Application Note: Humidity and Comfort indexes

This document discusses humidity measurements based on wet bulb temperatures, as well as digital sensors. The second part of the document is dedicated to comfort indexes, which are often related to humidity.

A wet bulb temperature is the temperature of a surface saturated with water and exposed to atmospheric air. This temperature is always equal or inferior to the dry bulb temperature, because heat is absorbed from the bulb during the evaporation process.

A wet bulb is used to evaluate the humidity content of ambient air by calculating the relative humidity or absolute humidity. It is also required in the calculations of comfort indexes (e.g., humidex). Applications of humidity measurements involve:

- Evaluate the human comfort in a given environment;
- Monitor the performance of HVAC equipment;
- Build a local weather station;
- Monitor the environment of an experiment (refrigerator humidity).

With its 16 channels dedicated to resistive measurements, the RDL device can measure simultaneously up to eight (8) distinct humidity sensors, as you need both a dry and a wet bulb temperature to calculate the humidity at a given location. Figure 1 shows the Jericho dry and wet bulb setup in its large form factor (TH-2). The wet bulb apparatus is made of a thermistor, a 10-15 cm capillary wick, a small container (30 mL) with lid and distilled water. The wet bulb can be made from either the TH-1 or TH-2 sensors, as seen in Figure 2.

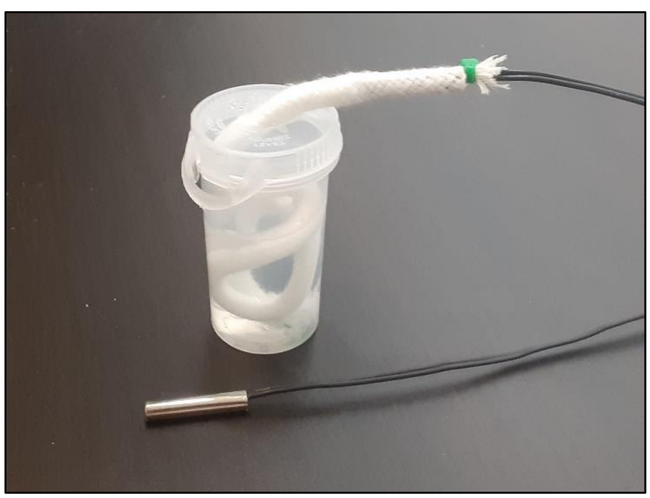

Figure 1 Dry bulb and natural wet bulb temperature sensors

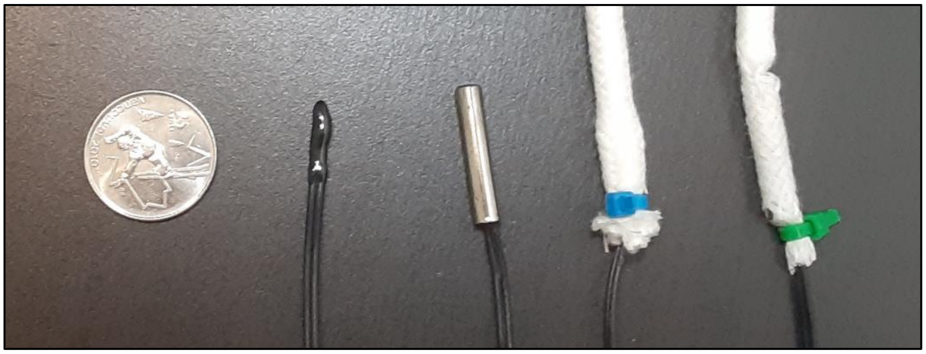

Figure 2 TH-1 (small) and TH-2 (large) thermistor probes with their wet bulb setup

The wick used is a polyester capillary sold for automatic plant watering purposes. To increase its capillary action, the wick is made of three inner ropes, as seen in Figure 3. For wet bulb purposes, these ropes are shortened to make space for the thermistor probe. A tie-wrap is then used to seal the thermistor inside the outer mesh.

