSV file, which can be download into Excel to manipulate the data.

There is no wireless option for EMS 200 to avoid the long pre-made probe cables. However, the larger EMS 300 is wireless (Figure 13). It is a sensor network manager that receives and manages signals from individual wireless sensors that can be displayed in a centralized, concise, and easy-to-access web interface. 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. Two features that make it suitable for small data centers are its easy and low-cost installation as well as its stand-alone operation that allows expansion. EMS 300 has a significant advantage over EMS 200: It can be left in one location while the wireless sensors are moved around the data center.



**Figure 12: Upsite Technologies: EMS 200 unit**



**Figure 13: Upsite Technologies: EMS 300 gateway**

**Purkay Labs (Audit-Buddy) [www.purkaylabs.com](http://www.purkaylabs.com)**

Purkay Labs' Audit-Buddy is a portable temperature (and humidity) monitoring tool developed for the data center market. It is battery operated and does not require a separate computer program to run or read time-stamped data, nor does it need to be integrated into the facility infrastructure systems.

The basic system configuration consists of three temperature and humidity (TH1) units and an adjustable six-foot carbon fiber rod (Figure 14). 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 door, as recommended by ASHRAE. The weighted triangular base allows the rod and its three TH1 units to be placed near the perforated door of the IT equipment rack.

The TH1 unit's fan draws air into the cavity where the temperature (and humidity) sensors are located. The units 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.



**Figure 14: PurkayLabs: Three temperature/humidity (TH1) units mounted on a carbon fiber rod (detail to right, not to scale)**

Although this tool can capture both real-time and long-term scans of the data center environmental conditions, this assessment focuses on real-time scans. The operator places the Audit-Buddy in front of the first equipment rack in an equipment aisle, takes a real-time scan, and moves the tool to the next rack. The process is continued until measurements have been taken for every selected rack along the aisles in the area of interest. Each rack takes around a minute (with a 30-second “wait time” before each sampling period), and the operator is guided by three multi-colored control lights on the top of the unit and an LCD display on the front. The data are uploaded to a laptop using a USB memory stick and can then be fed into a supplied Macro and other Audit-Buddy software to generate tabular data as well as a thermal contour map for each row of equipment racks.

### **Unpacking**

The Audit-Buddy system arrived in a box with dimensions of 50”L x 15”H x 13”W (similar in shape and size to a set of golf clubs) with a weight of 21 pounds. The box contained the entire system consisting of two light carbon fiber rods with pre-assembled bases and six TH1 units (three per rod). See far left part of Figure 14 for a fully assembled system of three sensors on a single rod. For the evaluation, one rod was used to measure the intake temperatures for one rack at a time. The two-rod, six-module system enables delta-T measurement (from front to back of the racks) or could be used to simultaneously take readings at two rack inlet faces.

The triangular base assembly does cause some disturbance of the airflow from the perforated tiles. However, helped by the fact that the assembly is open in the middle, the overall impact should be small.

The large outer box contained the two rods and six boxes containing the TH1 units and their accessories. Included in each of the six boxes is a TH1 temperature and humidity logging unit, a clamp for mounting the unit to the rod, a magnetic mounting plate (not used), a USB connector cord, and a pair of Velcro straps. Also included was a plastic bag containing two USB memory sticks and printed documents, including packing list, manuals, and spec sheets. There were also some unrelated documents in the bag. A memory stick contained the software.

As described above, the general idea is to attach three TH1 logging units to the carbon fiber rod at selected heights (usually top, middle, and bottom), and then place the rod so that the air intake ports on the units are as close as possible to the perforated front door of the equipment rack.

## Test Installation with Single-Rod Configuration

The installation was started by unpacking three of the TH1 units and screwing the included rod clamps to their backs. It was noted that, while the screws are the Phillips type, one needs a plain Phillips screwdriver with a shaft slender enough to fit through the hole in the clamp opposite the screw (a 4-in-1 screwdriver may not work as its shaft is usually too big). Also, one of the units had a defective threaded insert on the back, so the clamp screw would start but not tighten. Purkay was contacted, and they quickly sent a replacement unit.

