Instrument Test Report: 661

Evaluation of Vaisala HMP45D Humidity Probes

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Authorisation

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Overview

Humidity probes must conform to the Bureau of Meteorology Standard Calibration Procedure RH01SCP01 "Calibration of Relative Humidity Probes"[1] and their output must comply with equipment specification A2671 Provision of an Automatic Weather Station Type I[2]. Vaisala supplied 21 HMP45D humidity probes for evaluation.

Assumptions

1. It was assumed that the probes received are representative of **all** HMP45D probes ex-factory and that the probes received have not been altered/adjusted or specifically selected before receipt by RIC.
2. It was assumed that the Bureau's working reference for humidity, an Eastern General M2 Dew Point Hygrometer (S/N 2260298), provides a true reading within the bounds of uncertainty supplied with its calibration certificate[3] after the relevant correction has been applied at each Relative Humidity (RH).
3. Due to the uncertainty of the General Eastern humidity reference employed by the RIC (see Appendix A) a "significant error" for a probe is defined as a correction greater than 2% RH, or a drift in correction of greater than 1% RH.
4. It was assumed that the 15 months of laboratory storage experienced by these probes prior to testing was the equivalent of storage before issue.

Experimental

The Vaisala HMP45Ds were placed in groups of four into either the RIC's climate chamber, or the reference humidity generator, and their RH and temperature output logged by computer via a Datalogger Datataker800 (s/n: 0808-272). The Split Stream Humidity Generator was of Bureau design and construction and is described in a Bureau technical note[4]. The flow rate was set at 1 litre/min. The climate chamber used was a Heraus Votsch Model 4030 (s/n. 43315).
At each set point both temperature and relative humidity were allowed to stablise before recording data. During these experiment stable humidity is defined as a running standard deviation of less than 0.02 % RH taken over 21 successive samples. Stable temperature is defined as a running standard deviation of less than 0.01 degrees C taken over 21 successive samples. For the HMP45D the relative humidity measurement was a direct conversion of a voltage output (0 – 1000 mV equating to 0 to 100%RH) and the temperature was a four wire measurement of a Pt100 resistance (385 – 1/3 DIN 33760B). Reference humidity and temperature were measured by a General Eastern Model M2 Hygrocomputer (GE-M2 s/n: 2260298) with an uncertainty described in Appendix A and Reference 3. The tests were conducted in Sept./Oct. 2001 by laboratory staff[i]. Calibration was performed on the GE-M2 reference in April 2001 at the National Measurement Laboratory[3].

[i] Nilanga DeSilva PO1, J.Gorman PO2

Stage 1. "As-received" Distribution of Calibrations

This test was to examine the distribution of "calibration" within the population of probes received into the RIC. To achieve this all probes received were compared to the GE-M2 dew point hygrometer at room temperature (approx. 23^{o}C) for the range of humidity 5 to 90% RH. Both offset and variance were assessed for each probe.

Results.
The results of the measurement of probe RH correction (reference – probe) versus reference RH are plotted in Figure 1. The probes displayed a consistent and non-linear difference when compared to the GE-M2 in agreement with the data supplied by Vaisala for these probes[6]. The upper and lower limit levels shown are ±2% RH as per the current Bureau specification[1]. Figure 1 illustrates that the majority of probes would have passed the acceptance criteria without adjustment by the RIC.

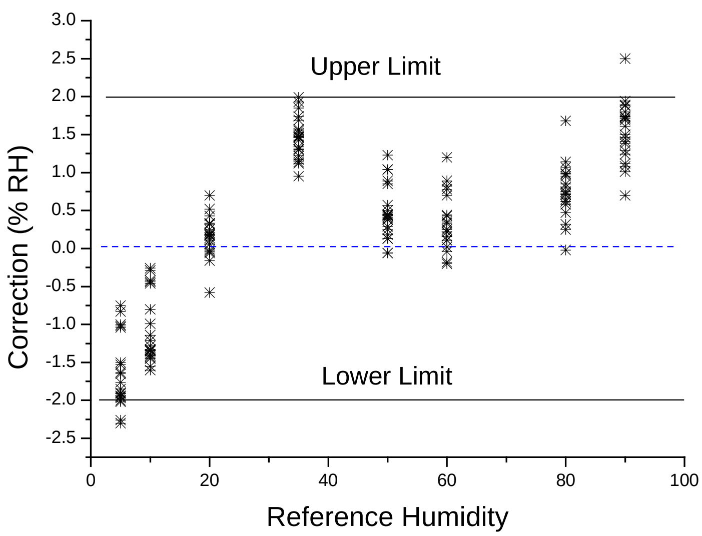

Figure 1. Correction (Ref-Probe) in % RH versus Reference Relative Humidity with Bureau specification limits shown.

Stage 2. Retention of Calibration with Time.

Short Term Drift
A comparison was made between 12 probes and the GE-M2 for a period of 1.5 hours at 35, 80 and 10% RH at room temperature to determine short-term drift or more complex non-stationary behavior. The results for four probes are shown in Figure 2, quantisation error is clearly seen in the output of the GE-M2 and the variations seen for the HMP45D probes are not viewed as significant and probably arise due to variations in the output of the humidity generator. No drift in offset was observed which would take the probes out of specification within a time frame of a few hours. The average standard deviation for the probes tested was highest at high RH (80% RH) and was approximately 0.1%RH (30 sample running standard deviation).

