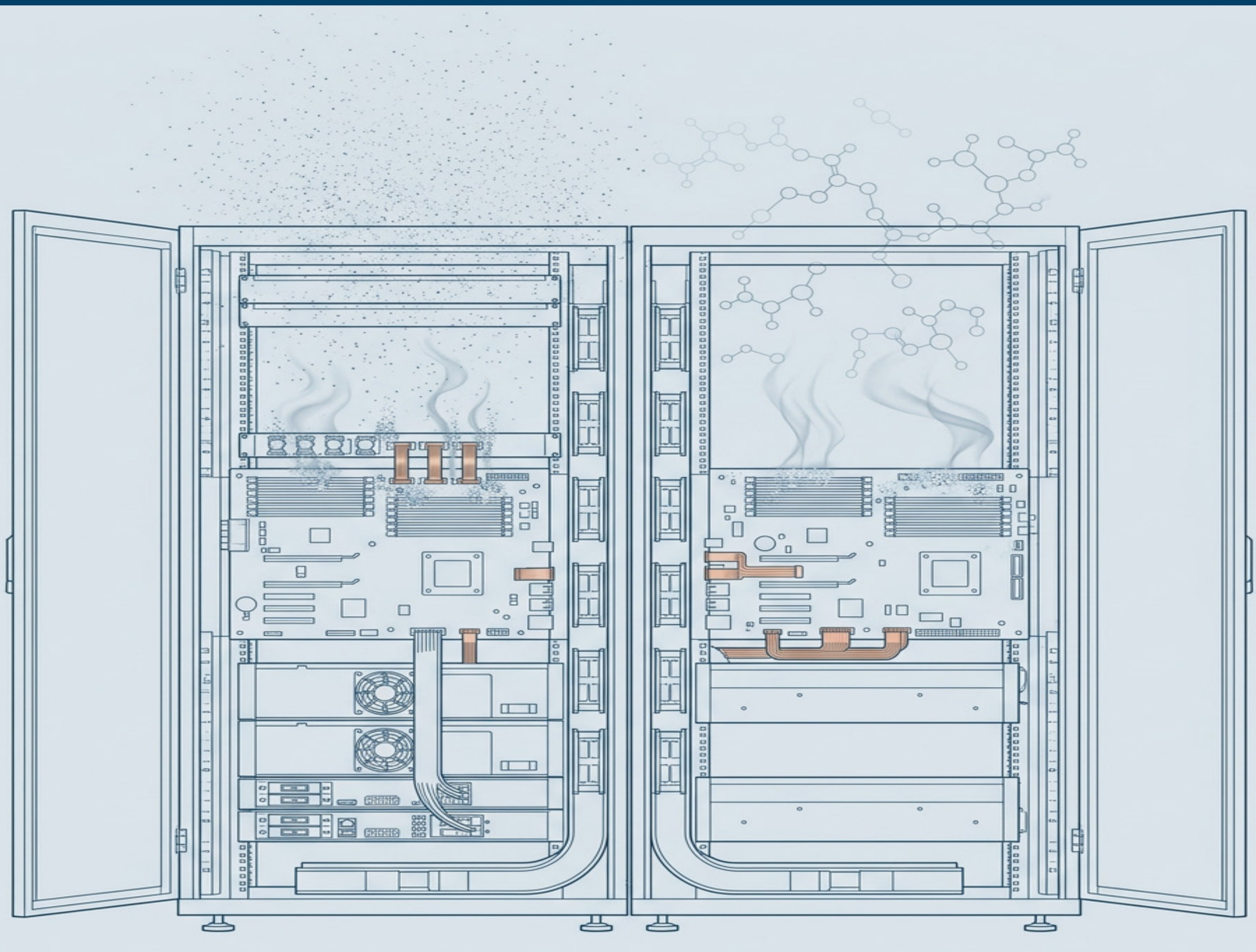
THE INVISIBLE ENEMY OF THE DATA CENTER

Humidity, Dust, and Corrosive Gases, the Silent Threats Infrastructure Professionals Cannot Ignore



Introduction

In the world of data centers, power and cooling are the usual protagonists in conversations about reliability. They are visible, measurable systems and, for the most part, well understood by operations teams.

However, there is a category of threats that operates silently, cumulatively, and often without generating alarms until the damage is already done: environmental conditioning. Relative humidity, dust particles, and corrosive gases are responsible for a significant percentage of hardware failures in facilities worldwide.