The three units were attached to the rod and turned on by hitting their “OK” buttons (the AA batteries were factory installed). The unit display guides the user setting the time and getting the three units names according to their position (only top, middle, and bottom prefixes are settable on the unit; the rest of the unit name can be defaulted to what’s already there or can be set using the Audit-Buddy software). Quick Scan (real-time) was selected, and the unit defaulted the delay between each move to 30 seconds as well as the temperature to degrees F. With all three units set up, when prompted by the control lights, we started logging on all three and moved the rod when directed by the lights. We stopped the logging as prompted on the displays, then downloaded the data to the USB stick as prompted.

The software was downloaded and installed. While trying to view the data using DPlot, it was apparent from an error message “not a DPlot file” that the files were of the wrong type (they are .qpl vs. the .grf expected by DPlot). Stymied by an attempt to run the system without reading the instructions, it was noticed on the “Meet Audit-Buddy” (aka “Read This First”) sheet that the “Base Excel Macro” should be used. The only macro on the USB stick was “Optimize Macro V5.8.xlsm”. However, that displayed a warning that the macro is designed for Excel 2010 as opposed to the 2007 on the assessment laptop. There is no such warning in the specifications, only Windows 7 or later is listed. For security, macros are disabled by default on LBNL laptops, so that needed to be over-ridden.

Two problems were noted when using the Macro on Excel 2007 <sup>1</sup>:

- 1) Radio buttons don’t line up with their descriptions.
- 2) On closing, it wants a “VBA Project Password”, just a time-consuming annoyance, as the computer must be re-booted to clear this prompt.

Nevertheless, the macro worked, when using the “Read Data” option, to generate tabular files of the data in the Macro sheet and export the data as .csv files. After contacting Purkay again, they explained that the radio button alignment is a known problem, and they sent a .pdf file with instructions on how to fix it. Following the instructions did fix the display problem, but it adjusts the zoom of the display for everything on the computer. Typically, such instructions are included in the box. Purkay confirmed that that the Excel warning could be ignored.

The TH1 units’ display prompts greatly facilitated set-up, gathering data, stopping a session, and downloading the data to a memory stick. Likewise, the three control lights on the top of the unit helped in the timing of the measurements.

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<sup>1</sup> After reviewing the draft write-up of this report, the vendor reported that their WIFI-Buddy product has addressed many of the interface limitations of Audit-Buddy. This demonstration did not include that product.

There was uncertainty about whether the air intake was the side opening on the unit or the bottom opening. It would help greatly if the openings were clearly marked on the unit. This was a surprising omission. Even the full manual is not clear on this point, although the illustrations imply that the intake is on the side of the unit. Furthermore, the assessment indicated no airflow through the unit, though fan operation was visually observed.

After further investigation and confirmation by Purkay, it was discovered that the side “inlet” actually is the exhaust opening! From a rack air intake temperature perspective, that configuration is not desirable since the bottom opening is farther away from the equipment rack and generally directly in the cold airstream from the perforated floor tiles. This issue is discussed in section Sensitivity of Sensor Placement.

Precision. After setting up three TH1 units in a line next to one another on a laboratory workbench, all drew in the same-temperature intake air. Table 3 shows the results for 10 measurements. The precision of the readings was good, with no more than 0.4°F difference between the maximum and minimum temperature readings in any of the side-by-side tests.

Accuracy. A calibrated thermometer (reference) was also used to check the accuracy of the units. In the nominal 10-run test, the accuracy was within +1.3°F compared with the reference, with all units reading higher than the reference. This accuracy is a bit outside the ±0.9°F specified by Purkay.

