# Guide to humidity measurements in equipment

## With emphasis on data loggers used for mission profiling

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# Introduction

This white paper presents a concise summary of FORCE Technology's many years of experience in the field of humidity measurements, focusing particularly on measurements inside equipment.

Humidity measurements are often perceived as somewhat of a mystery. Errors and discrepancies in specifications and interpretation of results frequently occur due to ambiguous definitions and a lack of understanding of the many different humidity units. This paper aims to clarify the most important definitions, measurement units and principles.

Humidity measurements inside equipment introduces an extra dimension to the complexity. The range of feasible measurement principles is significantly reduced when the instrument's influence on the internal humidity environment is taken into account. This paper introduces common failure mechanisms in equipment used in humid environments. Understanding these mechanisms enables better assessment of how a humidity measuring instrument measures and how it affects the results.

In the final part, several commercial humidity measuring instruments in the form of small data loggers are examined. Their main specifications are reviewed, and guidance is provided on key parameters to observe in their datasheets. Finally, results from FORCE Technology's characterisation of these loggers are presented.

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FORCE TECHNOLOGY

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# 1. Background

In recent years, the industry has been improving the power consumption of electronic equipment. As a result, heat dissipation inside the equipment has been reduced. This has led to an unintended side effect: an increasing number of failures in equipment used in humid environments (e.g. outdoor). At the same time, this has increased the importance of accurate humidity measurements inside equipment during use and testing.

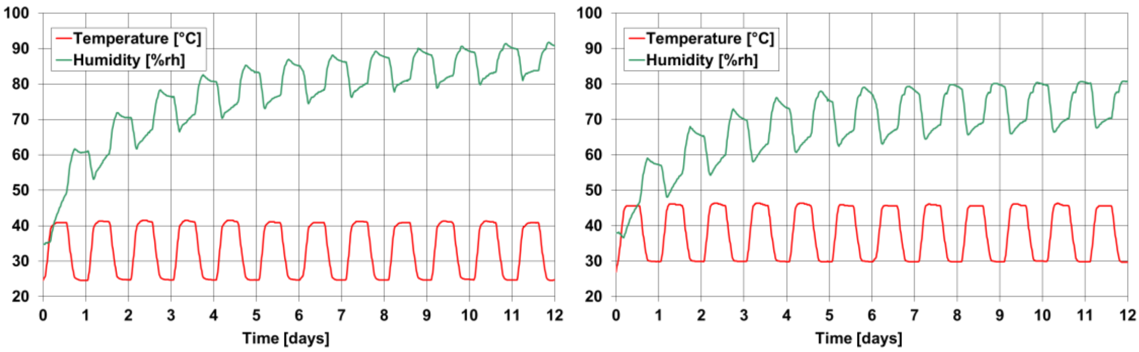


***Figure 1:*** *Humidity progression inside equipment during cyclic humidity testing. Left: Normal power dissipation. Right: Additional power dissipation.*

Performing accurate humidity measurements is challenging. Faulty or misleading measurements often lead to incorrect decisions. Common causes of measurement errors can be:

- Humidity measuring instrument influencing the internal environment itself
- Sensor/electronics insufficiently accurate
- Sensor/electronics responding slowly (long response time)
- Sensor/electronics being damaged due to condensation or corrosion
- Electromagnetic interference from the equipment affecting the instrument

For over 40 years, FORCE Technology has worked daily with humidity measurements in challenging environments and with the calibration of humidity instruments. These experiences are continuously shared with Danish industrial companies as part of FORCE Technology's performance contract with the Danish Agency for Higher Education and Science. In this context, a project on humidity measurement in equipment is being carried out, which includes:

- Characterisation of selected temperature/humidity sensors with associated measurement electronics (data loggers).
- Testing the immunity of the data loggers to close-proximity electromagnetic fields (100 V/m at 810 MHz to 1970 MHz)

This paper introduces the principles of humidity measurement and highlights the special challenges encountered when measuring humidity inside equipment.

Before proceeding to the project itself, a short introduction to important principles is presented.

# 2. Humid air

Humid air consists of:

- **Dry air**, including ~78% nitrogen ($N_2$), ~21% oxygen ($O_2$) and smaller amounts of various other gases.
- **Water vapour** ($H_2O$ in gas form).

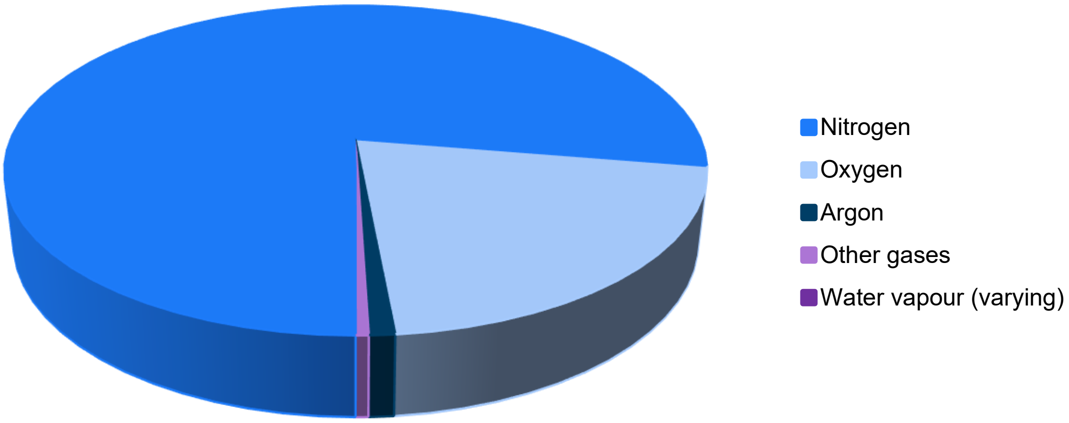


**Figure 2:** *Composition of air.*

The air around us always contains some amount of water vapour and can therefore be said to be more or less humid. The reason we use the term *vapour* rather than *gas* is that water, at normal temperatures and pressures, is below its critical point (374 °C and 22.1 MPa = 221 bar). Above this point, water can only exist in gaseous form. Below it, water can exist in multiple phases: solid/vapour, liquid/vapour, or even solid/liquid/vapour (at its triple point: 0.01 °C = 273.16 K). By convention, substances in gas form below their critical point are referred to as *vapours*, but there is no physical difference between a vapour and a gas.

The constant phase-changing behaviour of water under normal atmospheric conditions makes it particularly challenging to control where water goes. Water vapour can enter equipment through the smallest cracks or holes, even through solid plastic (by diffusion). Once inside, it can cause numerous problems, especially when it condenses and becomes electrically conductive in the presence of even minimal amounts of contamination. In liquid form, water is often impossible to remove the same way it entered, as it accumulates in large droplets.

### Absolute humidity

Absolute humidity expresses the mass of water vapour per volume unit of humid air. It is typically measured in grams per cubic meter ($g/m^3$). Note that absolute humidity is independent of how much dry air ($N_2$, $O_2$, etc.) is present.

## Vapour pressure

Vapour pressure is the pressure exerted by water vapour at a given temperature, usually expressed in pascals (Pa). The total pressure of humid air is the sum of the partial pressures from dry air and water vapour, the latter also called *vapour partial pressure*.

## Dew point

The dew point, or dew-point temperature, is the temperature to which humid air must be cooled for condensation (dew) to occur. It is also the point at which air becomes saturated with water vapour and is in equilibrium with liquid water.

## Relative humidity

Relative humidity (RH) is the ratio of the actual water vapour content in air to the maximum it could contain at that temperature (i.e. if fully saturated). RH is usually expressed as a percentage, from 0 to 100 %. The standard notation is %rh.

Relative humidity can be determined by the ratio of unsaturated/saturated absolute humidity and unsaturated/saturated vapour pressure. Because dew point and vapour pressure are easier to measure accurately, humidity calculations often rely on international empirical formulas for saturation vapour pressure as a function of temperature.

