Selecting Data Loggers

Fundamental questions to ask before buying a system

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Technology advances over the past 20 to 30 years have resulted in increasing applications of artificial intelligence in building systems; hence the term "smart buildings." These same technology advances have provided us with a mechanism to become smarter about buildings. The data logging and

Photo courtesy of AEC

Multi-input loggers interface with many types of sensing technology, once configured to match the inputs selected.

handling capabilities of modern electronics can provide us with a wealth of operating and diagnostic information in a small, integrated, cost-effective package to assist us in our learning process. The first step in using this technology to our advantage is selecting the specific data-logging technology that we will employ. This article focuses on how to go about selecting a data logger that meets the needs of your project and budget.

HARDWARE AND SOFTWARE

When selecting a data logger, you will be concerned with two general issues: hardware and software. From a hardware standpoint, you will be concerned with:

- Accuracy and repeatability.
- Package size and weight.
- Cost.
- Real time display capability.
- Time clock accuracy.
- Data format.
- Memory.
- Battery life.
- Speed or sampling rate.
- Starting modes (manually or automatically initiated).
- Input sensor compatibility.
- Ease of set-up and deployment.
- Ease of data retrieval and software compatibility.
- Ruggedness and robustness.

From a software standpoint, when selecting a data logger, you will be concerned with how the data set collected by your logger is formatted for analysis and use by other software packages. Most current technology loggers can provide the data they retrieve in some sort of delimited file (see "Delimited File" sidebar), making it nearly universally useable by other software. A related software feature is the ability to retrieve the data set from the logger while it remains active in the field. This will allow you to pull data from the equipment without having to remove it from the field and then redeploy it. Some equipment requires a computer to perform this operation, but other equipment can write data to flash memory, floppy disks, or other media without the intervention of a computer.

You might also be interested in what sort of supporting diagnostic software is available to assist you with analysis of the data you retrieve. Most manufacturers offer diagnostic software with whistles and bells that are designed to exploit the features of their particular equipment. Independent third parties also are starting to emerge with data-handling and diagnostic software packages that can work with data from multiple manufacturers, either by importing it in some sort of delimited format or by interfacing with the database-management routines in the logging equipment.

The sidebar "Resources for Sound Selection" describes two documents that offer guidance for the data-logger selection process.

Delimited Files

A delimited file is a file in which each of the data values is separated from each other by some sort of mark, such as a tab, comma, or space. Commas are one of the most common delimiters. The files that use commas as delimiters are termed CSV files for "comma-separated value." If a data logger was monitoring outdoor air temperature and humidity once a minute, and you asked it to export the data it had for the interval starting at midnight and ending at 12:05 a.m., the CSV file it generated might look like this:

```
DATE,TIME,TEMP,HUM
11-01-02,12:00AM,45.2,87
11-01-02,12:01AM,45.2,87
11-01-02,12:02AM,45.3,86
11-01-02,12:03AM,45.3,86
11-01-02,12:04AM,45.4,86
```

Commas separate each of the parameters, and a carriage return separates each time interval. When software capable of handling CSV files imports the data and sees a comma, it knows that the next number it reads is part of a new value that is not associated with the preceding string of numbers.

DATA POINTS

Regardless of the hardware and software package that you choose, an important aspect of any data-logging operation is the selection of the data points to be monitored. For commissioning and diagnostic purposes, the following points should be considered.

Outdoor Conditions. Logging the outdoor air temperature is nearly mandatory. This is because outdoor air temperature is a common denominator that can tie events together and provide a reference framework when you are analyzing a problem. Adding outdoor air humidity to the data set can provide additional dimensions beyond the two points logged by allowing outdoor psychrometric con-

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ditions such as enthalpy dew point to be calculated from the raw data using the ASHRAE psychrometric equations.

Key process parameters. Diagnostic analysis requires that process points other than those used to control the process be monitored. For instance, many HVAC systems can be controlled most of the time based on discharge air temperature. But if you are going to diagnose a problem with the process occurring within the unit, you will need data from before and after every heat and mass transfer element to paint a complete picture and verify that the discharge temperature control is working efficiently and not wasting energy by simultaneously heating and cooling. All may be required to truly understand if the discharge temperature control function is working at peak efficiency and not wasting energy by simultaneously heating or cooling the air stream.

Having more information may also allow you to assess other parameters indirectly. For instance, an outdoor air percentage may be implied based on conservation of mass and the outdoor air, return air, and mixed air temperatures. Bear in mind that it may not be necessary to trend all of the process data simultaneously although this can shorten the amount of time it will take to fully analyze the system. But, if you have limited data logging capacity, then you can usually break the data set down into logical subsets that match your logging capacity and provide the necessary information.

Key controlled variables. While inputs provide a great deal of the necessary diagnostic data required for the commissioning process, the outputs from the control system that impact the process can also provide valuable insight into what is going on. If an output can move something in the system or impact the flow through a heat-transfer element in the system, then it is bound to impact system performance. Being able to track the motivating input along with the system's response to it can speed the verification and diagnostic process.

CHOOSING AN INTERFACE

Interfacing this data with a data logger is really not that difficult, although the seemingly infinite variety of sensing technologies available can seem overwhelming when you first start looking into them. Fortunately, most manufacturers offer units with integral sensors that allow the user to simply pick a logger that will be dedicated to the intended measurement function. Of course, this approach sacrifices some flexibility when compared to approaches using loggers that can accept standard input signals generated by transducers designed to measure nearly any physical parameter imaginable. Most manufacturers can suggest a combination of logger and sensor technology that will meet the needs you present to them. But if you are curious and willing to spend a little time surfing the Web, you will find that there is a wealth of information available to you there, information that will aid you in making a more informed decision. Some good starting points include:

- The DDC system input/output technology tutorial on the Iowa Energy Center's DDC Online Website (*www.ddc-online.org*) will provide you with a good understanding of sensing, input and output technology used with current technology control systems. This technology is identical to the sensing technology required to interface data loggers with the physical world.
- Watch PECI's Website (*www.peci.org*) for notice of the public release of the "Control System Design Guide and Functional Testing Guide for Air Handling Systems: From the Fundamentals to the Field." This guide, funded by the California Energy Commission through a Public Interest Energy Research (PIER) grant, Lawrence Berkeley National Laboratory, and the U.S. Department of Energy, is in the final stages of development. The report will be released next year and will contain a chapter that takes a detailed look at various sensing and actuating technologies.

OTHER SELECTION OPTIONS

Palm Pilots. Personal organizers such as the Palm Pilot, are quickly making their way into the data handling field. Some manufacturers offer software that allows the data from the logger to be downloaded for viewing. Others offer software and hardware packages that actually allow the organizer to handle the data logging functions.

DDC system. If you are specifying a DDC system for your project, then, whether you know it or not, you are also specifying and selecting a data logger. Current technology DDC systems offer one of the most powerful but under-utilized data logging opportunities available. However, to be effective for trending and data logging, the system needs to be properly configured and programmed.

Using the control system to do your trending and data logging has numerous advantages, including:

Personal organizers can be data processors and data loggers. (Photo courtesy of the Verteq)

- You get more bang for your buck; instead of spending money to rent, deploy and then retrieve data loggers. This money is better spent to supplement the infrastructure of the control system to provide the desired data logging capacity for the system.
- A control system configured to perform data logging and trending will be a more robust system and generally exhibit superior, overall performance for day-to-day control functions.
- The trends that are set up in the system for startup and troubleshooting purposes can remain in the system as useful tools for the operators.
- Archiving the trend data can provide useful troubleshooting information be-

cause when a system starts acting funny in real time, you can go back and compare what it is doing now to what it was doing the last time the same operating conditions and triggers existed.

Most of the issues associated with successfully using the DDC system as a data logger come back to design requirements that should be addressed in the project's construction documents.

Small dedicated-purpose, self-contained loggers minimize the time required to set-up and deploy them.

NETWORK ARCHITECTURE

The network architecture employed for your DDC system is an important factor related to its performance as a control system, but it is an absolutely critical factor in the context of using the system for trending and data logging. Current technology controllers perform many of their functions in a stand-alone mode, thus poor network architecture will not have a direct impact on their control processes. But poor network architecture can make the large volumes of data that must be handled to retrieve and archive trend files very cumbersome and slow to accomplish.

