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# Calibrating DHT22 Hygrometers (Version 1)

## Introduction

This page accompanies my [main DHT22 page](#) and contains a few details of earlier versions of this experiment. The [main page](#) describes my best results. Everything herein is obsolete, but has been retained for reference because it describes some of the problems and solutions that led to the current design.

## Version 1 Hardware

Version one consisted of a sealed box containing the entire experiment; the sample solution, the sensors, all the electronics and power supply. The idea was to not require any holes for cables into the test cell. This was abandoned because the more there was inside the test cell, the more variables you had to worry about and the harder it was to establish really good equilibrium. It is better for the test cell to be as small as possible and contain nothing other than solution and sensor. Sealing the hole around a cable with caulk is easy enough.

I will not give much detail of the electronic setup. Since these are digital devices which output a calibrated numerical value, the external electronics ought to be irrelevant. Once you provide a d.c. supply voltage, everything else happens inside the sensor module itself. I read the devices using a [JeeNode v6](#), a small, low power, [Arduino](#)-like, [ATMega328P](#) board with an integrated [RFM12B](#) radio module. The JeeNode's designer provides the [JeeLib](#) software library making it very easy to get measurements out of the air tight test vessel wirelessly. Measurements were logged into a [MySQL](#) database via the [EmonCMS](#) data logging system developed by the [Open Energy Monitor](#) project. I enthusiastically recommend the combination of JeeNodes and EmonCMS as an easy way to get going on any wireless, distributed, environmental monitoring system like this.

The entire system was powered from four AA NiMH rechargeable cells. The JeeNode has its own on-board voltage regulator but the supply to the DHT22s was fed directly from the AAs and thus drifted as the battery depleted between charges. The raw supply voltage was monitored continuously and RH measurements only taken when in the range 5–5.5 V. All my DHT22 devices still gave believable results down to 4Vdc, though I know other folk have reported strange results below 5V from some units.

Inside the test cell were

- JeeNode microcontroller board
- Six DHT22 hygrometer/thermometers
- 4AA cells power supply
- A 50mm fan connected to a microcontroller digital output pin via a PN2222 transistor
- Pan containing the sample solution

Software on the microcontroller controlled [the fan](#), monitored its own power supply (raw ~5V and regulated 3.3V), read the DHT22s and wirelessly reported all the results back to an external [Raspberry Pi](#) hosting EmonCMS and the MySQL database.

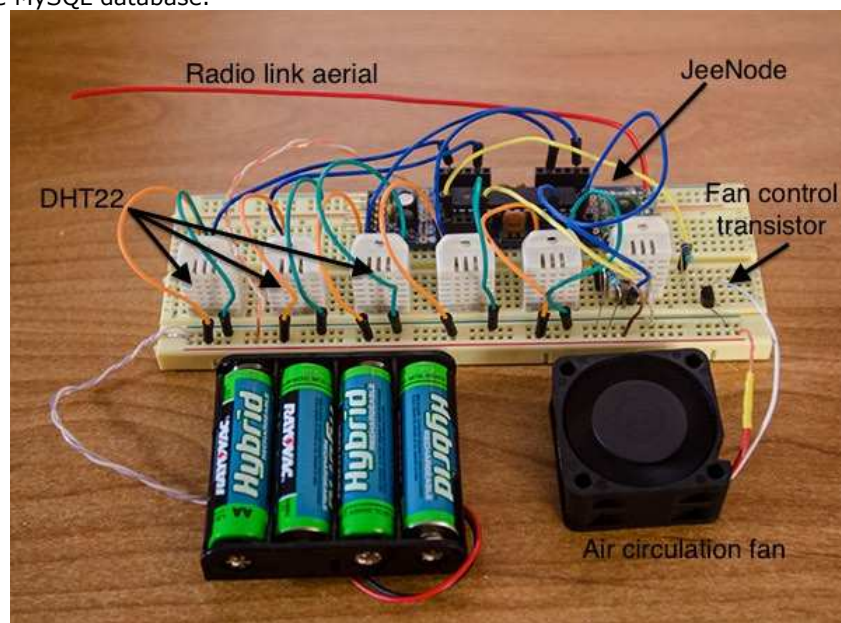


Figure 1. Hardware setup is very simple. Nothing clever, just the JeeNode and all the sensors plugged into breadboard. The pull-up resistors required for each DHT22 are hidden from sight behind the sensors.

