

**Ernest Orlando Lawrence
Berkeley National Laboratory**

**Air Corrosivity in U.S. Outdoor-Air-Cooled Data Centers is
Similar to That in Conventional Data Centers**

Part of the DOE Roadmap for Compressorless Cooling in Data Centers

Henry C. Coles, Taewon Han, Phillip N. Price, Ashok J. Gadgil and
William F. Tschudi

Lawrence Berkeley National Laboratory

March 2011 Rev.

Lawrence Berkeley National Laboratory
One Cyclotron Road
University of California
Berkeley, California 94720

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.

Acknowledgements

This work was supported by the California Energy Commission (CEC) Public Interest Energy Research (PIER) Program and by the Assistant Secretary for Energy Efficiency and Renewable Energy of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Lawrence Berkeley National Laboratory is grateful to the following companies or entities for participating in the corrosion coupon measurement study.

- Digital Realty Trust, San Francisco, California,
- NetApp, Sunnyvale, California
- Internal Revenue Service, Fresno California Campus
- Sybase, Inc., Dublin, California,
- Cisco Systems, Inc., San Jose, California,
- Gap, Inc., Data Center, Rocklin California,

Please cite this report as follows:

Coles, H.C., Han, T., Price, P. N., Gadgil, A.J. and Tschudi, W.F., *Air Corrosivity in U.S. Outdoor-Air-Cooled Data Centers is Similar to That in Conventional Data Centers.*, Department of Energy (EERE), March 2011 Rev.

Contents

1	ABSTRACT	5
2	EXECUTIVE SUMMARY	7
3	INTRODUCTION	10
4	OBJECTIVES.....	11
5	METHODS	12
6	RESULTS	17
7	CONCLUSIONS and RECOMMENDATIONS.....	21
8	REFERENCES.....	24
9	APPENDIX A: Data Center Locations Tested in the United States.....	26
10	APPENDIX B: Data Center Locations Tested in India	27
11	APPENDIX C: Coupon Placement Examples.....	28

1 ABSTRACT

There is a concern that environmental-contamination caused corrosion may negatively affect Information Technology (IT) equipment reliability. Nineteen data centers in the United States and two in India were evaluated using Corrosion Classification Coupons (CCC) to assess environmental air quality as it may relate IT equipment reliability. The data centers were of two basic types: “closed” and outside-air cooled. A closed data center provides cool air to the IT equipment using air conditioning in which only a small percentage of the recirculation air is “make-up” air continuously supplied from outside to meet human health requirements. An outside-air cooled data center uses outside air directly as the primary source for IT equipment cooling. Corrosion measuring coupons containing copper and silver metal strips were placed in both “closed” and outside-air cooled data centers. The coupons were placed at each data center (closed and outside-air cooled types) with the location categorized into three groups: 1) “Outside” - coupons sheltered, located near or at the supply air inlet, but located before any filtering, 2) “Supply” - starting just after initial air filtering continuing inside the plenums and ducts feeding the data center rooms, and 3) “Inside” located inside the data center rooms near the IT equipment. Each coupon was exposed for thirty days and then sent to a laboratory for a corrosion rate measurement analysis.

The goal of this research was to investigate whether gaseous contamination is a concern for U.S. data center operators as it relates to the reliability of IT equipment. More specifically, should there be an increased concern if outside air for IT equipment cooling is used? To begin to answer this question limited exploratory measurements of corrosion rates in operating data centers in various locations were undertaken. This study sought to answer the following questions:

- (1) What is the precision of the measurements?
- (2) What are the approximate statistical distributions of copper and silver corrosion rates in the sampled data centers?
- (3) To what extent are copper and silver corrosion measurements related?
- (4) What is the relationship of corrosion rate measurements between outside-air cooled data centers compared to “closed” data centers?
- (5) How do corrosivity measurements relate to IT equipment failure rates?

The data from our limited sample size suggests that most United States data center operators should not be concerned with environmental gaseous contamination causing high IT equipment failure rates even when using outside-air cooling.

The research team recommends additional basic research on how environmental conditions, specifically gaseous contamination, affect electronic equipment reliability.

Keywords: data center contamination, gaseous contamination, air-side economizer, corrosion coupon, IT equipment reliability, copper corrosion rate, silver corrosion rate, free-air cooling, outside-air cooling, silver corrosion coupon, copper corrosion coupon, corrosion classification coupon

2 EXECUTIVE SUMMARY

Introduction

Data center electricity use is estimated to be growing 12% annually. A large fraction of electricity used in data centers is for compressor-based cooling of information technology (IT) equipment. As the cost of electric power increases and data center designers strive for lower operational cost, direct use of outside air for IT equipment cooling is becoming more prevalent. Recent demonstrations have shown that direct use of outside air is a viable alternative to compressor-based cooling (e.g. using chilled-water) in many environments where United States data centers are located. However, some operators of data centers are concerned that the use of outside air for cooling poses an increased IT equipment failure risk caused by airborne contamination. In fact there are anecdotal reports of corrosion induced failures in data centers. All such reports that we are aware of are either from the developing world or near sources of unusually large amounts of corrosive gases.

ASHRAE's Technical Committee (TC) 9.9 Mission Critical Facilities, Technology Spaces, and Electronic Equipment published a white paper in 2009 entitled Gaseous and Particulate Contamination Guidelines for Data Centers. That paper has raised concerns with data center designers and operators by stating that there is a recent increase in IT equipment failures associated with airborne pollutants. While this reliability concern is an important subject, a casual interpretation of the white paper may cause unwarranted concern for managers of operating data centers in the United States.

Airborne contamination can be split into two distinct categories, particulate and gaseous. Particulate contamination can be easily controlled using commonly available filters (Shehabi et al., 2008 and Shehabi et al., 2010) and is considered to be a controllable issue as filtration guidelines are included in ASHRAE data center guide books. As a result most data centers already have proper filtering in place. The remaining concern over gaseous contamination effects has been raised more recently. Removal of lead from printed wiring board (PWB) construction in IT equipment as mandated by the RoHS legislation has led to constructions using silver-based materials that are more prone to corrosion.¹ When using outside air for cooling data center IT equipment there is concern that there may be an increase in failure rates due to corrosion, specifically creep-corrosion caused shorting, initiated by exposure to gaseous contamination.

¹ Restriction of Hazardous Substances (RoHS), The RoHS [directive](#) adopted in 2003 by the European Union took effect on 1 July 2006... This directive restricts the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment.

