A NOVEL HUMIDITY SENSOR DESIGNED FOR ACCURATE MEASUREMENTS IN WEATHER STATIONS

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ABSTRACT

The need for accurate surface weather measurements has become increasingly important. The quality of the measurements is to a large extent governed by how well the instruments work in the periods between the calibrations. Automated weather stations can be situated in remote areas or in other hard to reach locations. Some areas have large weather measurement networks, each station equipped with a number of instruments. To maintain a high quality of measurements, maintenance tasks including calibration is needed. These operations are often expensive but a necessity to give high-quality results. [1]

In outdoor applications humidity sensors are exposed to chemicals other than water vapor. Vaporized chemicals can diffuse into humidity sensors and cause disturbances in the measurements. Such vapors are present in most environments. For example, NO_x, SO_2 and different organic solvents are often present in ambient air. Dust particles or other solid pollutants on the sensor surface can be dissolved by dew and be diffused into the sensor materials. All these chemicals can cause the sensor to yield false readings. In polluted areas this translates into more maintenance for the humidity sensors. [2]

A new type of capacitive humidity sensor has been developed to cope with the demand for stable high accuracy measurements in weather observation. A series of tests were carried out both in pre-set laboratory conditions and in typical humidity sensor applications. The tested humidity sensors showed significantly lower measurement errors in all test environments compared to reference sensors. The tested humidity sensors performed better both in high chemical concentration tests set in a laboratory and in long-term field stability tests. In contrast to the earlier sensor versions developed to withstand demanding environments, these improvements have been obtained whilst maintaining a competitive level in the other properties of the sensor such as, high humidity stability, sensitivity and hysteresis.

1. INTRODUCTION

To better meet the needs of humidity measurements in weather observation, Vaisala has developed a new-generation version of its humidity sensor — the Vaisala HUMICAP®180R. The sensor is a thin-film polymer based capacitive sensor as its predecessors. In the new sensor, the thin-film structure has been re-designed with the aim of improving the performance.

The sensor has been tested both in laboratory conditions and in different applications. The test conditions in the laboratory tests were deliberately severe. They were aimed at finding the tolerance levels of the sensors and to study the behavior of the sensors in extreme conditions. Application tests were set up to verify the implications derived from the laboratory tests.

2. METHODS

The main purpose of the experiments was to study the performance of the sensors without any compensation from measurement electronics, heating systems or such other. These tests which have been conducted without the measurement instruments are referred to as sensor tests as opposed to tests done with the instruments, here referred to as transmitter tests. In the absence of the measurement electronics the sensor tests' capacitance measurements were done with an LCR-meter. As an exception, one test was carried out with the sensors connected to the measurement instruments. This test also included humidity measurement devices from other manufacturers.

The sensors and devices in the tests were exposed to different environments. All the samples were removed from the test medium at certain intervals and taken to a testing system at the Vaisala laboratory for measurement. It was assumed that the effects caused by chemical interference or other drift mechanisms are unaffected by transportation and the delay formed between the measurement event and the removal of the test samples from the test medium. The test locations and transporting methods were carefully considered to eliminate or minimize all possible factors distorting the test results.

2.1. Measurement method

All the relative humidity (RH) measurement points were created with a saturated salt solution system. The measurements were carried out with the same salt system each time. The salt systems are susceptible to temperature differences within the system. In addition, there are other known sources of uncertainty. [3] In the described experiments the major source of error is believed to be the temperature differences measured between the salt column and the adjacent air. The variations in the laboratory temperature were believed to be the second most significant source of error. Taking into account these two sources of error, it has been estimated that the measurements uncertainty is ±0.3 %RH at 75 %RH (sodium chloride) and ±0.4 %RH at 97 %RH (potassium sulfate).

The dry-point (approximately -70°C_{Tf}) was created with a nitrogen atmosphere. An error estimation test showed the measurement uncertainty to be ±0.2 %RH.

