Calibration of Relative Humidity Transducers for use in the Texas LoanSTAR Program

John A. Bryant, Dennis L. O'Neal

Energy Systems Laboratory
Mechanical Engineering Department
Texas A&M University

Abstract

In support of the Texas LoanSTAR Energy Conservation Program, the Texas A&M University Monitoring and Analysis Program (MAP) calibration facility has been performing relative humidity calibrations for transducers being used in field installations as well as for new units before installation. The sensors are all of the capacitive type with the element mounted on a polymer chip at the sensor probe tip. Saturated aqueous inorganic salt solutions are used as the calibration standard due to their wide use and acceptability as a relative humidity standard. The tests are conducted through a temperature range of 0 to 44°C (32 to 111°F) and five nominal relative humidity levels of 11%, 33%, 55%, 75%, and 83%. Early results from these tests indicate that for a given temperature, the relative humidity indicated may be significantly different than the true value. Many manufacturers claim an accuracy of ±2 to 3% over the range of 0 to 100% relative humidity. Differences found during the tests for some of the transducers have been typically 10% relative humidity high at low temperatures and 10 to 15% relative humidity low at high temperatures. Accurate relative humidity measurement is important in the analysis of building energy consumption, especially in hot and humid regions where the latent cooling load is a large percentage of the total load. Clean room facilities and health care facilities also have the requirement of accurate relative humidity measurement and control.

Introduction

The Texas LoanSTAR [1] program is a $98.6 million 8-year state-wide energy retrofit demonstration program which is administered by the Texas Governor's Energy Office. Under the program, a state agency (school, university, government office) may apply for monies to implement energy conserving retrofits. These projects range from lighting retrofits to changing from constant volume to variable volume fan operations up to complete replacement of central chillers and boilers. As a part of the program, energy use is monitored in many of the buildings receiving retrofits. A variety of instrumentation is used in assisting the analyst to determine energy use in the building and energy savings due to the retrofits. Relative humidity (RH) measurement is important to the building energy analyst to accurately determine changes in the psychrometric performance of AHUs which have been converted from constant volume to variable air volume operations, the impact of external latent loads on the building cooling load and the changes in internal RH levels and the subsequent effect on human comfort. Kao [2] studied HVAC sensor errors and found a 3 to 5% yearly energy waste due to a measurement error of 10% RH. Other typical uses of the RH measurement are in enthalpy control of economizer cycles, control of humidity levels in electronic industry clean rooms and in hospital/health care facilities. Sensors to be used in this program should be calibrated prior to installation and periodically recalibrated while in service.

To support the metering and analysis program, the calibration facility [3] located at the Riverside campus of Texas A&M University has been conducting tests and calibrations on these devices being used for the project. The majority of testing has centered on the thermal metering instrumentation [4], temperature sensors, electrical and power instrumentation, and relative humidity sensors. The latter are typically installed in air handler units (AHU) and in weather stations at several locations around the state.

The type of sensors used to measure relative humidity range from precision dew point hygrometers to the sling psychrometer. The most common sensor in use for common HVAC applications today is the thin-film capacitance type sensor. These sensors are

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constructed either as a plate with porous electrodes or with "fingers" on a substrate. The dielectric constant of the humidity sensitive material changes with changes in relative humidity. These sensors are popular due to their low cost and generally acceptable performance. These sensors also have an advantage compared to bulk polymer sensors at low RH because of their ability to allow water to enter and leave the thin material easily. This is desirable at low (< 15%) RH. These sensors do have a problem at very high RH (>90%) because they tend to saturate which gives unstable readings and unrepeatable results.

Thin-film sensors are the predominant type of RH transducers used in the LoanSTAR program. These sensors were chosen primarily based on low cost, ease of installation and operation, and acceptable accuracy. It was felt that the MAP calibration facility could provide the precise calibrations on individual sensors when high accuracy was required. At the MAP weather station in Houston, TX, a chilled mirror dew point sensor was used because of the frequent occurrence of high relative humidities along the Gulf coast.

