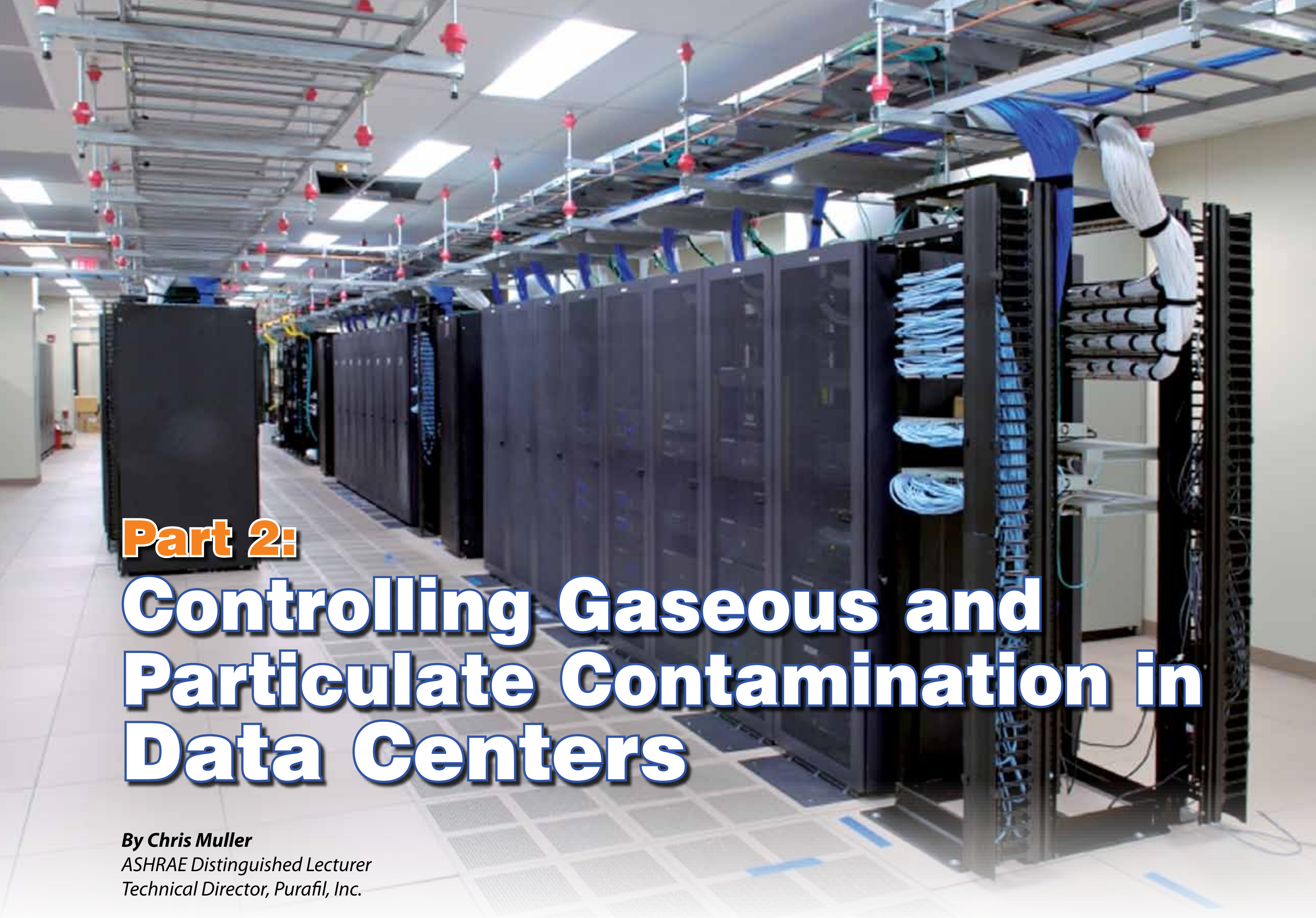

Part 2:

Controlling Gaseous and Particulate Contamination in Data Centers

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Abstract

Data centers operating in areas with elevated levels of ambient pollution have begun to experience hardware failures due to changes in electronic equipment mandated by a number of "lead-free" regulations that affected the manufacturing of electronics, including IT and datacom equipment. Implementation of these regulations have resulted in an increased sensitivity of printed circuit boards, surface mounted components, hard disk drives, computer workstations, servers, and other devices to gaseous contaminants. As a result, there is an increasing requirement for air quality monitoring in data centers. This is especially true for corrosive airborne contaminants.