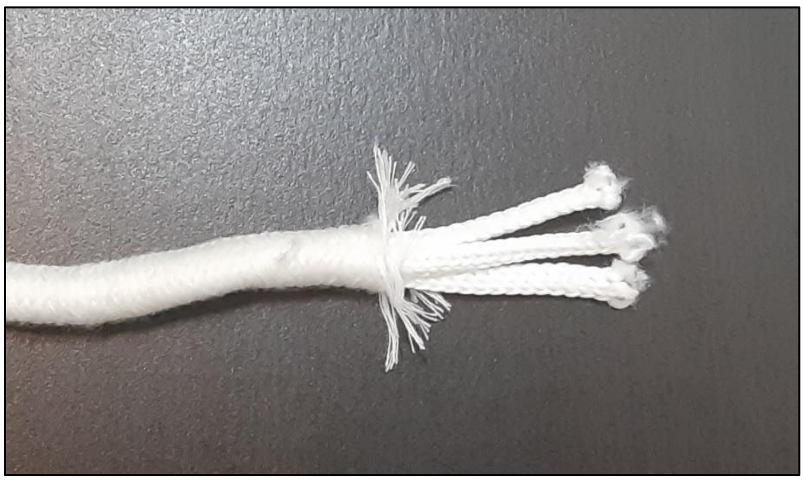

Figure 3 Capillary wick inner components before being cut

Wet bulb instructions

1. Clean the water reservoir with soapy water and rinse twice with distilled water.
2. Put some distilled water into the reservoir. Close the reservoir. Insert the thermistor probe completely into the wick. Wait 5 minutes for the wick to absorb water and stabilize in temperature. Start monitoring the temperature.
3. For good accuracy, use distilled water (or deionized water). Distilled water should be used to avoid the accumulation of scale on the cotton wick overtime. Lime can also form on the wick. Both scale and lime will reduce the evaporation rate, which is a source of error. A wick that has changed color (e.g. green or orange) should be replaced.

4. If using a closed reservoir, the water quantity should last a few days depending on the climate. Reducing to a minimum the wick surface outside the reservoir will reduce the total water evaporation rate and extend the time between refills.
5. The water reservoir should remain upright to avoid spilling water.
6. Wet bulb temperature devices only work above freezing temperature (0°C /32°F).
7. The Jericho wet bulb device will be good as long as 1) the wick remains clean and saturated with water, and 2) the temperature sensor is calibrated.
8. The dry bulb thermometer should not be in the wake of the wet bulb thermometer. The distance should be sufficient so that the dry bulb is not exposed to the humidity coming out of the wet bulb. A distance of 30 cm should be sufficient in most cases.
9. Unless aiming for a 'natural wet bulb', radiative heat transfer to the wick must be avoided (sun, hot surfaces in the surroundings).
10. Assuming that the wick is already wet, the reaction time of a natural wet bulb thermometer is typically 1-2 minutes, but could be more, depending on the conditions. Therefore, a wet bulb is generally not appropriate to monitor rapid changes in humidity.

Wet bulb temperature can be used to calculate air humidity. In Figure 4 can be seen data from the RDL device: two raw sensor values (dry bulb temperature and wet bulb temperatures) and the calculated relative humidity (RH).

