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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*

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ASHRAE 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 an unwarranted high level of concern for managers of operating data centers in the U.S. The white paper contains a number of statements and recommendations that are not well supported by the white paper or its references. There is a need for additional research on this subject to identify where and when airborne pollutants may be a problem and to develop solutions if the potential for equipment failure is identified. The Technical Committee is planning some research to determine how airborne pollutants accelerate corrosion rates in various data centers, however this work has not yet been authorized. At present, the conclusions of the ASHRAE paper draw attention to the need for future research on this important subject, however a rise in gaseous contamination failures due to the use of air-side economizers has not been established.

Review of ASHRAE White Paper and its References

This review of the TC 9.9 white paper and its references attempts to better understand the severity of the reliability threat airborne contamination poses to electronic equipment operating in data centers. In particular, research into corrosion rates in electronic equipment and the potential for equipment failures from gaseous contamination are explored. The following discussion provides comments to some of the key statements from the TC 9.9 white paper.

White Paper: "*The recent increase in the rate of hardware failures in data centers high in sulfur-bearing gases, highlighted by the number of recent publications on the subject (Reid 2007; Cullen 2004; Veale 2005; Sahu 2007; Schueller 2007; Hillman 2007; Xu 2007; Mazurkiewicz 2006), led to the need for this white paper that recommends that in addition to temperature-humidity control, dust and gaseous contamination should also be monitored and controlled*."

Comment: There are no data cited throughout the TC 9.9 white paper that provide any definitive information of the cause and effect relationship between specific levels of gaseous contaminants and the damage they caused to electronic equipment within data centers. The cited references highlight recent *interest* in gaseous corrosion on electronic equipment. None of these references contain information about actual hardware failures in data centers or the rate of hardware failure associated with gaseous contamination in data centers. The primary discussions in these cited references involve inducing corrosion under elevated gas concentrations and high relative humidity (RH) levels.

- Reid et al. (2007) measured silver corrosion on two different types of commercially available thick chip resistors in a lab setting of extremely high H_2S concentration (4 part per million, ppm) and extremely high temperature and humidity (140ºF and 90% RH) over a 60 day period. Clearly these conditions will not exist in any data center. The article states that "*hydrogen sulphide (H_2S) and high levels of relative humidity have been identified as the primary atmospheric constituents responsible for the degradation of Ag and some alloys commonly used in electronics industry*." The article does not establish if the observed degradation would result in equipment failure or if any degradation or failure would be expected at typical temperature and humidity levels or under different forms of sulfur-bearing gases. The important conclusions from this paper are that Ag_2S and Ni Sulphur residue were the main corrosion products and poor overlapping of the solder and Ni layer was the root cause of corrosion. However, nothing in this paper provided any information concerning increasing hardware failures in data centers.
- Cullen and O'Brien (2004) described testing methods to measure dendrite formation on immersion silver. There is no mention of data center environments or electronic equipment failures.
- Veale (2005) investigated four alternate PCB finishes (immersion gold, immersion silver, immersion tin, and an organic solderability preservative) to replace the tin/lead HASL coating. The important finding from this study was presented as follows: 1) the immersion gold and immersion silver surface finishes failed early in the testing, 2) the immersion tin and OSP coatings could be expected to survive a G2 (severity level) environment of the Instrument Society of America (ISA), and 3) the gold and silver coatings could not be expected to survive a mid to high G2 environment. However, this study was also the same kind of test as other corrosion tests. There is no direct relationship to data center failures.
- Sahu (2007) discusses the problem of waste dumping grounds in India. The connection here is that placing data centers next to or on landfill sites exposes the data center to the pollutants like higher hydrogen sulfide (H_2S) and methane (CH_4) emitted from the garbage. The observed consequences include severe failure of commercial buildings, continuous break down of electronic appliances in residential places, and deterioration of fabric paints. This is an interesting point but there is no evidence, or even discussion, of the breakdown of electronic equipment operating in data centers. Siting data centers in such locations would not be typical practice in any event.
- Shueller (2007) discusses a recent increase in failures of computer equipment in elevated humidity and high sulfur industrial environments such as

rubber manufacturing, water treatment, paper mills, are fertilizer plants. No mention is made of failures in non-industrial environments or data centers. In fact, the author notes: "there seemed to be a threshold of sulfur and humidity below which creep corrosion did not occur" and "Many millions of lead-free desktop and notebook systems, and related peripherals, have been put into service by Dell starting in 2005…field data shows the overall quality of Dell's lead-free products to be as good, and in some cases, better than the previous generation of tin-lead products."

