

Why isn't the sensor reading the same as my thermostat?

Appreciating the difference between automatic temperature monitoring system sensor readings and thermostat set point and display to better understand sensor placement and set alert levels.

One common question or comment heard by suppliers of automatic temperature monitoring systems is, "Why is the temperature reading from your device different from my thermostat?" More often this translates to, "Something's wrong with your device," or "It's not working (reading) correctly." While this could be true, and in some cases is true, in most cases the reason for the difference is real and easily explained.

Such questions are often heard in large, walk-in refrigerators and freezers where the space is relatively large, the heating and cooling unit located on the top rear of the unit, and the thermostat in a place determined by the installer as the optimum place to insure all products inside the cooler are at a safe temperature. In one such case, a customer using an automatic monitoring system noticed the difference and asked whether or not the sensor was defective or not calibrated properly.

Factors affecting sensor performance

Temperature sensors used in temperature monitoring systems are generally extremely accurate when used and maintained properly. The first consideration is whether or not the sensor is properly rated for the application, which it is in most cases. Only in extreme cases such as boilers or cryogenic coolers do temperatures exceed the specification of most commonly used sensors. That being said, it's good to check the operating temperature range because some sensors work well in one range but not in another.

The second consideration is the sensor's accuracy. Accuracy is extremely important in some applications, in complex chemical reactions for example. Here, accuracy of $\pm 0.1^{\circ}\text{C}$ ($\pm 0.2^{\circ}\text{F}$) or better is needed, requiring more costly sensors. Most applications do not need such accuracy. In home heating and cooling systems, in most refrigerator and freezer units and even in server room and data center applications, accuracy of $\pm 0.5^{\circ}\text{C}$ ($\pm 1.0^{\circ}\text{F}$) is generally sufficient both because the application is less critical and the cost more reasonable.

Real life examples: Second floor Bedroom case study

So why doesn't the sensor read the same as the thermostat on the control system? It is useful to use the example of a home heating system to see why. Figure 1 shows the output of a WiFi temperature monitoring system with two digital temperature sensors. The WiFi device employs a digital temperature sensor with an operating temperature range of -55°C to $+125^{\circ}\text{C}$ (-67°F to $+257^{\circ}\text{F}$) and is accurate to

±0.5°C (±1.0°F) over the range of -10°C to +85°C (+14°F to +185°F). This is as good as if not better than most refrigerator control systems.

The temperature sensors are in a small, east and south facing room in southern California. One sensor is at floor level, the other at 5.5 feet from the floor in the northeast corner of the room, out of direct sunlight or heating system vents. Figure 1 shows the cycling through one sunny day in January.