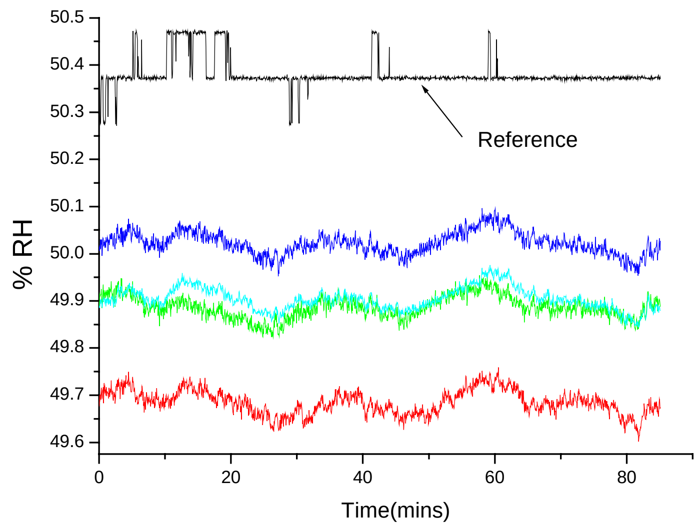

Figure 2. Typical plot of probe output versus time for 4 probes over 1.5 hours.

Medium Term Drift
A comparison was made between 12 probes and the EG-M2 for a period of 22 days at 35, 80 and 10% RH at room temperature for brief periods twice a day to estimate medium term drift. The results for probes designated 1 through 4 appear in Figures 3, 4 and 5.

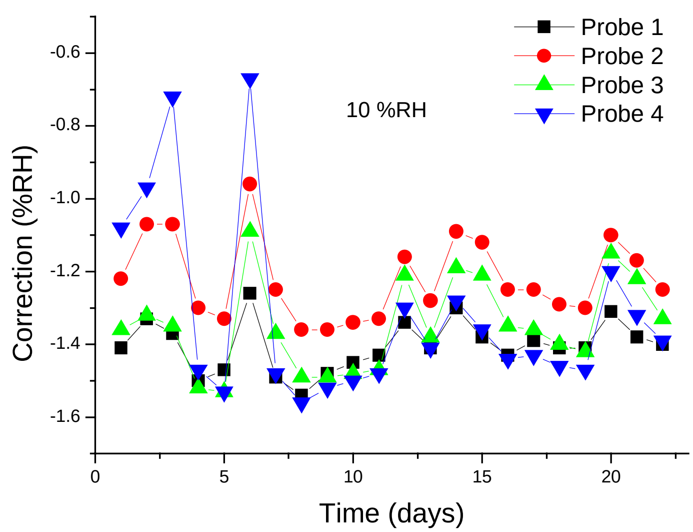

Figure 3. Typical plot of correction versus time for 22 days at 10 % RH.

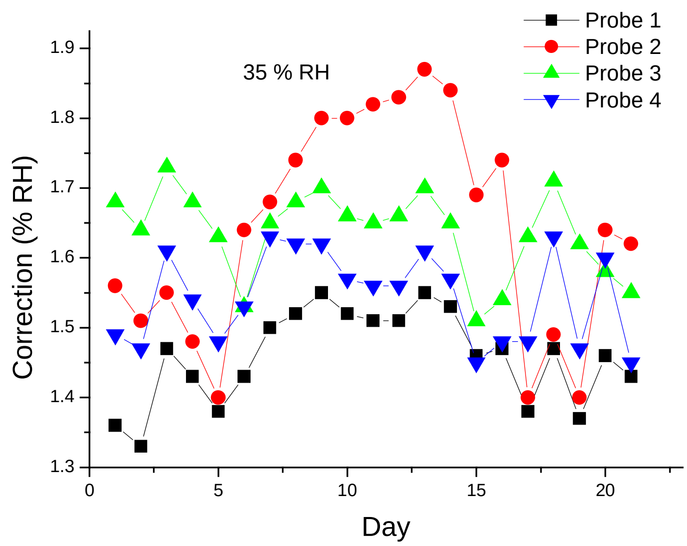

Figure 4. Typical plot of correction versus time for 22 days at 35 % RH.

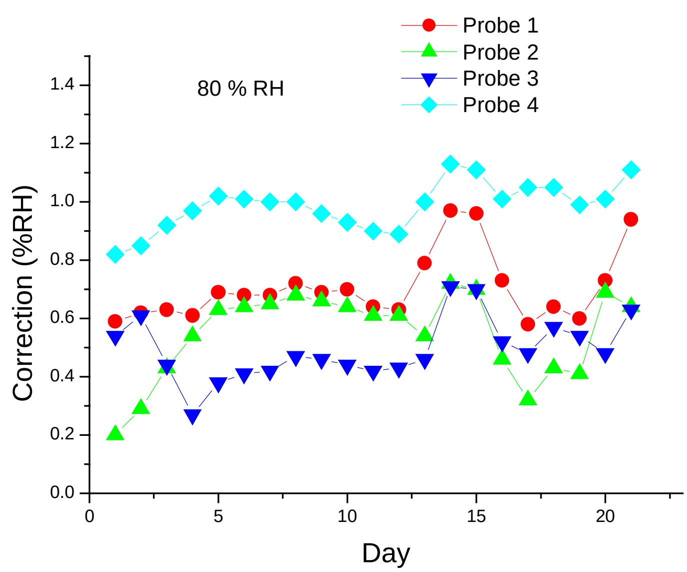

Figure 5. Typical plot of correction versus time for 22 days at 80 % RH.

Again no significant medium term drift was apparent at the RHs tested. Fluctuations seen may have been attributable to either the humidity generator or the working reference instrument. All probes studied remained within specification over the 22 days test period. From the data collected medium term drift was not significant enough to take the probes out of specification within 6 months.

Stage 3. Calibration Versus Temperature

Correction Versus Temperature

Comparisons were made between 4 probes and the GE-M2 at 10, 35, 80% RH and at temperatures of 5,15, 25, and 35°C.