Objective

The main objective of the project was to determine if the concern of increased corrosion caused failures of IT equipment is warranted for data centers located in the United States. In particular should data center operators in the U.S. be concerned if they are using outside-air cooling or are planning data centers that will use outside-air cooling. Such use of “free” cooling in most climates significantly improves overall data center energy efficiency. In addition the research team analyzed the data collected in an attempt to better understand the CCC method.

Methods

The project started with a literature review of studies relating environmental conditions and electronic equipment failures. Past significant investigations from the 1980’s (Battelle) and others were not successful with finding root cause gaseous contamination mixtures that cause electronic equipment failures.

To help with finding the latest information and research on the subject of environmental contamination and electronic failures some major IT equipment and component manufacturers provided research recommendations.

The relationship of environmental conditions causing IT equipment failures is complex and includes a number of parameters that need to be considered: corrosive gas types, mixtures of corrosive gases, combinations of gas concentrations, catalytic gases, temperature and humidity. In addition the materials and feature-size design rules for PWB’s change continuously. Also, many of the papers reviewed describe accelerated condition type tests exposing samples to very high levels of corrosive gases that would cause failures in days or weeks. This approach creates the additional estimation step of predicting how actual conditions, at much lower gas concentrations, affect IT equipment failure rates. The situation is further complicated by the fact that equipment deployment durations have been reduced over time compared to 20 plus years ago when much of the original research was completed.

The electronics industry developed a method to measure and evaluate copper corrosion rates. This method is termed “reactivity monitoring”. The method exposes a copper corrosion classification coupon (CCC) to the environment for a month or more and analyzes the corrosion product thickness using cathodic/electrolytic reduction to classify the environment into one of four severity levels (ANSI/ISA-71.04-1985). The measurements are used to assess the corrosivity of the IT equipment environment. In recent years especially after the RoHS mandate there has been an increased interest in measuring corrosion associated with the change in PWB construction from using lead-based to silver-based materials. Therefore the current common CCC contains copper and silver metal strips.

Data center operators have not published corrosion rate data, therefore we selected a number

of data centers across the United States to conduct a limited exploratory test of IT equipment environments inside data centers using the CCC method. The research team performed the exploratory study of 19 data centers in the United States. Two additional data centers in India were added because of recent anecdotal reports that some developing countries may have elevated IT equipment corrosion risk caused by high pollution levels in some locations. A number of CCC's containing one copper and one silver strip each were deployed for 30 days in each data center.

The goal of the study was to investigate the following questions:

- (1) What is the precision of the measurements?
- (2) What are the approximate statistical distributions of copper and silver corrosion rates in the sampled data centers?
- (3) To what extent are copper and silver corrosion measurements related?
- (4) What is the relationship of corrosion rate measurements between outside-air cooled data centers compared to "closed" United States data centers?
- (5) How do corrosivity measurements relate to IT equipment failure rates in the United States?

Results

The results of the study indicate:

- (1) Measurements within the same data center frequently differed by a factor of 2 or more.
- (2) Copper and silver coupon corrosion rates measured in our limited study were low in the United States compared to rates that are thought to be problematic per the current industry guidelines.
- (3) Silver corrosion rates were poorly correlated with copper corrosion rates.
- (4) Copper corrosion rates were not higher for outside-air-cooled data centers than for "closed" data centers. Silver corrosion rates were not higher in most air-cooled data centers, but one data center had high silver corrosion measurements.
- (5) Data centers with relatively high silver corrosion rates reported no unusual equipment failure rates, although detailed analysis of this question is not possible because only one data center in the sample had high silver corrosion rates.

Conclusions

Most United States data center operators need not be concerned with environmental gaseous contamination causing high IT equipment failure rates even when using outside-air cooling. Reactivity monitoring measurements used to assess the corrosiveness of gaseous contamination had poor precision at the low levels of contamination we encountered. Higher corrosion measurement rates may produce better relative precision but adequate data

needed to analyze this was not available. The copper compared to silver coupon measurements across all data centers tested are not well correlated. The lack of quantitative failure data did not allow IT equipment failure rates to be correlated with reactivity monitoring measurements.

3 INTRODUCTION

Data center electricity use is estimated to be growing 12% annually, making it the fastest-growing end-use of electricity. A large fraction of electricity used in data centers is for compressor-based cooling of IT equipment in data centers (Brill, 2007). As the cost of electric power increases and data center designers strive for lower operational cost, direct use of outside air for IT equipment cooling is becoming more prevalent. Direct use of outside air is often a viable alternative to chilled-water cooling in many environments (Sorell, 2007). Some reports suggest that 20 to 30 percent of the total electrical energy can be saved when outside air is used for cooling compared to a “closed” data center that uses much less outside air.

However, there is concern that the use of outside air for cooling will cause a higher frequency of the most commonly found damage of metallic components in the electronic manufacturing industry. This damage has been known to be the result of copper or silver corrosion on circuit boards from the effects of gaseous pollutants (Lopez et al., 2007; Reid et al., 2007; Veleva et al., 2008; Vargas et al., 2009). Gaseous corrosion-induced equipment failure would occur on the timescale of months, not hours (John, 1996).

ASHRAE’s Technical Committee (TC) 9.9, published a white paper in 2009 entitled Gaseous and Particulate Contamination Guidelines for Data Centers (ASHRAE, 2009). That paper raised concerns with data center designers and operators by stating that there is a recent increase in IT equipment failures, due in part to the Restriction of Hazardous Substances Directive (RoHS), associated with airborne pollutants (Cullen 2004; Veale 2005; Schueller 2007; Hillman 2007; Xu 2007; Mazurkiewicz 2006). A casual interpretation of the white paper may cause an unwarranted high level of concern for managers of operating data centers in the United States (Han et al., 2010), especially those using or planning to use outside-air as the primary cooling medium for IT equipment.

Airborne contamination can be split into two distinct categories, particulate and gaseous. Particulate contamination can be controlled using commonly available filters; filtration guidelines are included in ASHRAE data center guide books. As a result most data centers already have proper filtering in place. The remaining concern over gaseous contamination, and possible corrosion caused failures, has been raised more recently.

The electronics industry developed a method to measure and evaluate copper corrosion rates affected by the environment. This method is termed “reactivity monitoring” also referred to

as the corrosion classification coupon (CCC) method and is described in ANSI/ISA-71.04. But the use of copper coupons alone has some limitations including: copper is not sensitive to chlorine, a particularly corrosive contaminant to many metals; and copper corrosion may be overly sensitive to relative humidity (Rice et al., 1981).

