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Data Logging Through the Decades

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How we engage with a building and the data it produces has evolved quite a bit over my four-plus decades in the HVAC&R industry. Though some major differences exist related to advances in technology, I think the original data logging solution still has a place in our modern world.

Data Logging: A Building Dialogue

One of my definitions of commissioning is that it is a process during which buildings mentor us about our design and operating skills. Some of my most significant engineering and operations lessons came from the field via an interaction with a building system during a commissioning process. As a result, I learned something and, in many cases, was also able to improve the performance of the system.

But for that to happen, we need to have what I think of as a dialogue with the building. We ask questions by using forced and natural response testing techniques. The building answers our questions by providing data, often in the form of trends. Data loggers have a crucial role to play in this process.

The Original Data Logger

The original data logger was an operator with a clipboard who went around and read gauges and documented what they observed in a log. This is still a common practice in many facilities.

Constraints associated with this approach include sampling rate. The amount of data you can gather is limited to how quickly you can move from point to point and/or how quickly you can observe a condition, write it down and take another reading.

The accuracy of the data is subject to how the reading was taken and the accuracy of the instrument. For instance, if you do not look straight-on at a gauge, parallax can come into play, and you may misrepresent the indicated value, as illustrated in *Figure 1*.

Memory can also be an issue, in terms of remembering where you left off when you return from the diversion, and in terms of remembering what you observed if you did not write it down immediately.

Interestingly, the current technology approach to data logging can also have issues with sampling rate, accuracy and memory if it is not properly applied. And, the operator with a clipboard has a role to play in mitigating those problems.

The Electromechanical Data Logger

Early in my career, I was assigned the role of field technician for a project that involved renovating a built-up direct expansion refrigeration system that served a community ice rink in the winter and

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FIGURE 1 Parallax in action. Viewed straight-on, the gauge reads 40 psi (left). But, if you don't take the time to bend down and read it that way, you may think the reading is more along the lines of 41 to 42 psi (right).

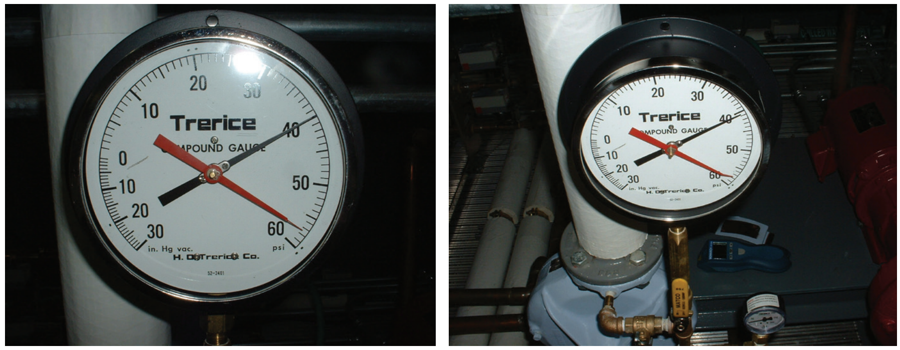


FIGURE 2 My electromechanical data loggers; single channel on the right and two channel plus on-off event on the left (left photo) and a close-up of the recording mechanism (right photo).

provided chilled water for cooling the community center during the summer. In addition to monitoring construction and starting up the systems, I returned four times a year for the first several years to perform ongoing commissioning. (Back then we called it keeping the system working properly.)

Because of the dynamics of the systems, we needed a way to track multiple events at once and create a record for our reports. Thus, I was introduced to my first electromechanical data logger. I still have a couple that still work (*Figure 2*).

These were a real blessing compared to the clipboard and pencil approach. You could capture an event even if you were not standing there when it happened. And, they provided a continuous record of events during a test or troubleshooting sequence. Models that sampled once every five seconds made loop tuning a bit easier compared to trying to document the rapidly changing process variable during your tuning effort.

