Particulate and Gaseous Contamination Guidelines for Data Centers[1]

EXECUTIVE SUMMARY

ASHRAE TC 9.9 recently published the supplement "2008 ASHRAE Environmental Guidelines for Datacom Equipment—Expanding the Recommended Environmental Envelope," which extended the temperature-humidity envelope to provide greater flexibility in data center facility operations, particularly with the goal of reducing energy consumption. The recommended temperature limits are from 18°C to 27°C (64.4°F to 80.6°F). The humidity is limited to less than 60%, with lower and upper dew-point temperatures of 5.5°C and 15°C (41.9°F and 59°F), respectively.

The recent increase in the rate of hardware failures in data centers high in sulfur-bearing gases, highlighted by the number of recent publications on the subject, led to the need for this white paper that recommends that in addition to temperature-humidity control, dust and gaseous contamination should also be monitored and controlled. These additional environmental measures are especially important for data centers located near industries and/or other sources that pollute the environment.

Effects of airborne contaminations on data center equipment can be broken into three main categories: chemical effects, mechanical effects, and electrical effects. Two common chemical failure modes are copper creep corrosion on circuit boards and the corrosion of silver metallization in miniature surface-mounted components.

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[1] This white paper on data center airborne contamination, prepared by ASHRAE TC 9.9, Mission Critical Facilities, Technology Spaces, and Electronic Equipment, supplements *Particulate and Gaseous Contamination in Datacom Environments* (ASHRAE 2009a). The members of ASHRAE TC 9.9 represent the following information technology (IT) equipment manufacturers: AMD, Cisco, Cray, Dell, EMC, Hitachi, HP, IBM, Intel, Seagate, SGI, and Sun.

Mechanical effects include heat sink fouling, optical signal interference, increased friction, etc. Electrical effects include changes in circuit impedance, arcing, etc. It should be noted that the reduction of circuit board feature sizes and the miniaturization of components, necessary to improve hardware performance, also make the hardware more prone to attack by contamination in the data center environment, and manufacturers must continually struggle to maintain the reliability of their ever-shrinking hardware.

Most data centers are well designed and are in areas with relatively clean environments, and most contamination is benign. Therefore, most data centers should not experience particulate or gaseous contamination-related hardware failures. This white paper is thus primarily targeted toward a minority of data centers that may have harmful environments arising from the ingress of outdoor particulate and/or gaseous contamination. In some rare instances, contamination has been known to be generated within the data center.

It is incumbent on data center managers to do their part in maintaining hardware reliability by monitoring and controlling the dust and gaseous contamination in their data centers. Data centers must be kept clean to Class 8 of *ISO 14644-1, Cleanrooms and Associated Controlled Environments—Part 1: Classification of Air Cleanliness* (ISO 1999). This level of cleanliness can generally be achieved by an appropriate filtration scheme as outlined in the following.

1. The room air may be continuously filtered with MERV 8 filters as recommended by *ANSI/ASHRAE Standard 127-2007, Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners* (ASHRAE 2007a).
2. Air entering a data center may be filtered with MERV 11 or MERV 13 filters as recommended by *Particulate and Gaseous Contamination in Datacom Environments* (ASHRAE 2009a).

Sources of dust inside data centers should be reduced. Every effort should be made to filter out dust that has deliquescent relative humidity less than the maximum allowable relative humidity in the data center. The gaseous contamination should be within the modified severity level G1 of *ANSI/ISA-71.04-1985, Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants* (ISA 1985), which meets

1. a copper reactivity rate of less than 300 Å/month and
2. a silver reactivity rate of less than 300 Å/month.

For data centers with higher gaseous contamination levels, gas-phase filtration of the inlet air and the air in the data center is highly recommended.

The adherence to the requirements outlined herein is important to maintain high reliability of the IT equipment and avoid the cost of hardware replacement not covered under warranty.

INTRODUCTION

The objective of this white paper is to describe the need to control airborne contaminants, both particulate and gaseous, in data centers and to specify their recommended acceptable limits.

The ever-improving performance of computers is being accomplished by decreasing the sizes of the transistors and the distances electrical signals have to travel to accomplish the tasks assigned to them. The net effect is the miniaturizing of all electronic components and their ever-increasing packaging density, which have the following detrimental effects on hardware reliability:

- The increased heat load per unit volume necessitates the need for more airflow to maintain hardware within acceptable temperature limits. The increased airflow increases the exposure of the electronics to the detrimental effects of accumulated dust and the increased ingestion of gaseous contaminates.
- The higher packaging density does not always allow the hermetic sealing of components, further exposing electronics to the detrimental effects of moisture, dust, and gaseous contamination.
- The decreased spacing between printed circuit board features at different voltages increases the possibility of dust and gases causing ion migration, leading to electrical short-circuiting.
- As the features in the components approach the sizes of the corrosion products, the components become more prone to the ill effects of corrosion.