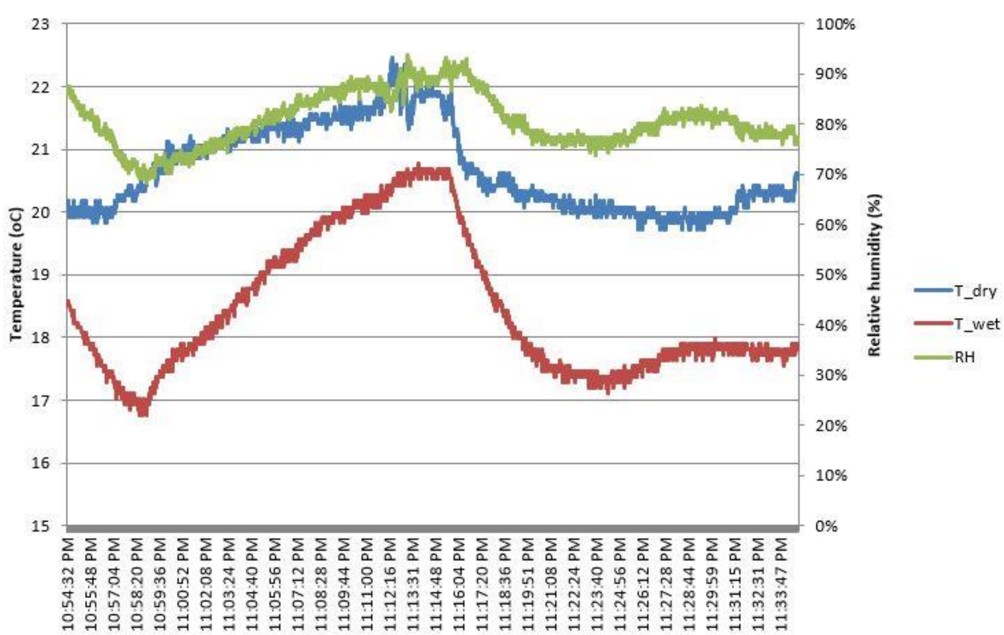

Figure 4 Example of data produced by the RDL: dry bulb, wet bulb and relative humidity of a bathroom during a shower

To evaluate the device performance, the relative humidity output can be compared with reference values, such as the data from the nearest official weather station (Figure 6). It can be seen that despite the 4 km distance between the two locations, correlation is very good. A light shower around noon caused a spike in the relative humidity of both locations.

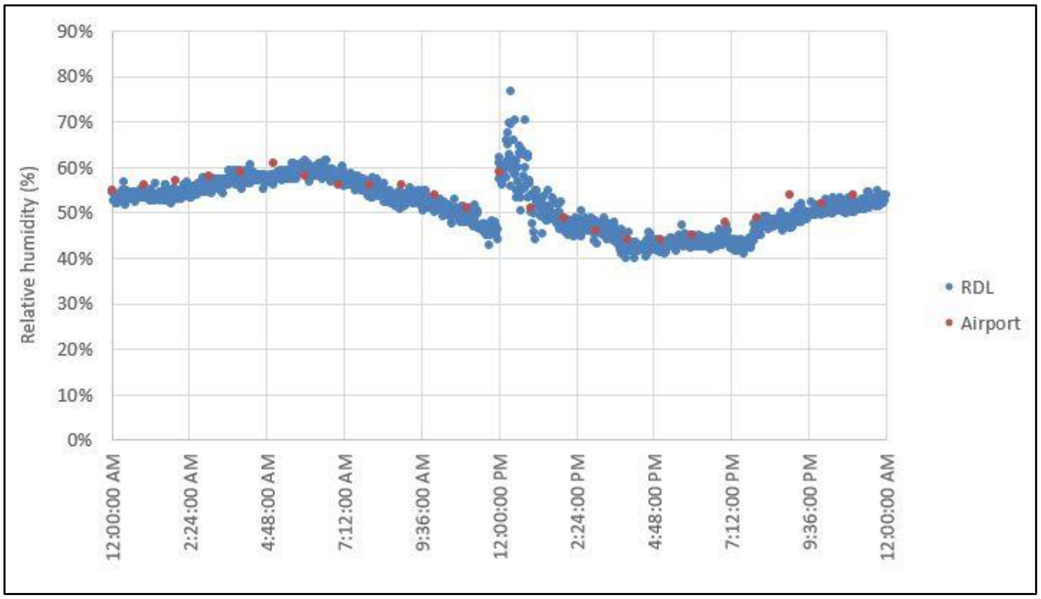

Figure 5 Comparison of RDL humidity data with nearest weather station data

The data can also be compared with another humidity sensor, such as a digital humidity sensor. In Figure 6, the RDL values are compared with the output from the low-cost AM2301b digital humidity sensor, seen in Figure 7. Data from the digital sensor was also measured with the RDL, since it has the ability to communicate with digital sensors that use the I2C protocol. Due to the lower reliability of the digital capacitive humidity sensors, it can be hard to determine if there is something wrong with the wet bulb calculations or the digital sensor output. In this example, the discrepancy between the two readings is mostly within the 5% uncertainty of the digital sensor.

