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Air-Side Economizer Cooling Is Safe for Most California Data Centers

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This report documents the results of testing the corrosivity of data center environments located primarily in California. Testing also included measurements from other locations in the United States and two in India through a DOE supported research project.

The research team is grateful to the following data center operators for their cooperation and participation:

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Cisco Systems, Inc., San Jose, California,

Gap, Inc. Data Center, Rocklin California,

In addition, during regularly scheduled meetings some large IT equipment and component manufacturers provided valuable information regarding recent and current industry research activities and provided key guidance for our study. Some of the IT equipment manufacturing companies wished to remain anonymous; to avoid inconsistency the research team decided to not list any of the IT equipment or IT component manufacturing companies participating in this project.

PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
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- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Air-Side Economizer Cooling Is Safe for Most California Data Centers is the final report for task 2.3 – Research related to the use of air economizers in the Data Center Energy Efficiency and Demonstration Project (contract number 500-09-002, conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to PIER's Industrial/Agricultural/Water End-Use Energy Efficiency Program).

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

There is a concern that environmental-contamination caused corrosion may negatively affect information technology (IT) equipment reliability. A limited exploratory study including ten data centers in California was completed using Corrosion Classification Coupons (CCC) to assess environmental air quality as it may relate IT equipment reliability. Nine centers in other parts of the United States and two in India were also evaluated through a synergistic project sponsored by DOE's Industrial Technology Program. The data centers tested were of two basic types: traditional "closed" (using a small amount of outside air for human health requirements) and outside-air cooled (using large amounts of outside air as the primary cooling medium for the IT equipment). Multiple coupons consisting of copper and silver metal strips used to assess the environmental corrosivity were placed for one thirty day period at the data centers and then sent to a laboratory for a corrosion rate measurement evaluation.

The goal of this research was to investigate whether gaseous contamination is a concern for California 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?

The measurements were compared to an environmental corrosivity classification standard. In addition other analyses of the data were performed to better understand the corrosion classification coupon test method to see if there is a difference in corrosivity measurements comparing "closed" and outside-air cooled data centers and to look for a relationship between corrosivity measurements and information technology equipment failure rates.

The data for the limited sample size shows that most California 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: outside-air cooling, copper coupon, silver coupon, data center environment, gaseous contamination, particulate contamination, free cooling, closed data center, air-side economizer, California data centers

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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 electricity increases and data center designers strive for lower operational cost, direct use of outside air for information technology equipment cooling is becoming more prevalent. Operating experience and 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 California environments where data centers are located. However, some data center operators 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 and have occurred in traditional "closed" data centers.

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 California and may discourage the use of air economizers.

Airborne contamination can be split into two distinct categories, particulate and gaseous. Particulate contamination can be easily controlled using commonly available filters and is considered to be controllable if filtration guidelines included in ASHRAE data center guide books are followed. As a result, most data centers already have adequate filtering in place. The remaining concern over gaseous contamination effects has been raised more recently. Removal of lead from printed wiring board construction in IT equipment as mandated by the removal of hazardous substances legislation that took effect in 2006 has led to constructions using silver-based materials that are more prone to corrosion. 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.

Purpose

The purpose of this study was to provide information to the data center community to encourage the use of air economizers, thus saving significant energy. Specifically, the study intended to find out if data center operators in California need to be concerned about gaseous contamination when using outside-air cooling in data centers. Industry standard corrosivity limits were identified and used in the analysis.

Objective

The main objective of the project was to determine if the concern of corrosion caused failures of IT equipment is warranted for data centers located in California. In particular whether data center operators in California should 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 California climates significantly improves overall data center energy efficiency. Since little research in this area of study has been undertaken, the possible research paths are extensive. This study was limited to determining a sampling of corrosion rates using existing corrosion measurement techniques. Additional analysis of the corrosion measurements were completed to better understand the measurement method and to see if IT equipment failure rates can be correlated to corrosivity measurements.

