# ZONAIR3D™

PURE AIR, JUST BREATHE

## Data Centers

**Zonair3D™ seeks to create pure air, become a lung for our cities and improve people's quality of life.**

# PURE AIR, JUST BREATHE

ZONAIR3D is a Spanish company established in all 5 continents whose objective is to develop air purification systems.

In partnership with the best institutions and scientific research centres, we have developed air purification systems aimed at providing responses to latent requirements in fields such as health, welfare or construction among others.

In order to win the trust of our clients, all our products are certified by official standards and clinical studies published by leading doctors in their field.
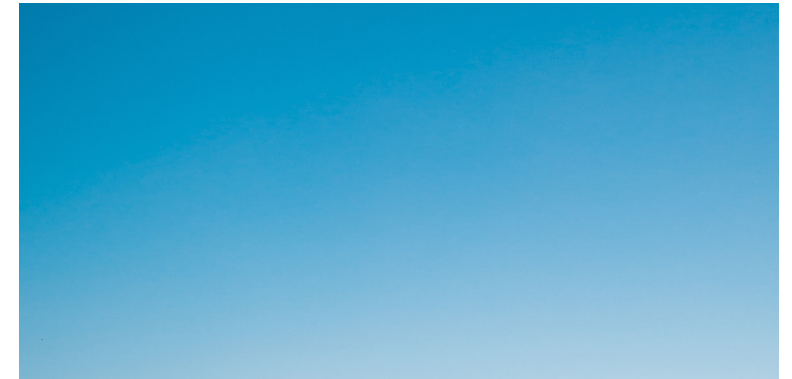
We are passionate about creating pure air and improving quality of life; from schools to offices and industry to public spaces, such as shopping centres, cinemas, car parks, swimming pools and, naturally, our homes. Zonair3D™ has designed a range of products tailored to suit every need.

In addition to the essential features as cooling and climate necessary in DATA CENTER rooms, it is vital to consider the quality of indoor air.

There are numerous pollutants present both outdoors and indoors that can affect your electronic equipment and Data Center staff. [Refer to APPENDIX 1: ASHRAE's Gaseous and Particulate Contamination Guidelines for Data Centers (2009) and APPENDIX 2: ASHRAE's Gaseous and Particulate Contamination Guidelines for Data Centers (2011).]

Suspended particulates and gases are factors of great importance to the effectiveness and results of the huge number of microprocessors and sensitive materials inside.

• Fine suspended particles can come into contact with the systems and causes failure modes due to dust. Coarse dust particles have a 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.

• Different gases in the environment combined with humidity may produce acidity (corrosion) resulting in a problem of great impact on system processors and microchips. For example, the combination of Sulfur-bearing gases, such as sulfur dioxide ($SO_2$) and hydrogen sulfide ($H_2S$) with other gases such as nitrogen dioxide ($NO_2$) and/or ozone ($O_3$) is very corrosive.



PURE AIR, JUST BREATHE

• 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. Harmful dust in data centers is generally high in ionic content, such as sulfur- and chlorinebearing salts. The source of this harmful dust is mainly outdoor dust.

• Additional consideration should be paid to the resultant damages covered neither by warranty nor by insurance. Not only do owners stand to lose their equipment, but also the information in it. These damages are traditionally not covered without incurring into additional premium costs.

• Large bodies of salt water are also a major source of airborne dust contamination in data centers. Sea salt can be carried 10 km inland or farther by high winds present in coastal areas and can damage electronic devices at this range. It can degrade the surface insulation resistance of the printed circuit board and, in the worst-case scenario, lead to electrical short-circuiting of closely spaced features.
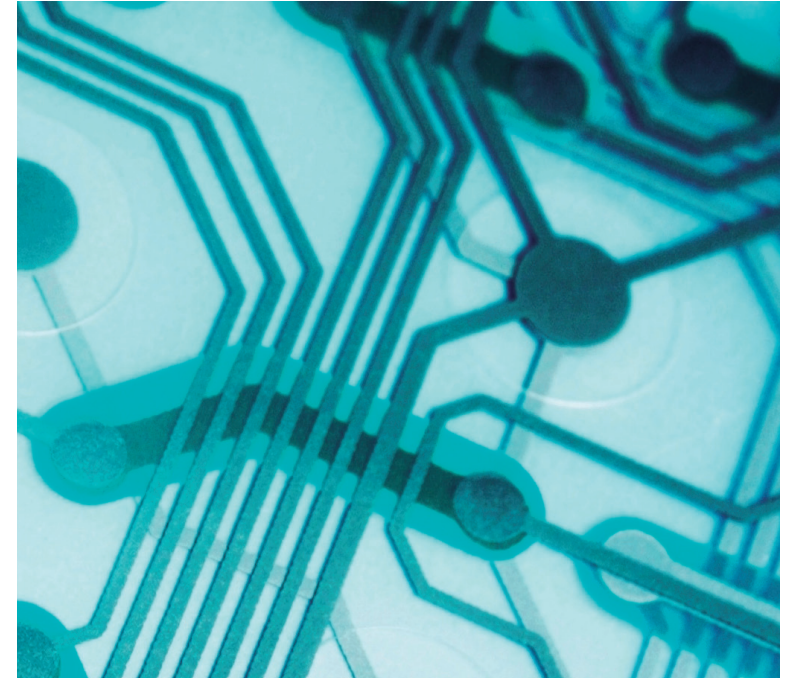
All of these examples contribute to life shortening of your equipment.

In addition to the corrosive gases, Volatile Organic Compounds (VOCs) are also present in almost all indoor environments. Moreover, electronic devices in data center release a high amount of VOCs.

These compounds cause a human response in the respiratory system and eye, nose and throat irritation; headaches, loss of coordination, nausea; damage to liver, kidney, and central nervous system. Some are suspected or known to cause cancer in humans.

Having a system that reduces all these pollutants to the maximum extent will have a positive effect both on electronic equipment and the employees working in data centers.

Monitoring what is happening in your data center is a good start, both reactive monitoring by using coupons aimed to determine and characterize the corrosion potential in a certain environment, and real-time monitoring are useful methods to monitor both gaseous pollutants present in your data center and real-time efficiency of your filtering system.

Therefore, the main solution is based on using the right air cleaning solution. Zonair3d's purified air solution ensures the excellence in terms of indoor air quality, because it provides an environment up to 99,995% free of particles, and a reduction of gases to comfort levels, by studying the real needs of your data center and implementing the best solution.

And as a result, you get a significant reduction in:
· Failures rates in electronic equipment triggered by pollution
· Equipment soling; less vulnerable to loss of HVAC system
· It limits reactions among indoor pollutants

This is achieved by its 3-phase filtration system:
· G4/F7 — Pre-filter for fine particles and dust, sand, pollen, etc.
· H14/U15 — Absolute filter with an efficiency of up to 99.995% for small particles up to 0.2 microns
· Zonair3D's Gas Reduction System (GRSystem), which reduces volatile compounds to comfort levels
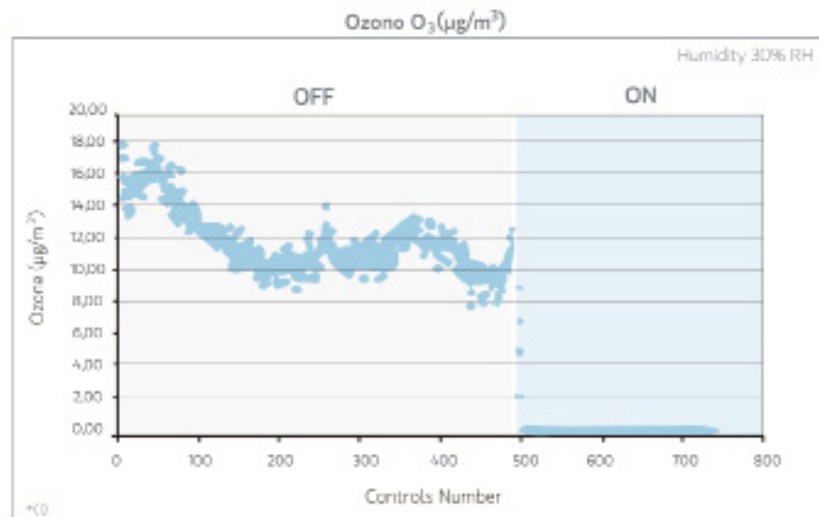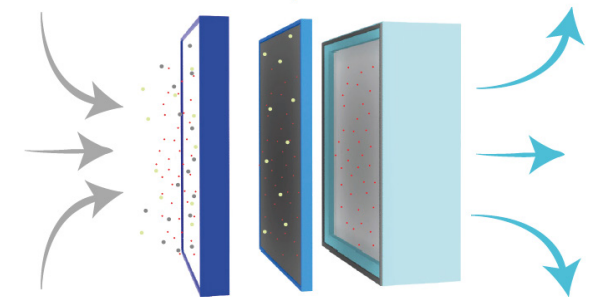


Ozono O$_3$(µg/m$^3$)

Humidity 30% RH

OFF          ON

FIGURE 5: ELIMINATION OF O$_3$ USING PURE AIR CONTROL TECHNOLOGY

PURE AIR, JUST BREATHE

**PORTABLE PRODUCTS**

AIR+ 600 & AIR+ 300/430 "S" are air recirculation units aimed for professional and home use. They filter and purify polluted air transforming it into **pure air**, **free from contaminating particulates and ozone,** and with a reduction of toxic, irritant and carcinogen **gases to comfortable limits.**

### AIR+ 600



| AIR+ 600 | AIRFLOW (m³/h) | DIMENSIONS (LxWxH / mm) | MAX.ABSORBED POWER (W) | REQUIREMENTS | WEIGHT |
|---|---|---|---|---|---|
| | 600 | 725 x 553 x 593 | 170 | 230 / 50-60 | 50 |

### AIR+ 300 /430 S



| AIR+ 300-430 "S" | AIRFLOW (m³/h) | DIMENSIONS (LxWxH / mm) | MAX.ABSORBED POWER (W) | REQUIREMIENTS | WEIGHT |
|---|---|---|---|---|---|
| | 332 / 430 | 382 x 380 x 791 | 87 / 165 | 230 / 50-60 | 30 |

## AIR PRO Range

**Air Pro range** is an innovative air purification system thay brings pure air to building interior. With a wide range of flow rates, Air Pro purifies the air in indoor spaces without being seen.