## Constraints and Considerations

### Time

Version 1 could take days to reach a good equilibrium, partly because of the larger air volume and many components (see later discussion of hygroscopic materials) but I think primarily it was too difficult to keep at a homogeneous temperature.

## Temperature

The single biggest source of error I was able to identify was temperature and temperature stability. There are three different, competing, temperature dependent effects. Most are detailed on the [main page](#). Only a few comments relating to previous failed attempts remain here.

Without active thermal control, the best I was able to achieve was a diurnal air temperature variation inside the test cell of 1°C peak-to-peak. That implies a maximum possible RH variability of 5% whereas the thermal variation of salt solubility typically results in variations of well under 0.1% RH. Hence my assertion that choosing salts with small thermal coefficients was pointless. Thermostatic control of the test cell solved this problem, but for version 1 the best I could do was give the test vessel as much thermal mass and insulation as possible. It was buried in a big box of sand and wrapped in blankets inside a closed closet with no air vents into the house. That slowed and smoothed the temperature excursions. The house living space varies daily by 5°C, the air inside the closet by about 3°C and buried in the box of sand, only 1°C. For [version 2](#), active thermal control and lots of forced air circulation proved absolutely necessary.

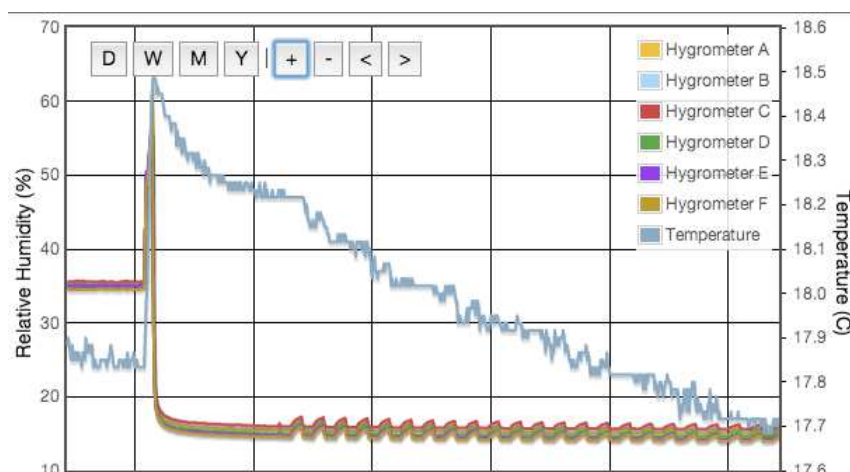
## Air Circulation

Forced convection definitely helps to speed the equilibrium and I also got the impression that a little air movement helps the sensors, possibly because of self heating of stagnant air trapped inside the sensor shroud. I used a small 50mm fan running at low speed inside the enclosure. This takes a lot of power from the battery and also creates heat, something we wish to avoid. The microcontroller was therefore used to cycle the fan on to stir the air and then off for a while. Various duty cycles, running between 10–100% of the time, were tried. Results did not vary much depending on the duty cycle, but I settled on running the fan 50% of the time and a cycle period of ten minutes. Rockland 1960 favoured 20 seconds on and 10 minutes off in order to minimise the heating effect of the fan.