The recent increase in the rate of hardware failures in data centers high in sulfur-bearing gases, highlighted by the number of recent publications on the subject (Reid et al. 2007; Cullen and O'Brien 2004; Veale 2005; Sahu 2007; Schueller 2007; Hillman et al. 2007; Xu et al. 2007; Mazurkiewicz 2006), led to the need for this white paper that recommends that in addition to temperature-humidity control, dust and gaseous contamination should also be monitored and controlled. The additional environmental measures recommended in this white paper are necessary to reduce the two most common recent failure modes of copper creep corrosion on circuit boards and the corrosion of silver metallization in miniature surface-mounted components:

1. Recent papers have reported copper creep corrosion on circuit boards (Cullen and O'Brien 2004; Mazurkiewicz 2006; Mukadam et al. 2006; Schueller 2007; Xu et al. 2007). The two common circuit board types suffering from copper creep corrosion are those with an immersion silver (ImAg) layer and those with an organic solderability preservative (OSP) coating. The sulfide-bearing gases and moisture can corrode any exposed copper metallization on the circuit board. The resulting corrosion product, copper sulfide, can creep over the circuit board and short-circuit closely spaced features.

2. Some recent papers have reported corrosion of miniature surface-mounted components that contain silver (Hillman et al. 2007; Reid et al. 2007). Sulfur-bearing gases, even in the absence of moisture, attack silver forming silver sulfide corrosion products that, being larger in volume, create mechanical stresses that undermine the integrity of the package. The package with its integrity breached exposes the underlying silver to further corrosive attack until all the silver in the section is consumed, leading to an electrical open. The silver sulfide corrosion product on the field-failed hardware is often visible under a low-power microscope as needles or nodules, as shown in Figure 1.

The reduction of circuit board feature sizes and the miniaturization of components, which is necessary in order to improve hardware performance, make the hardware prone to attack by corrosive particles and gases. Manufacturers are in a constant struggle to maintain the reliability of their hardware with ever-shrinking feature
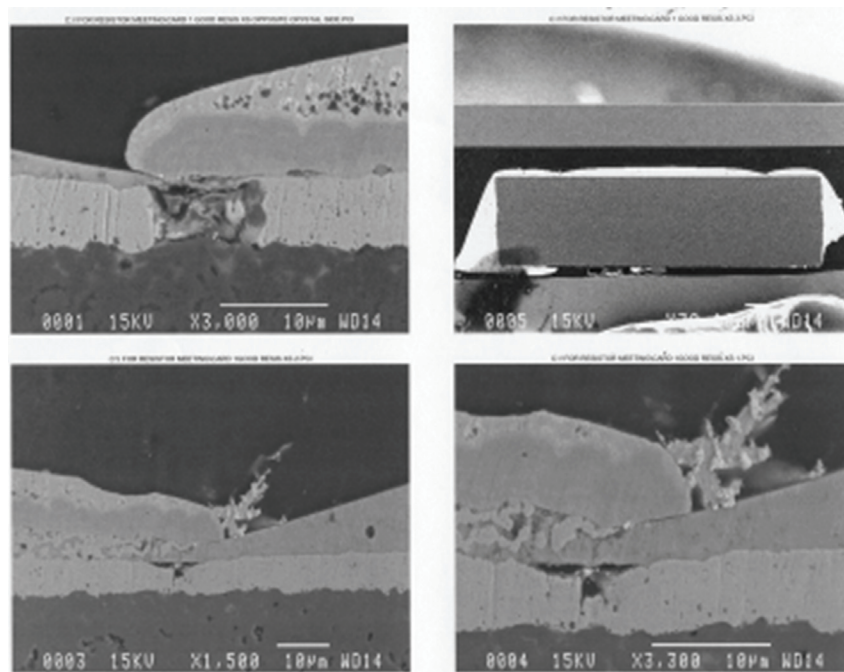
Figure 1. Cross section of a component that failed due to an environment high in sulfur-bearing gases attacking the silver metallization in the component, producing silver sulfide "flowers."

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sizes without taking the added costly measure of hardening all their IT equipment, most of which is not installed in corrosive environments where it can be exposed to higher risk of failure. Therefore, the need to control data center airborne contaminants and to specify their recommended acceptable limits is becoming critical to the continued reliable operation of IT equipment.

PARTICLE CONTAMINATION

### Airborne Dust and Zinc Whiskers

Failure modes due to dust include but are not limited to the following (ASHRAE 2009a).

- *Mechanical Effects.* Mechanical effects include obstruction of cooling airflow, interference with moving parts, abrasion, optical interference, interconnect interference, deformation of surfaces (e.g., magnetic media), and other similar effects.
- *Chemical Effects.* Dust settled on printed circuit boards can lead to component corrosion and/or to the electrical short-circuiting of closely spaced features.
- *Electrical Effects.* Electrical effects include impedance changes and electronic circuit conductor bridging.

Dust is ubiquitous. Even with our best filtration efforts, dust will be present in a data center and will settle on electronic hardware. Fortunately, most dust is benign. Only under rare circumstances will dust degrade electronic hardware.

Harmful dust in data centers is generally high in ionic content, such as chlorine-bearing salts. The source of this harmful dust is mainly outdoor dust in the size range of 2.5–15 μm for coarse dust and 0.1–2.5 μm for fine dust (Comizzoli et al. 1993). Coarse dust particles have mineral and biological origin, are formed mostly by wind-induced abrasion, and can remain airborne for a few days. Fine dust particles are generally the result of fossil fuel burning and volcanic activity and can remain airborne for years. Large bodies of salt water are also a major source of airborne dust contamination in data centers. Sea salt can be carried 10 km (6 m) inland or farther by high winds present in coastal areas and can damage electronic devices at this range (Bennett et al. 1969; Crossland and Wright 1973).

