An Experimental Evaluation of Duct-Mounted Relative Humidity Sensors:
Part 2—Accuracy Results

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ABSTRACT

This is the second paper in a three-part series reporting on the test and evaluation of typical duct-mounted relative humidity sensors used in building HVAC applications. In this paper, three duct-mounted humidity sensors from each of six different manufacturers were tested and evaluated to determine the sensor accuracy and to provide a comparison with manufacturer specifications. A total of 18 sensors were tested, nine of them were capacitive-type sensors and nine were resistive-type sensors. The sensors were tested at three different temperatures (i.e., 15°C, 25°C, and 35°C) and five different relative humidity (RH) levels (i.e., 10%, 30%, 50%, 70%, and 90% RH). The experimental procedure used for testing and evaluating the accuracy of the humidity sensors was described previously in Part 1 (Joshi et al. 2004a) of this paper.

The test and evaluation results show that at 25°C, two of the six humidity sensor models are within manufacturer-specified accuracy of ±3% for the entire relative humidity range of 10% to 90%. A third sensor model did not meet the manufacturer-specified accuracy of ±3% at any humidity level tested while the remaining three sensor models met the manufacturer-specified accuracy of ±3% for only part of the humidity range.

INTRODUCTION

This is part two of a three-part series of papers reporting on the test and evaluation of typical duct-mounted humidity sensors used in building HVAC systems. In this study, three duct-mounted humidity sensors of the same model were tested and evaluated from each of six different manufacturers in order to determine the sensor accuracy and to provide a comparison with the manufacturer-specified accuracy. The experimental procedure that was used to test and evaluate the sensors is described in Part 1 (Joshi et al. 2004a) paper. Out of the eighteen humidity sensors that were tested, nine sensors were capacitive-type sensors while nine were resistive-type sensors. A description of the capacitive and resistive type humidity sensors can be found in Part 1 (Joshi et al. 2004a) of this paper. Because they are commonly used in HVAC applications, humidity sensors with specified accuracies of ±3% were used in the present study.

This paper presents an overview of the past studies performed by researchers to evaluate the accuracy of relative humidity sensors used in HVAC environments. Further, a brief discussion on humidity sensor specifications and experimental test procedures (details are in Part 1 paper) is provided. In addition, the paper presents test and evaluation results, including comparisons of the accuracy of resistive and capacitive type sensors. Furthermore, the impact of errors on the operation of a building control HVAC system is discussed. A case study is provided in the paper that shows significant energy savings can be achieved with sensors that are more accurate. The third paper in this three-part series reports the results of a repeatability, hysteresis, and linearity study of humidity sensors.

PREVIOUS STUDIES

In the past, studies have been done to investigate the accuracy of relative humidity sensors that are used in different HVAC environments, such as agriculture and shipboard applications; however, none of these past studies has evaluated and tested relative humidity sensors in a building HVAC environment. A review of the past studies with a specific focus on the evaluation of relative humidity sensor accuracy is presented below. It should be noted that the test procedures used in these

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Table 1. Manufacturer-Specified Accuracy and Humidity Range for the Humidity Sensors

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Sensor Type</th>
<th>Manufacturer-Specified Humidity Range</th>
<th>Manufacturer-Specified Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>Capacitive</td>
<td>20% to 80%</td>
<td>±3% at 25°C</td>
</tr>
<tr>
<td>Model B</td>
<td>Capacitive</td>
<td>10% to 90%</td>
<td>±3%*</td>
</tr>
<tr>
<td>Model C</td>
<td>Capacitive</td>
<td>10% to 90%</td>
<td>±3% at 20°C</td>
</tr>
<tr>
<td>Model D</td>
<td>Resistive</td>
<td>20% to 95%</td>
<td>±3%*</td>
</tr>
<tr>
<td>Model E</td>
<td>Resistive</td>
<td>15% to 95%</td>
<td>±3%*</td>
</tr>
<tr>
<td>Model F</td>
<td>Resistive</td>
<td>20% to 95%</td>
<td>±3% at 25°C</td>
</tr>
</tbody>
</table>

* Manufacturer does not state a temperature

Past studies to evaluate accuracy of relative humidity sensors were described previously in Part 1 (Joshi et al. 2004a).