### AIR PRO 100/300
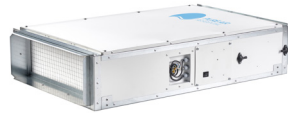


### AIR PRO 500/3000
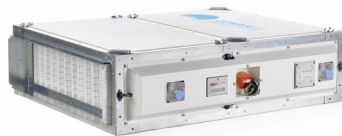


| PRODUCT RANGE | FLOW (m³/h) | DEVICE MEASURES (H x W x L / mm) | WEIGHT (kg) | CONSUMPTION (KW) |
|---|---|---|---|---|
| AIR PRO 100 | 195/115 | 207 x 639 x 929 | 45.5 | 0,027 |
| AIR PRO 300 | 300/140 | 207 x 639 x 929 | 46 | 0,055 |
| AIR PRO 500 | 500 | 310 x 972 x 1104 | 84 | 0,164 |
| AIR PRO 800 | 800 | 310 x 972 x 1104 | 85 | 0,328 |
| AIR PRO 1200 | 1200 | 353 x 972 x 1104 | 92 | 0,518 |
| AIR PRO 2000 | 2000 | 414 x 1174 x 1504 | 175 | 1,034 |
| AIR PRO 3000 | 3000 | 414 x 1174 x 1504 | 180 | 2,198 |

**ZONAIR**3D™

PURE AIR, JUST BREATHE
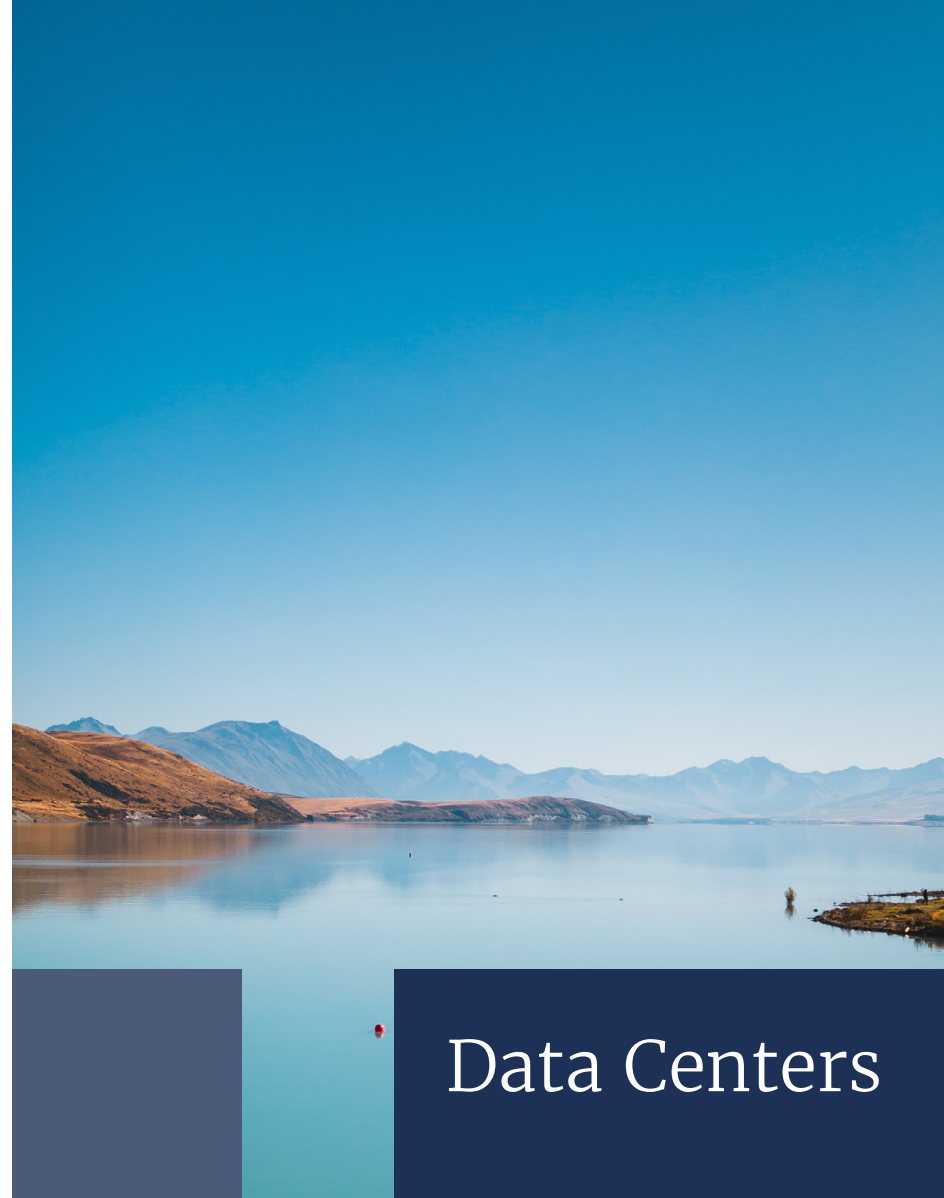
# Data Centers

# APPENDIX 1

## 1. ASHRAE: *Gaseous and Particulate Contamination Guidelines for Data Centers* (2009)

ZONAIR3D™
PURE AIR, JUST BREATHE

# Gaseous and Particulate Contamination Guidelines for Data Centers

**Whitepaper prepared by ASHRAE Technical Committee (TC) 9.9**
**Mission Critical Facilities, Technology Spaces, and Electronic Equipment**

This ASHRAE white paper on data center airborne contamination was developed by members of the TC 9.9 committee representing the following IT equipment manufacturers: AMD, Cisco, Cray, Dell, EMC, Hitachi, HP, IBM, Intel, Seagate, SGI, and Sun.

## Executive Summary

ASHRAE TC 9.9 committee recently published the 2008 ASHRAE Environmental Guidelines for Datacom Equipment 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 $18^{\circ}C$ (64.4°F) to $27^{\circ}C$ (80.6°F). The humidity is limited to less than 60% with the lower and upper dew point temperatures of $5.5^{\circ}C$ (41.9°F) and $15^{\circ}C$ (59°F).

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 datacenter 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. 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 makes the hardware more prone to attack by contamination in the data center environment. Manufacturers are in a constant struggle to maintain the reliability of their hardware with ever shrinking feature 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.

Most data centers are well designed and are in areas with relatively clean environments and most contamination is benign. Most data centers should not experience particulate or gaseous contamination related hardware failures. This paper is primarily targeted at a minority of data centers which 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 the 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 ISO 14644-1 Class 8. This level of cleanliness can generally be achieved by an appropriate filtration scheme as outlined here:

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.
2. Air entering a data center may be filtered with MERV 11 or MERV 13 filters as recommended by ASHRAE book titled, "Particulate and Gaseous Contamination in Datacom Environments".

Sources of dust inside data centers should be reduced. The gaseous contamination should be within the modified ANSI/ISA-71.04-1985 severity level G1 that meets:

1. A copper reactivity rate of less than 300Å/month, and
2. A silver reactivity rate of less than 300Å/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 size of the transistors and the distances electrical signals have to travel to accomplish the tasks assigned 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 air flow to maintain hardware within acceptable temperature limits. The increased air flow 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 size 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 2007; Cullen 2004; Veale; Sahu 2007; Schueller 2007; Hillman; Xu ; 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. These additional environmental measures 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 2004; Mazurkiewicz 2006; Mukadam 2006; Scheller 2007; Xu 2007). The two common circuit board types suffering from copper creep corrosion are immersion silver (ImAg) and organic solderability preservative (OSP) technologies. 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; Reid 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 as needles or nodules, under a low power microscope, as shown in Figure 1.

It should be noted that the reduction of circuit board feature sizes and the miniaturization of components, necessary to improve hardware performance, also makes the hardware more prone to attack by the corrosive particles and gases in the data center environment. Manufacturers are in a constant struggle to maintain the reliability of their ever shrinking hardware. 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.
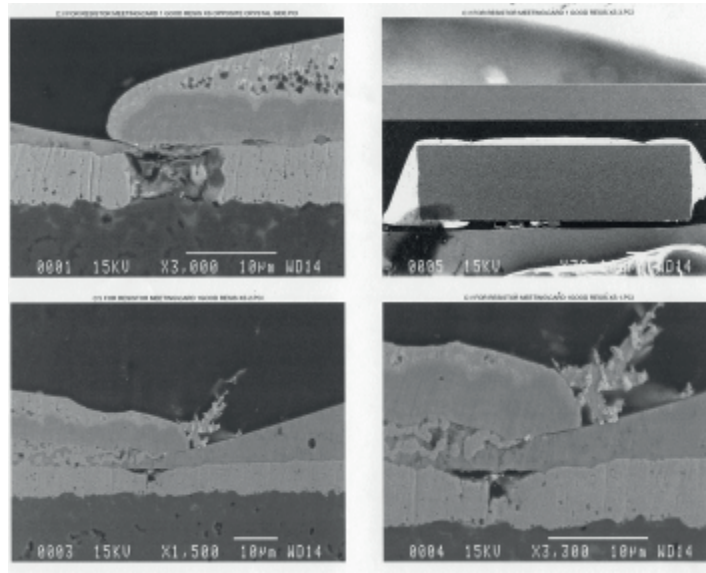
*Figure 1: Example of a component failure due to an environment high in sulfur-bearing gases attacking the silver metallization in the component producing silver sulfide "flowers."*

**Airborne dust**

Failure modes due to dust include, but are not limited to, the following (ASHRAE 2009a):
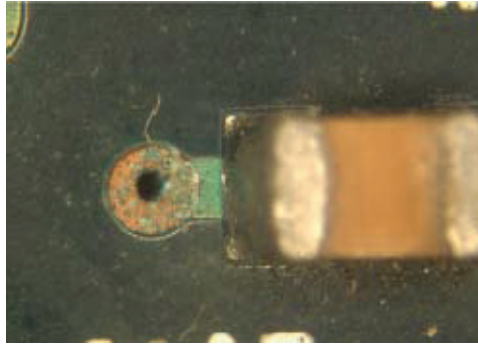
- Mechanical effects: These effects include obstruction of cooling airflow, interference with moving parts, abrasion, optical interference, interconnect interference, or deformation of surfaces (e.g., magnetic media) and other similar effects.
- Chemical effects: Dust settled on printed circuit boards can lead to component corrosion and/or to the electrical short circuiting of closely spaced features.
- Electrical effects: These 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 circumstance 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 2.5-15 μm for coarse dust and 0.1-2.5 μm for fine dust (Comizzoli 1993). The coarse dust particles have mineral and biological origin formed mostly by wind-induced abrasion and can remain airborne for a few days. The 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 10km (6 miles) inland or farther by high winds present in coastal areas and can damage electronic devices at this range (Bennett 1969; Crossland 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 is an example of copper corrosion caused by dust settled on a printed circuit board.

