Product Testing Report Supplement

Duct - Mounted Relative Humidity Transmitters

July 2005

Table of Contents

2 NBCIP Testing

Ageing Effects on Humidity Transmitters
Testing Methods
Response Time Tests
Testing Methods
Room Environment
Humidity Generator Environment
Stress Tests
Testing Methods

11 Test Results

Ageing Effects on Humidity Transmitters
Accuracy Testing
Repeatability
Linearity
Hysteresis
In-Situ Performance
Response Time Test
Stress Tests

26 Conclusions

27 Terms and Definitions

27 References

Program Sponsors
California Energy Commission
Iowa Energy Center
NSTAR Electric & Gas Corporation
United States Environmental Protection Agency

INTRODUCTION

This report is a supplement to the Product Testing Report: Duct-Mounted Relative Humidity Transmitters that was published by the National Building Controls Information Program (NBCIP) in April 2004.

From March to June 2002, NBCIP purchased three relative humidity transmitters of the same model from the following six leading manufacturers (Figure 1):

- Automation Components Inc.
- Building Automation Products Inc.
- General Eastern Inc.
- Johnson Controls Inc.
- MAMAC Systems Inc.
- Vaisala

NBCIP selected only humidity transmitters having an accuracy of ±3% RH and 0-10V output signal for testing. A total of 18 transmitters, of which half were resistive type sensors and half were capacitive type sensors, were tested from July to August 2002 for accuracy, repeatability, linearity, and hysteresis. The Product Testing Report: Duct-Mounted Relative Humidity Transmitters provides an overview of factors to consider when purchasing a humidity transmitter, presents manufacturer data for transmitters selected for testing, describes the test procedure and test apparatus used by NBCIP to evaluate transmitter performance, and presents test results for accuracy, repeatability, linearity, and hysteresis for each humidity transmitter model tested.

Download Information

Download your free copy of the Product Testing Report: Duct-Mounted Relative Humidity Transmitters by visiting the National Building Controls Information Program website at: www.buildingcontrols.org/.

This NBCIP Product Testing Report Supplement reports on further testing performed by NBCIP that includes:

- Effect of ageing
- Response time
- Stress testing, including cycling, dessication-saturation, and submergence

NBCIP's ageing tests are designed to assess the long-term performance of the duct-mounted relative humidity transmitters that have been exposed to a broad range of environmental conditions representative of a typical commercial building application. Long-term performance refers to how transmitter accuracy drifts over time and determines the frequency of calibration. A stable humidity transmitter would require less frequent calibrations.

The purpose of NBCIP's response time study is to determine the time required for a transmitter to respond to a step change in the relative humidity. The response time is a critical parameter that must be considered when using a humidity transmitter for control applications. The sensing technology as well as the quality of sensing materials used will influence the response time. Many industrial processes require humidity sensors with fast response times, on the order of seconds. In contrast, most building air-conditioning processes have response times on the order of minutes, and therefore, slower humidity sensor response times can be acceptable. Ultimately however, the importance of the response time depends on the application. For example, the response time is important in applications that require active control of a humidification process. A humidity transmitter with a slow response time may cause the control to overshoot or undershoot the desired humidity value because the sensed value will lag behind the actual condition. In economizer applications, the response time of the humidity transmitter is not a critical factor. The outdoor and return air relative humidity will generally change very gradually, so a sluggish transmitter has less impact on control. Furthermore, the humidity is not actually being controlled in this application; measurements of the outdoor and return air temperature and relative humidity are simply used to determine whether the outdoor air damper should be 100% open, or set at its minimum value for ventilation purposes.

Figure 1.
Sample of duct-mounted relative humidity transmitters selected from six manufacturers for NBCIP testing; from left to right: MAMAC Systems Inc., Building Automation Products Inc., Johnson Controls Inc., Vaisala, General Eastern Inc., Automation Components Inc.

The stress tests that NBCIP conducted on the relative humidity transmitters are designed to subject the transmitters to extreme conditions, and therefore, evaluate the robustness of the transmitters. NBCIP stress testing of humidity transmitters consists of three types of tests: cycling, desiccation-saturation, and submergence. The cycling test consists of subjecting the transmitters to cyclic variations of the relative humidity conditions, the desiccation-saturation test consists of exposing the test transmitters to 0% and 100% relative humidity conditions, and the submergence test consists of immersing the test transmitter sensing element in water.

This NBCIP Product Testing Report Supplement describes the test procedures and test apparatus used by NBCIP to evaluate transmitter performance, and presents test results for ageing, response time and stress testing for each humidity transmitter model tested. ■

NBCIP TESTING

Technical information for the transmitters, obtained from manufacturer product literature, is reported in Table 1. To ensure objectivity, NBCIP does not accept funding or products from manufacturers. Product manufacturers were not involved in developing the method of test and in conducting product testing, nor were they given an opportunity to view the test results prior to public release of this report. Manufacturers were contacted by NBCIP only to verify the correctness of the product information presented in Table 1.

From the three transmitters for each manufacturer that had previously undergone the accuracy tests described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters, NBCIP selected the most accurate and least accurate transmitters, producing a total of 12 transmitters, to undergo the ageing test. The remaining transmitter for each manufacturer was selected to undergo the response time tests and the stress testing.

Table 1. Technical information for duct-mounted relative humidity transmitters tested by NBCIP, as reported in manufacturer product literature.

Manufacturer	Automation Components Inc. (ACI)	Building Automation Products Inc. (BAPI)	General Eastern Inc. (GEA)	Johnson Controls Inc. (JCI)	MAMAC Systems Inc. (MAMAC)	Vaisala (Vaisala)
Model Number	A/RH3-D	BA/H310-D	MRH-3-D	HT-6703-0N00P	HU-224-3-VDC	HMD50U
Sensing Element	Resistive	Impedance type	Bulk polymer Resistive	All-polymer Capacitive	Bulk polymer Capacitive	Thin film polymer Capacitive
Price Paid by NBCIP ($US) [1]	$125	$150	$194	$248	$275	$180
Accuracy	±3% RH 20% to 95% RH *at 77° F (25°C)* [4]	±3% RH 15% to 95% RH	±3% RH at 77°F (25°C) 20% to 95% RH	±3% RH at 77°F (25°C) 20% to 80% RH ±5% RH at 77°F (25°C) 10% to 20% and 80% to 90% RH	±3% RH 10% to 90% RH	Better than ±3% RH at 68°F (20°C) 10% to 90% RH
Operating Range	-10°F to 160°F (-23.3°C to 71°C) 0% to 100% RH	*-20°F to 160°F (-28°C to 70°C)* [6] 0% to 100% RH	-20°F to 140°F (-29°C to 60°C) 0% to 95% RH	32°F to 122°F (0°C to 50°C) 0% to 100% RH	-30°F to 130°F (-35°C to 55°C) 10% to 90% RH	14°F to 140°F (-10°C to 60°C) 0% to 100% RH
Linearity	NA	±0.1% of span	Included in accuracy	NA	Included in accuracy	*Included in accuracy* [4]
Hysteresis	<0.4% RH	<0.4% RH	<1% RH Included in accuracy	NA	±1% RH	*Included in accuracy* [4]
Repeatability	0.5% RH	NA	0.5% RH Included in accuracy	NA	Included in accuracy	*Included in accuracy* [4]
Long Term Stability	<2% RH drift over 5 years	*<2% RH drift over 5 years* [6]	<1% RH drift per year	NA	NA	±2% RH over 2 years
Response Time	30 sec. for 63% step	*30 sec. for 63% step* [6]	NA	Within 5% RH in 15 min. for 10-30%, 30-90%, 40-90% RH	NA	*<20 sec. at 68°F (20°C) in still air* [4]
Sensitivity	0.1% RH	NA	0.1% RH	NA	NA	NA
Supply Voltage [2]	15-36 VDC for 250 Ohm load, 18-36 VDC for 500 Ohm load [5], or 24 VAC	24 VDC 24 VAC	12-36 VDC	14-30 VDC for 0-10 VDC output, 20-30 VAC for 0-10 VDC output, 16-30 VDC for 4-20mA output	12-40 VDC 12-35 VAC	12-35 VDC/12-24 VAC for 0-1 VDC output, 15-35 VDC/15-24 VAC for 0-10 VDC output
Output[3]	0-5 VDC, 0-10 VDC, 4-20mA Jumper select	0-10 VDC	0-5 VDC, 0-10 VDC, 4-20mA Jumper select	0-10 VDC, 4-20mA Jumper select	0-5 VDC, 0-10 VDC Jumper select	0-1 VDC, 0-10 VDC, Selectable voltage 3-wire output
Storage Temperature	*-10°F to 160°F (-23.3°C to 71°C) 0% to 100% RH* [4]	*-20°F to 160°F (-28°C to 70°C)* [6]	-85°F to 158°F (-65°C to 70°C)	-40°F to 176°F (-40°C to 80°C)	*-30°F to 130°F (-35°C to 55°C)* [4]	-40°F to 140°F (-40°C to 60°C)
Warranty	2 years	*Lifetime replacement* [4]	2 years	*3 years* [4]	2 years	*1 year* [4]

Notes:
NA indicates that the information was not available in the manufacturer's product literature.
1. Price shown in the table represents actual invoice cost to NBCIP. Your actual cost may differ depending on volume purchased, reseller, trade discounts and other pricing structures.
2. NBCIP tested the duct-mounted humidity transmitters using a supply voltage of 24 VDC.
3. NBCIP tested the duct-mounted humidity transmitters using an output voltage of 0-10 VDC. Other voltage outputs are available as indicated in the table.
4. Information in italics font was not available in manufacturer's product literature. Information in italics font was reported directly by the manufacturer.
5. The manufacturer's literature indicates a supply voltage of 17-36 VDC for 500 Ohm load. A supply voltage of 18 VDC was reported directly by the manufacturer.
6. Manufacturer reported that product literature is in the process of being updated. Information in italics font was reported directly by the manufacturer.

Ageing Effects on Humidity Transmitters

The purpose of NBCIP's ageing test is to determine the extent to which transmitter accuracy drifts after prolonged exposure to environmental conditions representative of a typical commercial building application. NBCIP installed the test transmitters in an outdoor air duct of the Iowa Energy Center's Energy Resource Station (ERS) test facility where they were exposed to the outdoor air stream from April 22, 2003 to June 30, 2004. NBCIP tested the transmitters for accuracy, repeatability, linearity, and hysteresis (hereafter collectively referred to as "accuracy testing") every four months using the Thunder Scientific Model 2500 Humidity Generator (Thunder Scientific, 2000) that was described in the NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters. Accuracy testing was performed at the Center for Building Energy Research (CBER), Iowa State University, under NBCIP's direction.

Testing Methods

The 12 relative humidity transmitters under test were installed in the outdoor air duct of air-handling unit 1 (AHU 1) at the ERS (Figure 2) according to the manufacturer's written installation instructions. The outdoor air duct was selected as a suitable location because it met two key criteria: (1) over the course of a year, the transmitters were expected to experience a broad range of relative humidity, temperature, and velocity conditions, and (2) the velocity distribution at the test location in the duct should be uniform in accordance with ASHRAE Standard 111 requirements. The test relative humidity transmitters were installed with the transmitter probes protruding into the duct air stream and were maintained a minimum of three inches from the nearest duct wall, as shown in Figure 3. The orientation of the transmitters was noted before the test began and remained consistent throughout the tests.

Figure 2.
Six of 12 relative humidity transmitters installed on one side of the outdoor air duct at the Iowa Energy Center Energy Resource Station.

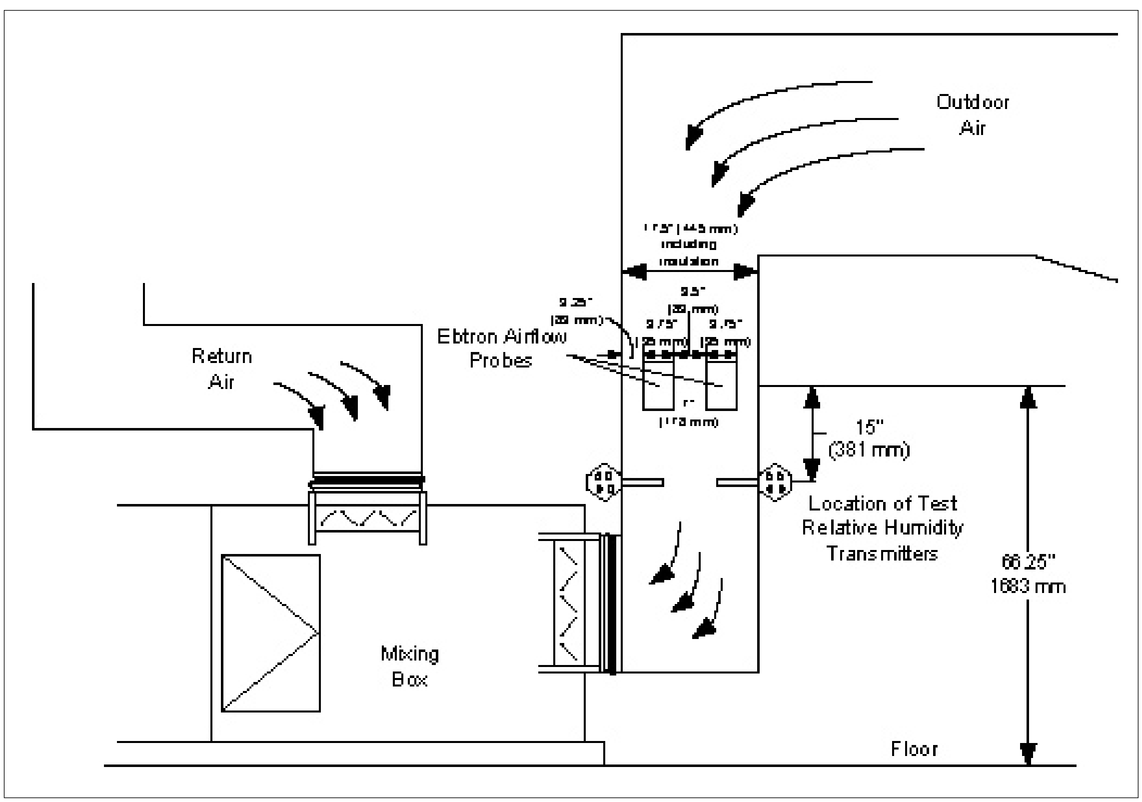


Figure 3.
Schematic diagram of the location for installation of the test relative humidity transmitters in AHU 1 at the Iowa Energy Center Energy Resource Station.