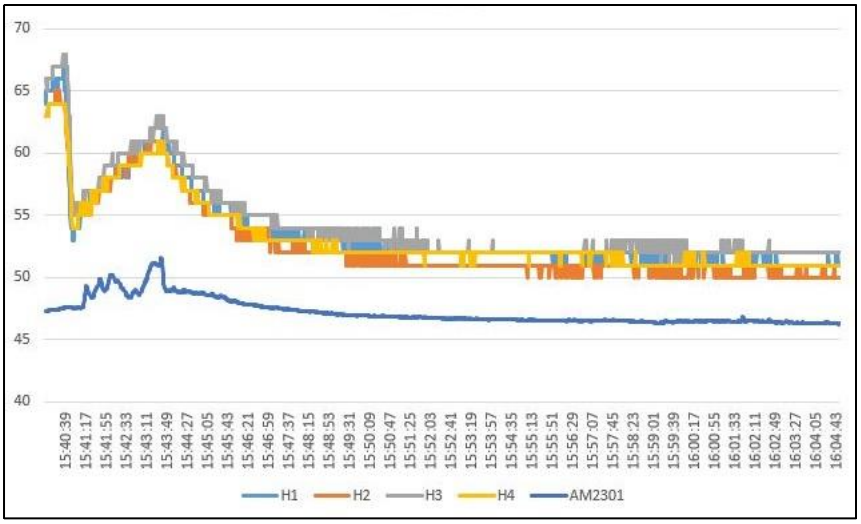

Figure 6 Comparison of 4 wet bulbs and one digital humidity sensor

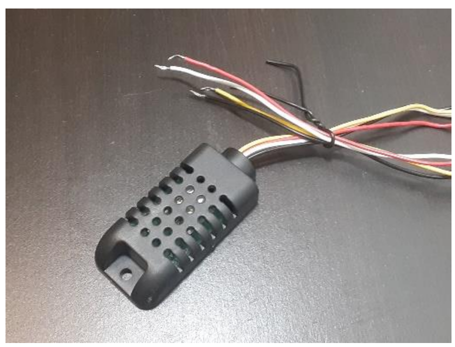

Figure 7 AM2301b digital humidity sensor

Wet bulbs and digital sensors both have pros and cons, which are summarized in Table 1.

Table 1 Pros and cons of wet bulb and digital sensors

	Wet bulb sensor	Digital humidity sensor
PROS	Highly reliable	No maintenance
	Robust	No calculation
	Low cost	Any position
	Tolerates 100% RH	Faster reaction rate
	Simple working principle	
	Useful for comfort indexes	
CONS	Cannot be upside down	Expensive
	Slower reaction time	Might not tolerate RH >95%
	Can spill water	Less reliable
	Requires water fill-up	No comfort indexes
	Occasional wick replacement	Complex working principle

Wet bulb work principle

As the water evaporates on the surface, it absorbs heat from the thermometer. Thermal equilibrium is eventually reached and the temperature stabilizes. In a low-humidity environment, water evaporates more easily as the vapor pressure is low. Hence, the difference between dry and wet bulb temperature is large. In a high-humidity environment, water evaporates less easily since the vapor pressure is already high. Hence, the difference between the dry and wet bulb temperature is lower. This difference is called a ‘wet-bulb depression’. As the wet bulb temperature increases, it is increasingly difficult for live organisms to cool themselves by evaporative cooling. It is usually considered difficult for humans to stay alive when the wet bulb temperature is 35°C and above.

Normal range of values

- In moderate climates, the wet bulb temperature will generally be 0 to 20°C below the dry bulb temperature.
- In terms of relative humidity, humans are most comfortable at 50%, but the acceptable broad range is 30 to 70% (Yunus A. Çengel 2007)
- The absolute humidity of air will often vary between 0 and 0.033 g of water per gram of air.

Relative humidity equations (based on Antoine equation from (Parsons,2014))

P_sa= exp(18.956 - 4030.18 / (Tdb + 235)) millibar

$$P\_swb = \exp(18.956 - 4030.18 / (Twb + 235))$$

$$P\_a = P\_swb - 0.667*(T\_db - T\_wb)$$

$$RH = P\_a / P\_sa \times 100$$

where

P_sa = saturation vapor pressure at the dry bulb temperature, millibar

P_swb = saturation vapor pressure at the wet bulb temperature, millibar

P_a = actual vapor pressure, millibar

RH = relative humidity (%)

N.B. Antoine equation does not take into account the impact of atmospheric pressure.