Removal of lead from IT equipment PWB construction mandated by the RoHS requirements was implemented in 2006. This added complexity to finding the root cause of corrosion because there was a change in PWB design from lead-based to silver-based materials. This change added considerably to the interest in silver related corrosion issues and prompted the addition of silver to the common reactivity monitoring method in hopes that silver might be a better indicator of failure rates compared to using copper only.

Since no reports consisting of coupon readings in data centers located in the United States have been published by data center operators, due to business reasons, we selected a number of data centers across the United States to conduct limited exploratory testing using corrosivity monitoring.

It should be noted that there are anecdotal reports of corrosion induced failures in data centers. All such reports that we are aware of are either from the developing world or near sources of unusually large amounts of corrosive gases.

4 OBJECTIVES

The main objective of the project was to determine if the concern of increased corrosion caused failures of IT equipment is warranted for data centers in the United States and should data center operators be concerned if they are using outside-air cooling or are planning data centers that will use outside-air cooling. After a review of the literature and discussion with industry experts an exploratory survey of environmental corrosivity using reactivity monitoring at data centers located mostly in the United States was planned. In addition the research team analyzed the data collected in an attempt to characterize the CCC method.

A number of questions were developed to assist with reaching the objectives, guide the data center site selection and coupon placement within each data center.

Question(1) - *What is the precision of the measurements?*

To assess the precision of coupon readings and assist with statistical analysis, one site was selected and 5 coupons were placed in one computer equipment cold aisle within 30 feet of each other. In addition 4 coupons were sent in for analysis without exposure to obtain a "background" level.

Question(2) - *What are the approximate statistical distributions of copper and silver corrosion rates in the sampled data centers?*

Because of recently implemented European RoHS regulations, some exposed PWB materials have transitioned from lead-based to silver-based. In the past copper corrosion rate was

considered the best measure of corrosion risk and currently only copper corrosion rate limits are listed in the ISA guidelines for IT equipment reliability. However with the recent shift to the use of silver-based materials there is now a question of whether silver corrosion rate is a better indicator of IT equipment corrosion risk.

Question(3) - *To what extent are copper and silver corrosion measurements related?*

Since silver corrosion coupon measurements are of increasing interest some standards setting bodies are considering updating ANSI/ISA-71.04-1985 guidelines by adding silver to severity level descriptions. Some propose using the same numerical limits for silver as currently exist for copper.

Question(4) - *What is the relationship of copper and silver corrosion rate measurements between outside-air cooled data centers compared to "closed" data centers?*

A key question is whether data centers using large amounts of outside air for cooling have more risk of IT equipment failures compared to "closed" data centers.

Question(5) - *How do corrosivity measurements relate to IT equipment failure rates?*

An important question is, do data centers with various copper or silver corrosion rate measurements experience a noticeable difference in IT equipment failure rates?

5 METHODS

The project started with a literature review of studies relating environmental conditions and electronic equipment failures. Past significant investigations from the 1980's (Battelle) and others were not successful with finding root cause gaseous contamination mixtures that cause electronic equipment failures.

The number of variables relating gaseous contamination to IT equipment failures is large and includes: gas types, mixtures of gases, combinations of gas concentrations, catalytic gases, temperature and humidity. In addition printed wiring board (PWB) materials and feature-size design rules change continuously. For example in 2006 the RoHS rules for electronic materials came into effect causing solder-based PWB materials to be phased out and replaced in some cases with silver-based materials. The combination of these variables makes finding a single or simple multivariate root cause difficult. Also, many of the papers reviewed describe accelerated condition type tests exposing samples to very high levels of corrosive gases that would cause failures in days or weeks. This approach creates the additional estimation step of predicting how actual conditions, at much lower gas concentrations, affect IT equipment failure rates. The situation is further complicated by the fact that equipment deployment durations have been reduced compared to 20+ years ago when much of the original research was completed.

To help with finding the latest information and research on the subject of environmental contamination and electronic failures an industry advisory group of major IT equipment and component manufacturers provided research recommendations. The guidance and

information obtained from this group were very valuable in developing the research approach and achieving the results.

The information provided by the advisory group and other organizations such as IPC Association Connecting Electronics Industries 3-11g Corrosion of Metal Finishes Task Group and iNEMI (International Electronics Manufacturing Initiative) Creep Corrosion Project Working Group confirmed our initial findings and thoughts relating to the complexity of finding a root cause. The research team concentrated on developing a plan to assess the severity of possible problems associated with gaseous contamination and IT equipment failures in the United States

The common way to determine the gaseous-caused corrosion risk in data centers is the “reactivity monitoring” method described in ANSI/ISA-71.04-1985. This method exposes a copper Corrosion Classification Coupon (CCC) to the environment for a month or more and analyzes the *copper* corrosion product thickness using cathodic/electrolytic reduction to classify the environment into one of four severity levels:

- G1 (Mild, <300Å/month-corrosion is not a factor in determining equipment reliability)
- G2 (Moderate, 300-1000 Å/month, corrosion may be a factor in determining equipment reliability)
- G3 (Harsh, 1000-2000 Å/month, high probability that corrosive attack will occur),
- GX (Severe, >2000Å/month, only specially designed and packaged equipment would be expected to survive).

But the use of copper coupons alone has some limitations including: copper is not sensitive to chlorine, a particularly corrosive contaminant to many metals; and copper corrosion may be overly sensitive to relative humidity. The industry is considering putting more importance on using silver corrosion measurement coupons as a potential failure indicator due to the unconfirmed belief that silver coupon measurements may better predict the failure of electronic equipment. As mentioned earlier the removal of lead from PWB construction in IT equipment mandated by RoHS requirements was implemented in 2006. This led to the use of silver-based replacing lead-based materials and new processes that may not protect adjacent metal structures or are more prone to create silver corrosion products themselves compared to previous constructions. Therefore 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 (ASHRAE TC 9.9, 2009).

The research team decided to use the CCC method with copper and silver metal strips to survey a number of data center sites primarily mostly in the United States with the idea to

obtain an initial idea of the environmental corrosiveness present, using the most common measurement method, in typical data centers in the United States

The team with the help of data center operators performed a limited exploratory study of 19 data centers in the United States and two in India. A number of coupons containing one copper and one silver strip were deployed for 30 days in each data center. The survey is limited as it covers one 30 day period at each of 21 data centers between the dates August through November 2010. A more comprehensive survey should include measurements spanning at least a complete calendar year and is suggested for further studies to account for seasonal changes that may affect the environment and therefore the corrosion rate of the coupons.