This e-book is aimed at professionals with experience in critical infrastructure. It is not an introduction to the subject: it is an in-depth analysis of the mechanisms of environmental degradation, their operational consequences, and the best practices for controlling them. If you manage or design data centers, this reading can save you the next unexplained incident.

What You Will Find in This E-Book

The three environmental threat vectors · Why high RH is more dangerous than high temperatures ·The Whiskers phenomenon and how to mitigate it · Corrosive gases: levels, sources and solutions · Action protocol for contaminated environments · Reference table of regulatory limits

Environmental Conditioning as a Critical System

The computer room of a data center has as its primary function to house IT equipment in an environment that guarantees its continuous operation and long-term integrity. To this end, TIA-942 and ISO-14644 standards establish that data centers must be treated as ISO Class 8 clean rooms.

Environmental conditioning is not an aesthetic complement or a bureaucratic requirement: it is an operational condition without which electronic equipment degrades at an accelerated rate. Three are the agents that must be controlled:

Relative Humidity → Accelerated corrosion, disk failures, short circuits from condensation, and activation of hygroscopic dust.

Dust & Particles → Thermal obstruction, electrical conduction (wet dust), deposit of corrosive agents, and generation of metallic Whiskers.

Corrosive Gases → Corrosion of copper and silver in circuits and connectors, progressive degradation with no visible symptoms until failure.

The three agents can act independently, but their combined effect is synergistic and exponentially more harmful. An environment with high RH, fine dust, and traces of H_2S is a combination that can systematically destroy hardware within months.

Relative Humidity, The Most Underestimated Risk

Most IT equipment tolerates RH ranges of up to 80% according to manufacturer specifications. This leads many operators to relax humidity control, assuming they are within safe margins. This is a conceptual error.

The manufacturer's limit considers the electrical behavior of isolated equipment. What it does not consider is the interaction between humidity and the contaminants present in the room environment. That is the critical factor that changes the entire analysis.

The Optimal Range and Its Critical Thresholds

Industry best practices, supported by ASHRAE TC 9.9, establish an ideal operating range of 45% to 50% RH. The thresholds defining risk zones are:

RH Level	Zone	Associated Risk
< 30%	ESD Risk Zone	Electrostatic discharge on sensitive hardware.
30% – 44%	Caution Zone	Higher probability of static charge accumulation.
45% – 50%	Ideal Range	Optimal control: minimum ESD and corrosion risk.
51% – 59%	Caution Zone	Beginning of corrosive risk if contaminants are present
>= 60%	High Risk Zone	Accelerated corrosion and activation of hygroscopic dust

The Scientific Evidence: High RH vs. High Temperature

A study published in Usenix FAST '16, conducted jointly by Microsoft Research and Rutgers University, analyzed thousands of disk failures in production environments. The conclusion was unequivocal: the correlation between high RH and hardware failures is significantly greater than the correlation with elevated temperatures.

Fundamental Operating Principle

High relative humidity is MUCH more dangerous for a data center than low relative humidity. The focus of environmental control must be on the upper limit, not the lower one

The damage mechanism is not humidity itself, but its interaction with the dust present in the room. When RH exceeds 60%, fine dust particles with low deliquescent relative humidity absorb water, become wet, and turn into electrical conductors. Wet dust acts as a conductive bridge between circuit board traces, generating short circuits and accelerating ion migration.

Dust and Particles, The Anticipated Threat

Particle control in a data center operates on two independent dimensions that must be managed separately: particle quantity and their corrosivity. An environment may have a low concentration of highly corrosive particles, or a high concentration of benign dust. Both scenarios require intervention, but of a different nature.

Classification and Origin of Particles

Type	Size	Origin	Air Residence Time
Coarse dust	2,5 – 15 µm	Wind abrasion, mineral and biological origin	Days
Fine dust (PM2.5)	0,1 – 2,5 µm	Fossil fuel combustion, volcanic activity	Years

Fine dust (PM2.5) is the most dangerous for two reasons: its air residence time is practically indefinite in environments without adequate filtration, and its size allows it to penetrate the densest circuits and the read/write mechanisms of hard drives.