When monitoring indicates that data center air quality does not fall within specified corrosion limits, and other environmental factors have been ruled out (i.e., temperature, humidity, etc.), gas-phase air filtration is recommended. This would include air being introduced into the data center from the outside for ventilation and/or pressurization as well as all of the air being recirculated within the data center. The optimized control of particulate contamination should also be incorporated into the overall air handling system design.

Data centers operating in areas with lower pollution levels may also have a requirement to apply enhanced air cleaning for both gaseous and particulate contaminants especially when large amounts of outside air being used for "free cooling" results in an increase in contaminant levels in the data center. As a minimum, the air in the data center should be recirculated through combination gas-phase / particulate air filters to remove these contaminants as well as contaminants generated within the data center in order to maintain levels within specified limits.

General design requirements for the optimum control of gaseous and particulate contamination in data centers includes sealing and pressurizing the space to prevent infiltration of contaminants, tightening controls on temperature and humidity, improving the air distribution throughout the data center, and application of gas-phase and particulate filtration to fresh (outside) air systems, recirculating air systems, and computer room air conditioners.

The best possible control of airborne pollutants would allow for separate sections in the mechanical system for particulate and gaseous contaminant control. However, physical limitations placed on mechanical

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systems, such as restrictions in size and pressure drop, and constant budgetary constraints have spurred the development of new types of, and delivery systems for, chemical filtration products.

This article will discuss application of particulate and gas-phase air filtration for the data center environment, with primary emphasis on the latter. General aspects of air filtration technology will be presented with descriptions of common filter types and where these may be employed within the data center environment to provide for enhanced air cleaning.

Introduction

The European Union (EU) directive 2002/95/EC "on the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment" or RoHS was implemented in July 2006 (EU 2003). However, this was only the first of many RoHS (-like) regulations that have been passed or are being considered in many countries. The aim being shared by almost all RoHS legislation is the elimination of lead in electronic products. These policies are now generally referred to as the RoHS Directive and are often referred to as "Lead-Free" legislation.

Research has shown that printed circuit boards made using lead-free materials can be more susceptible to corrosion than their tin/lead counterparts and it has been reported that many lead-free products will creep corrode in high sulfur environments. Creep corrosion failures have occurred on hard disk drives (HDD), graphic cards, and motherboards in desktop and workstation systems.

Corrosion-induced failures are frequent in electronics products used in industrial environments. However, now even in environments previously considered relatively benign with regards to electronics corrosion are experiencing serious problems as a direct result of RoHS compliance. Data centers in many urban locations have reported failures of servers and hard disk drives due to sulfur corrosion (Crosley, et al. 2009). Desktop and laptop computers, servers, data communications (datacom) equipment and other information technology (IT) equipment are now at risk due to RoHS. There are indications that this may even trickle down into personal computers and electronic devices.

Acidic gases and submicron particulates are typically found in urban environments from automobile and diesel exhaust, emissions from other forms of transportation, heat and power generation, and industrial activity. In the corrosion of electronic components, sulfur oxides, active sulfur compounds, and inorganic chlorides are the primary culprits. Additionally, oxides of nitrogen, produced from the combustion process in automobiles, trucks, buses, and trains can cause electronics to corrode. Although most computer rooms in commercial buildings are typically protected against temperature and humidity variations, particulates and acidic (corrosive) gases can be drawn in through the building's air handling system(s) and causing electronics to corrode over a period of time – especially those produced since the passage of various "lead-free" regulations.

Air Cleaning Technologies

Increasingly, enhanced air cleaning is being used in data centers to provide and maintain acceptable air quality with many options available for the control of particulate pollutants, and nearly as many options for the control of gaseous pollutants. Employing the proper level and type(s) of air filtration can effectively reduce airborne contaminants to well below specified levels and minimize equipment failure rates, but effective control of environmental pollutants requires the use of an air cleaning strategy optimized for both particulate and chemical removal.

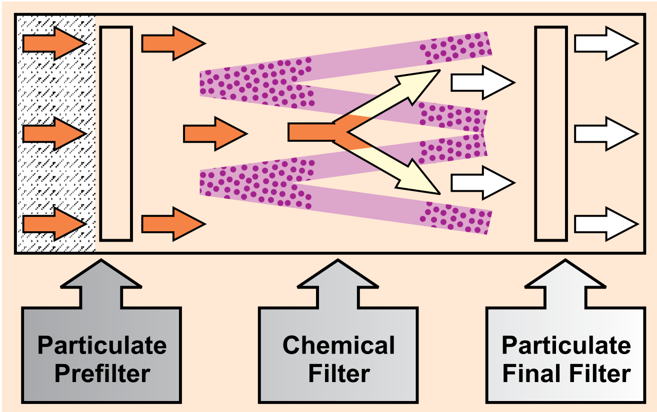

Figure 1. Schematic of enhanced air cleaning system.