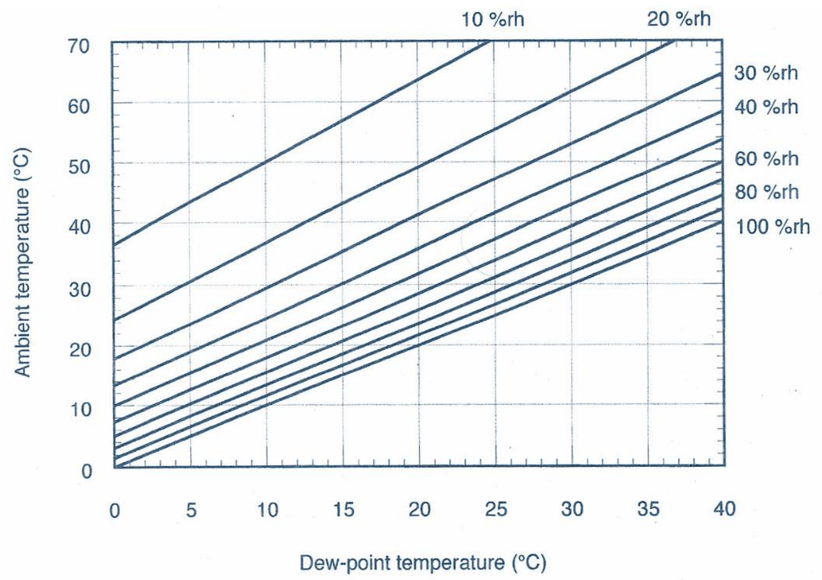


**Figure 3:** *Relationship between air temperature, dew point and relative humidity.*

Note that at 100 %rh, the dew point equals the air temperature, the air is fully saturated, and condensation begins.

Relative humidity changes significantly with temperature, especially at high RH. As seen in Figure 3, %rh lines are closer together at higher RH values. For example, a 1 °C temperature change at 25 °C and 20 %rh causes a 1.2 %rh change. At 90 %rh, the same temperature shift causes a 5.2 %rh change.

At higher temperatures, water increasingly “favors” the vapour phase over liquid. A sealed container with a bowl of water at 25°C will becomes saturated with ~23 g/m³ of water vapour. At 55 °C, it rises to ~104 g/m³, regardless of the amount of dry air present.

## Hygroscopic / hygrometry / hygrometer

The Greek word *hygros* means moist or wet. A material that tends to absorb humidity is called hygroscopic. Measurement of air humidity is called hygrometry, and a hygrometer is the instrument used to perform it.

# 3. Failures in equipment caused by humidity

Humidity is widely recognised as having a detrimental impact on electronic and mechanical equipment. To protect new products from humid environments, it is common practice to enclose them in a housing, effectively creating a semi-hermetic enclosure.

However, in many cases, this enclosure does not offer the protection needed or expected. Equipment may still fail after only weeks or months of use. Moreover, conventional notions of “sealed” and “unsealed” often prove inadequate, and failures continue to occur despite repeated design improvements.

Typical humidity-related failures in electronic and mechanical equipment include:

- **Leakage currents**
- **Short circuits**
- **Corrosion**
- **Degradation** of material properties
- **Delamination**
- **Condensation** on optical components etc.

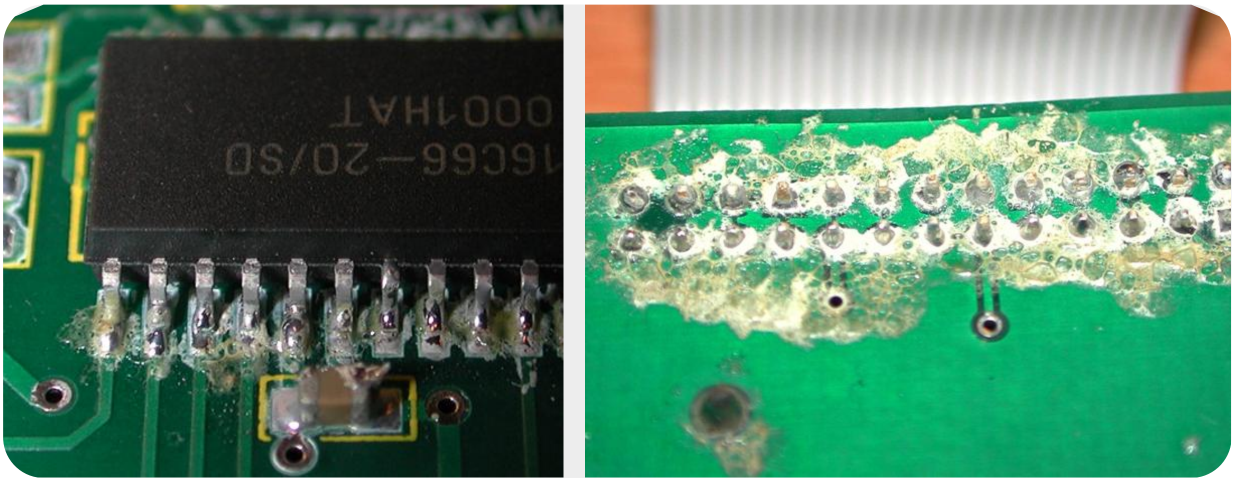

**Figure 4:** *Corrosion on a printed circuit board after two days of humidity testing.*

## Constant high relative humidity

Generally, higher relative humidity leads to more severe and more frequent failures. If the temperature also rises while maintaining a high relative humidity, the environment becomes even more aggressive.

Environments with a relative humidity above 80 % are typically considered harsh, with a high risk of humidity-related failures. In corrosion studies, a relative humidity above 50 – 60 % is often found to be critical. As a rule of thumb, keeping the relative humidity inside the equipment below 50 % prevents most humidity-related problems.

Humidity tests with constant temperature and relative humidity are often carried out according to:

- IEC 60068-2-78, Test Cab: Damp heat, steady state

Standard conditions include 85 %rh or 93 %rh at 30 °C or 40 °C, and often at 55 °C as well. Duration can range from 12 hours to 56 days. Some tests (e.g., IEC 60068-2-67) specify 85°C / 85 %rh for up to 2000 hours (mainly for electronic components).

## Cyclic conditions – water accumulation in a semi-hermetic enclosure

If the relative humidity is constantly high while the temperature cycles, water accumulation can occur due to the so-called "pumping effect". This happens, for example, with a phone in a warm, humid pocket or in an electronic road sign exposed to sun and rain showers.

In this case, it is not liquid water leaking through seals, but water vapour (see previous section). Vapour enters any path where dry air could also travel. When the temperature later drops, the vapour condenses, posing a risk to the internal electronics and mechanics.

Water vapour enters via two mechanisms:

- **Diffusion** (e.g. how perfume spreads in a room)
- **Flow**, driven by pressure differences (e.g. a punctured tire)

Both mechanisms occur in semi-hermetic enclosures.

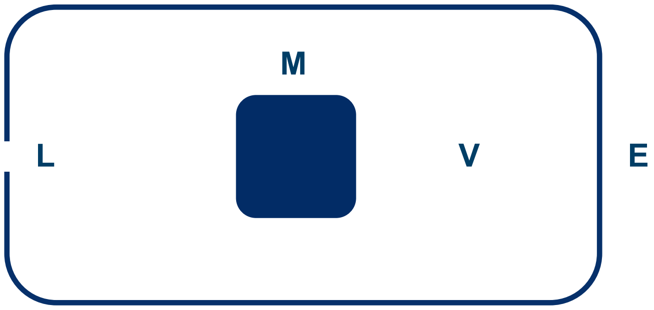


**Figure 5:** *Simplified model of a semi-hermetic enclosure.*

Water accumulation inside the **enclosure (E)** happens because **diffusion** through a **small leak (L)** is far slower than the **flow**, and a **mass (M)** inside the enclosure (e.g., transformer, battery, capacitor, coil) acts as a condensation trap during temperature increases.

Thus, the **hole (L)** is large enough to allow air and vapour in/out by flow, but not by diffusion. Water vapour accumulates because the **mass (M)** retains it as condensate when the temperature rises.

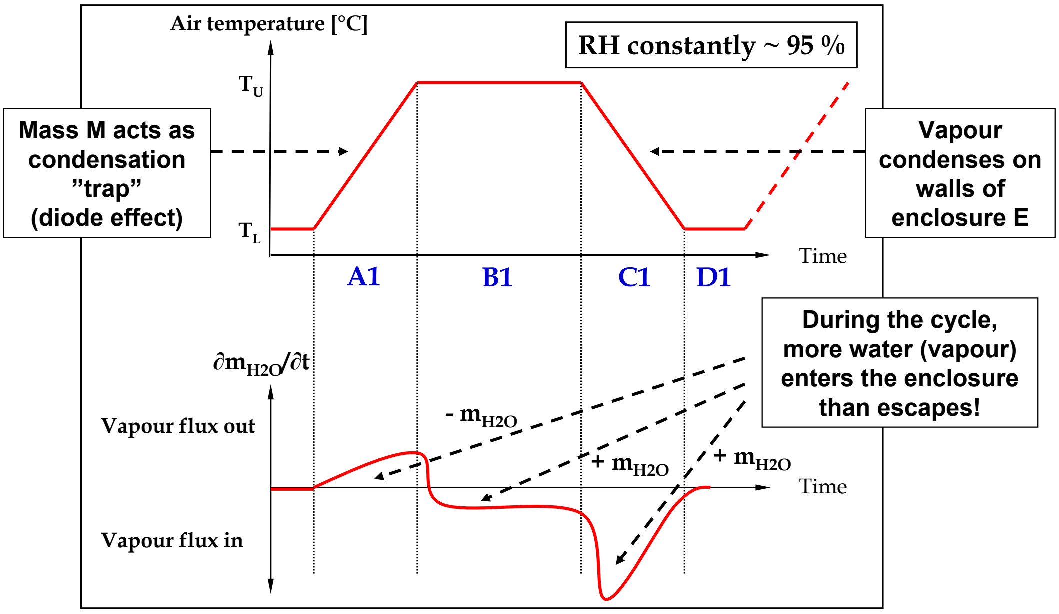


**Figure 6:** *Water accumulation in a semi-hermetic enclosure during temperature changes under high relative humidity.*

For a given enclosure **volume (V)**, there is a specific equivalent leak size that maximises water accumulation. Typical IP66, IP67 or IP69-rated enclosures have an equivalent leak diameter of 0.2 – 0.4 mm, which is close to worst-case conditions. Additionally, the larger the internal **mass (M)**, the more water can be accumulated.