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

3

*Figure 2: Corrosion of a plated through hole because of wetted ionic dust high in magnesium chloride.*

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-$\mu$A 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 data centers. Even low concentrations of these salts can be a serious corrosion and ion migration threat. These humidifier-related corrosion problems can be mitigated by treating the humidifier water using reverse osmosis (ASHRAE 2009a).

Fibrous dust from paper, cardboard or textiles can foul heat sinks and disrupt equipment cooling. Datacenter operators should avoid working with large amounts of these materials within the data center. For instance, new equipment should be unboxed outside of the datacenter, 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 the 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 2004; Lahtinen 2008).

Zinc whiskers, that may sometimes grow to be 1 to 2 mm 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 under-floor cables. If zinc whiskers are ingested by IT equipment, circuit with voltages higher than about 25V may suffer electrical short circuiting, arcing, signal perturbations, or catastrophic failures (Miller 2007).

A simple method to detect zinc whiskers is with the use of a flashlight.  Remove a raised-floor tile and place the tile on its edge in a dim 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 (SEM). If zinc whiskers are present, remediation involves replacing the contaminated raised-floor tiles and hiring professionals to clean the data center.

ISO 14644-1 has become the dominant, worldwide standard for classifying the cleanliness of air in terms of concentration of airborne particles. Table 1 below 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:

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.

2. Air entering a data center may be filtered with MERV 11 or MERV 13 filters as recommended by ASHRAE Book titled "Particulate and Gaseous Contamination in Datacom Environments." (ASHRAE 2009a)

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

Table 1: *ISO 14644-1 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 (3) significant figures be used in determining the classification level. | | | | | | |

**Gaseous contamination**

Sulfur-bearing gases, such as $SO_2$ and $H_2S$, are the most common gases in data centers causing hardware corrosion (Rice 1981). An example of corrosion on a RoHS-compliant circuit board due to gaseous contamination is shown in Figure 3.
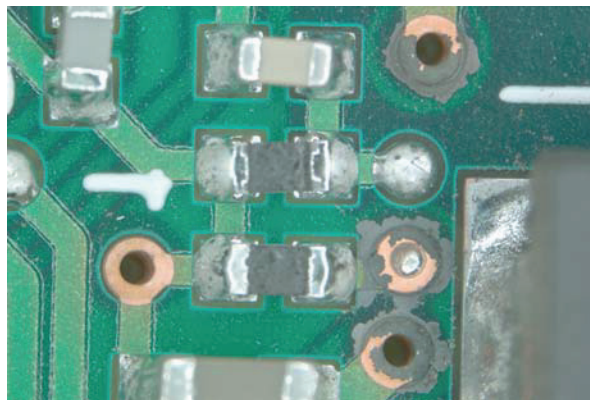


*Figure 3: Sulfur-bearing gas corrosive attack of copper on a RoHS-compliant circuit board protected by OSP finish.*

Gaseous composition environmental limits have been published in ANSI/ISA-71.04-1985. 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 straight forward exercise to predict the rate of corrosion from gaseous composition. An added complication is the synergy between gases. For example it has been shown that sulfur dioxide or hydrogen sulfide alone are not very corrosive to silver or to copper but the combination of these gases with other gases such as nitrogen dioxide and/or ozone 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 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 ANSI/ISA-71.04-1985. 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 decribed 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 contribtions of gasous 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 practive 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 ANSI/ISA-71.04-1985*

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

At present the ANSI/ISA-71.04-1985 standard 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 rates limits should not exceed 300Å/month. A recent copper and silver corrosion rate survey, done by IBM, of data centers with hardware failures from copper creep corrosion and/or silver corrosion is plotted in Figure 4. Only a small fraction of these problem data centers had copper corrosion rates greater than 100Å/month; and all these problem data centers had silver corrosion rates greater than 100Å/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 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.

The ANSI/ISA-71.04-1985 is a well established, widely accepted standard that states that severity level G1 has copper corrosion rate less than 300Å/month corresponding to a "mild environment sufficiently well-controlled such that corrosion is not a factor in determining equipment reliability." 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 300Å/month and a maximum corrosion rate of silver of 300Å/month should be used as the acceptable gaseous corrosivity limit for data centers. The gaseous contamination levels in a data center are a function of location and time of year. The
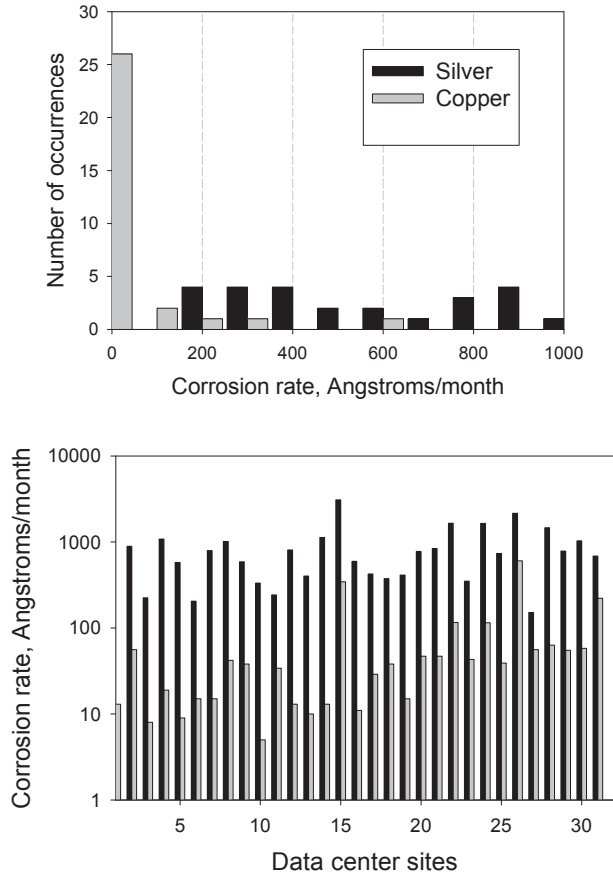
*Figure 4: IT equipment fails in data centers with reported copper creep corrosion and/or silver corrosion. Not shown in the top chart are 6 occurrences of silver corrosion rate greater than 1000Å/month. It shows 26 occurrences of copper corrosion between 0-100Å/month and none for silver; 2 occurrences for copper and 4 for silver between 100-200Å/month; 2 occurrence for copper and 4 for silver between 200-300Å/month; and so on. Notice that, as shown in the bottom chart, in these 31 sites with known hardware failures due to corrosion, the silver corrosion rate was typically an order of magnitude or more greater than the copper corrosion rate.*

location of interest for gaseous corrosivity monitoring is approximately 2 inches (5 cm) 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, 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 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 which 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 ANSI/ISA-71.04-1985 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 re-circulated 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 ANSI/ISA-71.04-1985 severity level G1 for copper and silver corrosion.

**2008 ASHRAE Environmental Guidelines for Datacom Equipment**

To provide greater flexibility in facility operations, particularly with the goal of reduced energy consumption in data centers, ASHRAE TC 9.9 committee has revisited these recommended equipment environmental specifications, specifically the recommended envelope for classes 1 and 2. The recommended envelope is the same for both of these environmental classes. The result of this effort has been to expand the recommended operating environment 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 the IT manufacturers, and operation within this envelope will not compromise overall reliability of the IT equipment. The previous and 2008 recommended envelope data is shown in Table 3.

**Table 3.** *ASHRAE Recommended Environment for Temperature and Moisture (ASHRAE 2009b)*

|  | 2004 Version | 2008 Version |
|---|---|---|
| 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% relative humidity | 5.5°C dew point (41.9°F) |
| High End Moisture | 55% relative humidity | 60% relative humidity and 15°C dew point (59°F dew point) |

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 portion of IT equipment racks. The inlet air temperature in many data centers tends to be warmer at the top portion 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 portion of the rack.

The details of the new guidelines are documented in the second edition of the Thermal Guideline book (Thermal Guidelines for Data Processing Environments, Second Edition, ASHRAE 2009b).

