ACCURACY AND LINEARITY OF SLING AND DIGITAL PSYCHROMETERS

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Abstract: Ambient conditions can be critical to the success or failure of a coatings project. It has generally been assumed by the industry that a sling psychrometer is more accurate in determining Relative Humidity and Dew Point than electronic sensors. While this may be true for meteorological sling psychrometers that meet the criteria of ASTM E337 "Measuring Humidity with a Psychrometer (the measurement of Wet- and Dry-Bulb Temperatures)"[1], the sling psychrometers in use in most coating applications appear to lose accuracy as temperatures increase above 80°F. In the 80°F range and above, electronic sensors appears to provide much more consistent data. When "red spirit" thermometers are slung in these temperature ranges, the dry bulb temperature may vary by ± 10 °F or more from the reading observed prior to slinging it.

INTRODUCTION

Many coating failures have been attributed to applying coatings when climatic conditions were not within specifications. When trying to determine Relative Humidity and Dew Point temperatures, an understanding of the wet bulb, dry bulb, relative humidity and dew point is useful in getting accurate values.

Typically, most project requirements are a Relative Humidity below 85% and 5°F between the surface temperature and the dew point. When Relative Humidity is around 50% and the Dew Point spread is 10°F to 15°F, accuracy in the tests are not critical. However, when the Humidity is close to 85% (or whatever the requirement is) and the dew point/surface temperature spread is about 5°F, it is important that readings be accurate.

There are two basic methods of measuring Relative Humidity and Dew Point Temperatures in the field. One is with a sling psychrometer and the second is with the newer electronic meters. The Sling Psychrometer is addressed in ASTM E 337, Standard Method for Measuring Humidity with a Psychrometer (The measurement of Wet and Dry Bulb Temperatures). It is generally assumed that the most accurate method of determining Relative Humidity and Dew Point is by using a Sling Psychrometer.

Sling psychrometers used by meteorologists meet ASTM E337-02 A1 and use mercury as an indicator. They have much greater accuracy than sling psychrometers typically used by inspectors and contractors which use "Red Spirit Thermometers". Even with Sling Psychrometers that meet ASTM E337 requirements, ASTM committee members estimate errors in Relative Humidity taken by trained observers of 5% to 7%[2].

In an Abstract from "Field Comparison between Sling Psychrometer and Meteorological Measuring Set AN/TMQ-22", [3] the military was trying to determine the accuracy of Sling Psychrometers and Electronic sensors. The AN/TMQ-22 was developed for use by special forces and the CIA during the Viet Nam crisis and continued in use at least into the 1980's.

> During the Service Check Test of Meteorological Measuring Set AN/TMQ-22, a discrepancy in dew point temperature readings was noted between it and the ML-224 Sling Psychrometer. From a series of independent tests designed to minimize error it was concluded that the AN/TMQ-22 yielded a more accurate dew point reading. **The average relative humidity error using the sling psychrometer was +9%** while the AN/TMQ-22 had a plus or minus 2% error. **Even with cautious measurement the sling yielded a ± 4% error.**

To achieve this degree of accuracy, the minimum requirements of a thermometer used to take measurements should have a scale a minimum of 130 mm (5.1 inches). The typical red spirit thermometer used by inspectors has a scale of 89 mm (3.5 inches).

The sling psychrometer measures two parameters, Dry Bulb (ambient temperature) and Wet Bulb.

The dry bulb temperature (DBT) or ambient temperature is the temperature of the air. This is the temperature that you would get in the shade and not the temperature in direct sun.

The wet bulb temperature (WBT) measures the temperature that results from evaporation. It is directly related to relative humidity. When moisture evaporates, it cools the environment, reducing the temperature slightly. The WBT will vary with **Relative Humidity** (RH). When the relative humidity is high, evaporation is low and there is less of a cooling effect. When relative humidity is low (air is dry) evaporation increases and the cooling effect is greater. The difference between the wet bulb and dry bulb temperature therefore gives a measure of atmospheric humidity.

Relative Humidity (RH) is the measure of how much moisture is in the air divided by the amount of moisture the air can hold times 100. The amount of moisture the air can hold is dependent on the atmospheric pressure. When the air is 100% saturated, evaporation will stop and the Dry Bulb Temperature will be equal to the Wet Bulb Temperature.