Ross and Daley (1990) evaluated the accuracy of four different types of capacitive-type relative humidity sensors. The manufacturer stated accuracy of sensors 1, 2, and 3 were ±3, ±2.5, and ±1.5%, respectively. The manufacturer stated accuracy for sensor 4 was not available in the paper. The authors report that sensors 1 and 2 met the manufacturers’ claims for accuracy of ±2.5% over the entire humidity range of 10.0%–97.6%. Sensor 3 met the manufacturers’ claims for accuracy over the 43.2%–97.6% humidity range, while at 10.0% the humidity reading was 6.1%, which did not meet the manufacturer stated accuracy of ±1.5%.

Erdebel and Leonard (1992), evaluated the accuracy of two capacitive-type sensors and an aluminum-oxide sensor. The results indicated that none of the sensors met the manufacturer-specified accuracy. For example, the manufacturer of the two capacitive-type sensors claimed an accuracy of ±2% RH, whereas the measured accuracy of these sensors was around ±7% RH. The manufacturer claimed accuracy of the aluminum-oxide sensor was ±2°C (dew-point), which, at the test temperature of 20°C, translates to ±5% at 35% RH and ±10% at 85% RH, respectively.

Thomas (1992) evaluated the accuracy of three different humidity sensors—one that measures dew-point and two others that measure relative humidity by using the resistive and capacitive approaches. The manufacturer-specified accuracies for the dew-point, capacitive, and resistive type sensors were 4.2%, 4.4%, and 2.8%, respectively. The authors reports that the dew-point sensors met the manufacturer-specified accuracy of 4.2%, while the capacitive and resistive type relative humidity sensors did not meet the manufacturer-specified accuracy of 4.4% and 2.8%, respectively, over the entire humidity range. For example, the percentage errors in the resistive and capacitive sensors were 11.5% and 27.8%, respectively, while it was 2.3% for the dew-point sensors.

In summary, two out of the above three studies (Ross and Daley 1990; Erdebel and Leonard 1992) reported the results of accuracy for capacitive-type sensors and found that they did not meet the manufacturer-specified accuracy. The remaining study (Thomas 1992) reported an accuracy evaluation of resistive-type sensors, and the study found that the resistive-type sensors did not meet the manufacturer-specified accuracy.

HUMIDITY SENSOR SPECIFICATIONS

Two types of relative humidity sensors, namely, resistive and capacitive, were purchased off-the-shelf from representative manufacturers. The manufacturers’ stated accuracy for each sensor along with the manufacturer-specified humidity range are shown in Table 1.

EXPERIMENTAL TEST PROCEDURE

The humidity sensors were tested by using a known standard that was traceable to the National Institute of Standards and Technology (NIST) standards. Specifically, a “two-pressure” humidity generator was used to produce both accurate and known humidity conditions. The eighteen humidity sensors were tested at five levels of relative humidity (10%, 30%, 50%, 70%, and 90% RH) and three different temperatures (15°C, 25°C, and 35°C), which are typical conditions encountered in a building HVAC system. The sensors were placed inside the generator by mounting them on a custom-made manifold that directed the conditioned air over the sensing element of the humidity sensors. Established procedures, including guidelines for steady-state conditions, described in detail in Part 1 (Joshi et al. 2004a) of this paper were used to perform the testing.

RESULTS AND DISCUSSIONS

The results for the analysis are presented in terms of the deviation of the pooled measured value from the actual value (e.g., deviation = RH_measured – RH_actual). The deviation of the pooled measured value represents the average deviation for all three sensors of a specific manufacturer at a given relative humidity and temperature.