**Summary of recommended acceptable environmental limits**

The recommended temperature-humidity, dust and gaseous limits are summarized in the following table:

**Table 4.** *ASHRAE Recommended Environments*

| **Recommended operating environment[1, 4]** | |
|---|---|
| Temperature | 18°C (64.4 °F) to 27°C (80.6 °F)[4] |
| Low end moisture | 5.5°C (41.9 °F) dew point |
| High end moisture | 60% relative humidity or 15°C (59 °F) dew point |
| Gaseous contamination | Severity level G1 as per ANSI/ISA 71.04-1985[2] which states that the reactivity rate of copper coupons shall be less than 300Å/month ($\equiv 0.0039$ $\mu g/cm^2$-hour weight gain)[6]. In addition, the reactivity rate of silver coupons shall be less than 300Å/month days ($\equiv 0.0035$ $\mu g/cm^2$-hour weight gain)[7]. The reactive monitoring of gaseous corrosivity should be conducted approximately 2 inches (5 cm) 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 class 8.<br>  a. For data center without airside economizer, the ISO 14644-1 class 8 cleanliness may be met simply by the choice of the following filtration:<br>    i. The room air may be continuously filtered with MERV 8 filters.<br>    ii. Air entering a data center may be filtered with MERV 11 or preferably MERV 13 filters.<br>  b. For data centers with airside economizers, the choice of filters to achieve ISO class 8 cleanliness depends on the specific conditions present at that data center.<br>2. The deliquescent relative humidity of the particulate contamination should be more than 60% RH[3].<br>3. Data centers must be free of zinc whiskers[5]. |
| **Recommended non-operating environment[4]** | |
| Temperature | 5°C (41 °F) to 45°C (113 °F) |
| Relative humidity | 8% to 80% |
| High end moisture | 27°C (80.6 °F) dew point |
| Gaseous contamination | Severity level G1 as per ANSI/ISA 71.04-1985[2] which states that the reactivity rate of copper coupons shall be less than 300Å/month ($\equiv 0.0039$ $\mu g/cm^2$-hour weight gain)[6]. In addition, the reactivity rate of silver coupons shall be less than 300Å/month ($\equiv 0.0035$ $\mu g/cm^2$-hour weight gain)[7]. The reactive monitoring of gaseous corrosivity should be conducted approximately 2 inches (5 cm) 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 lower corrosivity reading than if the machine was operating. |
| Particulate contamination | 1. Data centers must meet the cleanliness level of ISO 14644-1 class 8.<br>  a. For data center without airside economizer, the ISO 14644-1 class 8 cleanliness may be met simply by the choice of the following filtration:<br>    i. The room air may be continuously filtered with MERV 8 filters.<br>    ii. Air entering a data center may be filtered with MERV 11 or preferably MERV 13 filters.<br>  b. For data centers with airside economizers, the choice of filters to achieve ISO class 8 cleanliness depends on the specific conditions present at that data center.<br>2. The deliquescent relative humidity of the particulate contamination should be more than 60% RH[3].<br>3. Data centers must be free of zinc whiskers[5]. |

Notes:
1. Gaseous contamination is measured approximately 2 inches (5 cm) 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 300m (984ft) over 1800m (5906ft).  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. ANSI/ISA-71.04.1985. "Environmental conditions for process measurement and control systems: Airborne contaminants." Instrument Society of America, Research Triangle Park, NC, 1985.
3. 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.
4. The machine should be in an environment that satisfies the recommended operating environment specification for at least one day before it is powered on.
5. Surface debris is randomly collected from 10 areas of the data center on a 1.5-cm 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.
6. 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 $Cu_2S$ and $Cu_2O$ grow in equal proportions.
7. 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 $Ag_2S$ is the only corrosion product.

### References

- ASHRAE Standard 52.2-2007, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*, *2007*.
- ASHRAE book, Particulate and Gaseous Contamination in Datacom Environments, 2009a.
- ASHRAE book, Thermal Guidelines for Data Processing Environments, Second Edition, 2009b.
- ANSI/ISA-71.04-1985, *Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants*, ANSI/ISA-The Instrumentation, Systems, and Automation Society, 3 February 1986.
- ANSI/ASHRAE Standard 127-2007, Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners, 2007.
- Bennett, H.E., Peck, RL., Burge, D.K., Bennet, J.M., *Formation and growth of tarnish on evaporated silver films*, Journal of Applied Physics, 1969, 40 (8), pp. 3351-3360.
- Brusse J., Sampson M., NASA, Zinc whisker:  Hidden cause of equipment failure, IT Professional, v 6, n 6, p 43-46, Nov/Dec 2004.
- Crossland, W.A., Knight, E., Wright, C.R., *The accelerated tarnish testing of contacts and connectors employing silver alloy contacts*, Elect. Contacts, 1973, Proc. Holm Weminar, pub. IIT Chicago, pp. 265-282.
- Comizzoli R. B., Frankenthal R. P., Lobnig R. E., Peins G. A., Psato-Kelty L. A., Siconolfi D. J and Sinclair J. D., Bell Laboratories, *Corrosion of electronic materials and devices by submicron atmospheric particles*, The Electrochemical Society Interface, Feb 1993.
- Cullen D. and O'Brien G., UL Laboratories, *Implementation of immersion silver PCB surface finish in compliance with Underwriters Laboratories*, IPC Printed Circuits Expo, 2004.
- Hillman C., Arnold J., Binfield S., Seppi J., DfR Solutions, *Silver and sulfur: Case studies, physics and possible solutions*
- ISO 14644-1, *Cleanrooms associated controlled environments--Part 1: Classification of air cleanliness*, 1999.
- Lahtinen, R. and Gustafsson T., The Driving Force Behind Whisker Growth. Metal Finishing, 2008.
- Mazurkiewicz P., HP Corp., "*Accelerated corrosion of PCBs due to high levels of reduced sulfur gases in industrial environments,*" Proceedings of the 32nd ISTFA, Nov 12-16, 2006, Austin TX.
- Mukadam, N. et. al, "*Planar Microvoiding in Lead-Free Second Level Interconnect Solder Joints*", Intel, SMTA Proceedings, pg 293, Chicago, 2006.

- Ortiz, S. , Data Center Cleaning Services. Processor. Soc., vol. 28, Issue 14, April 7, 2006, pg. 4, http://www.processor.com/
- Peterson P. J., private communications, June 2009.
- Reid M., Punch J., Ryan C., Franey J., Derkits G. E., Reents W. D. and Garfias L. F., University of Limerick, The corrosion of electronic resistors, IEEE Trans on Components and Packaging Technologies, vol. 30, no. , Dec 2007.
- Rice D. W., Cappell R. J., Kinsolving W. and Laskowski J. J. , IBM Corp., *Indoor corrosion of metals*, J. Electrochem. Soc., pg.891-901, April 1980.
- Rice D. W., Peterson P., Rigby E. B., Phipps P. B. P., Cappell R. J. and Tremoureux, IBM Corp., Atmospheric corrosion of copper and silver, J. Electrochem. Soc., pg.275-284, Feb 1981.
- Sahu A. K., President , National Solid Waste Association of India, *"Present Scenario of Municipal Solid Waste Dumping grounds in India,"* International Conference on Sustainable Solid Waste Management, Chennai, India, Sept 2007.
- Schueller R., Dell Corp, *"Creep corrosion of lead-free printed circuit boards in high sulfur environments,"* SMTA Int'l Proceedings, Oct 2007.
- Singh P., Schmidt. R. R. and Prisco J., IBM Corp., *Particulate and gaseous contamination: Effect on computer reliability and monitoring*, ASHRAE 2009.
- Singh P., IBM Corp., Private communication, 2009.
- Veale R., Rockwell International, *"Reliability of PCB alternate surface finishes in a harsh industrial environment*. SMTA Int'l Proceedings, 2005.
- Volpe L., Peterson P. J., *Atmospheric sulfidation of silver in a tubular corrosion reactor*, IBM Corp, Corrosion Science, V 29, n 10, p 1179-1196, 1989.
- Volpe L., IBM Corp., *Environmental factors in indoor corrosion of metals*, IBM Internal Technical Report, 1989.
- Xu C., Flemming D., Demerkin K., Derkits G., Franey J., Reents W., Alcatel-Lucent, *"Corrosion resistance of PWB final finishes*, APEX 2007.
- Crossland, W.A., Knight, E., Wright, C.R., *The accelerated tarnish testing of contacts and connectors employing silver alloy contacts*, Elect. Contacts, 1973, Proc. Holm Webinar, pub. IIT Chicago, pp. 265-282.

**Appendix A: Relationship of μg/cm$^2$.hour and Å/30days corrosion rates for copper and silver**

Papers on atmospheric corrosion of metals often report corrosion rates in terms of rate of weight gain in μg/cm$^2$.hour. ANSI/ISA Standard 71.04-1985 reports corrosion rates in terms of the rate of increase of corrosion product thickness in Å/month.

The relationship of the two rates for silver corrosion is derived below. In this calculation, it is assumed that $Ag_2S$ is the only corrosion product and that the density of $Ag_2S$ is 7.23 g/cm$^3$.

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

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

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

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

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

$$\equiv 1.07 \times 10^{-6} \times 10^8 \text{ A/hour}$$

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

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

If we assume that the silver corrosion product is mostly $Ag_2S$, then 300Å/month rate of corrosion product growth is equivalent to 0.0039 μg/cm$^2$.hour rate of weight gain.

The relationship of the two rates for copper corrosion is derived below. In this calculation, it is assumed that $Cu_2S$ is the only corrosion product and that the density of $Cu_2S$ is 5.6 g/cm$^3$.

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

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

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

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

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

$$\equiv 0.9 \times 10^{-6} \times 10^8 \text{ A/hour}$$

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

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

The relationship between the two rates for copper corrosion is derived below. In this calculation, it is assumed that $Cu_2O$ is the only corrosion product and that the density of $Cu_2O$ is 6 g/cm$^3$.

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

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

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

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

$$1 \text{ µg/cm}^2.\text{hour} \equiv 1.5 \times 10^{-6} \text{ cm/hour}$$

$$\equiv 1.5 \times 10^{-6} \times 10^8 \text{ A/hour}$$

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

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

If we assume that copper corrodes to $Cu_2S$ and $Cu_2O$ in equal proportions we can estimate the relation of the two rates of copper corrosion as:

$1 \text{ µg/cm}^2.\text{hour} \equiv 8.6 \times 10^4 \text{ A/30 days}$

If we assume that the copper corrosion product is 50% $Cu_2S$ and 50% $Cu_2O$, then 300Å/month rate of corrosion product growth is equivalent to 0.004 µg/cm$^2$.hour rate of weight gain. Then, 300Å/month rate of corrosion product growth is equivalent to 0.0035 µg/cm$^2$.hour rate of weight gain.

# APPENDIX 2

## 2. ASHRAE: *Gaseous and Particulate Contamination Guidelines for Data Centers* (2011)!

ZONAIR3D™
PURE AIR, JUST BREATHE

# 2011 Gaseous and Particulate Contamination Guidelines For Data Centers[1]

## EXECUTIVE SUMMARY

Most data centers are well designed and are in areas with relatively clean environments, and most contamination is benign. Therefore, most data centers do not experience particulate or gaseous contamination-related information technology (IT) equipment failures. A small number of data centers, however, do. According to the major IT equipment manufacturers, the number of data centers with contamination-related failures is on the rise, though their numbers remain quite small.