Fortunately, you don't need to be an IT wizard to develop a control specification that will also give you good data logging capability with your DDC system. Most of the major control companies have the ability to do a reasonable job of trending and understand the details and nuances of their equipment and what it takes to make their system perform in this manner. What they need from you is the necessary criteria in your construction documents to allow them to provide the capabilities you need in a competitive bidding environment. Addressing the following issues in your specification will go a long way toward providing a useable data handling system in addition to a better control system:

• Configure the system to minimize low-level bus traffic due to trending operations: Most control systems have several levels of communication busses with the higher level busses being cable of much higher data handling speeds than the lower level busses. By employing some of the specification techniques outlined in the May 2001 "Control Freaks" column titled "All Controllers Are Not Created Equal; Knowledge of the Differences is Key to Specification," you can ensure that the system you spec will meet your needs for data logging as well as control. The Iowa Energy Center DDC Online Website (*www.ddc-online.org*) is another valuable resource in this area.

Other networks have controllers at both levels. This probably gives them an advantage in terms of data handling capability, but puts them at a cost disadvantage. In the context of the overall project budget, the cost differences are probably not that significant, but, if you are a control contractor trying to competitively bid a project, they can be the difference between winning and losing.

• *Consider specifying your trending requirements for each data point.* This can be accomplished by general statements to a specific trending requirement for each point that is called out as part of the point list. In either case, the goal is to define the frequency and number of points that must be simultaneously trended without noticeably impacting the usability and performance of the control system.

CONTROLLER MEMORY

The amount of controller memory can also have an impact on the system's ability to trend. "Too much" and "memory" are mutually exclusive terms, because you can't go wrong in specifying that the controllers installed on your project be provided with the maximum amount of memory available. Memory that is unused for programming purposes is available for trending. Having a large amount of memory available for trending minimizes the number of data transfers that need to occur to move the information from memory to permanent storage on the system's hard disk. This reduces network traffic and helps keep the system response time at low levels.

DATA RETRIEVAL AND ARCHIVING

No matter how much memory you put in your controllers, eventually it will fill up. If you are trending 16 data streams once per minute, you will generate 960 bits of information to store every hour. At that rate, it won't take long to fill up whatever memory is available at the controller level. Most controllers allow you to determine what happens next. The choices are usually suspending trending or over-writing the oldest data with newer data. Either way, you will loose data, which is undesirable in most instances. To circumvent this problem, the system needs to be programmed to periodically download the stored data from the controller's memory to permanent storage (usually a hard-drive in the operators work station), thus making room for fresh data. Most systems can deal with this issue, although for some it is a custom programming problem while others have canned routines that can deal with the problem.

From a cost standpoint, having hard drives with capacities measured in tens of gigabytes and read/write CDs, all available for a cost of $200 or less, the need to consider the cost of data storage is minimized. This is another area where you simply need to specify what is needed to level the playing field and allow the contractors bidding your project to include any costs in a competitive environment. The areas that will most likely be impacted by this are:

• The hardware supplied at the operators work station to permanently archive the data.

• The software supplied at the operator's work station for the control system "front end." For some systems, the economy version of their operator interface software will have a hard time supporting trending, whereas the more sophisticated versions will handle the problem as a matter of course.

• Field time to set up the necessary trends and archiving routines and verify that they work.

TIME SERIES VS. COV TRENDING

One technique that can be used to maximize the use of available memory is to allow some of the data points you are trending to only log data when there is a change of value (COV) rather than having every point write to memory once per interval. The COV limits that you set for a point can also impact the amount of memory used by controlling how often a point with a COV based record trigger writes to memory. For instance if a temperature point is set to trend based on COV with a COV limit of 5 F, then it will only write a value to memory if the temperature changes by 5 F from the previous reading. If all other things are equal a point with a 5-F COV limit will write to memory much less often than a point with a 0.5-F COV limit.

However, this is a double-edged sword. Keeping the COV limit on the high side will preserve memory and minimize traffic on your network. But, if set too high, this may mask some serious performance issues. For instance, if you specified a 5-F COV limit for a discharge air temperature sensor, you may not realize that the control loop is hunting 4.5 F under some operating conditions based on the data from the system. Thus, a problem that could be wasting energy and rapidly wearing out components would be undetected.

On the other hand, specifying a limit that is too small can create communication problems on the system by trying to log to memory even the slightest variation detected, be it real or false. For instance, if you set the COV limit for your discharge-air temperature point to 0.001-F, the system would attempt to log changes that were most likely attributable to noise rather than real process changes. In extreme cases, this can crash the system, especially if the system is an older system.

Resources for Sound Selection

In 1999, the Portland Energy Conservation Inc. (PECI) published a document entitled "Portable Data Loggers—Diagnostic Tools for Energy Efficient Building Operation" under a grant funded by the EPA and DOE. This document is available for free as a download by logging onto the PECI Website at *www.peci.org*.

The document addresses many of the important issues to consider when selecting a portable data logger, including an evaluation checklist and case studies, and is an excellent reference if you are considering purchasing such a device.

In May 2001, researchers at Lawrence Berkeley National Laboratories published "Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems." The effort was funded by the California Energy Commission's Public Interest Energy Research program and the U.S. Department of Energy and takes a detailed look at many of the commercial and publicly available diagnostic tools that are emerging or currently available for use. While many of the tools that are reviewed function by interfacing with the database that exists inside commercial DDC control systems, some of them can also work with imported data sets which can be generated by portable data loggers. Examples include:

• *Enforma.* A commercially available software package developed by a data logger manufacturer.

• *Universal Translator.* A publicly available software package developed by the Pacific Gas and Electric Pacific Energy Center that is currently coming out of Beta testing.

• *UC Berkeley Fan Tools.* A publicly available software package that was developed by researchers at the UC Berkeley Center for Environmental Design Research.

This document is also available on the PECI Website and is an excellent resource determining how to process the data of a particular type or model of data logger.

Based on experience, the following general rules will provide satisfactory results and minimize problems:

• Trend analog values based on time rather than COV. Initially, you will want to set the sample time at a very low value, perhaps a minute or so to avoid being fooled by "aliasing." Once you are through the commissioning process and have gained some knowledge about the system, you may want to consider expanding the time frame to maximize the use of memory and minimize network traffic. If you take this step, as an operator, you may still want to reduce the sample time to a minimum on occasion, just to be sure that things really are stable. HVAC systems must operate under a wide range of conditions, and it is not uncommon for a system that was stable during the summer months to become totally unstable during the swing season or winter months or vice versa.

• Trend digital values based on COV. By their nature, digital parameters can only have one of two possible values. Trending based on COV will capture any change and minimize the amount of memory that is used. When using this approach, check to be sure that the trend reports generated by the system will print COV data mixed in with time series data. Otherwise, you may find it difficult to load analog and digital data into a diagnostic software package or spreadsheet for simultaneous analysis with analog data. Being able to do this is quite helpful when diagnosing operational problems. Most systems place a time stamp with the COV information when they log it.

• Trend manually adjusted set points based on COV and automatically adjusted set points based on time.

Installation of Data Loggers

"Aliasing" and other pre-installation considerations

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In the first article in this series, "Selection of Data Loggers," we reviewed what kinds of data loggers are available. In this article, we will describe some of the application considerations associated with installing data loggers on your project.

HISTORY

Data loggers have been around for quite some time in the process and scientific communities, perhaps for 25 or 30 years. However it was not until the past 5 to 10 years that the package size and cost dropped to the point where they became viable tools for the commissioning agent's and HVAC system technician's toolbox.

Evidence suggests that some sort of data logging technology has been employed to allow us to document, analyze, and improve the performance of our technology since man developed his first simple machines. Prior to the advent of electronics, the techniques employed tended to be simple, innovative, and effective, but lacked the data-handling capability and accuracy that are available to us today. Examples of some of the older data-logging technologies include:

Operators with clipboards. This method is still used in some plants to ensure that key operating parameters are observed, documented and responded to by the staff charged with keeping things in line.

Alarm clocks across starters. Wiring an electric alarm clock across the coil in a 120-vac starter control circuit was a simple but effective means to gain insight into the number of hours unattended machines operated over the course of a shift.

Low amperage fuses across contacts. Low amperage fuses wired across interlocking contacts provided a method of detection if a contact changed state when nobody was watching. The current flowing through the fuse after the contact opened in an effort to keep the load engaged quickly blew the fuse, leaving a tell-tale indication for a troubleshooter.

Chart recorders. Circular chart and strip chart recorders provided a way for operating personnel to document various operating parameters over time. The format is so widely accepted and easily understood that several manufacturers offer electronic recorders with displays that emulate a strip chart or circular chart.

All of these approaches are still useful in certain situations. However, modern data-logging technology can provide speed, accuracy, and data-handling capabilities that technicians, engineers and operating personnel could only dream of 20 or 30 years ago.