One mechanism by which dust degrades the reliability of printed circuit boards involves the absorption of moisture by the settled dust from the environment. The ionic contamination in the wet dust degrades the surface insulation resistance of the printed circuit board and in the worst-case scenario leads to the electrical short-circuiting of closely spaced features via ion migration. Figure 2 shows an example of copper corrosion caused by dust settled on a printed circuit board.
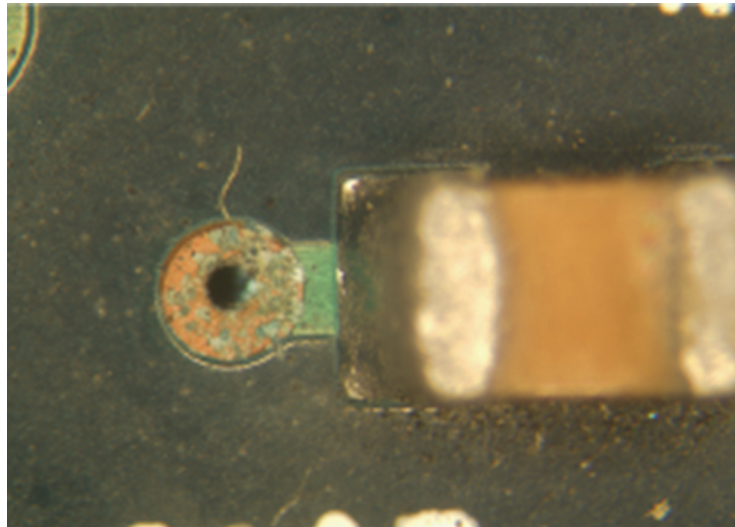
Figure 2.   Corrosion of a plated through-hole because of wetted ionic dust high in magnesium chloride.

Deliquescent relative humidity, the relative humidity at which the dust absorbs enough water to become wet and promote corrosion and/or ion migration, determines the corrosivity of dust. When the deliquescent relative humidity of dust is greater than the relative humidity in the data center, the dust stays dry and does not contribute to corrosion or ion migration. However, on the rare occurrence when the dust has deliquescent relative humidity lower than the relative humidity in the data center, the dust will absorb moisture, get wet, and promote corrosion and/or ion migration, degrading hardware reliability. A 1993 study by Comizzoli et al. showed that leakage current due to dust, from various locations worldwide, settled on printed circuit boards, increased exponentially with relative humidity. This study leads us to the conclusion that keeping the relative humidity in a data center below about 60% will keep the leakage current from settled fine dust in the acceptable sub-μA range.

Under rare circumstances, harmful dust can also be generated within a data center. Humidifiers that depend on airborne water droplets evaporating to increase the humidity in the room may cause harmful indoor dust pollution if the water feeding the humidifier is high in salts that have lower deliquescent relative humidity than the relative humidity in the data center. Even low concentrations of these salts can be serious corrosion and ion migration threats. These humidifier-related corrosion

problems can be mitigated by treating the humidifier water using reverse osmosis (ASHRAE 2009a).

Fibrous dust from paper, cardboard, and textiles can foul heat sinks and disrupt equipment cooling. Data center operators should avoid working with large amounts of these materials within the data center. For instance, new equipment should be unboxed outside of the data center, and high-volume printers should be located elsewhere.

In summary, most dust in benign. Corrosion and/or ion migration problems may arise under the rare circumstance when the settled dust has deliquescent relative humidity lower than the relative humidity in the data center. As a general rule, the relative humidity in the data center must be kept below 60% to avoid any dust from corroding the hardware.

Another form of particulate contamination very harmful to hardware reliability is zinc whiskers, which are the most common electrically conductive particles found in data centers. The undersides of some steel raised-floor tiles are coated with zinc to prevent corrosion. The stringers and pedestals supporting the tiles may also be coated with zinc. Zinc may be electroplated or hot dip galvanized. Although zinc whiskers may grow on both types of coatings, electroplated zinc is far more susceptible to whisker growth (Brusse and Sampson 2004; Lahtinen and Gustafsson 2005).

Zinc whiskers, which may sometimes grow to be 1 to 2 mm (0.04 to 0.08 in.) long, threaten IT equipment when they become dislodged and airborne, which could happen when the tiles are disturbed during their removal or when pulling or removing underfloor cables. If zinc whiskers are ingested by IT equipment, circuits with voltages higher than about 25 V may suffer electrical short-circuiting, arcing, signal perturbations, or catastrophic failures (Miller 2007).

A simple method to detect zinc whiskers is by using a flashlight. Remove a raised-floor tile and place the tile on its edge in a dimly lit area. Shine the flashlight across the underside of the tile at a 45° angle. Small speckles that twinkle in the bright light may be evidence of zinc whisker presence. To confirm the presence of zinc whiskers, specimens should be collected using carbon adhesive tabs and viewed under a scanning electron microscope. If zinc whiskers are present, remediation involves replacing the contaminated raised-floor tiles and hiring professionals to clean the data center.