The probes remained within specification for most of the temperature and humidity range tested. Results are plotted in Figures 6 to 8 for 10, 50 and 80 % RH respectively. Bureau specifications are shown as solid horizontal lines.

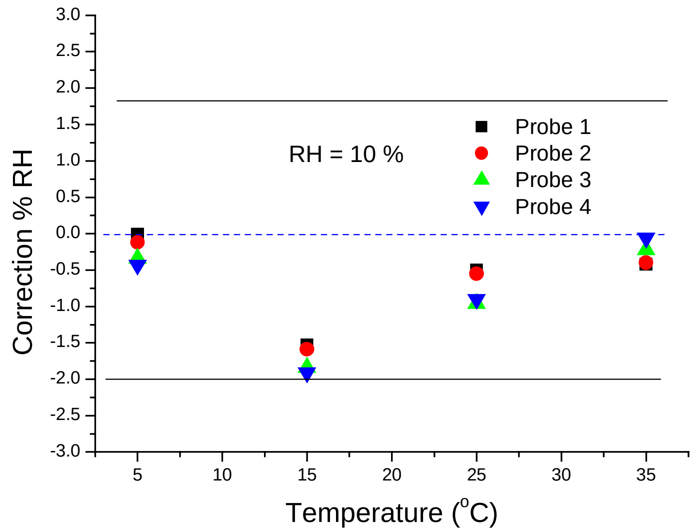

Figure 6. Correction in % RH versus Reference Temperature at 10% RH.

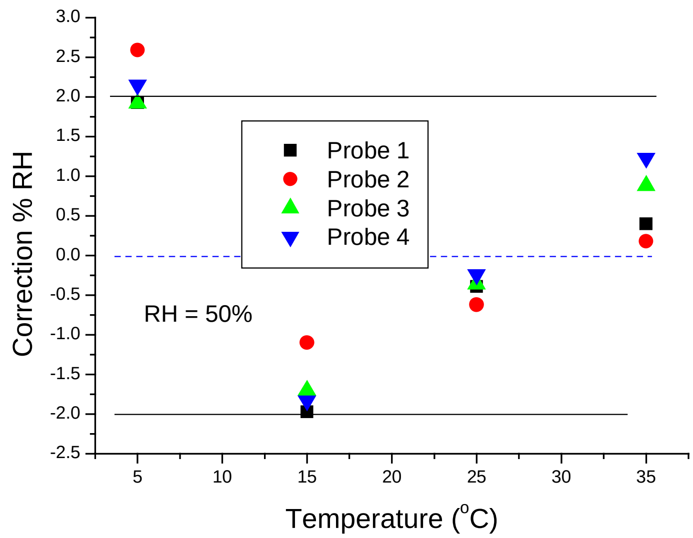

Figure 7.Correction in % RH versus Reference Temperature at 50% RH.

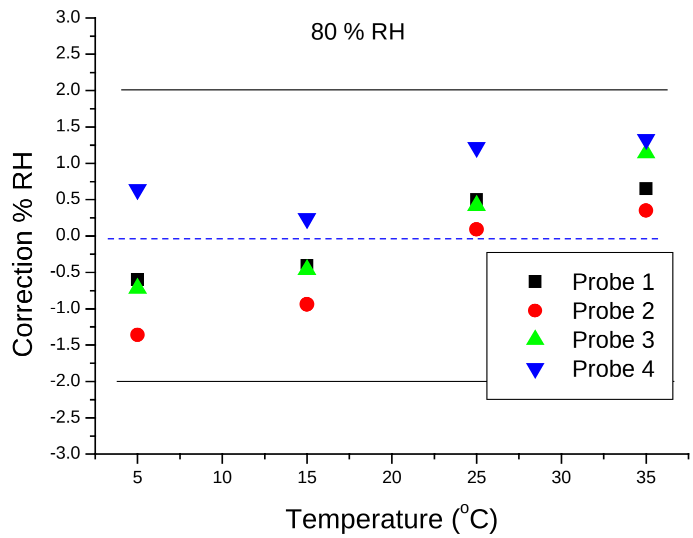

Figure 8.Correction in % RH versus Reference Temperature at 80% RH.

It can be seen in Figure 7 that two of the probes were out of specification at 5°C 50 % RH and the other two probes were borderline, and at 15°C three probes were borderline again confirming that the largest errors were seen at medium RH.

Correction After Sub-zero Exposure

4 probes were subjected to –40°C for 4 hours before returning them to room temperature and confirming retention of calibration. Figure 9 shows the drift in correction for the four probes after exposure.

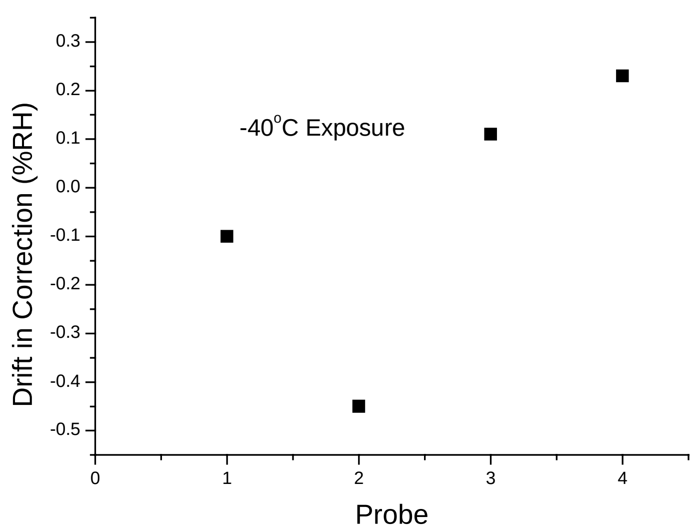

Figure 9. Drift in correction at 35% RH 23°C after exposure to -40 degrees C for 4 hours.