When DBT – WBT = 0 then RH = 100%

Detailed calculations for Relative Humidity and Dew Point are in the appendix.

ASTM E337-02 provides the following table for Precision and Bias (Table 2)

Uncertainty in Derived Relative Humidity, %RH	Uncertainty in Temperature Depression, °C (°F)	Uncertainty in Dry-Bulb Temperature, °C (°F)
±4	±0.3 (±0.54)	±0.2 ±(0.36)
±3	±0.2 (±0.36)	±0.2 ±(0.36)
±5	±0.3 (±0.54)	±0.6 ±(1.08)
±4	±0.2 (±0.36)	±0.6 ±(1.08)

Electronic meters come is several varieties from meters that just provide Wet Bulb and Dry Bulb Temperatures to meters such as the Elcometer 319 Dewmeter, that measure Wet Bulb, Dry Bulb, Relative Humidity, Dew Point, Surface Temperature, Calculate the ΔT between the surface temperature and the dew point., electronic time and date stamp data and can download information to a computer.

As for all electronics, the quality of the sensors is key to how well the meter works. Some of the early meters as well as some still manufactured today, suffer from using low cost sensors that can give erroneous readings and have given electronic meters a bad reputation. Be careful that the great price you got on an electronic meter doesn't affect the accuracy of the meter. For example, low cost instruments often carry the disclaimer "for laboratory use" or "for indoor use only".

Electronic meters have some distinct advantages over sling psychrometers. Because there are no moving parts, you can take readings close to where you will be doing the work. Atmospheric conditions at or near the surface of steel can be considerably different inches or feet from the surfaces. Because a sling psychrometer requires room to "sling" it, you can never get readings near the surface.

Example: An inspector/QC person is checking the inside side of a tank to be painted. One side of the tank is in the sun and one side is in the shade. The inspector uses a sling psychrometer to determine the atmospheric conditions in the tank four to five feet from the surface to measure ambient conditions. As you approach the steel, the metal is actually 10°F hotter than the surrounding area and as a result the air temperature near the surface of the tank is also hotter. An inspector using an electronic meter measuring conditions at the surface of the steel may get considerably different reading than the person using the sling psychrometer.

<u>TEST</u>

There have been many discussions in the industry on the accuracy of the Electronic meters verses the accuracy of sling psychrometers. Due to the simplicity of the sling psychrometer, it has always been assumed that any difference between the two measurements were due to problems with the electronic meter. To determine which was more accurate, a simple test was set up.

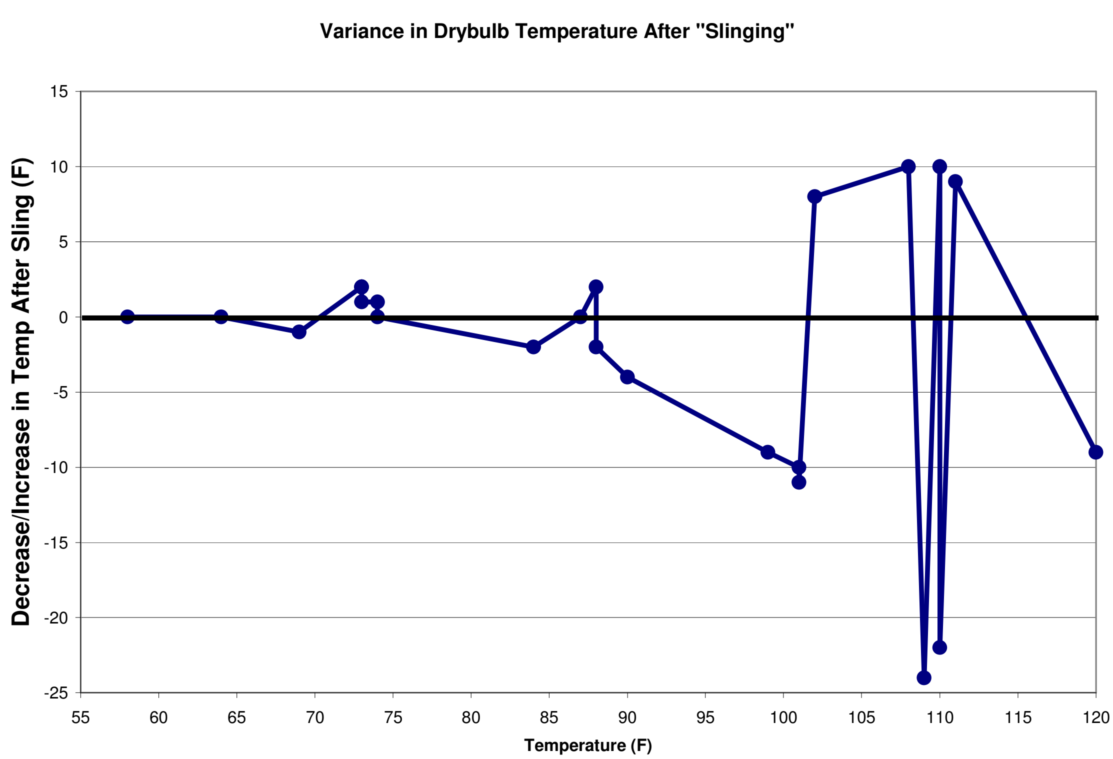
A total of Nine (9) Psychometric meters, three (3)of each type were used.
Three Manufacturer A - Electronic
Three Manufacturer B - Electronic
Three "Red Spirit" Sling Psychrometers