In 2009, the IT manufacturer members of ASHRAE TC 9.9 authored a white paper (ASHRAE 2009a), titled "Particulate and Gaseous Contamination Guidelines for Data Centers," primarily targeted toward a minority of data centers that may have harmful environments resulting from the ingress of outdoor particulate and/or gaseous contamination. The document stated that for a small number of data centers, located mostly in the emerging markets, contamination can be a serious risk, and it provided insight into how to manage the contamination risk.

This white paper is an update to the original 2009 ASHRAE paper. The update is based on an ASHRAE survey of the air quality in data centers and on lessons learned in cleaning the air in contaminated data centers.

The reasons for the increasing number of data centers experiencing corrosion-related hardware failures are as follows:

- Change from lead-containing solder to lead-free solder, such as copper-tin-silver solder
- Changes in data center temperature and humidity operating conditions

---

1. This white paper on data center airborne contamination was prepared by ASHRAE TC 9.9, Mission Critical Facilities, Technology Spaces, and Electronic Equipment. The committee's members represent the following IT equipment manufacturers: AMD, Cisco, Cray, Dell, EMC, Hitachi, HP, IBM, Intel, Oracle, Seagate, and SGI. Helpful information for technical and nontechnical readers can be found in *Particulate and Gaseous Contaminants in Datacom Environments* (ASHRAE 2009b).

- Continued miniaturizing of electronic components and ever-increasing circuit packaging density
- Proliferation of data centers into geographies with polluted environments

Two common modes of IT equipment failures due to environmental contamination are as follows:

- Copper creep corrosion on printed circuit boards
- Corrosion of silver termination in miniature surface-mounted components

Copper creep corrosion is the corrosion of copper plating to copper sulfide on printed circuit boards and the creeping of copper sulfide over the printed circuit boards, electrically shorting adjacent circuit-board features. The corrosion of silver termination, in surface-mounted components, to silver sulfide leads to the loss of silver metallization and eventual open circuiting of components such as resistors.

Data center contamination and its corrosive effects can be identified by well-defined and relatively easy means:

- Particulate (dust) contamination is characterized by its quantity and its corrosivity. The quantity of dust contamination can normally be identified by visual inspection of the IT equipment and by the filter replacement frequency. The corrosivity of the dust can be estimated by determining the deliquescent relative humidity, which is the relative humidity at which the dust becomes wet and, therefore, conductive (see Appendix B). Dust with high deliquescent relative humidity is generally more benign; dust with low deliquescent relative humidity is generally more corrosive. ASHRAE recommends that data centers be kept clean to ISO Class 8, which may be achieved simply by specifying the following means of filtration:
  - The room air may be continuously filtered with MERV 8 filters, as recommended by ASHRAE Standard 127 (ASHRAE 2007).
  - Air entering a data center may be filtered with MERV 11 or MERV 13 filters as recommended by ASHRAE (2009b).

For data centers utilizing free air cooling or air-side economizers, the choice of filters to achieve ISO class 8 level of cleanliness depends on the specific conditions present at that data center. In general, air entering a data center may require use of MERV 11 or, preferably, MERV 13 filters.

- Direct measurement of gaseous contamination levels is difficult and is not a useful indicator of the suitability of the environment for IT equipment. A low-cost, simple approach to monitoring the air quality in a data center is to expose copper and silver foil coupons in the data center for 30 days followed by coulometric reduction analysis in a laboratory to determine the thickness of the corrosion products on the metal coupons. ASHRAE recommends that data center operators maintain an environment with corrosion rates within the following guidelines:

- Copper reactivity rate of less than 300 Å/month
- Silver reactivity rate of less than 200 Å/month

Following this guideline will help ensure reliable equipment operation.

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. Gas-phase filtration systems are commercially available.

## 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 size 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 may have the following detrimental effects on hardware reliability:

- The increased heat load per unit volume in some cases 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 to the increased intake of gaseous contaminants.
- 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 contaminations.
- The decreased spacing between printed circuit board features at different voltages increases the possibility of dust and gases causing ion migration and/or creep corrosion 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 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 the 2009 white paper that recommended that in addition to temperature-humidity control, dust and gaseous contamination should also be monitored and controlled. The additional environmental measures recommended in the 2009 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:

- Papers have recently reported copper creep corrosion on circuit boards (Cullen and O'Brien 2004; Mazurkiewicz 2006; Mukadam et al. 2006; Schueller
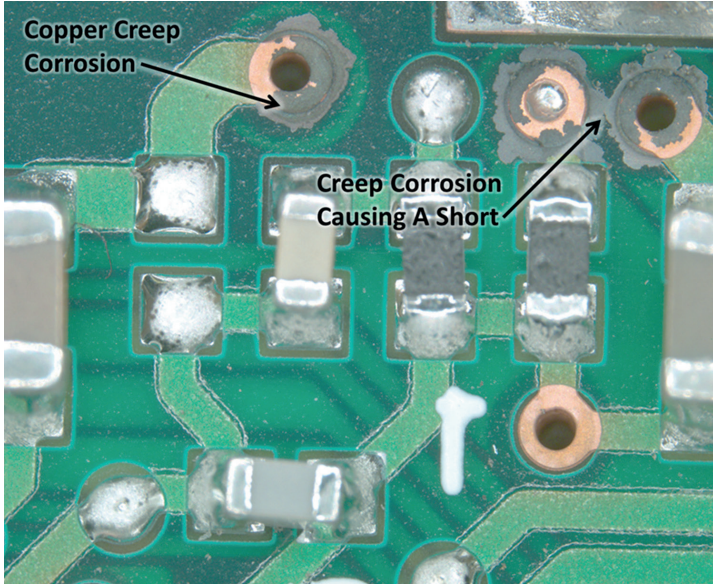
**Figure 1**     Example of copper creep corrosion on a lead-free circuit board.

2007; Xu et al. 2007). The two common circuit board types suffering from copper creep corrosion are those with an immersion silver (ImAg) finish and, to a lesser extent, those with an organic solderability preservative (OSP) coating. The sulfur-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, as shown in Figure 1.

- 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 which undermine the integrity of the package. With the integrity of the package breached, the underlying silver is exposed 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 2.

It should be noted that the reduction of circuit board feature sizes and the miniaturization of components, necessary to improve hardware performance, also makes the hardware more prone to attack by the corrosive particles and gases in the data center environment. Manufacturers are in a constant struggle to maintain the reliability of their ever-shrinking hardware. Therefore, the need to control data center
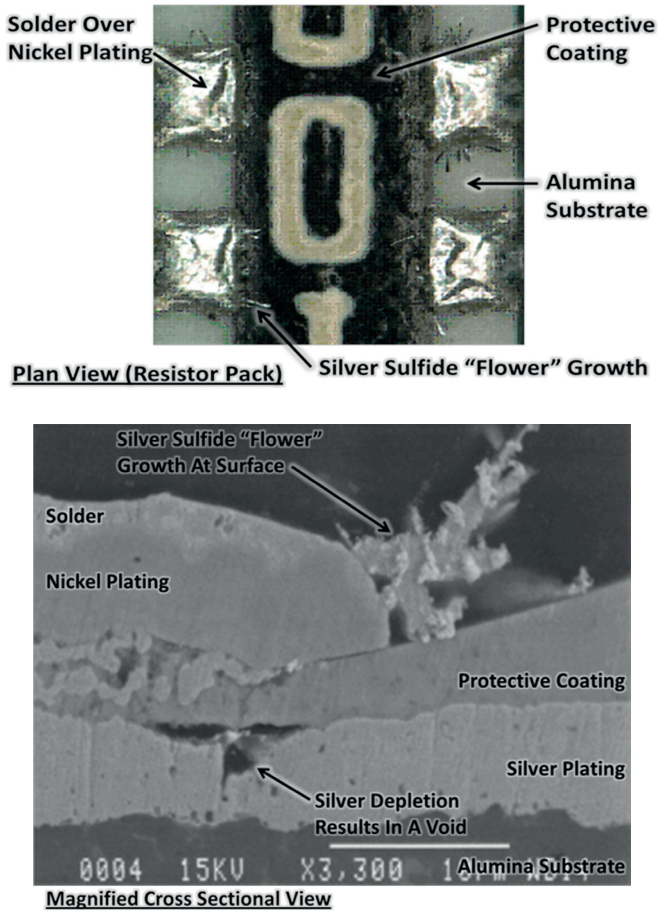
**Figure 2**    (Top) plan view and (bottom) magnified cross-sectional view of an example of a component failure due to an environment high in sulfur-bearing gases attacking the silver metallization in the component, producing silver sulfide "flowers."

airborne contaminants and to specify their recommended acceptable limits is becoming critical to the continued reliable operation of IT equipment.

## AIRBORNE DUST

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

- *Mechanical effects.* Mechanical effects include obstruction of cooling airflow, interference with moving parts, abrasion, optical interference, interconnect

interference, or 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 the 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 sulfur- and chlorine-bearing salts. The source of this harmful dust is mainly outdoor dust in the size range 2.5–15 µm for coarse dust and 0.1–2.5 µm for fine dust (Comizzoli et al. 1993). Coarse dust particles have a 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 mi) inland or farther by high winds present in coastal areas and can damage electronic devices at this range (Bennett et al. 1999; Crossland and Wright 1973).

One mechanism by which dust degrades the reliability of printed circuit boards involves the absorption of moisture from the environment by the settled dust. 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 electrical short circuiting of closely spaced features via ion migration. Figure 3 shows an example of copper corrosion caused by dust settled on a printed circuit board.