**Table 3: Temperature precision (max-min) and accuracy test of three Purkay TH1 units (°F).**

Measurement	Calibrated Sensor °F	S/N 00211	S/N 00179	S/N 00220	Max - Min	Max. Deviation from Calibrated
1	72.63	72.75	72.56	72.71	0.19	0.12
2	72.60	73.02	72.78	72.91	0.24	0.42
3	72.54	73.20	72.96	73.04	0.25	0.66
4	72.53	73.34	73.04	73.20	0.30	0.81
5	72.55	73.42	73.14	73.30	0.28	0.87
6	72.57	73.54	73.24	73.40	0.30	0.97
7	72.52	73.59	73.30	73.45	0.29	1.07
8	72.51	73.66	73.35	73.52	0.31	1.15
9	72.51	73.72	73.42	73.58	0.30	1.21
10	72.49	73.78	73.47	73.63	0.31	1.29
20	Interpolation					2.00
67	71.17	74.36	74.20	74.54	0.34	3.37

But it was noticed that on a previous set of 10 runs on the same morning, all units were reading slightly low, not slightly high. So the units were allowed to continue run past the 10 runs of the second set and by the 67th run, the maximum deviation from the reference was almost +3.4°F and nearly +4.0°F compared with the first set of 10 measurements. It was noticed that the fan aspirating the temperature sensor is located upstream of the sensor. The fan got warm to the touch and repeat temperature measurements confirmed self-heating (stray heat). As the measurements progress over time, the fan heat makes the reading increasingly higher. Furthermore, the rate-of-increase tapered off over time, which is another hallmark of self-heating.

Since the measured precision was good (among the three sensors), the self-heating was an indication of a systemic design problem. This temperature drift could be problematic when measuring inlet air temperatures in data centers.<sup>2</sup>

The temperature readings are reported by the Purkay system to the nearest 0.001 of a degree, which imply an accuracy that is simply not real, even without the accuracy problems described above. The numbers in Table 3 are rounded to the nearest 0.01 of a degree.

Speed. A spot test of the time required for the readings to converge into a new temperature in the room was not considered necessary since the unit is fan assisted with a 20-second sampling period (preset).

It was noticed that the internal clocks in the units drift as much as a few minutes per week so it is useful to check the clock in each unit and set it as needed. Also, the time can only be set to the minute on the unit, but the time stamps on the data are to the second, which would seem to be illusory precision. Also, since the three units need to be started one by one, there will be several seconds lag time between the first unit's and last unit's recording times. None of these issues caused problems in this assessment, but they could lead to the appearance of unsynchronized data acquisition.

## **Data Center Measurements**

The purpose of this next exercise was to test the user experience (ease of use) with the Purkay system when moving down a test aisle from rack to rack. The assessment of the Purkay units was conducted on the same cold aisle and on the same racks as the Packet Power assessment (see Figures 1 and 2). The racks are R-29 through V-29 (five racks) on the right side and R-26 through X-26 (seven racks) on the left side. Measurements were taken on R29, T29, V29, X26, V26, T26, and R26.

In assembling the system, it would help if the screw attachments for the units were replaced with quick clamps (like the one used to adjust the rod length). The screws are a bit challenging to handle while at the same time measuring the vertical distance. Also, the rubber tip of the screws tended to deform and otherwise make sliding the sensor difficult.

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<sup>2</sup> After reviewing the draft write-up of this report, the vendor recommended two solutions to manage the self-heating by allowing "cool down" periods, either between scans or between samples: 1) Stop the scan after 20 racks and wait for 5-10 minutes before proceeding to the next 20 racks [resulting in +2.00°F compared with the temperature reference; data from Table 3] or 2) increase the "wait time" before each sampling period from 30 s (default) to 60 s [resulting in +2.03°F compared with the reference for measurement #67; data from additional LBNL testing]. Please contact vendor for additional details on the management and control of the self-heating.



The clamp on the rod itself is located almost exactly half way up the rod (and the rack) which is unfortunate since the middle sensor is generally located (as per ASHRAE) exactly there. The assessment had to address this with an awkward work-around by attaching the sensor box clamp onto the rod clamp itself (Figure 15).



**Figure 15. PurkayLabs: Awkward clamp fix (TH1 clamp placed on the rod clamp).**

The Purkay units were attached at the ASHRAE recommended positions (vertically): Top, Middle, and Bottom (center points of the upper third of the rack, middle third, and lower third). The vertical positions of the units were not changed when moving down the aisle from rack to rack. If all racks are approximately the same height, and more or less filled with the same amount and type of equipment, this procedure is the recommended one. The vertical positions of the inlet ports were: 13.1", 39.3", and 65.5" above the floor. Figure 16 shows the fully assembled system at Rack R-29.