The drift in corrections was of the order of 0.25 % RH and showed no discernable pattern. All probes tested remained within specification after exposure to sub-zero temperatures.

Correction After High Temperature Exposure

Another 4 probes were subjected to 60^{o}C for 4 hours before returning them to room temperature and confirming calibration. The drift in corrections after exposure is displayed in Figure 10 below.

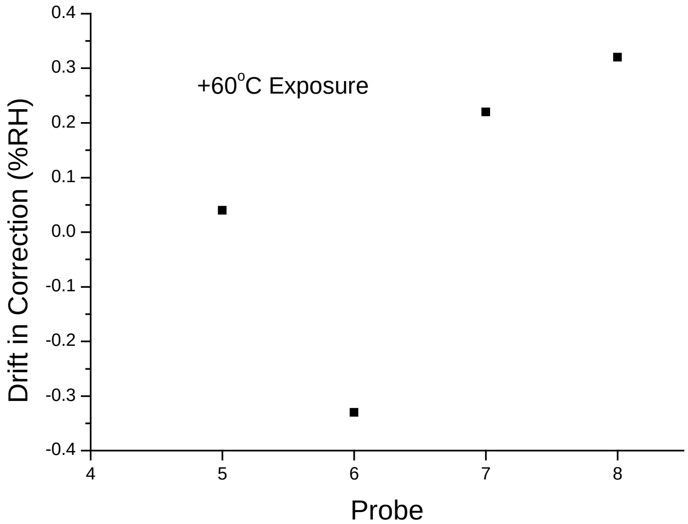

Figure 10. Drift in correction at 35% RH 23^{o}C after exposure to 60^{o}C for 4 hours.

Again no discernable pattern was observed and all probes remained within specification after exposure to 60^{o}C for 4 hours. The drift in correction was again of the order of 0.25% RH and is not considered significant.

Stage 4. Determination of response time and hysteresis

Step Response

Comparisons were made between 12 probes and the GE-M2 for unit step changes in RH at room temperature. Both step up and step down transitions were recorded for all probes. The humidity generator was cycled between 35%RH and 80%RH repeatedly. The response time of the probes was estimated to be the time taken for the probe output to read within 2% RH of the G.E- M2 hygrometer reading. This was less than 12 seconds in all cases for both rising and falling RH. Examples of the responses appear in Figures 11 and 12.

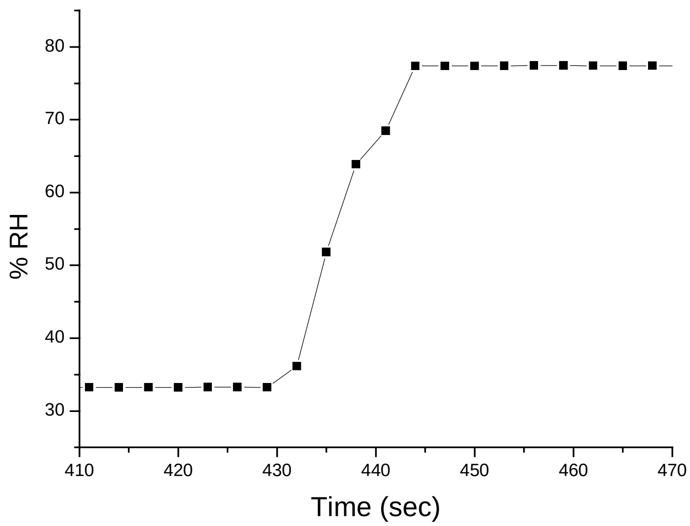

Figure 11. Typical response of probes to a step up in humidity.

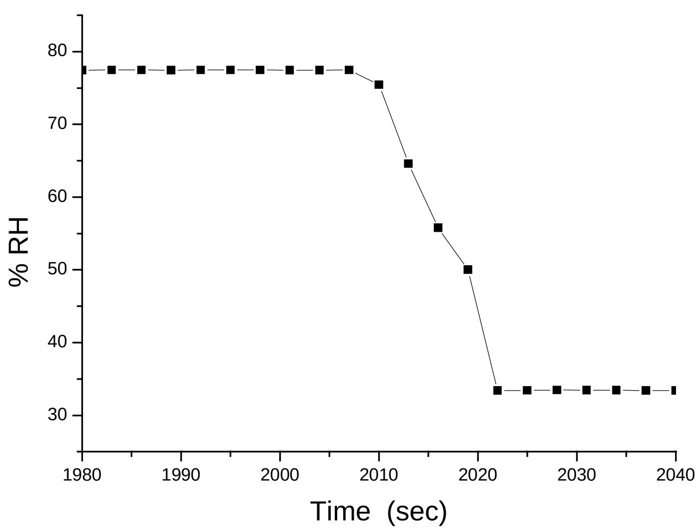

Figure 12. Typical response of probes to a step down in humidity.

Hysterisis

Probes were cycled from 35 to 80% RH then back to 35% RH several times to establish if any short term hysteresis was present in their response. That is, if short exposures to high RH at room temperature lead to a systematic drift in correction. The results are plotted in Figure 13.

