Kent W. Peterson

Understanding Sensor Terms

BY KENT W. PETERSON, P.E., BEAP, PRESIDENTIAL MEMBER/FELLOW ASHRAE

Many buildings and facilities rely on temperature, humidity, and pressure sensors and transmitters to provide stable environments. They are a key part of any control system and impact the cost, stability and accuracy of the data. Selecting the correct sensors, and making sure what is specified is provided, help ensure a quality control system installation. However, sensors often receive little attention as we design systems and develop specifications. This may be partly because selecting the correct sensor for the application can sometimes be intimidating. This month's column explores temperature sensor selection for HVAC&R control systems and explains general sensor components and terminology.

Understanding Terminology

As a designer or engineer, you must specify sensors for use in your designs. During the search, you can be confronted with an array of product specifications to rely upon to select the sensor with the right cost-performance ratio. Unfortunately, not all sensor specifications are presented in a way that allows direct comparison. A sensor will never reflect the actual conditions exactly, but a high-quality sensor can provide information that falls within a maximum stated error. Understanding sensor terminology[1] will assist in selecting and comparing sensors. See "Sensor Terminology" sidebar.

Despite their obvious differences (see the sidebar and *Figures 1* and *2*), accuracy and precision are frequently used interchangeably, especially in manufacturer literature for sensor products. *Figure 1* shows the statistical distribution for precision versus the proximity to an actual value for accuracy. A more precise sensor has a narrower distribution, and a more accurate sensor is closer to the actual value. Alternatively, *Figure 2* shows how precision and accuracy can increase or decrease independently.

Precision and resolution are also frequently confused. Unlike precision, resolution is the smallest measurement a sensor can reliably indicate, which is typically important in identifying input changes at low signal levels from noise in the application. An analog to digital converter that converts the smooth output of an analog sensor for use in a digital control application has increased resolution as the number of bits increases. *Figure 3* shows the difference between resolution and accuracy when the sensor's output is converted.

Accuracy is particularly important where sensors are replaced without field adjustment. Control applications sometimes require the controlled variable to be maintained within a narrow band around a desired setpoint. In this case both the accuracy and resolution of the sensor are important parameters. In choosing sensors it is important to understand the parameters that matter and those that do not. To specify sensors, evaluate first-cost effectiveness such as installation time, accuracy, reliability, repeatability, maintenance, etc.

Selecting Temperature Sensors

In heating and air-conditioning applications, temperature is typically the primary controlled variable. The majority of temperature sensors used in HVAC direct digital control (DDC) systems are thermistors and resistance temperature devices (RTDs). Temperature sensors require wiring and sometimes transmitters to read the temperature at the control system panel.

Thermistors

A thermistor is a piece of semiconductor made from metal oxides that are pressed into a small bead, disk, wafer, or other shape and sintered at high temperatures. Last, they are coated with epoxy or glass. Thermistors

Kent W. Peterson, P.E., is chief engineer/COO at P2S Engineering in Long Beach, Calif. He is former chair of Standard 189.1.

Sensor Terminology

Accuracy is the closeness of agreement between the measurement result and the true value. During calibration, measurements are compared to a reference, International Standards Organization (ISO) or National Institute of Standards and Technology (NIST) traceable where available. Accuracy is a combination of trueness and precision. Accuracy can be expressed either as a percentage of full scale and/or in absolute terms.

Precision is the closeness of agreement among independent test/measurement results obtained under stipulated conditions. Precision depends only on the distribution of random errors and does not relate to the true value or the accepted value.

Repeatability is precision under observation conditions. Independent test/measurement results are obtained with the same method on identical test/measurement items in the same test or measuring facility by the same operator using the same equipment within short intervals of time (e.g., ability to remain stable over many heating and cooling cycles). Repeatability is often the most important characteristic where small changes are being measured.

Drift is the low frequency change in a sensor with time. It is often associated with electronic aging of components or reference standards in the sensor. Drift generally decreases with the age of a sensor as the component parts mature.