The following information was recorded.

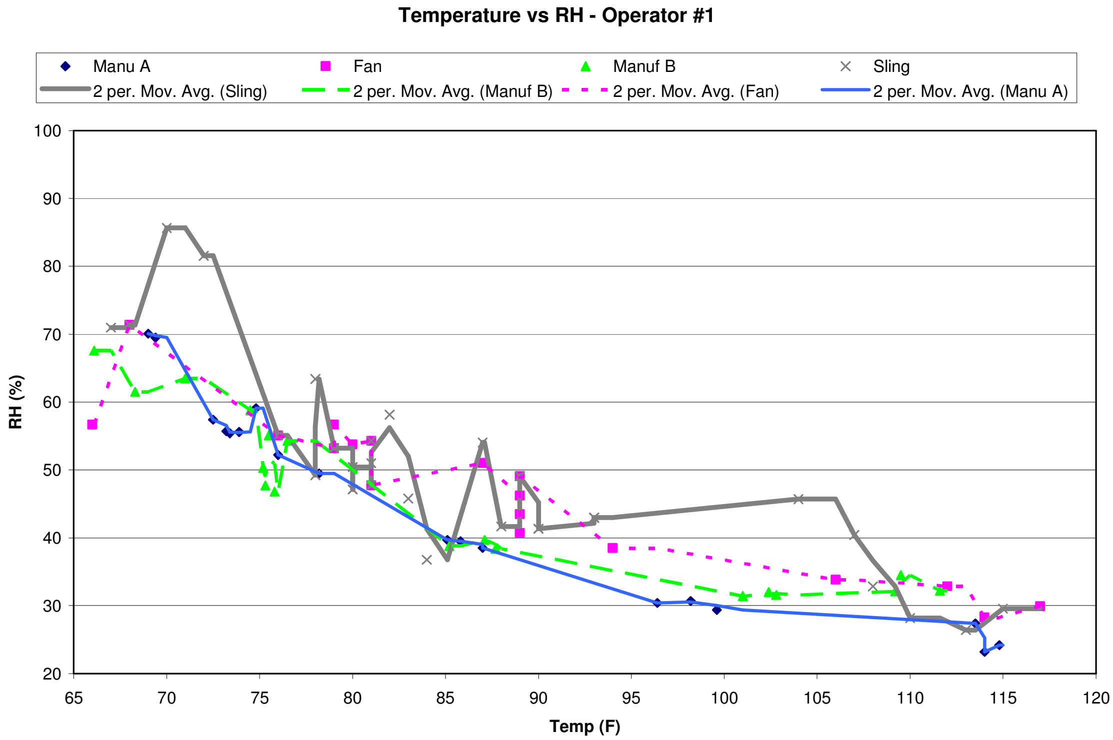
Time of Test
Location of Test
Relative Humidity
Ambient (Dry Bulb) temperature
Wet Bulb Temperature
Dew Point

