Take care of the MONEY SENSORS

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In a money sensor, a small error in accuracy can yield large changes in your client's utility bill. Here are some issues to watch for.

In 1997, I was working on a 17,000-ton central plant that served an industrial facility for the development of chip fabrication prototypes. The plant ran 24/7 and was never shut down—even for maintenance. We were working on a project to replace two of the chillers and optimize the control sequences. The plant was controlled by industrial programmable logic controllers and had high-quality instrumentation including three-wire platinum resistance temperature detector (RTD) sensors, each with a dedicated transmitter.

We were in the process of recalibrating the temperature sensors using a dry-well bath. I was at the front end computer reading the energy management control system (EMCS) signal and my business partner was with the operators removing sensors and putting them in the dry-well bath. They had just removed the condenser water return sensor and signaled on the walkie-talkie that it was in the dry-well bath. I looked at the screen and noted that its value had not changed.

“What temperature are you set at?” I asked. They replied with a number that did not match what was on the screen in front of me. They changed the setpoint on the bath and, to my surprise, it was the condenser water supply sensor reading (not the condenser water return sensor reading) that changed on the screen.

This, to our horror, was not only an error on the EMCS graphics but a mismapped sensor in the control logic as well. The owners had been controlling the entire 17,000-ton plant on a condenser water return sensor that was mismapped and improperly scaled.
in the EMCS system. To put this error in perspective, we achieved ~2.5 GWh/yr savings by upgrading the control sequences (and remapping the proper sensors).

Thus began my interest in (and obsession with) the money sensors. This article will present a few cases of money sensors gone awry, tips to recognize them, and some tools and techniques to keep them in line.

What are the money sensors?

Simply put, a money sensor is a sensor on which a small error in accuracy can yield large changes in your client’s utility bill. Examples include:

- Economizer high-limit switches
- Humidity sensors for control of space humidification (particularly in facilities like museums, data centers, and hospitals)
- CO₂ or CO sensors that are used for demand control ventilation
- Pressure sensors that are used to control fan speeds, pump speeds, and variable air volume (VAV) box airflow
- Supply air temperature sensors for large air conditioning and air handling units (AHU)
- Central plant control sensors like chilled water and condenser water supply temperatures, or flow meters if used for equipment staging
- Revenue meters like those for submetering gas, steam, chilled water, and electricity.

Noticeably missing are most zone controls, including thermostats. CO₂ sensors (located in the zone) are included as their logic often cascades to the control of the minimum outside air of the AHU or air conditioning unit for the entire building. VAV box pressure transducers (also in the zone) are another exception as sloppy box control can significantly impact the AHU fan energy and the amount of reheat. In the examples that follow, we’ll discuss issues that we’ve uncovered with money sensors and some tools and tips for making them more reliable.

**Economizer high-limit switches**

Economizers are required in energy codes including the International Energy Conservation Code and ASHRAE Standard 90.1. Both of these codes include limits on the types of high-limit switches that can be used based on climate. The purpose of the economizer high-limit switch is to determine when it is more beneficial to bring in outside air than return air. When these switches fail, you either lose the potential energy savings from “free” cooling or you inadvertently increase the cooling load by bringing in excess outside air.

There are three technologies for high-limit switches: temperature based, enthalpy based, and the H705A solid-state enthalpy controller from Honeywell that is commonly used in smaller packaged units. As shown in Figure 1, the solid-state enthalpy controller has a nonlinear curve that acts like a dry-bulb sensor in low humidity and a wet-bulb sensor in high humidity.

Temperature sensors are fairly stable and are the easiest of the three to validate in the field. The enthalpy sensors and solid-state enthalpy controllers are subject to drift and are almost impossible to calibrate in the field. Furthermore, the solid-state enthalpy controllers have a large

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*Figure 1: Honeywell solid-state enthalpy controller curves show a nonlinear curve that acts like a dry-bulb sensor in low humidity and a wet-bulb sensor in high humidity. Source: Honeywell*
MINNEAPOLIS

Minneapolis economizers offer significant savings potential, but they must deal with a wide range of operating conditions if they are to succeed, often going from preheat to cooling with dehumidification and back in the course of a single day. Accurate sensors for measuring process parameters and comparing them to ambient conditions to decide when the economizer should operate and coordinate its heat transfer elements are critical, as are properly sized dampers and valves with high quality, linear, hysteresis-free linkage systems.