Water accumulation and related condensation phenomena are typically studied via cyclic humidity testing, such as IEC 60068-2-30 or IEC 60068-2-38. These tests involve temperature cycling (e.g. 25 °C to 40 – 65 °C) under constant high relative humidity. Transition times are 2 – 3 hours, with 1 – 2 cycles per day over 2 to 12 days.

For detailed guidance on such test cycles, see:

- **SPM-176, Anders B. Kentved, "Humidity testing of electronics and mechanics", 2008.**

# 4. Humidity measurement in equipment

To prevent humidity-related failures in equipment, it is essential that the product is specifically designed for use in humid environments. One of the most effective tools during product development is to conduct humidity measurements inside the equipment, both during actual use and under humidity testing conditions.

Such measurements allow assessment of the effects of common design improvements, for example:

- Incorporating semi-permeable membranes (i.e., Gore-Tex®)
- Drying agents like silica gel
- Internal heating

## Requirements for the hygrometer

As described earlier, the internal humidity environment in an enclosure can be easily influenced. Even small additions, such as added mass, internal heating or leak paths via sensor cables, can significantly alter measurement precision. Additionally, both temperature and relative humidity must be measured accurately, often at high temperatures and RH levels.

Therefore, a suitable hygrometer for measurements inside equipment should preferably meet the following criteria:

- Lowest possible mass, size and power dissipation
- Wireless logging capability for temperature and RH
- Temperature range: -10 to +70 °C (or wider)
- Humidity range: 20 to 100 %rh (across the full temperature range)
- Temperature accuracy: ±0.5 °C or better
- Humidity accuracy: ±3 %rh or better
- Must tolerate condensation
- Response time: 30 minutes or less

**Additional practical guidelines:**

- The hygrometer's mass should be equal to or smaller than the largest concentrated mass inside the enclosure, to avoid altering condensation behaviour.
- The hygrometer’s volume should be less than 1/5 of the free internal volume, otherwise humidity pumping behaviour may be affected.

In harsh use environments, the hygrometer may also need to:

- Withstand corrosive atmospheres
- Be immune to electromagnetic noise from wireless modules or power supplies (e.g. switch-mode types)

## Humidity measurement – a challenging discipline

Humidity measurement is not as straightforward as many assume. Even high-end hygrometers often struggle to provide accurate results for specific tasks. This is especially evident in dynamic conditions at high RH and temperature, such as in standard humidity testing conditions.

For example, IEC 60068-2-78 defines one test condition as 40 ±2 °C and 93 ±3 %rh.
A thermometer costing €50 – €100 can easily measure temperature at an accuracy of ±0.2 °C, ten times better than the standard requirement. However, even the best humidity calibration laboratories, with scientific equipment costing hundreds of thousands of euros, struggle to meet ±1 %rh accuracy, only three times better than the test standard.

Data sheets for commercial hygrometers often state accuracies of ±1 – 2 %rh, which seems close to ideal. But a closer look usually reveals that this accuracy only applies at room temperature and moderate RH levels (10 – 90 %rh) and not the full range (0 – 100 %rh).

## Measurement principles

Most modern hygrometers are based on one of the following principles:

- Absorption in/on hygroscopic material (*capacitive or resistive sensor*)
- Evaporative cooling from a wet wick (*psychrometer*)
- Condensation on a cooled mirror surface (*chilled mirror hygrometer*)

Psychrometers and chilled mirror hygrometers are the most accurate, especially at high RH and temperatures, with minimal hysteresis and long-term drift. However, they are typically too large, heavy and heat-intensive, or add humidity via evaporation, making them unsuitable for measurements inside equipment.

Resistive sensors are sensitive to condensation and rarely offer high-quality results. As such, capacitive sensors remain the only practical choice, although their limitations must be taken into account.

## Capacitive humidity sensors

A capacitive humidity sensor consists of a hygroscopic material (dielectric) placed between two electrodes, forming a capacitor. The dielectric material is typically a polymer (e.g., polyimide, known commercially as Kapton®) or a metal oxide (e.g. aluminium oxide, $Al_2O_3$).

For mechanical stability, a substrate (supporting material) is used, usually glass, ceramic or silicon. One electrode is applied to the substrate, followed by the dielectric layer and finally the second electrode. The top electrode is perforated so that moist air can penetrate to the dielectric material.

- Metal oxides are mostly used for measuring very low humidity.
- Polymers are used across the entire range (0 – 100 %rh), making them ideal for measurements inside equipment.

The capacitance of the sensor as a function of RH can be calculated using:

$$\boldsymbol{C(RH)} = \boldsymbol{\varepsilon_{RH}} \cdot \boldsymbol{\varepsilon_0} \cdot \boldsymbol{A} / \boldsymbol{D}$$

Where:

- $\boldsymbol{\varepsilon_{RH}}$ = relative permittivity of the polymer at a given humidity
- $\boldsymbol{\varepsilon_0}$ = vacuum permittivity
- $\boldsymbol{A}$ = electrode area
- $\boldsymbol{D}$ = distance between electrodes

As RH increases, the polymer absorbs water, increasing $\epsilon_{RH}$, because water has a much higher permittivity (~80) compared to polyimide (~3.5). The result is that capacitance increases linearly with RH.

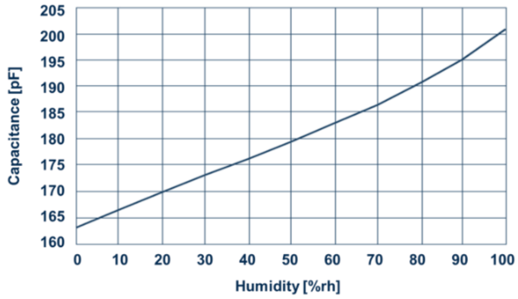


**Figure 7:** *Left: Example of a capacitive polymer sensor. Right: Typical sensor characteristic curve.*

The nominal capacitance at 50 %rh and 25 °C is typically 100 pF – 500 pF, and the sensitivity is often 0.2 – 0.5 pF / %rh. Because of the low capacitance, sensor cable length must be short, typically no longer than 3 meters, due to cable impedance.

Even with advanced manufacturing, sensors are not identical, meaning factory calibration is common practice. This enables post-installation correction or adjustment.

## Temperature influence

Water absorption in polymers decreases slightly with temperature, and water's permittivity ($\epsilon_r$) also decreases, from ~80 at 25 °C to ~55 at 100 °C. A non-temperature-compensated sensor will therefore typically underestimate RH at higher temperatures.

Capacitive sensors fundamentally measure water uptake (ideally proportional to relative humidity) but are sometimes (incorrectly) marketed as dew-point sensors, possibly due to the association with highly accurate mirror dew-point hygrometers.

To calculate the dew point or absolute humidity, RH measurements must be combined with temperature readings, ideally from the same location. Therefore, most capacitive hygrometers include an integrated temperature sensor.

**Figure 8:** *Humidity measurement probe without protection cap. Top: temperature sensor. Bottom: capacitive humidity sensor.*

## All-in-one sensors

Measuring sensor capacitance (and temperature) requires supporting electronics, microcontrollers and memory for correction data.

As a result, manufacturers have developed fully integrated digital humidity sensors, combining sensor, electronics and communication interface in a single package.


**Figure 9:** *Digital humidity sensors from Sensirion. Left: SHT7X (pin version). Middle: SHT3X (SMD version). Right: SHT2X (SMD version).*

These sensors only need a power supply. Measurements are transmitted digitally via I²C protocol (two connections).