Being electromechanical, they were not quite as rugged as my clipboard and pencil. If I dropped the latter, worst case, I might have to clip the paper back in and advance the lead in my mechanical pencil. If I dropped the former, I probably needed to recalibrate it or send it in for a service call.

But at the time they were a useful tool. And with the ability to record every five seconds, they were able to complement early direct digital control (DDC) systems' capabilities if you thought you were being aliased by trends that were based on sample times of one, five, or 10 minutes or more. (See the sidebar "Aliasing" for more.)

Modern Electronic Data Logger

By 1990, there were small, electronic, single-channel loggers that could be purchased for $100 or less, probably 20% to 30% the cost of one of the electromechanical loggers. This took the industry to a whole new level with a huge array of options for logging any parameter you

Aliasing

Harry Nyquist, an electronics engineer specializing in feedback control and stability, demonstrated that if you want to paint an accurate picture of a process, you need to sample it at least twice as quickly as the fastest disturbance that is going on in it. Consider a condensate pump where you are sampling motor current once every 15 minutes to prove the pump is running.

If the pump cycles on for one minute out of every four minutes at peak load, then to truly capture the operating cycle, you would need to sample the process once every 30 seconds (twice during the shortest disturbance time of one minute).

Fifteen minute samples would not reflect what was going on at all; the pump could have cycled multiple times between samples or shut down right after the first sample and started right before the next, creating the illusion that the pump had run for 15 minutes.

For more on aliasing, visit https://tinyurl.com/y99dmp3f ("Aliasing and Other Factors Affecting the Accuracy of Field Data").

can imagine. *Table 1* describes some of the features and options of these data loggers shown in *Figure 3*.

I want to highlight that current technology loggers can measure industry-standard signals such as 4-20 mA and 1-5 Vdc in addition to using the internal and external sensors in each vendor's product line (*Figure 4*). This opens the door to logging just about anything; if there's a parameter that needs to be measured, you are just about guaranteed that multiple vendors make a sensor that can measure it, and provide a 4-20 mA output..

Several vendors make web-enabled loggers like the one shown in *Figure 5*. While more expensive than the loggers illustrated in *Figure 3*, the added hardware cost can quickly pay for itself. Multichannel loggers sampling data at a high frequency can quickly fill up their memory. Web-enabled loggers allow you to retrieve the data without a trip to the field, saving time and travel costs in situations in which you need to gather a lot of data over a long period to establish a baseline or verify an improvement.

DDC Systems: The Ultimate Data Logger (Maybe)

For modern buildings, DDC systems perform the data logging function. Given current technology, they can be the ultimate data logger. But that only will become a reality if they are properly designed, commissioned and maintained.

TABLE Data logger features.

ITEM	VINTAGE (NOTE 4)	INTERFACE				SENSORS							SAMPLES			NOTES
						INTERNAL										
		USB	INFRARED	BLUETOOTH	WIRELESS	NUMBER OF DATA CHANNELS	TEMPERATURE	HUMIDITY	LIGHT	ACCELERATION	CO_2	EXTERNAL	RESOLUTION, BITS	DATA SAMPLE STORAGE CAPACITY	FASTEST TIME, S	
A	2000	X				4	X	X				X	8	7,944	0.50	1, 2, 8
B	2008	X				4	X	X	X			X	12	43,000	1.00	2, 3., 8
C	2016		X							X			8	21,800	0.01	5, 8
D	2013	X				4						X	16	1,900,000	1.00	2, 6, 8
E	2013	X				2	X	X				X	12	84,650	1.00	2, 8
F	2017				X		X						12	5,000	60.00	7, 8
G	2013	X				2	X					X	12	208,076	1.00	8, 9, 10
H	2008	X														11
I	2016			X			X	X			X		12	84,650	1.00	12
J	2016			X			X	X					12	84,650	1.00	12