## Hygroscopic Materials

Hygroscopy is tendency of a material to absorb water vapour into its surface and hold it within its molecular structure. Possibly surprisingly, many plastics (e.g., nylon, ABS, acrylic, polyurethane, polycarbonate, PET, PBT) which may be hydrophobic (water will bead on the surface and apparently just run straight off) are in fact hygroscopic (absorb water vapour). This manifests as a sink or source of humidity other than the saturated salt solution, greatly extending equilibration time. If the salt solution is releasing vapour to the air, the walls of the test cell itself could be absorbing it meaning you need to run the experiment for a very long time before equilibrium is eventually achieved. If you then switch to salt that yields a low humidity, the walls of the test vessel will slowly release that stored vapour back into the air.

Initially I used a polypropylene plastic tub. Polyethylene, polypropylene, polystyrene and PVC are all generally regarded as non-hygroscopic, but I definitely saw effects. When a new salt was placed in the cell it would take a couple of days to slowly reach a stable equilibrium. If I was then forced to break the seal (to replace batteries for example) the equilibrium would re-establish in just a couple of hours. This I take as evidence that the cell itself needed to reach the equilibrium, not just the air inside. The air got changed along with the battery. The second evidence relates to the fan cycling on and off. Take for example switching from a high humidity to a low humidity salt. When the fan comes on, the measurements would all instantly jump down to a stable value and stay there as long as air was circulating. Once the fan went off, the measured humidity would gradually creep back up; something seemed to be releasing moisture back into the air. The fan duty cycle thus induced an asymmetric sawtooth pattern to the plot. The pattern was reversed when moving from a low humidity to a high humidity data point. The measurement value would jump up as the fan came on, stay stable and then slowly drift down when the fan was off as the humidity in the air appeared to be being absorbed by something.



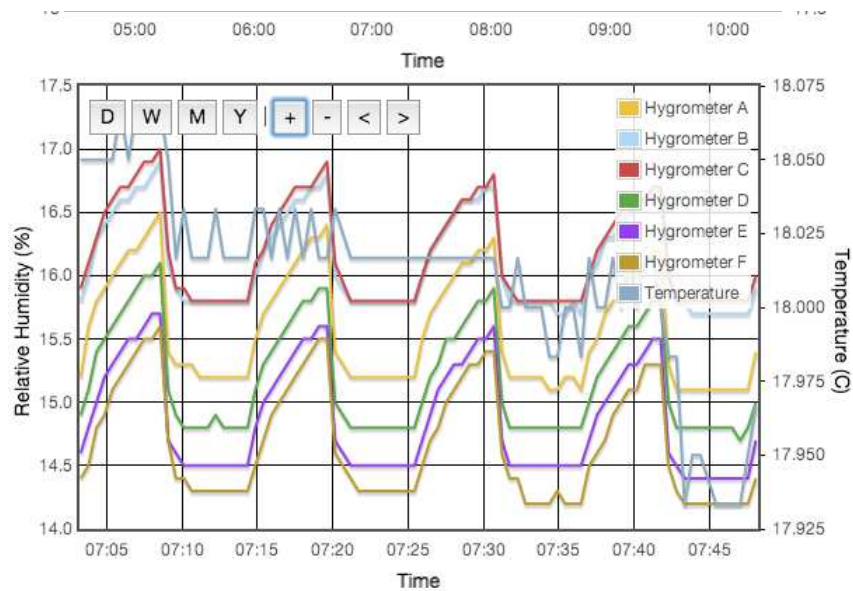


Figure 5. Top panel shows the six hygrometer readings around the time I swapped the test sample from calcium chloride (~35%) to lithium chloride (~15%). The asymmetric sawtooth profile as the fan cycles on and off is clearly visible. Lower panel shows a subset of the same data, rescaled to see detail of the sawtooth shape. The 50% fan duty cycle is clear; five minutes on and five minutes off. When the fan comes the readings drop rapidly. When the fan is off the values creep back up slowly as something is apparently leeching humidity into the air.