Conclusions and Recommendations

The data from our limited exploratory test indicate that most California data center operators need not be concerned with environmental gaseous contamination causing IT equipment failures 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. The copper coupon corrosion rates compared to silver coupon corrosion rate measurements across all data centers tested are not well correlated. There were no IT equipment failures reported in our study so failure rates could not be correlated with reactivity monitoring measurements.

The research team recommends further study using a larger sample with measurements spanning a complete year to account for seasonal variation. Basic research or access to field failure information is needed to correlate gaseous contamination constituents and concentrations to predict equipment failure rates.

CHAPTER 1: 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 electricity 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 air cooled with chilled-water in many environments (Sorell, 2007). Some reports show 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 failure rate 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 occurs 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 and filtration guidelines included in ASHRAE data center guide books. As a result most data centers already have adequate filtering in place. Prior PIER studies performed by LBNL have confirmed that the filtration specified in ASHRAE books adequately controls particulate contamination that could harm electronic circuits. The remaining concern over gaseous contamination, and possible corrosion caused failures, has been raised more recently.

The electronics industry previously developed a method to measure and evaluate copper corrosion rates affected by the environment. This method termed "reactivity monitoring" - also referred to as the corrosion classification coupon (CCC) method is described in ANSI/ISA-71.04. But the use of copper coupons alone has some limitations including the fact that 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 IT equipment beginning in 2006. This added complexity to finding the root cause of corrosion because there was a change in PWB designs 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 publically available reports of corrosion coupon readings in data centers located in California (or the United States) have been published by data center operators we selected a number of data centers in California and areas across the United States and conducted limited exploratory testing using the CCC monitoring method.

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 and they occurred in traditional "closed" data centers.

CHAPTER 2: Objective

The goal of this research was to investigate whether gaseous contamination is a concern for California and United States data center operators in general 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 these questions limited exploratory measurements, using the CCC method, in operating data centers were undertaken

A number of questions were developed to guide research to answer various hypotheses , 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 the 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 corrosion to severity level descriptions. Some propose using the same numerical limits for silver as currently exist for copper corrosion.

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 concern is whether California 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?

CHAPTER 3:
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 lead based solder- 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 project direction 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 with an emphasis on California.

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, <300 angstroms (Å)/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 yet to be confirmed belief that silver coupon measurements may better predict the failure of electronic equipment. As mentioned earlier the removal of lead from printed wiring board (PWB) construction in IT equipment mandated by RoHS requirements was implemented in 2006. This led to the use of silver-based materials 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 containing copper and silver strips to survey a number of data center sites located in California and across the United States with the goal to obtain an initial idea of the environmental corrosiveness present.

The team with the help of data center operators performed a limited exploratory study of 19 data centers in the United States, 10 were in California 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 to account for seasonal changes and is suggested for further studies.

Coupon Measurement

The use of metal coupons (CCC method) 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 angstrom angstroms (Å)/30 days. In addition the analysis can provide some information regarding what type of contaminate was the likely cause 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. See **Figure 1** showing a photograph of an unexposed corrosion classification coupon.

Figure 1: Picture of an Unexposed Corrosion Classification Coupon

Source: Author

The standard method for analyzing corrosion coupons is called cathodic/electrolytic reduction. The thickness of the corrosion film is determined by Purafil's laboratory analysis. The results included with each coupon report contain 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 placed a higher number of coupons at all of the three location types 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.

“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 aluminum 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 a location on the label and resealed. These coupons were then sent back to Purafil after a holding period of 30 days for analysis.

CHAPTER 4: Results

The results of analyzing the reactivity monitoring measurements from the limited study of 21 data centers follow. The results for data centers located in California are not analyzed separately due to requests from data center operators that the supplied information not allow data to be connected to a particular data center operator.

Figure 2 shows the copper and silver measurement for coupons used and recovered at all 21 data centers. 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 corrosion measurement ranges are associated with small copper corrosion measurement ranges.