Three sensor units (i.e., units 1, 2, and 3) of each model type (i.e., Models A through F) were tested at 10%, 30%, 50%, 70%, and 90% relative humidity and temperatures of 15°C, 25°C, and 35°C. The manufacturers’ literature for Models A, C, and F reports the sensor accuracy at 25°C, 25°C, and 20°C, whereas Models B, D, and E do not state a temperature corresponding to the stated sensor accuracy. The manufacturer-specified humidity range over which the stated ±3% accuracy is applicable varies from manufacturer to manufacturer. For example, the manufacturer-specified relative humidity range for the Model B sensor is 10% to 90%, while for the Model A sensor it is 20% to 80%.
**Analysis of Deviations for Each Model**

The analysis of deviations for each model is presented in this section. In particular, discussions on the effect of relative humidity on deviation, performance accuracy, and effect of temperature on deviation for each model are presented below. It should be noted that the performance accuracy of the sensors reported herein is compared with the manufacturer-specified accuracy at 25°C since most of the manufacturers report the sensor accuracy at 25°C (see Table 1); however, discussions of the performance accuracy at 15°C and 35°C are also presented.

**Model A (Capacitive Type)**

The deviations of the measured relative humidity from the actual relative humidity for the three Model A sensors are presented graphically in Figure 1 at 25°C. In addition, pooled deviations corresponding to Model A are presented in Figure 2 at 15°C, 25°C, and 35°C.

**Effect of Relative Humidity on Deviation.** The sensitivity of the deviation to relative humidity is evident in both Figures 1 and 2. The deviation shifts upward when the actual relative humidity is increased from 10% to 30%, while the deviation shifts downward when the actual relative humidity is increased from 30% to 90% for the three sensors at each of the three different temperatures. For example, the deviation for the forward measurement of sensor 1 at 25°C increases from –0.2% to 1.3% when the actual humidity is increased from 10% to 30% (see Figure 1), while the deviation decreases from 1.3% to –2.1% when the humidity is increased from 30% to 90%. This same trend is seen at all temperatures in Figure 2.

**Performance Accuracy.** The manufacturer stated accuracy for the Model A sensor is ±3% at 25°C for a relative humidity range of 20%-80%. The accuracy is not stated at 15°C and 35°C.

The performance of Model A can be evaluated by considering the pooled deviations in Figure 2. At 25°C, the pooled deviations are within the manufacturer stated range of ±3% at relative humidities of 50% and 70%. The pooled deviation is 4.1% at a relative humidity of 30%, which does not meet the manufacturer stated accuracy.

At 35°C, the pooled deviations are within ±3% over a relative humidity range of 10% to 70%, while the deviation is –3.6% at a relative humidity of 90%. At 15°C, the deviations...
FIGURE 3 Comparison of deviation from actual relative humidity for three Model B sensors at 25°C.

FIGURE 4 Comparison of pooled deviation from actual relative humidity for three Model B sensors.

are within ±3% for relative humidities of 70% and 90%, while the deviations are 5.1%, 6.6%, and 4.7% at relative humidities of 10%, 30%, and 50%, respectively.

Effect of Temperature on Deviation. The dependence of the pooled deviations on temperature is evident from Figure 2. At all relative humidity conditions, the data points corresponding to 15°C are located above the data points for 25°C, which, in turn, are located above the data points for 35°C. This indicates that for a given actual relative humidity the average measurement of the relative humidity decreases with increasing temperature. For example, at 10% relative humidity, the average deviations are 5.1%, 2.7%, and 1.1% corresponding to 15°C, 25°C, and 35°C, respectively.

Model B (Capacitive-Type)

Deviations of all three Model B sensors at 25°C are shown in Figure 3, while pooled deviations at 15°C, 25°C, and 35°C are shown in Figure 4.

Effect of Relative Humidity on Deviation. The sensitivity of the deviation to relative humidity is evident in both Figures 3 and 4. The deviation generally shifts upward when the actual humidity is increased from 10% to 50%, while the deviation shifts downward when the actual humidity is increased from 50% to 90% for the three sensors at each of the three different temperatures. For example, the deviation of the forward measurement for sensor 1 at 25°C increases from −4.1% to 3.0% when the actual humidity is increased from 10% to 50% (see Figure 3), while the deviation in humidity decreases from 3.0% to −2.1% when the humidity is increased from 50% to 90%. This same trend is seen at all temperatures in Figure 4.

Performance Accuracy. The specification of accuracy provided by the Model B sensor is ±3% for a relative humidity range of 10% to 90%. The accuracy is not stated at a particular temperature.