No matter what process you are installing your data loggers on, you need to be aware of aliasing and adjust your sample time accordingly. Aliasing is a phenomenon that results in the data set you collect not matching what really is going on. It occurs when the interval at which you sample data from a process is slower than a disturbance that is occurring in a process.

APPLICATIONS

Data loggers can be some of the most useful tools in an HVAC technician's tool set. They can make a world of difference in the ability to troubleshoot and optimize older systems with stand-alone pneumatic, electric or electronic controls and no form of large scale monitoring. In this sort of application they can:

• *Provide enhanced troubleshooting capability.* One of the more difficult aspects of troubleshooting HVAC problems is their intermittent nature. Most problems are difficult to pinpoint and solve without directly observing the event, especially if they leave few permanent clues. By their very nature, HVAC systems operate under varied operating conditions that can trigger relatively complex interactions between various components and other systems. Without data logging capabilities, a troubleshooting technician responding to a complaint related to an intermittent problem must attempt to simulate the conditions believed to have triggered the problem to be able to observe and diagnose it or "camp out" with the system until the event recurs. In either case, when the event occurs, the technician must be ready to observe and document multiple system parameters rapidly.

Strategically deployed data loggers allow unattended documentation of multiple data streams as the system they serve detects and responds to various operating situations. This data can be retrieved and

No-risk trial before you buy

Imagine a future where you can go to a library and check out data-logging equipment for free. In at least one place, the future is now. The Pacific Gas and Electric Co has created such a library, making a wide array of high quality, sophisticated instrumentation available to anyone in their service territory. To find out more go to www.pge.com/003_save_energy/003c_edu_train/pec/003c1_pac_energy.shtml. If nothing else, looking through the on-line card catalog of tools will help you learn more about what is available in current data-logging technology.

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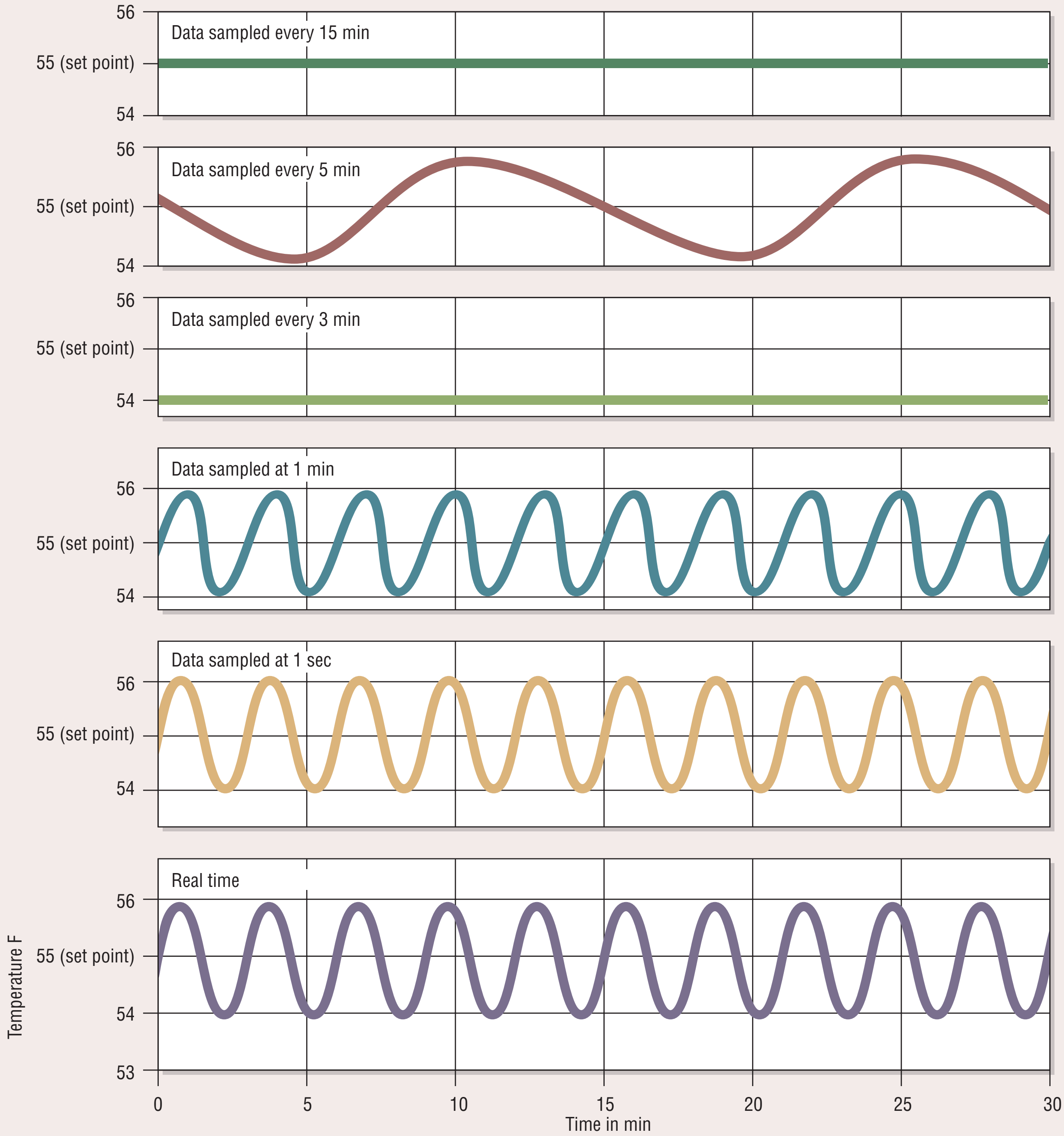

FIGURE 1. An illustration, using a manufactured data set, of the impact of sampling time on observed data vs what is really going on. When data is sampled every 15 min, everything looks fine. At every 5 min, a distorted wave form appears. Data sampled at every 3 min appears to be stable, but off-set from set point by about 1 F. The data sampled every minute appears to have a slightly lower peak and lower frequency than real time (bottom graph). The sampling rate of once per second reflects the real time data fairly accurately. The real time control system response shows a 2 F sinasoidal oscillation with a 3-min cycle time.

analyzed by the technician subsequent to the triggering event and without the pressures and potential errors associated with trying to observe and analyze multiple data streams as they occur in real time.

• *Support loop tuning.* Data loggers that can monitor, log, and display 2 or 3 points in real time can be very useful loop-tuning tools, especially if they incorporate a display feature that allows their data to be displayed graphically in real time. Not only do they allow the controlled variable, process variable, and set point to be displayed and analyzed simultaneously in real time as the loop is tuned, they also document the loop-tuning process, including the results of open loop tests.

• *Spot check equipment operating parameters for engineering studies.* Frequently, the first step in a retrocommissioning process or some other sort of engineering study involves a brief survey of the building or system targeted for the work to evaluate if additional effort is, in fact, warranted. Frequently, this effort involves several hours to a day spent in the field conducting a survey of the building systems and equipment. Deploying mini loggers to monitor the operation of lights, computers, motors, and other equipment coincidentally with the manual effort can provide a wealth of additional information to help firm up the assessment's recommendations for very little effort on the part of the assessor.

DDC APPLICATIONS

For current-technology computer based direct-digital-control (DDC) systems, data loggers can provide a useful supplement to the monitoring capabilities provided by the control systems input and output points. In addition to the functions listed previously, loggers deployed in this type of application can:

• *Provide data for troubleshooting processes not fully monitored by the DDC system.* It is not uncommon for DDC systems to be furnished with only the points necessary to control the HVAC process with which they are associated. Frequently, the points required to control a process may not provide sufficient information for diagnostic and/or functional testing purposes. Data loggers can fill this void by providing additional temporary monitoring capacity during troubleshooting and testing.

• *Provide a faster data logging time frame than is available from the DDC system.* Even the best current technology commercial DDC system tends to be limited to a data sampling frequency of once per minute or more. If you are dealing with a fast process or a fast disturbance, aliasing can distort data or even mask problems at this sampling speed. Figure 1 is a manufactured data set that illustrates some of the effects of aliasing. Notice that the wave form produced by 1-min samples is distorted from real time to some extent. While this distortion does not hide the problem, it can change your interpretation of it in some cases. Thus, it is always good to remember that reality may not be totally reflected in your data sets. Taking a walk out to the machinery and verifying the electronic information using your built-in data logging equipment (your eyes, ears, and experience) is often a good final step prior to taking action based on logged data. It is also a good excuse to go "play" in the field. You will just about always learn something useful to improve your engineering while you are there.