When I swapped to a glass test vessel these problems reduced but were not eliminated. My glass tub still had a polypropylene lid, but I do not know what polymers were used in the manufacture of my breadboard, fan, wires, battery holder etc. It might be worth trying to move as much of that as possible outside the vessel and running wires in through an airtight seal, but what about the sensor housings themselves? They come in a plastic screen sealed with an unidentified resin. Figure 6 provides evidence that something in the cell (breadboard, DHT22 themselves, etc) is hygroscopic. Even if the plastic from which it is made is not itself hygroscopic, it is quite easy to imagine humid air simply being trapped for some time within the structure of a breadboard which would yield a similar effect.

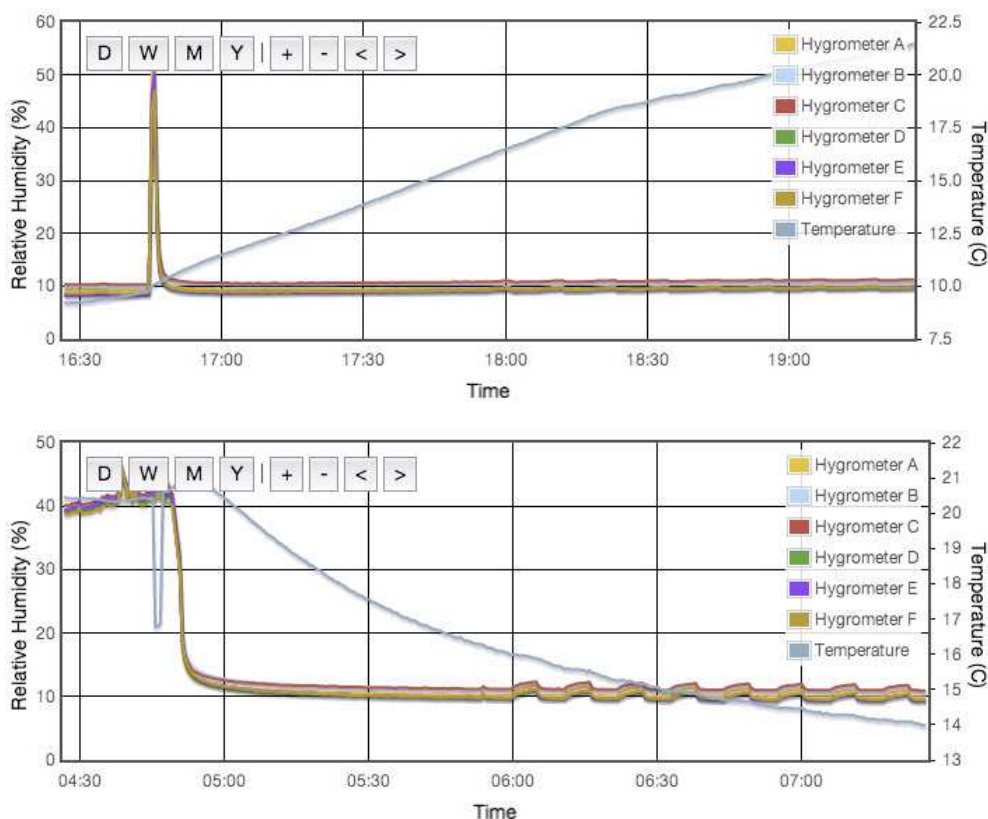


Figure 6. Data obtained with NaOH (~8%). Top panel shows a battery change. The cell was at 11%, opened to replace the battery and immediately resealed. Note the readings very quickly return to a stable value with very little sawtooth. For the lower panel the cell was sealed with NaOH inside while the breadboard and DHT22s were all outside exposed to household ambient humidity at 40%. This time when they were resealed in the cell the sawtooth effect is strong. Since the cell itself was sealed and equilibrated throughout, the source of released humidity must be the electronics (breadboard, DHT22, wires, JeeNode, fan or battery). It cannot be the polypropylene lid of the test cell.