ISO 14644-1 (ISO 1999) has become the dominant, worldwide standard for classifying the cleanliness of air in terms of concentration of airborne particles. Table 1 provides maximum concentration levels for each ISO class (ASHRAE 2009a).

Data centers must be kept clean to ISO Class 8 with the strictness of the 95% upper confidence limit (Ortiz 2006). For data centers without economizers, the ISO Class 8 cleanliness may be achieved simply by specifying the following means of filtration:

Table 1 ISO 14644-1 (ISO 1999) Air Cleanliness Classification vs. Maximum Particle Concentrations Allowed (particles/m^3)

ISO CLASS	Maximum Number of Particles in Air (Particles in Each Cubic Meter Equal to or Greater Than the Specified Size) Particle Size					
	> 0.1 μm	> 0.2 μm	> 0.3 μm	> 0.5 μm	> 1 μm	> 5 μm
Class 1	10	2				
Class 2	100	24	10	4		
Class 3	1000	237	102	35	8	
Class 4	10,000	2,370	1,020	352	83	
Class 5	100,000	23,700	10,200	3,520	832	29
Class 6	1,000,000	237,000	102,000	35,200	8,320	293
Class 7				352,000	83,200	2,930
Class 8				3,520,000	832,000	29,300
Class 9					8,320,000	293,000

Note: Uncertainties related to the measurements process require that data with no more than three significant figures be used in determining the classification level.

1. The room air may be continuously filtered with MERV 8 filters as recommended by ASHRAE Standard 127 (ASHRAE 2007a).
2. Air entering a data center may be filtered with MERV 11 or MERV 13 filters as recommended by ASHRAE (2009a).

For data centers with air-side economizers, the choice of filters to achieve ISO Class 8 cleanliness depends on the specific conditions present at that data center.

GASEOUS CONTAMINATION

Sulfur-bearing gases, such as sulfur dioxide (SO_2) and hydrogen sulfide (H_2S), are the most common gases in data centers causing hardware corrosion (Rice et al. 1981). An example of corrosion due to gaseous contamination on a circuit board that is compliant with the Restriction of Hazardous Substances Directive (RoHS) (EU 2003) is shown in Figure 3.

Gaseous composition environmental limits have been published in ISA 71.04 (ISA 1985). These limits serve as guides for specifying data center environmental cleanliness, but they are not useful for surveying the corrosivity or predicting the failure rates of hardware in the data center environment for several reasons. First, gaseous composition determination is not a trivial task. Second, it is generally not a straightforward exercise to predict the rate of corrosion from gaseous composition.
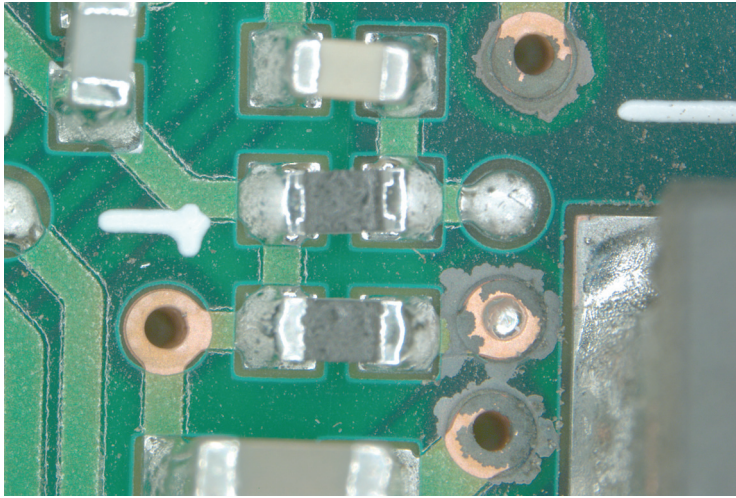
Figure 3. Sulfur-bearing gas corrosive attack of copper on a RoHS-compliant circuit board protected by organic surface protectant finish.

An added complication is the synergy between gases. For example, it has been shown that SO_2 or H_2S alone are not very corrosive to silver or to copper but the combination of these gases with other gases such as nitrogen dioxide (NO_2) and/or ozone (O_3) are very corrosive to copper and to silver (Volpe 1989). The corrosion rate of copper is a strong function of relative humidity, while the corrosion rate of silver has no dependence on humidity (Rice et al. 1981).

A very convenient and quantitative way to determine the gaseous corrosivity of a data center environment is the so called "reactive monitoring" method described in ISA 71.04 (ISA 1985). This method exposes a copper coupon to the environment for one month and analyzes the corrosion product thickness and chemistry using coulomeric reduction to classify the environment into one of four severity levels (described in Table 2). But the use of copper coupon alone has two major limitations: one is that copper is not sensitive to chlorine, a particularly corrosive contaminant to many metals, and the other is that copper corrosion is overly sensitive to relative humidity. The inclusion of a silver coupon helps differentiate the corrosivity contributions of gaseous contamination and relative humidity. If it turns out that the relative humidity is playing a dominant role in the corrosion process, then the corrosivity can be decreased simply by lowering the relative humidity in the data center. It is now common practice to include silver coupons along with copper coupons to gain greater insight into the chemistry of the corrosive gases in the environment.