## Typical weaknesses of capacitive sensors

Capacitive sensors are:

- Cheap, small, lightweight and ultra-low power consumption
- Rated for 0 – 100 %rh up to 200 °C
- Characterised by a response time of typically 30 – 60 seconds for a 63% step change

However, they suffer from:

1) Humidity saturation effects – long response times at high RH
2) Hysteresis – readings vary depending on recent humidity exposure history
3) Long-term drift – especially when exposed to aggressive gases or chemicals

Example:

After prolonged high humidity exposure, a sensor might temporarily overestimate low RH due to hysteresis. Although reversible, the recovery time varies significantly.

# 5. Terminology relevant to hygrometer measurements

In this section, several terms that frequently cause confusion when interpreting datasheets and evaluating hygrometer performance are explained.

### Calibration

Calibration means determining the display error of a hygrometer by comparing it to a more accurate reference. The most precise calibrations use reference instruments (standards), which represent the unit of measurement with known uncertainties.

The reference instruments with the highest accuracy are:

- Gravimetric hygrometers (measuring the actual mass of water in the air)
- Dew-point generators (primary standards).

Second best is a mirror dewpoint hygrometer, calibrated against a primary standard.

Note: The term "calibration" is often (incorrectly) used to mean *adjustment*. However, according to international definitions, these are distinct concepts.

### Adjustment and correction

Adjustment involves “fine-tuning” a hygrometer’s output, usually based on a prior calibration, to minimise measurement errors. This changes the output permanently.

Previously, this was done with a physical potentiometer screw. Today, adjustments are typically software-based, although this is often misnamed "software calibration".

However, perfect accuracy is not achievable due to inherent uncertainty. Also, adjustments are limited by the hygrometer’s computational power and memory.

Sometimes, manufacturers do not adjust the instrument but provide a correction table or spreadsheet for post-processing the data. This is normally referred to as “correction”.

### Error, uncertainty and accuracy

Traditional error theory divides measurement deviations into:

- **Systematic errors**: consistent, predictable deviations (i.e. over a long time)
- **Random errors**: unpredictable, scattered deviations (not “true” errors, but variability)

Ideally, systematic errors are corrected for via adjustment, while random errors define the measurement's uncertainty. But in practice, this separation is difficult.

Some error components are partly systematic and partly random, and long-term drift may make correction impractical.

Therefore, the term "uncertainty" is sometimes extended to include well-characterised systematic errors (limited by a minimum and maximum). However, it is still important to distinguish actual systematic errors (now simply called errors or bias) from the uncertainty.

- **Uncertainty** is mostly used in calibration contexts and includes random errors and well-characterised systematic errors (limited by a minimum and maximum).
- **Accuracy** is commonly used in industrial and datasheet contexts. It assumes that the instrument is already adjusted, and that remaining systematic and random errors are reflected in the stated accuracy.

# 6. Characterisation of four different data loggers

The following is an excerpt from the latest results of FORCE Technology’s project on humidity measurement in equipment. It contains a characterisation of four different data loggers, all of which can measure and log both temperature and relative humidity.

## Data Loggers

The data loggers (Figure 10) have been selected to primarily meet the requirements in Section 4 on humidity measurement in equipment. They all use capacitive humidity sensors and are battery-powered with minimal power consumption. The loggers also come with software and the possibility of connecting to a PC, either directly via a USB plug or through a special logger station that must be purchased separately.


**Figure 10:** Data loggers for temperature and humidity measurements. From left: DBT-H90, RS-191A, OM-CP-MICRORHTEMP and TrackSense Pro.

The DBT-H90 (SHT30) and the RS-191A (SHT20) both use almost the same type of sensor from Sensirion.

In the following table, the most important data for the loggers are gathered from their respective datasheets:

| | RS-191A (RS) | OM-CP-MICRORHTEMP (OMEGA) | DBT-H90 (Labsystem Kft.) | TrackSense Pro (Ellab) |
|---|---|---|---|---|
| Temperature range [°C] | -30 to 60 | 0 to 60 | -20 to 70 | 0 to 90 |
| Max temperature for full humidity range [°C] | 60 | 40 | 65 | 90 |
| Accuracy, temperature (full range) [°C] | ± 1.0 | ± 0.5 | ± 0.5 | ± 0.1 |
| Accuracy, humidity (lim. range) [%rh] | ± 3.5 | ± 2 | ± 3 | ± 2 |
| Accuracy, humidity (full range) [%rh] | ± 5.0 | ± 3 | ± 4 | N/A |
| Hysteresis humidity [%rh] | N/A | N/A | NA | N/A |
| Long term stability [%rh/year] | N/A | N/A | N/A | N/A |
| Repeatability (“noise”) [%rh] | N/A | N/A | N/A | N/A |
| Response time (T90 - humidity [s]) | N/A | 60 | 900 | 15 |
| Resolution temperature (best) [°C] | 0.1 | 0.1 | 0.1 | 0.01 |
| Resolution humidity (best) [%rh] | 0.1 | 0.1 | 0.1 | 0.001 |
| Max loggings at highest resolution | 20010 | 16383 | 25920 | 60000 |
| Battery life [h] | 8760 | 8760 | 8760 | 1500 |
| Interchangeable battery? | Yes | Yes | Yes | Yes |
| Dimensions [mm] | 75 x 35 x 16 | 15 x 38 (dia.) | 50 x 19 (dia.) | 74 x 25 (dia.) |
| Weight [g] | 30 | 30 | 34 | 50 |
| Approximate price [€] | 60 | 385* | 55 | 450* |
| Communication | USB-A | USB-A | Bluetooth | Docking station* |

* Software and equipment purchased separately

The main differences between the loggers’ data are:

- Temperature range
- Max number of loggings
- Mass/size
- Response time

## Accuracy of the data loggers

To get a satisfactory understanding of the loggers' actual performance, the datasheets must be closely examined. A few examples are provided below.

A common shortcoming for all of them is that neither hysteresis, long-term stability nor repeatability is mentioned in the datasheets.

**RS-191A:**


For the RS-191A, the accuracy is divided into three ranges:

1. From 0 to 20 and 80 to 100 %rh, the accuracy is ± 5 %rh
2. From 20 to 40 and 60 to 80 %rh, the accuracy is ± 3.5 %rh
3. From 40 to 60 %rh, the accuracy is ± 3 %rh

An important note in the datasheet is that these accuracies only apply at a temperature of 25 °C. No information is given about temperature dependency or correction, so it is expected that the accuracy applies across the entire temperature range.

**OM-CP-MICRORHTEMP:**

For the OM-CP-MICRORHTEMP, the accuracy is divided into two ranges:

1) From 10 to 80 %rh the accuracy is 2 %rh
2) From 0 to 10 and 80 to 95 %rh, the accuracy is 3 %rh


Again, the datasheet states that the limited accuracy only applies at a temperature of 25 °C. Furthermore, the response time is stated as a 90% change in slow-moving air over a period of 60 seconds. No information is given about temperature dependence or correction, so it is expected that the accuracy applies across the entire temperature range.

**DBT-H90:**

For the DBT-H90, the accuracy is divided into two ranges:

1) From 10 to 90 %rh, the accuracy is 3 %rh
2) From 0 to 10 and 90 to 100 %rh, the accuracy is 4 %rh


Once again, the datasheet states that the limited accuracy only applies at a temperature of 25 °C. Furthermore, the response time is stated as a 90% change over a period of 15 minutes (900 seconds). No information is given about temperature dependency or correction, so it is expected that the accuracy applies across the entire temperature range.

**TrackSense Pro:**

For the TrackSense Pro, only one accuracy is stated: ± 2 %rh, and it only applies to the humidity range from 10 to 90 %rh at 25 °C.
Furthermore, the response time is stated as a 90% change over a period of 15 seconds, making it the fastest in terms of response time. The TrackSense Pro also has the shortest battery life.

## Characterisation

In the characterisation, the basic measurement properties of the data loggers have been further investigated under different combinations of temperature and humidity, which are relevant for measurements inside equipment. The characterisation includes:

- Calibration at 25 °C and 20, 60 and 95 %rh
- Calibration at 55 °C and 20, 60 and 95 %rh
- Measurement of hysteresis at 25 °C and 55 °C
- Measurement of response time (humidity) at 25 °C and 55 °C

Furthermore, an EMC immunity test is performed to see the performance of the loggers during interference:

- EMC immunity of data loggers to close-proximity electromagnetic fields (100 V/m at 810 MHz to 1970 MHz), in accordance with EN 61000-4-39 (2017).