**Figure 16. PurkayLabs: System fully assembled outside of rack R-29.**

However, the awkward clamp fix limited the rotation of the unit on the rod, which would not have been a problem had the foot on the rod been adjustable (rotationally). The result was that the units cannot

always be placed flush with the perforated rack fronts. Racks with seismic bracing do not allow sliding one of the feet underneath the rack. It is also becoming more common that racks are equipped with blanking panels under the rack at the front, which would create the same challenge (i.e., the base can't be partially slid under the rack). Compare Figures 17 and 18.



**Figure 17. PurkeyLabs: Seismic bracing. Units cannot be placed close to the rack fronts.**



**Figure 18. PurkeyLabs: No obstruction. Units can be placed close to the rack fronts.**

Seismic bracing also often makes the floor surface uneven, with the result that when the base is put as close to the rack as possible, it doesn't sit flat on the floor, making the rod lean outwards toward the top which creates a one-inch plus gap between the upper unit and the rack front (Figure 19). This will have an impact on the temperature accuracy, see next section.

This problem could have been resolved by having a screw adjustment on the feet of the base for quick adjustment. A few sheet metal pieces were fabricated and slid under the feet to make the rod vertical.



Figure 19: PurkayLabs: Leaning rod due to uneven floor.

After these numerous fixes<sup>3</sup>, the temperature readings were stored on the memory stick, three sequential readings at the three vertical levels: Top, Middle, and Bottom. The readings were retrieved with the supplied software without problems.

### Summary and Conclusions

Purkay Labs Audit-Buddy is a portable tool for monitoring temperature (and humidity) in data centers. One unique and potentially problematic feature of this tool is its built-in temperature probe and fan-aided air sampling. The system includes “everything” except a computer. Manuals and software make data analysis uncomplicated, although it may require some learning and set-up time. The system was relatively easy to use in quickly gathering and downloading data. However, a number of shortcomings were noted that makes it more difficult, slower, and less accurate to use. Most significantly, self-heating of the internal temperature probe was observed, which resulted in compromised accuracy. There is a need to manage and control this self-heating. In addition, the system did not allow the preferred placement of the sampling site on the rack door, introducing another temperature inaccuracy. A potential additional downside to this tool is the cost, especially if multiple systems are desirable.

### OTHER FINDINGS

#### Sensitivity of Sensor Placement

The perforated floor tiles in front of the equipment racks provide cold air upwards in front of the racks. The resulting “jet” will entrain warmer surrounding air into the jet. Consequently, it can be expected that the temperature will increase in the outer parts of the jet. Therefore, placing a sensor just an inch in

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<sup>3</sup> After reviewing the draft write-up of this report, the vendor reported that they plan to address some of these items.

front of the perforated front door (rather than on the door) may give a lower temperature reading. Although the magnitude of this error depends on a number of local factors in the data center, the general behavior should be correct. This merited further investigation.

To better understand the impact of the probe location, a test was conducted. The Packet Power probes were used since they were best suited for this particular test, and measured the temperature 1" outside the perforated front door, flush to the door, 1" inside the door, and immediately in front of the actual inlet opening to the server (3" inside the door). Table 4 shows the results.

**Table 4. The impact of the placement of a temperature probe.**

1" Outside	On Door	1" Inside	Server Intake
[F]	[F]	[F]	[F]
23.7	25.0	24.9	25.1

Although this was only a single test, it does provide support for the general behavior discussed above. Therefore, it is recommended to put the sensors as close as possible to the front door and preferably on the door. The Packet Power system allowed the sensors to be placed on the door, whereas the Purkay system did not allow the preferred placement, as discussed earlier.

It can also be noted that in this test all three temperature readings on and inside the rack door are virtually identical. If the temperatures are measured some distance outside the rack, they will be more affected by the cold air jet from the perforated floor tiles and will not include hot air recirculation inside the rack. Consequently, such measurements may not accurately reflect the actual IT equipment intake temperatures.