Coupon Measurement

The use of metal coupons is the best known and simplest of all corrosion monitoring techniques. At least two companies offer coupons and the required analysis; we selected Purafil. The method involves exposing a coupon specimen to the environment for a given duration (e.g. 30 days). Following exposure, the specimens were analyzed. The magnitude of corrosion film, or corrosivity, was quantified by corrosion growth rate as angstroms (\AA)/30 days. In addition the analysis can provide some information regarding what type of contaminate was the likely caused of most of the corrosion growth. Under the scope of this project, the research team was not able to analyze this information, but the data is available and this type of analysis is recommended for future studies. Each coupon set (copper and silver) is attached to a Plexiglas support (approximately 4" x 3" x 1/4") and coupon number, date, and location information recorded on the transmittal label (Figure 1). In order to minimize any background corrosion, coupons are provided packed in a zip-lock plastic bag with a Purafil Sachet that acts as a scavenger for any ambient contamination that may have been sealed inside the bag with the coupon. After the exposure period the coupons are repackaged in the original plastic bag with the Sachet and returned for analysis.



Figure 1 – Unexposed Corrosion Classification Coupon Containing Copper and Silver Metal Strips

The standard method for analyzing corrosion coupon is called cathodic/electrolytic reduction. The thickness of the corrosion film is determined by Purafil's laboratory analysis. The results of the report included a photograph of the returned coupon, ISA Environmental Classification, and film thickness/30 days.

Coupon placement

The total number of coupons available was 100 and a plan for the coupon quantity per data center cooling type was developed. The strategy for most sites was to place 4 coupons at each data center; 2 just after the incoming outside-air filter for outside-air cooled data centers and "closed" data centers and 2 coupons inside the data center room typically in a cold aisle area and in the hot aisle or at the grill for the room return air. In one data center we decided to place a higher number of coupons at all of the three location categories as defined below.

The coupons were placed at each data center site in three location types:

- **"Outside"** – the coupons were exposed to non- filtered air located at the building exterior air intake location feeding the data center room or ducting leading to the data center being surveyed. For these locations the coupons were typically sheltered by the building façade overhang structures. The measurements of this type were mostly limited to the one data center that had the high number of coupon placements. The data centers tested did not have air-to-air heat exchangers separating the Outside air from the Inside air.
- **"Supply"**-air path between the Outside air inlet and data center room supply point – these coupons were located inside ductwork and hallway type rooms where data center supply air was being transferred and/or temperature controlled using louver systems in the case of outside-air cooled data centers. Some measurements were taken just after the filters for the air supplied from the outside. Some measurements were taken at the inlet grill just as the air enters the data center room, these measurements are considered to be "Supply" type.
- **"Inside"** – the coupons were exposed to cold aisle and hot aisle locations near the IT equipment and some coupons were located at room return duct locations.

Measurements collected from Outside and Supply location types were thought to be of interest for the purpose of investigating a possible corrosivity change as the air comes in contact with surfaces during transport from the outside or source to the data center room. Also of interest was seeing if coupon measurements taken Outside were significantly different than those measured Inside. Understanding something about Outside measurements relative to those Inside the data center room may help evaluate potential data center sites.

The coupons were mounted using wire or aluminium duct tape and removed after 30 days. Appendix C has images showing mounting and location examples. Four coupons were not installed and exposed at a data center site but were used as “base-line” or background readings. These background coupons were removed from the zip-lock bag for a very short period, a matter of minutes, to record location information on the label and resealed. These coupons were then sent back to Purafil after a holding period of 30 days for analysis.

6 RESULTS

The results of analyzing the reactivity monitoring measurements from 21 data centers follow. Figure 2 shows the copper and silver measurement for all coupons used and recovered. The location type Outside, Supply or Inside is shown by letter O, S or I respectively. The “unexposed” or background measurements are indicated by “B”. The measurements from outside-air cooled data centers have a circle around the location type indicator. Observations are:

- Some measurements from coupons exposed in data centers for 30 days were below the background or unexposed coupon measurements.
- Large silver measurement ranges are associated with small copper measurement ranges.
- Large copper measurement ranges are associated with small silver measurement ranges.

