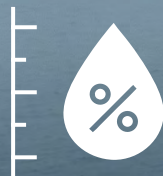




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Humidity Monitoring in Dry Container Fleets

A practical framework
for deploying humidity
monitoring where it creates
measurable value



Executive Summary

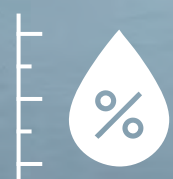
As container fleets become more connected, the challenge is no longer collecting more data. It is deciding where additional sensing creates measurable operational value.

Humidity monitoring illustrates this shift. The question is not whether a smart container tracking device can measure humidity. Modern technology can do that.

The real question is where humidity should be measured, and what is the most effective way to deploy that capability across a fleet. Answering that question requires balancing operational needs, engineering constraints, and fleet economics

Based on this analysis, this paper concludes that a two-layer deployment model provides the optimal approach for most dry container fleets: a permanently installed, fully sealed tracking device for long-term fleet visibility, combined with a cargo-level humidity sensor deployed only when environmental monitoring is required. This approach improves measurement accuracy, preserves device reliability, reduces lifecycle costs, and provides the flexibility to deploy humidity monitoring only where it is needed.

Ultimately, the objective is not to collect more data, but to collect the right data, in the right place, at the right cost.



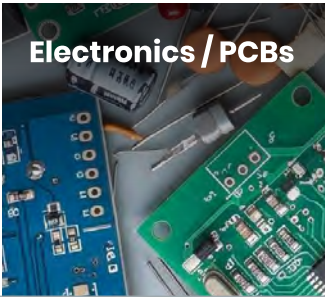
Humidity Matters, But Not Equally Across All Cargoes

Moisture remains one of the most common causes of cargo quality degradation in global logistics.¹

Humidity-related damage results from condensation, cargo respiration, moisture migration, packaging absorption, and environmental changes as containers move between climate zones.² The consequences include mold growth, corrosion, packaging deterioration, product degradation, cargo claims, and reduced customer satisfaction.

Certain cargo categories are particularly vulnerable. Table 1 sets out the primary categories, their key humidity risks, and the typical operational RH thresholds that define safe transport conditions.



Cargo Category	Key Humidity Risk	Recommended RH Threshold	Notes
 Coffee & Cocoa	Mold, clumping, flavor loss	Green coffee: 50–60% RH; Cocoa beans: <65% RH; Max: 70% RH	Above 70% RH mold growth accelerates sharply. Instant coffee degrades critically at 65% ERH within one week. *Source
 Pharmaceuticals	Degradation, tablet cohesion	General: <60% RH; Dry storage: ≤40% RH; Sensitive APIs: 10–30% RH	WHO TRS 961 Annex 5 sets <60% RH benchmark. USP <659> defines "dry place" as ≤40% at 20°C. Hydrolysis-prone APIs may need ≤10% RH. *Source
 Electronics / PCBs	Oxidation, ESD susceptibility	Ambient storage: 40–60% RH; Moisture barrier bags: <5% RH; Damage threshold: >60% RH	IPC-1601A recommends 40–65% RH ambient. Below 30% RH increases ESD risk. IPC-1602 governs assembly environments. *Source

1. IMO/ILO/UNECE Container Transport Unit (CTU) Code (2014) identifies condensation and moisture as among the leading cargo risk factors in international freight transport.

2. GDV/TIS (Transport Information Service, German Insurance Association) container climate guidance describes the steel-skin heat exchanger effect, dew point dynamics, and condensation mechanics in detail. See: tis-gdv.de

Cargo Category	Key Humidity Risk	Recommended RH Threshold	Notes
	Mold, discoloration	Optimal: 45–55% RH; Leather max: 65% RH; Mold risk: >60–70% RH	Below 40% RH leather cracks and fibers embrittle. Above 70% RH mold establishes. Daily fluctuation should stay within $\pm 5\%$ RH. *Source
	Distortion, ink migration	Optimal: 35–55% RH; Max: 60% RH; Damage risk: >65% RH	Smithsonian Institution and NARA recommend minimum 30% RH, with fluctuations no greater than 5% RH in any 24-hour period. *Source
	Mold, quality loss	Optimal: 65–70% RH; Acceptable: 60–72% RH; Mold/pest risk: >75% RH	Habanos recommends 65–70% RH at 16–18°C. Below 60% RH tobacco loses essential oils; above 75% RH mold and tobacco beetle hatching become significant risks. *Source
	Hydrolysis, caking	General: <60% RH; Hygroscopic chemicals: 30–50% RH; Critical threshold: >60% RH	WHO advises <60% RH for chemical storage. Hydrolysis and caking risks rise sharply above 60% RH. Molecular sieves used for precision low-RH applications. *Source
	None critical	Target: 50–70% RH; Acceptable: up to ~80% RH	No strict product-driven threshold. Container air at sea regularly exceeds 80–90% RH; desiccants recommended for voyages over 2 weeks to prevent container rain. *Source

Table 1 – Humidity-sensitive cargo categories, risk mechanisms, and typical operational RH thresholds.