The performance of Model B can be evaluated by considering the pooled deviations in Figure 4. At 25°C, the deviations are within the specified accuracy of ±3% for relative humidities of 30% and 70%, while the deviations are −3.9%, 3.3%, and −4.5% at relative humidities of 10%, 50%, and 90%, respectively.

At 35°C, the deviations are within ±3% for a relative humidity range of 30% to 70%, while the deviations are −5.5% and −6.4% at relative humidities of 10% and 90%, respec-
tively. At 15°C, the deviations are within ±3% for relative humidities of 10% and 90%, while the deviations are 5.9%, 6.1%, and 3.3% at relative humidities of 30%, 50%, and 70%, respectively.

Effect of Temperature on Deviation. The dependence of the pooled deviations on temperature is evident from Figure 4. At all relative humidity conditions, the data points corresponding to 15°C are located above the data points for 25°C, which, in turn, are located above the data points for 35°C. This indicates that for a given actual relative humidity, the average measurement of the relative humidity decreases with increasing temperature. For example, at 10% relative humidity, the deviations are -1.7%, -3.9%, and -5.5% corresponding to temperatures of 15°C, 25°C, and 35°C, respectively.

Model C (Capacitive-Type)

Deviations of all three Model C sensors at 25°C are shown in Figure 5, while pooled deviations at 15°C, 25°C, and 35°C are shown in Figure 6.

Effect of Relative Humidity on Deviation. The sensitivity of the deviation to relative humidity is evident in both Figures 5 and 6. The deviation generally shifts downward when the actual humidity is changed from 10% to 30%, then the deviation is almost constant for a 30% to 70% humidity range, and finally it shifts downward when the humidity is increased from 70% to 90% for the three sensors at each of the three different temperatures. For example, the deviation for the forward measurement of sensor 1 at 25°C decreases from 0.6% to -0.7% when the actual humidity is increased from 10% to 30%, then the deviation changes by only 0.1% when the actual humidity is increased from 30% and 70%, and, finally, the deviation decreases from -1.8% to -3.0% (see Figure 5) when the actual humidity increases from 70% to 90%. This same trend is seen at all temperatures in Figure 6.

Performance Accuracy. The specification of accuracy provided by the Model C sensor is ±3% for a relative humidity range of 10% to 90%. The accuracy is not stated at 15°C and 35°C.

The performance of Model C can be evaluated by considering the pooled deviations in Figure 6. At 25°C, the deviations are within the manufacturer specification of ±3% for a relative humidity range of 10% to 70%, while the deviation is
Effect of Temperature on Deviation. The dependence of the pooled deviations on temperature is evident from Figure 6. At all relative humidity conditions, the data points corresponding to 15°C are located above the data points for 25°C, which, in turn, are located above the data points for 35°C. This indicates that for a given actual relative humidity, the average measurement of the relative humidity decreases with increasing temperature. For example, at 10% relative humidity, the deviations are 0.3%, 0.1%, and −0.1% corresponding to 15°C, 25°C, and 35°C, respectively.

Model D (Resistive-Type)

Deviations of all three Model D sensors at 25°C are shown in Figure 7, while pooled deviations at 15°C, 25°C, and 35°C are shown in Figure 8.
within \pm 3\% for a relative humidity range of 30\% to 90\% and the deviation is 4.8\% at a relative humidity of 10\%.

**Effect of Temperature on Deviation.** The dependence of the pooled deviations on temperature is shown in Figure 8. A downward shift in deviation occurs for the three sensors at 10\% relative humidity as the temperature increases from 15\°C to 35\°C. For example, at 10\% relative humidity, the deviations are 4.9\%, 1.2\%, and −1.1\% corresponding to 15\°C, 25\°C, and 35\°C, respectively. There is no obvious effect of temperature on deviation in the 30\% to 90\% humidity range as seen from Figure 8.

**Model E (Resistive-Type)**

Deviations of all three Model E sensors at 25\°C are shown in Figure 9, while pooled deviations at 15\°C, 25\°C, and 35\°C are shown in Figure 10.