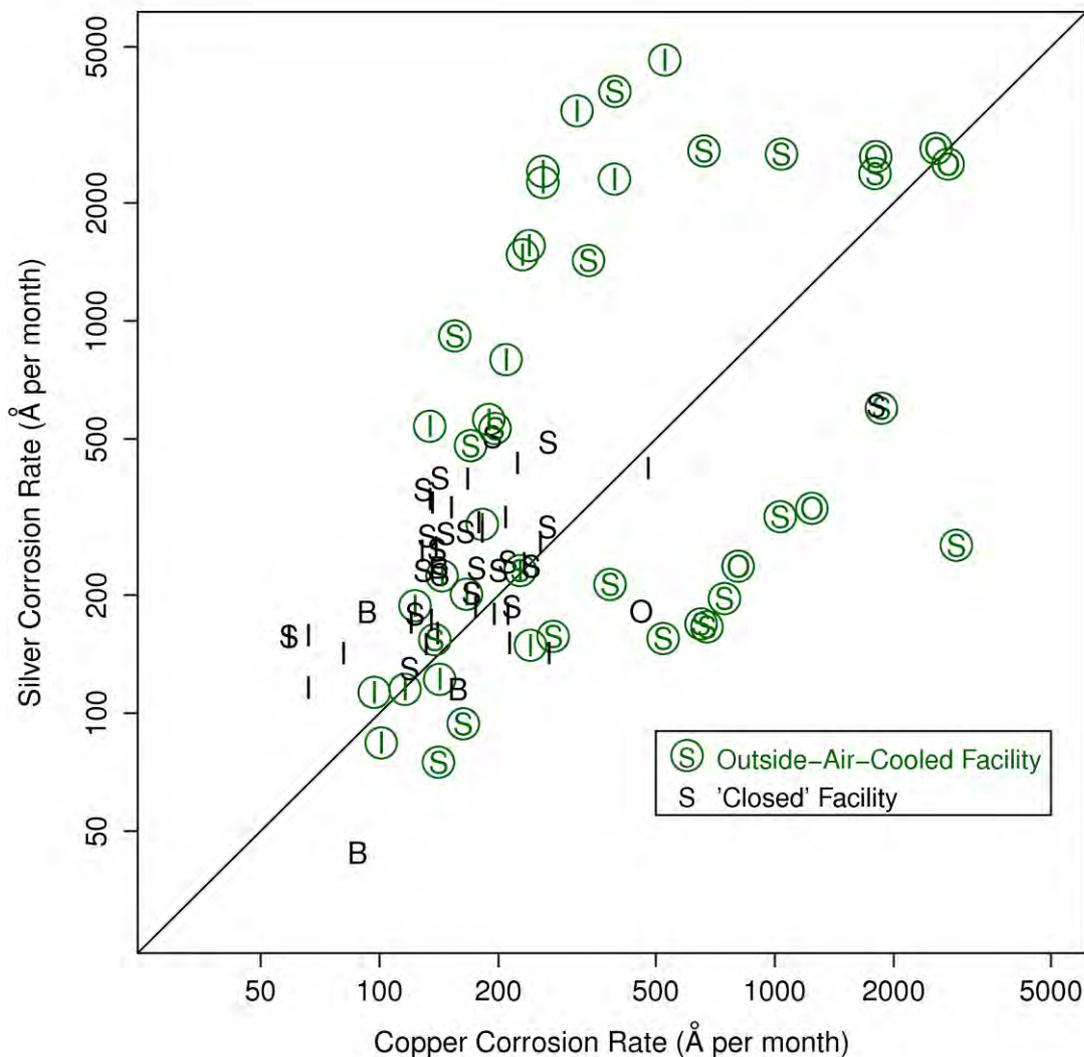


Figure 2 - Measurements From All Data Centers Including All Location Categories, Measurements from Outside-Air Cooled Data Centers are Circled Background or Unexposed Indicated by “B”, Outside Indicated by “O”, Supply indicated by “S”, Inside Indicated by “I”

Figure 3 shows the “Inside” only copper and silver measurement for all coupons recovered. The data center identification number is plotted and indicates the measurement value for each coupon. Observations are:

- All copper corrosion rate measurements are below the levels thought to be problematic.
- The correlation between silver and copper corrosion “Inside” rate measurements is poor. The best-fit relationship is shown by the dashed line. Many points fall far off the line, implying that one cannot use a copper corrosion rate measurement to accurately predict the silver corrosion rate measurement in the same facility, or even on the same coupon. (Technical note: the best-fit power-law relationship is linear, and the silver corrosion rate is, on average, 1.4 times the copper corrosion rate. However, the value of R^2 for the fit in log space is only 0.33).
- Note: The highest 7 silver “Inside” measurements came from one (#2) United States data center.

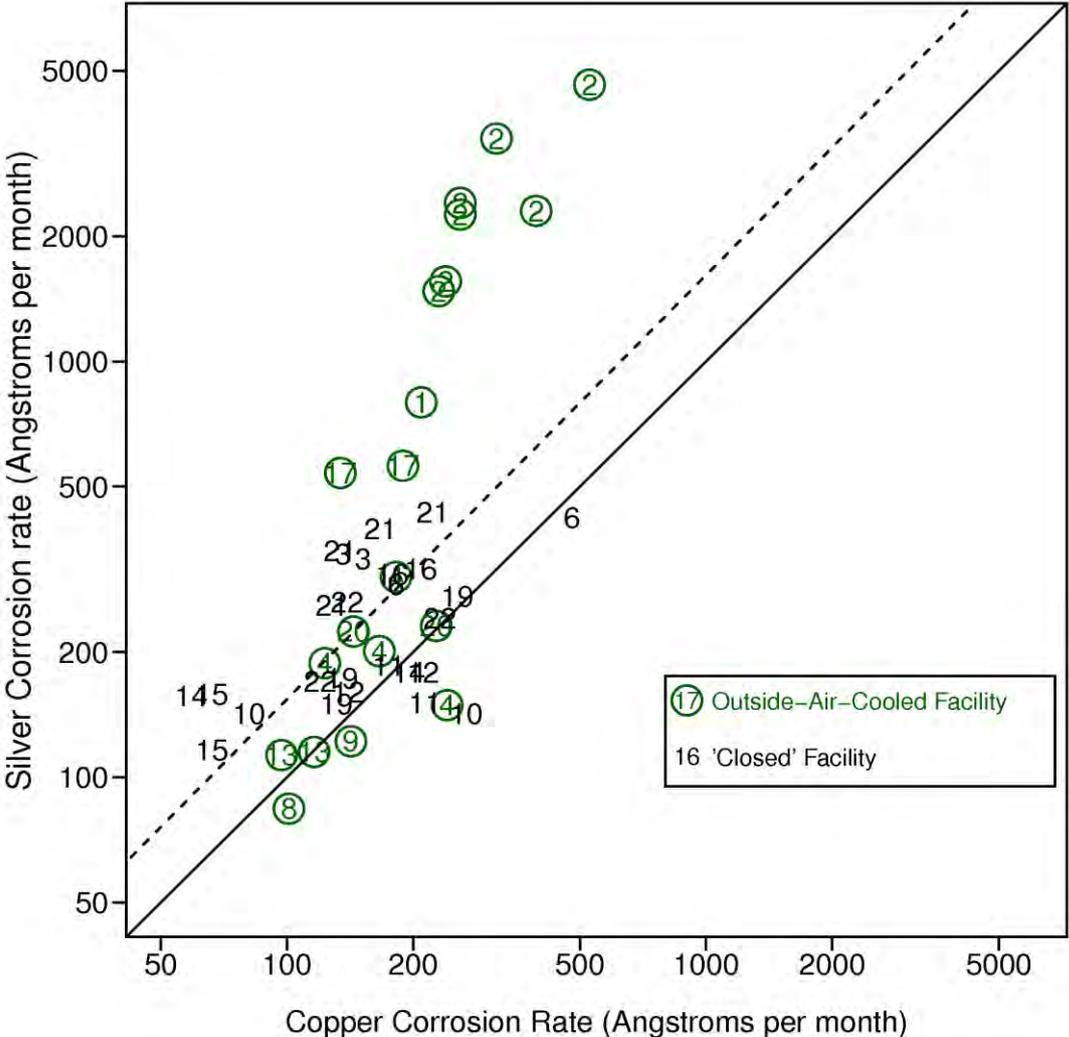


Figure 3 - Measurements From "Inside" Only, Data Center ID Number Located to Indicate Copper and Silver Measurement For Each Coupon, Numbers are Circled for Data Centers Using Outside-Air Cooling, Data Center ID#5 was Not Assigned.