Relative humidity calculations require the aspirated wet bulb temperature, and the natural wet bulb temperature is no substitute. Correlations exist to approximately convert the natural wet bulb to an aspirated wet bulb temperature (Brake, 2001), but they require some assumption about air velocity or the convection coefficient. The current RDL source code assumes the use of the aspirated value. Absolute (or specific) humidity is currently not part of internal RDL calculations output. It has to be done as post-treatment in a spreadsheet. Both the natural wet bulb correlation and the absolute humidity are potential future developments.

Wet bulb temperature measurement accuracy for revision D3:

- Dry bulb temperature: +/- 0.5°C;
- Aspirated wet bulb temperature: +/- 0.6°C;
- Relative humidity: to be determined;
- Absolute humidity: to be determined unknown at the moment;
- Dew point temperature: unknown at the moment.

Note: Aspirated wet bulbs designed according to ASHRAE Standards 41.6-1994 (RA 2006) and 41.1-1986 (RA 1991) can achieve an uncertainty of +/- 0.1°C (Brenner, 2010). Combined with the dry bulb temperature measurement uncertainty, the wet bulb uncertainty cannot be lower than +/- 0.6°C.

Wet bulb wick

Professional wicks are usually made out of pure cotton and cost a few dollars per wick. As an alternative, one can also use polyester capillary wicks for plant watering or even shoestrings.

The most important thing is that the wick/fiber has a good capillarity effect, so that the wick surface remains moist at all times, despite gravity, wind, etc.

Use of digital humidity sensors with the RDL

Digital humidity sensors can also be used. The capacitive and resistive types are the most popular. These sensors have a smaller form factor, can be used upside down and do not require adding water on a regular basis. However, they are more expensive, should not be exposed to condensation (100% relative humidity) and require proper calibration at least once a year. The accuracy and durability depend greatly on the price of the device. The typical accuracy of the calculated relative humidity is ±2% for high-end models and ±10% for low-end models.

Typical cost of the various instruments for humidity measurements

- Electronic humidity sensor: US$ 30 – 500 per unit
- Sling psychrometer: US$ 20 –100 per unit
- Professional cotton wick: US$ 1 per unit

Figure 8 Sling psychrometer with its two thermometers: the wet bulb (top) and the dry bulb (bottom) thermometers.

Figure 9 Using a sling psychrometer by imposing a fast rotation

To be accurate, the sling psychrometer must generate a minimum air velocity of 5 m/s at the bulb (Parsons, 2014). Above this value, the temperature is not dependent on air velocity (adiabatic saturation temperature). This minimum speed usually requires at least 2 rotations per second and should be maintained until the reading is stable (typically 2 minutes). A sling psychrometer is a bit more precise than a static wet bulb because the absence of air movement might cause the water vapor to accumulate in the surroundings of the wick, which constitutes a bias on the measurement. However, the sling psychrometer is not well suited to continuous measurements, as it requires constant human labor.

HUMIDITY KEY TERMS DEFINITIONS

- Stevenson screen
  - A Stevenson screen (or 'weather screen) is a white wooden box with louvers that protects multiple measuring instruments from the sun and allows the circulation of air. It is usually made out of wood, but there are also miniature version made of plastic for a single instrument (e.g. cotton wick of a wet bulb thermometer. It is common for people to build their own Stevenson screen, by following the key concepts. Two examples can be seen in Figure 10.

Figure 10 Traditional Stevenson screen made of wood (left) and a smaller plastic version (right)