Stability deals with the degree to which sensor characteristics remain constant over time. Changes in stability, also known as drift, can be due to components aging, decrease in sensitivity of components, and/or a change in the signal-to-noise ratio.

Resolution is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the reading (or the full-scale reading) or in absolute terms. The electrical noise in a sensor's output is the primary factor limiting its smallest possible measurement.

Range is the region between limits within which a quantity is measured, transmitted, or received, expressed by stating the lower and upper range values.

Response Time describes the time required for a sensor output to change from its previous state to a final settled value within a tolerance band of the correct new value.

Offset Error is the amount of difference between the actual condition and the sensed condition in physical sensors before any signal conditioning.

Linearity Error can be described as the maximum difference between the measured data and the data as approximated by a best straight-line equation of the recorded data. It is generally expressed as a percentage of full scale. Full scale is the entire range of the sensing device.

Hysteresis Error describes the maximum difference, as a percentage of full scale, between the data points in a ramping from zero to full scale and back to zero again.

resistance decreases with increasing temperature. Thermistors are negative temperature coefficient (NTC) sensors because the resistance characteristic falls off with increasing temperature. The nonlinearity of the sensors limits their useful temperature span to about 100°C (212°F). While these devices are inexpensive to purchase, the real savings comes with the fact that they do not require installation calibration or recalibration during the sensor's life. Today, they are typically aged before leaving the manufacturer so that drift is minimized. And, while these sensors generally respond rapidly to slight temperature variations, the reaction time of probe-type thermistors is material-dependent.

There are no industry or governmental standards for thermistors. In HVAC&R, there are at least five different temperature versus resistance curves for 10K thermistors. All the thermistors have 10,000 ohms of resistance at 25°C (77°F), but they vary greatly the further you get away from 25°C (77°F).

Digital control systems translate the variable resistance to a temperature signal using a software look-up table that maps the temperature corresponding to the measured resistance, or by solving an exponential equation using exponents and coefficients provided by the manufacturer. Thermistors typically have a stability of ±0.2°C (±0.1°F) but they can be as stable as ±0.1°C (0.06°F) when using extra precision (XP) thermistors. Today, commercial-grade thermistors are available with a guaranteed maximum drift of 0.02°C (0.01°F) over a 10-year period.

The resistance of thermistors is normally several orders of magnitude greater than any wiring lead resistance. The wiring lead resistance, therefore, has a negligible effect on the temperature reading, and

FIGURE 1 The relationship between accuracy and precision.

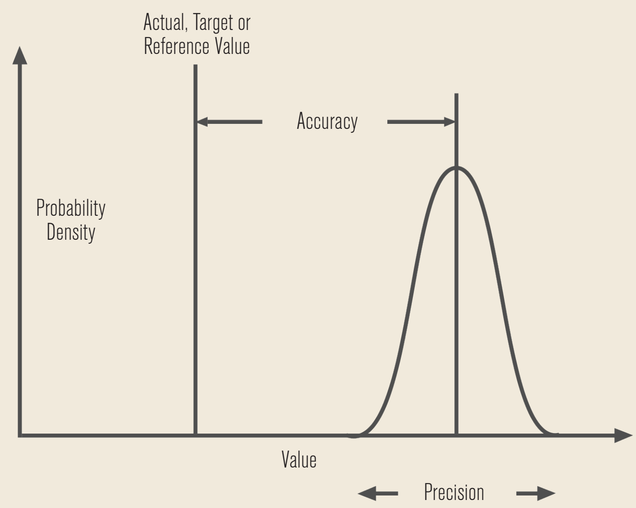
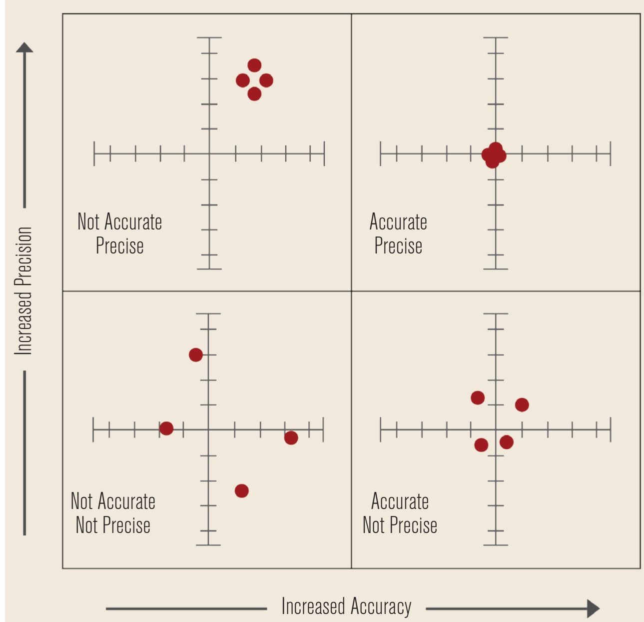