Manufacturers of relative humidity instrumentation generally state an accuracy for their instruments of ±2 to 3% RH over the entire operating range of 0 to 100% RH. Most often, the manufacturer also states the accuracy of the instrument at only one temperature (typically 25°C (77°F)) but they go on to say that their sensor has an operating temperature range of 0 to 50°C (32 to 120°F). These claims and some performance problems in the field installations have led to the current round of testing on these sensors.

Experimental Setup

A multi-port glass flask was fabricated which would allow up to 4 devices simultaneously to sample the same conditions. Saturated salt solutions were used to generate a known humidity in the sealed glass flask. This is a setup similar to that used by Wexler and Hasegawa [5]. The behavior of these inorganic salts has been well documented and experimentally determined beginning as early as the late 1800's. Greenspan [6] collected data on salts from various studies and fit third order equations to the experimentally determined relative humidities for the different salts. These equations provide the reference or "known" relative humidity in the present study and a plot of the equations as a function of temperature is shown in Figure 1.

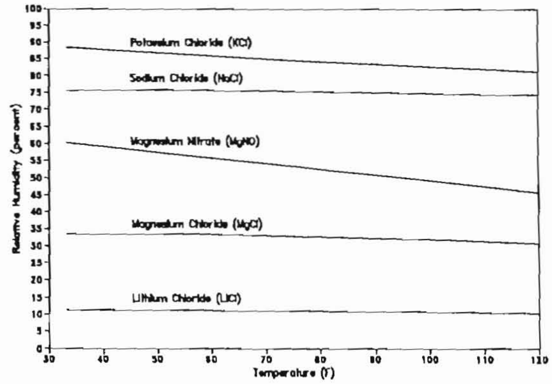

Figure 1. Saturated Salt Solution Relative Humidity as a Function of Temperature.

The National Institute of Standards and Technology (NIST) also recognizes saturated salt solutions as an acceptable RH standard [7]. Many manufacturers of RH instrumentation provide "calibration" standards which consist of either a saturated or a titrated salt solution which provides a "known" level of relative humidity. These units are usually packaged such that they can be used only with a particular manufacturer's RH transducer. They are small, tightly sealed devices, into which the instrument to be calibrated is inserted. After equilibrium is reached, the transducer reading is compared to the cell reference and any differences noted.

The salt solution was prepared as a molal solution of the selected reagent grade salts dissolved into distilled water. The solubility of the salts [8] was used as a guide to ensure that a saturated solution was achieved. The salts used for these tests are shown in Table 1. After the saturated salt solution was placed in the flask, the RH transducers were inserted into the ports and sealed with tight-fitting neoprene stoppers. The flask, with the transducers installed, was then placed into an environmental chamber which was set to an initial temperature of 25°C (77°F). The environmental chamber was able to maintain temperatures to within ± 0.1 °F. Data were collected by a dedicated logger which sampled the transducer signals every 6 seconds and stored the averaged values at 5 minute intervals. Data were taken at each of five different temperature settings (1°, 11°, 25°, 33°, and 44°C). At each change in temperature, the

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system was allowed to reach a stable equilibrium point before proceeding to a new setpoint. Depending upon the salt being used, this time varied from 3 to 5 hours per temperature change. Upon completion of a round of testing, the salt solution was changed and the process repeated at the new solution RH level. The resulting data were downloaded to a PC where further data reduction and statistical analysis was performed.

Table 1. Relative Humidities for some selected saturated salt solutions.

SALT	RH at 25°C
Lithium Chloride (LiCl)	11.3%
Magnesium Chloride ($MgCl_2 \cdot 6H_2O$)	32.8%
Magnesium Nitrate ($Mg(NO_3)_2 \cdot 6H_2O$)	52.9%
Sodium Chloride (NaCl)	75.3%
Potassium Chloride (KCl)	84.3%

Results

A plot of the raw data for a typical test for three candidate transducers is shown in Figure 2. The five steps of temperature are evident as is the time response of the system to a change in temperature. It can be seen in this graph that two of the transducers have a marked dependence on temperature at a nominal relative humidity of 83% (KCl).