Capacitance values were measured using an HP 4284A LCR-meter. A simple linear model was used to convert the measured capacitance values to RH-readings. Accordingly the drift of a given sensor at a selected RH-level was calculated using the derived equation 1:

$$\Delta RH = \left(\frac{C_x - C_0}{C_{75} - C_0} \right) \cdot 75\% RH - RH_x \qquad (1)$$

where,
ΔRH = drift of the sample sensor in a RH-point
RHx = relative humidity at the measurement point
Cx = capacitance value of the sample at the measurement point
C0 = initial capacitance value of the sample at 0 %RH
C75 = initial capacitance value of the sample at 75 %RH

The sensors were always measured at least at two different humidity levels to show changes in the sensitivity and offset. All the tests included preceding versions of the Vaisala HUMICAP® sensors as reference sensors

3. EXPERIMENTAL

The sensor tests included four different categories of testing: general performance tests, chemical exposure tests, demanding application tests (wood dryer) and outdoor tests. The outdoor tests also included a transmitter test where different manufacturers' instruments were compared.

In the sensor tests, the performance of the Vaisala HUMICAP®180R sensors was compared to other HUMICAP® sensors. In the transmitter test a Vaisala humidity transmitter equipped with a HUMICAP®180R sensor was compared to other manufacturers' instruments. In each test there were several samples of each test species with the exception of the transmitter tests.

3.1. General performance test

To study the possible adverse effects of the new structure and the polymer the sensors were subjected to a general performance test. The test had several different steps at different humidity levels. The initial measurement was done at 0 %RH and 75 %RH. It was then followed by a 97 %RH step at which the sensors were kept for 16 hours. The measurement after the 16 hours exposure determines the drift which is an indication of the sensors high humidity stability and it is referred to as creep in this text. The sensors were then placed into 75 %RH for one hour and 0 %RH to determine the hysteresis and offset error. The sensors' sensitivity was determined from the initial measurement at 0 %RH and 75 %RH.

3.2. Chemical tests

The chemicals for the chemical test were selected by choosing three chemicals with different molecule size and functional groups. The selected chemicals were methyl ethyl ketone (MEK), diethyl ether and isopropyl alcohol. The tests were conducted with three different chemical concentrations. The chemical concentrations were carefully selected by studying earlier such experiments. [2] The tests were run for approximately one month or until a 3 %RH drift was seen at 75 %RH.

The chemical exposure setup is depicted in Figure 1. The setup is the same as described in the work done by Leppänen, Stormbom and Åström. [2]

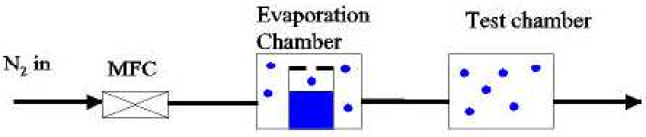

Figure 1 — Chemical exposure setup

The setup includes a small bottle containing the test substance in an evaporation chamber. The chemical evaporates and mixes with nitrogen gas which flows through the evaporator. The chemical concentration can be derived from the chemical's loss of weight and the nitrogen flow rate.

During the chemical exposure the chemical can enter the sensors' active material and cause adverse drifting effects. To remove the chemical from the active material, a Vaisala-patented method of heating the sensor can be applied to cleanse the sensor and in that way re-attain the original sensor performance. This treatment of the sensors is referred to as chemical purge.

3.3. Wood dryer

To test the performance of the sensor in a demanding application and to evaluate the functionality of the chemical purge, the sensors were subjected to a wood dryer environment at Timberwise Oy located in the town of Loimaa, Finland. The test was carried out for over three years to get reliable long-term stability data. The temperature conditions at the dryer varied from -30°C up to almost +100°C. At the same time humidity varied over the whole scale. In a typical wood drying process the temperature is 85°C and the initial humidity level is nearly 100 %RH. The chemicals that are evaporated during the process include such adverse chemicals as formic acid, acetic acid, other acids, alcohols, ketones, aldehydes, and terpenes. The quantities and the exact chemical pallet vary depending on the type of wood dried.