FIGURE 2 Visual difference between accuracy and precision.



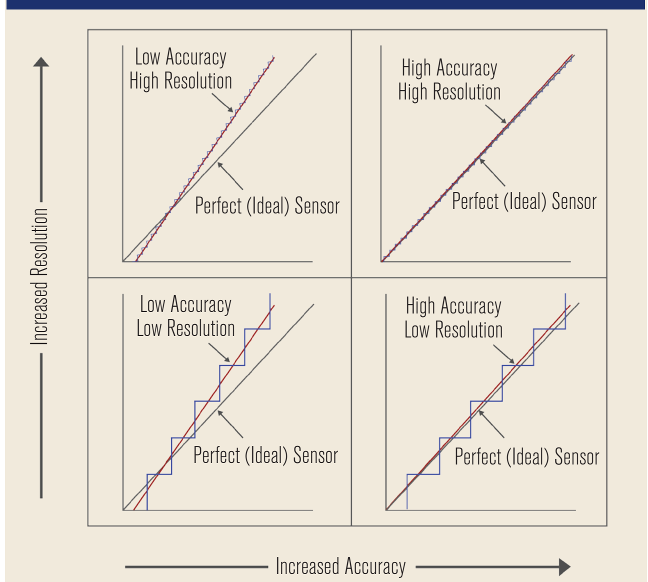
thermistors are almost always connected in a two-wire configuration.

Resistance Temperature Devices (RTDs)

The electrical resistance of metals in an RTD varies with temperature. RTDs are positive temperature coefficient (PTC) sensors because the resistance characteristic increases with increasing temperature. They are typically constructed of a fine-coiled metal (typically platinum, nickel, or copper) wrapped on a ceramic substrate and then covered with a protective sheath. RTDs can provide an accurate and repeatable temperature by allowing a predictable change in resistance. The most widely used sensor is the 100Ω or 1KΩ RTD. Some HVAC systems are designed to hold space temperature to within 1.8°C (1°F). To achieve such performance, the HVAC controller should be able to resolve temperature changes as small as 0.18°C (0.1°F). A 0.18°C (0.1°F) change in a 1KΩ RTD is the same resistance change as a 1.8°C (1°F) change in a 100Ω RTD. Most DDC controllers' universal inputs only measure 1KΩ RTDs for better resolution.

Depending on materials and construction, RTDs can be the most accurate sensors for HVAC applications and also offer the best long-term stability. IEC 751[2] is the International Electrotechnical Commission's standard that defines the temperature versus resistance for 100Ω, 0.00385 Ω/Ω/°C platinum RTDs. 1KΩ, 0.00385 Ω/Ω/°C platinum RTDs are defined as 10 times the IEC 751 specification. IEC 751 defines two classes of RTD: Class A and Class B. Class A RTDs operate over the temperature

FIGURE 3 Visual difference between accuracy and resolution.



range of –200°C to 650°C (–328°F to 1,201°F). Class B RTDs operate over the temperature range of –200°C to 850°C (–328°F to 1,562°F). Class B RTDs have about twice the uncertainty of Class A RTDs. The accuracy of an RTD sensor is typically expressed in percent of nominal resistance at 0°C (32°F). RTDs with accuracies of 0.2% to 0.01% are commonly available. While the "accuracy" of an RTD element is usually denoted by its initial element accuracy measured at one point, usually 0°C (32°F), it does vary with temperature. Further, it is also

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dependent on the tolerance of the base resistance at the calibration temperature of the element.