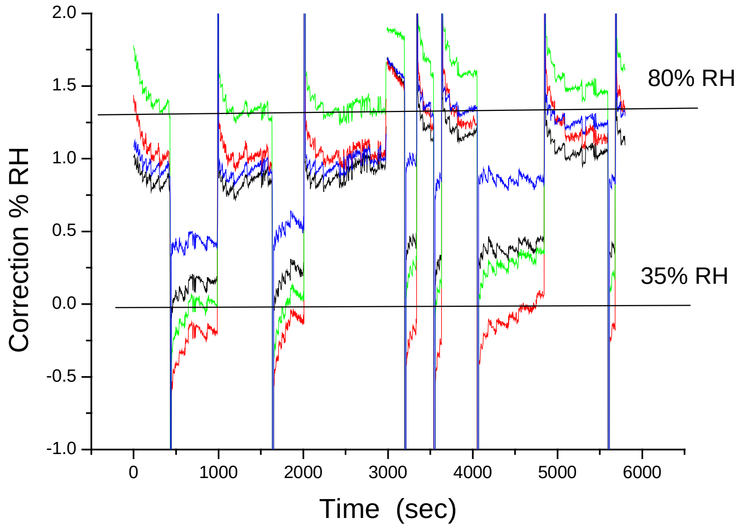

Figure 13. Plot of Correction versus time during RH level switching experiment.

During testing the probes remained at each RH level for approximately 3 minutes. Reference and probe output data were logged throughout the process. The results appear in Figure 13 and show the probes returning to approximately the level of correction after each step transition, however there does appear to be a systematic shift up in correction for all probes at both 35 and 80% RH after repeated exposure. Horizontal lines have been placed on Figure 13 to assist the reader in judging the amount of drift exhibited during this experiment.

Stage 5. "Recalibration" using Vaisala Suggested Procedures.

Four probes were then verified across the range of RH at room temperature before their offsets were adjusted to provide closer agreement with the EG-M2. As per the procedure suggested by Vaisala [5]the "dry" potentiometer was adjusted to minimize the offset error between the GE-M2 and the probes at low RH (nominally 10 %RH at 25°C) and then the "wet" potentiometer was adjusted to minimize the offset error at high RH (80 % RH at 25°C). The offset errors during the adjustment process are recorded in Table 1.
The calibration procedure was difficult when using the screwdriver provided with the probes and the adjustment pots were extremely sensitive.

Table 1. Offset Error from GE-M2 after Calibration Adjustment

Probe	Low RH	High RH
P1	0.18	0.07
P2	0.22	0.21
P3	0.21	0.08
P4	0.20	-0.25

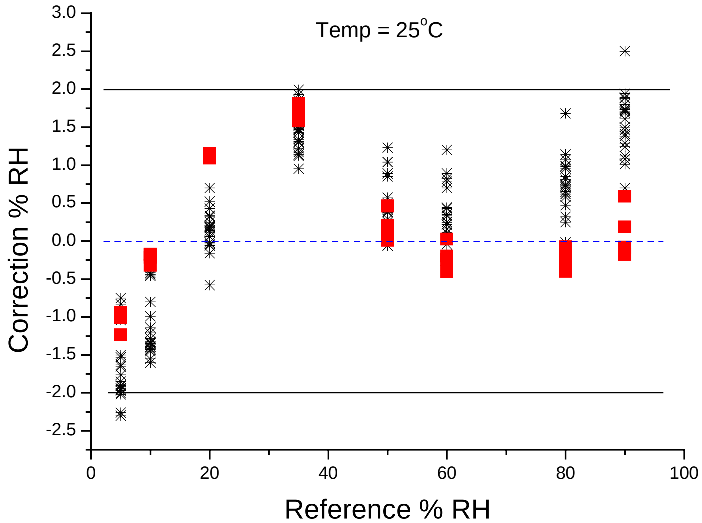

Figure 14. Overlay of the RH response of the 4 re-calibrated probes on the original distribution data.

The application of the suggested Vaisala calibration procedure led to the four probes (shown in Figure 14 as red squares) being closer to zero offset error over the range of RH than the original distribution suggesting that the calibration procedure in the manual will reduce offset errors if applied correctly.

Stage 6. Non Destructive Testing

Supply Voltage Drop Out

12 probes had their power interrupted several times over a period of approximately 2 hours to confirm retention of calibration following power-down/power-up cycling. The results appear in Figure 15. No significant offset errors were seen and all probes tested remained within specification.

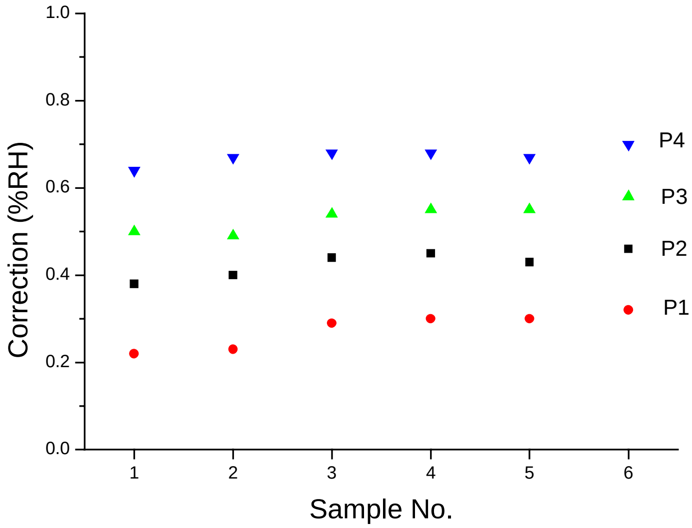

Figure 15. Typical plot of probes corrections after repeated power interruption over a period of approximately 2 hours.

Sensor Saturation

The sensors of 12 probes were saturated, and then dried in a dessicator at 40°C for one hour before having their calibration re-confirmed. The drift in correction after this procedure is shown in Figure 16 and confirms that the probes tested remained within specification after water exposure and drying. The data in Figure 16 appears to be random in nature suggesting that water exposure does not damage the humidity sensor if the probe is dried in a dessicator.