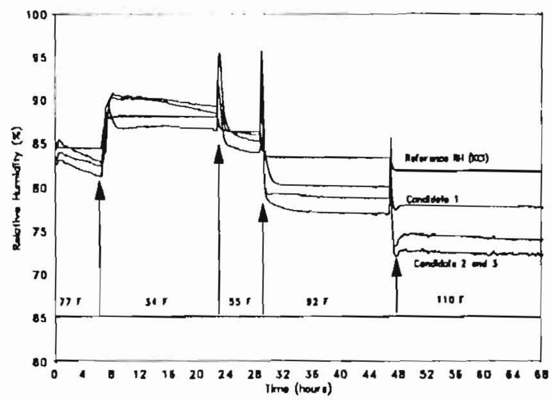

Figure 2. Time Series Plot for 3 Candidate Relative Humidity Transducers.

These data were further reduced to produce a steady-state RH value for a given temperature setting. A graph of these values versus the known RH values as a function of temperature is shown in Figure 3 for candidate 1. This sensor had a much smaller dependence on temperature than did candidate 2 or 3. It should be noted that candidates 2 and 3 were both from the same manufacturer and that all three units were new.

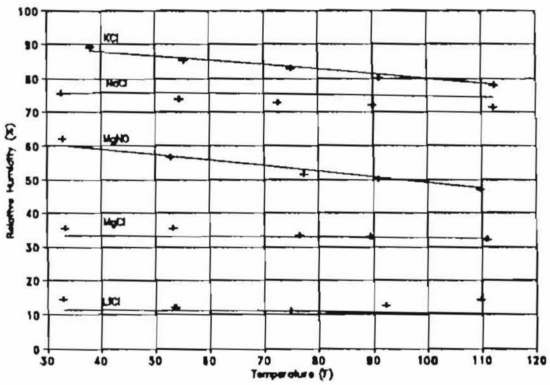

Figure 3. Reduced Data for Candidate 1 vs Reference Humidity Values as a Function of Temperature.

Figures 4, 5, and 6 show the plots of the data and a linear regression line vs the saturated salt RH. It was found that candidate 2 and 3 can reliably report the level of RH in an air sample provided the RH is greater than approximately 30%. This is evidenced by the statistics for the regression and by the plot of the data (note the RH spread for candidates 2 and 3 with the LiCl test).

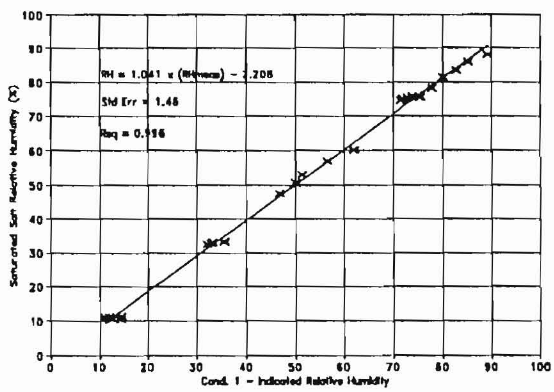

Figure 4. Linear Regression Results for Candidate 1.

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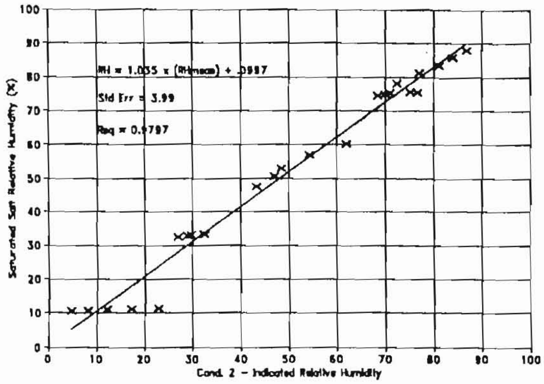

Figure 5. Linear Regression Results for Candidate 2.

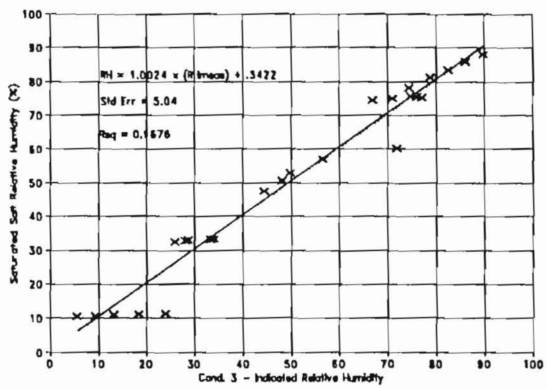

Figure 6. Linear Regression Results for Candidate 3.