3.4. Outdoor test set-up

Humidity measurements outdoors pose a problem during cold periods of the year, such as, late autumn, winter and early spring when the temperature often falls below the dew point, especially in the early morning. As a consequence, dew sets on the surface of the thin polymeric sensor. When the dew has evaporated, some water-soluble ingredients in air such as sulphur or nitrogen compositions, which may have diffused inside the sensor layers, cause an irreversible drift of the sensor-signal. [4]

In previous experiments the sensors have been heated above the ambient temperature to keep the dew from settling on the sensors. [5] In the sensor tests of this study, the sensors were kept unheated at all times to find the performance of the sensors without the instruments' electronics and algorithms. To add to the understanding of the new sensors' performance, a transmitter test with heating and chemical purge was also done. In this test the performance was also compared to other manufacturers' humidity measurement instruments.

The outdoor tests were carried out at two locations. One group of test samples were placed in the Vaisala outdoor test field located in Vantaa, Finland. The other set was placed into a roadside weather station in Helsinki, Finland near a motorway junction were the amount of traffic reaches a maximum of 1500 vehicles per hour.

The roadside test was carried out for nearly two years. The simultaneously started sensor test at Vaisala ran for nearly four years. The other outdoor sensor test was started later with three different manufacturing batches to evaluate the conformity of the performance. This test was continued for a little over one year. The transmitter test where different manufacturers' devices were compared was carried out for a little over one year.

4. RESULTS

All the following test results shown include several test samples of each test species. The measurement results represent the average values of the test species, if not otherwise stated. The results show the values at least at two different humidity levels to show changes in sensitivity and in offset. For consistency, all the results shown in this text include the measurement results at 0 %RH and 75 %RH humidity levels.

The results show that the new Vaisala HUMICAP®180R sensor has less drift than the reference sensors in all of the experiments. The general humidity performance of the sensor is essentially the same as the current version of the HUMICAP® sensor. The chemical purge increases the sensors' resistance to chemical interference and therefore, increases the long-term stability.

4.1. General performance test

The general performance test shows that the behavior of the new Vaisala HUMICAP®180R sensor is similar to the HUMICAP® sensor. The new structure and polymer have no adverse affects on the sensors general behavior. The results from the general performance test are shown in Table 1.

Table 1 — General performance test

	Sample sensors		Reference sensors	
	average	3σ	average	3σ
Creep (%RH)	0.3	0.1	0.2	0.2
Hysteresis (%RH)	1.2	0.1	1.0	0.2
Offset (%RH)	0.0	0.0	-0.1	0.0

where,

3σ = 3·Standard deviation

The creep and offset values in both the reference sensors and the new sensors show little or no drift. The hysteresis values are approximately 1 %RH for both sensors. In addition, a similar sensitivity and base capacitance level were reached with no difficulty.

4.2. Chemical tests

The new Vaisala HUMICAP®180R sensors showed significantly less drift in all chemical tests compared to the reference sensors. From the tested chemicals diethyl ether gives a clear example of this. The graphs in Figure 2 show the average drift of the sensors exposed to three different concentration levels of diethyl ether. The concentration levels were 1000 ppm, 10000 ppm and 28000 ppm.

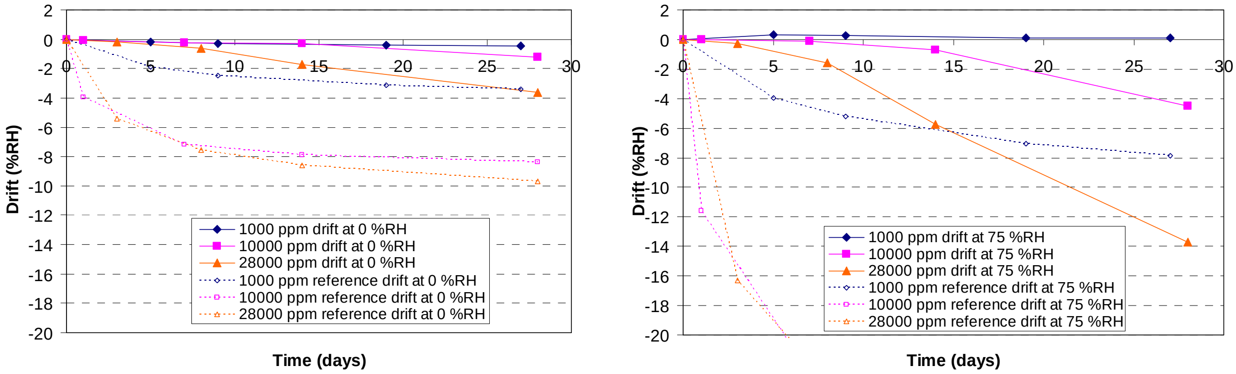

Figure 2 — Sensor drift in diethyl ether at 0 %RH (left) and drift at 75 %RH (right). Solid lines: HUMICAP®180R sensors, dotted lines: HUMICAP® reference sensors.