Sources: CTU Code (2014); ICH Q1A(R2); GDV/TIS; ASHRAE 90.1.

The important observation is that humidity sensitivity is cargo-specific rather than fleet-wide. A container fleet transports hundreds of cargo types throughout its lifecycle. Not every shipment requires continuous environmental monitoring.

The First Challenge: Measuring the Right Environment

A humidity sensor is only valuable if it measures conditions relevant to the cargo. Most smart container devices are installed on container doors or external structural elements, an ideal location for tracking performance, communications, installation, and maintenance access. It is not necessarily the right location for cargo condition monitoring.

Consider a humidity sensor embedded in a permanently installed device on a container steel door: the steel-skin microclimate is not the cargo microclimate. The steel container wall acts as a heat exchanger: it heats and cools far faster than the cargo mass inside. During nocturnal cooling, the steel skin reaches dew point well before interior air, creating a systematic humidity gradient between the door zone and the cargo interior. During daytime solar heating, the reverse applies.

Beyond thermal dynamics, door-open events at loading, unloading, and inspection introduce instantaneous step-changes in RH at the door position, representing ambient port or warehouse conditions, not cargo conditions. A door-mounted sensor captures these transients directly. A cargo-interior sensor, positioned away from the door, is buffered from this effect.



Measurement Characteristic	Door-Mounted (Embedded)	Cargo-Interior (Add-On)
Measures cargo microclimate	No: steel skin / door zone	Yes: adjacent to goods
Thermal buffering by cargo mass	None: thin steel skin	High: cargo acts as heat sink
Door-open artifact sensitivity	High: direct ambient exposure	Low: buffered by cargo/packaging
Placement flexibility	Fixed at door	Optimised per stow plan
Alarm threshold reliability	Lower: position artifacts	Higher: representative data

Table 2 – Physical placement characteristics: door-mounted embedded sensor vs. cargo-interior add-on sensor.

Sensor placement is not a minor detail. It determines whether the data you collect is meaningful for the shipment it is meant to protect, i.e. a sensor which is a part of the permanent track-and-trace device installed on the container steel body is not delivering sufficient results. An add-on humidity sensor located closer to the cargo serves better the purpose of the HR monitoring.

The Second Challenge: Reliability Over Time

Container tracking devices are expected to operate for many years in the harshest environments in global logistics: salt and moisture, temperature extremes, vibration, impact, high-pressure washing, and continuous handling.³

Humidity sensing introduces a structural problem. To measure humidity accurately, the sensing element must be exposed to ambient air. This requires vents, membranes, or diffusion pathways, which become entry points for contamination, fouling, and degradation over time. Because that opening breaks the sealed enclosure, it can also remove the intrinsic-safety (ATEX/IECEX) certification that many terminals and carriers require for handling dangerous goods.

For container trackers certified for use in hazardous areas, ATEX Zone 1 or IECEx under IEC 60079, this enclosure conflict carries an additional consequence. Intrinsic safety certification under IEC 60079-11 requires that every enclosure opening, conductive pathway, and potential ignition source be analysed as part of a unified certified entity. A vent or membrane, however small, introduces new elements to that analysis: a permanent dust and moisture ingress pathway, a potential electrostatic discharge surface at the membrane support structure, and a corrosion fault channel through the vent zone. If the sensor model, membrane specification, or vent geometry changes at any point during the device lifetime, full re-certification of the entity is required. The encapsulation techniques used to achieve intrinsic safety in a sealed tracker are fundamentally incompatible with the need to expose a capacitive polymer sensing element to ambient air, the two requirements cannot be simultaneously optimised.

The gap can be measured. Under clean laboratory conditions, a good humidity sensor drifts by only about 0.2% per year. Inside a shipping container the conditions are far harsher: chemical fumes from packaging and adhesives, together with long spells above 80% humidity, push that drift much higher. The sensor can recover from the occasional damp period, but constant exposure ages it and can cause permanent damage, and even a protective membrane cannot keep every contaminant out. The result is that while the tracker's core electronics stay stable, the humidity sensor can lose accuracy within a few years, and because it is sealed inside the device, there is no practical way to recalibrate or replace it.