NBCIP monitored the relative humidity, temperature, and average air velocity conditions experienced by the test relative humidity transmitters using reference transmitters installed in proximity of the test transmitters. Refer to the side bar *Reference Transmitters* for more information on these transmitters. Two Sola/Hevi-Duty model SLS-24-012T power supplies having regulated output voltage of 24 VDC ± 1.2 V were used to power the test transmitters as well as the reference relative humidity transmitter that was used for monitoring purposes. One power supply powered six test transmitters and the second power supply powered the other six test transmitters and the reference transmitter. The output of each test transmitter and the reference transmitters was sampled, recorded and stored at five-minute intervals continuously using Johnson Controls DX 9100-8454 controllers and Johnson Controls Metasys trending and archiving software.

The reference relative humidity transmitter, temperature transmitters, and velocity transmitter used for monitoring purposes were calibrated prior to commencing the ageing tests. Also, the input channels on the Johnson Controls DX 9100-8454 were calibrated using a five-point calibration procedure. The calibration points were evenly distributed over the transmitter output range (0-10V) to ensure accurate scaling and linear recording of the input signal to the controller.

NBCIP conducted the ageing tests over a one-year period from April 22, 2003 to June 30, 2004. NBCIP removed the test transmitters from the duct and tested them for accuracy at four-month intervals. The intervals during which the transmitters were in the duct are shown in Table 2. The accuracy testing was performed using the test hardware and procedures described in the NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters, with the exception that the test conditions were restricted to a single temperature, 77°F (25°C).

Following each phase of the accuracy testing, the input channels of the Johnson Controls DX 9100-8454 were recalibrated and the transmitters re-installed in the outdoor air duct. The positions were changed every four months to ensure that each transmitter would spend an equal amount of time in each area of the duct (i.e., Area 1, Area 2, and Area 3) identified in Figure 4.

Table 2.
Intervals when transmitters were in the outdoor air duct for NBCIP ageing tests.

Date installed in duct	Date removed from duct for accuracy testing
April 22, 2003	August 25, 2003
October 9, 2003	February 9, 2004
March 2, 2004	June 30, 2004

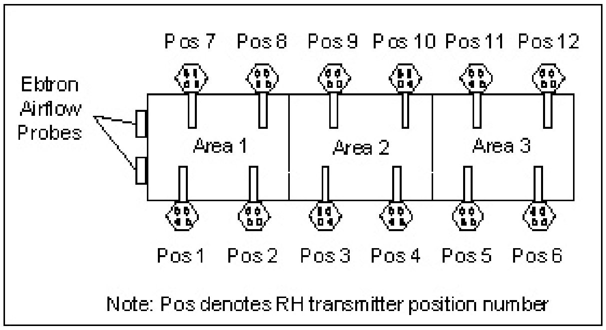


Figure 4.
Schematic diagram of the outdoor air duct cross-section divided into three equal areas. Transmitter positions were rotated every four months.

Reference Transmitters

NBCIP used a Vaisala model HMP 233 relative humidity/temperature transmitter as the in-situ reference relative humidity transmitter for the duration of the ageing test. The reference transmitter was installed near the location of the relative humidity transmitters under test. This transmitter has a measurement range of 0-100% RH and has a rated accuracy of ±1% RH for 0-90% RH and ±2% RH for 90-100% RH.

NBCIP measured the temperature near the location of the relative humidity transmitters under test using four Weed model 110-10BH-A-4-C-24 1000 Ω Platinum RTD immersion probe temperature transmitters wired in a series-parallel arrangement to produce an average temperature. This transmitter has a rated accuracy of ±0.27°F at 32°F (±0.15°C at 0°C) and ±0.63°F at 212°F (±0.35°C at 100°C).

The average air stream velocity was measured using Ebtron IAQ Enforcer Series-D airflow/temperature satellite transmitters for ducts. The velocity measurements have an accuracy of ±2% of the reading for velocities greater than or equal to 500 ft/min (2.54 m/s) and ±10 ft/min (±0.051 m/s) for velocities less than 500 ft/min (2.54 m/s).

Response Time Tests

The purpose of NBCIP's response time study is to determine the time required for a transmitter to respond to a step change in the relative humidity. The response time, also commonly termed the time constant, of a relative humidity transmitter is defined as the amount of time it takes for the transmitter output to reach 63% of its final value when subjected to a step change (i.e., either increasing or decreasing the relative humidity) in the relative humidity that it is measuring. The definition of the response time is depicted in Figure 5 and an explanation on how the response time is determined is provided in the sidebar *Measuring Response Time.*

NBCIP selected the remaining transmitter (i.e., those not undergoing the ageing test) from each manufacturer to undergo the response time testing described in this section. Response time tests were performed from April 22 to 23, 2004, and on May 15, 2004, at CBER under NBCIP's direction.

Testing Methods

The response time test of the humidity transmitters requires two stable environmental conditions and involves moving the test transmitters from one environmental condition to the other to create a step change in the relative humidity. For NBCIP's response time tests, one environmental condition was established by exposing the test transmitters to room conditions as room air was drawn through a duct, and the second environmental condition was established by exposing the test transmitters to relative humidity conditions inside the Thunder Scientific 2500 two-pressure humidity generator. Additional information on the humidity generator can be found in the NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters. Descriptions of the test transmitter installation in the two environments are presented in the following paragraphs.

Room Environment

The room environment for NBCIP's response time test consisted of a laboratory at CBER, Iowa State University. The test transmitters were installed in a duct whose inlet and outlet were open to the air in the CBER laboratory where testing was performed. The duct was used to mimic normal application of the test transmitters. A 12 VDC fan was used to draw air through the duct, and provide uniform velocity conditions inside the duct. The fan operated at a single speed so that air velocities on the order of 591 ft/min (3m/s) were obtained.

Measuring Response Time

Referring to Figure 5, the initial relative humidity reading is designated RH_i and the final relative humidity reading is designated RH_f. The difference between the two humidity values is given by:

$$\Delta RH = RH_f - RH_i \qquad (1)$$

The relative humidity value obtained from the test transmitter corresponding to a 63% change (i.e., one time constant) from the initial relative humidity reading to the final reading is given by:

$$RH_{0.63} = (0.63 \times \Delta RH) + RH_i \qquad (2)$$

Therefore, the time constant or response time of the test transmitter is the amount of time Δt required for the test transmitter to reach the value $RH_{0.63}$ given by equation (2).

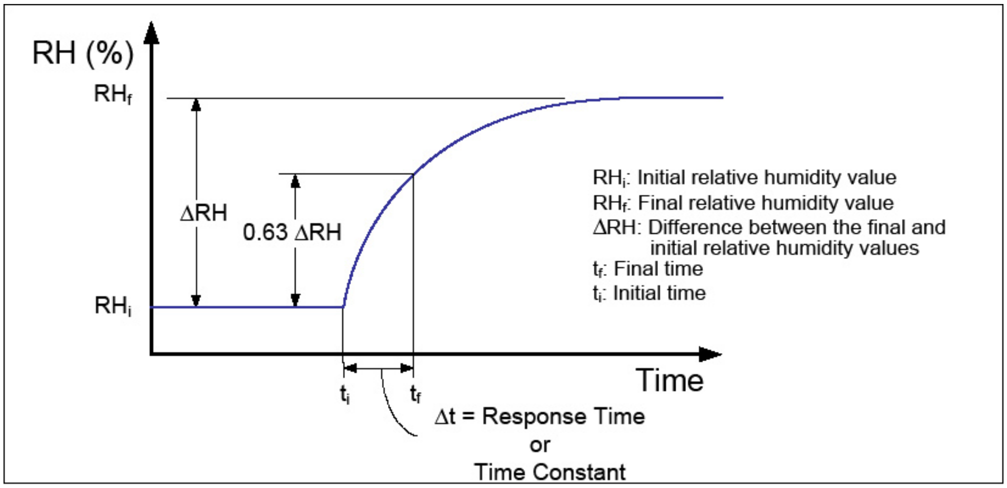


Figure 5.
Definition of the response time of a relative humidity transmitter.

The test transmitters were installed according to the manufacturer's written instructions and they were oriented in a similar manner when installed in both the duct and the humidity generator. Two test transmitters were installed in the duct and tested simultaneously. Installation was such that the test transmitters experienced similar velocity conditions.

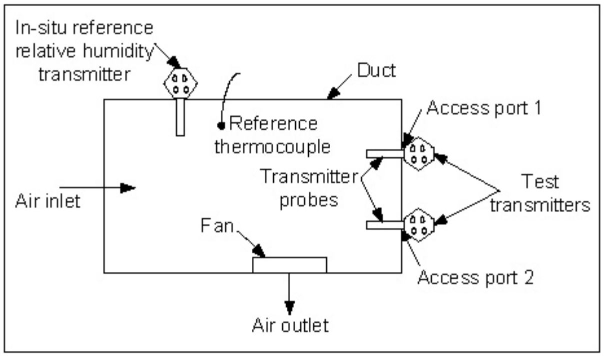


Figure 6.
Room environment for NBCIP response time tests: transmitter mounting layout inside the duct in the CBER test laboratory.

Room relative humidity conditions were measured using a Vaisala model HMP 233 relative humidity/ temperature transmitter, which is referred to as the in-situ reference relative humidity transmitter, or more simply the reference transmitter. The reference transmitter was installed in close proximity to the test transmitters. The characteristics of the HMP 233 transmitter are described in the side bar *Reference Transmitters*. A T-type thermocouple was used to measure the air temperature in the duct. A schematic of the duct showing the relative locations of the test transmitters, reference transmitter, reference thermocouple and fan is provided in Figure 6. The power supply and data acquisition equipment described in the NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters were used to power the test and reference transmitters and to measure the outputs of the transmitters and reference thermocouple.

Humidity Generator Environment

The test transmitters were installed in the humidity generator through access ports so that the transmitter electronics remained outside the humidity generator while the transmitter probe was exposed to the conditioned air in the humidity generator. A 12 VDC fan was used to move air across the sensor element of the transmitter so that the velocity conditions were similar to those in the duct. A schematic showing transmitter probe location, transmitter electronics, and access ports on the humidity generator is presented in Figure 7. Since the apparatus has two access ports, two relative humidity transmitters were tested at the same time.

A step change in relative humidity was created by moving the test transmitters from one environmental condition to a second environmental condition. NBCIP's response time test consisted of two parts: a **forward step test** and a **reverse step test.**

In the **forward step test** the relative humidity transmitters were moved from room conditions to

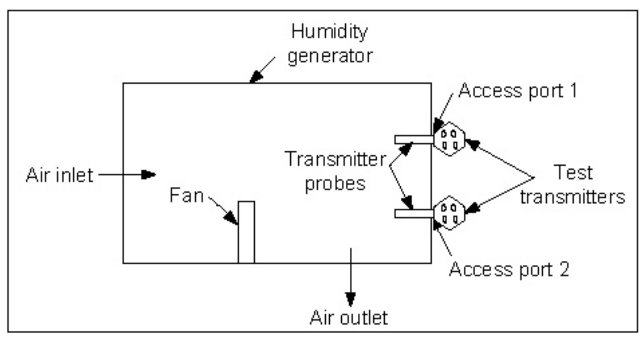


Figure 7.
Humidity generator environment for NBCIP response time tests: transmitter mounting layout through humidity generator access port.

Table 3.
Steady-state criteria for the test transmitters, reference thermocouple and humidity generator for NBCIP's response time test.

Device	Parameter	Steady-State Conditions
Test Transmitters	Transmitter Relative Humidity	Change of less than ±1% RH for 10 minutes based on measurements taken at one-second intervals
T-Type Reference Thermocouple	Room Temperature	Change of less than ±1.8˚F (±1˚C) for 10 minutes based on measurements taken at one-second intervals
Humidity Generator	Actual Relative Humidity in the humidity generator	Change of less than ±0.5% RH for 10 minutes

the humidity generator conditions, i.e., from a lower humidity condition to a higher humidity condition. The room relative humidity typically ranged from 20-55% RH and the temperature typically ranged from 68-77°F (20-25°C). Testing of the transmitters was carried out only when the room relative humidity was between 20-55% RH. The humidity generator operated at 80% RH and the temperature inside the humidity generator was adjusted to match the room temperature. The test transmitters were exposed to room conditions until the room conditions, humidity generator conditions and measurements from the test transmitters satisfied the steady-state criteria shown in Table 3. The test transmitters were then moved abruptly to the humidity generator and were exposed to the humidity conditions inside the generator and remained there until the transmitters satisfied the steady-state criterion in Table 3. In the forward step test, the room condition represents the initial relative humidity test condition and the condition inside the humidity generator represents the final relative humidity test condition.