**Free and Easy-to-Use Graphing and Metric Tool: the Air Management Estimator**

Lawrence Berkeley National Laboratory has developed two Excel tools that can be used to quickly and easily plot the intake temperatures, as well as calculate the Rack Cooling Index (RCI) metric, which is a measure of the conformance with the selected equipment intake temperature specification such as those from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) or Telcordia Technologies (NEBS). Both tools, the "Air Management Tool" and the "Air Management Estimator" (LBNL, 2017), can be downloaded and used for free (including manuals) from <https://datacenters.lbl.gov/tools>.

Figure 20 shows a screen shot of the RCI tab in the Air Management Estimator, which is a condensed version of the Air Management Tool. The yellow cells allow input of measured air intake temperatures. As with any other Excel spread sheet, the data can be manipulated (e.g., re-ordered) if an alternative view of the data is desirable. To the right of the yellow input cells, the data is shown graphically together with the Rack Cooling Index ( $RCI_{HI}$  and  $RCI_{LO}$ ).

This metric is designed to gauge, in an unbiased and objective way, the compliance with the recommended (normal operation) and allowable (not-to-exceed) IT equipment intake temperature

ranges of the thermal guidelines of ASHRAE and NEBS. RCI is a proxy for IT equipment reliability. As such, it is often used to ensure that no degradation of the thermal IT equipment environment occurs when air management is introduced for the purpose of saving energy. Air management is key in data centers, since it is a prerequisite for many other energy-saving measures.

RCI<sub>HI</sub> is a measure of the absence of over-temperatures, and a score of 100% means no over-temperatures. Over-temperature conditions exist once one or more intake temperatures exceed the maximum *recommended* temperature. The lower the percentage, the greater the risk that IT equipment experiences temperatures above the maximum *allowable* temperature. A value below 90% indicates poor compliance.

RCI<sub>LO</sub> is an analogous index for temperature conditions at the low end of the temperature range. An RCI<sub>LO</sub> of 100% mean no under-temperatures. Both RCI numbers at 100% mean that all intake temperatures are within the recommended temperature range; i.e., absolute compliance.