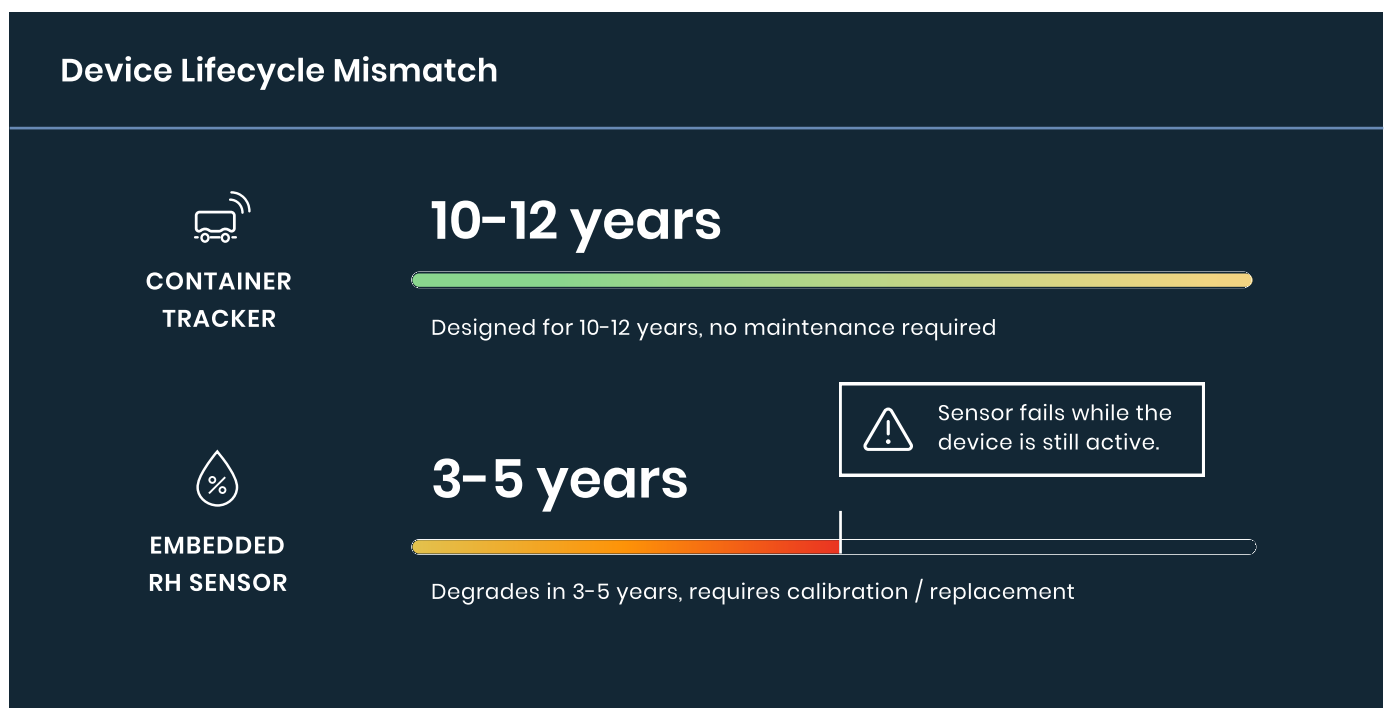


3. Container tracking devices are typically required to meet IEC 60068-2 environmental test standards and, for hazardous area use, ATEX Directive 2014/34/EU and/or IECEx certification under IEC 60079.

Failure Mechanism	Embedded RH Sensor (door-mounted)	Add-On Cargo Sensor
Chemical contamination (NaOH, QAC)	HIGH Direct washdown exposure	LOW Interior cargo placement
Water ingress	HIGH Vent membrane attack surface	NEGLIGIBLE Inside container
Long-term drift (0.2% RH/yr)	CRITICAL 12-yr uncorrectable drift ~2.4%+	MANAGED replaced per shipment
Membrane fouling	HIGH repeated external wash cycles	LOW controlled environment
Condensation saturation events	HIGH temperature cycling at steel skin	MODERATE buffered by cargo mass
Physical impact / abuse	MODERATE door area exposure	LOW cargo packing protection

Table 3 – Failure mode comparison: embedded RH sensor vs. add-on cargo sensor.
Based on container operational conditions per IEC 60068-2 and manufacturer application notes.

The device lifecycle mismatch is clear and straightforward: the container tracker is designed for a 10-12-year operational life with no maintenance required. Capacitive RH sensors degrade after 3-5 years and require regular calibration to remain within specification. **Embedding a sensor with a 3-5-year life inside a sealed device rated for 12 years means the sensor fails while the device is still active, with no practical way to replace or recalibrate it.**



Fleet Economics:

Why Selective Deployment Wins

The economics of humidity monitoring look very different when evaluated at fleet scale.

Embedding humidity sensing into every tracker means every asset carries the additional hardware, testing, engineering, and maintenance burden of that capability, regardless of whether any given shipment is humidity-sensitive. The alternative, deploying humidity sensors selectively, only on shipments that require environmental monitoring, changes the economics entirely.