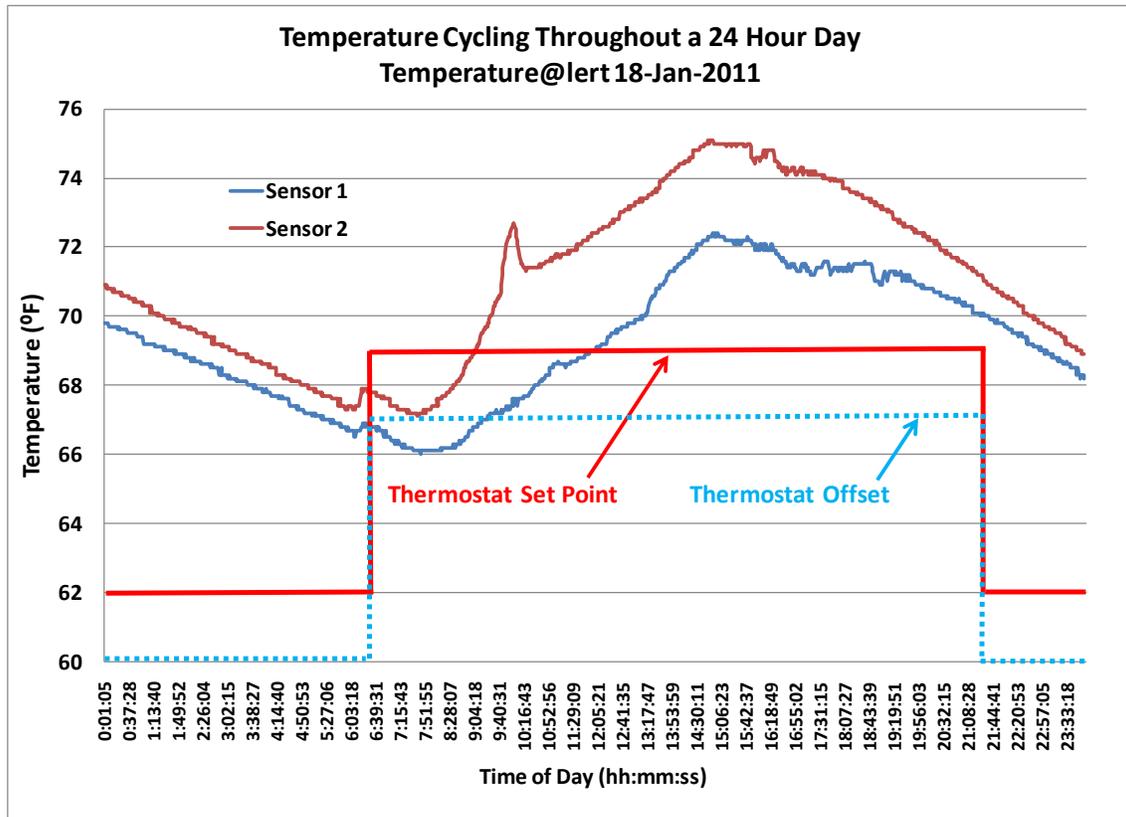


Figure 1: WiFi temperature monitoring system with two (2) temperature probes during a 24 hour cycle.

The digital thermostat is programmed to start the heating system at 6:30 a.m. The heating system stay on until it reaches the Thermostat Set Point of 69°F. The thermostat shuts off the heating system until the temperature drops to the Thermostat Offset temperature, 67°F, when it restarts the heating system. Over the next two to three hours the heating system cycles on and off as the thermostat warms to the Set Point, then subsequently cools to restarts the system again.

The sunlight on this day was particularly strong and the outside air temperature of 75°F by mid afternoon, meaning the room continued warming through a combination of outside air temperature, occupant activity and the sun.

The first observation is that the temperature sensors only read the same as the thermostat at two points in the graph, around 9:00 a.m., for sensor 2, the one nearer the ceiling, and around noon for sensor 1, the one on the floor. So what's happening here?

The thermostat is in a hallway at the top of the stairs to the second floor, half way between two bedrooms to the east and west and about 4.5 feet from the floor. The wall it is on is shared with a south facing bathroom. The bathroom and therefore the walls warm throughout the day, helping make the thermostat warmer than the air as a consequence.

Forced air heat outlets in the two bedrooms and the bathroom are in the ceiling. Heat coming out of them mixes with the air but not completely before it tends to rise to the 8-foot ceiling due to convection. Sunlight through the windows warms the air, floor, furnishings which subsequently radiate heat, contributing to the complexity of the thermodynamic behavior of the room.

The significance of this example is that sensor placement can explain the difference between what is expected and what is reported. Again, the thermostat Set Point is 69°F from 6:30 a.m. to 8:30 p.m. During the morning the thermostat display rises from the nighttime temperature low of 64°F to 69°F by mid morning as the heating system does its job. The thermostat reading continues to climb to 74°F by mid afternoon due primarily to heating by the sun. In this example of a dynamic system, the two sensors only report the Temperature Set Point reading of 69°F once as each sensor reading rises to the highest daytime temperature.

The nighttime thermostat setting is 62°F from 8:30 p.m. until 6:30 a.m. the next morning. The thermostat display shows a low of 65°F in the early morning before the heating system starts its daytime cycle. The two sensors show readings above 66°F during evening operation which is in reasonable agreement with the thermostat display since the two locations are coming to equilibrium without the sun's heating or the cycling of the heating system.

Which temperature readings are correct? The most likely answer is both, since they are measuring two different locations with different thermodynamic influences. Only by placing the monitoring system's sensor next to or inside the thermostat could there be good agreement between the two sensors. This is demonstrated by the fact that even within the same room at two different elevations there is a marked difference between the two sensor readings. Indeed, when customers ask the question, "Why is the sensor showing a different temperature than my thermostat?" the difference is most often resolved when the "same location sensor placement" test is performed.