**Effect of Relative Humidity on Deviation.** The sensitivity of the deviation to relative humidity is evident in both Figures 9 and 10. The deviation generally shifts downward when the actual humidity is increased from 10\% to 70\%, while the deviation shifts upward when the actual relative humidity is increased from 70\% to 90\% for the three sensors at each of the three different temperatures. For example, the deviation for the forward measurement of sensor 1 at 25\°C decreases from −1.5\% to −10.1\% at 25\°C when the actual humidity is increased from 10\% to 70\% (see Figure 9), while the deviation in humidity increases from −10.1\% to −6.7\% when the humidity is increased from 70\% to 90\%.

**Performance Accuracy.** The specification of accuracy provided by the Model E sensor is \pm 3\% at 25\°C for a relative humidity range of 15\% to 95\%. The accuracy is not stated at a particular temperature.

The performance of Model E can be evaluated by considering the pooled deviations in Figure 10. At 25\°C, the deviations are outside the specified accuracy of \pm 3\% and are −5.5\%, −7.9\%, −9.3\%, and −8.6\% at relative humidities of 30\%, 50\%, 70\%, and 90\%, respectively.

At 35\°C, the deviations are −3.6\%, −6.6\%, −9.2\%, −10.0\%, and −10.7\% at relative humidities of 10\%, 30\%, 50\%, 70\%, and 90\%, respectively. At 15\°C, the deviations are −3.2\%, −5.7\%, −8.1\%, −8.9\%, and −7.7\% at relative humidities of 10\%, 30\%, 50\%, 70\%, and 90\%, respectively.

**Effect of Temperature on Deviation.** The dependence of the pooled deviations on temperature is shown in Figure 10. For a 10\% to 70\% relative humidity range, the data points
Figure 11 Comparison of deviation from actual relative humidity for three Model F sensors at 25°C.

Figure 12 Comparison of pooled deviation from actual relative humidity for three Model F sensors.

corresponding to 25°C are located above the data points for 15°C, which, in turn, are located above the data points for 35°C, while for the relative humidity changing from 70% to 90%, the data points corresponding to 15°C are located above the data points for 25°C, which, in turn, are located above the data points for 35°C. Hence, there is no obvious effect of temperature on deviation in the 30% to 70% humidity range as seen from Figure 10.

Model F (Resistive-Type)

Deviations of all three Model F sensors at 25°C are shown in Figure 11, while pooled deviations at 15°C, 25°C, and 35°C are shown in Figure 12.

Effect of Relative Humidity on Deviation. The sensitivity of the deviation to relative humidity is evident in both Figures 11 and 12. The deviation generally shifts upward when the actual humidity is increased from 10% to 30%, while the deviation shifts downward when the actual humidity is increased from 30% to 90% for the three sensors at each of the three different temperatures. At 15°C, the deviation shifts downward for the entire relative humidity range. For example, the deviation for the forward measurement of sensor 1 at 25°C increases from −4.0% to 1.2% when the actual humidity is increased from 10% to 30% (see Figure 11), while the deviation in humidity decreases from 1.2% to −2.0% when the humidity is increased from 30% to 90%.

Performance Accuracy. The specification of accuracy provided by the Model F sensor is ±3% at 25°C for a relative humidity range of 15% to 95%. The accuracy is not stated at 15°C and 35°C.

The performance of Model F can be evaluated by considering the pooled deviations in Figure 12. At 25°C, the deviations are within the manufacturer specification of ±3% for a relative humidity range of 30% to 90%.

At 35°C, the deviations are within ±3% for a relative humidity range of 30% to 70% and the deviations are −8.1% and −3.7% at relative humidities of 10% and 90%, respectively. At 15°C, the deviations are within ±3% for a relative humidity range of 50% to 90%, and 5.7% and 4.2% at relative humidities of 10% and 30%, respectively.

Effect of Temperature on Deviation. The dependence of the pooled deviations on temperature is evident from Figure 12. At all relative humidity conditions, the data points corresponding to 15°C are located above the data points for 25°C, which, in turn, are located above the data points for
35°C. This indicates that for a given actual relative humidity, the average measurement of the relative humidity decreases with increasing temperature. For example, at 10% relative humidity, the deviations are 5.7%, -0.1%, and -8.0% corresponding to 15°C, 25°C, and 35°C, respectively.