Another way to compare the data from the different transducers is to calculate the percentage error in readings between the measured relative humidity and the relative humidity produced by the saturated salt. This error is given by

$$\%error = \frac{RHmeas - RHsalt}{RHsalt}$$

A plot of the percent error for each of the candidate sensors is shown in Figure 7, 8, and 9. Candidates 2 and 3 show a distinct problem at low (<15% RH) humidities. The strong linear trend for five points are the data taken for Lithium Chloride (LiCl, 11% RH). The same trend is also noticed, though not as pronounced, for Magnesium Chloride (MgCl, 35% RH). Candidate 1 also shows some error at the low relative humidity level. Further tests will be required to better quantifiy this behavior.

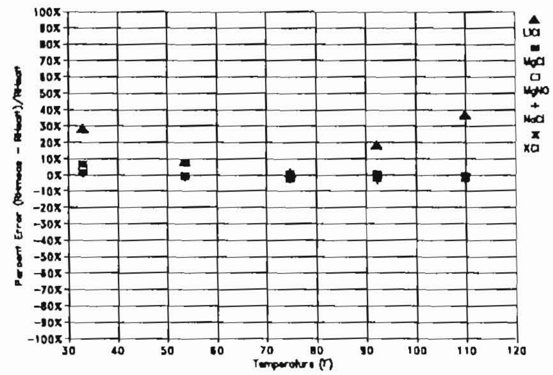

Figure 7. Percent Deviation From Reference Relative Humidity for Candidate 1.

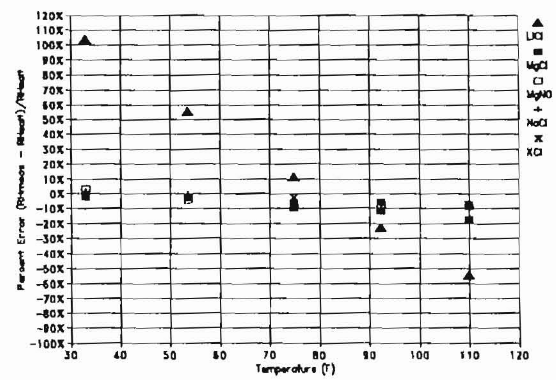

Figure 8. Percent Deviation From Reference Relative Humidity for Candidate 2.

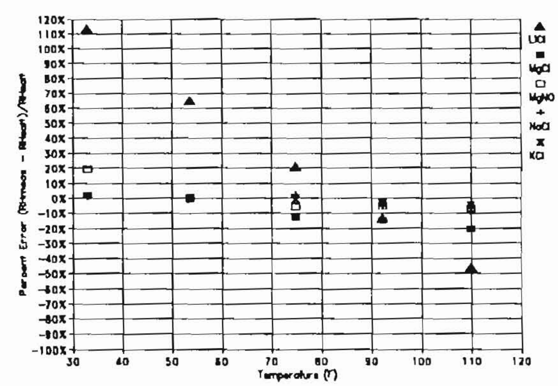

Figure 9. Percent Deviation From Reference Relative Humidity for Candidate 3.

Conclusions

If the application for a given RH transducer is to be in a tight temperature range (20°C to 33°C), then most manufacturers standard RH device will provide

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results that are within their stated accuracy. If, however, the application will cover an extended temperature and RH range (weather station, enthalpy control), then much more care must be taken when selecting the proper device. If cost is a major concern, then the less expensive RH transducers must be calibrated before being installed so that any dependence on temperature or relative humidity can be quantified. These devices should also be calibrated at least every six months or sooner if a degradation in performance is noted. The calibration of RH sensors for the LoanSTAR program will consist of replacing sensors in field installations with devices which have been through a three salt calibration in the laboratory. The sensors which are brought in will be cleaned checked and recalibrated for use in another installation. These preliminary results have shown that accurate RH measurement is available and that inaccuracies can be quantified and taken into account so that accurate information can be provided to the building energy analyst.

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