- Natural wet bulb temperature
    - The ‘natural wet bulb’ is a static wet bulb that is not protected from the sun or wind. The measurement is therefore representative of the combined effect of air temperature, humidity, radiation and wind. It is used by the Wet Bulb Globe Temperature (WBGT) comfort index, but it is not recommended to calculate the relative humidity.
- Static wet bulb temperature (or screen wet bulb temperature)
    - It is the temperature of damp cloth or wet thermometer when exposed to stagnant air (0 m/s) and protected from the sunshine and other radiant heat transfer. This temperature is close to the thermodynamic wet bulb temperature from an aspirated hygrometer or sling psychrometer. Calculations of relative and absolute humidity must take into account the type of wet bulb. The static wet bulb is used inside a Stevenson screen.
- Absolute humidity
    - Absolute humidity (or humidity ratio) is the total mass of water vapor contained in a given mass of dry air. It is not dependent on air temperature. In some cases, absolute humidity is defined per volume of air, instead of mass. In that case, the value is dependent on temperature.
- Thermodynamic wet bulb temperature
    - It is a synonym of ‘adiabatic saturation temperature’. It is the coldest temperature achievable as a gas cool down to adiabatic saturation. It is achieved by evaporation of water in a flowing air. The sling psychrometer and the

aspiration psychrometer are two ways to achieve the thermodynamic wet bulb temperature.

- Dew point
    - It is the temperature at which the given absolute humidity will be the maximum amount of water vapor that can be sustained (i.e., relative humidity = 100%). If the temperature goes below the dew point, condensation will occur. Water droplets or ice crystals will form in the air or on the surface.

Figure 11 Morning dew (Image: britannica.com)

- Hygrometer vs psychrometer
    - A hygrometer is defined as any instrument that can measure water vapor content of the atmosphere. The psychrometer is a sub-type of hygrometer, one which uses a dry bulb and wet bulb, whether static or dynamic.

COMFORT INDEXES

Various comfort indexes can be calculated from the RDL data output. In the current version of the RDL, only one index can be calculated within the device, the Wet Bulb Globe Temperature. Other comfort indexes can be calculated from the raw data as post-treatment by the user. The required equations are provided in the present document. A more advanced user could also add the equations into the source code.

Some of the main comfort indexes used around the world are:

- Wet Bulb Globe Temperature (WBGT);
- Wind chill temperature;
- Heat Index;
- Humidex.

- <u>Wet Bulb Globe Temperature</u> (WBGT)
    - The WBGT is commonly used as a measure of comfort. Devices like the QuesTEMP 32 are used to measure this index (Figure 12). The equation is:
        - WBGT = (0.7 × Tw) + (0.2 × Tg) + (0.1 × Ta)
        - Tw = Natural wet bulb temperature, °C
        - Tg= Black globe temperature, °C
        - Ta= Ambient air temperature ('shade air temperature'), °C
    - In the absence of sunlight, such as in a room without windows, the equation is reduced to:
        - WBGT = (0.7 x Tw) + (0.3 x Tg)

Figure 12 QuesTEMP 32 device for WBGT measurements

- Wind chill temperature
    - Broadly speaking, the wind chill temperature (or wind chill index) is the apparent temperature perceived by the human face due to the increased heat loss caused by air velocity. The equation has evolved overtime and varies depending on regions, but the U.S. and Canada use a model accepted by the National Weather Service (see below). Wind chill is useful to evaluate thermal comfort and the risk of frostbites. The wind chill temperature is only defined for temperature at or below 10°C and wind speeds above 4.8 km/h.
    - The wind chill equation is …
        - $R = 13.12 + 0.6215\ T - 11.37\ (V^{0,16}) + 0.3965\ T\ (V^{0,16})$
        - where R is the wind chill index; T is the air temperature in degrees Celsius (°C); V is the wind speed at 10 meters (i.e., standard anemometer height), in kilometers per hour (km/h).
- Humidex
    - Humidex was invented by Canadians in 1965 to describe how hot, humid air feels on the human body. The equation is:
        - $H = T + (5 / 9)(Pv - 10)$
        - where H is humidex index, T is temperature in Celcius and Pv is the water vapor pressure in millibar (mbar)

Table 2 Degrees of comfort associated with humidex values

Range of humidex	Degree of comfort
Less than 29	No discomfort
30 to 39	Some discomfort
40 to 45	Great discomfort; avoid exertion
Above 45	Dangerous
Above 54	Heat stroke imminent

REFERENCES

Yunus A. Çengel. 2007. *Heat & Mass Transfer: A Practical Approach*. McGraw-Hill Education (India) Pvt Limited.

1. https://www.weather-above.com/blackball%20sensor.html
2. Instructions for using the sling psychrometer, Prof Petty, https://www.aos.wisc.edu/~aos330/labs/psychro.pdf