Particulate Filtration

The control of particulates can be a considered a "mature" air cleaning application based on the number of technologies in everyday use and the relative ease of applying these technologies for a specific application (Muller and Jin 2009). ASHRAE Technical Committee 9.9 has published their recommended particulate filtration requirements for data centers. These requirements are described in Part 1 of this article, titled, "Gaseous and Particulate Contamination Limits for Data Centers."

Gas-Phase Air Filtration

Just as there are many options available for the control of particulate pollutants, there are nearly as many options for the control of gaseous pollutants. The problem is that for most data center designers this type of air cleaning is not as well understood and is not as easily applied – from an application perspective and also because most ventilation systems or computer room air conditioners (CRACs) are not designed to readily accommodate this type of air cleaning technology.

For many years, packed-bed (1-3" [25-75 mm]) gas-phase air filters employing one or more granular adsorbent materials, used in combination with particulate filters, have proven to be very effective for the control of pollutants (Figure 1). This "one-two punch" allows for the maximization of both particulate control and gaseous pollutant control within the same system. Common adsorbents include granular activated carbon (GAC), permanganate-impregnated alumina (PIA), and other manufactured media. These media are employed individually or as blends to provide control of many common gaseous pollutants such as sulfur and nitrogen oxides, hydrogen sulfide, chlorine, ozone, formaldehyde, ammonia, toluene, and many volatile organic compounds (VOCs).

Physical limitations placed on these systems, such as restrictions in size and pressure drop, and constant budgetary constraints spurred the development of new types of, and delivery systems for, chemical filtration products. Foremost among these are filters using monolithic extruded carbon composite (MECC) media (Muller and Jin 2009) and adsorbent-loaded nonwoven fiber (ALNF) media (Middlebrooks and Muller 2001).

Contamination Control For Data Centers

There is no one standard for data center design, thus the application of air cleaning in a data center may be one or more of several different technologies depending on whether the air handling system uses outdoor air to provide for ventilation, pressurization, and/or (free-) cooling, or whether CRAC units are used as 100% recirculating air systems.

The optimum control of airborne pollutants would allow for separate air cleaner sections in the mechanical system for particulate and gaseous contaminant control. If this is not practical from a logistical or cost standpoint, air cleaning may be integrated directly into the fresh air systems or CRAC units or applied as stand-alone systems. Again, because most of these air handling systems already have particulate filtration as part of their standard design, the manufacturers would have to be consulted to determine what limitations there might be for the addition of gas-phase air filters. Most of these concerns would center on the additional static pressure from these filters.

The following sections will describe some basic steps for the optimization and application of enhanced air cleaning for the data center environment.

Basic Data Center Design Requirements

Before one considers adding enhanced air cleaning for either particulate or gas-phase contamination in a data center, there are specific mechanical design requirements which must be understood. These include:

- Room air pressurization
- Room air recirculation
- Humidity control
- Temperature control
- Proper sealing of the critical space(s)

Room Air Pressurization. In order to prevent contaminated air from entering the data center from the outside, all critical areas must be maintained at a slight positive pressure. This can be achieved by pressurizing the room to ~0.05 - 0.1 iwg (13 – 25 Pa) by introducing outdoor (ventilation) air at a rate of 3 to 6 air changes per hour (5 to 10% of the gross room volume per minute).

Room Air Recirculation. Air cleaning systems can be design that can function as pressurization only systems or as pressurization and recirculation systems. Depending upon how well the data center environment is sealed, the level of pedestrian traffic into and out of the space, and the level of other internally-generated contaminants, pressurization only may be sufficient to provide an acceptable level of contamination control.

The general recommendation is the recirculation of tempered air through an air cleaning unit if:

1. The room is not properly sealed.
2. The space has high pedestrian traffic.
3. Sources of internally-generated contaminants have been identified and source control is not practical.
4. The CRAC units or negative pressure ductwork are located outside the data center environment.
5. One or more of the walls of the data center are outside walls.

The rate of room air recirculation will be determined by the type of equipment used and the construction parameters of the data center. Typical recommendations call for 6 to 12 air changes per hour (approximately 10 to 20% of the gross room volume per minute).