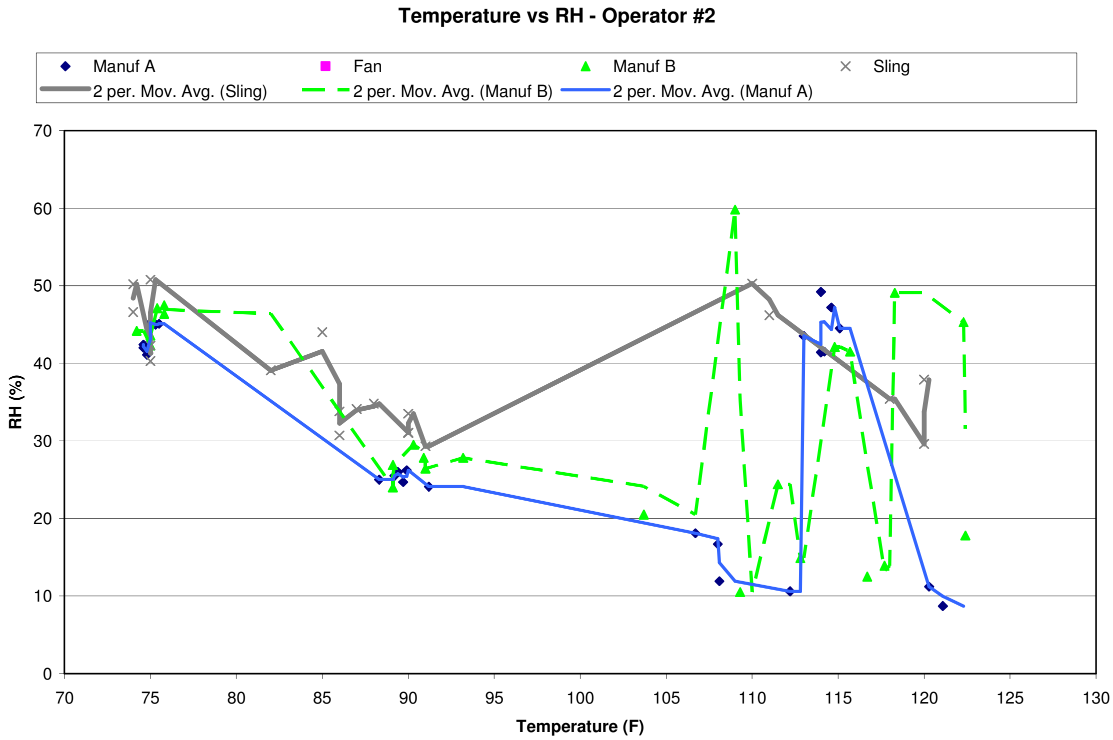
<u>RESULTS</u>

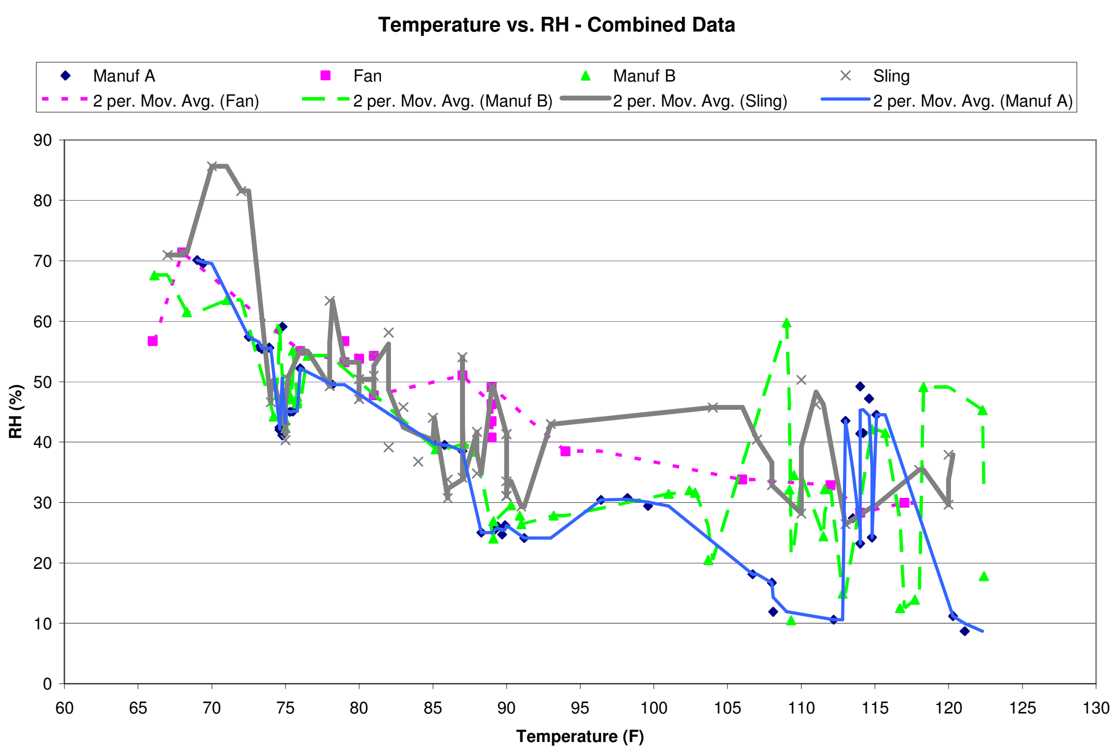
The above instruments were used to take several sets of readings between 58^{o}F and 110^{o}F. Dry bulb temperatures were taken before they were slung as well as afterwards. As the temperature increased, the before and after temperatures varied widely. Since this reading should stay the same, it indicates a possible problem with the red spirit thermometers. The below graph shows how before and after dry bulb temperatures varied as the ambient temperature increased.