NOTES

1. Even though this is one of the older loggers, it had the fastest sampling rate up until the Item C loggers showed up in 2016.
2. Loggers with external sensor jacks can interface with a wide array of sensors, including thermistors, current transformers (CT) and industry standard signals like 4-20 mA, 1-5 Vdc, and 2-10 Vdc.
3. The black device plugged into the external port is a 20 amp CT. The odd-looking extension cord is set up to break out the hot, neutral and ground conductors so the logger can be used to log data from an appliance or a PC. If you clamped the CT around the entire extension cord, the fields in the two current-carrying conductors would cancel each other out.
4. I estimated the vintage of the logger based on when I became aware of the product or procured my first one, which generally was around the time they appeared on the market.
5. I am experimenting with these loggers to see if I can pick up things like damper blade rotation or the motion of the inlet guide vane actuator on a centrifugal chiller.
6. The logger is shown with thermistor inputs for two of the four channels and a 600 amp CT on the third channel, a configuration you might use to gather information regarding the power consumed and load on an air-cooled chiller. But the external sensors could be any of the inputs listed in Note 2.
7. The logger I happen to have just has a temperature sensor. But the product line is capable of multiple inputs and can monitor any of the signals listed in Note 2. The sampling time is much slower than the other loggers. I suspect this is due to limitations associated with transmitting the data wirelessly. But, it is competitive with low-end current technology and legacy DDC systems. For a facility with no central monitoring system, even at once a minute, this logging solution would provide the user with useful data that would pick up most of the common problems that might otherwise go unnoticed, including scheduling issues, simultaneous heating and cooling and an unstable control loop.
8. For some of the loggers, the analog to digital conversion bit count is not specified, so I estimated it based on the temperature sensor resolution called out in the specifications.
9. While thermocouples like the one this logger uses as an input are less accurate than thermistors generally speaking, they can tolerate much higher temperatures. In addition, they are thin and flexible, which allows you to weave them through a preheat coil to capture the temperature downstream of it in situations where the coil is bolted directly to the cooling coil with no access in-between, allowing you to detect and document simultaneous heating and cooling.
10. You may notice that one of the thermocouple loggers looks a bit discolored. I was using it to monitor boiler flue temperature, and the mounting system failed, causing it to be blown around, tethered to the flue by its little sensor lead, but exposed to the flue gases, which discolored and deformed it. I included it to illustrate how tough these little guys are; when I plugged it in, it was fully functional and had captured the data I was after. It now is retired, resting in a place of honor on a shelf in my office.
11. This is not a logger; it is a data shuttle. It allows you to pull data from loggers and relaunch them without having to connect them to your computer. If you have ever balanced your laptop on top of a step ladder while trying to connect a USB cable to a logger about 4 feet above you, you will appreciate this little gizmo. I have also used it as a way to retrieve data from a remote site by sending it back and forth in the mail with the operators so they can pull the data for me.
12. The Bluetooth communication feature of this product line is very handy in situations where you want to log data in an occupied zone, perhaps the supply temperature coming out of a diffuser because once the logger is deployed, you can retrieve the data without having to go up on a ladder, move tables, etc. I have retrieved data from a meeting room while a meeting was going on, standing outside the door to the room.

FIGURE 3 Part of my collection of electronic data loggers.

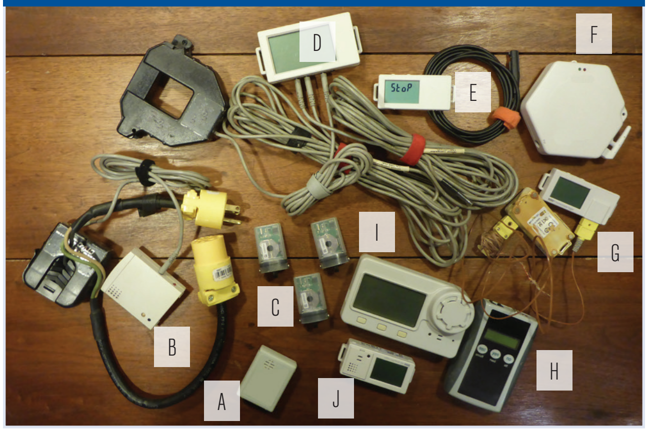


FIGURE 4 A current technology logger set up to log conventional 0-5 Volt dc pressure transducers; a similar arrangement can be used for 4-20 ma signal.