Large copper corrosion measurement ranges are associated with small silver corrosion measurement ranges.

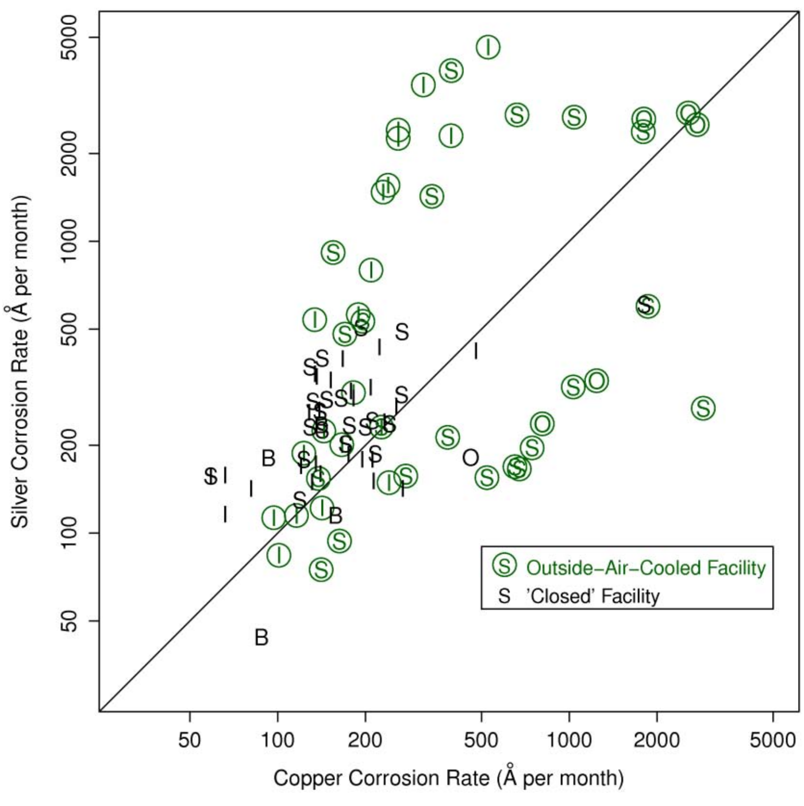

Figure 1: Measurements From All Data Centers Including All Location Types, Measurements from Outside-Air Cooled Data Centers are Circled; Background or Unexposed Indicated by "B", Outside Indicated by "O", Supply indicated by "S", Inside Indicated by "I"

Source: Author

Figure 3 shows the "Inside"only copper and silver corrosion 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 R2 for the fit in log space is only 0.33).

Note: The highest 7 silver "Inside "measurements shown in **Figure 3** came from one (#2) United States data center.