A higher chemical concentration causes more drift at 0 %RH and 75 %RH measurement points. The references show a much more severe drift. For example at 1000 ppm diethyl ether concentration the drift at 75 %RH after 28 days is negligible for the HUMICAP®180R sensors while the reference sensors show nearly an 8 %RH drift.

In the beginning of the chemical exposure, there is typically a phase where the sensors' readings are unaffected by the chemical and there is little or no drift. As more time passes the sensors exhibit a downward drift. The angle of the drift and the point at which this occurs depends on the level of the concentration. This pattern was seen with the new Vaisala HUMICAP®180R sensors in all the tested chemicals when the chemical concentration was high enough.

The new Vaisala HUMICAP®180R sensors were highly resistant to isopropyl alcohol vapor compared to the reference sensors. Drift was seen only in saturated isopropyl alcohol vapor, see Figure 3. The measurement result here is used to demonstrate the principle of the chemical purge feature, which is applicable when the sensor is connected to an instrument.

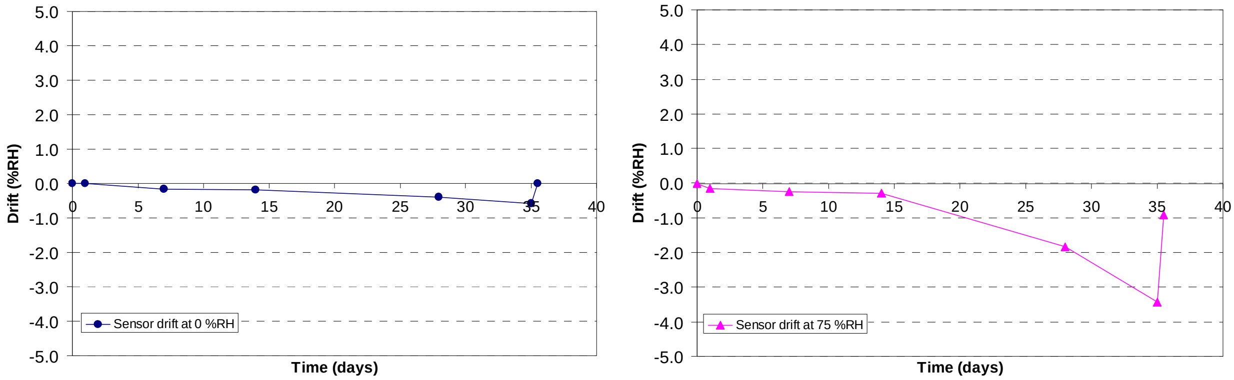

Figure 3 — Chemical purge after 35 days of exposure to saturated isopropyl alcohol vapor. Drift at 0 %RH (left), drift at 75 %RH (right)

A heating step simulating a chemical purge was done at the end of the test after 35 days exposure to isopropyl alcohol vapor. The Vaisala HUMICAP®180R sensors showed significant signs of recovery. The drift was reduced from over a 3 %RH drift to a drift of less than 1 %RH.

The results from the methyl ethyl ketone were similar to the other two chemicals tested. After a seven-day exposure to methyl ethyl ketone, the sensors began to show signs of drift with a correlation to the chemical concentration. The drift was less severe than that of the reference sensors. After drifting the sensors showed signs of recovery after a chemical purge.

4.3. Wood dryer tests

To test the chemical purge in a true humidity sensor application, six samples of the Vaisala HUMICAP®180R sensors were placed into a wood dryer chamber. The chemical purge feature was simulated by a heating cycle done before the measurement. This treatment was done to three different sensors while the other three sensors were left without it. Figure 4 shows the drift of the HUMICAP®180R sensors at nine checkpoints during the wood dryer test.