Table 2   Gaseous Corrosivity Levels per ISA 71.04 (ISA 1985)

| Severity Level	Copper Reactivity Level	Description
G1 Mild	300 Å/month	An environment sufficiently well controlled such that corrosion is not a factor in determining equipment reliability
G2 Moderate	300–1000 Å/month	An environment in which the effects of corrosion are measurable and may be a factor in determining equipment reliability
G3 Harsh	1000–2000 Å/month	An environment in which there is high probability that corrosive attack will occur
GX Severe	>2000 Å/month	An environment in which only specially designed and packaged equipment would be expected to survive

At present ISA 71.04 (ISA 1985) applies only to copper corrosion, but as already explained it is desired that copper and silver coupons be used together to classify data center corrosivity. In other words, for a data center to be classified as severity level G1, the copper and silver corrosion rate limits should not exceed 300 Å/month. An unpublished copper and silver corrosion rate survey of data centers with hardware failures from copper creep corrosion and/or silver corrosion is plotted in Figure 4 (Singh et al. 2009). Only a small fraction of these problem data centers had copper corrosion rates greater than 100 Å/month and all the problem data centers had silver corrosion rates greater than 100 Å/month. Notice that in these 31 sites, the silver corrosion rate was typically an order of magnitude or more greater than the copper corrosion rate. This survey, which is limited to data centers with reported hardware failures, clearly indicates that the copper corrosion rate is not a good indicator of the potential of hardware failures. To improve the prediction of corrosion-related failures based on copper and silver corrosion rates, a random survey of data centers, with and without corrosion-related failures, is needed.

ISA 71.04 is a well-established, widely accepted standard that states that severity level G1 has a copper corrosion rate of less than 300 Å/month corresponding to a "mild environment sufficiently well-controlled such that corrosion is not a factor in determining equipment reliability" (ISA 1985, p. 13). While Figure 4 shows and while many agree that this level of copper corrosion may be too high for reliable operation of electronic hardware, more work needs to be done to justify lowering the acceptable copper and silver corrosion rates. In the meantime, a maximum corrosion rate of copper of 300 Å/month and a maximum corrosion rate of silver of 300 Å/month should be used as the acceptable gaseous corrosivity limits for data centers.

The gaseous contamination levels in a data center are a function of location and time of year. The location of interest for gaseous corrosivity monitoring is approximately 5 cm (2 in.) in front of the rack on the air inlet side at one-quarter and three-quarter frame height off the floor. Ideally, monitoring should be done all year round,
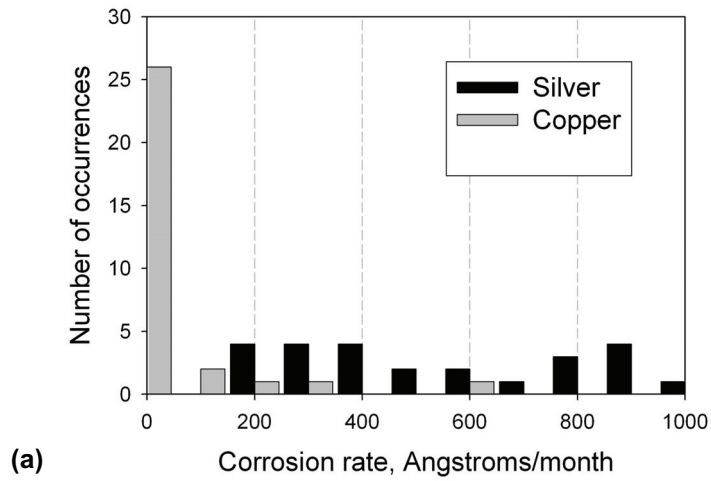
(a)
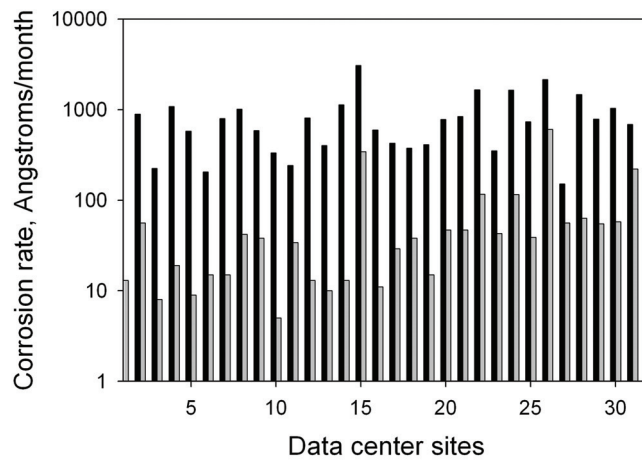
(b)

Figure 4. IT equipment failure in data centers with reported copper creep corrosion and/or silver corrosion: (a) 26 occurrences of copper corrosion and none for silver corrosion between 0 and 100 Å/month, 2 occurrences for copper and 4 for silver between 100 and 200 Å/month, 2 occurrences for copper and 4 for silver between 200 and 300 Å/month, and so on (not shown are 6 occurrences of silver corrosion rates greater than 1000 Å/month) and (b) the silver corrosion rate was typically an order of magnitude or more greater than the copper corrosion rate.

but as a data center's history builds up monitoring may be limited to the months with known high levels of gaseous contamination.