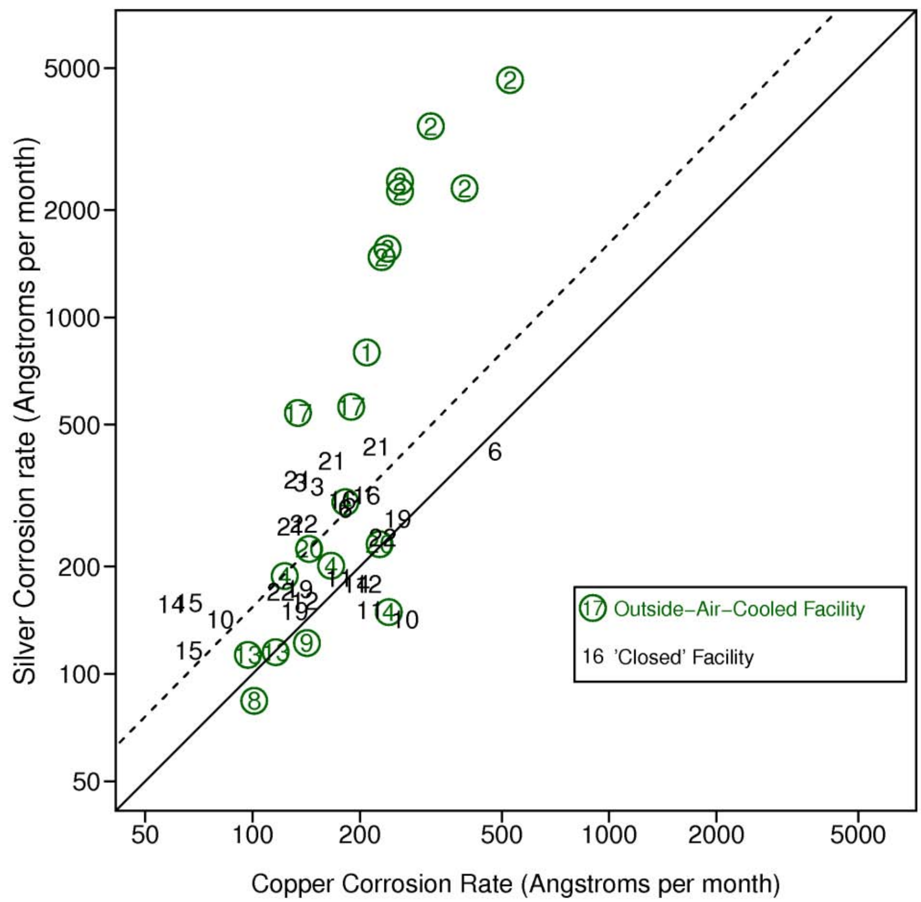

Figure 2 - Measurements From "Inside" Only, Data Center ID Number Located to Indicate Copper and Silver Measurement For Each Coupon, Numbers are Circled for Data Centers Using Outside-Air Cooling, Data Center ID#5 was not Assigned.

Source: Author

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.