- Hillman et al. (2007) provide an overview of known silver sulfide corrosion failure through their several case studies: sulfur reactions with silver, humidity and temperature effects, other reactive gases, and accelerating corrosion behavior. This study suggests that the industry needs additional information about the sulfur-based corrosion of silver in electronic components and assemblies. It identifies tools and techniques to prevent these mechanisms from leading to failure. There is no mention of data centers.
- Xu et al. (2007) discusses the corrosion resistance of lead-free printed wiring board (PWB) finishes, which were evaluated in a highly accelerated (high concentration) mixed flowing gas test. These lead-free finishes are compared with popular choices such as organic solderability preservatives (OSP), immersion silver (ImAg), electroless nickel and immersion gold (ENIG), and immersion tin (ImSn). All are exposed to very severe corrosion conditions (typically 1,700 ppb H_2S). One of the key features for this study is to understand how the lead-free PWB finishes affect the long-term reliability of electronic devices in these aggressive environmental conditions. This paper had no mention of actual data center IT equipment failures.
- Mazurkiewicz (2006) introduced four examples of field failures observed on printed circuit board (PCB) present in industrial environments that contained abnormal levels of hydrogen sulfide (H_2S) and elemental sulfur: e.g., model facility, power plant, and sulfur refining and distribution center. The sustained sulfur concentrations at these facilities was in the ppm range, orders of magnitude higher than typical ambient conditions.

These articles do not support the conclusions of the TC 9.9 white paper yet could give the impression that there is extensive supporting research.. The references in the white paper provide information on general research into corrosion in electronic equipment, however there is no link from this research to actual failures that affect reliability.
The authors of this paper have contacted the authors of the TC 9.9 white paper, data center operating with air economizers, and other industry experts and have requested evidence of equipment failures in data centers. The manufacturers provided anecdotal evidence mainly centered on data centers in India and China in areas with extremely poor air quality. This highlights potential concern for data centers operating in these countries, however, the received feedback indicates that the data centers that have experienced failures were of traditional, legacy design and did not utilize airside economizers.

White Paper: "*For data centers with air-side economizers, it is necessary to have real-time monitoring to react quickly to events outside the data centers that may release corrosive gases which may flow into the data centers*."

Comment: Industry feedback has indicated that equipment failure is not tied to the use of air economizers. Based on conversations with the white paper authors, observations of gaseous corrosion have occurred in non-economizer data centers with prolonged exposure to a constant source of gaseous emissions, rather than a sudden spike in gaseous concentration (i.e. chemical spill). Published lab tests and the limited anecdotal evidence indicate that gaseous corrosion-induced equipment failure would occur on the timescale of months, not hours (John, 1996). While additional monitoring can only add assurance, most data center operators would not want to add the expense or complexity for maintaining an additional monitoring system for the unlikely event of a major chemical release. Additionally, there is no reason to believe that more air quality monitoring would be needed at an economizer data center than at a data center without an economizer. We do not agree that it is necessary to have monitoring – rather it would be an optional expense similar to adding layers of security or multiple levels of redundancy.

White Paper: "*For data centers with air-side economizers, the choice of filters to achieve ISO class 8 cleanliness depends on the specific conditions present at that data center*."

Comment: Specific outdoor conditions at a data center can always affect the indoor air quality, regardless of whether economizers are used. When choosing filters, economizer-equipped data centers can be thought of as conventional data centers operating with additional makeup air. ASHRAE recommends using MERV 11 filters to filter outside air while using MERV 7 filters for the recirculating air conditioning units (Sorell, 2007). Applying this recommendation to data centers with economizers is supported by previous research (Shehabi et al 2010), which has shown that using MERV 11 filters in a data center with an economizer produces about the same or lower indoor/outdoor ratio of particles than a conventional non-economizer data center operating with MERV 7 filters. (Most centers that study were using MERV 7 filters rather than ASHRAE recommended MERV 8.) Furthermore, the average absolute indoor concentration measured in Shehabi et al. (2010) when using MERV 11 filters in an economizer data center, was below the ISO class 8 level of cleanliness. The study showed that using MERV 11 rather than MERV 7 filters increased the fan energy, but the increase was modest (~10%) and was eclipsed by the energy savings gained from economizer use.