The reactive monitoring method requires the copper and the silver coupons to be exposed for one month to get a good measure of the corrosivity of the environment. For data centers with air-side economizers, it is necessary to have real-time monitoring to react quickly to events outside the data centers that may release corrosive gases that may flow into the data centers. Two types of real-time reactive monitors are commercially available. One is based on measuring the rate of increase of corrosion product mass using a quartz crystal microbalance. The other determines gaseous corrosivity by measuring the rate of increase of resistance of metal thin films. Changes in gaseous corrosivity can be detected on a real-time basis that may allow preventive measures to be taken, such as shutting off outside corrosive air from entering the data center.

GAS-PHASE FILTRATION OF AIR IN DATA CENTERS

For data centers that do not fall within the modified ISA 71.04 (ISA 1985) severity level G1 for copper and silver corrosion, gas-phase filtration is recommended. The air entering the data center should be gas-phase filtered to prevent gaseous contaminants from entering the data center. The blowers at the air inlet could be used to pressurize the data center to avoid contaminated outdoor air from leaking into the data center. The air in the data center should be recirculated through gas-phase filters to remove contaminants that are generated within the data center. With these measures, it is recommended that the level of gaseous contaminants be brought within the modified ISA 71.04 severity level G1 for copper and silver corrosion.

2008 ASHRAE ENVIRONMENTAL GUIDELINES FOR DATACOM EQUIPMENT—EXPANDING THE RECOMMENDED ENVIRONMENTAL ENVELOPE

To provide greater flexibility in facility operations, particularly with the goal of reduced energy consumption in data centers, ASHRAE TC 9.9 committee members have revisited the recommended equipment environmental specifications, specifically the recommended envelope for Classes 1 and 2 (the details of these environmental envelope guidelines are documented in the second edition of *Thermal Guidelines for Data Processing Environments* [ASHRAE 2009b]; a free supplement can be downloaded from the ASHRAE Datacom Series Web page at www.ashrae.org/datacenterefficiency). The recommended envelope is the same for both of these environmental classes. The result of this effort has been to expand the recommended operating environmental envelope. The purpose of the recommended envelope is to give guidance to data center operators on maintaining high reliability and also operating their data centers in the most energy efficient manner. The allowable envelope is where IT manufacturers test their equipment in order to verify that

the equipment will function within those environmental boundaries. Typically manufacturers will perform a number of tests prior to announcement of a product to verify that their product meets all the functionality requirements within this environmental envelope. This is not a statement of reliability but one of functionality of the IT equipment. However, the recommended envelope *is* a statement on reliability. For extended periods of equipment operation, the IT manufacturers recommend that data center operators maintain their environment within the recommended envelope. Exceeding the recommended limits for short periods of time should not be a problem, but running near the allowable limits for months could result in increased reliability issues. In reviewing the available data from a number of IT manufacturers, the 2008 expanded recommended operating envelope is the agreed-upon envelope that is acceptable to all IT manufacturers, and operation within this envelope will not compromise overall reliability of the IT equipment. The 2004 and 2008 recommended envelope data are shown in Table 3.

The ranges apply to the inlets of all equipment in the data center (except where IT manufacturers specify other ranges). Attention is needed to make sure the appropriate inlet conditions are achieved for the top portions of IT equipment racks. The inlet air temperature in many data centers tends to be warmer at the top portions of racks, particularly if the warm rack exhaust air does not have a direct return path to the air-handling units. This warmer air also affects the relative humidity, resulting in lower values at the top portions of the racks.

SUMMARY OF RECOMMENDED ACCEPTABLE ENVIRONMENTAL LIMITS

The recommended temperature-humidity, dust, and gaseous limits are summarized in Table 4.

Table 3   ASHRAE Recommended Environmental Envelope for Temperature and Moisture (ASHRAE 2009b)

	2004 Recommendation	2008 Recommendation
Low-End Temperature	20°C (68°F)	18°C (64.4°F)
High-End Temperature	25°C (77°F)	27°C (80.6°F)
Low-End Moisture	40% RH	5.5°C (41.9°F) dew point
High-End Moisture	55% RH	60% RH and 15°C (59°F) dew point

Table 4   ASHRAE Recommended Environments

Recommended Operating Environment[1, 3]	
Temperature	18°C to 27°C (64.4°F to 80.6°F)[3]
Low-end moisture	5.5°C (41.9°F) dew point
High-end moisture	60% RH or 15°C (59°F) dew point
Gaseous contamination	Severity level G1 per ISA 71.04 (ISA 1985), which states that the reactivity rate of copper coupons shall be less than 300 Å/month ($\equiv$ 0.0037 $\mu g/cm^2 \cdot h$ weight gain).[5] In addition, the reactivity rate of silver coupons shall be less than 300 Å/month ($\equiv$ 0.0039 $\mu g/cm^2 \cdot h$ weight gain).[6] The reactive monitoring of gaseous corrosivity should be conducted approximately 5 cm (2 in.) in front of the rack on the air inlet side at one-quarter and three-quarter frame height off the floor or where the air velocity is much higher.