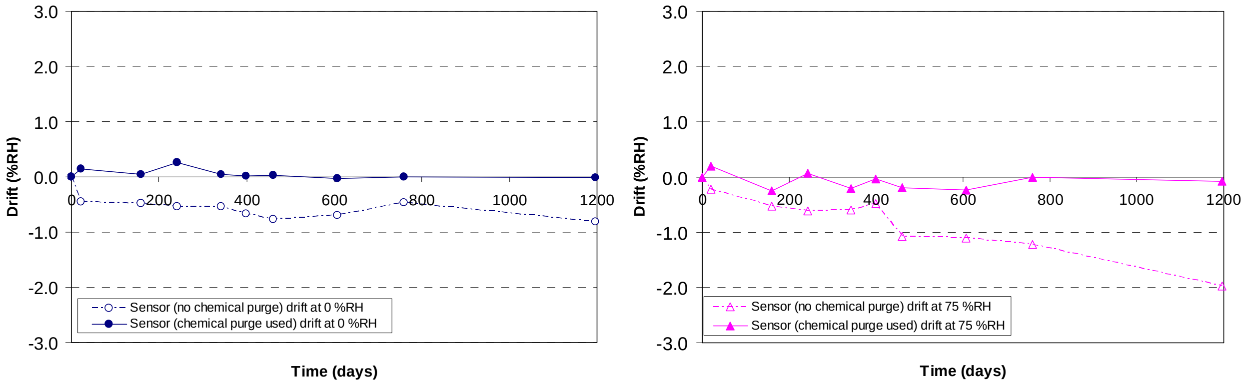

Figure 4 — Wood dryer test. Drift at 0 %RH (left) and 75 %RH (right) after 1200 days of exposure. Solid lines: HUMICAP®180R sensors with a chemical purge, dotted lines: HUMICAP®180R without chemical purge

The Vaisala HUMICAP®180R sensors with the chemical purge showed less drift at all points of the experiment compared to the sensors without the feature.

4.4. Outdoor tests

The first outdoor test carried out at the Vaisala test field included three Vaisala HUMICAP®180R sensors and three HUMICAP®180 sensors as references. Figure 5 shows the drift of each sensor type at a given time. All HUMICAP®180R sensors show less than a 1 %RH drift from the initial measurements during the 1400-day experiment. In addition, the deviation between the individual sensors was small.

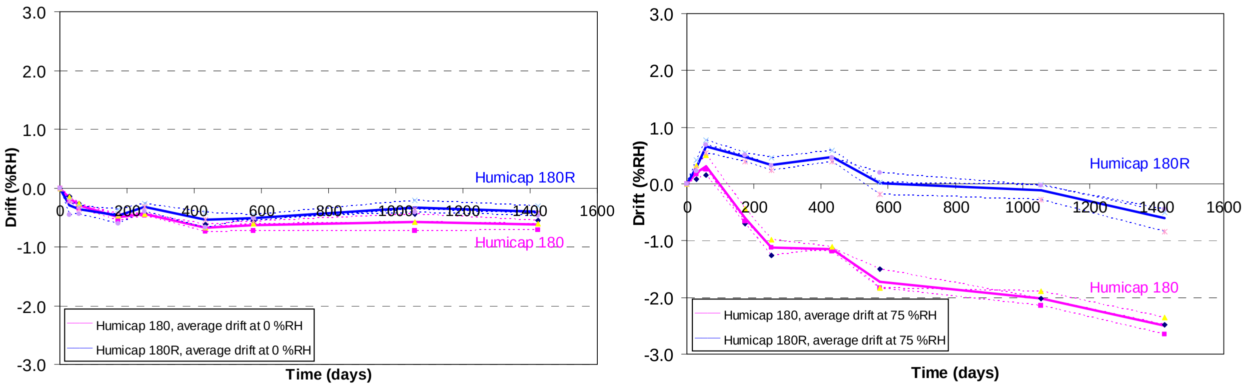

Figure 5 — Outdoor test, Vaisala test field. Three sensors deviation from initial measurement at 0 %RH (left) and 75 %RH (right) after 1400 days of exposure. Dotted lines: individual sensors, solid lines: average values.

The second outdoor test results in Figure 6 show the drift of ten individual sensors from three different manufacturing batches. The stability behavior of the sensors was similar to the first outdoor test. The variation from one batch to another was also small.