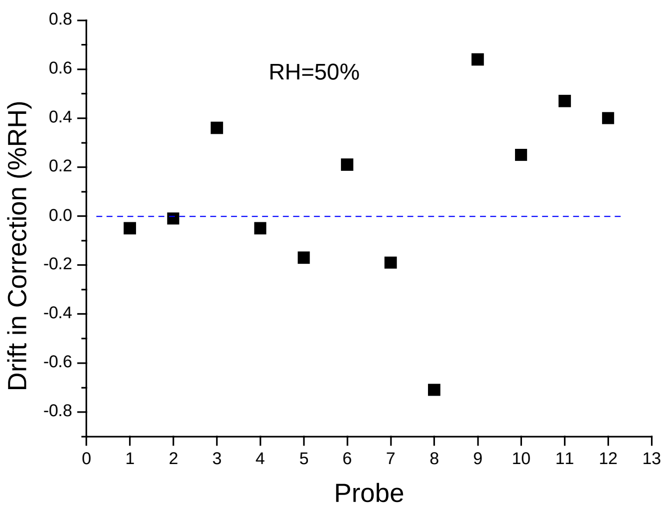

Figure 16. Plot of the drift in probe corrections for 12 probes after water exposure at a reference RH of 50%.

Supply Voltage Variation

8 probes had their supply voltage varied over the manufacturer's suggested range to confirm retention of calibration with variations in supply voltage. The results (mean and standard deviation) for 35% RH appear in Figures 17 and 18.

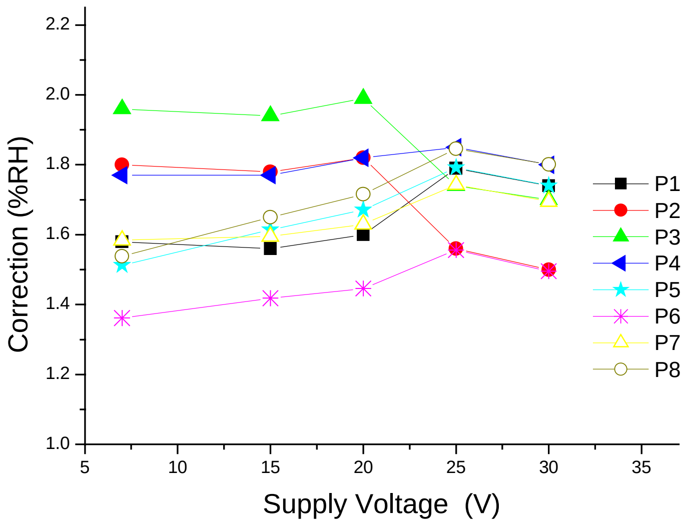

Figure 17. Variation in correction with supply voltage at nominally 35 % RH and 23^{o}C.

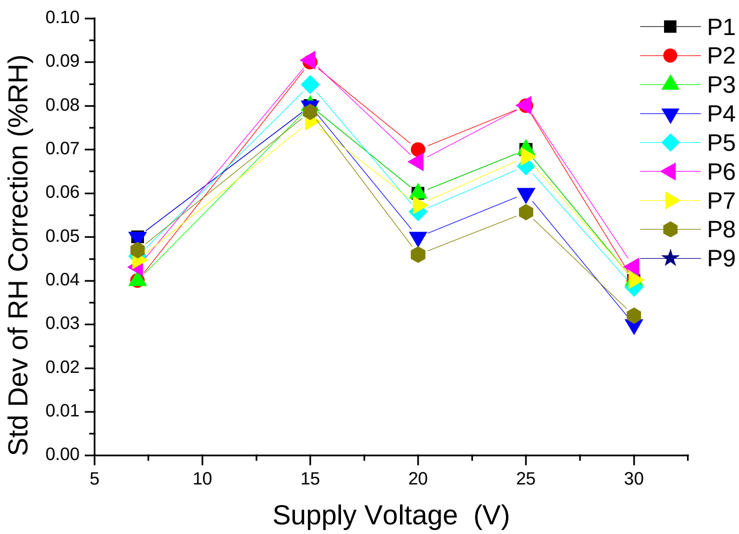

Figure 18. Variation in output standard deviation with supply voltage at nominally 35 % RH and 23^{o}C.

These figures show that there was no significant variation in reading due to fluctuations in supply voltage. All probes remained within specification over the manufacturer's suggested supply voltage range[5].

Performance in Mist

Probes were evaluated as to their performance in the presence of mist. To achieve this the 0.4 micron output filter was removed from the output stage of the humidity generator allowing fine water droplets to pass through to the probes under test.

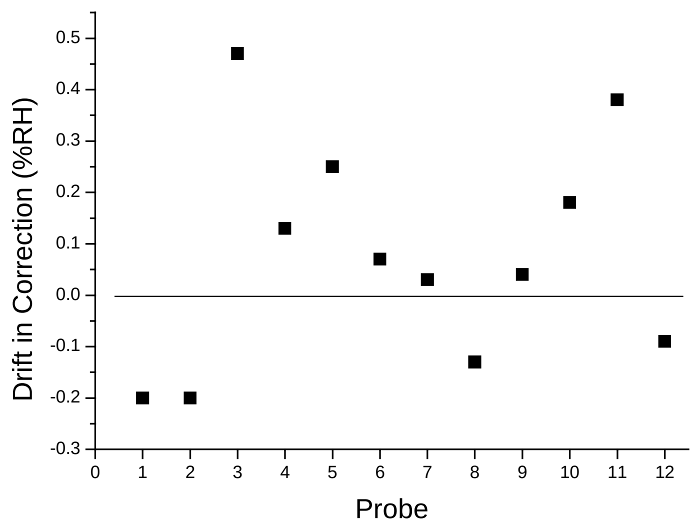

Figure 19. Plot of the drift in correction for 4 probes after exposure to mist conditions at nominally 35 % RH.