SAN FRANCISCO

In the mild San Francisco climate, freezeplugs and mixing problems with economizers are virtually unheard of; most systems spend a lot of time at or near 100% outdoor air. As a result, spending a lot of money to optimize the minimum outdoor air percentage with a demand-controlled ventilation strategy may not be a wise investment. However, good blade seals on the return damper may be critical for maximizing the benefits of the economizer because leaking return air dilutes the free cooling from outdoor air.

KEY WEST, FLA.

For most applications, economizers probably don’t even make sense in Key West due to the high ambient humidity and dry-bulb temperatures that predominate. But demand-controlled ventilation strategies with accurate sensors have the potential to save a lot of cooling and dehumidification by optimizing the minimum outdoor air quantities for systems that serve loads with highly variable occupancy rates like conference rooms, classrooms, and auditoriums.
Accuracy is relative

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Even though absolute accuracy is important at certain points in our HVAC systems, from an operational standpoint, the relative accuracy of sensors controlling a process may be more important, as illustrated in this example where two sensors that meet a project's accuracy specification of ±0.5°F produce an unintended result.

The system above consists of an air handling unit with 100% outdoor air that has an intake damper, filters, a face-and-bypass type preheat coil, a chilled water cooling coil, and a supply fan. The system is located in an environment where temperatures are below freezing part of the year, thus the preheat coil is independently controlled to protect the chilled water coil. A freezestat provides an added measure of protection by shutting down the system if the preheat process fails.

The sensors controlling the preheat and cooling coils were required to be accurate to ±0.5°F. By pure coincidence, the fan discharge sensor is at the upper end of the accuracy spec while the preheat coil discharge sensor is at the lower end of the accuracy spec.

On the day in question, the outdoor air temperature is a pleasant 55°F, which happens to be the set point required by the system's controllers. The system has been properly tuned and calibrated and PI loops are being used to eliminate proportional error.

The graph below the diagram tracks the temperature of the air as it moves through the system and is processed by the various heat transfer elements. The heat transfer processes are controlled by sensors with minor errors in terms of absolute accuracy and in relation to each other. The colored dots indicate the actual air temperature (green) as well as the temperature the preheat controller (red) and discharge controller (blue) would see at each point in the system. We start with 55°F air entering the system, which the preheat controller would see as 0.5°F too cold and the discharge controller would see as 0.5°F too warm.

Because the preheat controller thinks the air is 0.5°F too cold, it modulates the system's face- and-bypass dampers to raise the temperature of the air to its set point of 55°F. But, the controller thinks the air is too cold because it is reading the temperature 0.5°F below its actual temperature (as the result of its accuracy tolerance), so the real air temperature is increased from 55°F to 56°F.

From the perspective of the discharge controller, the air entering the cooling coil is now 1.0°F warmer than it should be.

Responding to what it believes is a supply temperature that is 1.0°F over set point, the discharge controller modulates the chilled water valve to cool the air to what it thinks is 55°F. But, because of its accuracy tolerance, it actually delivers the air to the loads 0.5°F cooler than desired.

The bottom line is that sensors meeting their absolute accuracy specification have taken air that was already at the required temperature and used energy to simultaneously heat and cool it and deliver it at a temperature different from what is desired.

Continued from page 31

dead-band that makes their control very sloppy in practice.

A seminar at the ASHRAE 2010 Winter Meeting investigated the "Impact on Humidity & Enthalpy Sensor Error on Economizer Performance." This presentation demonstrated the energy impact of a relatively small error in either an enthalphy or solid-state enthalphy controller (1 Btu/lb or ~5% RH) in the climates of Chicago, Albuquerque, N.M., San Francisco, and Atlanta. The presentation concluded that the inevitable sensor drift makes enthalphy and solid-state enthalphy controllers less efficient dry-bulb sensor technologies. It recommends a differential dry-bulb switch in a mild or dry climate and a fixed reference dry-bulb switch in a humid climate. Unfortunately, many smaller packaged units are available with only the solid-state enthalphy controller, and several of the major air conditioning unit manufacturers don't offer differential dry-bulb switches.