It is also useful to look at the data showing Relative Humidity verses Temperature. In the below graphs, it can be seen that both Electronic Psychrometers track relatively closely with temperature to slightly over 100ºF. Relative Humidity using a fan type psychrometer also tracked closer to the electronic meters but in general tracked higher than the electronic meters and lower than the sling psychrometer. In all tests, the sling psychrometer showed the greatest variation from the other test instruments

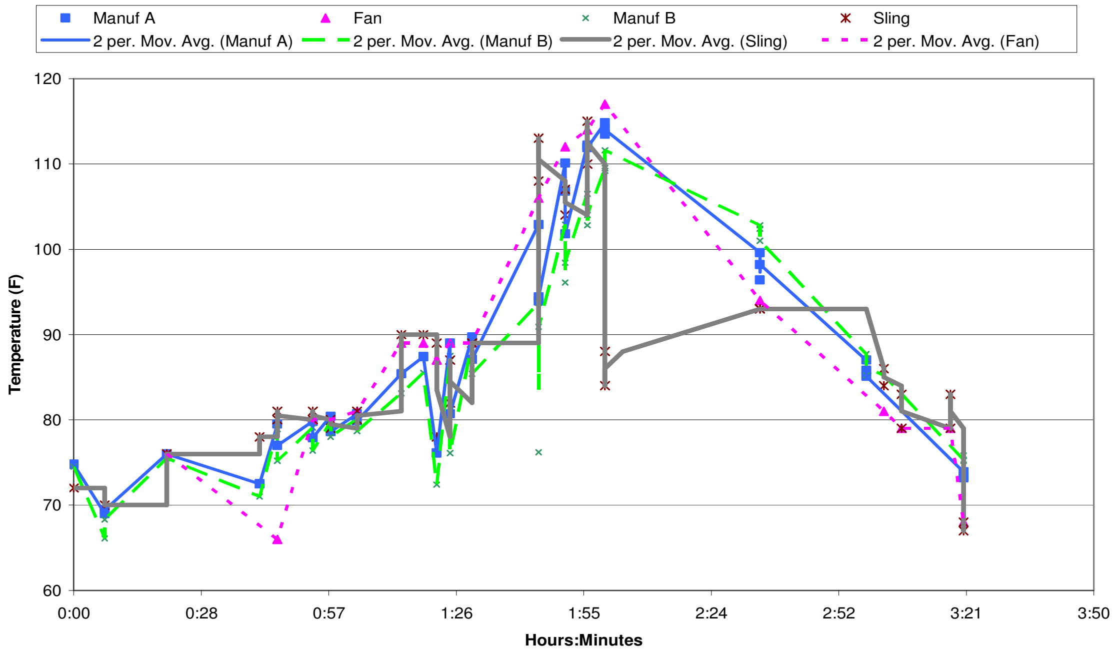



Temperature vs RH - Operator #2
Manuf A
Fan
Manuf B
Sling
2 per. Mov. Avg. (Sling)
2 per. Mov. Avg. (Manuf B)
2 per. Mov. Avg. (Manuf A)
RH (%)
Temperature (F)
0
10
20
30
40
50
60
70
70
75
80
85
90
95
100
105
110
115
120
125
130


