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Introduction

Datacom equipment center owners and operators focus much of their attention on the physical structure and performance of the datacom infrastructure environment (e.g., power, cooling, and raised-access floor equipment). However, today's intricate and sensitive information technology (IT) equipment (also called *datacom equipment* or *computer equipment* throughout the book) requires a certain level of environmental control for gaseous and particulate contamination that is present within the facility's datacom equipment center environment. Datacom equipment center contamination is frequently overlooked and, if left unrestrained, can degrade the reliability and the continuous operation of mission-critical IT equipment within a facility.

To maintain a high level of IT equipment dependability and availability, it is critical to view contamination in a holistic way. It should be acknowledged that the datacom equipment center is a dynamic environment where many maintenance operations, infrastructure upgrades, and IT equipment change activities occur on a regular basis. Airborne contaminants harmful to sensitive electronic devices can be introduced into the operating environment in many ways during these and other activities. The fundamental focus areas that necessitate examination start with the outdoor ambient air pollutants surrounding the facility. Outdoor air that purposely enters the building for datacom equipment center free cooling, datacom equipment center positive pressurization, or human occupancy air changes must be filtered and possibly conditioned. Once inside the building, maintenance operations within the building's environmental envelope and the datacom infrastructure equipment itself must be considered. Datacom workers also add contamination from hair, lint on clothing, and other contaminants tracked in on footwear to the datacom equipment center. With proper planning and controls, datacom equipment center operators can minimize contamination and potential negative effects in the datacom equipment center.

Datacom managers and operators should include a datacom equipment center environmental contamination section as part of the standard operating procedure.

The association between contamination and hardware failures is often overlooked. Occasionally, the absence of contamination controls results from cost-cutting actions or from lack of knowledge. Particle and gaseous contamination can result in intermittent equipment glitches or in unplanned shutdowns of critical systems that often mean significant business and financial losses. Examples of contamination events are provided throughout the book. In many cases, the events are written generically to illustrate points that support the text.

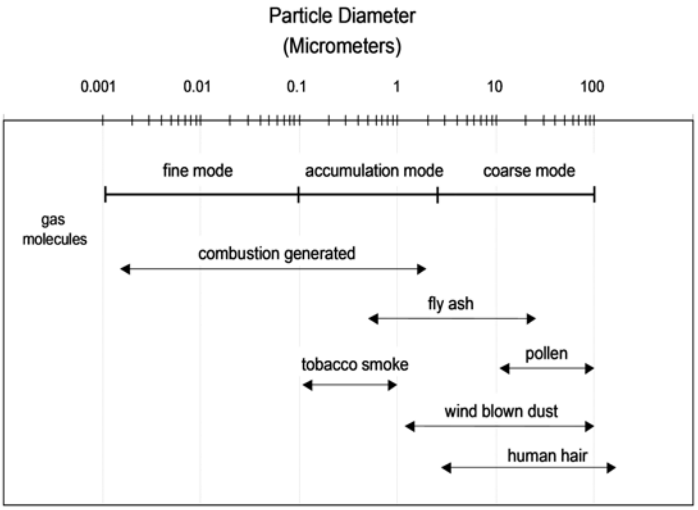
The intent of this publication is to provide basic information that is essential to the control and prevention of particulate and gaseous contamination within datacom facilities. Understanding the critical parameters outlined in this publication will provide equipment manufacturers and facilities operations personnel with a common set of guidelines for contamination control that can enhance the longevity of datacom equipment. The book does not cover issues related to contamination and filtration of open water systems, such as condenser water systems, used in datacom environments.

The intended audience for this publication is:

- planners and datacom facility operation managers
- datacom facility architects and engineers who require insight on datacom environmental controls for gaseous, organic, and particulate contamination
- datacom facility service providers
- datacom equipment manufacturers

1.1 GENERAL DESCRIPTION OF PARTICULATE MATTER

Particulate matter (PM) refers to small solid or liquid particles that can become airborne with different airborne lifetimes. For the purposes of this book, the terms *particle*, *particulate*, *aerosol*, and *dust* will be considered equivalent and all are represented by the term *PM*. The size of PM spans a vast size range from 0.001 to more than 100 micrometers (μm) (3.93701×10^{-8} to more than 0.003937008 in.) in diameter. The United States Environmental Protection Agency (EPA), which monitors PM from a health point of view, categorizes particle mass concentration as PM2.5 and PM10, representing particles smaller than 2.5 and 10 μm (9.84252×10^{-5} and 0.000393701 in.), respectively. More specifically, PM can be categorized in three size modes: fine mode (0.001–0.1 μm [3.93701×10^{-8}–3.93701×10^{-6} in.]), accumulation mode (0.1–2.5 μm [3.93701×10^{-6}–9.84252×10^{-5} in.]), and coarse mode (2.5–10 μm [9.84252×10^{-5}–0.000393701 in.]), which is often limited to particles smaller than 10 μm (0.000393701 in.) but can include fibers and particles as large as 100 μm (0.003937008 in.). PM in each of these size categories may be composed of different materials, come from different sources, and vary in airborne suspension lifetime. See Figure 1.1 for typical size ranges of PM (Bell 2000). Consequently, PM



I-P conversions:
0.001 μm = 3.94×10^{-8} in.
0.01 μm = 3.94×10^{-7} in.
0.1 μm = 3.94×10^{-6} in.
1 μm = 3.94×10^{-5} in.
10 μm = 3.94×10^{-4} in.
100 μm = 3.94×10^{-3} in.

Figure 1.1 Size ranges of various PM sources.

in each size category is associated with different equipment reliability concerns. This book discusses particles in each of these size modes.