For a fleet of 100,000 containers, the arithmetic is clear:

Parameter	Embedded in Every Tracker	Add-On (Cargo-Deployed)
Cost per sensing unit	~\$7 (BOM + enclosure tooling)	~\$10 (standalone sensor)
Units required (100k fleet)	100,000 (all trackers)	~2,000 (humidity-sensitive shipments)
Total fleet cost	~\$700,000	~\$20,000
Cost ratio	35×	Baseline
Enclosure integrity	Compromised (vent introduced)	Fully preserved
Measurement location	Door skin (non-representative)	Cargo interior (meaningful)
Sensor lifecycle match	No (3–5 yr vs. 12-yr tracker)	Yes (matched to shipment)
Replaceable / upgradable	No	Yes

Table 4 – Fleet economic comparison: embedded vs. add-on humidity sensing. Based on a 100,000-device fleet. Cost estimates: Hoopo internal research (2026). Note: ~10,000 is illustrative; assumes approximately 2% of annual voyages carry humidity-sensitive cargo. Carriers should model against their own portfolio

A selective deployment model aligns investment with actual cargo requirements. Tracking remains available across the entire fleet. Humidity sensing is deployed only where it creates measurable operational value, concentrating resources on shipments that genuinely benefit from environmental monitoring.

35x

The cost ratio of embedding humidity sensing in every tracker versus deploying add-on sensors only where needed

Two Main Approaches to Humidity Monitoring

	MODEL 1	MODEL 2
	Embedded Humidity Monitoring	Cargo-Level Humidity Monitoring
Overview	The tracking device includes both fleet visibility and humidity sensing in a single unit.	The tracking device provides asset visibility. Humidity sensing is deployed as a separate cargo sensor when required.
Advantages	• Single hardware platform • Simplified procurement • Unified installation	• Measurement closer to cargo • Greater deployment flexibility • Cost aligned to operational need • Independent upgrade cycles • Tracker reliability preserved
Indicative hardware price *prices are the subject to changes and provided for indication only	• hardware price: permanent device with multiple embedded sensors depending on the volume of the order: on average \$170–\$300/unit for the full tracker (humidity sensing is part of the package, not separately priced). Fleet-wide SaaS subscription applies regardless of cargo type.	• hardware price: \$5–\$30/unit for basic passive single-use USB loggers (Elitech, Tsure); \$50–\$110/unit for multi-use or display loggers (LogTag UHADO-16 ~\$105; Sensitech TempTale 4H ~\$80–\$120). Deployed only on shipments that require humidity monitoring.
Challenges	• Measurement may not reflect cargo conditions • Added complexity within the tracker • Fleet-wide cost regardless of cargo • Lifecycle mismatch between tracking and sensing • Enclosure compromise (ATEX implications)	• Additional process for sensor deployment • Management of an additional device type

Table 5: Architectural model comparison.

Conclusion



STRATEGIC RECOMMENDATION

Keep the permanent installation device sealed, durable, and operationally simple. Deploy humidity sensing selectively, as an add-on cargo sensor, only where operational value justifies it.

Humidity monitoring delivers clear value for selected cargo categories. That does not automatically mean every dry container tracking device should permanently include a humidity sensor.

As container fleets become increasingly digital, operators face an important architectural decision.

The objective is not to collect more data. The objective is to collect the right data, in the right place, at the right cost.

Location tracking and cargo condition monitoring serve different operational purposes:

- **Tracking** supports fleet visibility, utilization, exception management, and operational intelligence.
- **Humidity monitoring** supports cargo quality assurance for selected shipments.

Treating these as separate layers provides greater flexibility, stronger economics, and more relevant measurements than combining them into a single device architecture.

The recommended architecture:

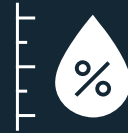
- **Permanent tracking device:** fully sealed, no vent or membrane, 10–12-year reliability commitment, GPS, door, shock, temperature; battery life optimized for sparse-event reporting.
- **Add-on cargo sensor:** cargo-interior placement, shipment-matched lifecycle (single voyage or reusable), communicates with the tracker via BLE or RF, humidity data delivered through the same platform dashboard as all other tracker telemetry.

The separation is in hardware and lifecycle. The data experience is unified.

Six independent lines of evidence, spanning sensor physics, enclosure engineering, reliability under harsh conditions, measurement placement, fleet economics, and energy management, converge on the same conclusion. The embedded humidity sensor is not the right tool for fleet-scale dry container deployments. The cargo-level add-on sensor is. The difference between these two choices, multiplied across a fleet of hundreds of thousands of devices over a decade of operation, is material.

HUMIDITY MONITORING IN DRY CONTAINER FLEETS

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