Air Quality in Data Centers: Humans vs. the Machines

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SUMMARY

When one hears the phrase "indoor air quality" or IAQ, most associate this with the health, well-being, and comfort of humans in an occupiable space. However, in mission critical facilities such as data centers, IAQ is being scrutinized less for the human occupants and more for the "health" of the critical informational technology (IT) and datacom equipment.

Regulatory changes in place since 2006 resulted in much higher failure rates for IT and datacom equipment in facilities located in regions with high air pollution levels. The use of outdoor air for free cooling as a way to reduce energy costs has reached the mainstream of data center design and for many companies it is now the standard design approach for all new facilities. However, as the use of free cooling expands, many locations are experiencing higher equipment failure rates due to the effects of gaseous pollutants, higher temperatures, and fluctuating humidity inside the data center.

INTRODUCTION

Indoor air quality (IAQ) is a term that resonates throughout the commercial and residential building sectors and refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. IAQ can be affected by airborne contaminants such as fine particulate matter and gaseous contaminants whose source can be either indoors or outside the building. Poor IAQ can result in occupant complaints due to odors, irritation of eyes and mucous membranes, allergic reactions, and other acute and chronic symptoms.

Particulate and gaseous contaminants cannot only be detrimental to the health of the human occupants of a building, they can also be responsible for damage to other building "occupants" such as the sensitive electronic and electronic devices used in IT and datacom equipment. Whereas IAQ for humans can be affected by indoor or outdoor pollutants, the failure of information technology (IT) equipment is almost exclusively caused by pollutants with sources outside the building. These include sulfur and nitrogen oxides (SOx, NOx), hydrogen sulfide (H_2S), ozone (O_3), chlorine (Cl_2), diesel particulate matter (DPM), and fine and ultrafine particulate matter ($PM_{2.5}$, $PM_{0.1}$) generated from motor vehicle exhaust.

DATA CENTER EQUIPMENT RELIABILITY

The physical environment surrounding a printed circuit board (PCB) is defined by the temperature, humidity and gaseous and particulate contamination in the air. Environmental factors can cause PCBs to fail in two ways: First, electrical open circuits can result from corrosion, such as the corrosion of silver terminations in surface mount components. Second, electrical short circuits can be caused by (a) copper creep corrosion, (b) electrochemical reactions such as ion migration and cathodic-anodic filamentation or (c) settled, hygroscopic particulate matter contamination reducing the surface insulation resistance between closely spaced features on PCBs.

In 2006, the European Union's RoHS directive banning the use of lead in solders led to changes in PCB finishes and the elimination of lead from solders (European Commission 2003). These changes dramatically increased the PCB failure rates due to creep corrosion. Another common failure mode during this period was that of surface mount resistors suffering open circuits due to the corrosion of their silver terminations. IT equipment manufacturers have since learned to make their hardware more robust against these two failure modes, which used to occur predominantly in geographies with high levels of sulfur bearing gaseous contamination (Muller, et al. 2014). However, even as these IT equipment manufacturing changes were being widely implemented, a change in the design and operational practices used for the data centers in which this equipment was being used has caused a renewed concern with regards to reliability and uptime.

FREE COOLING FOR ENERGY CONSERVATION

It has been reported that data centers account for up to 1.5% of global electricity use and that in the U.S.A. it may be as high as 2.5%. Of the electricity consumed in a data center, as much as 50% or more goes towards cooling the IT equipment. And with the total number of data centers worldwide surpassing 3 million, energy consumption is only be expected to increase. This has not gone unnoticed and significant efforts are being made to reduce the overall energy consumption of data centers – specifically the energy required for cooling. One data center design approach that can offer tremendous energy savings is the use of economizers.

In most climates, data center cooling can be satisfied when the ambient air temperature is cold enough to supplement or replace the refrigeration equipment. This process is known as an "economizer" or "free cooling" cycle because the refrigeration equipment can be shut off and cooling can instead be provided from the outdoor air with lower energy consumption.

ASHRAE Technical Committee 9.9 for Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment created the first edition of the "Thermal Guidelines for Data Processing Environments" in 2004 (ASHRAE 2004). In 2008 and 2011 the temperature and humidity ranges for data centers were expanded so that an increasing number of locations throughout the world would be able to operate with more hours of economizer usage.

In certain geographical locations, economizers can be run using 100% outdoor air for part or all of the year to meet both the cooling and ventilation requirements for data centers. Although this addresses the goal of overall lower energy use in data centers, it can come with a hidden penalty. This being an increase in the amount of particulate and gaseous contamination coming into the data center along with the outdoor air and a concurrent increase in IT equipment reliability concerns.