White Paper: "*Gas phase filtration is highly recommended to maintain copper and silver corrosion rates below 300 Å/month*."

Comment: Our preliminary investigation indicates that this recommendation may be premature since research into silver corrosion rates exposed to various pollutants and humidity levels is not as well studied as that for copper. In fact this is a very difficult problem to solve. This recommendation appears to be based on monitoring performed on

31 data centers with reported equipment failures (Figures 1 and 2). According to the white paper authors these 31 data centers are in high pollution areas in India and China. The corrosion rate in these 31 data centers appear to be a random scatter. 26 of 31 have less than 100 Å/month of copper corrosion and 4 of these also have less than 300 Å/month of silver corrosion (Figure 1).

Figure 2 presents another way to analyze this data. Here, the corrosion rates for each of the 31 data centers are shown – each data center has a stacked bar showing the CR-copper and CR-silver, and the ratio of CR-silver to CR-copper each site is displayed as a number on top of each bar of the histogram. The figure shows that at most sites, the CR-silver was about an order of magnitude higher than CR-copper, while at most sites (26 out of 31), CR-copper fell within the range for severity class G1. Based on this, the TC 9.9 white paper suggests: *this level (G1) of copper corrosion may be too high for reliable operation of electronic hardware*. Thus the TC 9.9 white paper authors suggest that the definition of severity level G1 in the ANSI/ISA-71.04-1985 standard may be arbitrary (or irrelevant) for determining the hardware failures associated with corrosion rates.

It remains unclear how the hardware failures were identified as related to the magnitude of corrosion rate obtained from a conventional coupon-monitoring method. From the failure occurrence in the field, it The TC 9.9 white paper conclusion that low ranges of copper corrosion rate (< 63 Å/month or even < 10 Å/month) by themselves are unacceptably high seems premature based on these hardware failures alone.. No monitoring was done in data centers without reported equipment failures and therefore no correlation between corrosion rates and equipment failures is demonstrated. Apparently none of these 31 data centers has airside economizers. It is not clear if the IT equipment is pre- or post-RoHS. Also no evidence is provided that gas phase filtration is effective at reducing copper or silver corrosion rates.

Rice et al. (1981) measured indoor silver and copper corrosion rates above 300 Å/month in large portions of the US, including Indiana, South Carolina, New Jersey, New York, Pittsburg and St. Louis (see Figure 3). The lack of reported corrosion related hardware failures in US data centers is counter to the white paper position that high copper and silver corrosion rates lead to equipment failures and that gas phase filtration is necessary.

Conclusion

The TC 9.9 white paper brings up what may be an important issue for IT equipment in harsh environments but the references do not shed light on IT equipment failures and their relationship to gaseous corrosion. While the equipment manufacturers are reporting an uptick in failures, they are not able to provide information on the types of failures, the rates of failures, or whether the equipment failures are in new equipment or equipment that may be pre-Rojas. Data center hardware failures are not documented in any of the references in the white paper. The only evidence for increased failures of electronic equipment in data centers is anecdotal and appears to be limited to aggressive environments such as in India, China, or severe industrial facilities. Failures that have been anecdotally presented occurred in data centers that did not use air economizers. The white paper recommendation that gaseous contamination should be monitored and that gas phase filtration is necessary for data centers with high contamination levels is not supported.