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, thereby degrading hardware reliability. A study by Comizzoli et al. (1993) for various locations worldwide showed that leakage current due to dust that 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 within 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 control the humidity in the room may increase the levels of 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 data centers. Even low concentrations of these salts can be serious corrosion and ion migration threats. These humidifier-related
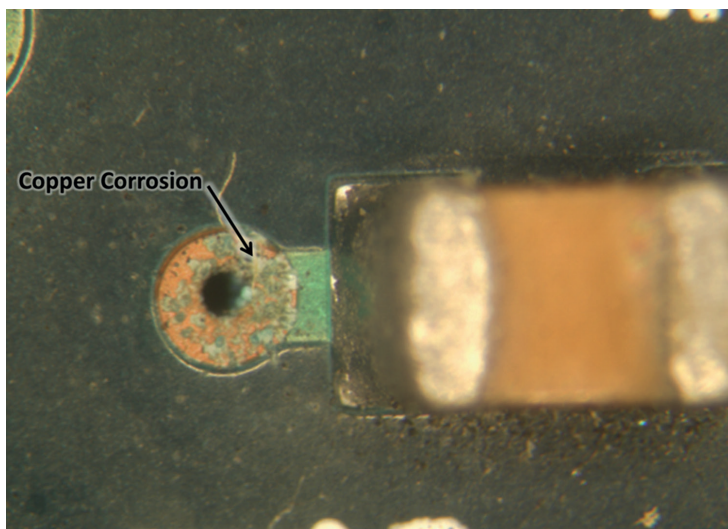
**Figure 3**     Corrosion of a plated through hole because of wetted ionic dust high in magnesium chloride.

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

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

In summary, most dust is benign. Corrosion and/or ion migration problems may arise under rare circumstances 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 a data center should be kept below 60% to avoid dust corroding the hardware.

Another form of particulate contamination very detrimental 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 1–2 mm (0.04–0.08 in.) in length, 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 with the use of 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 whiskers. To confirm the presence of zinc whiskers, specimens should be collected using carbon adhesive tabs and viewed in 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 has become the dominant, worldwide standard for classifying the cleanliness of air in terms of concentration of airborne particles (ISO 1999). Table 1 provides maximum concentration levels for each ISO class (ASHRAE 2009b).

ASHRAE recommends that data centers 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 level may be achieved simply by specifying the following means of filtration:

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

For data centers utilizing free air cooling or air-side economizers, the choice of filters to achieve ISO class 8 level of cleanliness depends on the specific conditions present at that data center. In general, air entering a data center may require use of MERV 11 or, preferably, MERV 13 filters.

## GASEOUS CONTAMINATION

Sulfur-bearing gases, such as sulfur dioxide ($SO_2$) and hydrogen sulfide ($H_2S$), are the most common gases causing corrosion of electronic equipment (Rice et al. 1981). An example of corrosion, due to gaseous contamination, on a circuit board compliant with the Restriction of Hazardous Substances Directive (RoHS) (EU 2003) is shown in Figure 1.

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. 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 copper, but the combination of these gases with other gases such as nitrogen dioxide ($NO_2$) and/or ozone ($O_3$) are very corrosive (Volpe 1989). The corrosion rate of copper is a strong function of relative

### Table 1   ISO 14644-1 (ISO 1999) Air Cleanliness Classification vs. Maximum Particle Concentrations Allowed (particles/m³)

| ISO CLASS | Maximum Number of Particles in Air (Particles in Each Cubic Meter Equal to or Greater Than the Specified Size) | | | | | |
|---|---|---|---|---|---|---|
| | Particle size, µm | | | | | |
| | >0.1 | >0.2 | >0.3 | >0.5 | >1 | >5 |
| Class 1 | 10 | 2 | | | | |
| Class 2 | 100 | 24 | 10 | 4 | | |
| Class 3 | 1000 | 237 | 102 | 35 | 8 | |
| Class 4 | 10,000 | 2370 | 1020 | 352 | 83 | |
| Class 5 | 100,000 | 23,700 | 10,200 | 3520 | 832 | 29 |
| Class 6 | 1,000,000 | 237,000 | 102,000 | 35,200 | 8320 | 293 |
| Class 7 | | | | 352,000 | 83,200 | 2930 |
| 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 (3) significant figures be used in determining the classification level.

humidity, while the corrosion rate of silver has lesser dependence on humidity (Rice et al. 1981).

A very convenient and quantitative way to determine the corrosivity of air in a data center 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 coulometric reduction to classify the environment into one of four severity levels, described in Table 2. According to ISA-71.04, the copper corrosion rate should be less than 300 Å/month for an environment sufficiently well controlled such that corrosion will not be a factor in determining equipment reliability. But the use of copper coupon alone has two major limitations: One is that copper is not sensitive to chlorine, a contaminant particularly corrosive 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 corrosive contributions of gaseous contaminations and relative humidity. 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.

The 2009 ASHRAE particulate and gaseous contamination white paper recommended that copper and silver corrosion rates should be less than 300 Å/month to minimize the impact of corrosion on IT equipment reliability. This position was based partly on an unpublished survey that compared the copper and silver corrosion

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

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

rates in data centers with and without reported corrosion-related hardware failures. The study concluded that the data centers with copper and silver corrosion rates <300 Å/month had a low probability of corrosion-related hardware failures and that silver corrosion rate is a better indicator than copper corrosion rate of the reliability impact of gaseous contamination (Singh et al. 2009).

In mid-2010, some members of ASHRAE TC 9.9, representing the IT equipment manufacturers, started a year-long survey of equal numbers of data centers with and without corrosion-related hardware failures. The results of the survey thus far are shown in Figure 4. The silver corrosion rates in data centers that have reported corrosion-related hardware failures rates are above about 200 Å/month; whereas, those with no reported corrosion-related hardware failures have silver corrosion rates below about 200 Å/month. Copper corrosion rates, on the other hand, for data centers with and without corrosion-related hardware failures show significant overlap, though in general the copper corrosion rates are higher in data centers with corrosion-related hardware failures. The ASHRAE data center survey will continue for a few more months, but there is enough evidence to conclude that the maximum corrosion rate of silver should be reduced to 200 Å/month to ensure that corrosion is not a factor determining hardware reliability.

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, but as a data center's history increases, monitoring may be limited to the months with known high levels of gaseous contamination. The reactive monitoring method requires that the copper coupons and silver coupons be exposed for one month in order to obtain a good measure of the corrosivity of the environment. Air-side economizers increase the reliability risk in data centers. In data centers with air-side economizers, supplemental real-time monitoring is recommended to enable quick reaction to outdoor events that may introduce corrosive gases into the data centers.
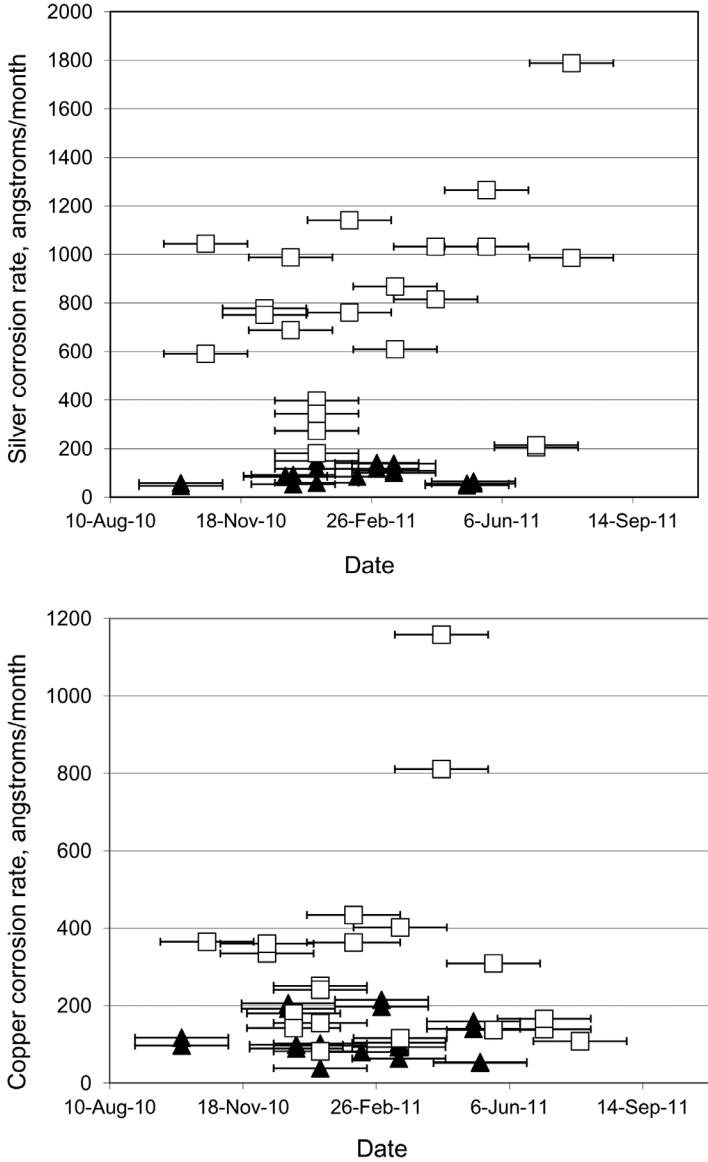
**Figure 4** The open square data points are for data centers with known corrosion-related hardware failures. The solid triangle data points are for data centers with no known corrosion-related hardware failures. Notice that the silver corrosion rates for data centers with and without corrosion-related hardware failures show no overlap; whereas, the copper corrosion rates for the two types of data centers show some overlap.

Real-time monitoring is also recommended in data centers with gas-phase filtration air-cleaning systems in order to track the efficiency of the filters. 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 electrical resistance increase of metal thin films.

Figure 5 is an example of a corrosion monitor based on silver thin-film resistance change tracking the corrosion rate on an hourly basis in a data center. Notice the association between the silver corrosion rate and the concentrations of $SO_2$ and $NO_2$ and fine dust in the outdoor air. The silver corrosion rate (slope of corrosion product thickness versus time in top plot of Figure 5) is very low between noon and 8 p.m. and high (approximately 2500 Å/month) between 8 p.m. and noon the next day. This example illustrates the power of real-time monitoring in helping to understand the source of the contamination. With real-time monitoring, changes in gaseous corrosivity can be detected quickly to allow preventive measures, such as shutting off outside corrosive air from entering the data center.

## GAS-PHASE FILTRATION OF AIR IN DATA CENTERS

For data centers with or without air-side economizers that do not fall within the modified ISA-71.04 (ISA 1985) severity level G1 for copper (<300 Å/month) and silver (<200 Å/month) corrosion, gas-phase filtration is recommended. The blowers at the air inlet, fitted with particulate and gas-phase filters, can be used to fill the data center with clean air and to pressurize it to prevent contaminated outdoor air from leaking into the data center. The air in the data center can 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.