Commissioning Data Loggers

Caulk, duct-tape, flashlights, and other essential tools

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In the past three articles in this series, we have reviewed how to select data loggers and data-logging technology and apply it to your HVAC systems. One of the biggest benefits of this technology is as a commissioning tool. But, since the data loggers are also machines, there are a few commissioning steps associated with getting them up and running reliably and making use of their data.

DEPLOYING THE EQUIPMENT

After going to all the effort to obtain data-logging equipment and set up a data-logging plan, you are probably just itching to get the equipment out in the field to gather information for you so it can start paying for itself. Taking a few minutes to pay attention to a few key points as you place the equipment in the field will be well worth your while and can make the difference between success on the first try and a meaningless or empty data set.

CHECKING POWER SUPPLIES

Most portable data loggers use batteries for power when they are deployed in the field. For this reason, it is a good idea to get in the habit of checking and charging the batteries in your loggers a day or two prior to the time you are actually going to deploy them. In many cases, the charge cycles are several hours to nearly a day, so discovering that your batteries are dead after you have flown to Poughkeepsie for the day to deploy data loggers can create some problems, especially if your loggers have built-in batteries. Loggers with replaceable batteries may give you an out in such a situation, so carrying a few spares is always a good idea.

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SOFTWARE AND CONFIGURATIONS

It is also a good idea to verify the software that you will be using to configure the data loggers and retrieve information from them prior to heading out into the field. There could be some subtlety about that new laptop you just purchased that renders useless the interface software you have been using for years. Discovering this in the field on the only day you will be on site to deploy the loggers can be a big problem. If you configure the loggers in your office a day or so before you will be heading out with them, you provide yourself with some "wiggle room" if you run into problems. This can be an especially important consideration the first time you work with a logger, computer, or software that is new to you.

SENSOR INSTALLATION

Before heading out to the field, it is a good idea to think about where you will be installing sensing elements and if those locations will require that you bring along any special supplies. Things that you may want to carry with you as standard items might include:

- Duct tape can come in quite handy for securing sensors, cables and even data loggers in temporary locations. It can also be used to patch insulation if you have to cut into it to pick up a reading.
- Hole plugs are useful for sealing openings in ductwork after you have removed your sensor and will win you points with owners and operators who are looking for signs of your professionalism and/or are concerned with the integrity of the systems. Sometimes, little things make big, long lasting impressions as can be seen from the story in the sidebar, "On Being Prepared." Plugs come in a variety of shapes and sizes for different applications and are available from a variety of sources.

For high-pressure applications, you may want "official" test ports from a sheet-metal supply house.

For less-demanding, low-pressure applications, rubber stoppers or plastic-tube plugs from a science supply house will suffice. Don't forget to bring a portable drill.

- Silicon caulk is also useful for sealing and vapor proofing holes you may have to create in insulation to install your probe, as well as repairing the holes after the probe is removed.
- Quick-ties or tie-wraps are another handy item to have in your tool bag for securing things temporarily. If you need a long one, just string several shorter ones together.
- Heat-transfer grease can come in handy to improve the thermal response of wall-mounted sensors and improve the approach of surface-mounted sensors. It can be a little messy to work with, so you may also want to carry a few rags with

On Being Prepared

A problem came up on one of my long-term projects and I was unable to get to it immediately due to other commitments. So, Phil, one of my mentors, who was also familiar with the project and happened to be in the area for a meeting on another project, stopped by the site to take a look . One of the mechanics whom I had worked with for years walked him out to the problem area and, as Phil climbed up the ladder to take a look above the ceiling, he asked if he could borrow a flashlight. As the mechanic handed him flashlight, his only comment was "Dave always brought his own flashlight". Phil's expertise and quick solution to the problem rapidly gained the respect of the operating staff, but for that one moment, the fact that I had shown up with the right tool when I was on site to troubleshoot made more of an impression than Phil showing up with 10 times the knowledge and experience that I had at the time.

you to wipe your hands subsequent to the installation.

• DC-voltage data loggers set up for some of the more common input voltages, such as 2 to 10 VDC or 1 to 5 VDC can provide a convenient way to piggyback onto the signals coming into an existing DDC system.

This can be particularly helpful if you run into a signal you need to monitor but don't have the appropriate sensing element for.

Remember that most current loops can be easily converted to voltage by simply running the signal through a precision resistor. So, carrying a few 250 and 500 Ω precision resistors can be quite handy. One caution when using this approach is that it's a good idea to run the connection you plan to make past someone familiar with the wiring practices for the system you are working with to be sure that you don't cause problems with their I/O boards. (To learn more about how a current loop works, there is a good application note from Scan Data at *www.scan-data.com/app-1115.pdf.*)

Once you are out in the field and ready to install your sensors, there are several things to keep in mind:

• Many of the ducts and pipes that you will need to monitor will be insulated, requiring you somehow penetrate the insulation to get a good reading. From a safety standpoint, if the insulation is asbestos, you should not disturb it. At this point in most facilities, people know where they have asbestos, but if there is any question in your mind, then it is best not to disturb it until you have assurances that it is not dangerous to your health.

Sometimes, you cannot make a hole in a duct or there is not a well in the pipe where you need to measure. All hope is not lost, however. If you insert the sensor under the insulation so it is in intimate contact with the surface of the pipe or duct, the reading you obtain will be very close to the actual line temperature, especially if you take a minute to clean the pipe and place the sensor in a dab of heat transfer grease. (Minco's Application Aid 16 on sensing fluid temperatures with thermal ribbons contains some interesting and useful information regarding surface-temperature measurement. Visit *www.minco.com/pdf/aa16.pdf.*)

When using this approach, it is important that you cover the sensor with insulation so that the impacts of the ambient temperatures are minimized. If the line is cold and could condense moisture out of the local environment, then vapor sealing your penetration with silicon caulk is important to keep the insulation from becoming water logged, which will ruin it and also ruin your measurement since the water will interfere with the surface-to-surface contact between your probe and the line.

Remember, too, that intimate contact with the line is important for the temperature probe, but can be a disaster for the cable attached to it. Lines with steam, hot water, or hot air can quickly melt the insulation on the cable if it is lying against them, ruining your probe assembly and data set.

• Even though a sensor installation is temporary, it is important that it not be too temporary. For instance, the sensor that you dangled through a hole in the duct at the fan inlet could get tangled up in the fan drive system. Generally, this is not good for the sensor, the data logger, the drive, or your ego (not that anything like that has ever happened to me).

• It is also important to make sure that you position your sensors so they pick up the data you want in a meaningful manner. For example, if you are installing a temperature sensor near a tee, mixing valve or mixing damper in a pipe or duct, you may want to double check that you have selected the appropriate branch, especially if the tee is mixing two different fluid streams. On electrical gear, it is important to be sure that the signal at the point you are monitoring is compatible with your sensor and will give you a meaningful data stream. For instance, installing a CT on the conductors leaving a variable-speed drive may not provide useful data because at that point, the voltage, current, and frequency have been manipulated by the drive to control the motor speed, and most CTs are intended for use with 60 cycle alternating current.

CHECKING RELATIVE CALIBRATION

If the parameters you will be measuring will be subtracted from each other to document the performance of a heat-transfer element or a prime mover (temperature difference, pressure difference, etc.), then it is a good idea to place all of the probes together and log 10 or 15 min of data with them all referenced to the same value. This will give you a good idea of the relative accuracy of the sensors to each other. If there are differences (there probably will be), you will have documented them and can use a formula in your analysis spreadsheet to make any appropriate corrections. If you retain this data as a part of your data set, you will always have the correction factors available to you. If absolute accuracy is important, you may also want to note the sensor readings relative to a calibration standard that is subjected to the same condition as the sensors during relative calibration.

CONCLUSION: TURN ON THE DATA LOGGER

This may seem obvious, but you would be amazed by how easy it is to forget to turn on a data logger. With some loggers, you simply have to trust that they are running—there are no real indicators. But many of them have some sort of indication, ranging from a flashing light to an actual display of the most recent data string. Taking a few minutes to make sure that there is really something there can save you weeks of time and ensure that you capture an important, non-reoccurring event.

For previous Equipment Notebook articles, visit www.hpac.com.

Datalogger Operation Tips

Working with data: trend analysis and spreadsheeting

By DAVID A. SELLERS, PE
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The data provided to you by your data-logging equipment can provide a wealth of insight into what is really going on in your HVAC systems. It is not uncommon for trend data to reveal myriad problems in situations where the more traditional indicators (occupant comfort, sound, etc.) would indicate everything is fine.