Figure 4 shows the copper and silver measurement for all coupons recovered listed by data center identification. The location type either Outside, Supply or Inside is shown by letter O, S or I. Background measurements are indicated with "B". Observations are:

- Outdoor (Outside) corrosion measurements were made at data centers 1, 2, 8, and 11. In all cases, the copper corrosion rate was much higher Outside than Inside: the ratio of average Outside to average corrosion Inside rate was 12, 7, 8, and 2.4. For silver, the ratio was 3.5, 1.0, 2.8, and 1.1.
- In 75% of data centers, the average copper corrosion rate was higher in the air Supply system than in Inside, and in half of the data centers the ratio of Supply-side to Inside corrosion rate exceeded 1.5; in 25% of centers, the ratio exceeded 2.8. Similarly, in 75% of data centers the average silver corrosion rate was higher in the Supply system than in the Inside, and in half the ratio exceeded 1.3; in 25% of centers, the ratio exceeded 1.8.
- The variation of copper corrosion rates among data centers is lower in the Inside than in the air Supply system: the standard deviation of copper corrosion rate is 63 angstroms/month in the Inside, and 590 angstroms/month in the Supply system. For silver, the standard deviations are 546 angstroms/month for Inside and 602 angstroms/month in the Supply system.

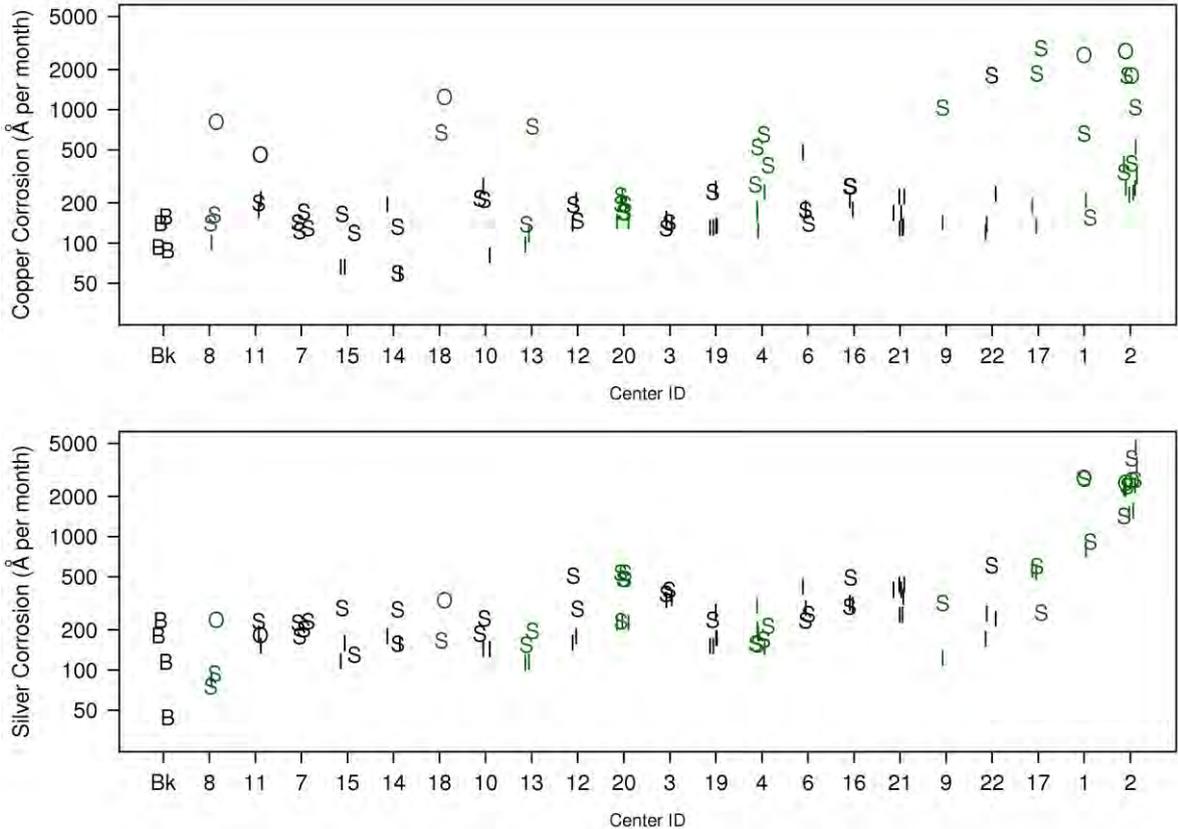


Figure 4 - All Measurements Sorted by Combined Average of Copper and Silver Measurements and Identified by a Data Center ID#, Background or Unexposed Indicated by "B", Outside Indicated by "O", Supply Indicated by "S", Inside Indicated by "I"; ID Number Does Not Correspond to Listing Sequence in Appendix A. Data Center ID#5 was Not Assigned.

The results as they address the original questions are:

What is the precision of the measurements?

If two measurements are made at the same location at the same time, they should ideally yield the same result. If they do not, the measurements are said to be *imprecise*. Even if measurements are precise, they may not be *accurate*. We have no way to assess the accuracy of the coupon measurements, but the precision can be assessed by examining: (1) the variation in measurements among 5 coupons placed within 6m (20ft) of each other in the same cold aisle of one data center; (2) the variation among the 4 unexposed or “background” coupons; and (3) the variation among coupons that were placed in the same data center. All of these approaches yield roughly the same result: two corrosion rate measurements in the same data center have about a 20-30% chance of differing by more than a factor of 2, for either copper or silver at these apparently low corrosion rate levels. Even the coupons that were for the most part kept sealed (unexposed) in their bags, and might be expected to have little or no corrosion and consistent measurements, had highly variable measurements; in fact, the highest silver measurement was more than five times higher than the lowest, and was higher than the measurement from many coupons that were placed in data centers for a month. It may be that higher corrosion readings would have much better relative precision but the team did not have an adequate quantity of high corrosion measurements from a controlled environment.

What are the approximate statistical distributions of copper and silver corrosion rates in the sampled data centers?

The average corrosion rate in each facility was calculated, for both copper and silver. Most facilities have an average Inside copper corrosion rate between 125-200 Å/month, and an Inside silver corrosion rate between 140-350 Å/month. These corrosion rates are considered safe per the ANSI/ISA-71.04-1985 guidelines. Note that silver corrosion rate severity levels are not currently included in the ANSI/ISA guidelines.

To what extent are copper and silver corrosion measurements related?