In the **reverse step test** the relative humidity transmitters were moved from the humidity generator to room conditions, i.e., from a higher humidity condition to a lower humidity condition. The humidity generator operated at 80% RH and the temperature inside the humidity generator was adjusted to match the room temperature. In the reverse step test, the conditions inside the humidity generator represent the initial relative humidity test condition. The test transmitters were exposed to the conditions in the humidity generator until the room conditions, humidity generator conditions and measurements from the test transmitters satisfied the steady-state criteria in Table 3. Testing of the transmitters was carried out only when the room relative humidity was between 20-55% RH. The final relative humidity test condition for the reverse step test was established by exposing the test transmitters to room conditions until the measurements from the test transmitters satisfied the steady-state criterion in Table 3.

The forward and reverse step tests were performed three times each to establish the response time of each test transmitter. In addition, a forward step test was performed with the fan inside the humidity generator turned off for the purpose of comparing the response times of the transmitter when the fan *is* operating and when the fan is *not* operating. This test had a forward step only, and was performed only once.

Stress Tests

NBCIP's stress testing of the relative humidity transmitters consists of three types of tests: cycling, desiccation-saturation and submergence. The *cycling test* consists of subjecting the transmitters to cyclic variations of the relative humidity conditions, the *desiccation-saturation test* consists of exposing the test transmitters to 0% and 100% relative humidity conditions, and the *submergence test* consists of immersing the test transmitter sensing element in water. Following each phase of the stress test, the accuracy of the transmitters was measured at several relative humidity conditions to assess the extent to which the transmitters were affected by each test.

The relative humidity transmitters were powered by a 24 VDC supply voltage. Readings from the transmitters were recorded using laboratory grade data acquisition and control equipment and software. The Thunder Scientific two-pressure humidity generator was used to perform the accuracy testing following each phase of the stress test.

Testing Methods

Cycling Test

In the cycling test, NBCIP repeatedly exposed the transmitters to extreme relative humidity conditions at fixed temperatures. Cycling tests were performed on the relative humidity transmitters from April 27, 2004 to May 20, 2004, at CBER under NBCIP's direction.

NBCIP subjected the transmitters to an environment in which the relative humidity was cycled between 10% and 95% RH while the temperature was held constant. These test conditions were generated with the Thunder Scientific two-pressure humidity generator. The maximum and minimum humidity conditions for the cycling test are based on relative humidity conditions that can be generated by the humidity generator; however, these relative humidity conditions also represent the extreme range of conditions that a transmitter would likely be exposed to in an actual application.

Three transmitters were tested simultaneously inside the humidity generator using the custom-made manifold described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters. The cycling test was conducted at two test temperatures, 41°F (5˚C) and 95°F (35˚C), using the following procedure:

- Three relative humidity transmitters were installed in the manifold and the humidity generator conditions were set at 41°F (5˚C) and 10% RH.
- The conditions were allowed to stabilize for 30-minutes, and then the relative humidity of the generator was changed to 95% RH.
- The conditions were again allowed to stabilize for 30-minutes before the humidity was changed back to 10% RH.
- The above procedure constituted one cycle. The transmitters underwent 50 consecutive cycles while the temperature inside the humidity generator was maintained at 41°F (5˚C).
- After completing the 50 cycles at 41°F (5˚C), the transmitters underwent 50 cycles at 95°F (35˚C).

During the cycling test, readings from the transmitters were collected and stored at 5-minute intervals using the data acquisition and control equipment and software described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters.

Following the cycling test, the accuracy of the transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The procedure for accuracy testing is described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters.

Desiccation-Saturation Test

NBCIP's desiccation-saturation test consists of exposing the test transmitters to a dry environment (i.e., 0% RH) and a saturated environment (i.e., 100% RH) at room temperature, followed by accuracy testing at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. Desiccation-saturation tests were performed on the relative humidity transmitters from June 17 to June 25, 2004, at CBER under NBCIP's direction.

The dry environment (0% RH) was produced by sealing a container that was partially filled with desiccant. This is referred to as the desiccant bath. Given sufficient time, the air in the space above the desiccant will come to equilibrium at 0% RH. The saturated environment (100% RH) was produced by sealing a container that was partially filled with water. This is referred to as the water bath. Given sufficient time, the air in the container will come to equilibrium at 100% RH. A Vaisala model HMP 233 relative humidity/temperature transmitter was used to ensure that the environments in the containers were at or near the desired 0% and 100% RH conditions. The characteristics of this transmitter are described in the side bar *Reference Transmitters.*

A schematic of the test setup is shown in Figure 8. The test transmitters were installed such that the transmitter element protruded into the container while the transmitter electronics remained outside the container. The container had dimensions of 36 x 15 x 12 inches (91.4 x 38.1 x 30.5 cm) and had six openings in the lid to accommodate the test transmitters. After installing the transmitters in their respective openings, the openings were sealed so that there would be no ingress/egress of air and, as a result, the moisture content inside the container would remain unaltered. In addition, care was taken to ensure that the tips of the transmitters did not touch the desiccant/water surface and that all tips were a uniform distance above the surface of the desiccant/water bath.

The first step in the desiccation-saturation test procedure was to generate the dry and saturated environments in separate containers. Once these environments were established, the test transmitters were divided into two sets of three transmitters and the test procedure outlined below was conducted. During the time periods when the test transmitters were installed in the dry and saturated environments, readings from the transmitters were collected and stored at 5-minute intervals using the data acquisition and control equipment and software described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters. All accuracy

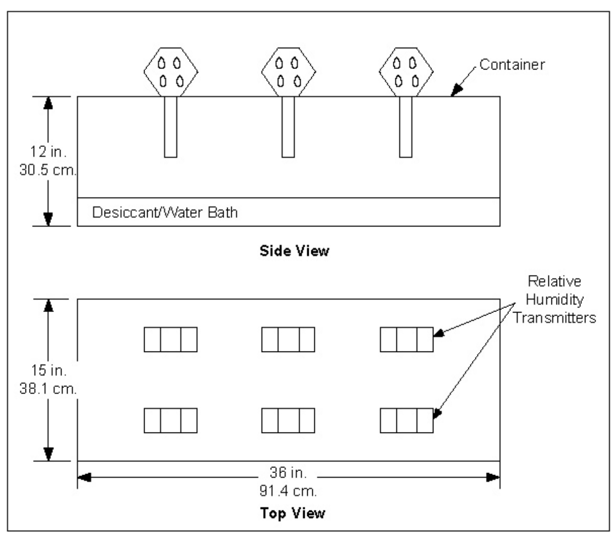


Figure 8.
Schematic of the container used for NBCIP's desiccation-saturation test showing how the relative humidity transmitters were installed.

measurements identified in the test procedure were made in the Thunder Scientific 2500 two-pressure humidity generator using the test procedures described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters. In addition, a ±3% RH transmitter was used to measure the relative humidity of the storage location during the periods of the test when the test transmitters were in storage. The test schedule is shown in Figure 9 and described below.

Day-1: The first set of three transmitters were installed in the container with the dry environment and remained there for two days. The second set of transmitters was placed in storage.
Day-2: The second set of three transmitters was installed in the dry environment and remained there for two days.
Day-3: The first set of transmitters was removed from the dry environment and the accuracy of this set of transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH.
Day-4: The second set of transmitters was removed from the dry environment and the accuracy of this set of transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The first set of transmitters was transferred to the container with the saturated environment and remained there for two days.
Day-5: The second set of transmitters was installed in the saturated environment and remained there for two days.
Day-6: The first set of transmitters was removed from the saturated environment and the accuracy of this set of transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH.
Day-7: The second set of transmitters was removed from the saturated environment and the accuracy of this set of transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The first set of transmitters was placed in storage.
Day-8: The accuracy of the first set of transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The second set of transmitters was placed in storage.
Day-9: The accuracy of the second set of transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The first set of transmitters was placed in storage.

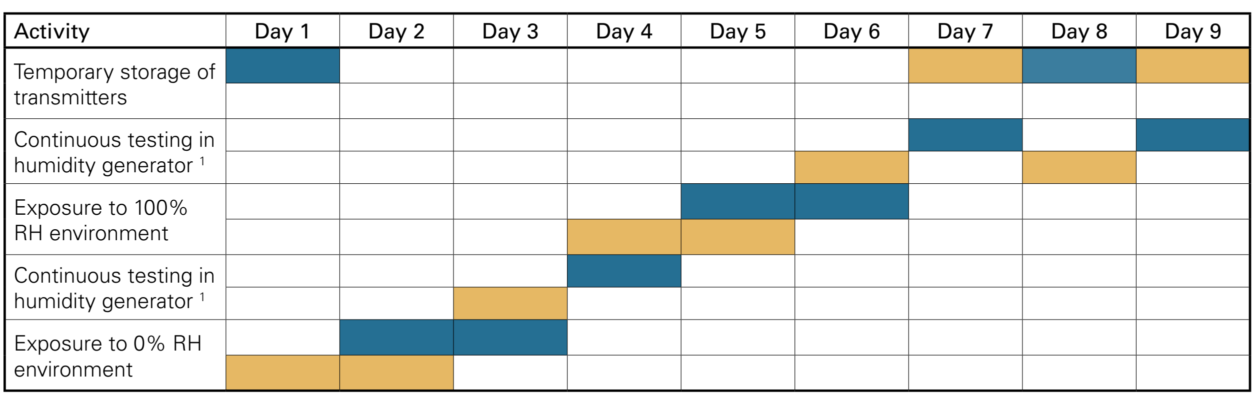
Accuracy testing on Day-8 and Day-9 was designed to determine if the transmitter performance improved after the transmitters were removed from the extreme environments for two days.

Submergence Test

NBCIP performed the submergence test after the cycling and desiccation-saturation tests were completed. The submergence test was performed from June 25 to June 30, 2004, at CBER under NBCIP's direction.

The test setup for the submergence test is shown in Figure 10. In this setup, sensor elements were submerged in water for a one-day period while the transmitter electronics remained outside the container.

NBCIP divided the transmitters into two sets of three transmitters and tested them over a period of five days following the test procedure outlined below. During the time period when the sensor elements were submerged, readings from the



Legend — First set of three transmitters — Second set of three transmitters

Note:
1. Test conditions: 77˚F (25˚C) and 20, 30, 50, 70, 90, 70, 50 and 30% RH.

Figure 9.
Test schedule for NBCIP desiccation-saturation test.

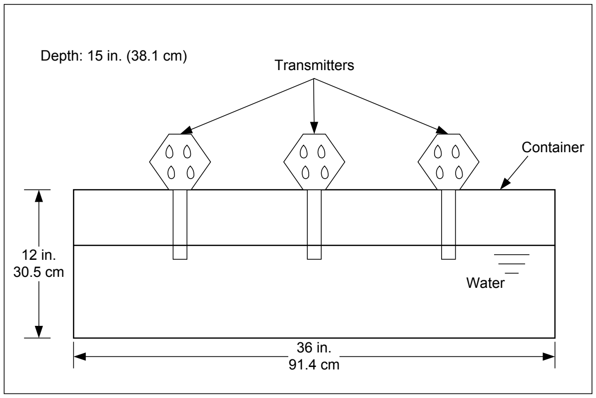


Figure 10.
Schematic of the NBCIP submergence test setup.

transmitters were collected and stored at 5-minute intervals using the data acquisition and control equipment and software described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters. All accuracy measurements identified in the test procedure were made in the humidity generator using the procedures described in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters. In addition, a ±3% RH transmitter was used to measure the relative humidity of the storage location during the periods of the test when the test transmitters were in storage. The test schedule is shown in Figure 11.

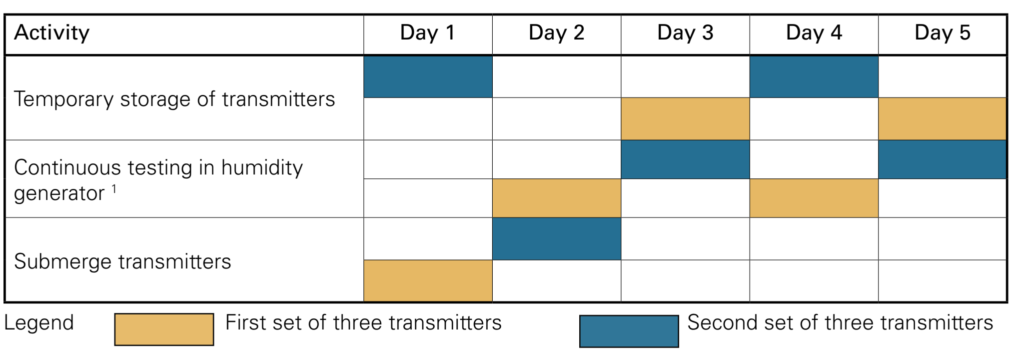
Day-1: The first set of transmitters was installed in the container such that the sensor elements were submerged in water. The second set of transmitters was placed in storage.
Day-2: The first set of transmitters was removed from the container and the accuracy of the transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The second set of transmitters was installed in the container such that the sensor elements were submerged in water.
Day-3: The second set of transmitters was removed from the container and the accuracy of the transmitters was measured at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The first set of transmitters was placed in storage.
Day-4: The accuracy of the first set of transmitters was measured again at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The second set of transmitters was placed in storage.
Day-5: The accuracy of the second set of transmitters was measured again at 77°F (25˚C) and 20%, 30%, 50%, 70%, 90%, 70%, 50% and 30% RH. The first set of transmitters was placed in storage.