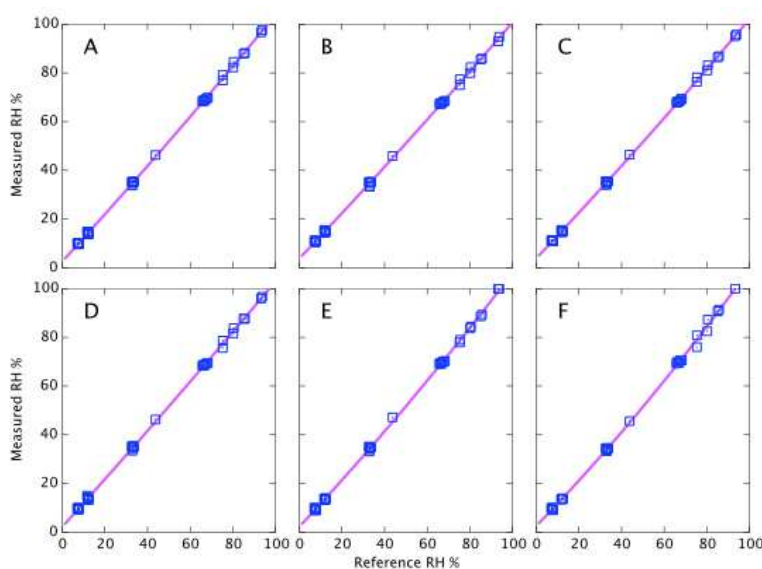
To minimize the problems caused by this, I suggest working systematically through the list of salts from driest

to wettest. Jumping around between high and low humidity salts extends the equilibration time at each step. If you can possibly use a glass, stainless steel or other truly non-hygroscopic test vessel, do so. The second generation test cell (all glass and steel with no electrical components inside) showed no problems at all.

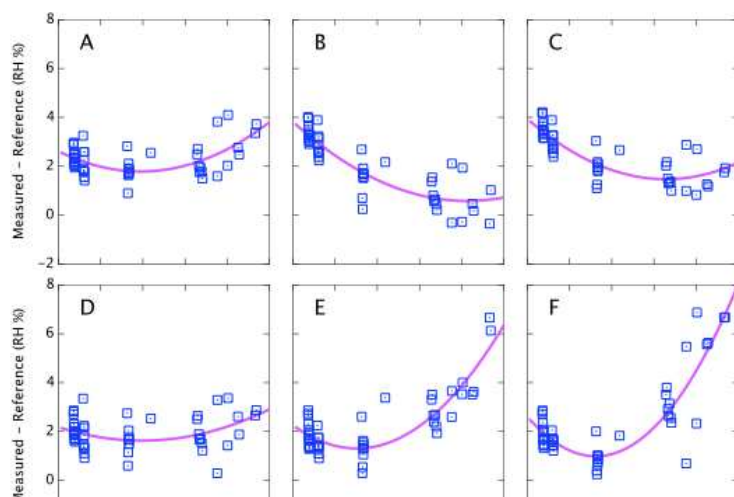
## Version 1 Results

Salt	Reference	Measured RH %					
	RH %	A	B	C	D	E	F
NaOH	7.57	9.77	10.84	10.99	9.42	9.42	9.57
LiCl	12.13	14.71	15.36	15.41	15.36	13.88	13.82
CaCl	33.49	35.3	35.21	35.59	35.18	35.03	34.51
MgCl	33.31	35.22	35.01	35.29	34.98	34.75	34.28
KCO <sub>3</sub>	43.75	46.31	45.93	46.42	46.29	47.14	45.59
NH <sub>4</sub> NO <sub>3</sub>	67.35	69.30	68.01	68.68	69.07	70.03	70.50
NaCl	75.32	76.9	75.0	76.3	75.6	77.9	76.0
NH <sub>4</sub> SO <sub>4</sub>	80.17	82.2	79.9	81	81.6	83.7	82.5
KCl	85.09	87.9	85.6	86.4	87.7	88.6	90.7
K <sub>2</sub> NO <sub>3</sub>	93.24	96.6	92.9	95.0	95.9	99.9	99.9
H <sub>2</sub> O	100.00	99.9	99.4	99.9	99.9	99.9	99.9