Particulate contamination	1. Data centers must meet the cleanliness level of ISO 14644-1 (ISO 1999) Class 8.
	   a. For data centers without air-side economizers, the ISO 14644-1 Class 8 cleanliness may be met simply by the choice of the following filtration:
	      i. The room air may be continuously filtered with MERV 8 filters.
	      ii. Air entering a data center may be filtered with MERV 11 or preferably MERV 13 filters.
	   b. For data centers with air-side economizers, the choice of filters to achieve ISO 14644-1 Class 8 cleanliness depends on the specific conditions present at that data center.
	2. The deliquescent relative humidity of the particulate contamination should be more than 60% RH.[2]
	3. Data centers must be free of zinc whiskers.[4]

Recommended Non-Operating Environment[3]	
Temperature	5°C to 45°C (41°F to 113°F)
Relative humidity	8% to 80%
High-end moisture	27°C (80.6°F) dew point
Gaseous contamination	Severity level G1 as per ISA 71.04, which states that the reactivity rate of copper coupons shall be less than 300 Å/month ($\equiv$ 0.0037 $\mu g/cm^2 \cdot h$ weight gain).[5] In addition, the reactivity rate of silver coupons shall be less than 300 Å/month ($\equiv$ 0.0039 $\mu g/cm^2 \cdot h$ weight gain).[6] The reactive monitoring of gaseous corrosivity should be conducted approximately 5 cm (2 in.) in front of the rack on the air inlet side at one-quarter and three-quarter frame height off the floor. Note that since gaseous corrosivity is a function of air velocity, measuring corrosivity in front of a non-operating machine with no airflow will give a lower corrosivity reading than if the machine was operating.

Table 4 ASHRAE Recommended Environments

Particulate contamination	1. Data centers must meet the cleanliness level of ISO 14644-1 Class 8.
	 a. For data centers without air-side economizers, the ISO 14644-1 Class 8 cleanliness may be met simply by the choice of the following filtration:
	  i. The room air may be continuously filtered with MERV 8 filters.
	  ii. Air entering a data center may be filtered with MERV 11 or preferably MERV 13 filters.
	 b. For data centers with air-side economizers, the choice of filters to achieve ISO Class 8 cleanliness depends on the specific conditions present at that data center.
	2. The deliquescent relative humidity of the particulate contamination should be more than 60% RH.[2]
	3. Data centers must be free of zinc whiskers.[4]

Notes:
1. Gaseous contamination is measured approximately 5 cm (2 in.) in front of the rack on the air inlet side at one-quarter and three-quarter frame height off the floor. Derate the maximum recommended ambient temperature by 1°C (1.8°F) for every 300 m (984 ft) over 1800 m (5906 ft). For extended periods of time, IT manufacturers recommend that data center operators maintain the recommended envelope for maximum reliability. The allowable envelope is where IT manufacturers test their equipment in order to verify that the equipment will function. This is not a statement of reliability but one of functionality of the IT equipment.
2. The deliquescent relative humidity of particulate contamination is the relative humidity at which the dust absorbs enough water to become wet and promote corrosion and/or ion migration.
3. The machine should be in an environment that satisfies the recommended operating environment specification for at least one day before it is powered on.
4. Surface debris is randomly collected from 10 areas of the data center on a 1.5 cm (0.59 in.) diameter disk of sticky electrically conductive tape on a metal stub. If examination of the sticky tape in a scanning electron microscope reveals no zinc whiskers, the data center is considered free of zinc whiskers.
5. The derivation of the equivalence between the rate of copper corrosion product thickness growth in Å/month and the rate of weight gain assumes that copper sulfide (Cu_2S) and copper oxide (Cu_2O) grow in equal proportions.
6. The derivation of the equivalence between the rate of silver corrosion product thickness growth in Å/month and the rate of weight gain assumes that silver sulfide (Ag_2S) is the only corrosion product.

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APPENDIX A—
RELATIONSHIPS OF $\mu g/cm^2 \cdot h$ AND Å/30 DAYS CORROSION RATES FOR SILVER AND COPPER

Papers on atmospheric corrosion of metals often report corrosion rates in terms of rate of weight gain in $\mu g/cm^2 \cdot h$. ISA 71.04 (ISA 1985) reports corrosion rates in terms of the rate of increase of corrosion product thickness in Å/month.

The relationships between the two rates for silver and copper corrosion are derived in the following.

Silver Corrosion Rate Relationship

In this calculation, it is assumed that silver sulfide (Ag_2S) is the only corrosion product and that the density of Ag_2S is 7.23 g/cm^3.

$$\text{Silver specimen weight gain of } 1 \ \mu g \equiv \frac{2 \times 107.9 + 32}{32} \ \mu g \text{ of } Ag_2S$$

$$\equiv 7.74 \times 10^{-6} \text{ g of } Ag_2S$$

$$\equiv \frac{7.74 \times 10^{-6}}{7.23} \text{ cm}^3 \text{ of } Ag_2S$$

$$\equiv 1.07 \times 10^{-6} \text{ cm}^3 \text{ of } Ag_2S$$

$$1 \ \mu g/cm^2 \cdot h \equiv 1.07 \times 10^{-6} \text{ cm/h}$$

$$\equiv 1.07 \times 10^{-6} \times 10^8 \text{ Å/h}$$

$$\equiv 107 \times 24 \times 30 \ \text{ Å/30 days}$$

$$\equiv 7.7 \times 10^4 \text{ Å/30 days}$$

Silver corrosion product rate of growth of 300 Å/month is equivalent to 0.0039 $\mu g/cm^2 \cdot h$ rate of weight gain.