While the software packages discussed in the first two parts of this series can help you analyze your data to reveal a lot of useful information about what is going on with your systems, modern spreadsheets can provide you with quite a bit of insight for little or no first cost since you probably already have them installed on your computer.

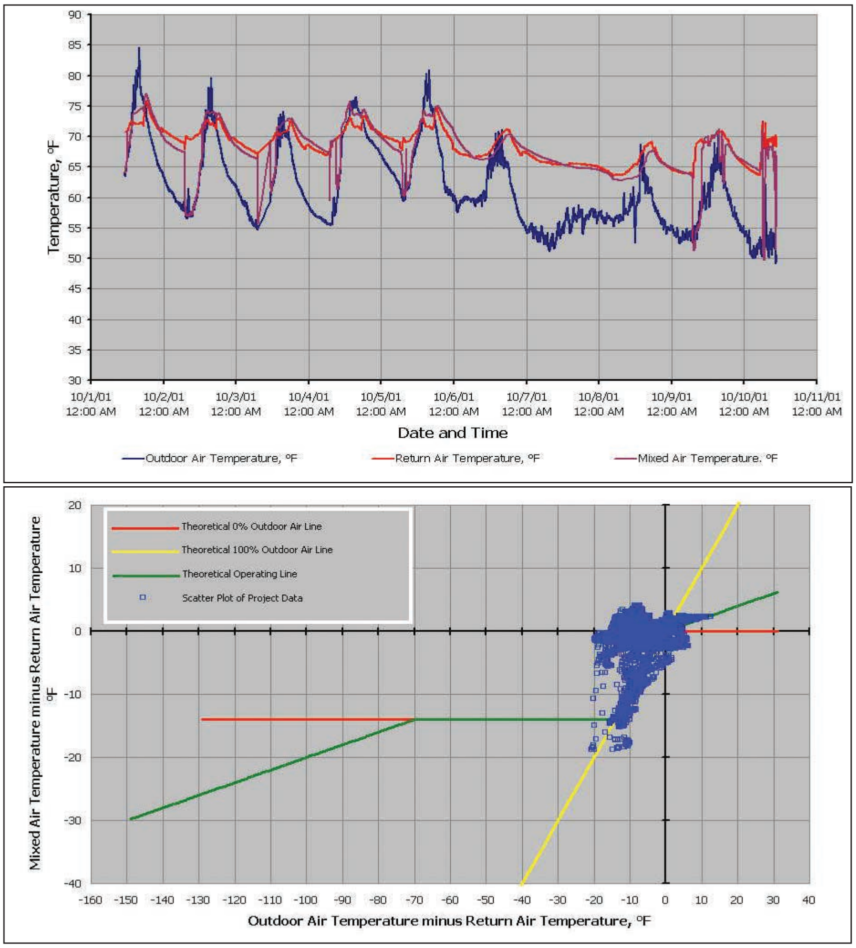
PRESENTATION IS IMPORTANT

The primary analysis technique when using spreadsheets is to look at the data in a graphical format. There are a variety of formats for this. For example, you could look at a data set as time series data or as a scatter plot contrasting different parameters. Often, it is best to look at the same data set in different presentation formats because the different formats will tell you different things.

The plots in Figures 1a & b are different views of the same data set. Both were generated from data loaded into a spreadsheet. The one on the top is a more conventional time series plot of an air handling system's outdoor air, return air and mixed air temperature. This type of presentation is good for investigating:

• *Instability*. Hunting control loops quickly show up as very "squiggly" lines. Stable loops show up as straight or gradually changing lines with a narrow span between peak and valley. The data in figure 1 indicate a reasonably stable system but also reveal that the outdoor air sensor may be influenced slightly by something since it is unlikely that the outdoor air temperature actually varied by 3 or 4 F in a matter of minutes as the "squiggly" line seems to indicate.

• *Inter-relationships*. Plotting data streams simultaneously in this format will allow you to understand which event triggered what. For example, assume that the system under analysis had an integrated economizer cycle. At the outdoor air temperatures that were occurring when the data set in Figure 1 was obtained, one would anticipate that when the economizer was active, the mixed air temperature would nearly match the outdoor air temperature because the outdoor air temperature was above the required discharge temperature for the system and the economizer would be driven to the 100 percent outdoor air position. If the economizer was disabled, the mixed air temperature would be slightly below the return air temperature because mixing the cooler minimum outdoor air quantity with the return air stream would lower the mixed temperature slightly. When the system was off, one would expect the mixed air temperature to nearly match the return air temperature as temperatures in the unit



FIGURES 1a (top) and 1b. Different views of an identical temperature data set from an air-handling system. While not immediately obvious, the manipulations associated with Figure 1b, which were developed by researchers at some of the National labs and a data-logger manufacturer, can quickly reveal a lot about how an economizer is working.

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equalized. When the economizer changed over, there would be a sudden shift in the mixed air temperature.

The data set indicates that there seems to be no particular correlation between the economizer change over and the outdoor air temperature, and in fact, it turned out that the operators were manually controlling this changeover rather than allowing the automation system to handle it. The data set also reveals that the relative calibration of the sensors is reasonably good because the mixed-air temperature sets on top of the outdoor-air temperature when the system is probably using 100 percent outdoor air and the return-air temperature and mixed-air temperature nearly match during what appear to be the off cycles.

• *Sequence of events.* Sudden changes in mixed-air temperature most likely indicate that the economizer was enabled or disabled or that the system shut down. In this particular instance, changes early and late in the day correlated with the scheduled operation of the unit and changes in between correlated with the operators making the decision to enable or disable the economizer function.

The scatter plot in Figure 1b allows for a quick assessment of the general performance of the economizer it represents, once you understand the data patterns. Specifically, the plot is of the difference between mixed-air temperature and return-air temperature vs. the difference between outdoor-air temperature and return-air temperature. The solid lines are theoretical operating lines that represent:

• The line generated by a system operating on 100-percent outdoor air (yellow).

• The line generated by a system operating with minimum outdoor air (red).

• The line generated by a perfect system with perfect sensors operating with the setpoints associated with the economizer under study; i.e. the economizer's theoretical operating line (green).

Points generated by the real data are then plotted against these reference lines. If the economizer was working perfectly, then the data pattern would tend to generate a cloud around the green line. Clouds that are not on the line will have characteristic shapes and locations relative to the axes that will tell you something. For instance, the cloud that is forming along the negative part of the X axis is generated by the temperatures created in the system when it is off with the hot water valve only opening as necessary to prevent the mixed air plenum temperature from dropping below 40 F (as desired by the required control sequence). If the hot-water valve were kicked wide open any time the system was off, as is the case for some systems, then you would still get a cloud along the X axis, but it would shift to the left with the magnitude of the shift controlled by the temperature generated in the mixed air plenum in that mode. A system that operates 24 hr per day would not exhibit this cloud. Thus, a data set from a system that was supposed to be scheduled but didn't reveal this cloud, might cause you to question if the scheduled operation were really occurring.

Note that to generate a cloud that covered the entire green line, you would need a data set that covered the entire operating season. The data set associated with this particular plot is 10 days worth of 1-min data. Note also that for data plotted in this format, the sampling interval is not nearly as critical as it is for the other format. The points on this plot will fall on the line if the measured conditions are what they should be at the instant measured, regardless of what was going on immediately before or after that instant.

"PRIMING" YOUR DATA-COLLECTION EQUIPMENT

No matter what software package is used, there are few things to be done up front to allow the retrieved data to be more easily digested for analysis, especially if an EMS is being used as the data logger. Some of this relates to specifying the correct performance parameters in the first place, as has been discussed in preceding articles in this series. But much of it also relates to telling the control technician specifically how you will be using the data to allow him or her to set up the trending package appropriately.

Most control systems offer a variety of options to define how trend data is reported out of the system. From the control system's standpoint, the trend data is just a bunch of numbers, probably hexadecimal numbers or ones and zeros, neither of which is very easy to interpret. But by setting up the trend reporting parameters properly, you can get the control system to provide this data in a meaningful format. For example, it is generally easier for spreadsheets and analysis programs to deal with data presented in vertical columns with a time stamp—basically a table of values with the point names across the top and the date and time down the left-hand side. This is in contrast to a single long string where all of the times and values for the first parameter are presented, followed by the second and then the third, etc. From a specification standpoint, what matters is that the contractor is informed that you want to be able to define how the data is presented along with some key features, such as the tabular format describe above. This will allow the contractor to build some time into the price to work with you to get the exact format you want when programming the system. At a minimum, you will probably want the system to be able to:

• Export data in a delimited format as discussed in the previous articles.

• Maximize the number of parameters presented in each report. In the tabular format, this would be analogous to maximizing the number of columns in the table.