The presence of mist did lead to an increase in the signal/noise ratio of the probes as expected due to the presence of water droplets. Figure 19 shows however that there were no significant errors in the mean reading as a result of mist and all probes remained within specification. The larger variations seen in probes 3 and 11 are thought to be within normal statistical variation.

Exposure to Saturating Humidity

Four probes were exposed to 100% RH for an extended period to assess their ability to recover calibration. They were placed in a sealed chamber at room temperature for 3 days in the presence of water to simulated 100% non-condensing humidity. The results for the drift in correction are plotted in Figure 20. The probes were not dried or exposed to low (<20 % RH) before retesting, however they were equilibrated to laboratory air (50% RH @ 23^{o}C) for approximately 30 minutes to ensure condensed water had evaporated from the probe sensor.

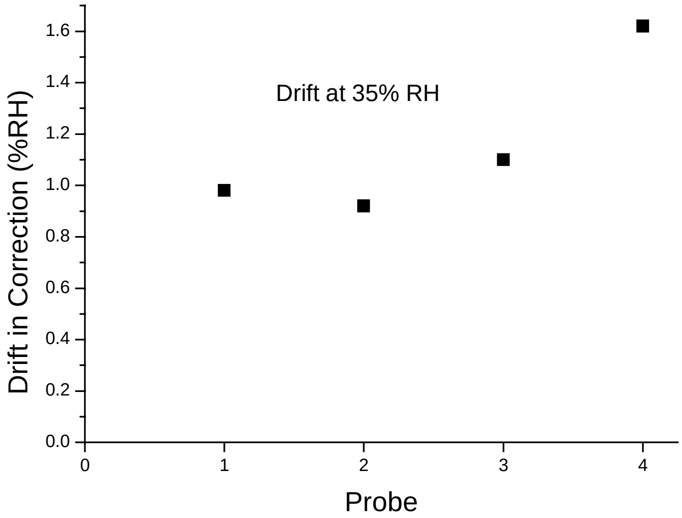

Figure 20. Drift in correction at 35 % RH before and after exposure to 100% RH for 3 days.

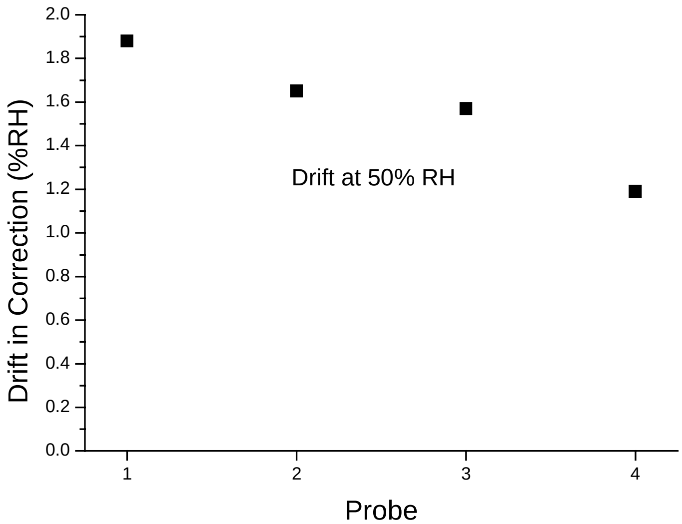

Figure 21.Drift in correction at 50 % RH before and after exposure to 100% RH for 3 days.

All probes tested displayed a positive shift in correction as a result of their exposure to saturated air. This drift was of the order of 1 % to 1.5% RH and this may be significant for some Bureau sites.

Additional Testing.

Five new and unused HMP45D humidity probes became available from another source at the end of this study. The probes were tested in order to ascertain whether the 21 probes

Vaisala supplied for testing were representative of all HMP45D probes issued from the factory. The corrections for the 5 probes versus the reference instrument are plotted in Figure 22 for the range of RH 5 – 90% as red squares, the distribution of errors for the 21 probes initially tested appear as black crosses. The 5 probes tested came from 3 separate batches and none were from the same batch as the initial 21 probes tested.

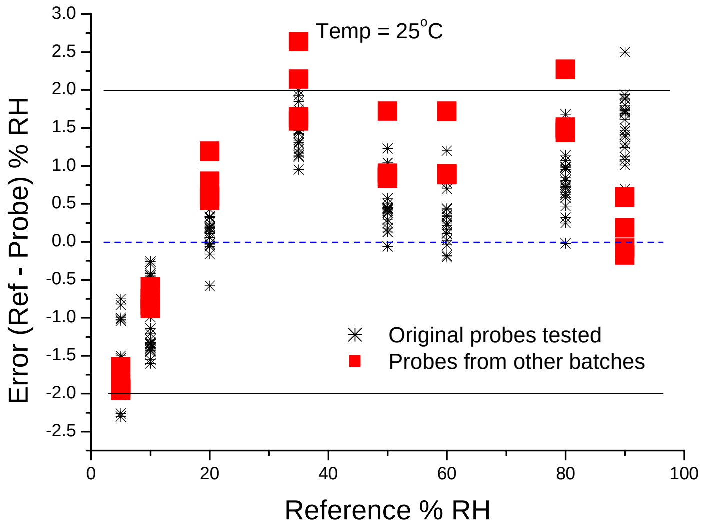

Figure 22. Offset error at 25°C for the initial 21 probes tested (stars) and the probes from other batches (squares).

From Figure 22 it is surmised that the 5 probes were likely to have been selected from the same population as the 21 probes tested, or to put it in the opposite sense, the 21 probes tested appear to have come from the general population of factory issued probes and do not appear to have been specifically selected for this study, validating assumption 1 in the opening section of this report.