For all calibration points, a stabilisation time of approximately 24 hours has been used. The reason for the long stabilisation time is that the DBT-H90 has a very long response time (humidity).

Hysteresis is measured by repeating the calibration point at 20 %rh, before and after the loggers have had the time to be saturated with water vapour at both 60 and 95 %rh. The indicated hysteresis is the difference between the errors in the two repeated measurements.

The response time (humidity) is measured in two different ways. "Response time (up)" is measured when changing from 60 to 95 %rh. The indicated time is measured from the start of the change to the point where the hygrometer's reading has reached within 63 % of the final reading at 95 %rh. "Response time (down)" is measured when changing from 95 to 20 %rh. The indicated time is measured from the start of the change to the point where the hygrometer's reading has reached within 63 % of the final reading at 20 %rh.

The measurements were conducted in FORCE Technology's calibration laboratory with an uncertainty (for the calibration conditions) of ± 1 %rh for relative humidity and ± 0.07 °C for temperature. The results in the following tables (temperature first, followed by humidity) are the averages of the 3 measurements for each type.

Figure 11 shows the calibration setup inside FORCE Technology's calibration chamber.

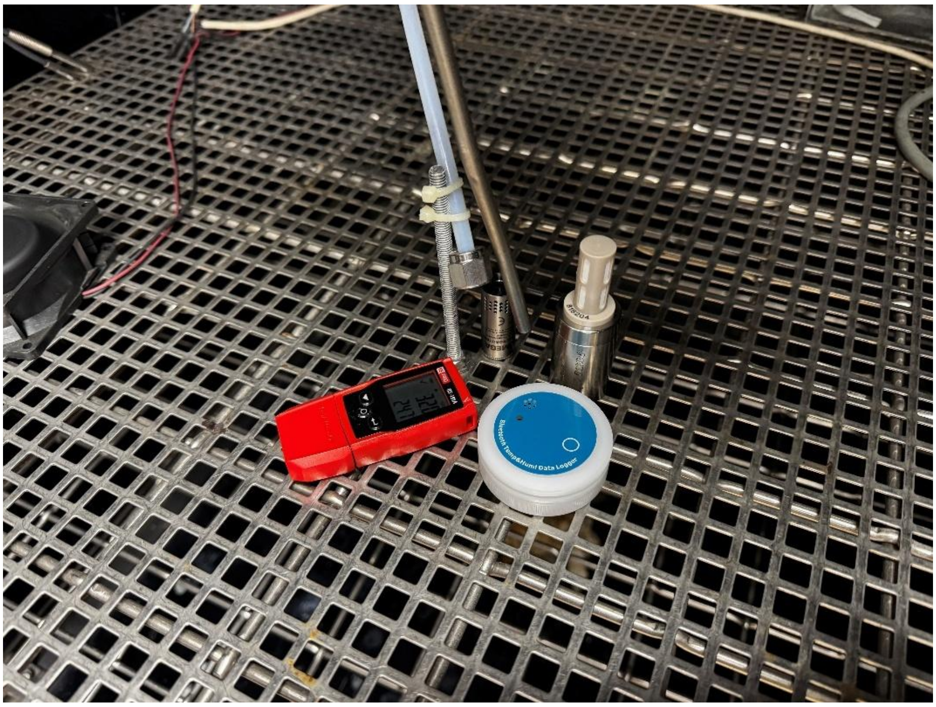

Figure 11: Calibration setup inside calibration chamber

## Calibration

| Calibrations: | RS-191A (RS)<br>Temp. error [°C] | OM-CP-MICRORHTEMP (OMEGA)<br>Temp. error [°C] | DBT-H90 (Labsystem Kft.)<br>Temp. error [°C] | TrackSense Pro (Ellab)<br>Temp. error [°C] |
|---|---|---|---|---|
| 25 °C / 20 %rh | -0.04 | 0.06 | -0.04 | 0.01 |
| 25 °C / 60 %rh | -0.08 | 0.02 | -0.08 | 0.01 |
| 25 °C / 95 %rh | 0.02 | 0.02 | 0.02 | 0.02 |
| 25 °C / 20 %rh | -0.07 | 0.03 | -0.07 | -0.13 |
| 55 °C / 20 %rh | -0.01 | -0.01 | -0.11 | -0.01 |
| 55 °C / 60 %rh | -0.06 | -0.06 | -0.06 | -0.06 |
| 55 °C / 95 %rh | -0.01 | -0.01 | 0.19 | -0.01 |
| 55 °C / 20 %rh | 0.10 | 0.10 | 0.00 | 0.00 |
| Hysteresis, 25 °C | -0.03 | -0.03 | -0.03 | 0.14 |
| Hysteresis, 55 °C | 0.11 | 0.11 | -0.11 | -0.01 |

As shown in the table above, all the data loggers measure temperature as good as or better than specified, even after long periods at high temperature and humidity.

| Calibrations: | RS-191A (RS)<br>Hum. error [%rh] | OM-CP-MICRORHTEMP (OMEGA)<br>Hum. error [%rh] | DBT-H90 (Labsystem Kft.)<br>Hum. error [%rh] | TrackSense Pro (Ellab)<br>Hum. error [%rh] |
|---|---|---|---|---|
| 25 °C / 20 %rh | -3.92 | 2.38 | 3.28 | 0.06 |
| 25 °C / 60 %rh | -1.03 | 0.87 | -1.03 | -0.90 |
| 25 °C / 95 %rh | 4.16 | 2.66 | -3.54 | -0.06 |
| 25 °C / 20 %rh | -4.50 | 2.20 | 3.60 | 0.12 |
| 55 °C / 20 %rh | -4.12 | 1.58 | 2.68 | -0.39 |
| 55 °C / 60 %rh | 0.19 | 0.69 | 0.59 | -0.57 |
| 55 °C / 95 %rh | 5.28 | 2.08 | -0.82 | 0.86 |
| 55 °C / 20 %rh | -5.02 | 0.88 | 2.68 | -0.81 |
| Hysteresis, 25 °C | -0.58 | -0.18 | 0.32 | 0.06 |
| Hysteresis, 55 °C | -0.90 | -0.70 | 0.00 | -0.42 |
| Response time (up), 25 °C [min] | 3.33 | 3 | 61 | 2.5 |
| Response time (up), 55 °C [min] | 3.33 | 3 | 15 | 5 |
| Response time (down), 25 °C [min] | 24 | 14 | 39 | 2.5 |
| Response time (down), 55 °C [min] | 13 | 10 | 14 | 10 |

The results for humidity show a significant difference between the four loggers. However, all loggers measure within specifications at 25 °C and 55 °C, except the RS-191A, which is just outside the claim of ±5.0 %rh at 55 °C & 20/95 %rh.

It is also interesting to see the difference between the RS-191A and DBT-H90, which both use nearly the same type of humidity/temperature sensor from Sensirion. A reason could be the choice of housing of the DBT-H90, which seems to be made of a material more prone to being hygroscopic than the RS-191A.

### Response times

The DBT-H90 has very long response times. If the measurements need to be within 3 %rh of the final reading, one generally has to wait 2-6 hours, and up to 10 hours to get within 1-2 %rh.

In contrast, the OM-CP-MICRORHTEMP and TrackSense Pro generally measured faster than the changes generated in FORCE Technology's calibration chamber. This means that the response times of these can be misleading as they are following the conditions within the chamber. Figure 12 shows the step response of the loggers when switching from 60 to 95 %rh (55 °C).