Accuracy testing on Day-4 and Day-5 was designed to determine if the transmitter performance improved after the transmitters had been given two days to recover. ■

TEST RESULTS

Nine relative humidity transmitters failed during the course of NBCIP's long-term performance tests, four of which failed only after NBCIP submerged the transmitters in water. The condition of each transmitter from all six manufacturers is reported in Table 4. Where possible, NBCIP replaced failed transmitters with newly purchased ones, except in cases where the transmitter failed during the ageing tests or in cases where the particular transmitter model was no longer available or had changed substantially. It is important to note that NBCIP's submergence test represents an extreme condition that the transmitters would not normally encounter and are not necessarily designed to withstand.

None of the test transmitters from Vaisala failed during testing. One transmitter failed for both General Eastern Inc. (GEN EAST-2) and Johnson



Note:
1. Test conditions: 77˚F (25˚C) and 20, 30, 50, 70, 90, 70, 50 and 30% RH.

Figure 11.
Test schedule for NBCIP submergence test

Table 4. Condition of relative humidity transmitters during NBCIP ageing tests, response time tests, and stress tests.

Manufacturer	Transmitter Model Number	Transmitter Number [1]	Test	Condition [2]	Comments
Automation Components Inc.	A/RH3-D	ACI-1	Response time	Failed on 04/23/2004	Transmitter failed during response time tests. Replaced by transmitter 4. New transmitter could not be purchased because model A/RH3-D has changed since NBCIP first purchased this transmitter.
		ACI-2	Ageing	Operational	Transmitter used for ageing tests.
		ACI-4	Ageing Response time Stress	Operational until submergence test	Transmitter used for ageing tests. Removed from duct on 04/27/2004 to replace failed transmitter 1, and subsequently used for response time and stress tests. Transmitter failed after submergence test.
Building Automation Products Inc.	BA/H310-D	BAPI-1	Ageing	Operational	Transmitter used for ageing tests.
		BAPI-2	Response time	Failed on 11/19/2003	Transmitter failed prior to response time tests. Replaced by newly purchased transmitter (number 7).
		BAPI-4	Ageing	Impedance problems	Transmitter used for ageing tests. Transmitter experienced impedance problems during testing and could not read above 45% RH in the duct.
		BAPI-7	Response time Stress	Operational until submergence test	Transmitter purchased on 01/09/04 to replace failed transmitter 2. Transmitter 7 used for response time tests and stress tests. Transmitter failed on 06/29/04 during final round of accuracy testing after the submergence test was completed.
General Eastern Inc.	MRH-3-D	GEN EAST-1	Response time Stress	Operational	Transmitter used for response time tests and stress tests.
		GEN EAST-2	Ageing	Failed on 03/01/04	Transmitter used for ageing tests. Transmitter failed due to loose probe and disconnected wire. Repair attempted but not successful. Transmitter not replaced as ageing tests were already in progress.
		GEN EAST-4	Ageing	Operational	Transmitter used for ageing tests.
Johnson Controls Inc.	HT-6703-0N00P	JCI-1	Ageing	Operational	Transmitter used for ageing tests.
		JCI-2	Response time Stress	Operational until submergence test	Transmitter used for response time tests and stress tests. Transmitter failed after submergence test.
		JCI-4	Ageing	Operational	Transmitter used for ageing tests.
MAMAC Systems Inc.	HU-224-3-VDC	MAMAC-1	Ageing	Failed on 07/05/04	Transmitter used for ageing tests. Wire connector found failed prior to final round of accuracy testing after ageing tests were completed. Accuracy testing could not proceed.
		MAMAC-2	Response time	Failed on 04/23/04	Transmitter failed prior to response time tests due to loose cap that encases transmitter element. Replaced by newly purchased transmitter (number 5) for response time and stress tests.
		MAMAC-4	Ageing	Operational	Transmitter used for ageing tests.
		MAMAC-5	Response time Stress	Operational until submergence test	Transmitter purchased on 04/20/04 to replace failed transmitter 2. Transmitter used for response time tests and stress tests. Transmitter failed after submergence test.
Vaisala	HMD50U	VAISALA-1	Ageing	Operational	Transmitter used for ageing tests.
		VAISALA-2	Response time Stress	Operational	Transmitter used for response time tests and stress tests.
		VAISALA-4	Ageing	Operational	Transmitter used for ageing tests.

Notes:

1. Gaps in transmitter numbers represent extra transmitters that were purchased for development of the method of test and were not used for testing. The condition of the extra transmitters is not reported.
2. An "operational" transmitter condition indicates that the transmitter produces a useable output that changes with environmental conditions. A "failed" transmitter consistently produces output that is at or near the extreme of the humidity range, either 0% RH or 100% RH. An "operational until submergence test" condition indicates that the transmitter only failed after the submergence test was completed, but operated during other NBCIP tests. It is important to note that the transmitters tested by NBCIP are not necessarily designed to withstand submergence.

Controls Inc. (JCI-2). NBCIP did not replace transmitter GEN EAST-2 from General Eastern Inc. because it failed after eight months while the ageing test were already in progress. Accuracy test results for the NBCIP ageing tests reported in this Product Testing Report Supplement for GEN EAST-2 are therefore based on eight months of ageing instead of 12 months. Transmitter JCI-2 from Johnson Controls Inc. failed as a result of the submergence test.

Two transmitters failed for Automation Components Inc. (ACI-1 and ACI-4) and Building Automation Products Inc. (BAPI-2 and BAPI-7); ACI-4 and BAPI-7 both failed after being submerged in water. Transmitter model A/RH3-D from Automation Components Inc. has undergone significant design changes since NBCIP first purchased and tested the transmitters in 2002. Therefore, NBCIP did not purchase a new transmitter to replace failed transmitter ACI-1, and test results reported in this Product Testing Report Supplement pertain to a version of the transmitter that is no longer available from Automation Components Inc. Since NBCIP could not purchase a new transmitter of the same design as those tested from Automation Components Inc., NBCIP replaced ACI-1 with ACI-4, which was removed from the ageing tests after eight months of testing.

Transmitter BAPI-2 from Building Automation Products Inc. was replaced by a newly purchased transmitter BAPI-7. The transmitter labeled BAPI 4, while not considered "failed", was unable to read above 45% RH when it was installed in the outdoor air duct for the ageing tests. NBCIP investigated this problem and determined that this particular transmitter experienced an impedance mismatch with the Johnson Controls DX 9100-8454 controller used to collect the operating data from the ageing test. This characteristic was not observed when transmitter BAPI-1 was connected to the same controller. This characteristic was also not demonstrated when transmitters BAPI-1 and BAPI-4 were connected to a controller from another manufacturer, nor was it demonstrated when the BAPI transmitters were connected to the laboratory-grade data acquisition system described in the NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters. NBCIP investigated this finding further by contacting representatives of Building Automation Components Inc. The company indicated that the transmitters require custom configuration for applications that use Johnson Controls systems. Since NBCIP purchased the transmitters anonymously, they were not configured to operate with controllers from Johnson Controls.
Three transmitters failed for MAMAC Systems Inc. (MAMAC-1, MAMAC-2 and MAMAC-5). Transmitter MAMAC-1 was not replaced because it failed after eight months while the ageing tests were already in progress. Accuracy test results for the NBCIP ageing tests reported in this Product Testing Report Supplement for MAMAC-1 are therefore based on eight months of ageing instead of 12 months. Transmitter MAMAC-2 was replaced by a newly purchased transmitter MAMAC-5, which failed after it was immersed in water for the submergence test.

NBCIP performed accuracy tests at 77°F (25°C) on the newly purchased transmitters BAPI-7 and MAMAC-5 to establish the baseline performance of these transmitters before they were subjected to the long-term performance tests. The results of the accuracy tests on the BAPI-7 transmitter are shown in Figure 12. For comparison, Figure 13 shows the accuracy test results for the same transmitter model from Building Automation Products Inc. that NBCIP reported in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters. NBCIP found a considerable performance difference between the transmitter BAPI-7 that was purchased in January 2004, and the transmitters that were purchased from March to June 2002 for the first Product Testing Report. BAPI-7 performed within the specified accuracy of ±3% RH over a 30% to 90% relative humidity range.

The results of the accuracy tests on the MAMAC-5 transmitter are shown in Figure 14. For comparison, Figure 15 shows the accuracy test results for the same transmitter model from MAMAC Inc. that NBCIP reported in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters. There is no significant performance difference between MAMAC-5 and the transmitters previously tested by NBCIP.

The shaded area in Figures 12 to 15 shows the range in relative humidity for which the stated accuracy is ±3% RH, according to manufacturer product literature. NBCIP tested the accuracy of the humidity transmitters over a range of 10% to 90% RH at the temperatures shown in the figures. Refer to Table 1 for product information reported in manufacturer literature.

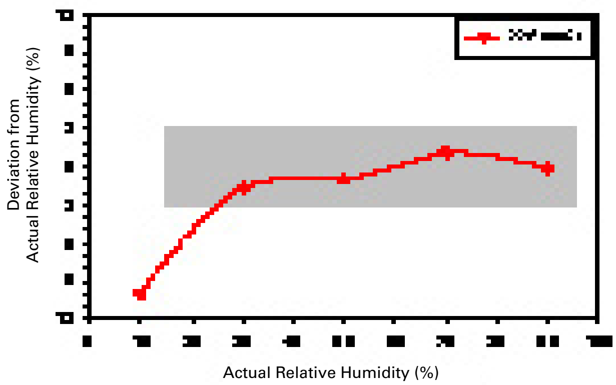


Figure 12.
NBCIP measured accuracy of Building Automation Products Inc. humidity transmitter 7 (BAPI-7), model BA/H310-D.

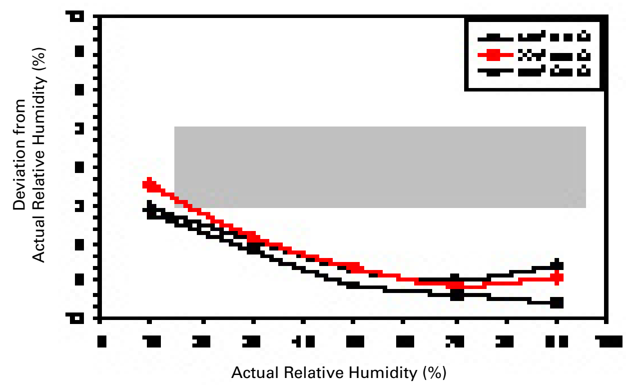


Figure 13.
NBCIP measured accuracy of Building Automation Products Inc. humidity transmitters, model BA/H310-D; originally published in NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters. The figure represents the average performance of three transmitters.

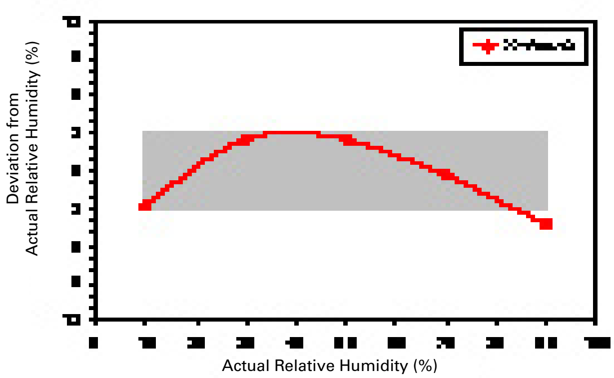


Figure 14.
NBCIP measured accuracy of MAMAC Systems Inc. humidity transmitter 5 (MAMAC-5), model HU-224-3-VDC.

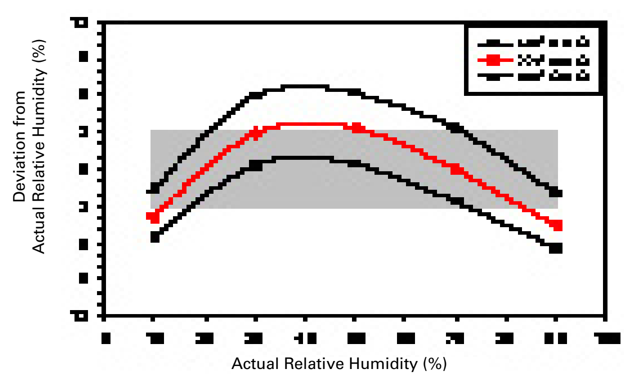


Figure 15.
NBCIP measured accuracy of MAMAC Systems Inc. humidity transmitters, model HU-224-3-VDC; originally published in NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters. The figure represents the average performance of three transmitters.

Ageing Effects on Humidity Transmitters

Test results for ageing effects on humidity transmitters are presented in two parts to show transmitter performance under: (1) the controlled conditions of the Thunder Scientific 2500 humidity generator used for periodic testing of the transmitters at four month intervals, and (2) the in-situ environmental conditions experienced by the transmitters when they were installed in the outdoor air duct at the ERS. First, the results of accuracy tests that were performed using the Thunder Scientific 2500 humidity generator at four, eight and 12 months are presented. These results are compared to the baseline performance of the transmitters to show how accuracy has drifted over time; accuracy testing of the newly purchased transmitters is reported in detail in the NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters. Second, NBCIP analyzed in-situ performance data that were monitored while the transmitters were installed in the outdoor air duct of the ERS during the course of one year. These results show actual transmitter performance when exposed to varying environmental conditions.

Accuracy Testing

NBCIP determined the effects of ageing by assessing the drift in accuracy of the relative humidity transmitters over a one year period. Accuracy testing in the context of this Product Testing Report Supplement comprises tests for accuracy, repeatability, linearity, and hysteresis that NBCIP performed on the relative humidity transmitters at four month intervals after prolonged exposure to varying environmental conditions during the course of one year. NBCIP tested the accuracy of the transmitters using the Thunder Scientific 2500 humidity generator. The methods to calculate the performance parameters are detailed in the Product Testing Report: Duct-Mounted Relative Humidity Transmitters.