We are concerned that data center owners will choose to eliminate air economizers (or not operate them if installed) based upon the ASHRAE white paper since there are implications that contamination could be worse if air economizers are used. This does not appear to be the case in practice, or from the information presented by the ASHRAE white paper authors. Additional research, as planned by the ASHRAE TC, the IT equipment manufacturers, and other bodies is needed to understand the current equipment susceptibility to corrosion. This research will likely narrow the areas of concern to specific environments. Data center owners will need to consider whether their center is sited in a harsh environment. For example if a pulp and paper mill is deciding to add a data center, they might choose to locate it outside of the immediate vicinity of the mill. Unless an additional preponderance of failure data is produced, it is premature to condemn the use of air economizers

This article illustrates the gaps in our understanding of hardware failure caused by gaseous contaminants. A series of recommendations that could form the next phase of research into hardware failure have been suggested. A survey-type coupon monitoring study of data centers from industry partners is currently underway as a needed first step. Secondly, a guideline is being develop to help identify appropriate data center locations Third, to improve the prediction of actual corrosion-related failures or to develop a new monitoring method would be considered a better approach than the use of copper or silver coupons, because it is hard to find the relationship between the reactivity of a coupon and actual hardware failures in data centers.

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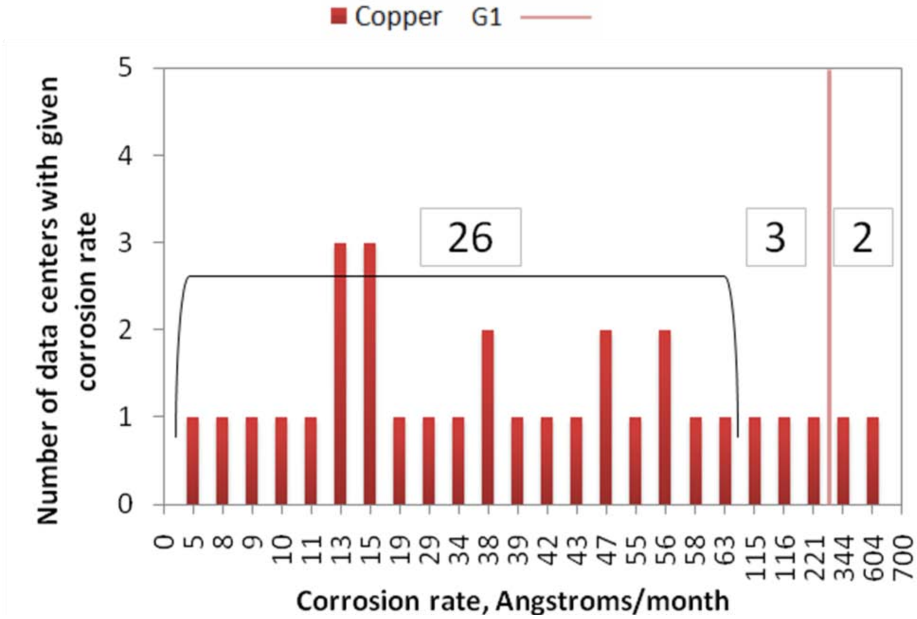
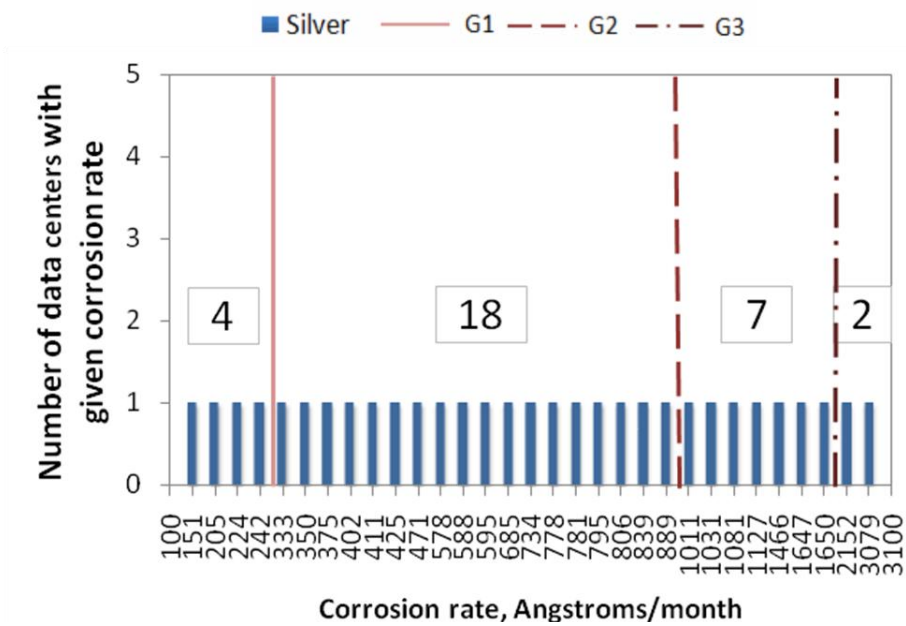