The correlation between silver and copper corrosion rate Inside measurements is poor, as can be seen in Figure 3. The correlation if all measurements location types are considered is much lower. The best-fit relationship for Inside measurements is shown in Figure 3 by the dashed line. Many points fall far off the line, implying that one cannot use a copper corrosion rate measurement to accurately predict the silver corrosion rate measurement in the same facility, or even on the same coupon. (Technical note: the best-fit power-law relationship is linear, and the silver corrosion rate is, on average, 1.4 times the copper

corrosion rate (indicated by the dotted line in Figure 3). However, the value of R^2 for the fit in log space is only 0.33).

What is the relationship of corrosion rate measurements between outside-air cooled data centers compared to “closed” data centers?

In our data, the statistical distribution of copper corrosion rate measurements is comparable in the two types of data centers. The statistical distribution of silver corrosion rate measurements has approximately the same median in both types of data centers, but is more variable in outside-air-cooled data centers than in “closed” data centers. The highest and lowest silver corrosion rate measurements were in outside-air-cooled facilities. However, the sample includes only 9 outside-air-cooled facilities and only facility #2 (see Figure 3 and 4), which is outside-air-cooled, has notably high silver corrosion measurements. It is possible that the high corrosion measurements in this facility are unrelated to the use of outside air for cooling.

How do corrosivity measurements relate to IT equipment failure rates?

Quantitative failure data are not available. The data centers participating in this survey report no unusual failure rates during or in the few months after the survey, even in data center #2 with its relatively high silver corrosion rate (1500-4600Å/30 days).

7 CONCLUSIONS and RECOMMENDATIONS

Conclusions

Most facilities in the study, including outside-air-cooled facilities, did not have elevated corrosion rates, so even if measured corrosion rates do correlate with failure rates, the use of outside-air cooling does not seem problematic for most data centers in the United States. One data center had elevated silver measurements; there is the possibility these were caused by a one-time or very-low-frequency event, and an investigation looking for a cause and additional environmental corrosivity measurements at this site are in process at the time of this report.

Quantitative data on failure rates are not available for the data centers in our study, so a correlation between reactivity monitoring coupon measurements and IT equipment failure rates could not be determined. The low precision of the measurements, at the corrosion rates in our data and the apparent lack (according to the data center operator) of an elevated equipment failure rate in the only facility with a high measured silver corrosion rate, suggest that corrosion coupon measurements may not be useful for predicting equipment failure rates for most data centers. Possibly there would be a relationship if corrosion rates were higher, but at the observed rates the time to a corrosion-induced failure may be longer than

the normal equipment replacement period.

The reactivity coupon measurements were imprecise at the low safe levels found. Two corrosion rate measurements in the same data center have about a 20-30% chance of differing by more than a factor of 2, for either copper or silver. The occurrence of similar, or in some cases higher corrosion measurements from coupons that were kept sealed inside their bags compared to 30 day exposures in data centers implies that corrosion measurements may be inaccurate, at least at relatively low corrosion rates such as those in our study.

In our data, the statistical distribution of copper corrosion rate measurements is comparable between closed and outside-air cooled data centers. The statistical distribution of silver corrosion rate measurements has approximately the same median in both types of data centers, but is more variable in outside-air-cooled data centers than in "closed" data centers. Except for one data center (#2) the coupon measurements inside all data centers tested ranged from 59Å/month to 527Å/month for copper and 84Å/month to 797Å/month for silver. These corrosion rates are not thought to be problematic per the ANSI/ISA-71.04-1985 guidelines.

Copper and silver corrosion measurements can differ substantially, which is not surprising since these elements react differently to corrosive gases. There is some correlation between these measurements, suggesting that the coupons are in fact measuring something real about the corrosivity of the environment, in spite of the substantial measurement errors.

The data indicates that the copper and silver coupon corrosion rates are lower Inside the data center equipment rooms compared to the rates found in the Supply air plenums and ducts and much lower than measurements taken from Outside air.

Additional Comments:

- (1) There is considerable concern over the use of outside air for cooling data centers. Industry experts disagree on the severity of the concern.
- (2) There currently is no public information on failure rates of IT equipment due to contamination. There is no publicly available data linking use of outside air cooling with equipment failure rates. Anecdotal evidence suggests that equipment failures have occurred inside data centers that were closed.
- (3) Industry is attempting to determine gas mixtures and concentrations that could cause failures in IT equipment or could be used as an industry approved accelerated test of IT equipment components.
- (4) No standard indicators or guidelines for silver corrosion and its effect on electronics have been determined.

Recommendations

The corrosion classification coupon (CCC) method of assessing IT equipment environments for corrosion induced failure risk is economical and the most common practical method. This method is likely to gain popularity as more data center designers consider designs incorporating outside-air cooling. Considering the coupon measurement variation along with other interesting observations from the small amount of data collected in our study additional studies are suggested to better understand the CCC method and further quantify correlations as they relate to IT equipment housed in United States data centers. A list of areas for future study follows.

- Basic research is needed to correlate gaseous contamination to IT equipment component failure rates.
- Research is needed to characterize and compare the current corrosively measurement methods and devices currently on the market.
- The current study indicates that the corrosivity of the air is reduced as it passes through plenums and ducts. This phenomenon could be investigated as an economical method to improve the IT equipment environment when harsh conditions exist.
- The limited number of corrosion coupon measurements of outside air indicates these measurements are much higher than what would be expected inside a data center equipment room. Additional understanding of this relationship could help site planners confirm the environmental safety of potential data center locations.
- Does the data center with the high silver coupon measurements continue to have high readings? Do the high readings correspond to the time of year or other phenomena?
- How do coupon measurements vary during a one year period? Our study was limited to a single 30 day exposure period at each data center during the time August to November 2010.
- What are the reactivity coupon measurement data at data centers experiencing high failure rates caused by corrosion? Contacts made during the end of this study indicate we may get access to failure information at sites outside of the United States experiencing corrosion caused failures.
- The industry is considering the addition of silver coupon levels to the ISA severity guidelines. A large number of coupons placed at more data centers may better quantify the correlation between silver and copper measurements. Our study included only one data center measured with a relatively large number of coupons.