The rapid expansion of the IT equipment market in the polluted geographies of Asia that have high levels of gaseous and particulate contaminants in the ambient air and the increasing use of free cooling has resulted in an uptick in corrosion related IT equipment failure rates that had been declining in previous years.

AIR QUALITY AND THE EFFECTS OF CONTAMINATION IN DATA CENTERS

Three types of gases are the prime suspects in the corrosion of electronics: acidic gases, such as hydrogen sulfide, sulfur and nitrogen oxides, chlorine, and hydrogen fluoride; caustic gases, such as ammonia and amines; and oxidizing gases, such as ozone. Of the gases that can cause damage to electronic devices, acidic gases are typically most harmful.

Although less of a problem than gaseous contaminants, particulate matter has come under increased scrutiny (Singh et al. 2015). Most attention is being paid to the fine particles (<2.5µm), of which there are of two types. Primary particles are directly emitted from a source. Secondary particles, which comprise the bulk of the fine particulate pollution, are those formed as a result of chemical reactions in the atmosphere. SO_2 and NO_2 can interact with <0.1 µm carbonaceous material seed particles in a complex, multi-step photochemical process to produce sulfuric and nitric acids. The presence of ozone, a contaminant increasing in both outdoor levels as well in regional coverage, serves to catalyze these reactions.

Each site may have different combinations and concentration levels of corrosive gaseous and particulate contaminants and IT equipment performance degradation can occur rapidly in weeks or months or over many years, depending on the concentration levels and combinations of contaminants present at a site. The currently prescribed level of contaminant control in data centers is listed in Table 1.

Table 1. Particulate and gaseous contamination guidelines for data centers (ASHRAE 2011)

Data centers must be kept clean to ISO 14644-1 Class 8 (ISO 2014). This level of cleanliness can generally be achieved by an appropriate filtration scheme as outlined here: 1. The room air may be continuously filtered with MERV 8 filters (G4/F5, 25-30% dust spot). 2. Air entering a data center may be filtered with MERV 11 (F6, 60-65% dust spot) or MERV 13 (F7, 80-90% dust spot) filters. Sources of dust inside data centers should be reduced. Every effort should be made to filter out dust that has deliquescent relative humidity greater than the maximum allowable relative humidity in the data center.
Gaseous contamination should be within the ISA-71.04-2013 severity level of G1-Mild that meets: 1. A copper reactivity rate of less than 300 angstroms (Å) per month, ***and*** 2. A silver reactivity rate of less than 200 Å per month.
For data centers with higher gaseous contamination levels, gas-phase filtration of the inlet air and the air in the data center is highly recommended.

THE COST OF FREE COOLING

Where free cooling is being employed the number and types of data center equipment failures have increased dramatically in locations with high pollution levels. Because most failures occur in the most common components, there is no simple solution. Faced with this reality, the world’s leading IT and datacom equipment manufacturers changed have their warranties to include requirements for the control of corrosion due to gaseous contamination.

Another concern with free cooling is the degree of temperature and relative humidity (RH) control possible. Whereas temperature appears to be generally well controlled, RH is subject to wide fluctuations; with rates of change as high as 10-15% per hour being observed. Couple this with upper boundaries for the recommended and acceptable level of RH being expanded and the potential for equipment failures increases even in areas with moderate pollution – especially for corrosion-related failures due to gaseous contamination.

Corrosion of metals due to gaseous contaminants is a chemical reaction that is accelerated by heat and moisture. Rapid shifts in either temperature or humidity can cause small portions of circuits to fall below the dewpoint temperature, facilitating the condensation of contaminants. RH above 50% accelerates corrosion by forming conductive solutions on electronic components. These microscopic pools of condensation can absorb contaminant gases to become electrolytes where crystal growth and electroplating occur. Above 80% RH, electronic corrosive damage will occur regardless of the levels of contamination.

CONCLUSIONS

IAQ is a term that not only has relevance to humans but also when considering the health of the nonhuman “occupants” of mission critical environments such as data centers.

Miniaturization of electronic components combined with reductions in feature spacing on PCBs and the loosening of the data center temperature and humidity envelope to save energy is making electronic hardware more prone to failure due to exposure to ambient pollutants.

Increasing the maximum allowable temperature and RH ranges for IT equipment means free cooling can be used in more locations than ever before. While this has led to dramatic energy savings and overall lower operational costs, in many locations this has come at the cost of equipment reliability. Although climatic conditions may allow for the use fee cooling, other factors now have to be considered. Primary among these are local and regional air quality.

This does not mean that free cooling should not be considered where feasible; just that additional steps are required to assure reliable operation of datacom equipment. These steps include a determination of the types and levels of particulate and gaseous contamination, establishing a monitoring program inside the data center to check against standard levels and equipment warranty requirements, and lastly upgrading or adding the required type of filtration to remove and reduce contamination to manufacturers’ requirements.

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