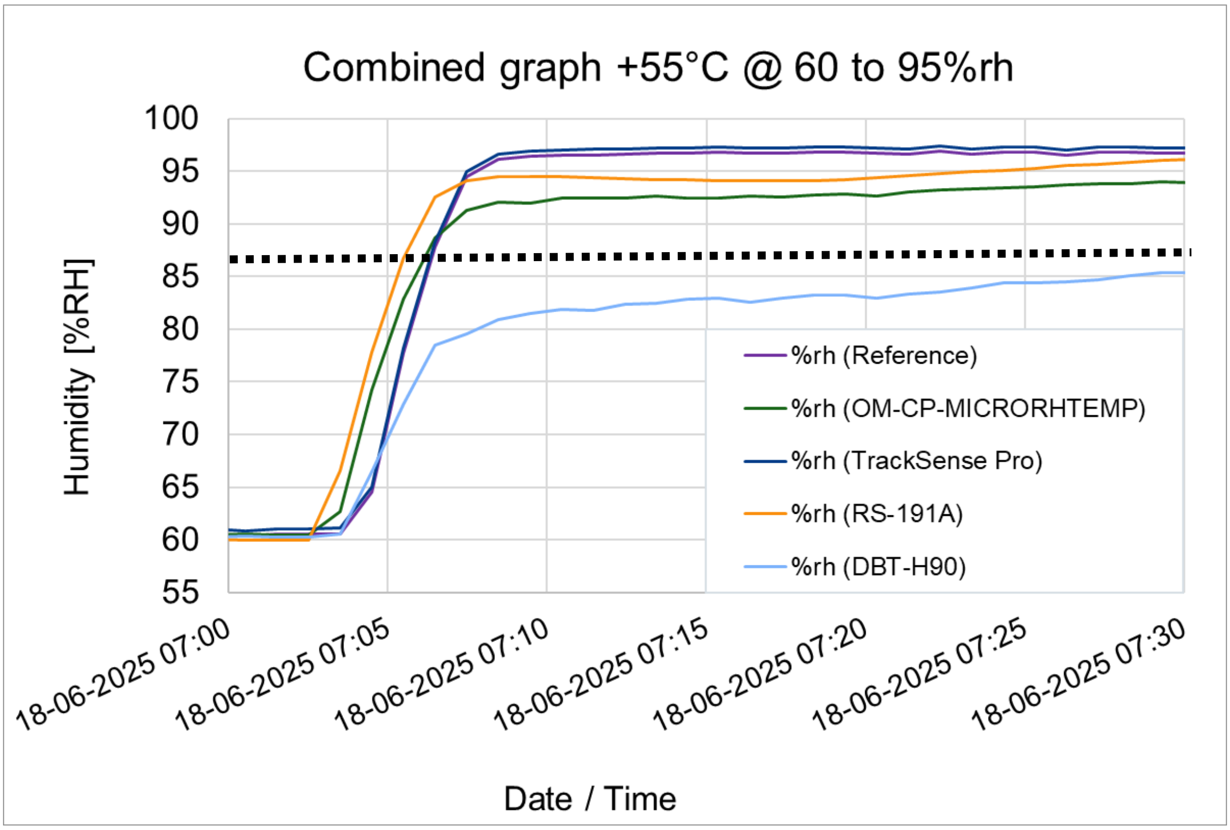


Figure 12: Example of response time from 60 to 95 %rh (55 °C).

The dashed line in the figure indicates the point at which the measurement value is within 63 % of the final reading.

The very long response times for some of the loggers are undesirable, especially because the settling curves closely resemble those typically seen with humidity accumulation in equipment during a humidity test. This means that the measurement results could easily be misinterpreted in actual measurement situations.

Figure 12 also shows that all loggers have a reasonable response time to 63 % of the final reading. The large difference between the four loggers only becomes evident in the final part of the settling process. As an example, the DBT-H90 has not settled after 24 hours at 25 °C / 95 %rh as shown in Figure 13.

If you look at the datasheets for the Sensirion sensors in two of the loggers, the "tau 63 %" times are between 5 and 30 seconds. If we traditionally multiply them by 5 to come within 99 % of the final reading (i.e. assuming an exponential increase/decay), the result is far from the many hours observed during the characterisation. The datasheets for the sensors describe that when using the sensors outside of the "normal range" (> 80 %rh), a "temporarily offset" of about 3 %rh should be expected. There are also two "reconditioning" procedures listed, which can be used to bring the sensors back within specifications: "Baking" for 10 hours at < 5 %rh / 100 °C and "Re-Hydration" for 12 hours at ~75 %rh / 25 °C. However, almost the same settling behaviour and response times were observed for all combinations of temperature and relative humidity during the characterisation.

## General performance

Overall, all the data loggers performed as expected during the characterisation, and no significant differences were observed between the three measured loggers within each type.