• Maximize the number of samples presented in each report. For example, maximizing the number of rows in the table in a tabular format.

CONCLUSION

By setting specifications up properly and then coordinating with the control technician before they set up the trending you requested, you can ensure that the delimited data files that will be provided for analysis will be in a format that is the easiest to work with. This will minimize the amount of time you need to spend manipulating the data and maximize the amount of time you get to spend having fun.

Visualize BAS Data

A picture is worth at least a thousand words when working with BAS data

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Many new HVAC systems come with a powerful built-in data logger in the form of the DDC system, which may also be referred to as the Building Automation System (BAS) or the Energy Management and Control System (EMCS). When properly configured, these systems can provide an abundance of performance data. Many systems have software modules available that enable graphic analysis of the trended data. But even if you do not have the software module that enables this function under the umbrella of the control system software, virtually all current technology systems (and many older systems) will allow you to export the trend data in a delimited file format,[1] which can then be imported into a standard spreadsheet program for analysis.

In most instances, you will still need to manipulate the delimited data files to make them more readily analyzed in a spreadsheet program. After you do this for a while, you will discover that there are a few tricks you can use to make your work easier. This article describe a few that I have used in the course of my work. I have used all of the techniques described below with Excel (97 and later versions) and have used many of them with Lotus prior to working in Excel. Many of them will also work in the spreadsheet program contained in Microsoft Works, although some of the more powerful formatting functions will probably not be available. These techniques can also be used on delimited files exported from traditional data loggers. In fact, you can use a spreadsheet program to combine data obtained from data loggers, the EMS, and even the National Weather Service (see the sidebar "Supplementing HVAC Data with Weather Data") and other sources to further enhance your analysis.

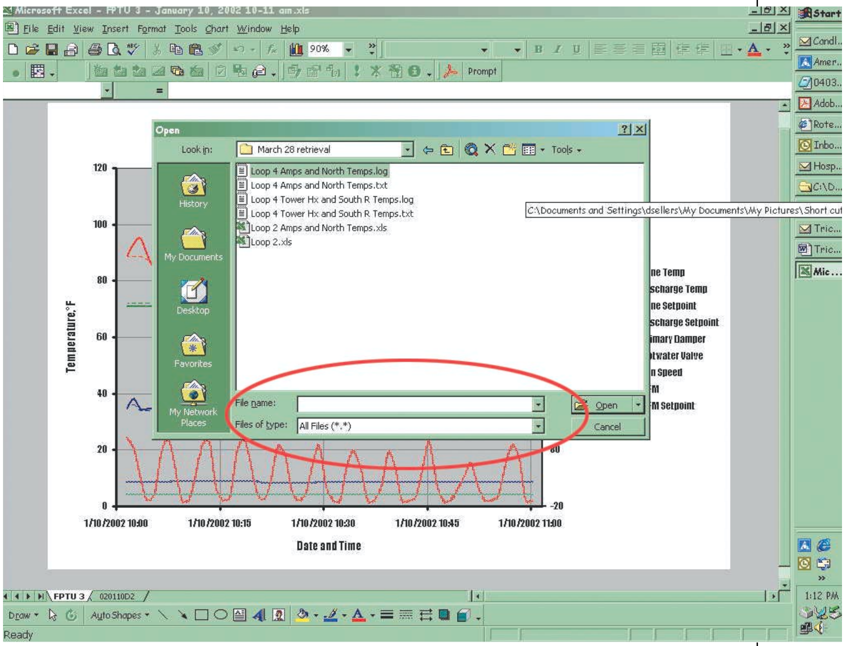

PHOTO 1. Don't forget to select "All Files (*.*)" when you go to open your CSV file for the first time.

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Column	B	C	D	E	F	G
Row	Month	Day	Year	Hour	Minute	Value
3	1	3	3	22	05	55.3
4	1	3	3	22	05	55.2
5	1	3	3	22	05	55.3
6	1	3	3	22	05	55.4

FIGURE 2. Illustration of a spread sheet with raw data set from a system that breaks the time and date down into separate values for each parameter Figure 3 illustrates this process for the data in Figure 2.

OPENING THE CSV FILE IN A SPREADSHEET PROGRAM

For many, it would seem that the first obstacle in this process is to get the comma -separated-value (CSV) file from the data logger or control system to open up in the spreadsheet. Five or six years ago, that could be a little tricky, requiring several steps including "parsing" data, a process that scanned the data file, found the commas or other delimiters, and created cells based on what it found. Recent versions of Excel will allow you to simply use the "Open" command on the "File" tab to select the file from your hard disc or a floppy.[2] The spreadsheet will then use a string of questions in a dialog box to allow you to control how the data is separated into cells; but, in my experience, if you simply accept the defaults offered by the software, you will create a usable spreadsheet file.

For me, the biggest trick during this step of the process is to remember to select the "All Files (*.*)" option when the "Open" dialog box appears (see Figure 1). Otherwise, you won't be able to see your file. Remember, when you start, it is raw data in the form of a CSV, and probably has a file extension like .CSV or .TXT. On most systems, the default file type selected by Excel in its "Open" dialog box is for Excel file types, i.e., files with extensions like .XLS, .XLT, etc. and thus, only files with those extensions will be displayed.

After you have opened the file, you will want to save it as a spreadsheet file so that you can take advantage of the formula and graphing features available in the spreadsheet format. In Excel, you accomplish this by simply selecting the "Save As" option on the "File" tab and entering the name of your choice.

SORTING DATA TO ELIMINATE THE THINGS YOU DON'T NEED

Once you have opened your CSV file and turned it into a spreadsheet file, you probably will need to go through a few quick steps to clean things up so that the graphing can be accomplished more readily. Usually, there will be things like header lines for every page and point definitions that, while useful when viewing the data as text, get in the way of plotting it. There will probably also be some holes in the data where the data collection hardware simply didn't capture a value.

The sorting features of spreadsheets provide a way to easily group and eliminate these sorts of things. For example, if you simply sort the spreadsheet based on the first column in ascending order, the sort will pull all of the header lines together at the top followed by the time series data in ascending order. Be careful to unhide everything and select all of the cells before you do this, otherwise you can get some strange results.[3] Similar techniques can be used to pull empty cells and rows together for elimination or rows that have things like "NO DATA" in them. If you are doing scatter plots, eliminating these data sets will not really impact the graph you get if you format the data series as lines. If you are using dots, you will have gaps in the patterns created by the scatter plot where you eliminated the data.

HANDING MISSING DATA

Many spread sheet programs allow you to control what the graphing function does with missing data under the general options setting. In Excel, this is under the "Tools" tab and the choices are to not plot the data, to plot it as zero, or to interpolate between values.

Excel will also allow you to add a trend line to a data set. This technique can also be used to create a solid line from a data set with holes or to project what might happen based on what you know. If you want to be really clever, you can format the data series color to match the chart background and it disappears (except for where it crosses grid lines or other data series) and the trend line remains as the visible indicator.

GETTING AT DATE/TIME COLUMN FROM RAW DATA

It is not unusual for the exported file to contain the date/time stamp as two separate values, date and time. Some systems break this down even further so that you end up with a column that represents each parameter (year, month, day, hour, and minute). Figure 2 is an example of the raw data from such a system. When you graph the data, it is usually best to have the date and time together in one column because many spreadsheet programs treat date and time as a serial number. The most common bases are January 1, 1900 or January 2, 1904. These dates are represented as one and are then incremented by 1 for each day there-after. In this system, 1 hour is 1/24, 1 minute is $1/(24 \times 60)$, etc. which is helpful to remember when you are trying to scale the time and date axis of a time series graph.[4]

In any case, if you initially have two columns, one for date and one for time, you can generate the desired date plus time column by simply inserting a column into the spread sheet and then using a formula in each cell of the new column to add the value of the date and time columns for that sample together. Data sets that break the date and time down into individual components, like those in Figure 2, require a little more effort to

Column	B	C	D	E	F	G	H	I	J	K	L
Row	Month	Day	Year	Hour	Minute	Month, day, and year combined	Hour and minute combined	Serial number that represents date	Serial number that represents time	Serial numbers added and formatted as a date and time	Value
3	1	3	3	22	05	1/3/03	22:05	37624.00	0.920139	1/3/03 10:05 pm	55.3
Formulas						=B4&"/"&C4&"/"&"0"&D4	=E4&":"&F4	=DATEVALUE(G4)	=TIMEVALUE(H4)	=I4+J4	
5	1	3	3	22	06	1/3/03	22:06	37624.00	0.90833	1/3/03 10:06 pm	55.2
6	1	3	3	22	07	1/3/03	22:07	37624.00	0.921528	1/3/03 10:07 pm	55.3
7	1	3	3	22	09	1/3/03	22:09	37624.00	0.922917	1/3/03 10:09 pm	55.4

FIGURE 3. Manipulating a rough data set to provide a serial number that represents date and time for graphing purposes. The columns highlighted in yellow were inserted into the original data set. Then, the formulas shown in the row highlighted in green were placed in the cells in these new columns to generate the data that fills them. Column K was then formatted as a date and time, which caused the spreadsheet to display the serial number obtained by adding columns I and J as a date and time. Columns K and L can now be used to plot a graph of temperature vs. date and time.

make the conversion from integers to a serial number that represents the date and time.