Temperature & Humidity Control. The corrosive potential of any environment increases dramatically with increasing relative humidity. Rapid changes in relative humidity can result in localized areas of condensation and, ultimately, in corrosive failure.

ASHRAE Technical Committee (TC) 9.9 (Mission Critical Facilities, Technology Spaces and Electronic Equipment) recently published the 2008 ASHRAE Environmental Guidelines for Datacom Equipment (ASHRAE 2008) which extended the temperature-humidity envelope to provide greater flexibility in data center facility operations, particularly with the goal of reducing energy consumption.

For high reliability, TC 9.9 recommends that data centers be operated in the ranges shown in Table 1. The table also shows the changes that were made from the 2004 version. These guidelines have been agreed to by all major IT manufacturers and are for legacy IT equipment. A downside of expanding the temperature-humidity envelope is the reliability risk from higher levels of gaseous and particulate contamination entering the data center.

Table 1: Temperature and Humidity Recommendations for Data Centers

	2008 Guidelines	2004 Guidelines
Low End Temperature	18°C (64.4 °F)	20°C (68 °F)
High End Temperature	27°C (80.6 °F)	25°C (77 °F)
Low End Moisture	5.5°C DP (41.9 °F)	40% RH
High End Moisture	60% RH & 15°C DP (59 °F DP)	55% RH

Proper Sealing of Protected Space. Without a tightly sealed room, it will be very difficult to control the four points mentioned

[1] *The gross room volume would include the space above the drop ceiling and below the raised floor.*

[2] *If pressurization only is used, care must be taken that the pressurization air volume is not too high such that temperature and humidity problems are encountered.*

continued on page 92

continued from page 90

above. It is essential that the critical space(s) be protected by proper sealing. Actions taken to accomplish this include the use of airlock entries/exits, sealing around doors and windows, use of door sweeps, closing and sealing all holes, cracks, wall and ceiling joints and cable and utility penetrations. Care should be taken to assure that any space above a drop ceiling or below a raised floor is sealed properly.

Particulate Control

Filtration is an effective means of addressing airborne particulate in the data center environment. It is important that all air handlers serving the data center have the appropriate particulate filters to ensure appropriate conditions are maintained within the room – in this case to meet the cleanliness level of ISO Class 8 (ISO 1999). The necessary efficiency is dependent on the design and application of the air handlers.

In-room process cooling with recirculation is the recommended method of controlling the data center environment. Air from the hardware areas is passed through the CRAC units where it is filtered and cooled, and then introduced into the subfloor plenum. The plenum is pressurized, and the conditioned air is forced into the room through perforated tiles and then travels back to the CRAC unit for reconditioning. The airflow patterns and design associated with a typical computer room air handler have a much higher rate of air change than do typical comfort cooling air conditioners. This means that the air is filtered much more often than would be the case in an office environment. Proper filtration can thus accomplish a great deal of particulate arrestance.

Any air being introduced into the data center for ventilation or positive pressurization should first pass through high efficiency filtration. Ideally, air from sources outside the building should be filtered using high efficiency particulate air (HEPA) filtration rated at 99.97% efficiency (USDOD 1995) or greater at a particle size of 0.3 microns.

It is also important that the filters used are properly sized for the air handlers. For instance, gaps around the filter panels can allow air to bypass the filter as it passes through the CRAC unit. Any gaps or openings should be taped, gasketed, or filled using appropriate materials, such as stainless steel panels or custom filter assemblies. The filtration requirements for CRAC units and the air coming into the data center are described in Part 1 of this series on Contamination in Data Centers and an ASHRAE white paper on gaseous and particulate contamination guidelines for data centers (ASHRAE 2009a).

Gaseous Contamination Control

Assuming a building's HVAC system is already equipped with adequate particulate filtration; gaseous air cleaning can be used in conjunction with the existing air handling systems. Gas-phase air filters or filtration systems employing various adsorbent and/or chemisorbent media can effectively reduce gaseous contaminants to well below specified levels. Properly applied, gaseous air cleaning also has the potential for energy savings.

Gas-phase air filtration can be applied in several locations within and outside the data center environment. Filters can be added to existing air handling equipment given proper design considerations or supplied in standalone pressurization and/or recirculation equipment.