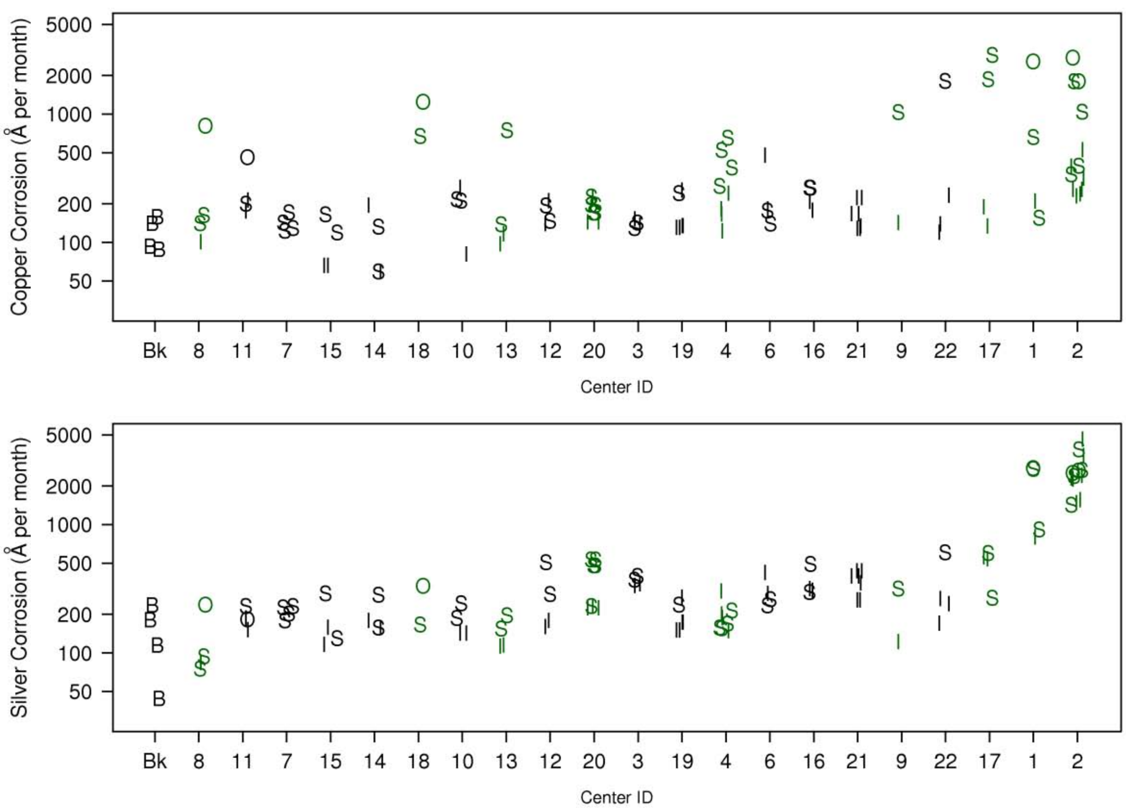

Figure 4: Copper and Silver Coupon Measurements Sorted by Combined Copper and Silver Average Measurement and Listed by Data Center ID #. The location type either Outside, Supply or Inside is shown by letter O, S or I. "Background" measurements are indicated with "B", Data Center ID#5 was Not Assigned.

Source: Author

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 the 5 co-located coupons; (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 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.

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).

CHAPTER 5: Conclusions and Recommendations

Conclusions

Data centers located in California and in the United States have little risk of corrosion caused failures due to environmental gaseous contamination. 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. One data center had elevated silver measurements, there is the possibility these were caused by a one-time or very-low-frequency event, an investigation looking for a cause and additional environmental corrosivity measurements at this site are in process at the time of this report.

We found no evidence that a high corrosion rate measured by corrosivity monitoring implies a high equipment failure rate. Because quantitative data on failure rates are not readily available a correlation between reactivity monitoring coupon measurements and IT equipment failure rates could not be determined. The low precision of the measurements, and the apparent lack of an elevated equipment failure rate in the only facility with a high measured silver corrosion rate, suggest that corrosion coupon measurements, at the low levels we found at all but one site, may not be useful for predicting equipment failure rates. 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 that occur in many data centers.

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

There is considerable concern over the use of outside air for cooling data centers. Industry experts disagree on the severity of the concern.

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.

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.

No standard indicators or guidelines for silver corrosion and its effect on electronics have been determined.

Recommendations

The corrosivity monitoring method of assessing IT equipment environments for corrosion induced failure risk is economical and the most common 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 corrosivity monitoring method and further quantify correlations as they relate to IT equipment housed in California data centers. A list of areas for future study follow.

- Basic research is needed to correlate gaseous contamination to IT equipment component failure rates.
- Research is needed to characterize and compare the current CCC corrosively measurement methods and other electronic corrosivity measurement devices on the market.
- The current study indicates that 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 California 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.
- Once failure mechanisms are understood, a study of potential remedies should be undertaken.
- Corrosion failures of electronic products such as PCs and cell devices should also be studied to see if there is correlation to failures in data center environments.

CHAPTER 6: References

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CHAPTER 7: Glossary

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CCC	corrosion classification coupon
iNEMI	International Electronics Manufacturing Initiative
ISA	Instrumentation Systems and Automation
IT	information technology
PWB	printed wiring board
RoHS	restriction of hazardous substances
TC	technical committee