Conclusions

1. The majority of the received probes tested fall within the Bureau specification over the range of testing, from, 5°C and 10% RH to 35°C and 80% RH without adjustment (Working Reference ±2.0% RH).
2. The probes "as-received" probes exhibited their greatest error in humidity in the mid range, approximately 20 – 50 % RH and at high RH > 80 % (see Figure 14).
3. The temperature returned by the HMP45D Pt100 temperature sensor was within the Bureau specification for humidity probes (correction of less than ±0.2°C), but a significant number of the probes fell outside the criteria for AWS dry-bulb temperature measurement (correction less than ±0.08°C) and therefore the probes cannot be considered for AWS "dry bulb" measurements. This is in accord with data supplied for these probes by Vaisala[6].
4. The results of non-destructive testing in saturated air and the hysterisis results suggest that the HMP45D probes may exhibit long-term drift (up) in reading when exposed to high humidity for lengthy periods. This is supported by anecdotal evidence from other sources and requires further investigation.
5. The output connector for humidity measurement employed by Vaisala is not currently compatible with that used on the ALMOS AWS. However both the supply and humidity signal output voltages are compatible with ALMOS AWS. Currently ALMOS AWS does not have a spare resistive input to read the Pt100 of the HMP45D.
6. The adjustment of the probes was difficult and therefore any agreement on purchase must state that the probes will only be accepted if they pass the Bureau's acceptance criteria without adjustment by RIC.
7. End-users should familiarize themselves with Figure 1 to obtain an understanding of where in the RH range the largest errors occur for these probes since their response is quite different from that of the current AWS humidity probe.

Appendix A – General Eastern M2 Dew Point Hygrometer Calibration

The calibration was performed at the National Measurement Laboratory in Sydney Australia during April 2001. The results (corrections) for both relative humidity and temperature are shown below in Figures *A* and *B*.

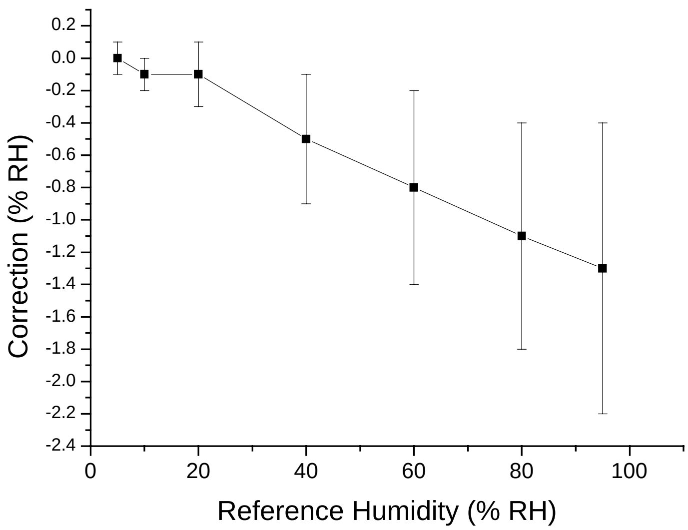

Figure A. RH correction versus reference humidity for the General Eastern M2. Error bars shown are the 95% confidence limits.

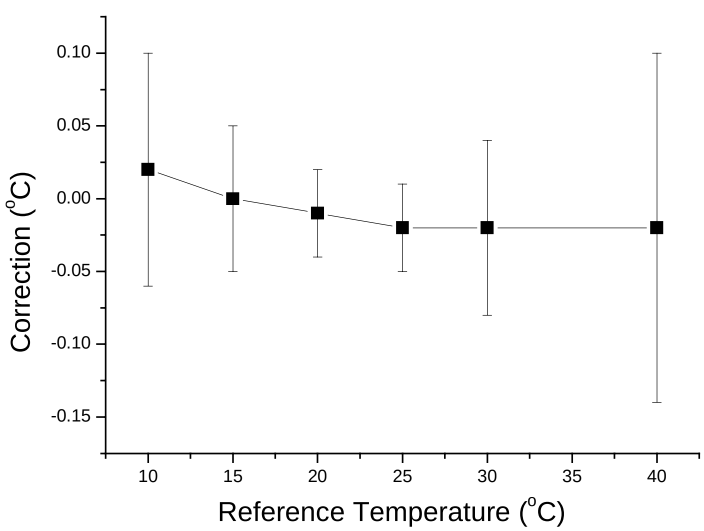

Figure B. Temperature correction versus reference temperature for the General Eastern M2. Error bars shown are the 95% confidence limits.

Appendix B – Serial Numbers of HMP45D Probes Tested

Supplied by Vaisala

Batch	Serial Number
VO72	0007
VO72	0016
VO72	0017
VO72	0018
VO72	0020
VO72	0021
VO72	0022
VO72	0023
VO72	0024
VO72	0025
VO72	0026
VO72	0027
VO72	0028
VO72	0029
VO72	0030
VO72	0031
VO72	0032
VO72	0033
VO72	0034
VO72	0035

Externally Sourced

Batch	Serial Number
W452	0001
W431	0052
W441	0060
W441	0061
W441	0062

References

[1] Bureau of Meteorology Standard Calibration Procedure RH01SCP01 *"Calibration of Relative Humidity Probes"* 2nd Feb. 1998 by J.Warne
[2] Bureau of Meteorology Equipment Specification A2671 *"Provision of an Automatic Weather Station Type I"*
[3] National Measurement Laboratory *"Measurement Report on A Dew/Frost Point Meter Serial No.2260298"* – 19th April 2001
[4] Bureau of Meteorology Technical Note RH – TN – 05v1 *"Description of the Regional Instrument Centre's Split Stream Humidity Generator System. V1.0"*
[5] Vaisala *HMP45A&HMP45D Humidity and Temperature Probes Operating Manual* – Sept.1997 - Vaisala
[6] Vaisala report on probe calibrations supplied by S.Harrod of Vaisala Australia.