Thermodynamics of this relatively simple system demonstrates how there can be significant differences between two locations within the same room or between adjacent rooms. The temperature difference between the sensor and the thermostat is not so significant to cause alarm in the example shown since the temperature range is in a comfortable zone for habitation, putting on or taking off a sweater or sweatshirt during the day is enough to make one happy. These temperature differences can be very significant in critical applications, however.

Lessons for critical applications

Server and telecommunication rooms as well as walk-in freezers and refrigerators behave in the same complex manner as the house heating system example above. In the case of server and telecommunication rooms, some have evolved from makeshift closets or small offices to rooms stuffed with electronic equipment. As companies grow and rely on reliable communications, these rooms house the electronic heartbeat of many companies. Very likely no special heating and cooling system (HVAC) changes were made to accommodate the added heat load to the room. In all likelihood the thermostat is not in the same room as the equipment. In some cases the heating and cooling outlet for

the server room is tied to other occupied spaces, so the comfort of the occupants determines the thermostat setting.



Figure 2: Server rooms present challenges with floor to ceiling and rack temperature gradients.

The result is that in many cases electronic equipment may be operating at or above the high end of the manufacturers' recommended operating range. In such cases it is easy to visualize a significant heat gradient from floor to ceiling, and if the ceiling is low enough, from floor to top of electronic racks. Long term operation at elevated temperatures is known to negatively affect reliability. To insure the equipment is operating at acceptable temperatures it is often recommended that at least two sensors, one near the ceiling or top of a server rack and one near the air system inlet be used, the latter giving the lowest reading and therefore the more useful to provide early warning of HVAC system problems. The monitoring system can also be used to provide data on the thermostat vs. server room temperature readings to help define the optimum operating range throughout the year. In very critical equipment additional sensor can be placed inside the electronics racks where temperatures are often higher in order to assess the need for additional cooling within the enclosures.

For walk-in refrigerators and freezers similar lessons can apply. The good news is that the cooling system for these units is dedicated to the interior of the walk-in, and the walls and ceiling are insulated to prevent outside heat from warming the interior. The bad news is the contents are not typically well organized for airflow, but more for access. This means that some areas of the walk-in may not receive adequate cooling, and the food, vaccines or medications stored in those areas exposed to temperatures higher than manufacturer's recommendations, leading to shorter shelf-life or premature spoilage, which in the case of medications and vaccines may not be easy to determine. In other cases, the walk-in contents may be exposed to lower than recommended temperatures, which can in some cases cause product freezing or becoming freezer burned, leading to unattractive or unsalable products.



Figure 3: Walk-in refrigerator interior showing challenges to uniform airflow from chiller fans.

Similarly, the thermostat sensor can be in an area that is in the direct path of or shielded from the cooling unit discharge, with similar results of over or under cooling of the unit's contents. To insure the unit and its contents are working properly, it is recommended the temperature monitoring system be used to baseline the walk-in's operation, offset between sensor location and thermostat set point, and determination of optimum sensor placement. The results can help better understand how the unit operates, define the ideal thermostat set point, and pinpoint any areas that are not adequately cooled, possibly due to voids in the walk-in's insulation. After this is accomplished and the walk-in operation is well understood, permanent sensor installation can be determined for normal operation, protected by the monitoring system's ability to send alerts when there is a problem.

Summary

Accurate temperature measurement presents challenges when monitoring critical systems such as server and telecommunication rooms as well as walk-in freezer and refrigerators. The difference between the temperature set point of the thermostat and the monitoring system can often be explained by the different location within the space being monitored. A simple test is to place the sensor next to the thermostat sensor to determine best agreement.

Monitoring critical environment temperatures requires an understanding of the heating and cooling pathways within the critical space. Conducting a baseline study of the temperature profile within the critical space can help with optimum sensor placement and thermostat set point.

And if all else fails, think of the heating and cooling system in your own home, and how some rooms or locations are warmer or cooler. Applying these simple principals to the critical environment will help point to optimum sensor placement and heating and cooling system operation.