APPENDIX A:
Locations Tested in the United States

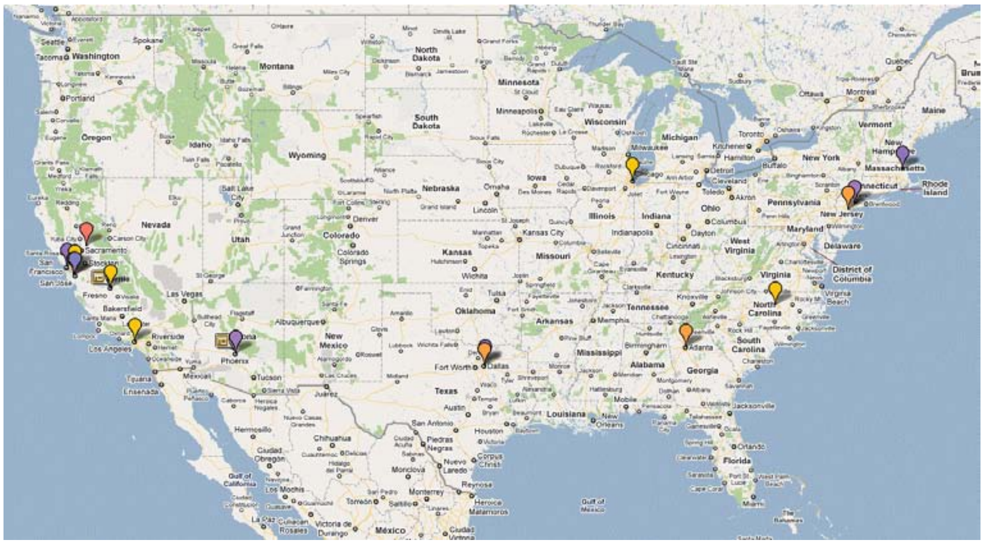

Figure 5 - Map of the United States Showing LocationsTested Using Corrosion Classification Coupons

Source: Author/Google Maps

Data center locations tested in the United States (number tested):

- San Francisco, California(1)
- Dublin, California(1)
- Silicon Valley, California (5)
- Rocklin, California(1)
- Fresno, California(1)
- Los Angeles, California(1)
- Phoenix, Arizona(1)
- Chicago, Illinois(1)
- Boston, Massachusetts (1)
- Research Triangle Park, North Carolina(1)
- Richardson, Texas(1)
- Dallas, Texas(1)
- Atlanta Georgia(1)
- Piscataway, New Jersey (2)

APPENDIX B:
Locations Tested in India

Figure 6 shows the location of two data centers in Bangalore India tested using corrosion classification coupons.

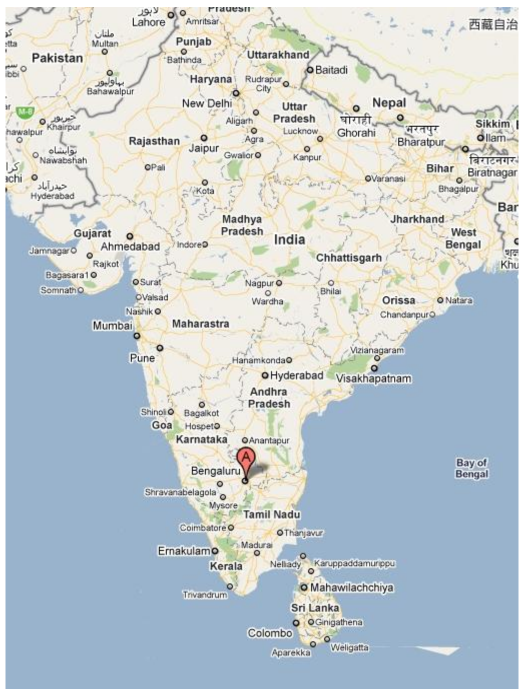

Figure 3 - Map of India Showing the Location of Two Data Centers Tested Using Corrosion Classification Coupons

Source: Author/Google Maps

APPENDIX C:
Coupon Mounting Examples

Figure 4 - Typical Coupon Mounting - Example Shown at Supply Air Filters as Found in Large Roof Top Fan Units

Source: Data Center Operator

Figure 5 - Typical Coupon Mounting, Example Shown is Just Prior to Cooling Air Entering IT Equipment

Source: Data Center Operator

Figure 6: Typical Coupon Mounting, Example Shown at Data Center Room Supply or Return Grill

Source: Data Center Operator