(a) Copper



(b) Silver

Figure 1. Number of data center with given (a) copper creep corrosion and (b) silver corrosion rate (replotted from the Figure 4 in the TC 9.9 white paper). The severity levels, G1, G2, and G3, were defined by the ANSI/ISA-71.04-1985 standard.

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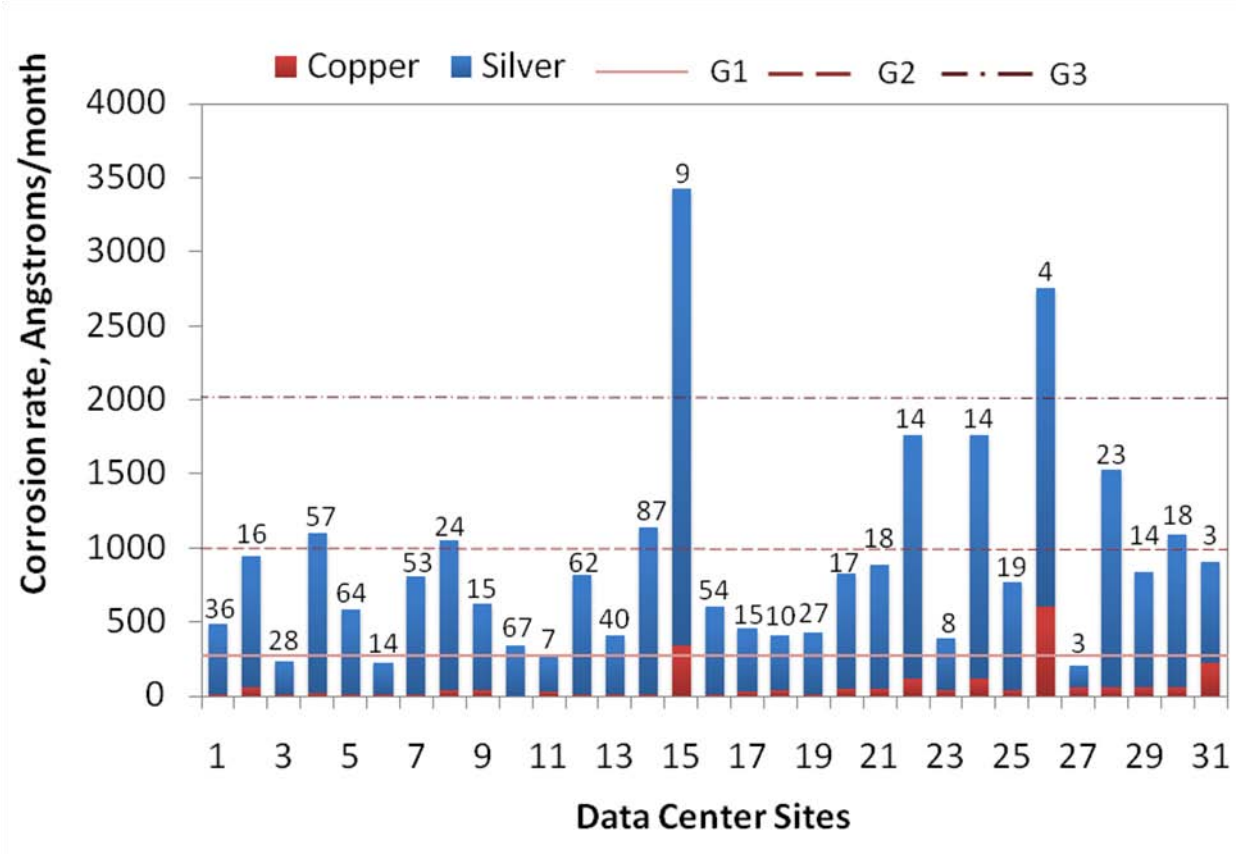

Figure 2. Corrosion rates in these 31 data centers with reported hardware failure due to copper creep corrosion and/or silver corrosion (replotted from the Figure 4 in the TC 9.9 white paper). Note: It shows the ratio of a silver corrosion rate to a copper corrosion rate at each bar.