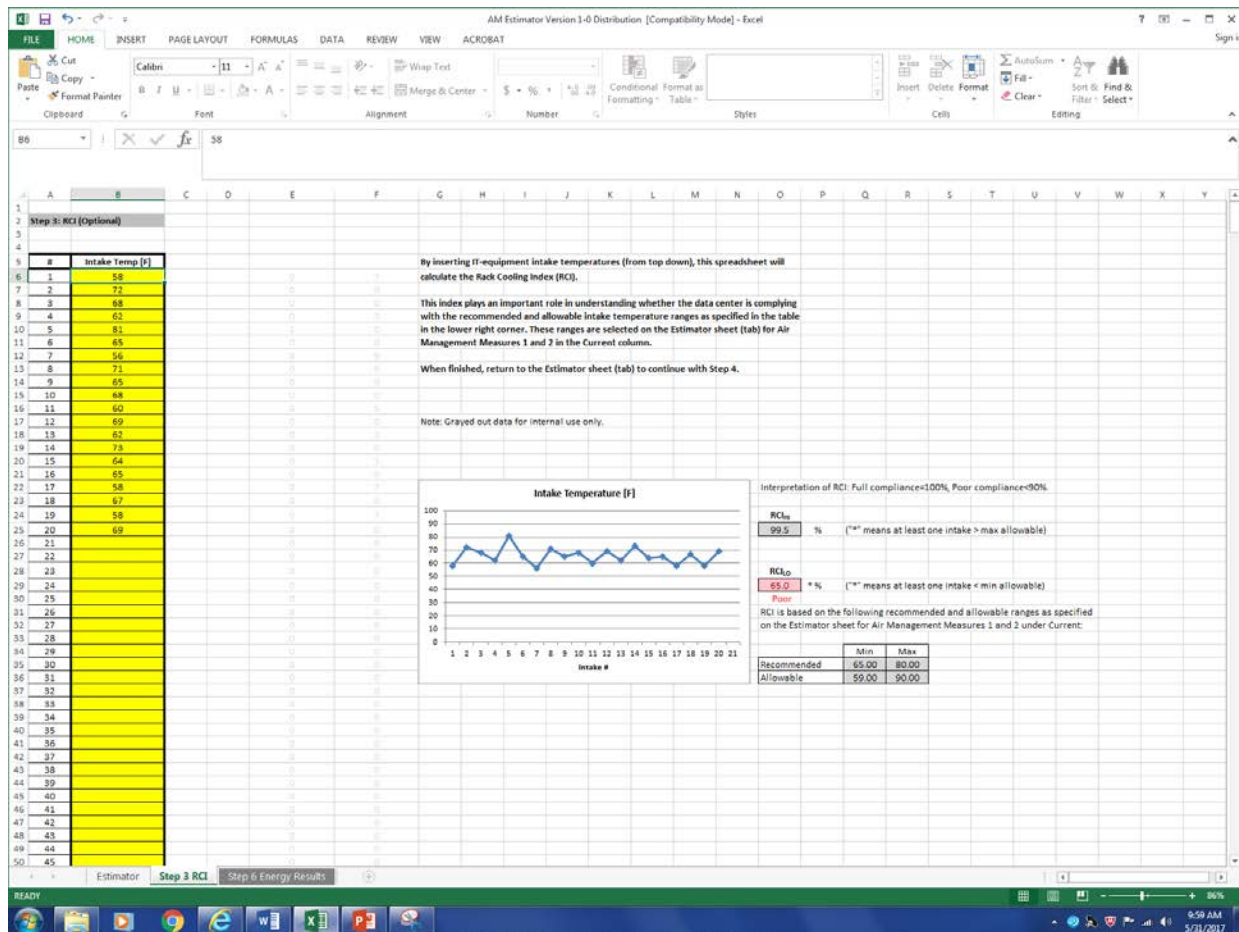


Figure 20: Screen shot of the RCI tab in the Air Management Estimator.

The Air Management Estimator could be especially useful for portable systems with no graphing capabilities but also useful for more advanced systems lacking the capability of calculating the RCI metric. The associated manual provides more information about the use of the Air Management Estimator, including a description of RCI.

## SUMMARY AND RECOMMENDATIONS

Table 5 shows a summary of the two portable air management measurement tools included in this demonstration.

Packet Power RDP (E302/E306/E312) is a wireless tool not originally intended as a portable system, but due to the simple and compact design it can easily be adapted into a portable tool. The system was found to be very easy to use in quickly gathering highly accurate data on rack air inlet temperatures. It is an inexpensive, pocket-sized system that does not need extra equipment besides a laptop and an Ethernet cable to be functional. The simplicity of use is an advantage for small data centers with limited resources and expertise. It can also be inexpensively expanded to include additional sensors and graphing capabilities. No major shortcomings were noted. In addition, the probes can readily be used for measuring CRAC supply and return temperatures as well as other temperatures. This tool may be viewed as a “representative” of a family of tools from different vendors. Similar tools from two other vendors are described in some detail but not demonstrated.

Purkay Labs Audit-Buddy is a portable tool for monitoring temperature (and humidity) in data centers. One unique and potentially problematic feature of this tool is its built-in temperature probe and fan-aided air sampling. The system includes “everything” except a computer. Manuals and software make data analysis uncomplicated, although it may require some learning and set-up time. The system was relatively easy to use in quickly gathering and downloading data. However, a number of shortcomings were noted that makes it more difficult, slower, and less accurate to use. Most significantly, self-heating of the internal temperature probe was observed, which resulted in compromised accuracy. There is a need to manage and control this self-heating. In addition, the system did not allow the preferred placement of the sampling site on the rack door, introducing another temperature inaccuracy. A potential additional downside to this tool is the cost, especially if multiple systems are desirable.

**Table 5: Summary of the two portable air management measurement tools**

Company	Product	Temperature Sensors	Wireless (Wi-Fi)	First Cost with Sensors (\$)	Install Cost (\$)	License Fee (\$)
Packet Power	RDP (E302/E306/E312)	3 (expandable)	Yes	500/700/800 <sup>1</sup>	Own Labor	50/year for EMX
Purkay Labs	Audit-Buddy	3 (expandable)	No (option)	3,200 <sup>2</sup>	Own Labor	No

1. Includes 1 year EMX monitoring subscription; no computer and Ethernet cable included.
2. No computer included. A wireless (Wi-Fi) version costs \$7,000.

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