Manufacturer stated accuracy for newly purchased humidity transmitter models tested is ±3% RH. Manufacturer stated drift in accuracy over a long-term period is reported in Table 1. Automation Components Inc. and Building Automation Products Inc. report a drift in accuracy of less than 2% RH over a period of five years, General Eastern Inc. reports less than 1% RH drift in accuracy per year, Vaisala reports a ±2% RH drift in accuracy over two years, while Johnson Controls Inc. and MAMAC Systems Inc. do not report the drift in accuracy in their product literature. Note that humidity transmitter manufacturers may use different methods than those used by NBCIP to test long-term performance of transmitters. Therefore, results reported in this Product Testing Report Supplement should be used to compare transmitter performance among manufacturers, rather than comparing individual results with manufacturer reported data.

Figures 16 to 27 show the results of NBCIP's evaluations of humidity transmitter accuracy at four, eight and twelve months for each manufacturer, while the curve labeled "New" represents the baseline performance of each relative humidity transmitter prior to the commencement of the ageing tests (i.e., when the transmitters were newly purchased for the NBCIP Product Testing Report: Duct-Mounted Relative Humidity Transmitters). The accuracy of the humidity generator introduces a maximum uncertainty of ±0.5% RH in the calculated deviations.

Curves of humidity transmitter accuracy at four, eight and twelve months follow the same trend as the baseline accuracy curves of new humidity transmitters for models from Automation Components Inc., Building Automation Products Inc., Johnson Controls Inc., MAMAC Systems Inc. and Vaisala, whereas the accuracy curves for General Eastern Inc. transmitters appear to mirror the baseline performance. The greatest drift in accuracy for transmitter models from Automation Components Inc., Building Automation Products Inc. (BAPI-4), General Eastern Inc., MAMAC Systems Inc. (MAMAC-1), and Vaisala (VAISALA-1) is noted at four months, after which the drift in accuracy changes very little or remains relatively stable at eight and twelve months. Transmitter 4 from Vaisala (VAISALA-4) showed very little drift in accuracy throughout the ageing tests across all relative humidity conditions. Transmitters from Johnson Controls Inc. showed very little drift in accuracy at four months, but more significant drift at eight and twelve months. Transmitter 4 from Building Automation Products Inc. (BAPI-4) showed the greatest drift in accuracy. MAMAC-1 showed very little drift in accuracy for humidity conditions ranging from 10% to 70% RH. At 70% and 90% RH the drift in accuracy for MAMAC-1 is greater; however, the transmitter still performs within the manufacturer stated accuracy at these humidity conditions.

The shaded area in Figures 16 to 27 shows the range in relative humidity for which the stated accuracy is ±3% RH, according to manufacturer product literature. NBCIP tested the accuracy of the humidity transmitters every four months for 12 months over a range of 10% to 90% RH at 77°F (25°C). Refer to Table 1 for product information reported in manufacturer literature.

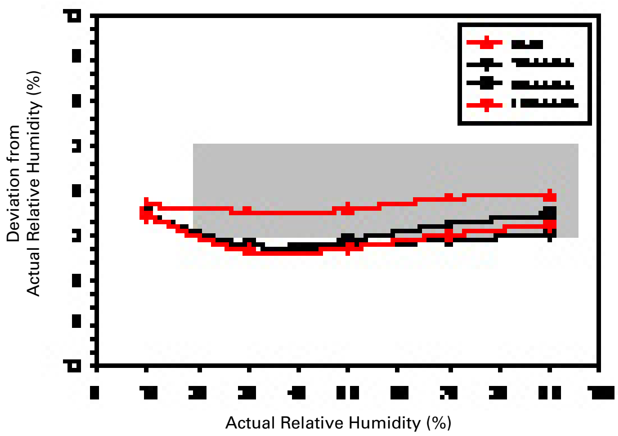


Figure 16.
NBCIP measured accuracy of Automation Components Inc. humidity transmitter 2 (ACI-2), model A/RH3-D, at four-month intervals during ageing tests.

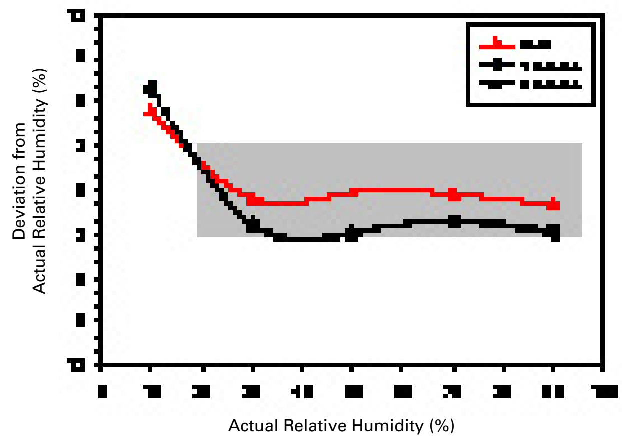


Figure 17.
NBCIP measured accuracy of Automation Components Inc. humidity transmitter 4 (ACI-4), model A/RH3-D, at four-month intervals during ageing tests. Testing was terminated at eight months because transmitter was removed from the duct and used for response time tests and stress tests after failure of ACI transmitter 1 (ACI-1).

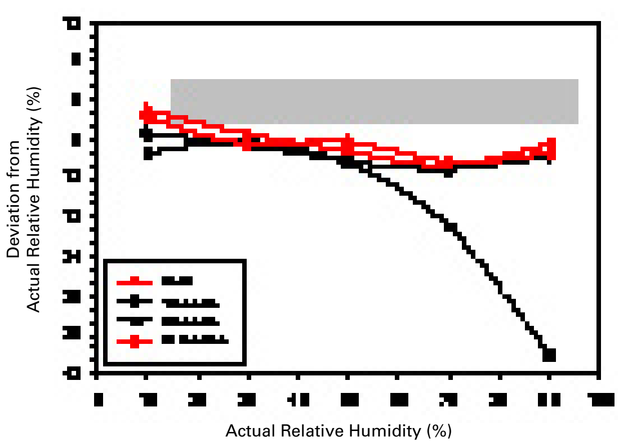


Figure 18.
NBCIP measured accuracy of Building Automation Products Inc. humidity transmitter 1 (BAPI-1), model BA/H310-D, at four-month intervals during ageing tests.

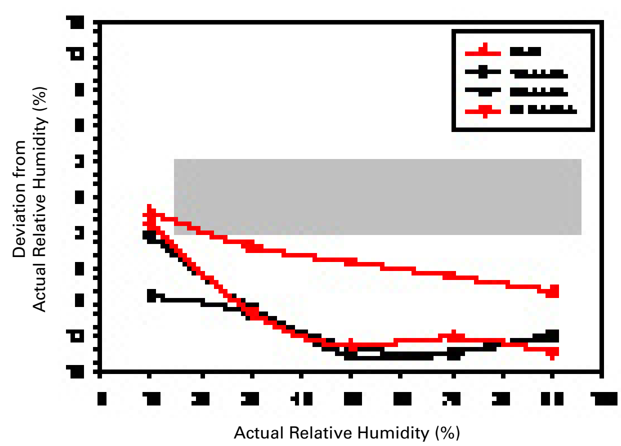


Figure 19.
NBCIP measured accuracy of Building Automation Products Inc. humidity transmitter 4 (BAPI-4), model BA/H310-D, at four-month intervals during ageing tests.

(Figures continued)

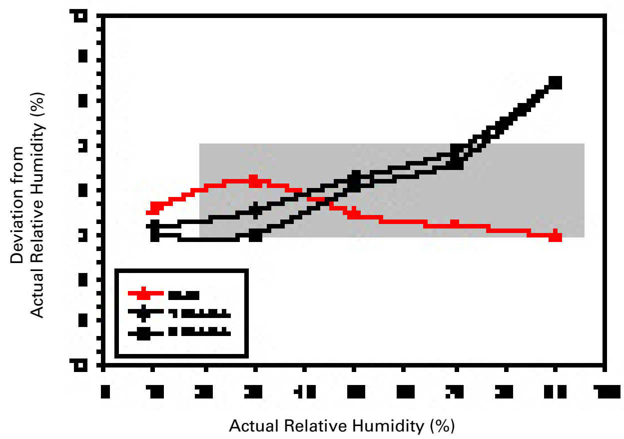


Figure 20.
NBCIP measured accuracy of General Eastern Inc. humidity transmitter 2 (GEN EAST-2), model MRH-3-D, at four-month intervals during ageing tests. Testing was terminated at eight months because transmitter failed due to a loose probe.

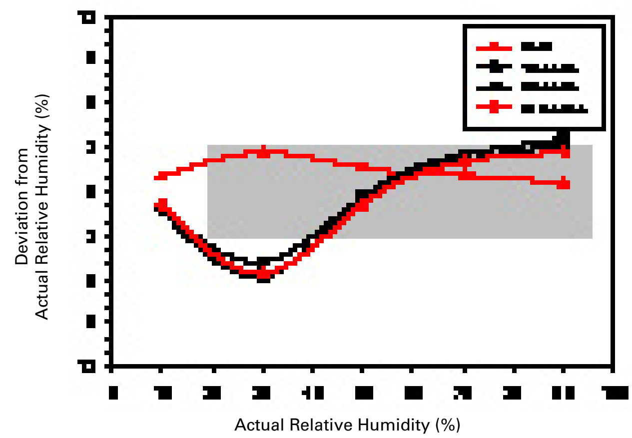


Figure 21.
NBCIP measured accuracy of General Eastern Inc. humidity transmitter 4 (GEN EAST-4), model MRH-3-D, at four-month intervals during ageing tests.

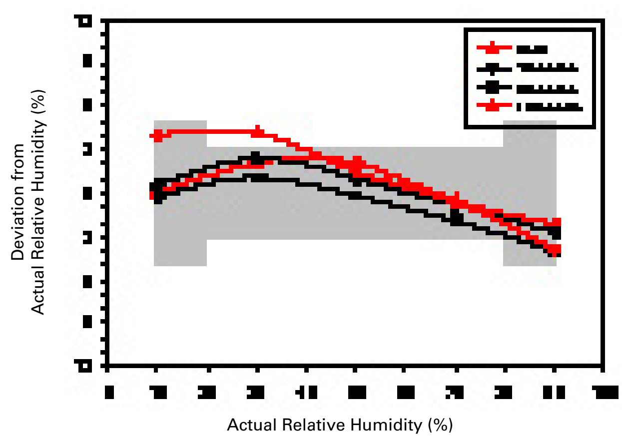


Figure 22.
NBCIP measured accuracy of Johnson Controls Inc. humidity transmitter 1 (JCI-1), model HT-6703-0N00P, at four-month intervals during ageing tests.

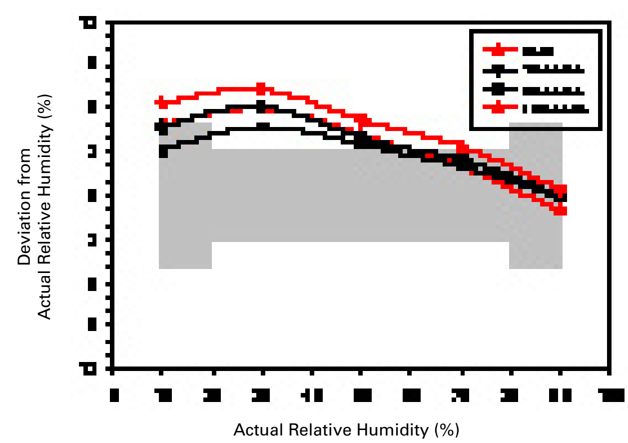


Figure 23.
NBCIP measured accuracy of Johnson Controls Inc. humidity transmitter 4 (JCI-4), model HT-6703-0N00P, at four-month intervals during ageing tests.

(Figures continued)

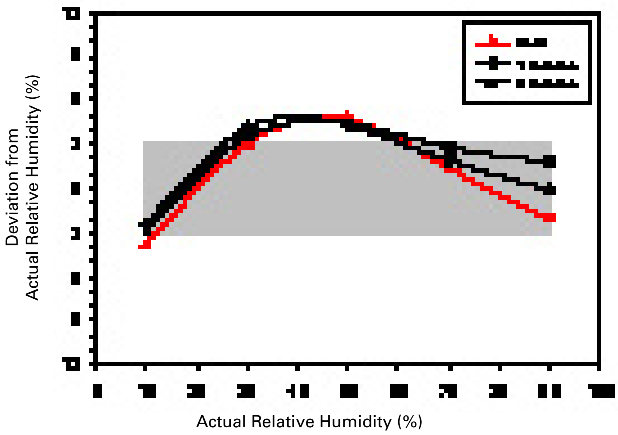


Figure 24.
NBCIP measured accuracy of MAMAC Systems Inc. humidity transmitter 1 (MAMAC-1), model HU-224-3-VDC, at four-month intervals during ageing tests. Testing was terminated at eight months due to transmitter failure.