**SUMMARY OF RESULTS**

**Performance Accuracy**

In summary, at 25°C, two of the six humidity sensors, namely, Model D (i.e., resistive type) and Model F (i.e., resistive type) sensors, are within specified accuracy of ±3% for the entire 10% to 90% humidity range. For each of the other sensors, the specified accuracy was satisfied for only part of the humidity range. For example, at 25°C, Model C (i.e., capacitive type) sensors are within ±3% accuracy for a 10% to 70% humidity range; however, they are outside of the specified accuracy range at 90% humidity. Furthermore, for Model E (i.e., resistive type) sensors, the specified accuracy is ±3% for a 15% to 95% humidity range; however, measured deviations are outside of the specified accuracy for the full humidity range. Model A (i.e., capacitive type) sensors are within ±3% for a 20% to 80% humidity range, while the deviations are outside of the specified accuracy range at 30% relative humidity. Model B (i.e., capacitive type) sensors are within the ±3% accuracy at 30% and 70% humidity; however, they are outside of the specified accuracy range at 10%, 50%, and 90%.

**Effect of Relative Humidity**

In summary, it was observed that the deviations showed sensitivity to the actual relative humidity over the entire range. It also showed that the deviations from the three sensors for each manufacturer’s model follow similar patterns over the entire range of humidities. However, no obvious trends in deviations are observed among the sensor models of different manufacturers. For example, the deviation of the Model A sensor shifts upward when the actual relative humidity is increased from 10% to 30%, while the deviation shifts downward when the actual relative humidity is increased from 30% to 90%. In contrast, for the Model C sensor, the deviation generally shifts downward when the actual humidity is changed from 10% to 30%, then the deviation is almost constant for a 30% to 70% humidity range, and finally it shifts downward when the humidity is increased from 70% to 90%.

**Effect of Temperature**

In summary, the accuracy testing also revealed a significant and consistent temperature dependency for Models A, B, C, and F. For example, at all relative humidity conditions, the measured values for Model A corresponding to 15°C are higher than those for 25°C, which, in turn, are higher than those for 35°C. The same is true for Models B, C, and F. Sensitivity to temperature is generally not addressed by manufacturer literature and, as evidenced by the results of this study, may have a significant impact on accuracy.

**COMPARISON OF RESISTIVE AND CAPACITIVE SENSORS**

As previously mentioned, the most commonly used humidity sensors in building HVAC systems are the capacitive and the resistive type relative humidity sensors. One of the advantages of capacitive-type sensors includes being accurate (i.e., the sensor meets the manufacturer-specified accuracy) in the low RH (<15%) range, while the advantages of resistive-type sensors includes being accurate (i.e., the sensor meets the manufacturer-specified accuracy) in the high RH (>90%) range (Wiederhold 1997). Based upon the testing reported herein, it was observed that at 25°C, capacitive sensors meet the manufacturer-specified accuracy in the low RH (i.e., at 10% RH) range, while the resistive sensors meet the manufacturer-specified accuracy in the high RH (i.e., at 90% RH) range. For example, two of the three capacitive sensor models, namely, Models A and C, meet the manufacturer-specified accuracy at low humidity (see Figures 2 and 6) and two of the three resistive sensor models, namely, Models D and F, meet the manufacturer-specified accuracy at high humidity (see Figures 8 and 12).

In addition, the deviations of both the capacitive (i.e., Models A, B, and C) and resistive (i.e., Models D, E, and F) sensors show sensitivity to the changes in relative humidity. However, no common pattern in variation is observed between the capacitive and resistive sensors. For example, at 25°C, the deviation for the Model A sensor shifts upward when the actual relative humidity is increased from 10% to 30%, while the deviation shifts downward when the actual relative humidity is increased from 30% to 90%. In contrast, for the Model E sensor, the deviation shifts downward when the actual humidity is increased from 10% to 30%, while the deviation shifts upward when the actual humidity is increased from 70% to 90%.