Makeup (Outdoor, Fresh) Air Handlers

When outdoor air is being delivered either directly to the data center or indirectly through a mechanical room, standard side-access systems can be used as powered or non-powered units designed to control low-to-moderate levels of gaseous contaminants. This type of system can offer a wide range of pre-filters, chemical filters (MECC, ALNF, bulk-fill modules, etc.), and final filters to accommodate specific air flow requirements within the primary outside air handling system. A secondary unit can be used for recirculation in mechanical or equipment rooms.

Air-Side Economizers. By definition, an economizer is a mechanical device used to reduce energy consumption. Economizers recycle energy produced within a system or leverage environmental temperature differences to achieve efficiency improvements. The primary concern in this approach to data center cooling is that outside air contaminants – both particulate and gas-phase – will have a negative impact on electronics.

Research performed by Lawrence Berkley National Laboratory (Shehabi, et al. 2007) stated "The pollutant of primary concern, when introducing particulate matter to the data center environment, is fine particulate matter that could cause conductor bridging," The study also concluded that "…filtration systems in most data centers do just fine in keeping contaminants out." However, this was referencing particulate filtration and not the use of gas-phase air filtration to address the potential damage to electronic equipment from the introduction of unwanted gaseous contaminants.

Air-side economizers typically include filters with a minimum ASHRAE-rated particulate removal efficiency of 40% (MERV 9) (ASHRAE 1992, ASHRAE 2007a) to reduce the amount of particulate matter or contaminants that are brought into the data center space. However, in areas with high ambient particulate levels ASHRAE 60-90% (MERV 11-13) filter may be required. No references have been found describing the use of gas-phase air filter in economizers, even with the advent of RoHS and other "lead-free" regulation. MECC filters and/or ALNF filters can be easily applied in these systems to address this serious data center contamination issue.

continued on page 94

continued from page 92

Recirculating Air Handlers

These are typically in-room, self-contained units used to provide increased amounts of recirculation air to areas with low-to-moderate gaseous contaminant levels. In data center applications, recirculating air handlers (RAH) would contain a pre-filter, one or two stages of 4" (100 mm) MECC filters or 1-3" (25-75 mm) bulk-fill media modules, a blower section and a 90% final filter. These units are used to further filter and polish room air in order to maintain very low contaminant levels.

Positive Pressurization Unit (PPU)

A positive pressurization unit (PPU) is designed to filter low-to-moderate concentrations of outside air contaminants. It is used to supply cleaned pressurization air to the critical space(s) and would contain a pre-filter, two stages of 4" (100 mm) MECC filters or 1-3" (25-75 mm) bulk-fill media modules, a 90% final filter, a blower section, and an adjustable damper for control of pressurization air into the air handling system or directly into the data center.

Computer Room Air Conditioning (CRAC) Units

Many CRAC units already have high efficiency air filtration built in which can be retrofitted to use combination particulate + chemical filters using an adsorbent-loaded nonwoven fiber medium. Using this type of filter one can maintain the same level of particulate filtration while adding the chemical filtration required to control low levels of gaseous contamination. The pressure drops of these filters are somewhat higher than the particulate filters they replace, but still well below the maximum terminal pressure drop. Most CRAC units can take standard filters of 2-4 in (50-100 mm) in depth, but some units may employ "non-standard" or proprietary sizes.

Filters using monolithic extruded carbon composite (MECC) media are also being used in CRAC units to provide control of low-to-moderate levels of gaseous contamination. Standard 2" and 4" (50 and 100 mm) filters are available, but do not provide particulate filtration. If this is required, a 2" (50 mm) particulate filter can be supplied in front of 2" (50 mm) MECC filter as a packaged unit.

Under-Floor Air Filtration

The latest innovation for the application of gas-phase air filtration is the use of MECC filters under the perforated panels on the cold aisles in raised floor systems. The filter is placed in a customized "tray" under the perforated panel and fits the dimensions of the existing access floor grid. Gasketing around the filter assembly assures that 100% of the air being delivered into the data goes through the MECC filter for total gaseous contaminant control. Sealing the subfloor plenum will also help to maximize the amount of air going through the underfloor MECC filters and ultimately the amount of clean air being delivered to data center.

Monitoring for Filtration Effectiveness and Filter Life

Once enhanced air cleaning has been specified and installed, one must be able to determine the effectiveness of the particulate and gas-phase air filters. One must also be able to replace the filters on a timely basis so as not to comprise the data center environment.

Particulate Contamination Monitoring

Filtration effectiveness can be measured using real-time particle counters in the data center. Excess particle counts or concentrations can indicate filter failure, filter bypass, and/or internal sources of particle generation, e.g., CRAC belt dust, tin whiskers, etc.