The result of a recent example of implementation of gas-phase filtration in a contaminated data center is shown in Figure 6. The silver corrosion rate of about 1000 Å/month was brought down to levels well below 100 Å/month by pressurizing the data center with gas-phase filtered air and by replacing the particle filters in the computer room air conditioners with gas-phase filters. Notice that the copper corrosion rates in this data center, like those in many other data centers with reported hardware corrosion, were well within the ISA-71.04 (ISA 1985) severity level G1.

## THERMAL GUIDELINES FOR DATA PROCESSING ENVIRONMENTS— EXPANDED DATA CENTER CLASSES AND USAGE GUIDANCE

ASHRAE TC 9.9 published the supplemental white paper, "2008 ASHRAE Environmental Guidelines for Datacom Equipment—Expanding the Recommended Envelope" and updated it in 2011 to provide greater flexibility in facility operations, particularly with the goal of reduced energy consumption in data centers, by expanding the recommended operating temperature-humidity environmental envelope (ASHRAE 2008, 2011).
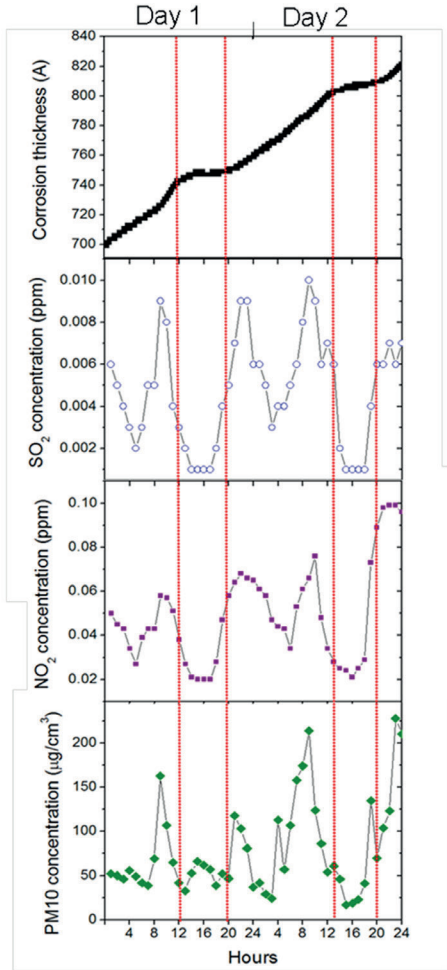
**Figure 5**    Silver corrosion thickness, $SO_2$, $NO_2$, and dust level as a function of time of day in a data center.

The purpose of the recommended envelope is to give guidance to data center operators on maintaining high reliability and operating their data centers in the most energy efficient manner.

In addition to the recommended envelope is the allowable envelope in which IT manufacturers verify that their equipment will function. Typically, manufacturers perform a number of tests prior to announcement of a product to verify that it meets all the functionality requirements within the allowable 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.
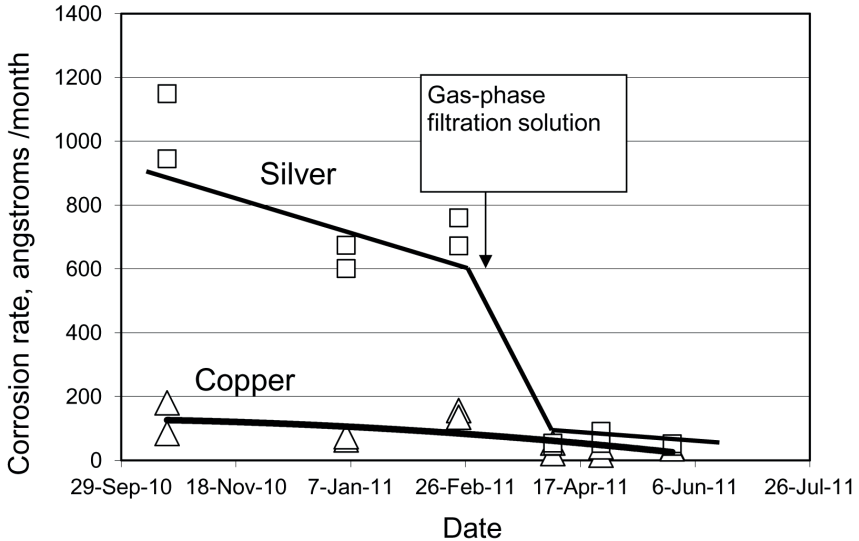
**Figure 6**    Gas-phase filtration solution to a contaminated data center.

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 and 2011 expanded recommended operating envelope is the agreed-upon envelope that is acceptable to all the IT manufacturers, and operation within this envelope will not compromise overall reliability of the IT equipment. The previous 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 portion of IT equipment racks. The inlet air temperature in many data centers tends to be warmer at the top portion 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 portion of the rack.

The recommended upper limit of 60% relative humidity in the 2008 and 2011 white papers on thermal guidelines for data processing environments arises from the following:

• Corrosion products, such as oxides, may form and protect the metal and slow down the corrosion rate. In the presence of gaseous pollutants, such as $SO_2$

### Table 3    ASHRAE Recommended Environment for Temperature and Moisture (ASHRAE 2008, 2011)

|  | 2004 Version | 2008/2011 Version |
| --- | --- | --- |
| 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% relative humidity | 5.5°C (41.9°F) dew point |
| High-end moisture | 55% relative humidity | 60% relative humidity and 15°C (59°F) dew point |

and $H_2S$, and ionic pollutants, such as chlorides, the corrosion-product films are less protective, allowing corrosion to proceed somewhat linearly. When the relative humidity in the data center is greater than the deliquescent relative humidity of the corrosion products, such as copper sulfate, cupric chloride, and the like, the corrosion-product films get wet, dramatically increasing the rate of corrosion. Cupric chloride, a common corrosion product on copper, has a deliquescent relative humidity of about 65%. In a data center with relative humidity greater than 65%, the cupric chloride would absorb moisture, get wet, and aggravate the copper corrosion rate.

• Dust is ubiquitous. Even with our best filtration efforts, fine dust will be present in a datacenter and will settle on electronic hardware. Fortunately, most dust has particles with high deliquescent relative humidity, which is the relative humidity at which the dust absorbs enough water to become wet and promote corrosion and/or ion migration. 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 datacenter, the dust will absorb moisture, get wet, and promote corrosion and/or ion migration, degrading hardware reliability. A study by Comizzoli et al. (1993) for various locations worldwide showed that leakage current due to dust that 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.

In summary, mission-critical data center equipment should be protected from corrosion by keeping the relative humidity below 60% and by limiting the particulate and gaseous contamination concentration to levels at which the copper corrosion rate is <300 Å/month and the silver corrosion rate is <200 Å/month. The less than 60% relative humidity requirement may be relaxed in clean data centers relatively free of sulfur-bearing gaseous contamination and particulate contamination with high deliquescent relative humidity.

Given these reliability concerns, data center operators need to pay close attention to the overall data center humidity and local condensation concerns, especially when running economizers on hot/humid summer days. When operating in polluted geographies, data center operators must also consider particulate and gaseous contamination, because the contaminants can influence the acceptable temperature and humidity limits within which data centers must operate to keep corrosion-related hardware failure rates at acceptable levels. Dehumidification, filtration, and gas-phase filtration may become necessary in polluted geographies with high humidity.

## SUMMARY

The recent increase in the rate of hardware failures in data centers high in sulfur-bearing gases—due to copper creep corrosion on printed circuit boards and corrosion of silver in some miniature surface mount components—highlighted by the number of recent publications on the subject, led to the need for the original 2009 white paper on particulate and gaseous contamination in data centers that recommended 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.

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

- The room air may be continuously filtered with MERV 8 filters as recommended by ASHRAE Standard 127 (2007a).
- Air entering a data center may be filtered with MERV 11 to MERV 13 filters as recommended in *Particulate and Gaseous Contamination in Datacom Environments* (ASHRAE 2009b).

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 ISA-71 (ISA 1985) that meets

- a copper reactivity rate of less than 300 Å/month, and
- a silver reactivity rate of less than 200 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. For a summary of recommendations, see Table 4.

## Table 4  Summary of Recommended Acceptable Environmental Limits

### Recommended Operating Environment[1, 3]

| | |
|---|---|
| Temperature | 18°C (64.4°F) to 27°C (80.6°F)[3] |
| Low-end moisture | 5.5°C (41.9°F) dew point |
| High-end moisture | 60% relative humidity or 15°C (59°F) dew point |
| Gaseous contamination | Severity level G1 as per ISA 71.04 (ISA 1985) which states that the reactivity rate of copper coupons shall be less than 300 Å/month (= 0.0039 $\mu g/cm^2 \cdot h$ weight gain)[5]. In addition, the reactivity rate of silver coupons shall be less than 200 Å/month (= 0.0024 $\mu g/cm^2 \cdot h$ weight gain)[6]. The reactive monitoring of gaseous corrosivity should be conducted approximately 2 in. (5 cm) 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 with or without air-side economizers must meet the cleanliness level of ISO class 8.<br>2. The deliquescent relative humidity of the particulate contamination should be more than 60%[2].<br>3. Data centers must be free of zinc whiskers[4].<br>4. For data center without air-side economizer, the ISO class 8 cleanliness may be met simply by the choice of the following filtration:<br>  a. The room air may be continuously filtered with MERV 8 filters<br>  b. Air entering a data center may be filtered with MERV 11 or preferably MERV 13 filters.<br>5. 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. In general, air entering a data center may require to be filtered using MERV 11 or preferably MERV 13 filters. |

### Recommended Non-Operating Environment[3]

| | |
|---|---|
| Temperature | 10°C–43°C (50°F–109.4°F) |
| Relative humidity | 8% to 80% |
| Wet bulb | Less than 23°C (73°F) |
| Gaseous contamination | Severity level G1 as per ISA 71.04 (ISA 1985) which states that the reactivity rate of copper coupons shall be less than 300 Å/month (=0.0039 $\mu g/cm^2 \cdot hour$ weight gain)[5]. In addition, the reactivity rate of silver coupons shall be less than 200 Å/month (= 0.0024 $\mu g/cm^2 \cdot hour$ weight gain)[6]. The reactive monitoring of gaseous corrosivity should be conducted approximately 2 in. (5 cm) 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 lower corrosivity reading than if the machine was operating. |

**Table 4    Summary of Recommended Acceptable Environmental Limits**

**Recommended Non-Operating Environment[3] (continued)**

| | |
|---|---|
| Particulate contamination | 6. Data centers with or without air-side economizers must meet the cleanliness level of ISO class 8. |
| | 7. The deliquescent relative humidity of the particulate contamination should be more than 60%[2]. |
| | 8. Data centers must be free of zinc whiskers[4]. |
| | 9. For data center without air-side economizer, the ISO class 8 cleanliness may be met simply by the choice of the following filtration: |
| |   a. The room air may be continuously filtered with MERV 8 filters |
| |   b. Air entering a data center may be filtered with MERV 11 or preferably MERV 13 filters. |
| | 10. 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. In general, air entering a data center may require to be filtered using MERV 11 or preferably MERV 13 filters. |

Notes:
1. Gaseous contamination is measured approximately 2 in. (5 cm) 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 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 $Cu_2S$ and $Cu_2O$ 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 $Ag_2S$ is the only corrosion product.