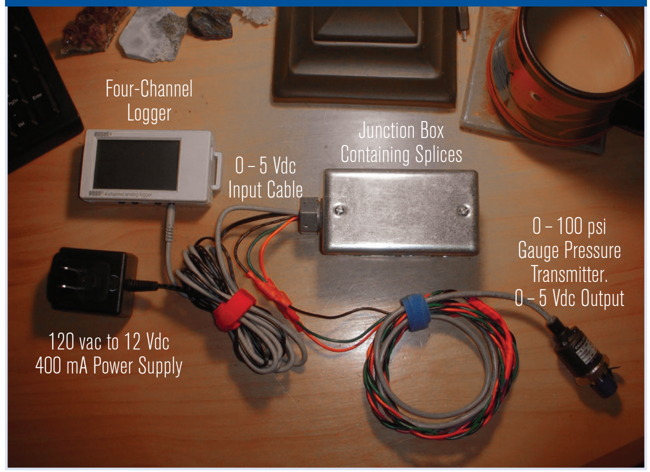
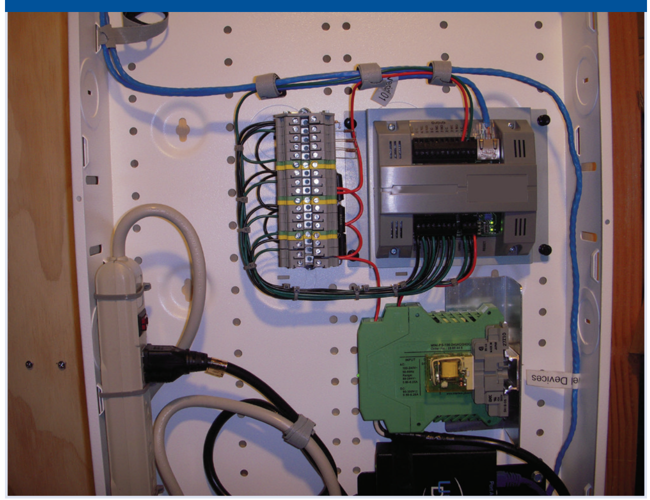


FIGURE 5 A web enabled logging solution.



It may be beneficial to think of your DDC system as a direct digital control and data logging (a DDCDL, if you will) system when you design it. That's because to be truly useful for commissioning processes, the control system will need to have more data points than those required for control.

For example, it is possible to control the discharge temperature for an air-handling system using the discharge temperature alone, by using sequencing to manage the interactions of various processes such as the economizer, cooling and heating coils. But having sensors that report the mixed air temperature and the temperatures leaving each of the coils will allow you to detect and correct something like a leaking warm-up coil valve that might otherwise be masked by the cooling process downstream if all you had to go on was discharge temperature.

The Need for Speed

For many systems, network architecture is a crucial factor in determining communication speed. While it may be technically possible for a controller to sample data at once a minute or faster, the traffic this creates on the network could crash it if it has not been designed to support it.

One solution is to simply not sample the data very quickly; a lot of systems default to sampling rates of once every 15 minutes or more for that reason. But if you accept that, you are giving up a lot of the utility you otherwise would have procured with your system.

For example, when you are tuning control loops, a graphic with dynamic trends painting the response of the process when you upset it in real time is a huge benefit. But for that to be useful, the data needs to be refreshed frequently: at least once a minute and for many processes five or 10 times a minute would be even better.