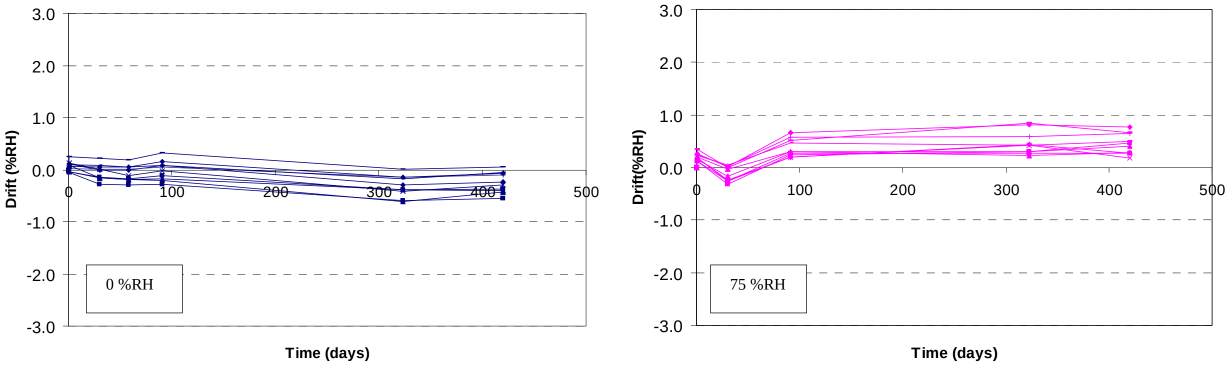

Figure 6 — Ten pieces of HUMICAP®180R sensors from three manufacturing batches. Drift at 0 %RH (left) and drift at 75 %RH (right) after 420 days of exposure

The sensors placed into the roadside weather station show a similar stability behavior as in the other outdoor tests. The measurement results are shown in Figure 7.

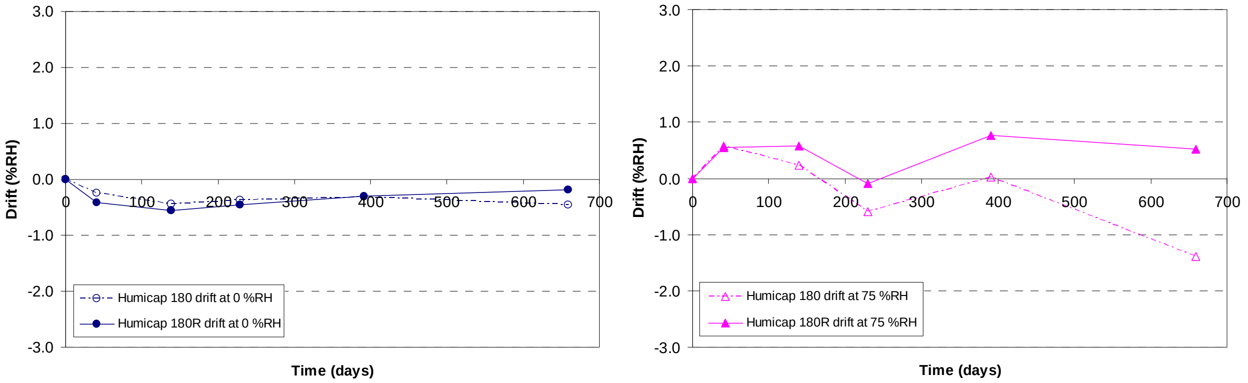

Figure 7 — Outdoor test, roadside weather station. Drift at 0 %RH (left) and 75 %RH (right) after 659 days of exposure

In the outdoor transmitter test, the Vaisala HUMICAP®180R sensor was placed into the Vaisala HUMICAP® Humidity and Temperature Transmitter HMT337 and compared to three different manufacturers' instruments (see Figure 8). The HMT337 instrument was configured to perform a chemical purge once a day. The test in the Vaisala outdoor test field was carried out for approximately 400 days. The HMT337 transmitter equipped with the HUMICAP®180R shows less drift than the comparison devices. The chemical purge function exhibits a similar behavior as in the wood dryer test.