## REFERENCES

ASHRAE. 2007. ANSI/ASHRAE Standard 127-2007, *Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners*. Atlanta: American Society of Heating, Refrigeration and Air-Conditioning Engineers.

ASHRAE. 2008. 2008 ASHRAE environmental guidelines for datacom equipment—Expanding the recommended environmental envelope. TC 9.9 white paper, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, GA.

ASHRAE. 2009a. Particulate and gaseous contamination guidelines for data centers. TC 9.9 white paper, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, GA.

ASHRAE. 2009b. *Particulate and Gaseous Contaminants in Datacom Environments*. Atlanta: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

ASHRAE. 2011. 2011 Thermal guidelines for data processing environments—Expanded data center classes and usage guidance. TC 9.9 white paper, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, GA.

Bennett, H.E., R.L. Peck, D.K. Burge, and J.M. Bennet. 1999. Formation and growth of tarnish on evaporated silver films. *Journal of Applied Physics* 40(8):3351–60.

Brusse, J., and M. Sampson. 2004. Zinc whisker: Hidden cause of equipment failure. *IT Professional* 6(6):43–6.

Crossland, W.A., E. Knight, and C.R. Wright. 1973. The accelerated tarnish testing of contacts and connectors employing silver alloy contacts. *19th Annual Proceedings of the Holm Conference on Electrical Contact Phenomena*, Chicago, IL, pp. 265–82.

Comizzoli R.B., R.P. Frankenthal, R.E. Lobnig, G.A. Peins, L.A. Psato-Kelty, D.J. Siconolfi, and J.D. Sinclair. 1993. Corrosion of electronic materials and devices by submicron atmospheric particles. *The Electrochemical Society Interface* 2(3):26–34.

Cullen, D., and G. O'Brien. 2004. Implementation of immersion silver PCB surface finish in compliance with Underwriters Laboratories. *IPC Printed Circuits Expo*, SMEMA Council APEX Designers Summit 2004, Anaheim, CA. pp. 23–37.

EU. 2003. Restriction of Hazardous Substances Directive (RoHS). European Union.

Hillman C., J. Arnold J., S. Binfield, and J. Seppi. 2007. Silver and sulfur: Case studies, physics and possible solutions. *SMTA International Conference Proceedings*, Orlando, FL.

ISA. 1985. ANSI/ISA 71.04-1985, *Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants*. The Research Triangle Park, NC: Instrumentation, Systems, and Automation Society.

ISO. 1999. ISO 14644-1, *Cleanrooms Associated Controlled Environments—Part 1: Classification of Air Cleanliness*. Geneva, Switzerland: International Organization for Standardization.

Lahtinen, R., and T. Gustafsson. 2005. The driving force behind whisker growth. *Metal Finishing* 103(12):33–6.

Mazurkiewicz, P., 2006. Accelerated corrosion of PCBs due to high levels of reduced sulfur gases in industrial environments. *Proceedings of the 32nd ISTFA*, Austin, TX, Nov 12–16.

Miller, S.K. 2007. Whiskers in the data center. *Processor* 29(30).

Mukadam, N., N. Armendariz, and R. Aspandi. 2006. Planar microvoiding in lead-free second level interconnect solder joints. *SMTA Proceedings*, Chicago, IL, pp. 293.

Ortiz, S. 2006. Data center cleaning services. *Processor* 28(14):4.

Reid, M., J. Punch, C. Ryan, J. Franey, G.E. Derkits, W.D. Reents, and L.F. Garfias. 2007. The corrosion of electronic resistors. *IEEE Transactions on Components and Packaging Technologies* 30(4):666–72.

Rice, D.W., P. Peterson, E.B. Rigby, P.B.P. Phipps, R.J. Cappell, and R. Tremou-
reux. 1981. Atmospheric corrosion of copper and silver. *Journal of the Elec-
trochemical Society* 128(2):275–84.

Sahu, A. K. 2007. Present scenario of municipal solid waste dumping grounds in
India. International Conference on Sustainable Solid Waste Management,
Chennai, India, September 5–7.

Schueller, R. 2007. Creep corrosion of lead-free printed circuit boards in high sul-
fur environments. *SMTA International Proceedings*, Orlando, FL, October.

Singh, P., Z.Q. Zhang, G.U. Kuo, and G. Luo. 2009. IBM Corporation. Private
communication.

Veale, R. 2005. Reliability of PCB alternate surface finishes in a harsh industrial
environment. *SMTA International Proceedings*, Chicago, IL.

Volpe, L. 1989. Environmental factors in indoor corrosion of metals. IBM Internal
Technical Report, Armonk, NY.

Xu, C., D. Flemming, K. Demerkin, G. Derkits, J. Franey, and W. Reents. 2007.
Corrosion resistance of PWB final finishes. APEX 2007, Los Angeles, CA.

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

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 Standard 71.04 (ISA 1985) reports corrosion rates in terms of the rate of increase of corrosion product thickness in Å/month.

The relationship of the two rates for silver corrosion is derived below. In this calculation, it is assumed that $Ag_2S$ is the only corrosion product and that the density of $Ag_2S$ is 7.23 $g/cm^3$.

Silver specimen weight gain of

$$1\,\mu g \equiv \frac{2 \times 107.9 + 32}{32}\mu g \text{ of } Ag_2S$$

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

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

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

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

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

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

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

If we assume that the silver corrosion product is mostly $Ag_2S$, then 200 Å/month rate of corrosion product growth is equivalent to 0.0026 µg/cm²·h rate of weight gain.

The relationship of the two rates for copper corrosion is derived below. In this calculation, it is assumed that $Cu_2S$ is the only corrosion product and that the density of $Cu_2S$ is 5.6 g/cm³.

Copper specimen weight gain of

$$1\,\mu g \equiv \frac{2 \times 63.55 + 32}{32}\mu g \text{ of } Cu_2S$$

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

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

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

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

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

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

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

The relationship between the two rates for copper corrosion is derived below. In this calculation, it is assumed that $Cu_2O$ is the only corrosion product and that the density of $Cu_2O$ is 6 g/cm³.

Copper specimen weight gain of

$$1\,\mu g \equiv \frac{2 \times 63.55 + 16}{16}\mu g \text{ of } Cu_2O$$

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

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

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

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

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

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

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

If we assume that copper corrodes to $Cu_2S$ and $Cu_2O$ in equal proportions we can estimate the relation of the two rates of copper corrosion as follows:

$$1 \ \mu g/cm^2 \cdot h \equiv 8.6 \times 10^4 \ \text{Å}/30 \ \text{days}$$

If we assume that the copper corrosion product is 50% $Cu_2S$ and 50% $Cu_2O$, then 300 Å/month rate of corrosion product growth is equivalent to 0.004 $\mu g/cm^2 \cdot h$ rate of weight gain. Then, 300 Å/month rate of corrosion product growth is equivalent to 0.0035 $\mu g/cm^2 \cdot h$ rate of weight gain.

## APPENDIX B—
## MEASURING THE DELIQUESCENT RELATIVE HUMIDITY OF DUST

Dust should be lifted off the easily accessible surfaces of the computers in the data center, collected in clean plastic bags, and shipped to an analysis laboratory. The dust should be sprinkled on the interdigitated areas of a surface insulation resistance (SIR) test circuit board (part number IPC-B-24 obtained from IPC vendors listed in the website http://www.ipc.org/ContentPage.aspx?pageid=Test-Board-Vendors) shown in Figure B1. The spacing between the interdigitated combs is 0.5 mm (0.02 in.). The sprinkled dust should bridge the 0.5 mm gap. The circuit board should then be placed in a humidity chamber with a starting relative humidity of about 20% at room temperature and a 10 V bias applied across the interdigitated combs. The relative humidity should be raised at a constant rate from 20% to 90% over the period of a week and the leakage current between the interdigitated combs plotted as a function of time. The relative humidity at which the leakage current rises sharply is the deliquescent relative humidity of the dust.
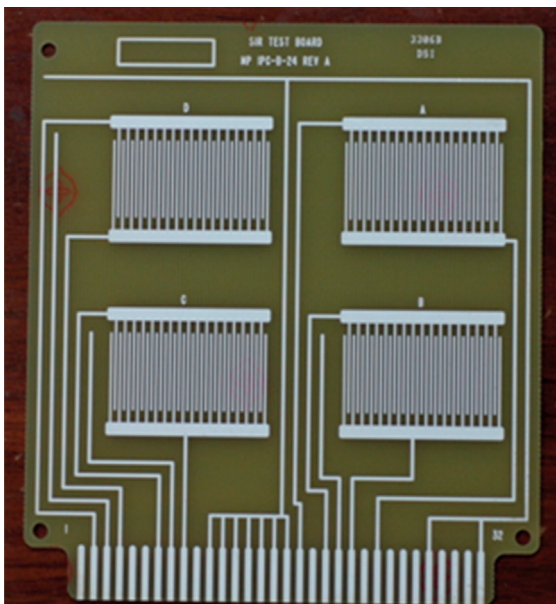


**Figure B1**    Test circuit board (part number IPC-B-24).