Temperature vs. RH - Combined Data
Manuf A
Fan
Manuf B
Sling
2 per. Mov. Avg. (Fan)
2 per. Mov. Avg. (Manuf B)
2 per. Mov. Avg. (Sling)
2 per. Mov. Avg. (Manuf A)
RH (%)
Temperature (F)
0
10
20
30
40
50
60
70
80
90
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130

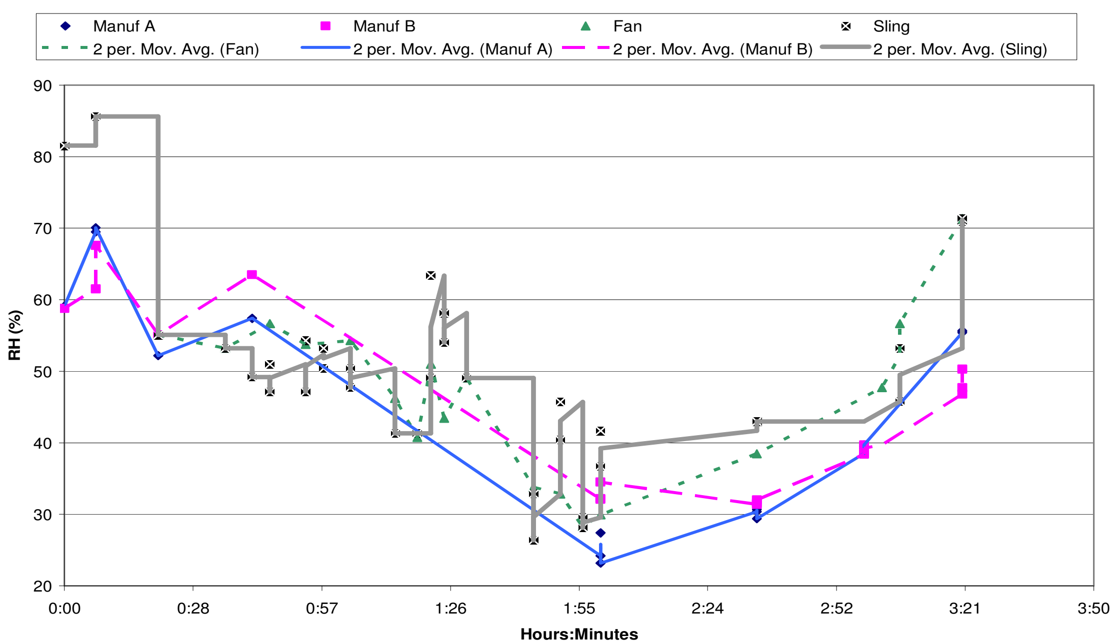
Test Data by Operator #1 was taken at a facility with a large oven and the temperature was gradually increased to take readings. Operator #2 took readings in full shade, partial shade, full sun and in a closed up car.

Temperature Change vs Time



The above chart shows the reaction time of the temperature sensors of the meters used in this test. The steeper the slope, the quicker the reaction time. It is seen in this graph that the thermometers in the sling psychrometer respond much quicker than the Electronic Sensors.

Relative Humidity vs Time



Manufacturer A Relative Humidity sensor appears to react slightly quicker than the Manufacturer B. The sling psychrometer appears to react quickly but it is uncertain, based on other readings that it is as accurate as the electronic sensors.

CONCLUSIONS

Determining the accuracy of each of the test instruments was beyond the scope of this study. We do believe it is safe to say, based on the data that caution should be used when using a sling psychrometer. ASTM E 337 precision and bias numbers and testing by the US Military show that using a sling psychrometer that meets the standards of the method would yield at best ±5%[2] to ±9%[3] error in Relative Humidity and with the typical thermometers used in the coating industry, that error would easily exceed this amount. Relative Humidity taken using a sling psychrometer appears to be much greater than electronic sensors in the 85°F range and greater. Both electronic meters appear to track well together to slightly over 100°F

Under field conditions, it is much more likely inspectors/operators would get much more reliable data using electronic psychrometers. This paper should be a starting point to gather more data and should not be considered a scientific study. Round Robin testing using both electronic meters and sling psychrometers would be a next step that would be recommended

In the interim, when using a sling psychrometer to determine Dew Point and Relative Humidity when conditions may warrant shutting down a coatings project, readings should be confirmed using a "quality" electronic meter. When there is a disagreement between a sling psychrometer, especially when temperatures are greater than 80°F, these tests indicate preference should be given to the electronic meter.