Furthermore, the deviations of both the capacitive (i.e., Models A, B, and C) and resistive (i.e., Models D, E, and F) sensors show sensitivity to the changes in temperature. However, no common pattern in variation is observed between capacitive and resistive sensors. For example, the average measurement of the relative humidity for the Model C sensor decreases with increasing temperature for a given actual relative humidity, while there is no obvious effect of temperature on deviation seen for the Model E sensor over a 30% to 70% humidity range.

**EXAMPLE OF THE EFFECT OF HUMIDITY ERRORS ON BUILDING ENERGY USE**

An air-handling system operating with an enthalpy-based economizer is analyzed for the purpose of demonstrating the effect of errors (i.e., erroneous relative humidity measurements) on the annual energy consumption of a typical building HVAC system. An enthalpy-based economizer compares the

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enthalpy of the return air from the occupied zones to the enthalpy of the outdoor air. If the outdoor air enthalpy is less than the return air enthalpy, the dampers are positioned to allow 100% outdoor air to enter the air-handling unit. Otherwise, the dampers are positioned to allow only the minimum amount of outdoor air necessary for ventilation purposes. This strategy minimizes the energy that must be removed from the air in the cooling coil. Temperature and relative humidity measurements are necessary to establish the enthalpy condition of the air. The following simplified worse-case example involving a typical air-handling system illustrates the energy penalty (cost) that can result from erroneous relative humidity measurements, consider:

- Chicago weather
- 50,000 CFM capacity with 20% outdoor air required for ventilation
- Return air condition is fixed at 24°C and 50% RH
- Return air relative humidity measurement is 5% high (i.e., sensor reads 55% RH)
- Outdoor air relative humidity measurement is 5% low
- Energy efficiency ratio of the cooling plant is 12
- 24 hours a day operation
- $0.10 per kWh electricity

The cost associated with using 100% outdoor air when minimum outdoor air is appropriate is approximately $650 per year. If the sensors errors are 2.5%, the cost is approximately $130 per year and if the sensor errors are 7.5%, the cost is approximately $1540 per year. By comparison, the savings potential from using an enthalpy-based economizer with perfect measurements instead of a dry-bulb economizer with a 20°C switchover temperature (i.e., 100% outdoor air is used if the outdoor dry-bulb temperature is less than 20°C; otherwise minimum outdoor air is used) is approximately $1960 per year.

CONCLUSION

Three duct-mounted humidity sensors from each of six different manufacturers were tested to evaluate the sensor accuracy and to provide a comparison with manufacturer-specified accuracy. Out of the six different humidity sensors that were tested, three sensors were of the resistive type, while the other three sensors were of capacitive type. The manufacturer-specified accuracy for all sensors is ±3%. Testing of the sensors was performed at 10%, 30%, 50%, 70%, and 90% relative humidity for each of three different temperatures, namely, 15°C, 25°C, and 35°C.

Based upon the testing, it was observed that two of the three capacitive sensors are accurate in the low RH (i.e., at 10%) range, while two of the three resistive sensors are accurate in the high RH (i.e., at 90%) range. Furthermore, at 25°C, two of the six humidity sensor models, namely, Model F (i.e., resistive type) and Model D (i.e., resistive type) are within manufacturer-specified accuracy of ±3% for the entire humidity range. A third sensor model, namely, Model E (i.e., resistive type), did not meet the manufacturer-specified accuracy of ±3% at any humidity level tested, while the remaining three sensor models, namely, Model A (i.e., capacitive type), Model B (i.e., capacitive type), and Model C (i.e., capacitive type) met the manufacturer-specified accuracy of ±3% for only part of the humidity range. It should be noted that the manufacturer-specified accuracy of ±3% is typically specified at 25°C, and the manufacturers do not make accuracy claims at 15°C and 35°C.

All sensor models showed relative humidity dependence for the entire humidity range. For example, the deviations of all three Model E sensors generally shifted downward when the actual humidity is increased from 10% to 70%, while the deviations shift upward when the actual humidity is increased from 70% to 90% at each of the three different temperatures.

In addition, all sensor models except Model D showed temperature dependence for the entire humidity range. For example, the data points for Model A, B, and C sensors at 15°C are located above the data points for 25°C, which, in turn, are located above the data points for 35°C.

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REFERENCES