The stability of an RTD sensor refers to its change in resistance per degree change in temperature. It is both a function of its base resistance and its temperature coefficient of resistance. A sensor with higher stability is not necessarily more accurate, but the larger signal it produces will tend to be less susceptible to lead-wire effects and electrical noise, as it generally improves the signal-to-noise ratio of the sensor interface. A larger resistance also produces the same output voltage with less excitation current, which helps to mitigate self-heating effects in the sensor element by allowing lower currents to be used to excite it.

Since the electrical resistance varies with temperature, a constant current is passed through the RTD and the voltage drop across it is measured to evaluate the output signal. This voltage drop follows Ohm's Law, V=IR. The measuring current should be selected to be as small as possible in order to avoid heating of the sensor. It can be assumed that a measuring current of 1 mA does not introduce any appreciable errors. The signal voltage must be transmitted through the connecting cables to the controller with minimum value alteration. Because an RTD is a resistance type sensor, resistance introduced by connecting wires between the control instrument and RTD will add to the resistance readings. There are three common methods of connecting circuits for RTDs in HVAC applications:

Two-Wire Circuit. This type of circuit uses a typical Wheatstone bridge circuit to measure the thermistor resistance. This is an uncompensated circuit, meaning that resistance in the connecting wires can lead to significant measurement error. Larger gauge extension wires and 1KΩ, instead of 100Ω, RTDs can reduce the connecting wire error.

Three-Wire Circuit. This type of circuit also uses a typical Wheatstone bridge but uses three wires from the RTD. Two wires carry the measuring current, while the third wire acts as a potential lead serving as a reference. All three wires should have close matching resistance. The 3-wire circuit compensates for the line resistance and temperature variation. This is the most popular means of connecting RTDs when not using transmitters.

Two-Wire Transmitters. A two-wire current transmitter converts the RTD resistance to a 4 to 20 mA current signal that is proportional to the temperature. Its proportional signal is unaffected by stray electrical noise

TABLE 1 Comparison of thermistors and RTDs.

CONSIDERATION	THERMISTOR	RTD
Typical Range	0°C to 70°C	–200°C to 850°C
Accuracy	Good	Good to Best
Stability & Repeatability	Best	Good
Resistance Change	High	Low
Response Time	Fast	Slower
Linearity	Nonlinear	More linear
Wiring	2-wire	2-wire, 3-wire, or 2-wire Transmitter
Costs	Low	Expensive

as well as wire resistance and can maintain accuracy over distances of several thousand feet. Transmitters are typically mounted directly to the RTD to minimize wire resistance between the transmitter and RTD. Transmitters have a limited range, e.g., 0°F to 100°F (–18°C to 38°C); the range appropriate for the application must be specified.

Temperature Sensor Selection

Table 1 shows a comparison of thermistors and RTDs. Today, thermistors are as stable and accurate as RTDs, easier to wire, cost less, and almost all automation panels accept them directly. RTDs have a larger temperature measurement range than thermistors. When temperature transmitters are used with RTDs, it typically adds $100 per point. RTDs are useful when measuring very small changes in temperature like a chilled water or hot water energy meter. In this application, the RTDs are typically bath calibrated and matched for a combined accuracy of 1.5% of reading.

Today's DDC controllers are typically set up to handle thermistors, so a sensor's output linearity is not really an issue. Therefore, a thermistor is typically the best choice in most applications requiring a resistive sensing element by itself (without a transmitter).

Summary

Understanding the terms used by various sensor manufacturers can assist designers and engineers compare and select appropriate sensors used in control systems.

References

1. ISO. 2006. ISO 3534-2:2006, *Statistics—Vocabulary and Symbols—Part 2: Applied Statistics*.

2. IEC. 2008. IEC 60751:2008, *Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors*. ■

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