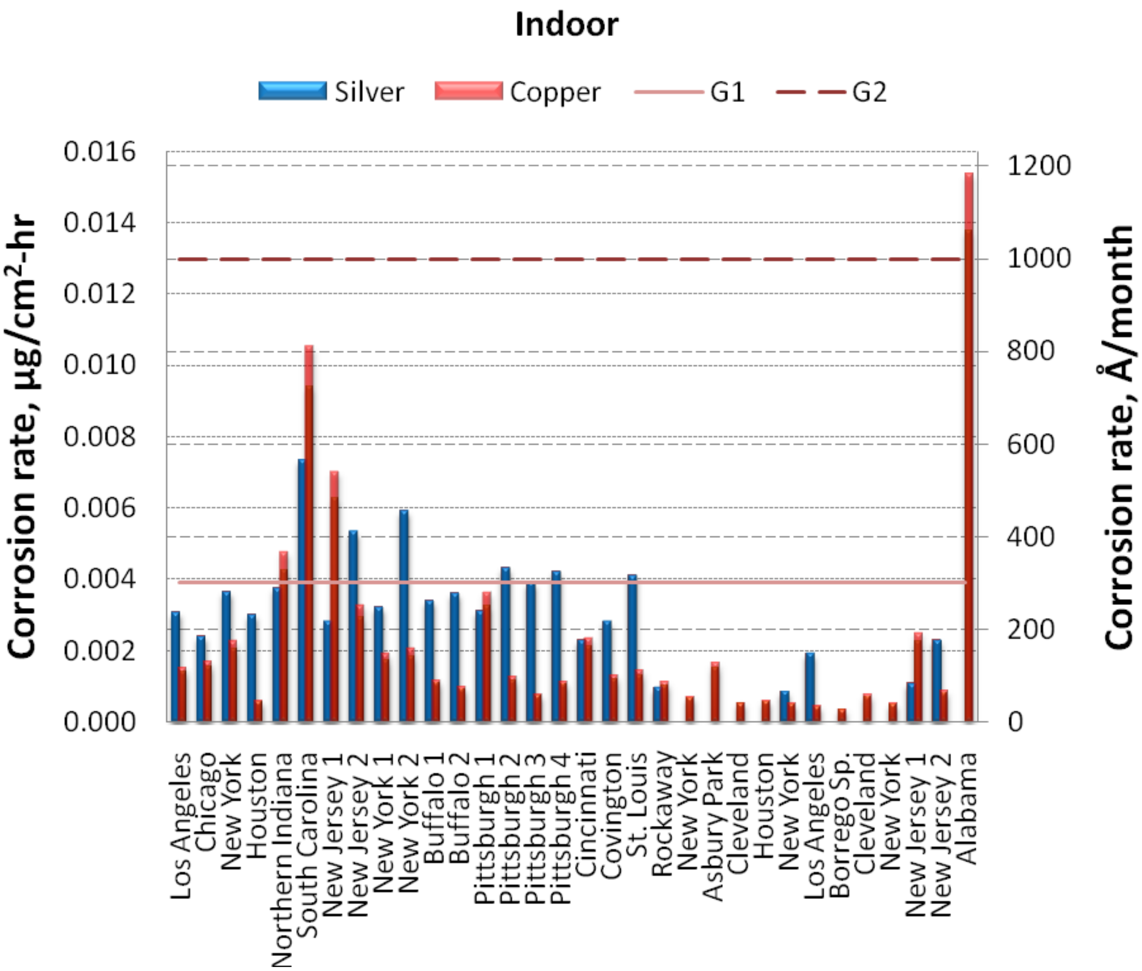

Figure 3. Indoor copper and silver corrosion rates (µg/cm^2-hr or Å/month) at different sites in the Unite States (converted from the Tables 5 and 6 in Rice et al., 1981).