Another issue that can adversely impact the performance of an air-side economizer is the location of the outdoor sensor for the high-limit switch. If this sensor is placed in direct sunlight and is not shielded, it will be biased to a higher reading than the ambi-
ent dry-bulb temperature. The result is that many hours of free cooling will be missed. Similar bias can be introduced by locating the sensor in an exhaust stream. One solution is to buy an aspirated sensor with a radiation shield. However, this solution is expensive and is not cost effective for smaller air conditioning or AHUs. For Web-based control systems there is another solution: using the Internet to report the ambient dry-bulb temperature from a nearby high-quality weather station such as a National Oceanic and Atmospheric Administration (NOAA) site. All NOAA sites are available through XML protocols. NOAA has nearly 300 locations in the United States.

Humidity sensors

Humidity sensors are used to control humidification and dehumidification for a wide variety of energy-intensive facilities including data centers, manufacturing facilities, hospitals, and museums. The Iowa Energy Center did extensive testing of the commercially available humidity sensors and found that very few met the manufacturers' stated accuracy out of the box, and that nearly all of these sensors experienced significant degradation of accuracy over time. In an application with tight humidity control, sensor error can result in huge amount of wasted energy. Review these reports for selection of control sensors.

A recent survey of computer room air conditioning (CRAC) units reveals the result of both sensor inaccuracy and poor placement of sensors. Table 1 presents a survey of six water-cooled CRAC units with humidifiers. The first three columns are a survey of the temperature and humidity at the location of the CRAC unit control sensor using a highly accurate humidity transmitter that had just been factory recalibrated. The next three columns show the readings from the CRAC unit panel using the unit-mounted control sensors that are located in the CRAC unit return. Comparing these to the reference probe reveals inaccuracy in both the dry-bulb and RH sensors used by the manufacturer. For both the reference and CRAC unit sensor readings, the dewpoint temperature was calculated.

Enthalpy controllers are subject to drift and are almost impossible to calibrate in the field.

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Table 1: Field survey of CRAC units with reference temperature and humidity sensor

<table>
<thead>
<tr>
<th></th>
<th>Reference probe</th>
<th>CRAC unit panel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tdb F</td>
<td>RH</td>
</tr>
<tr>
<td>AC-005</td>
<td>84.0</td>
<td>27.5</td>
</tr>
<tr>
<td>AC-006</td>
<td>81.8</td>
<td>28.5</td>
</tr>
<tr>
<td>AC-007</td>
<td>72.8</td>
<td>38.5</td>
</tr>
<tr>
<td>AC-008</td>
<td>80.0</td>
<td>31.5</td>
</tr>
<tr>
<td>AC-010</td>
<td>77.5</td>
<td>32.8</td>
</tr>
<tr>
<td>AC-011</td>
<td>78.9</td>
<td>31.4</td>
</tr>
<tr>
<td>Min</td>
<td>72.8</td>
<td>27.5</td>
</tr>
<tr>
<td>Max</td>
<td>84.0</td>
<td>38.5</td>
</tr>
<tr>
<td>Avg</td>
<td>79.2</td>
<td>31.7</td>
</tr>
</tbody>
</table>

As can be seen in this table, the dewpoint remained nearly constant in the measurements of the reference probe but varied wildly in the readings from the CRAC unit control sensors. The results of this inaccuracy are displayed in the last column: Two of the units, AC-008 and AC-011, were actively humidifying, and a third unit, AC-006, was actively dehumidifying. The units were using electrical energy to boil water in two units only to use more electrical energy to condense that water in a third unit. Furthermore, the placement of the control sensor in the CRAC unit return combined with the use of relative humidity (as opposed to dew-point temperature) for control caused the unit with the lowest dew-point temperature, AC-006, to be dehumidifying when it should have been humidifying if its sensors had been accurate.