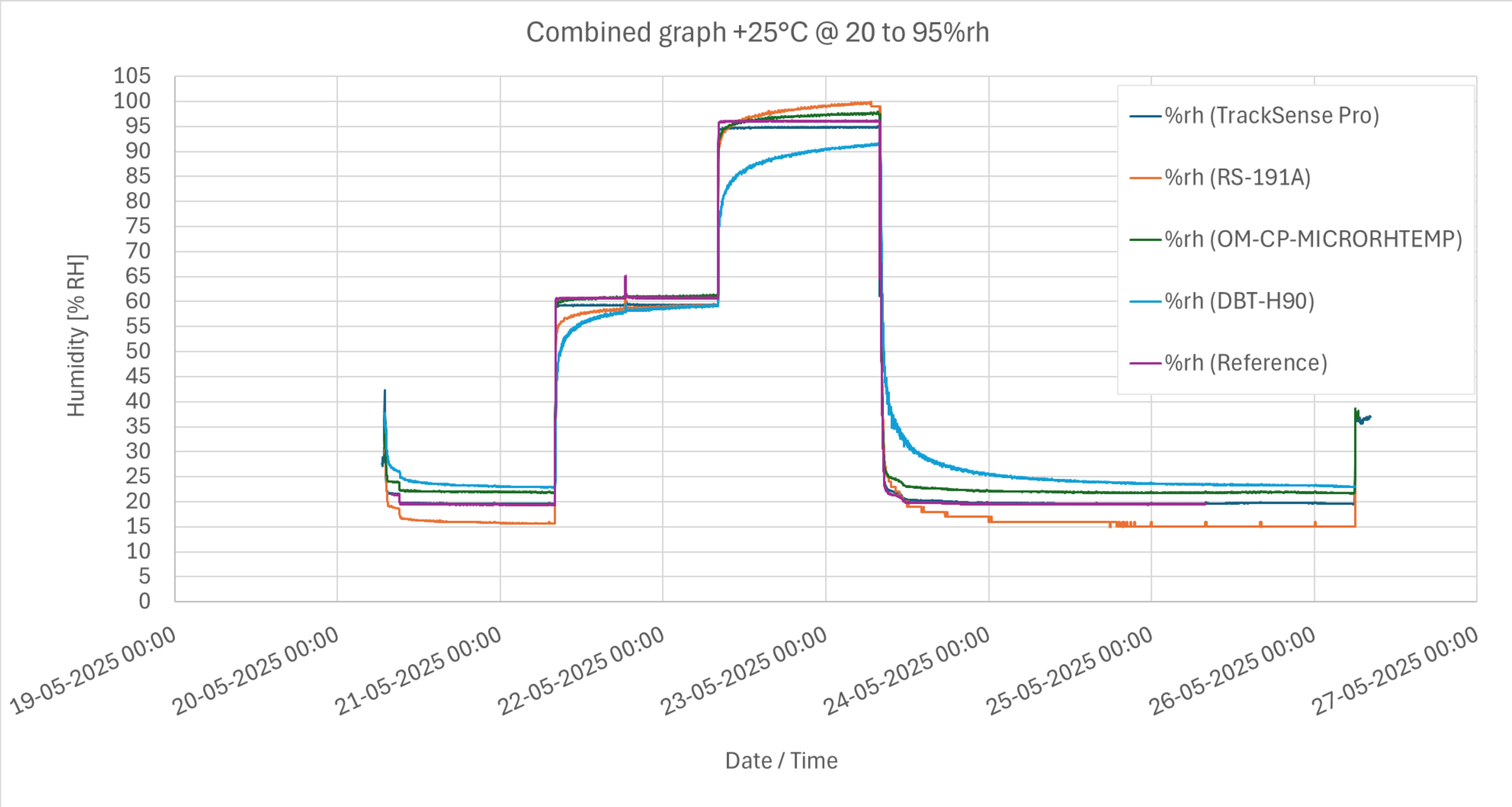


Figure 13: Combined calibration graph for all loggers in all points at 25 °C

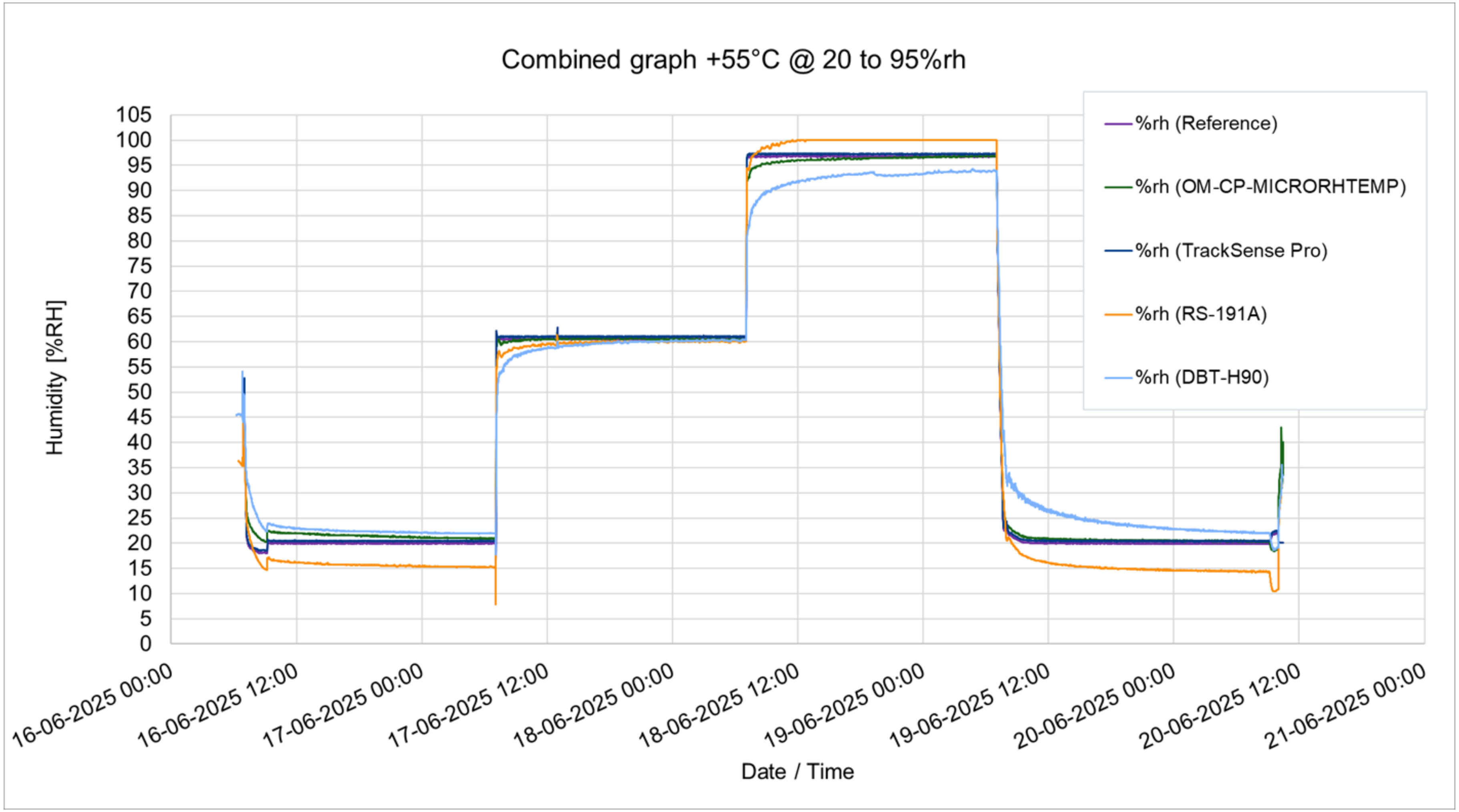


Figure 14: Combined calibration graph for all loggers in all points at 55 °C

## EMC immunity of data loggers to close-proximity electromagnetic fields

The data loggers have been exposed to a close-proximity electromagnetic field. This test evaluates the logger's ability to function correctly when exposed to electromagnetic disturbances from nearby electronic devices, which is common for measurements inside equipment.

**Purpose of the close-proximity test**

The close-proximity test ensures that the data logger:

- Maintains accurate measurements during electromagnetic exposure
- Does not produce signal or data errors
- Continues to communicate properly

**How the test works**

During the test:

- The data logger is exposed to electromagnetic fields at a short distance (typically 10 cm).
- A series of frequencies is applied, i.e. between 810 MHz and 1970 MHz, simulating interference from nearby devices such as mobile phones, radios or Wi-Fi routers.
- The performance of the data logger is monitored to detect any degradation or malfunction.

An example of the test setup is shown below:

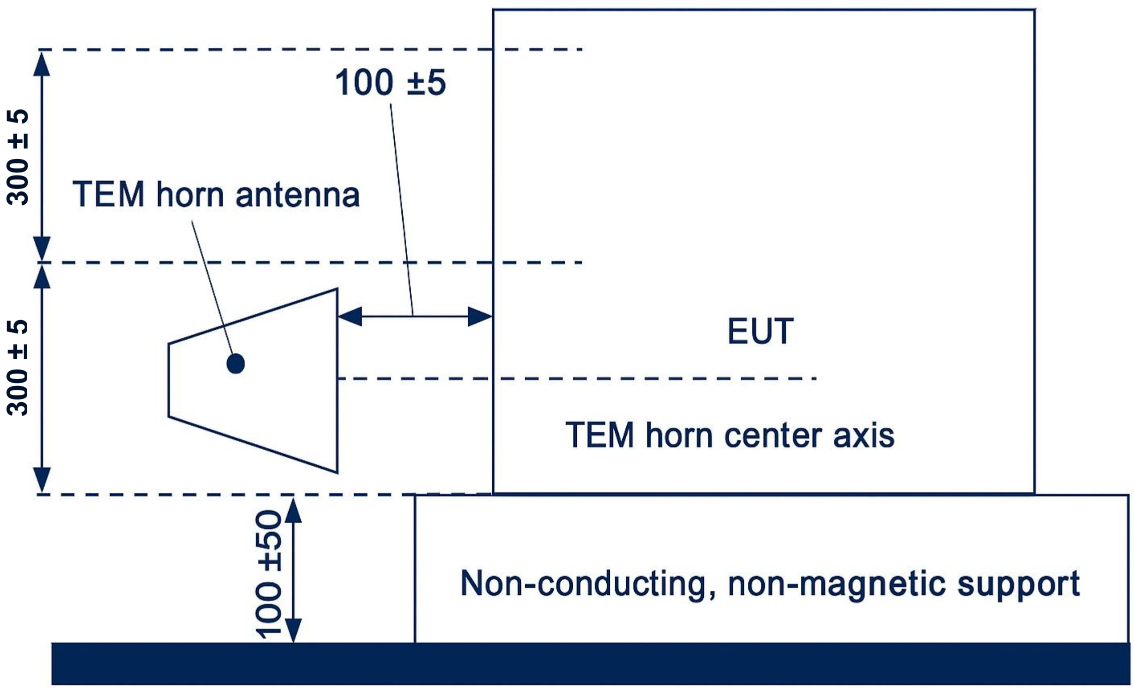


**Figure 15:** *Example of close-proximity test setup.*

The data loggers (EUTs) are placed 10 cm from the antenna and turned so that all surfaces are exposed.

The data loggers are exposed to 100 V/m at the following spot frequencies: 830, 870, 930, 1720, 1845 and 1970 MHz with a 217 Hz pulse modulation (50% duty cycle) for 30 seconds at each frequency before proceeding to the next frequency or orientation.