Copper Corrosion Rate Relationship

In this calculation, it is first assumed that copper sulfide (Cu_2S) is the only corrosion product. Then the corrosion rate relationship is calculated assuming that copper oxide (Cu_2O) is the only corrosion product. Lastly, the calculation is completed assuming that copper corrodes to Cu_2S and Cu_2O in equal proportions.

Calculation Assuming that Cu_2S (Density = 5.6 g/cm^3) is the Only Corrosion Product

$$\text{Copper specimen weight gain of 1 } \mu g \equiv \frac{2 \times 63.55 + 32}{32} \text{ } \mu g \text{ of } Cu_2S$$

$$\equiv 5 \times 10^{-6} \text{ g of } Cu_2S$$

$$\equiv \frac{5 \times 10^{-6}}{5.6} \text{ cm}^3 \text{ of } Cu_2S$$

$$\equiv 0.9 \times 10^{-6} \text{ cm}^3 \text{ of } Cu_2S$$

$$1 \text{ } \mu g/cm^2 \cdot h \equiv 0.9 \times 10^{-6} \text{ cm/h}$$

$$\equiv 0.9 \times 10^{-6} \times 10^8 \text{ Å/h}$$

$$\equiv 90 \times 24 \times 30 \text{ Å/30 days}$$

$$\equiv 6.4 \times 10^4 \text{ Å/30 days}$$

Copper corrosion product rate of growth of 300 Å/month is equivalent to 0.0047 $\mu g/cm^2 \cdot h$ rate of weight gain when it is assumed that Cu_2S is their only corrosion product.

Calculation Assuming that Cu_2O (Density = 6 g/cm^3) is the Only Corrosion Product

$$\text{Copper specimen weight gain of 1 } \mu g \equiv \frac{2 \times 63.55 + 16}{16} \text{ } \mu g \text{ of } Cu_2O$$

$$\equiv 8.94 \times 10^{-6} \text{ g of } Cu_2O$$

$$\equiv \frac{8.94 \times 10^{-6}}{6} \text{ cm}^3 \text{ of } Cu_2O$$

$$\equiv 1.5 \times 10^{-6} \text{ cm}^3 \text{ of } Cu_2O$$

$$1 \text{ } \mu g/cm^2 \cdot h \equiv 1.5 \times 10^{-6} \text{ cm/h}$$

$$\equiv 1.5 \times 10^{-6} \times 10^8 \text{ Å/h}$$

$$\equiv 1.5 \times 10^2 \times 24 \times 30 \text{ Å/30 days}$$

$$\equiv 10.8 \times 10^4 \text{ A/30 days}$$

Copper corrosion product rate of growth of 300 Å/month is equivalent to 0.0028 μg/cm^2·h rate of weight gain when it is assumed that Cu_2O is their only corrosion product.

Calculation Assuming that Copper Corrodes to Cu_2S and Cu_2O in Equal Proportions

If it is assumed that copper corrodes to Cu_2S and Cu_2O in equal proportions, the relation of the two rates of copper corrosion can be estimated as

$$150 \text{ Å } Cu_2S \equiv 150 \times 10^{-8} \times 5.6 \text{ g/cm}^2 \ Cu_2S$$

$$\equiv 150 \times 10^{-8} \times 5.6 \times \frac{32}{2 \times 63.55 + 32} \text{ g/cm}^2 \text{ weight gain}$$

$$\equiv 1.6895 \text{ μg/cm}^2 \text{ weight gain}$$

$$150 \text{ Å } Cu_2O \equiv 150 \times 10^{-8} \times 6 \text{ g/cm}^2 \ Cu_2O$$

$$\equiv 150 \times 10^{-8} \times 6 \times \frac{16}{2 \times 63.55 + 16} \text{ g/cm}^2 \text{ weight gain}$$

$$\equiv 1.0063 \text{ μg/cm}^2 \text{ weight gain}$$

$$150 \text{ Å } Cu_2S + 150 \text{ Å } Cu_2O \equiv 1.6895 + 1.0063 \text{ μg/cm}^2 \text{ weight gain}$$

$$(150 \text{ Å } Cu_2S + 150 \text{ Å } Cu_2O)/30 \text{ days} \equiv \frac{2.6958}{30 \times 24} \text{ μg/cm}^2 \cdot \text{h weight gain}$$

$$\equiv 0.0037 \text{ μg/cm}^2 \cdot \text{h weight gain}$$

Copper corrosion product rate of growth of 300 Å/month is equivalent to 0.0037 μg/cm^2·h rate of weight gain when it is assumed that copper corrodes to Cu_2S and Cu_2O in equal proportions.