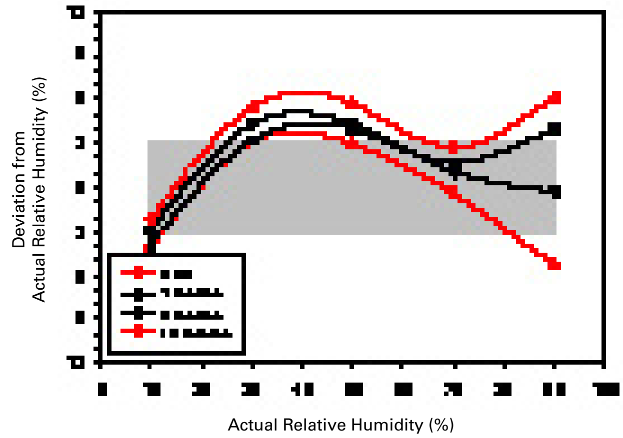


Figure 25.
NBCIP measured accuracy of MAMAC Systems Inc. humidity transmitter 4 (MAMAC-4), model HU-224-3-VDC, at four-month intervals during ageing tests.

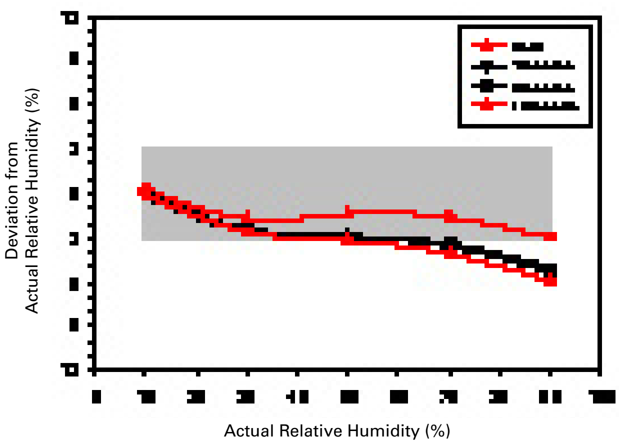


Figure 26.
NBCIP measured accuracy of Vaisala humidity transmitter 1 (VAISALA-1), model HMD50U, at four-month intervals during ageing tests.

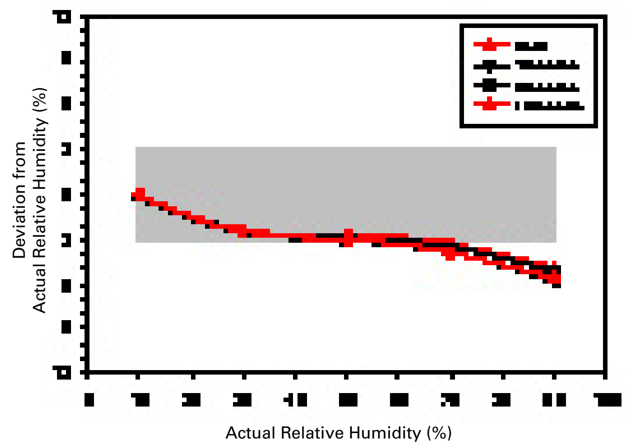


Figure 27.
NBCIP measured accuracy of Vaisala humidity transmitter 4 (VAISALA-4), model HMD50U, at four-month intervals during ageing tests.

Repeatability

The error in repeatability of the transmitters tested by NBCIP after undergoing 12 months of ageing tests is shown in Table 5. Note that humidity transmitter manufacturers may define and report repeatability differently than NBCIP; therefore, the results in Table 5 should be used to compare transmitter performance among manufacturers, rather than comparing individual results with manufacturer reported data. Table 5 also includes the error in repeatability of the transmitters tested by NBCIP prior to the commencement of the ageing tests (i.e., newly purchased).

In general, there was no significant increase in the error in repeatability after 12 months of ageing. Transmitters from Automation Components Inc., Building Automation Products Inc. (BAPI-1), General Eastern Inc., MAMAC Systems Inc. (MAMAC-4) and Vaisala had the lowest error in repeatability, ranging from 0% to 0.3% RH after 12 months of testing. BAPI-4, transmitters from Johnson Controls Inc., and MAMAC-1, had the highest error in repeatability, ranging from 1.1% to 1.4% RH after 12 months of testing. In several cases, the error in repeatability after 12 months of testing was lower than the error in repeatability of the newly purchased transmitters.

Linearity

The error in linearity of the transmitters tested by NBCIP after undergoing 12 months of ageing tests is shown in Table 6. Note that humidity transmitter manufacturers may define and report the error in linearity differently than NBCIP; therefore, the results in Table 6 should be used to compare transmitter performance among manufacturers, rather than comparing individual results with manufacturer reported data. Table 6 also includes the error in linearity of the transmitters tested by NBCIP prior to the commencement of the ageing tests (i.e., newly purchased).

Of all the transmitters tested by NBCIP, the two transmitters from Vaisala have the lowest error in linearity at 0.7% RH and 0.6% RH, respectively, while transmitter ACI-4 from Automation Components Inc. has the highest error in linearity at 7.3% RH after 12 months of testing. The error in linearity for transmitter ACI-2 from Automation Components Inc., transmitter BAPI-4 from Building Automation Products Inc., and both transmitters from General Eastern Inc. more than doubled after 12 months of testing.

Hysteresis

The maximum hysteresis of the transmitters tested by NBCIP after undergoing 12 months of ageing tests is shown in Table 7. Note that humidity transmitter manufacturers may define and report hysteresis differently than NBCIP; therefore, the results in Table 7 should be used to compare transmitter performance among manufacturers, rather than comparing individual results with manufacturer reported data. Table 7 also includes the maximum hysteresis of the transmitters tested

Table 5. NBCIP test results for repeatability of relative humidity transmitters at 50% RH after 12 months of ageing. Testing was performed at 77˚F (25˚C).

Manufacturer	Model Number	Transmitter Number	Error in Repeatability at 50% RH (%RH)	
			New	At 12 months
Automation Components Inc.	A/RH3-D	ACI - 2	0.1	0.0
		ACI - 4	0.1	0.1*
Building Automation Products Inc.	BA/H310-D	BAPI - 1	0.4	0.3
		BAP - 4	0.0	1.3
General Eastern Inc.	MRH-3-D	GEN EAST - 2	0.4	0.0*
		GEN EAST - 4	0.0	0.0
Johnson Controls Inc.	HT-6703-0N00P	JCI - 1	2.9	1.4
		JCI - 4	0.5	1.3
MAMAC Systems Inc.	HU-224-3-VDC	MAMAC - 1	3.8	1.1*
		MAMAC - 4	0.3	0.2
Vaisala	HMD50U	VAISALA - 1	0.1	0.1
		VAISALA - 4	0.4	0.2

Notes:
1. Only the magnitude of the error in repeatability is shown in the table; consequently negative signs have been omitted.
2. * indicates that the error in repeatability is reported at eight months of testing. Refer to Table 4 for details.

Table 6. NBCIP test results for error in linearity of relative humidity transmitters after 12 months of ageing. Testing was performed at 77˚F (25˚C).

Manufacturer	Model Number	Transmitter Number	Error in Linearity (%RH)	
			New	At 12 months
Automation Components Inc.	A/RH3-D	ACI - 2	1.1	2.8
		ACI - 4	5.4	7.3*
Building Automation Products Inc.	BA/H310-D	BAPI - 1	3.5	3.4
		BAP - 4	1.2	4.4
General Eastern Inc.	MRH-3-D	GEN EAST - 2	1.5	4.2*
		GEN EAST - 4	2.1	5.9
Johnson Controls Inc.	HT-6703-0N00P	JCI - 1	2.3	4.4
		JCI - 4	5.1	5.8
MAMAC Systems Inc.	HU-224-3-VDC	MAMAC - 1	4.0	3.3*
		MAMAC - 4	4.0	3.3
Vaisala	HMD50U	VAISALA - 1	0.7	0.7
		VAISALA - 4	0.8	0.6

Notes:
1. Only the magnitude of the error in linearity is shown in the table; consequently, negative signs have been omitted.
2. * indicates that the error in linearity is reported at eight months of testing. Refer to Table 4 for details.

by NBCIP prior to the commencement of the ageing tests (i.e., newly purchased).

In general, there was no significant increase in the maximum hysteresis of the transmitters after 12 months of ageing. Transmitters from Vaisala and transmitter GEN EAST-4 from General Eastern Inc. had the lowest maximum hysteresis, ranging between 0.2 and 0.4% RH after 12 months of testing. Transmitters from Johnson Controls Inc. as well as transmitter MAMAC-1 from MAMAC Systems Inc. had the highest maximum hysteresis, ranging from 2.1 to 2.7% RH, after 12 months of testing.

In-Situ Performance

NBCIP developed three histograms to present the relative humidity, temperature, and average velocity conditions in the outdoor air duct that occurred during the course of the ageing tests (Figures 28 to 30). These conditions were monitored by the reference transmitters described in the sidebar

Table 7. NBCIP test results for maximum hysteresis of relative humidity transmitters after 12 months of ageing. Testing was performed at 77˚F (25˚C).

Manufacturer	Model Number	Transmitter Number	Maximum Hysteresis (%RH)	
			New	At 12 months
Automation Components Inc.	A/RH3-D	ACI - 2	0.8	0.8
		ACI - 4	0.6	0.7*
Building Automation Products Inc.	BA/H310-D	BAPI - 1	1.0	1.1
		BAP - 4	0.9	1.3
General Eastern Inc.	MRH-3-D	GEN EAST - 2	1.2	1.6*
		GEN EAST - 4	1.6	0.4
Johnson Controls Inc.	HT-6703-0N00P	JCI - 1	1.6	2.3
		JCI - 4	3.0	2.1
MAMAC Systems Inc.	HU-224-3-VDC	MAMAC - 1	1.5	2.7*
		MAMAC - 4	1.2	1.0
Vaisala	HMD50U	VAISALA - 1	0.3	0.2
		VAISALA - 4	0.6	0.3

Notes:
1. Only the magnitude of the maximum hysteresis is shown in the table; consequently, negative signs have been omitted.
2. * indicates that the maximum hysteresis is reported at eight months of testing. Refer to Table 4 for details.

Reference Transmitters. Each histogram consists of 10 bins that show the frequency of occurrence of each condition over a one year period and indicates the predominant conditions experienced by the humidity transmitters under test. The data in Figures 28 to 30 were sampled at 15 minute intervals and have been filtered to eliminate instances of data loss.

The predominant relative humidity conditions during the one-year test period ranged from 40% to 80% RH (Figure 28). The predominant temperature conditions ranged from 30 to 80°F (-1.11 to 26.67°C). The temperature data are skewed toward higher temperatures because the data collection period included May, June, July, August, October, November, December of 2003, and January, March, April, May, June of 2004. The months of December 2003 and January 2004 were unusually mild. The predominant velocity conditions ranged from 0 to 150 ft/min (0 to 0.76 m/s), followed by 150 to 300 ft/min (0.76 to 1.52 m/s).

Figures 31 to 36 show the performance of the relative humidity transmitters in the outdoor air duct using readings from the reference relative humidity transmitter as the actual relative humidity. Data have been filtered to exclude data collected when the average air velocity in the outdoor air duct was less than 100 ft/min (0.5 m/s). It is important to keep in mind that the reference transmitter itself also introduces some inaccuracy in the data. This is explained further in the side bar *Reference Transmitter Accuracy*. Figures 31 to 36 however provide important qualitative information about the long-term in-situ performance of the relative humidity transmitters tested by NBCIP. The mean provides a measure of the average deviation of the relative humidity measured by a given test transmitter from the actual relative humidity measured by the reference transmitter over the one year test period. The standard deviation is a more revealing statistic as it provides a measure of the spread in the data; a small standard deviation indicates a tight grouping of the data, usually within a well defined accuracy range. A large standard deviation indicates significant scatter in the data across a wide range in accuracy.

Performance data for transmitters from Vaisala show the least scatter of all the transmitter models tested by NBCIP as indicated by the standard deviation. Transmitters from Automation Components Inc. and General Eastern Inc. follow closely, with maximum standard deviations in the data of 2.3% RH and 3.2% RH, respectively. The data for the two transmitters from MAMAC

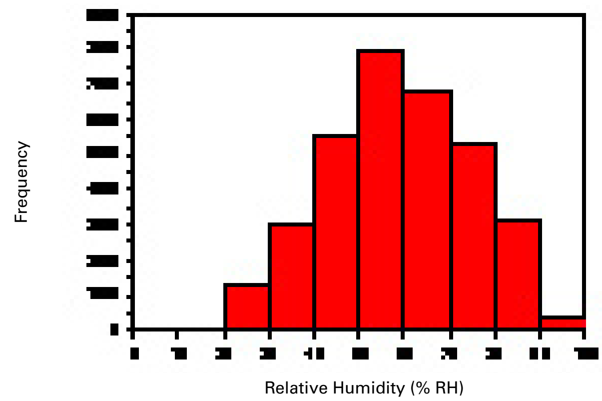


Figure 28.
Relative humidity in the outdoor air duct measured by the reference relative humidity transmitter using a 15-minute sampling interval during NBCIP ageing tests.

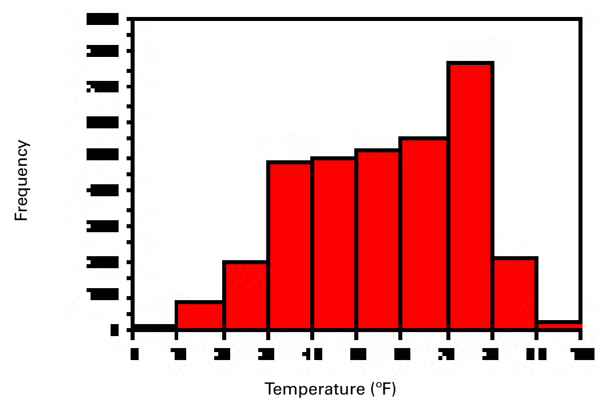


Figure 29.
Temperature in the outdoor air duct during NBCIP ageing tests.