**Results:**

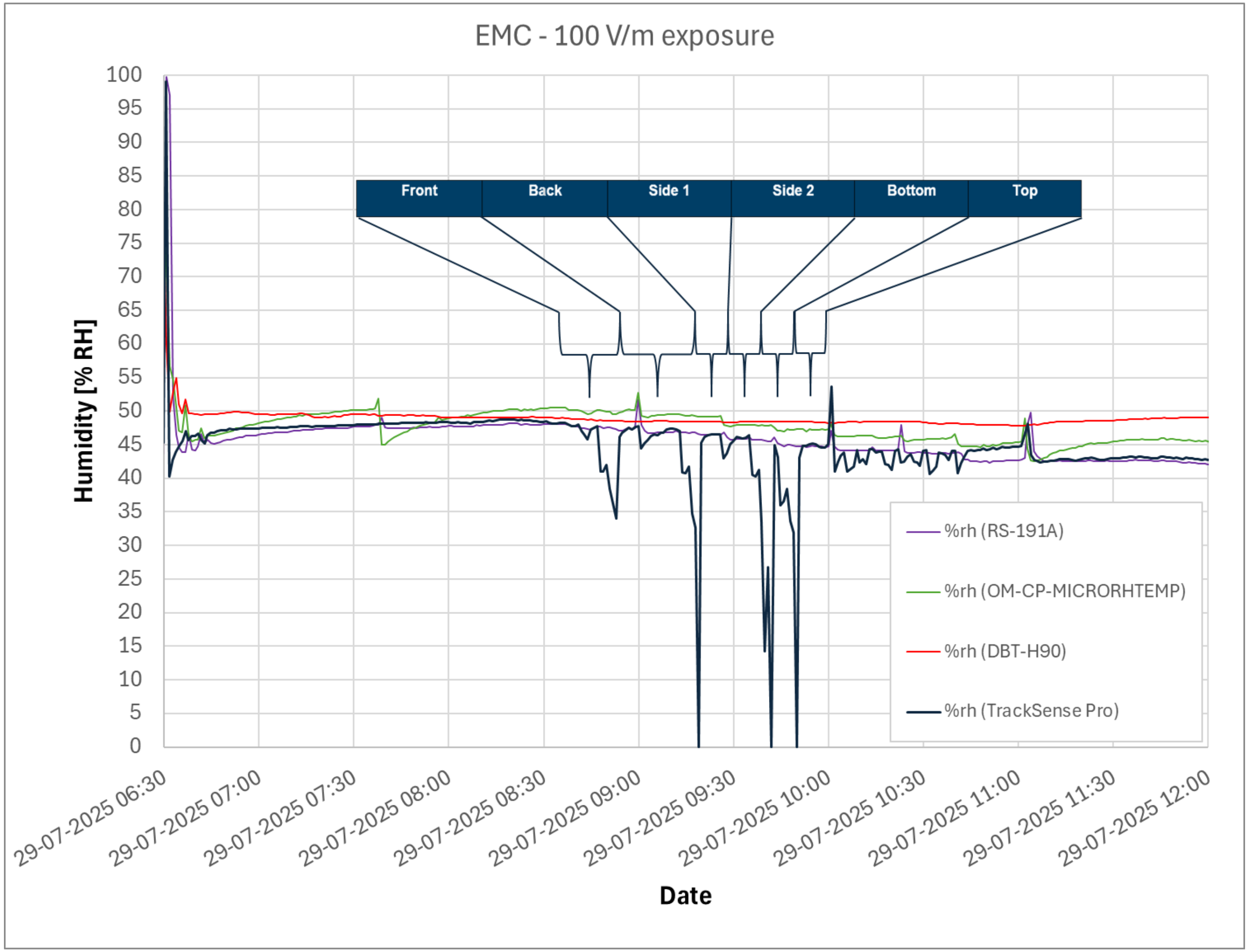


Figure 16: Combined graph for all data loggers during the close-proximity test.

From the results shown in Figure 16 it can be seen that during the exposure, the only logger influenced by the electromagnetic field seems to be the TrackSense Pro datalogger. The measurements fluctuate towards 0 %rh in some of the orientations. This means that the measurement results could easily be misinterpreted. It should be noted, that the TrackSense Pro datalogger tested, had a polymer filter around the sensing element. However, the TrackSense Pro also comes in a version with a metal filter, which is expected to perform better in EM environments.

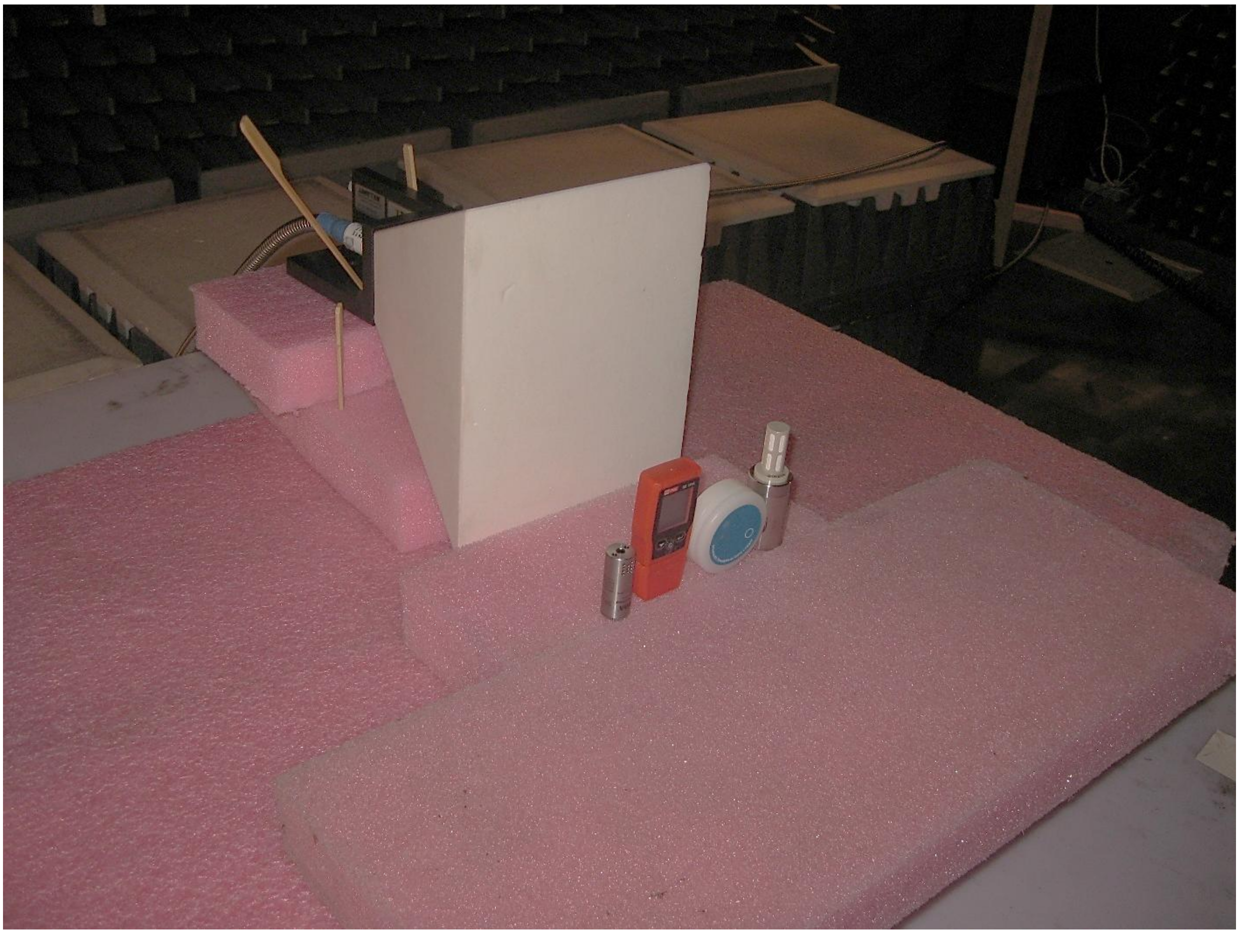

**Figure 17:** *Test setup during close-proximity test (exposure to the back of the data loggers)*

# 7. Conclusion

To make accurate humidity measurements inside equipment, a suitable hygrometer is essential. In most cases, this means a hygrometer that is small, light, robust, accurate, and has a very low power consumption. Additionally, it is very beneficial to have a reasonable understanding of typical failure mechanisms for equipment used in humid environments. This allows one to assess whether and how a given hygrometer will influence the measurement result.

Often, the many specific requirements for the hygrometer in practice can only be met by wireless data loggers with built-in temperature and humidity sensors. The majority of commercially available data loggers use capacitive-type humidity sensors. This means that one must be aware of the typical weaknesses of capacitive sensors to ensure satisfactory measurement results. These weaknesses include temperature dependence, hysteresis and long-term drift. The first two can usually be disregarded if the right data logger is selected, while the latter can often be managed through ongoing calibration of the data logger against an appropriate reference.

In this white paper, the measurement properties of four different commercial data loggers have been examined:

1) RS-191A (RS)
2) OM-CP-MICRORHTEMP (OMEGA)
3) DBT-H90 (Labsystem Kft.)
4) TrackSense Pro (Ellab)

The four loggers all have advantages and disadvantages, depending on the parameter being considered.

For example, the OM-CP-MICRORHTEMP is very small and light, with a fast response and minimal hysteresis. However, it only has memory for a relatively small number of loggings, and its battery life is shorter than expected.

The TrackSense Pro, on the other hand, seems to have the best measurement properties, but it is also the heaviest of the tested loggers, which can cause issues with measurements in equipment with small masses. Also, the TrackSense Pro seems to be the only logger affected by the electromagnetic field during the close-proximity test. This means that, in some scenarios, this logger might be unable to measure correctly.

There are, however, many other important parameters to consider before identifying the best of the four data loggers for a specific task. The characterisation described here does not address the performance of the loggers under harsh conditions, such as prolonged condensation, saline air or other electromagnetic interferences than the one tested in this white paper. Additionally, there are large variations in the software of the data loggers, which can be an equally important selection parameter.

## About this white paper

FORCE Technology regularly publishes white papers to communicate the latest international knowledge within our fields of expertise. The goal is to support the advancement of the timing when new technological breakthroughs provide a business return for companies.

## About FORCE Technology

FORCE Technology helps its customers make effective use of advanced technologies to achieve commercial success in a complex world. We handle design, development, testing, certification, and consulting in electronics, software technology, lighting, optics, acoustics, vibration, and sensor systems.

FORCE Technology is one of Europe's leading development houses and one of the seven Approved Technological Service Institutes (GTS) in Denmark with around 1000 employees and collaborate with more than 7000 different clients in over 90 countries.

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