*Experimental results. 'Reference RH' is the expected value taken from published literature interpolated to the temperature at the time the measurement was obtained. 'Measured RH' are the raw values as returned from the DHT22/AM2303 devices. I have arbitrarily chosen data points around the range 17–20°C to include here. Work is ongoing to more accurately investigate the temperature dependence of these results. It is certainly strong enough to be of significance.*



*Figure 7. For all six devices there is very tight correlation between measured value and the expected reference value. I.e., the manufacturer's calibration is good. Magenta curves are quadratic polynomial best fits, though they hardly deviate from straight lines. On this scale you cannot tell much about systematic deviations though you can for example see that A, E and F hit saturation well below 100%.*





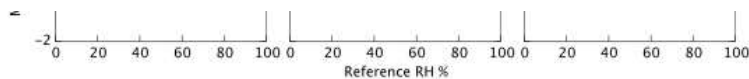


Figure 8. The same data and same quadratic polynomials are replotted but the vertical axis is now the difference between measured and reference values. These plots effectively show the error that would result from using the measured values directly from the sensor without applying any re-calibration.

Figure 8 above essentially represents the main conclusion of the experiment. Devices A & D consistently read about 2% high. Devices B & C read 4% high when dry but tend towards quite accurate at high humidity. Devices E & F read slightly high when dry but deviate quite strongly (up to 6% absolute error) at high humidity. I reiterate that this does not yet represent the temperature dependence of these devices which, though not yet fully investigated, is clearly at least 2% RH. Repeatability (on time scales of a few weeks) is about 1% RH as specified (Figure 9).

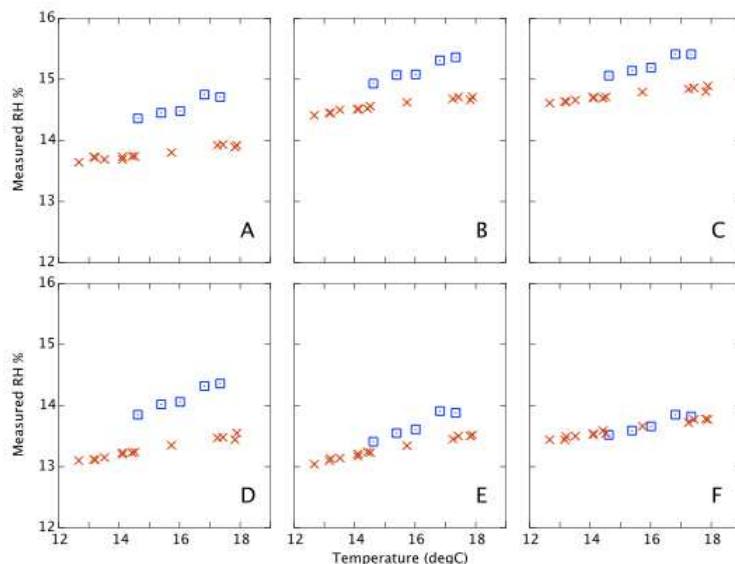


Figure 9. Two epochs of measurement for LiCl, separated by a couple of weeks. The data sheet specification requires repeatability of 1%, a good representation of what I actually see.

## Future Plans

Possible future extensions of this work:

- I would love to compare to a more serious, high quality sensor, such as the Sensirion SHT15 or SHT25, but they are quite a lot more expensive.
- Compare to the DHT11 which has highly inferior specs and is much cheaper. I have already bought one, but not yet tested it. **Done in version 2**
- I have started looking into active thermal regulation. **Done in version 2**
- Move all the electronics (especially the breadboard) outside the test cell. **Done in version 2**
- Repeat for the same devices described here. **Done in version 2**
- Try another batch of sensors with very different serial numbers

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