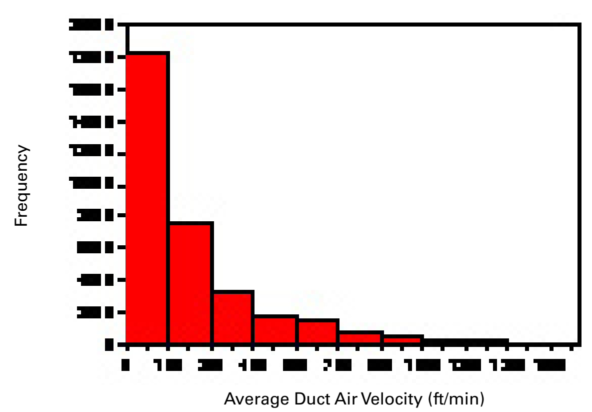


Figure 30.
Average air velocity in the outdoor air duct during NBCIP ageing tests.

The boxed area in Figures 31 to 36 shows the range in relative humidity for which the stated accuracy is ±3% RH, according to manufacturer product literature. Refer to Table 1 for product information reported in manufacturer literature.

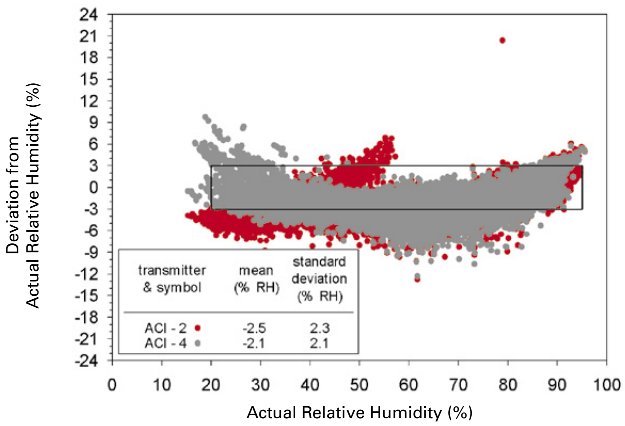


Figure 31.
In-situ performance of Automation Components Inc. humidity transmitters, model A/RH3-D, in the outdoor air duct during NBCIP ageing tests. Testing for transmitter ACI-4 was terminated at eight months because the transmitter was used for response time tests and stress tests after failure of ACI-1.

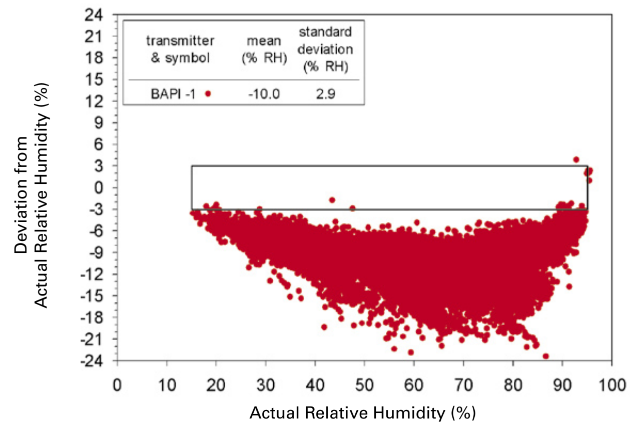


Figure 32.
In-situ performance of Building Automation Products Inc. humidity transmitters, model BA/H310-D, in the outdoor air duct during NBCIP ageing tests. The performance of transmitter BAPI-4 is not shown because it experienced an impedance mismatch with the controller and never read above 45% RH in the duct.

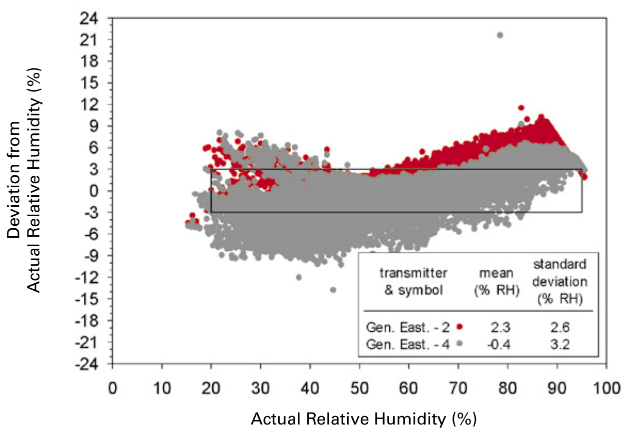


Figure 33.
In-situ performance of General Eastern Inc. humidity transmitters, model MRH-3-D, in the outdoor air duct during NBCIP ageing tests. Testing for transmitter GEN EAST-2 was terminated at eight months due to transmitter failure

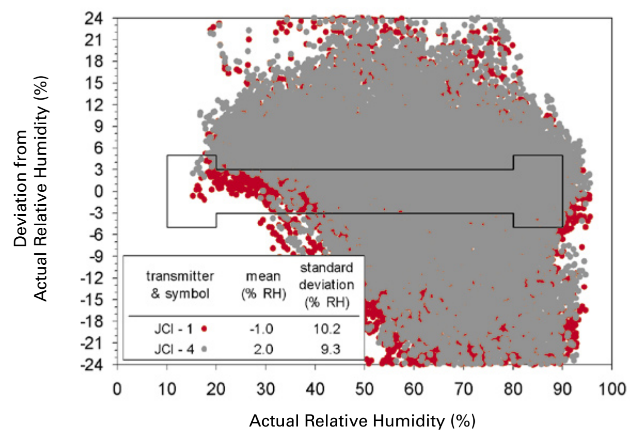


Figure 34.
In-situ performance of Johnson Controls Inc. humidity transmitters, model HT-6703-0N00P, in the outdoor air duct during NBCIP ageing tests.

(Figures continued)

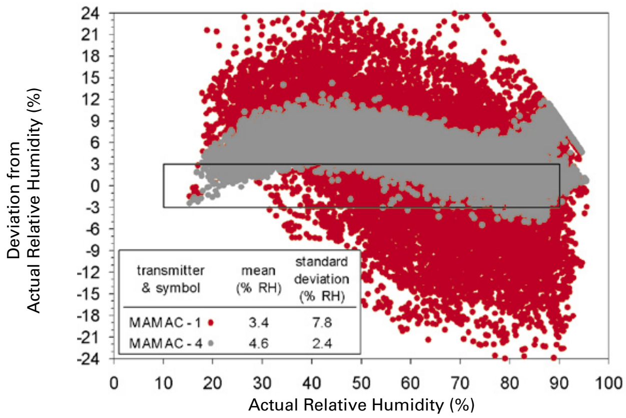


Figure 35.
In-situ performance of MAMAC Systems Inc. humidity transmitters, model HU-224-3-VDC, in the outdoor air duct during NBCIP ageing tests.

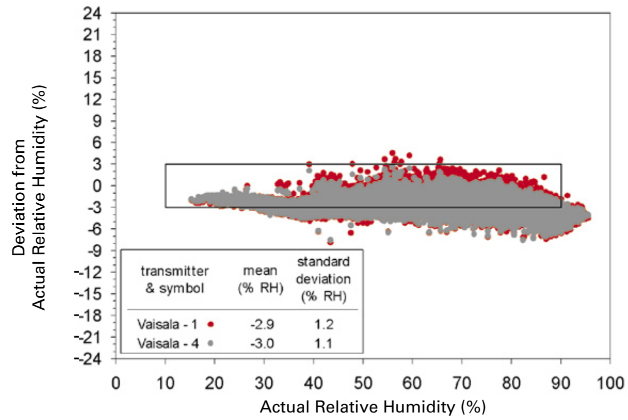


Figure 36.
In-situ performance of Vaisala humidity transmitters, model HMD50U, in the outdoor air duct during NBCIP ageing tests.

Reference Transmitter Accuracy

A condition check was performed on the Vaisala model HMP 233 relative humidity transmitter that was used as the in-situ reference relative humidity transmitter during the ageing test. This transmitter has a measurement range of 0-100% RH and a rated accuracy of ±1% RH for 0-90% RH and ±2% RH for 90-100% RH. The condition check was performed after the ageing test was completed (i.e., after 12 months) and involved verifying the accuracy of the reference transmitter at 20 points including four temperature and five relative humidity conditions. The accuracy of the reference relative humidity transmitter at the conclusion of the ageing test is shown in Figure 37.

In general, after one year of ageing, the reference transmitter maintained an accuracy of ±1% RH over a humidity range of 10 to 70% RH, with the exception of a single data point at 42.4°F (5.8°C), and an accuracy of ±3% RH at 90% RH.

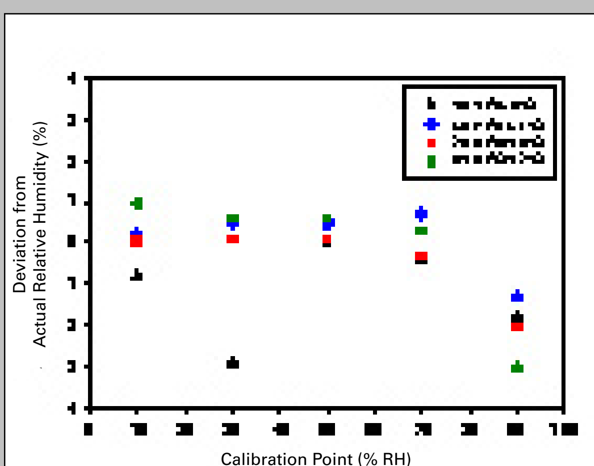


Figure 37.
Accuracy data for the Vaisala model HMP 233 reference relative humidity transmitter after completion of the ageing tests.

Systems Inc. show different patterns; the transmitter labeled MAMAC-1 shows wide scatter in the data and a standard deviation of 7.8% RH, while the transmitter labeled MAMAC-4 shows less scatter in the data and a much lower standard deviation (2.4% RH). Performance data for transmitters from Johnson Controls Inc. show the greatest scatter and the highest standard deviation of all the transmitters tested by NBCIP.

Response Time Tests

The results of NBCIP's response time tests are shown in Table 8. The values in Table 8 represent the average value of the response time measured during three forward step tests, the average value of the response time measured during three reverse steps, and the average of the forward and reverse step response times. NBCIP performed the forward and reverse step tests for each transmitter while the fan inside the humidity generator was on. NBCIP also measured the response time during forward step tests while the fan inside the humidity generator was off; these values of the response time match closely to the values shown in Table 8 and are not reported here.

The transmitter model from Vaisala has the fastest average response time at 7.2 seconds, followed by the transmitter model from General Eastern Inc., which has an average response time of 10.1 seconds. The transmitter model from Automation Components Inc. has the longest average response time at 94.5 seconds.

Table 8. NBCIP test results for response time of relative humidity transmitters (fan ON)

Manufacturer	Model Number	Transmitter Number	Response Time (seconds)		
			Forward	Reverse	Average
Automation Components Inc.	A/RH3-D	ACI-4	99.6	89.4	94.5
Building Automation Products Inc.	BA/H310-D	BAPI-7	81.0	98.0	89.5
General Eastern Inc.	MRH-3-D	GEN EAST-1	9.2	11.0	10.1
Johnson Controls Inc.	HT-6703-0N00P	JCI-2	48.0	82.0	65.0
MAMAC Systems Inc.	HU-224-3-VDC	MAMAC-5	37.2	56.2	46.7
Vaisala	HMD50U	VAISALA-2	9.4	5.0	7.2

It is interesting to note the differences between the forward and reverse response times. The reverse response time is significantly higher than the forward response time for transmitter models from Johnson Controls Inc. and MAMAC Systems Inc., while the reverse response time for the Vaisala transmitter is significantly lower than the forward response time.

Stress Tests

The results of NBCIP's stress tests are shown in Figures 38 to 43 for each transmitter model tested. The figures show the accuracy of each transmitter after each stress test (cycling, desiccation-saturation, and where possible, submergence). The baseline performance of the transmitters when they were new is also presented. Note that the accuracy measurements shown in Figures 38 to 43 are limited to a relative humidity range of 30 to 70% RH.

The transmitter from Vaisala (VAISALA-2) continued to perform within the manufacturer stated accuracy of ±3% RH after having been subjected to all three stress tests (cycling, desiccation-saturation, and submergence). Transmitters from Automation Components Inc. (ACI-4) and Building Automation Products Inc. (BAPI-7) generally performed within the ±3% RH accuracy range after the cycling and desiccation-saturation tests only. The transmitter from General Eastern Inc. (GEN EAST-1) continued to perform within the ±3% RH accuracy range after the cycling test only. The transmitter from Johnson Controls Inc. (JCI-2) experienced a substantial deterioration in accuracy after the desiccation-saturation test. The transmitter from MAMAC Systems Inc. (MAMAC-5) only performed within the ±3% RH accuracy range at 70% RH after the cycling and desiccation-saturation tests.

The HVAC grade humidity transmitters tested by NBCIP will likely never face submergence conditions and are not designed for this type of use. Therefore NBCIP test results for submergence of the humidity transmitters only provide an indication of the robustness of the sensor element and casing. Few of the transmitters tested by NBCIP survived the submergence test. Transmitters from General Eastern Inc. and Vaisala were the only two that were operational after undergoing the submergence test. The transmitters from Automation Components Inc., Building Automation Products Inc., Johnson Controls Inc. and MAMAC Systems Inc. produced output at the extremes of the relative humidity range, either at 0% RH or close to 100% RH. NBCIP did not show accuracy results from transmitters that were no longer operational after the submergence tests. ■

The shaded area in Figures 38 to 43 shows the range in relative humidity for which the stated accuracy is ±3% RH, according to manufacturer product literature. NBCIP tested the accuracy of each transmitter after each stress test within a relative humidity range of 30 to 70% RH. Refer to Table 1 for product information reported in manufacturer literature.