At first, placing formulas in all of the cells created by the inserted columns can seem like a formidable task, especially if there are thousands of data points. But remember, all you really have to do is create the formulas in the cells for one row. You can then copy and paste them to the remaining cells in a matter of seconds via a couple clicks of the mouse.

USING THE TRANSPOSE FUNCTION

Sometime DDC systems only print the point names at the top of the data set and the labels for the data columns are generic such as point 1, point 2, etc. While this is not the end of the world, it would be nice to be able to get the actual point names at the top of the columns so that they show up as labels in your graphs. The transpose function allows you to easily do this an is illustrated in Figure 4. @

The key things to remember when using this function is that it is an array function. So, to use it, you first highlight the cells you want to transpose the data into (it should be the same number of cells as the source of your data). Then you type in the transpose formula. However, rather than simply pressing enter after you are done, you need to press CTRL + SHIFT + ENTER. When you do this, the curly brackets will be added to your formula, it will be placed in all of the cells in the array you selected and the results will show up.

SCATTER PLOTS FOR TIME SERIES DATA

Scatter plots are a good way to plot time series data because they allow you to use different time parameters for the x axis, thus you can pull data from multiple files together into one graph. It also solves some problems associated with missing data or blank cells. You can still get lines instead of little dots or squares by playing with the formatting parameters associated with each data series. Lines are useful if you are trying to present things as a time series, i.e., this happened then this and then this. Individual dots or points are useful when you are trying to present the data in terms of number of occurrences of one condition when another condition was present. For example, plotting mixed-air temperature minus return air temperature against outdoor temperature minus return-air temperature to look for patterns (See Figure 1b in "Datalogger Operation Tips" [5]

USING THE "CHART WIZARD"

The chart wizard feature provided with Excel frequently will provide a quick way to take a first look at your data set. In most cases, if you can set up your data file with the time/date information in the left-most column and the point names in the top row, you can generate a graph by:

1) Highlighting the data set, (including the time/date column and point name rows).

2) Clicking on the Chart Wizard Icon (it's the one that looks like a little 3-D bar graph).

3) Selecting one of the scatter plot options.

4) Selecting the "Data in Columns" option on the data range tab.

5) Selecting "Finish"

What you should get is a basic graph containing all of the data you highlighted. You can now use this as a sort of base-line graph to develop all of the other graphs by copying it and then adding titles, deleting data series, changing the scale of the axes, etc. Once you have gone through the process a couple of times, you will find that you can go from data set to this base-line graph with a few simple key clicks.

Often, what you will see in the baseline graph can guide you on where you want to focus your attention. For instances, a set of wildly oscillating lines may tell you that you need to focus in on those parameters at that time frame to see if there is an unstable control loop. This can be accomplished by saving the graph to a new sheet and then eliminating the series that are not of interest, rescaling the time axis to only cover the range of time of interest and then "tweaking" the other chart options and parameters like the axis scale, colors, line weights, titles, etc. to

	A	B	C	D	E	F	G	H	I
	Before transposing								
1	**Key**	**Name: suffix**			**Trend definition used**				
2	Point 1:	B311.C01AP	Chiller 1 alarm		Trend COV (1.0000)				
3	Point 2:	B311.C01EE	Chiller 1 enable		Trend COV (1.0000)				
4	Point 3:	B311.C02AP	Chiller 2 alarm		Trend COV (1.0000)				
5	Point 4:	B311.C02EE	Chiller 2 enable		Trend COV (1.0000)				
6	Point 5:	B311.C03AP	Chiller 3 alarm		Trend COV (1.0000)				
7	Point 6:	B311.C03EE	Chiller 3 enable		Trend COV (1.0000)				
8	Time interval: 5 min.								
9	Date range: 08/29/2002 00:00:00 – 09/04/2002 23:59:59								
10	Report timings: all hours								
11	**Date**	**Time**	**Date and Time**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**
12	08/29/02	0:00:00	08/29/02 12:00 am	Off	Off	Off	On	Off	On
13	08/29/02	0:05:00	08/29/02 12:05 am	Off	Off	Off	On	Off	On
	After transposing								
1	**Key**	**Name: suffix**			**Trend definition used**				
2	Point 1:	B311.C01AP	Chiller 1 alarm		Trend COV (1.0000)				
3	Point 2:	B311.C01EE	Chiller 1 enable		Trend COV (1.0000)				
4	Point 3:	B311.C02AP	Chiller 2 alarm		Trend COV (1.0000)				
5	Point 4:	B311.C02EE	Chiller 2 enable		Trend COV (1.0000)				
6	Point 5:	B311.C03AP	Chiller 3 alarm		Trend COV (1.0000)				
7	Point 6:	B311.C03EE	Chiller 3 enable		Trend COV (1.0000)				
8	Time interval: 5 min.								
9	Date range: 08/29/2002 00:00:00 – 09/04/2002 23:59:59								
10	Report timings: all hours								
11	**Date**	**Time**	**Date and Time**	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**	**Point 6**
12				B311.C01AP	B311.C01EE	B311.C02AP	B311.C02EE	B311.C03AP	B311.C03EE
13				Chiller 1 alarm	Chiller 1 enable	Chiller 2 alarm	Chiller 2 enable	Chiller 3 alarm	Chiller 3 enable
	Formulas			{=TRANSPOSE(B2:B7)}	{=TRANSPOSE(B2:B7)}	{=TRANSPOSE(B2:B7)}	{=TRANSPOSE(B2:B7)}	{=TRANSPOSE(B2:B7)}	{=TRANSPOSE(B2:B7)}
	Formulas			{=TRANSPOSE(C2:C7)}	{=TRANSPOSE(C2:C7)}	{=TRANSPOSE(C2:C7)}	{=TRANSPOSE(C2:C7)}	{=TRANSPOSE(C2:C7)}	{=TRANSPOSE(C2:C7)}
14	08/29/02	0:00:00	08/29/02 12:00 am	Off	Off	Off	On	Off	On
15	08/29/02	0:05:00	08/29/02 12:05 am	Off	Off	Off	On	Off	On

FIGURE 4. Before transposing, the columns in the data set only contained the generic labels Point_1, Point_2, etc. (top illustration). The transpose function allowed the numbers and labels in the vertical column to be displayed horizontally in two rows inserted below the generic labels. (For reference the formulas used to do this are show in the two rows in blue)

help you understand what is going on and present the results. However, when you do this, bear in mind that the auto-scaling that occurs when you use the chart wizard in this manner may hide some interesting data. For example a duct pressure that is hunting 2 or 3 in. w.c. will probably look like a flat line when it is plotted on the same axis as with temperature and flow data that may be auto scaled in terms of hundreds, thousands or tens of thousands on the Y axis. Similar things can happen with regard to the time frame of reference when a month's worth of one minute data is compressed onto one graph.

FORMATTING

There are several formatting tricks that you can use to make your data more presentable and do it quickly.

- If you click on a chart and copy it, and then click on another chart and select "Paste Special" from the "Edit" drop down menu and then pick the "Formats" button, you will paste most of the formatting information from the first chart into the second chart: things like fonts, colors, scaling etc.
- Sometimes, it is helpful to use similar colors to graph related information. For

example, if you were graphing the mixed air temperature, preheat coil leaving air temperature and chilled water coil leaving air temperature on the same graph as the outputs that controlled them, you might want to consider dark red, green, and blue for the temperatures and light red, green, and blue for the related outputs controlling them. For many people, the similar colors will help them correlate an input with its related output and assimilate the information more readily.

• Excel will allow you to add a second axis to your plots. This can be handy when you are plotting things like process values along with the outputs controlling them or when concurrently plotting data sets that have very different orders of magnitude (e.g., plotting duct static pressure along with flow rate). For instance, if you were plotting temperatures from coils along with the pneumatic pressures that were controlling the valves associated with the coils, you might consider plotting the valve data on a second axis with a range of 0 to 20 rather than on the same axis as the temperature data, which may need a range more along the lines of 0 to 120 to show all of the data. Doing this allows you to better see the peaks and valleys in the data, which are often useful diagnostic indicators.