Deliquescent Relative Humidity

Deliquescent relative humidity is the RH value at which a dust particle absorbs water from the environment. This value varies depending on the chemical composition of the dust. Particles with low deliquescent humidity are the most dangerous: they are activated sooner and remain wet for longer.

When dust becomes wet, two simultaneous processes occur:

- Dust becomes an electrical conductor, creating leakage paths between circuit board traces.
- Ion migration accelerates, depositing metallic ions at points of highest electrical stress.

Required cleanliness level

According to ISO-14644, data centers must maintain ISO Class 8 cleanliness levels. This implies continuous monitoring of particles per cubic meter and MERV 8 filtration systems for ambient air and MERV 11 to MERV 13 for outdoor air intake.

Measurement and Control

Dust corrosivity is measured in angstroms per month (Å/month) on copper and silver coupons exposed in the room. The regulatory limits are:

- Copper: maximum 300 Å/month.
- Silver: maximum 200 Å/month.

Particle concentration is measured in particles/m³ using real-time particle counters. Operational control is carried out through:

- MERV 8 filtration on interior air return.
- MERV 11–13 filtration on outdoor air intake.
- Maintaining RH levels below 60%.
- A documented and certified technical cleaning program.

Whiskers metálicos, la amenaza que nadie ve venir

De todos los fenómenos de degradación ambiental en los data centers, los Whiskers metálicos son probablemente los menos conocidos y los más difíciles de gestionar una vez que se han establecido en una instalación. Su mecanismo es contraintuitivo y sus consecuencias pueden ser catastróficas.

What They Are and How They Form

Whiskers are microscopic crystalline structures, similar to filaments or hairs, that grow spontaneously on galvanized metal surfaces. The metals that generate them most frequently in data center environments are zinc (Zn), tin (Sn), and cadmium (Cd). All of them are present in galvanized raised floors, conduits, cable trays, and standard cabinets.

The growth process has three phases:

Phase	Duration	Description
Incubation	Days to years	No visible growth. The material is accumulating internal stresses
Active Growth	Months to years	Filaments grow from the surface. Typical length < 1 mm, up to 10 mm
Stabilization	Indefinite	Growth may stop, but material already present does not disappear

Whiskers have a diameter of a few micrometers, making them invisible to the naked eye. However, they are long enough to create conductive bridges between circuit board traces in today's electronic equipment, where trace separation is also measured in micrometers.

Operational Consequences

Failures caused by Whiskers have a characteristic that makes them especially insidious from an operational point of view: they are intermittent. The filament can create a transient short circuit, trigger a system restart or a voltage variation, and then disappear when it melts due to the current. The event is logged as a failure with no apparent cause.

Alert Pattern

If your data center experiences unexplained restarts, voltage variations unrelated to electrical events, or hardware failures with no identifiable cause, metallic Whiskers must be included in the diagnostic protocol.

Action Protocol When Whiskers Are Detected

The only complete and accepted elimination of Whiskers is the removal and replacement of the source material. There is no treatment that eliminates already-formed filaments without replacing the substrate. The action protocol when Whiskers are detected in the room

- Label and identify every contamination source (floor panels, conduits, cabinets, cable trays).
- Train all personnel on visual identification and safety procedures.
- Establish a prioritized plan for replacing the source material.
- Implement a hardware failure monitoring program correlated with room location.
- Install test sites with periodic sampling (metal coupons) to track the evolution.
- Reinforce the technical cleaning program to minimize filament dispersion.

Corrosive Gases, The Silent Poison

Corrosive gases are the environmental threat most difficult to detect without specific instrumentation. They generate no visible alarms, produce no immediate symptoms, and their action on electronic circuits is progressive and cumulative. When the damage becomes visible, it has generally already affected multiple pieces of equipment.

The Main Corrosive Agents

Sulfur-containing gases are the most common causes of corrosion in electronic equipment. Sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) react with the copper and silver surfaces present in circuits, forming non-conductive compounds that degrade electrical connections. Their effect is significantly amplified in the presence of other gases:

Corrosive Gas Synergy

The combination of SO_2 or H_2S with nitrogen dioxide (NO_2) or ozone (O_3) produces a mixture significantly more corrosive than any of the gases individually. In urban environments with heavy traffic or nearby industrial facilities, monitoring of this combination is mandatory.