For commissioning work, if you really want to pick up a control process that has gone unstable, you probably will need to sample it at least once a minute to avoid being aliased. More than once, after flagging a control process as being unstable and requiring tuning by the control vendor, I have discovered that the "tuning solution" had been to set the trend sampling time to once every 30 minutes with the averaging option enabled. Generally, that will make anything look flat and smooth, despite the chaos going on behind the scenes.

The bottom line is that "sampling time" and "too fast" are mutually exclusive phrases until you know what is going on. Once you have identified and corrected a problem like an unstable control loop, you can slow the trends down for data archiving purposes. But having the ability to sample fast for initial and ongoing commissioning is a huge benefit, so don't give it up by accepting a network architecture that can't deliver it.

Similarly, the controllers and operator work station (OWS) need to have the memory required to store data for both the short- and long term. This capability can be quite important for a project seeking incentives from a utility, or a sustainability program that requires maintenance and verification. A system that has not been designed for this may not deliver, compromising the owner's ability to perform the measurement and verification required to claim the incentive offered by the utility program.

For systems facing these challenges, data loggers can provide a solution that bridges the gap by providing the data granularity necessary for a retrocommissioning project, a troubleshooting effort or even a semipermanent installation that gets you by until a controller upgrade can be implemented.

FIGURE 6 The proof of operation DP switches serving the pumps will not provide accurate data, as discussed in the article under data integrity.

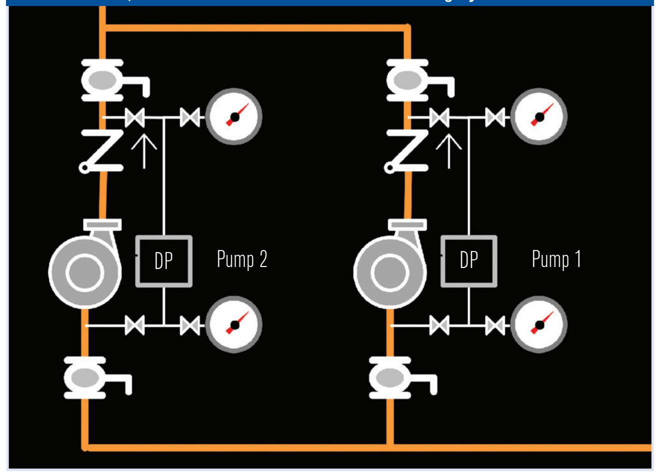
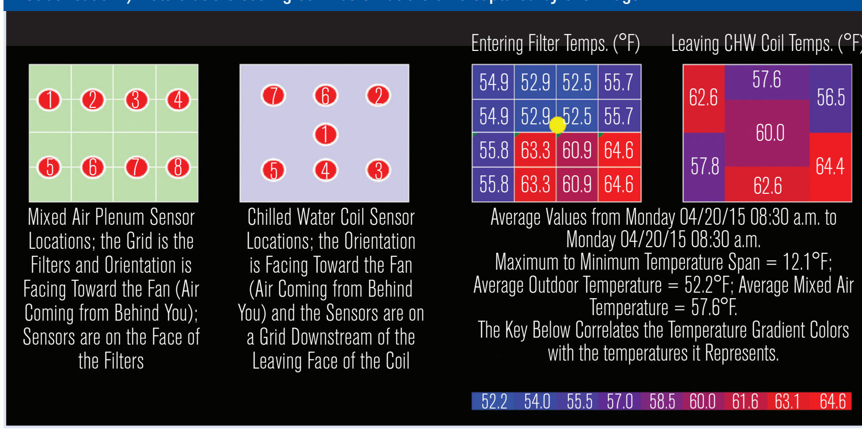


FIGURE 7 Mixed air plenum temperature profile vs. the temperature at the sensor location. (For more details and a video that shows how the temperature pattern varied over time, visit https://tinyurl.com/yd73sr7b, "Economizer Stratification.") Note that the cooling coil was off at the time captured by this image.