Demand control ventilation

Demand control ventilation (DCV) is used to save energy in systems serving high-density occupancies like conference rooms, theaters, and classrooms. It typically employs CO₂ sensors that are placed at the breathing level of the occupants. As occupants enter the room, the CO₂ levels increase and the controls increase either the outside air or zone box minimums to dilute the CO₂ and other occupant-borne contaminants. These controls are required by many energy codes including those based on ASHRAE Standard 90.1.

The Iowa Energy Center is just completing testing of CO₂ sensors across the range of commercially available technologies. These include single-beam, single-wavelength sensors with and without automatic background calibration; dual-beam, single-wavelength sensors; and single-beam, dual-wavelength sensors. The results of this testing showed a wide variation of accuracy over the range of products and even across manufacturers using the same core sensors. The researchers also documented the effect of humidity and atmospheric pressure on sensor accuracy.

There have been a number of field studies on the accuracy and drift of DCV sensors. Michael Apte of Lawrence Berkeley National Laboratory in California wrote an excellent summary of the studies in 2006. These studies investigate issues of both sensor accuracy and sensor placement.

Switch selectable pressure transmitters

Switch selectable pressure transmitters are popular with control contractors as they can use the same product on a range of applications and simply "flick a switch" in the field to get them to work. They work by amplifying the signal over a portion of the sensor's range. For example, if you have a 0-10-in. pressure transducer, you flick a switch and the section from 0 to 1 in. is amplified to the full range of output. Although this works in theory, it often fails in practice. Amplifying the signal devices also amplifies the sensor error. As a result, you have a larger signal-to-noise ratio on the amplified section of the sensor.

On a recent laboratory retrofit project with tracking VAV boxes, the control contractor submitted switch selectable pressure transducers for the VAV box airflow that were prohibited in our control specifications. I rejected the control contractor's submittal. The contractor appealed to the owner, stating that they had already purchased several hundred transducers and the owner allowed the contractor to install them. During the commissioning, the contractor could not get the boxes to keep from hunting. The culprit was the switch selectable pressure transducers, which never should have been installed in the first place.

Special cases

I have made a case for the application of high-quality sensors and transducers at critical locations such as those used for plant or large AHU supply temperature or pressure control. An exception is a sensor that is used with demand-based resets. An example is a duct supply pressure sensor for a VAV fan whose setpoint is reset to keep the most demanding VAV box damper at...
or near 100% open. When demand-based reset is employed, the pressure (or temperature) setpoint is reset over a range. The actual temperature or pressure is not critical. A drift in the control sensor will be corrected automatically by the actual demand from the zones.

When you design control systems, take care to identify the money sensors. Specify high-quality sensors that are stable, and verify their performance in the field through spot checks or calibration. Use resources like the Iowa Energy Center and the national laboratories, where researchers have independently tested the range of available technologies. If the project is large enough, consider independent testing of critical sensors at a third-party laboratory. For example, the University of Utah and the University of Colorado both have flow testing facilities.

Where possible, use demand-based reset of temperatures or pressures to reduce the impact of sensor error on operating costs. These controls save energy in addition to reducing the sensitivity to sensor error.

And by all means avoid switch selectable sensors where you need to rely on sensor performance.

A little extra money spent up-front for quality instrumentation field verification can save significant money down the road, not only in energy costs but also in loss of product from sloppy controls, increased labor to troubleshoot systems, and from costs to locate and replace components like actuators that can fail prematurely from excessive hunting.

Hydeman is a principal and founding partner at Taylor Engineering. He is the current vice-chair of ASHRAE/EESNA Standard 90.1 and the principal investigator in ASHRAE RP 1455, a project to develop standardized best-of-class control sequences. Hydeman specializes in the energy-efficient design, retrofit, and commissioning of high-technology facilities including chilled water plants, laboratories, and data centers. He has developed master control specifications for a wide range of public and private clients.

When you design control systems, take care to identify the money sensors. Specify high-quality sensors that are stable, and verify their performance in the field.

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