This approach can also be used to offset the data strings so you can view them concurrently but not on top of each other. To continue the coil temperature and valve output example, if all of the temperatures were in the 40 to 110 F range and the associated valve commands were all between 3 and 15 psig, scaling the temperature axis for 0 to 120 would put the temperature data higher on the graph. You could then scale the pressure data for 0 to 50 or 60. Since the pressure data never exceeds 15 or 20, it will all appear below the temperature data but will have the peaks and valleys amplified more than if they were simply plotted on the same axis as the temperature parameters. Figure 5 demonstrates this concept applied to display temperature differential independently and magnified relative to the temperatures.

• One of the frustrations you may experience with Excel involves what happens when you add circles, lines, and notes to a graph, then copy and paste it into a Word document. Sometimes when you do this, the scaling becomes corrupt and the lines, circles and notes do not end up in the correct place when the image is pasted into Word. There are a couple of ways that I have found to get around this. One is to add the lines, arrows, and notes to the image after you paste it into Word. Another is to create the lines with equations rather than by inserting a line. For example, if you want a horizontal dashed line through the graph at 55 F, then insert a column in your spreadsheet, copy and paste the value "55" into all of the cells, then select it as a series to be included in the graph. You can then format the series to give you the effects you want such as color, dots, dashes, etc. If you don't want it to show up in the legend, then you can click on the legend and then click on the symbol for the line and delete it.

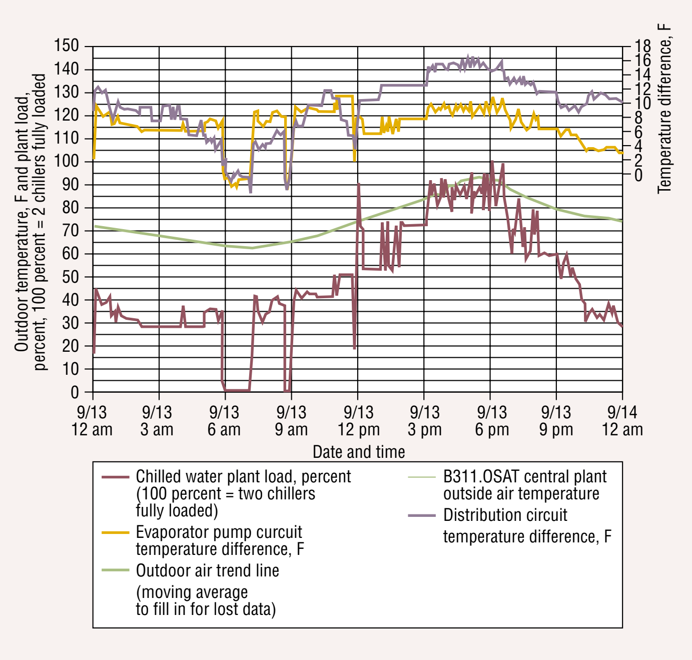

Figure 5 - Plant load profile generated from the distribution circuit temperature difference by assuming a constant flow through the chiller (determined from a pump test) and using the equation Load in btu/hr equals the flow in gpm times the difference between entering and leaving water temperature in degrees F. In this particular plot, the differential temperature data was also generated using math to allow us to understand the performance of the plant v.s. the load in that area.

CREATE USEFUL DATA FROM OTHER DATA

At first, this may sound like some of the alleged practices of unscrupulous testing and balancing contractors. And, while you could probably do something like that, its not what I am advocating. Rather, I am suggesting that if you have some good information in your data set, you can use it to perform calculations that will tell you more about the system. For example, if you know the entering and leaving water temperature from a chiller, and have some idea of the flow (which is often constant and easily determined by a simple pump test or the balance report data), then you can calculate tons for each sampling interval and use this information to generate a load profile, and perhaps even ton-hours if you have a lot of confidence in the accuracy of the data. If the relative calibration check you performed on your sensors before you deployed them shows that they all read the same, then you probably can have a high degree of confidence in the secondary data you generate[6] If there are apparent errors, then you may want to

Supplementing HVAC Data with Weather Data

Most control systems now have at least one outdoor air temperature sensor and including this information in the data set you pull for analyzing your HVAC process can provide a lot of insight into what is going on. But, in many cases, outdoor temperature only paints a part of the picture. Other parameters like relative humidity and dew point are necessary to fully understand what is really happening. If you have two psychrometric properties, you can use a psych chart to determine the others. Or for large data sets, you can use the equations presented in the ASHRAE handbook of fundamentals to calculate some of the other parameters. However, if you don't have or only know outdoor air temperature or if you question the validity of the outdoor air moisture content information you are getting from the system (or are math phobic) you may find yourself wishing for information that is unavailable to you.

Fortunately, all hope is not lost. If you have an Internet connection and are willing to hunt around a little bit on the National Weather Service web sites, you can obtain hourly weather data for any location with an automated weather station (virtually all airports of any significant size). Typically, the report will include the date and time, air temperature, relative humidity, dew point, barometric pressure, wind direction and speed, precipitation, and an assessment of the general conditions (fair, cloudy, etc.)

If you want to know what was going on for the past 4 or 5 days, then you can pick it up directly off of the web page; i.e. its for free. To retrieve the data, you just need to select it, copy it, and then paste it into a word processing document as text, save the document as a text file, and then import it into Excel as a delimited file. If you need older information, you can obtain it for a nominal fee from the regional climate center. The exact fee structure will vary from place to place, but for the Western Regional Climate Center that I use, it is; Service charge per request - $10, One month of hourly data (per location)- $12, One year of hourly data (per location) - $25. Turn around time ranges from a couple of hours to a day. Data is available back through 1992, but a format change in 1996 makes the data from that point in time forward much easier to use. You can get the data in a hard copy format via the mail or a FAX or they can e-mail it to you as an ASCII file which will import into Excel(r)

apply corrections or limit your manipulations to more generalized values like percent full load instead of tons. The shape of the curve you generate can still provide valuable insights into the process even if it does not provide absolute accuracy.

Similar techniques can be used to make the analysis of equipment sequencing easier. For instance, if you are trying to understand the sequencing of three parallel pumps, the raw data you get will typically contain only one of two values for each pump, On or Off, or perhaps 1 or 0. If you plot the three pumps on the same graph, all of the lines will rest on top of each other making things hard to decipher. But, if you insert a couple of columns and do some math, you can make the values for On and Off be 1 and (-1) for the first pump, 2 and (-2) for the second pump, 3 and (-3) for the third pump. Or, if you don't care so much about which pump is running, just how many, you can insert a column that sums the status values for the three pumps in question and generates a number between 0 and 3 as an indication of how many pumps are running.

CONCLUSION

The bottom line is that the processing power of modern spreadsheet software can open many doors to you in terms of enhancing your analysis capabilities once you have a delimited data set from your data logging equipment. So, if you find yourself faced with data that is not in the format you had hoped for or you are wishing you had one more piece of information, spend a little time looking at the possibilities available to you. (Clicking on the paste function button—the one that looks like a lower case f with an x subscript (f_x) on the standard Excel toolbar usually gives you a pretty complete list of the possibilities.) You may find that once you get going, the real problem is making yourself stop.

END NOTES

1) Sellers, D. (December, 2002). "Selecting Data Loggers"*HPAC Engineering*.

2) In most cases things will go faster if you put the files you will be working with into a folder on your hard disk.

3)It is a good idea to get in the habit of always saving before you do any major operation that could destroy your data set in the spreadsheet program That way, you can abandon the results and reopen the file without loosing anything. There are some operations that cannot be undone but the "Undo" function.

4) Visit the *Networked Controls* microsite at *www.hpac.com* to see a spreadsheet template that has the serial numbers associated with 1 minute, 5 minutes, etc. and each hour of the day calculated. It also has a spot where you can enter a date and time and it converts it to a serial number. Its a useful tool when you are scaling an axis and saves having to calculate it each time.

Also available on the *Networked Controls* microsite at *www.hpac.com* is an expanded version of this article which includes additional advice on what points should be trended and how often to sample them, as well as establishing a file naming protocol to avoid confusion.

5) Sellers, D. (February 2003). "Datalogger Operation Tips" *HPAC Engineering*.

6) Sellers, D.(March 2003). "Commissiong Data Loggers," *HPAC Engineering*.

For HPAC Engineering *feature articles dating back to January 1992, visit* www.hpac.com.