8 REFERENCES

- ASHRAE Technical Committee (TC) 9.9 Mission Critical Facilities, Technology Spaces, and Electronic Equipment *Gaseous and Particulate Contamination Guidelines for Data Centers*, 2009.
- ANSI/ISA-71.04-1985, Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants, ANSI/ISA-The Instrumentation, Systems, and Automation Society, February 3, 1986.
- Brill, K.G. (2007) Data Center Energy Efficiency and Productivity, Uptime Institute, Inc., Santa Fe, NM, Final Report, 2007.
- Cullen, D. P. and O'Brien, G. (2004) Implementation of Immersion Silver PCB Surface Finish In Compliance With Underwriters Laboratories. IPC Printed Circuits Expo.
- Han, T., et.al. (2010) Should Data Center Owners be Afraid of Air-side Economizer Use? — A Review of ASHRAE TC 9.9 White Paper titled *Gaseous and Particulate Contamination Guidelines for Data Centers*. Lawrence Berkeley National Laboratory Technical Publications (<http://eetd.lbl.gov/ea/mills/ht/library.html>).
- Hillman, C. A., et.al. (2007) Silver and Sulfur: Case Studies, Physics and Possible Solutions. SMTA Inter., October, 2007.
- John, W.O. (1996) Corrosion-induced degradation of microelectronic devices, *Semicond. Sci. Technol.*, 11, 155-162.
- Lopes, B.G., et.al. (2007) Corrosion of metals at indoor conditions in the electronics manufacturing industry, *Anti-Corrosion Methods and Materials*, 54 (6), 354-359.
- Mazurkiewicz, P. (2006) Accelerated Corrosion of PCBs due to High Levels of Reduced Sulfur Gases in Industrial Environments. Proceedings of the 32nd ISTFA, November 12-16, 2006, Austin TX.
- Reid M., et al. (2007) The corrosion of electronic resistors, *IEEE Trans on Components and Packaging Technologies* 30(4): 666-672. Rice, D.W., et.al. (1981) Atmospheric Corrosion of Copper and Silver, *Electrochem. Soc.*, 128 (2), 275-284.
- Schueller, R. (2007) Creep Corrosion of Lead-Free Printed Circuit Boards in High Sulfur Environments. *SMTA International*, 2007.
- Shehabi, A., Horvath, A., Tschudi, W., Gadgil, A.J., and Nazaroff, W.W. (2008) Particle concentrations in data centers, *Atmospheric Environment*, 42, 5978-5990.
- Shehabi, A., Ganguly, S., Gundel, L.A., Horvath, A., Kirchstetter, T.W., Lunden, M.M., Tschudi, W., Gadgil, A.J., and Nazaroff, W.W. (2010) Can combining economizers with improved filtration save energy and protect equipment in data centers?, *Building and Environment*, 45, 718-726.
- Sorell, V. (2007) OA Economizers for Data Centers. *ASHRAE Journal*, December, 2007, 32-37.
- Vargas, O.L., et.al. (2009) The corrosion of silver in indoor conditions of an assembly process in the microelectronics industry, *Anti-Corrosion Methods and Materials*, 56(4):218-225.

Veleva, L., et.al. (2008) Atmospheric corrosion of electro-electronics metals in urban desert simulated indoor environment, *Corrosion Engineering Science and Technology*, 43(2):149-155.

Veale, R. (2005) Reliability of PCB Alternate Surface Finishes in a Harsh Industrial Environment. SMTA International, 2005.

Xu C., et.al. (2007) Corrosion resistance of PWB final finishes, Alcatel-Lucent, APEX, 2007.

9 APPENDIX A: Data Center Locations Tested in the United States

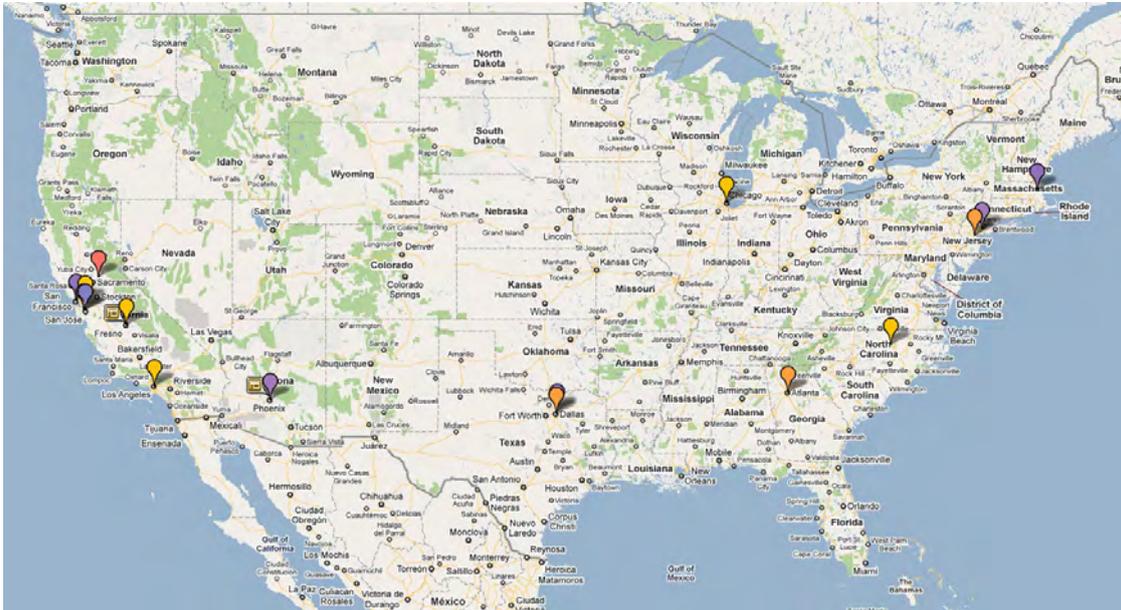


Figure 5 - Map of the U.S. Showing Data Center Locations Tested Using Corrosion Classification Coupons

Data center locations tested in the United States:

- San Francisco, California
- Dublin, California
- Silicon Valley, California
- Rocklin, California
- Fresno, California
- Los Angeles, California
- Phoenix, Arizona
- Chicago, Illinois
- Boston, Massachusetts
- Research Triangle Park, North Carolina
- Richardson, Texas
- Dallas, Texas
- Atlanta Georgia
- Piscataway, New Jersey

10 APPENDIX B: Data Center Locations Tested in India

Two data centers located in Bangalore India were tested using corrosivity monitoring.



Figure 6 - Map of India Showing the Location of Two Data Centers Tested Using Corrosion Classification Coupons

11 APPENDIX C: Coupon Placement Examples



Figure 7 - Typical Coupon Mounting - Example Shown is Immediately Downstream of Supply Air Filters as Found in Large Roof Top Fan Units



Figure 8 - Typical Coupon Mounting, Example Shown is Just Prior to Cooling Air Entering IT Equipment



Figure 9 - Typical Coupon Mounting, Example Shown at Data Center Room Supply or Return Grill