Data Integrity

It's easy to forget that what you are seeing on the OWS may not actually be what is going on out there. If the sensing network has not been thoroughly commissioned, the OWS graphics might be a fairy tale.

For instance data reported by a differential pressure switch that is being used as proof of operation for one of two parallel pumps would provide misleading data if the high port of the switch was connected to the header downstream of the check valve associated with the pump it served instead of upstream of the check valve (*Figure 6*).

Consider what happens if both pumps are running and Pump 1 is shut down. When this happens, Pump 1's check valve will close due to the loss of pressure it was creating and the pressure created by Pump 2. Because the differential pressure (DP) switch is sensing the pressure on the header side of the check valve, it will still see a pressure difference because Pump 2 is operating and pressurizing the header. Thus, the switch will report Pump 1 as running, even though it isn't.

If the DP switch was connected on the pump side of the check valve (between the pump discharge and the check valve), when Pump 1 shuts down (and the check valve closes), the pressure across it will equalize and the switch will correctly report that Pump 1 is off.

The mixed air temperature reported by a single point sensor vs. an averaging sensor is another example of the potential for misleading information. Because mixed air plenums can be quite stratified, it is unlikely the data from a single point sensor will be at all representative of the actual mixed air conditions. It is not unusual for economizer diagnostics to incorrectly report economizer functionality due to this issue.

Figure 7 illustrates the phenomenon for an economizer equipped air-handling unit in a facility in Monterey, Calif.

As a part of a retrocommissioning project, we deployed an array of data loggers across the filter bank in the unit, which was close coupled to the economizer section. We complemented this with a second array downstream of the cooling coil, the entering face of which was about 6 in. (152 mm) after the filter bank.

The image in *Figure* 7 is from a spreadsheet we built that allows you to select a day and time from the data set to see what the constantly varying temperature stratification pattern looked like. The sensors were calibrated relative to each other, so temperature differences indicated are true temperature differences, not differences that are the result of sensor error.

At the time, the outdoor temperature was 52.2°F (11.2°C), and the single point, mixed air sensor (located where the yellow dot is) "thought" the temperature was about the same. But the numerical average mixed air temperature was actually 57.6°F (14.2°C), and the numerical average temperature leaving the inactive cooling coil was 60.2°F (15.7°C).

Two reasons exist for the difference between the average mixed air temperature and the average cooling coil discharge temperature. One is that the thermal mass of the water-filled cooling coil places a thermal lag between the two temperatures.

The other is that there was significant velocity stratification in the plenum. Think of it this way: if you mix 1 gallon (4 L) of 50°F (10°C) water with 99 gallons (375 L) of 100°F (37°C) water, you don't end up with 100 gallons of 75°F (24°C) water, even though the numerical average of the temperatures is 75°F (24°C).

Bottom line: even if you have an averaging sensor, the temperature reported by it assumes that the velocity profile the sensor sees is uniform across its length. In a mixed air plenum,with stratification patterns varying as dampers modulate, this is often not the case.

The Original Data Logger Still Has a Place

Significant advances have been made in terms of our ability to dialog with our buildings over the past 40 years. It may even seem there is no longer a place for the original data logger, the operator with a clipboard. I think the original data logging strategy will always have a crucial role, even with current technology doing most of the actual logging.

For one thing, it places the person observing the data in the immediate proximity of the data source. As a result, the observer, properly trained, can assess the integrity of the sensing system, catching issues like those described above.

The "properly trained" part is important, especially the ability to perceive information in the context of the system it is coming from, interpret it in real time and identify things that don't add up in terms of the physics of the system. These are all critical skills and help ensure the integrity of the data we use to manage our facilities. That data is key to achieving the resource conservation and carbon reduction goals we must achieve moving forward.

So, when the opportunity presents itself, get out in the field and practice being a data logger. Spending time mingling with the building systems and the people operating them will make you a better designer; I'm sure you will learn something that will further your career. And I bet you'll have fun doing it. ■

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