Particulate filters have specified initial and final pressure drops at rated air flows so differential pressure gauges can be used to observe filter life and set alarm limits. Timely replacement of pre-filters, primary and final filters not only protects the electronic equipment but also maintains optimum performance of the air handling equipment.

Gaseous Contamination Monitoring

The primary role of gas-phase air filters and filtration systems in the data center is to prevent corrosion from forming on sensitive electronic equipment. Therefore, the best measure of their effectiveness would be to use either passive corrosion classification coupons (CCCs) or real-time atmospheric corrosion monitors (ACMs) to monitor the copper and silver corrosion rates (England, et al. 1999, Muller 2010). Copper and silver coupons and their use are described in Part 1 of this series, titled "Gaseous and Particulate Contamination Limits for Data Centers."

CCCs can be placed upstream and downstream of the gas-phase air filters to gauge the efficiency of the systems for reducing total corrosion and against individual corrosion species and to determine when filter replacement is indicated. They can also be placed throughout the data center to provide ongoing verification of environmental specifications. ACMs can be placed in the controlled environment and on or in server cabinets to provide a real-time data on corrosion rates and the effectiveness of various gaseous contaminant control strategies – whether they involve the use of gas-phase air filtration or not.

While proper operation and maintenance of the particulate and gas-phase filtration system may require monitoring at various locations within and outside the data center, ASHRAE specifically recommends monitoring at the primary locations of concern, which are in front of the computer racks at one-quarter and three-quarter height off the floor (ASHRAE 2009a).

Summary

Electronic equipment used in data centers are protected against the potential threats posed by fire, power, shock, humidity,

continued on page 96

continued from page 94

temperature and (to a degree) particulate contamination. Unfortunately, the potential damage to this equipment caused by the corrosive effects of gaseous contaminants has still not been fully recognized or addressed.

Recognizing the severity of the problem, the world's leading manufacturers of computer systems have jointly published a white paper titled, "Particulate and Gaseous Contamination Guidelines for Data Centers," (ASHRAE 2009a) that summarizes the acceptable levels of data center contamination as follows:

Data centers must be kept clean to ISO 14644-1 Class 8. This level of cleanliness can generally be achieved by an appropriate filtration scheme as outlined here:

1. *The room air may be continuously filtered with MERV 8 filters as recommended by ANSI/ASHRAE Standard 127-2007, Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners (ASHRAE 2007).*
2. *Air entering a data center may be filtered with MERV 11 or MERV 13 filters as recommended by ASHRAE book titled "Particulate and Gaseous Contamination in Datacom Environments" (ASHRAE 2009b).*

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.

The gaseous contamination should be within the modified ANSI/ISA-71.04-1985 (ISA 1985) severity level 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 300 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.

Enhanced air filtration systems for data centers should be designed to the ASHRAE guidelines as described in Part 1 of this series. The length of time that these levels of cleanliness can be provided is a function of the total contaminant load, air cleaning system design and filters / equipment employed. Factors that may cause the data center environment to exceed these classifications include critical space(s) not being properly sealed, high pedestrian traffic, high levels of internally-generated contaminants, the air conditioning system and/or negative pressure ductwork being located outside the protected space, and air filtration system being undersized. In properly sealing a room, often the spaces beneath raised floors and/or the space above dropped ceilings are neglected. These areas are critical, especially when they are used as supply and return plenums. Long forgotten cable penetrations, floor drains, cracks in the walls and ceiling, etc. can cause infiltration of contaminated air. The solution is to seal all penetrations, supply an adequate amount and distribution of supply and recirculation air, provide clean outdoor air to achieve positive pressure, and balance the system.

With the increasing pressure to reduce energy consumption in data centers, and the increasing use of air-side economizers, data centers located in regions with poor ambient air quality will struggle to maintain efficient operations without the application of enhanced air cleaning. This means increasing particulate filter efficiencies to at least ASHRAE 85% and the addition of gas-phase air filtration designed to control specific contaminants of concern.

The issue and potential problem of corrosion in data centers has been presented (ASHRAE 2009a, Muller 2010, Singh 2010). The problem needs to be addressed by monitoring of the environment and removal of contaminants where needed. Ultimately, the successful implementation of a contamination control program requires:

- Knowledge and understanding that corrosion of electronic equipment is a serious problem.
- Commitment to a monitoring program to detect the potential for equipment failure before electronic equipment is damaged and costly shutdowns occur.
- Commitment to an integrated contamination control system.
- Commitment to take corrective action whenever necessary.

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