[1]E337-02 Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

[2]E337-84 Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)

[3]Waite,Ronald W., "Field Comparison between Sling Psychrometer and Meteorological Measuring Set AN/TMQ-22", ARMY ELECTRONICS COMMAND WHITE SANDS MISSILE RANGE N MEX ATMOSPHERIC SCIENCES LAB, AUG 1971

APPENDIX

Calculations

Relative Humidity and Dewpoint Temperature from Temperature and Wet-Bulb Temperature

From the user, an air temperature (***T***), a wet-bulb temperature (T_w), and a station pressure (P_{sta}) are given. The temperature values must be converted to units of degrees Celsius (^oC).

Also, the station pressure must be converted to units of millibar (***mb***) or hectoPascal (***hPa*****).**

Then, an actual vapor pressure needs to be calculated. To accomplish the calculation, a vapor pressure related to wet-bulb temperature (e_w) and a saturated vapor pressure (e_s) must be calculated first using the equations below:

$$e_s = 6.112 \times e^{\frac{17.67 \times T}{T+243.5}} \qquad e_w = 6.112 \times e^{\frac{17.67 \times T_w}{T_w+243.5}}$$

where **e** is the number e.

Then, an actual vapor pressure (***e***) can be calculated using the equation below:

$$e = e_w - p_{sta} \times (T - T_w) \times 0.00066 \times (1 + (0.00115 \times T_w))$$

Finally, a relative humidity (***rh***) and a dewpoint temperature (T_d) can be calculated using the equations below where ***e*** is the actual vapor pressure:

$$rh = \frac{e}{e_s} \times 100 \qquad T_d = \frac{243.5 \times \log\left(\frac{e}{611.2}\right)}{17.67 - \log\left(\frac{e}{611.2}\right)}$$

Wet-bulb Temperature and Dewpoint Temperature from Air Temperature and Relative Humidity

From the user, an air temperature (***T***), a relative humidity (***rh***) , and a station pressure (***P_{sta}***) are given. The air temperature must be converted to units of degrees Celsius (***^{o}C***), and the station pressure must be converted to units of millibars (***mb***) or hectoPascals (***hPa***).

Next, the equation for calculating relative humidity:

$$rh = \frac{e}{e_s} \times 100$$

can be solved for the dewpoint temperature:

$$T_d = \frac{237.7 \log\left(\frac{e_s \times rh}{611}\right)}{7.5 - \log\left(\frac{e_s \times rh}{611}\right)}$$

The dewpoint temperature will be in units of degrees Celsius (***^{o}C***),

Pressure Conversion

From the user, a value for atmospheric pressure (***P***) is given to be converted to different

To convert between inches of mercury (***inHg***) and millibars (***mb***) or hectopascals (***hPa***), use the formulas below:

$$P_{mb} = 33.8639 \times P_{inHg}$$

$$P_{inHg} = 0.0295300 \times P_{mb}$$

Spreadsheet Formula to Calculate Relative Humidity and Dew Point.

A	B	C
1	Dry Bulb (T)	Enter Dry Bulb Temperature Here (F)
2	Wet Bulb (Tw)	Enter Wet Bulb Temperature Here (F)
3	Convert T (F) to T(C)	=5/9*(C1-32)
4	Convert Tw (F) to Tw(C)	=5/9*(C2-32)
5	es	=6.112*EXP((17.67*C3)/(C3+243.5))
6	ew	=6.112*EXP((17.67*C4)/(C4+243.5))
7	e (Vapor Pressure)*	=C6-(1015*(C3-C4)*0.00066*(1+(0.00115*C4)))
8	RH (%)	=C7/C5*100
9	Td (C)	=(237.7*(LOG(C5*C8/611))/(7.5-(LOG(C5*C8/611))))
10	Convert Td (C) toTd(F)	=9/5*C9+32

NOTE: Station Pressure of 1015 mb (approx 30 inches/Hg) is used to calculate e