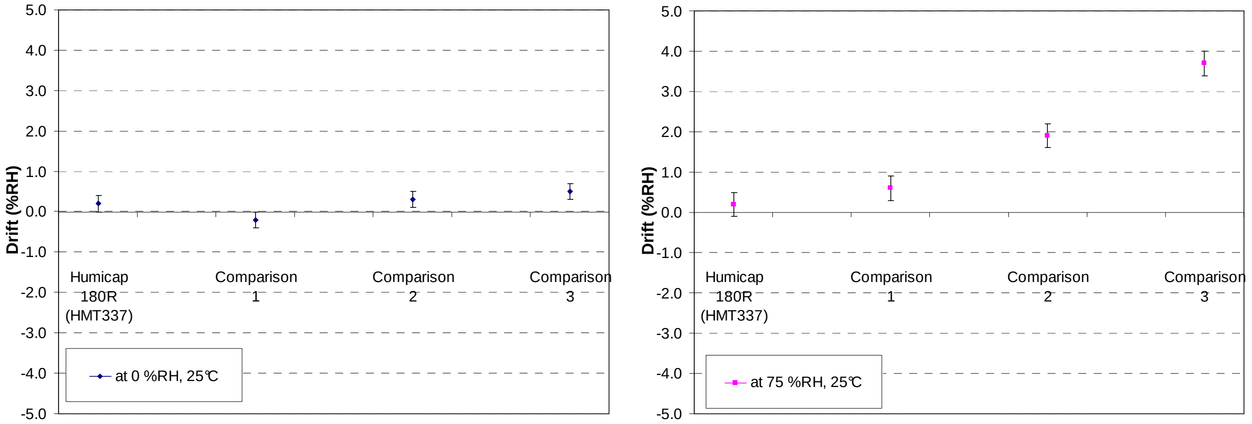

Figure 8 — Transmitter outdoor test. Drift at 0 %RH (left) and 75 %RH (right) of HMT337 with HUMICAP®180R sensor and three other manufacturer's instruments after approximately 400 days of exposure.

5. DISCUSSION AND CONCLUSIONS

The new Vaisala HUMICAP®180R sensor was tested and compared against reference sensors in four test categories: general humidity tests, chemical exposure tests, demanding application tests, outdoor tests. The tests show that the general humidity performance of the HUMICAP®180R is at the same good level as that of the current HUMICAP® sensor. However, the HUMICAP®180R has significantly less drift in all the chemical tests compared to reference sensors.

The new structure and the polymer make the sensor highly resistant to chemical interference. Similar results to those seen in Figure 2 and 3 are also observed for other chemicals. Using this information and setting the purge parameters accordingly the sensor can be used even in harsh chemical conditions.

In both the wood dryer test and the outdoor tests, the Vaisala HUMICAP®180R sensors showed excellent long-term stability behavior. In the outdoor tests HUMICAP®180R sensors drifted less than 1 %RH during the 1400 days of the experiment.

The sensors perform well even without a heating system. Therefore, the good long-term stability of the sensors can also be put to use in applications where heating or chemical purge are not possible. In less severe conditions, the improved resistance to chemical interference can, for example, be used to extend the calibration interval.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] M. Leroy, "Documentation of Surface Observation, Classification for Siting and Performance Characteristics", TECO-2006 - WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation

[2] J. Leppänen, L. Stormbom, S. Åström, “Chemical Interference in a Capacitive Humidity Sensor”, Proceedings of the 4th International Symposium on Humidity and Moisture, pp. 471-478

[3] L. Greenspan, "Humidity Fixed Points of Binary Saturated Aqueous Solutions", Journal of Research of the National Bureau of Standards - A. Physics and Chemistry, Vol. 81A, No. 1, January-February 1977, pp 89-96

[4] U. Demisch, J. Hall, “High Level Applications for Polymer Humidity Sensors”, Proceedings of the 4th International Symposium on Humidity and Moisture ISHM 2002, Taipei 2002, pp. 435-443

[5] Timo Ranta-aho, Lars Stormbom, "Real Time Humidity Measurement Using the Warmed Sensor Head Method", 4th International Symposium on Humidity and Moisture ISHM 2002, Taipei 2002, pp. 583-588

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