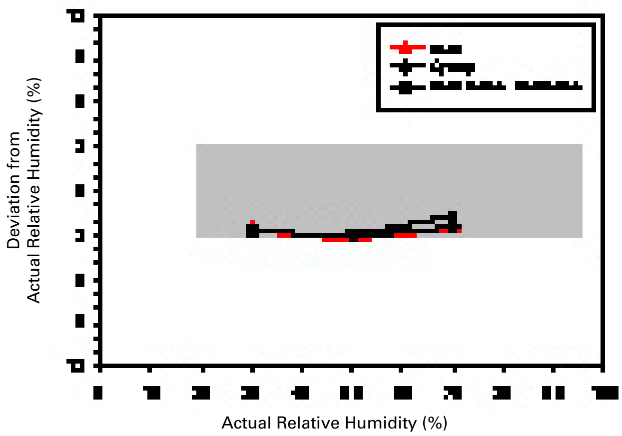


Figure 38.
Results of NBCIP stress tests for Automation Components Inc. humidity transmitter 4 (ACI-4), model A/RH3-D. The transmitter was no longer functional after the NBCIP submergence test and consistently produced readings of 0% RH; results for the submergence test are therefore not shown.

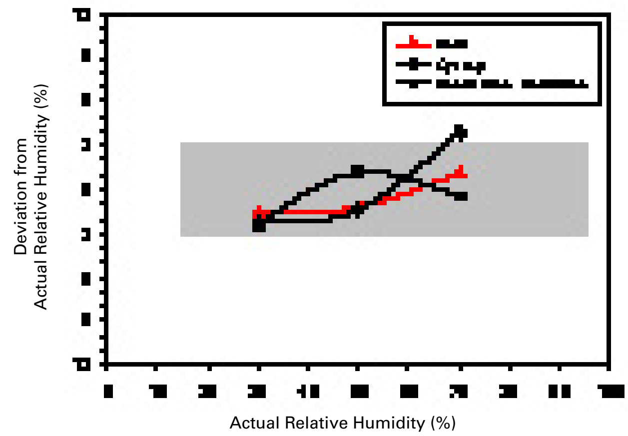


Figure 39.
Results of NBCIP stress tests for Building Automation Products Inc. humidity transmitter 7 (BAPI-7), model BA/H310-D. The transmitter was no longer functional after the NBCIP submergence test and produced readings between 0 and 20% RH; results for the submergence test are therefore not shown.

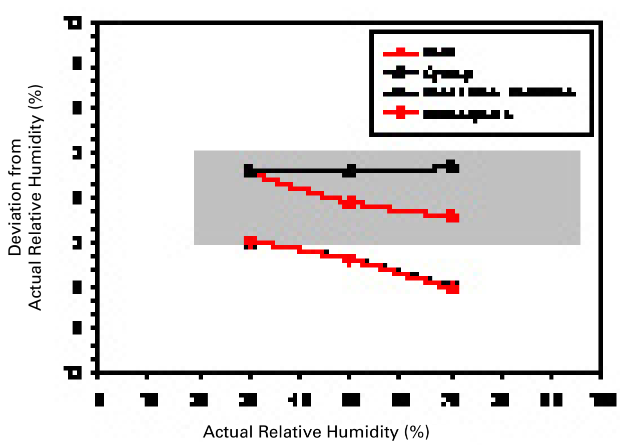


Figure 40.
Results of NBCIP stress tests for General Eastern Inc. humidity transmitter 1 (GEN EAST-1), model MRH-3-D.

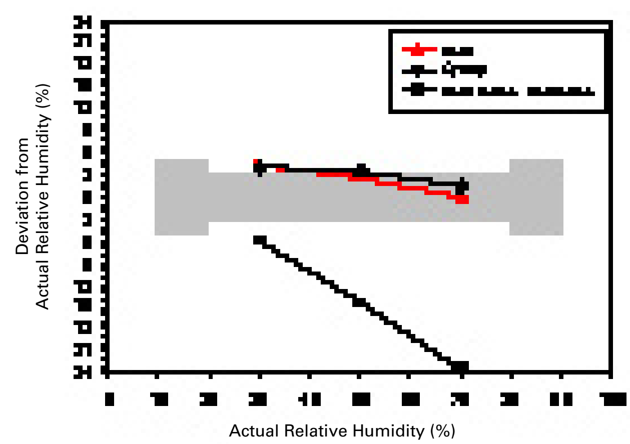


Figure 41.
Results of NBCIP stress tests for Johnson Controls Inc. humidity transmitter 2 (JCI-2), model HT-6703-0N00P. The transmitter was no longer functional after the NBCIP submergence test and produced a reading of 43% RH at an actual condition of 30% RH and readings of 87% RH at all other test conditions; results for the submergence test are therefore not shown.

(Figures continued)

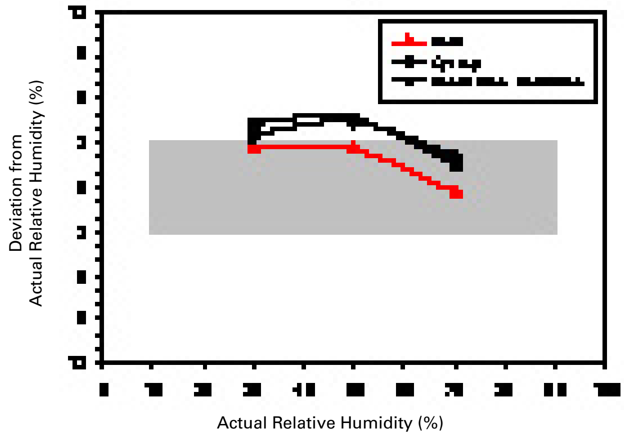


Figure 42.
Results of NBCIP stress tests for MAMAC Systems Inc. humidity transmitter 5 (MAMAC-5), model HU-224-3-VDC. The transmitter was no longer functional after the NBCIP submergence test and produced a reading of 79% RH at an actual condition of 30% RH and readings of 99% RH at all other test conditions; results for the submergence test are therefore not shown.

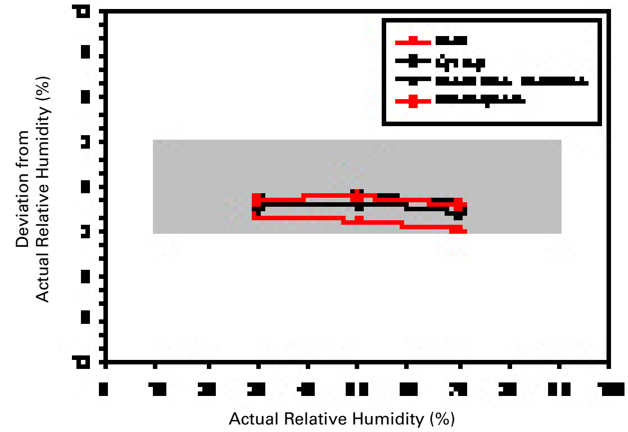


Figure 43.
Results of NBCIP stress tests for Vaisala humidity transmitter 2 (VAISALA-2), model HMD50U.

Conclusions

This NBCIP Product Testing Report Supplement focused on the long-term performance of relative humidity transmitters and is a companion document to NBCIP's Product Testing Report: Duct-Mounted Relative Humidity Transmitters that was published in April 2004. NBCIP performed three types of tests on transmitters from six manufacturers: effects of ageing on transmitter performance to determine the drift in accuracy of the transmitters over a period of time; response time tests to determine how quickly the transmitters respond to a step change in the relative humidity; and stress tests to determine the robustness of the transmitters under extreme conditions through cycling, desiccation-saturation, and submergence.

Ageing test results showed that in most cases, the greatest drift in accuracy occurred after four months of ageing and remained relatively stable thereafter. Of the 12 transmitters tested, a transmitter from Vaisala showed the least drift in accuracy throughout the ageing tests. Considering all transmitters tested, in general, the error in repeatability and hysteresis did not drift significantly during the ageing tests; however, the error in linearity did drift significantly for about half of the transmitters tested.

The in-situ performance of the relative humidity transmitters in the outdoor air duct revealed a wide variation in transmitter accuracy over the course of the one-year test period. The results illustrate the need for designers and product specifiers to be aware of how humidity transmitters perform under real conditions to ensure that the selected transmitter is appropriate for the intended application. NBCIP test results showed that performance data of transmitters from Automation Components Inc., General Eastern Inc., and Vaisala was generally clustered or grouped within the manufacturer stated accuracy range of ±3% RH, while transmitters from Building Automation Products Inc., Johnson Controls Inc., and MAMAC Systems Inc. showed wide scatter in the data.

Transmitters from General Eastern Inc. and Vaisala had the fastest response times while the transmitter from Automation Components Inc. had the slowest average response time. The importance of the response time depends on whether the application requires active control of a humidification process; therefore, the concept of a "fast" or "slow" response time must be weighed against the need of the application.

Results of NBCIP stress tests showed that the transmitter from Vaisala continued to perform within the ±3% RH accuracy range after all three stress tests, while transmitters from Automation Components Inc. and Building Automation Products Inc. performed within the ±3% RH accuracy range after the cycling and desiccation-saturation tests only.

Several transmitters tested by NBCIP failed during the course of ageing and stress testing. The three Vaisala transmitters did not experience any failures and were still operational after all NBCIP tests were completed. Transmitters from MAMAC Systems Inc. experienced the highest rate of failure.

It is not recommended to judge or select a humidity transmitter on one single performance parameter; rather, it is important to carefully weigh overall transmitter performance with the requirements of a specific application. Overall, cost is not a reliable indicator of the performance quality of humidity transmitters. In several tests conducted by NBCIP, transmitters in the low to mid cost range outperformed the high cost transmitters. The long-term performance tests conducted by NBCIP provide an indication of the degree of maintenance, checking and calibration that may be required over the transmitter life to ensure successful operation of the control strategies that depend on data provided by relative humidity transmitters. ■

Terms and Definitions

Accuracy:
Accuracy is the deviation of the relative humidity measured by a humidity transmitter from the actual, or known, humidity.

Actual Relative Humidity:
The relative humidity generated by the reference standard.

Deviation:
Deviation is the difference between the measured and actual relative humidity at a given test condition, and is defined by the following equation:

$$\text{Deviation} = RH_{measured} - RH_{actual}$$

Humidity sensor:
Refers to the humidity sensing element.

Humidity transmitter:
A device that consists of a sensor as well as a transducer that converts the sensor reading into an output signal.

Hysteresis:
Hysteresis is the error in measurement when the same humidity condition is approached from a lower and then higher humidity condition.

Linearity:
Linearity is the extent to which the humidity transmitter input and output can be approximated by a linear function through the origin.

Measured Relative Humidity:
The relative humidity reading from a humidity transmitter.

Repeatability:
Repeatability is the degree to which a humidity transmitter produces the same measurement when subjected repeatedly to the same conditions as they are approached from the same direction.

References

Thunder Scientific Technical Catalog, "Thunder Scientific Corporation", 623 Wyoming S. E. Albuquerque, NM 87123, USA, 2000.

Product Testing Report Supplement

Principal Investigators: Shailesh Joshi, Iowa State University; John M. House, Iowa Energy Center; Michael Pate, Iowa State University; Ron Nelson, Iowa State University
NBCIP Project Manager: John M. House
Project Technical Advisor: Curtis J. Klaassen
Program Technical Directors: Floyd E. Barwig and John M. House
Report Authors: Maria Corsi and John M. House
Communications Manager: Amy Swenson

The following persons provided technical review of this report: William M. Healy, National Institute of Standards and Technology; Ed Kutrowski, Public Works and Government Services Canada.
The following persons provided technical review of the method of test: William M. Healy, National Institute of Standards and Technology; Thomas H. Kuehn, University of Minnesota.
Reviewers are listed to acknowledge their contributions to the final publication. Their approval or endorsement of this report is not necessarily implied.

The National Building Controls Information Program

The National Building Controls Information Program (NBCIP) was established by the Iowa Energy Center in 2001 with support from the U.S. Environmental Protection Agency to facilitate the adoption of energy efficient building control products and strategies through testing, demonstration, education and dissemination of product information. The Iowa Energy Center has launched this national initiative based on our investment in the Energy Resource Station, a unique facility that serves as NBCIP's testing laboratory, and the expertise our researchers have acquired in building controls.

NBCIP recognizes that improving the operation of control systems is a major energy saving opportunity. NBCIP research is aimed at understanding the cause of problems with building controls, evaluating the performance of control systems and strategies, and developing best-practice recommendations for implementing energy-efficient control strategies.

NBCIP provides unbiased, accurate, reliable, manufacturer-specific information on building control systems to guide and improve the selection, installation, operation and maintenance of control products and strategies for building applications.

NBCIP establishes building control product performance in a consistent manner. The NBCIP label signifies that testing was performed using an established process that includes peer review of the method of test and the test results. To ensure objectivity, NBCIP does not accept funding from control product manufacturers.

Contacting NBCIP

National Building Controls Information Program
Iowa Energy Center Energy Resource Station
DMACC, 2006 S. Ankeny Blvd.
Ankeny, IA 50021
Phone: (515) 965-7055
Fax: (515) 965-7056
Email: nbcip@energy.iastate.edu

Visit NBCIP online at: www.buildingcontrols.org