Maximum Concentration Limits

Gas	Formula	Maximum Concentration	Typical Source
Hydrogen sulfide	H_2S	< 3 ppb	Wastewater, chemical industry
Sulfur dioxide / trioxide	SO_2/SO_3	< 10 ppb	Combustion, industry, volcanoes
Chlorine	Cl_2	< 1 ppb	Water treatment, cleaning products
Nitrogen oxides	NO_x	< 50 ppb	Traffic, combustion
Hydrogen fluoride	HF	< 1 ppb	Aluminium industry, electronics
Ammonia	NH_3	< 500 ppb	Refrigeration, cleaning
Ozone	O_3	< 2 ppb	Electrical equipment, photocopiers, outdoor air

These values are based on ASHRAE TC 9.9 guidelines for gaseous and particulate contamination in data centers (2011 revision). The limits are very low, in the parts-per-billion range, making precision gas monitors essential for their control.

Control and Filtration

Control of gaseous contamination is achieved through gas-phase filtration, which uses adsorbent materials such as impregnated activated carbon or zeolites that capture corrosive gases before they reach the room. The critical filtration points are:

- Outdoor air intake: first gaseous filtration barrier.
- Air return in CRAC/CRAH units: second barrier for internally generated gases.
- Adjacent rooms with potential sources (lead-acid batteries, which emit H_2S during charging).

Special Attention: Battery Rooms

Lead-acid battery rooms are internal sources of H_2S during charging cycles. Physical separation and dedicated ventilation of battery rooms are not optional: they are basic design requirements that protect the server room from internal gaseous contamination.

The Environmental Control Program

Effective environmental control is not a one-off event: it is a continuous program combining real-time monitoring, preventive maintenance, and response protocols for deviations. The recommended action framework is described below.

Real-Time Monitoring

The first requirement is to have real-time visibility of the three environmental agents. Monitoring systems must cover:

- RH and temperature sensors distributed at multiple points in the room (air inlet and outlet of each aisle).
- Real-time particle counters with alarms configured for ISO Class 8.
- Gas monitors for H_2S, SO_2, and NO_x as a minimum, with historical logging.
- Corrosivity coupons (copper and silver) with monthly or quarterly readings.

Technical Cleaning

Technical cleaning of a data center is a specialized activity requiring trained personnel, specific equipment, and documented procedures. The key elements are:

- Frequency: general room cleaning at least semi-annually; raised floor inspection annually.
- Equipment: HEPA-filtered vacuums, anti-static cloths, dry vacuum cleaners.
- Scope: raised floor and plenum, interior of racks (with equipment in

production), cable trays, CRAC/CRAH units, air filters.
- Documentation: record of each cleaning with particle measurements before and after.
- Complete floor system inspection every five years per manufacturer specifications.

Control Frequency Reference Table

Control Action	Frequency	Tool / Method
RH and temperature reading and logging	Real-time	BMS / DCIM
Review of out-of-range RH alar-ms	Daily	BMS / DCIM
Particle count in room	Weekly	Particle counter
CRAC/CRAH filter inspection	Monthly	Visual inspection
Corrosivity coupon reading	Quarterly	Accredited laboratory
Corrosive gas monitoring	Continuous or monthly	Gas monitor / samples
Technical room cleaning	Semi-annual	Specialist contractor
Sub-floor plenum inspection	Annual	Inspection + cleaning
Complete raised floor inspection	Every 5 years	Specialist contractor

Conclusion: What Is Not Measured Cannot Be Managed

Environmental conditioning is the data center discipline that benefits most from Peter Drucker's principle: what cannot be measured cannot be managed. Relative humidity, dust, and corrosive gases do not give warning before causing damage. They operate silently, cumulatively, and invisibly until hardware fails.

Professionals who understand these mechanisms have a real operational advantage: they can anticipate failures, explain incidents that would otherwise remain without an identified cause, and design maintenance programs that protect the infrastructure investment in the long term.

The Three Principles of Effective Environmental Control

1. Maintain RH between 45% and 50%. The critical limit is the upper one, not the lower one. 2. Treat dust as a chemical risk, not just a mechanical one. Its interaction with RH converts it into an electrical conductor.
3. Monitor corrosive gases continuously. The damage is invisible but measurable before it becomes irreversible.

The good news is that all these risks are manageable with the right tools and procedures. The first step is to recognize them for what they are: critical threats that deserve the same attention as power and cooling.