1.2 GENERAL DESCRIPTION OF GASEOUS CONTAMINATION

Gaseous contamination is an impurity in the air that has an adverse effect on computer hardware. The gases can occur naturally or can be by-products of industrial or manufacturing processes. Gases tend to occupy an entire air volume uniformly at standard room pressure and temperature. The gases can either act alone or in conjunction with other gases or PM to form compounds that can result in oxidation on metallic materials. The oxidation results from a chemical reaction, which causes irreversible destruction on the surface of a circuit board, on the leads of a connector, or on pins of an integrated circuit.

Gaseous contamination in the form of outside pollution (e.g., smog), particularly when composed of sulfur, bromine, and chlorine compounds, can corrode power and cooling equipment, electronic circuit boards, and datacom connections, which over time will degrade the overall reliability of datacom equipment.

1.3 CONTAMINANT SOURCES

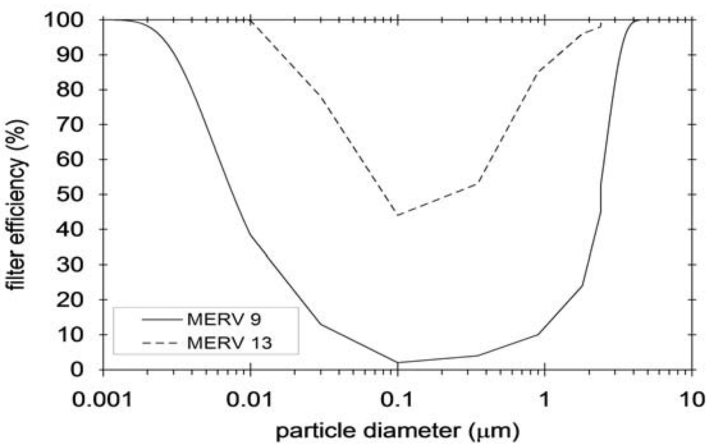
PM is generated both naturally and by humans (anthropogenically). In the outdoors, fine-mode (0.001–0.1 µm [3.93701×10^{-8}–3.93701×10^{-6} in.]) and accumulation-mode particles (0.1–2.5 µm [3.93701×10^{-6}–9.84252×10^{-5} in.]) are formed primarily during combustion processes. Significant urban PM sources include automobiles, electricity generation, and wood-burning fireplaces (Seinfeld and Pandis 1998). Larger particles can include sea salt, natural and artificial fibers, plant pollens, and wind-blown dust. Accumulation-mode particles are the PM of principal concern when outdoor air is entering the datacom equipment center environment. Conventional filters in mechanical ventilation systems are able to very efficiently remove PM in the coarse mode (> 2.5 µm [> 9.84252×10^{-5} in.]). Figure 1.2 shows the minimum efficiency reporting value (MERV) filter efficiency of MERV 9 and MERV 13 filters as a function of particle size (Hanley et al. 1994; Riley et al. 2002). More information about air filtration can be found in Chapter 4. Particles with diameters larger than about 1.0 µm (3.93701×10^{-5} in.) are effectively removed by filtration since the mass of these particles prevents them from following the quickly changing airflow pattern of air moving across the filter. This causes these larger particles to crash into the filter fibers. Particles smaller than about 0.1 µm (3.93701×10^{-6} in.) are also effectively removed by filtration since the small size of these particles causes them to drift away from the air maneuvering through the filter and collide with the filter fibers. Particles in the in-between range (the accumulation-mode size range) are most difficult to remove, because these particles most easily follow the airflow through the filter fibers. Outdoor particles beyond the accumulation-mode size range can enter datacom equipment centers through openings in the building envelope, but datacom equipment centers can be positively pressurized to avoid this form of particle infiltration. However, one study indicates that introduction of outdoor air for the sole purpose of guarding against infiltration actually carries more particles into the building than the added pressure keeps out (Herrlin 1997).

Previous measurements have shown outdoor air to be the main source of PM in the data center environment (Shehabi et al. 2008), but anecdotal evidence suggests that episodic indoor events can potentially contribute to indoor PM concentrations. Indoor-generated PM can include particles in all size ranges. Fan belt wear in air-handling units (AHU), toner dust from copiers, and printers can be sources of coarse-mode particles. Coarse-mode particles can also come from occupant hair and clothing or occupant activities, such as the unpacking of equipment or construction (e.g., cement dust, drywall dust, insulation, paper/cardboard fiber). Small fibers from occupants or occupant activities represent particles greater than 10 µm (0.000393701 in.) that can be of concern. Other documented fibers include small zinc formations, commonly referred to as *zinc whiskers*, which have been observed forming on the surface of zinc electroplated steel.

Gases entering the datacom equipment center from the outdoors can react once inside the environment and form particles in the fine- and accumulation-mode size range.

1.4 HOW CONTAMINANTS SETTLE ON EQUIPMENT

PM is transported with the movement of air, also known as *advection*, throughout the datacom equipment center. Computer room air-conditioning (CRAC) units or computer room air-handling (CRAH) units often provide air conditioning in datacom equipment centers, where either the CRAC or CRAH is situated on the data center floor. Datacom equipment centers can be raised-access floor or non-raised-access floor environments. Figure 1.3 shows the airflow in a typical raised-access floor data center. Outside air, also referred to as *makeup air*, enters the side of the AHU, where it passes through a series of filters and is conditioned. The conditioned air is then supplied to the servers through the raised floor. Fans within the datacom equipment pull air through the



I-P conversions:

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Figure 1.2 Filter efficiency of commonly used filters in datacom environments.

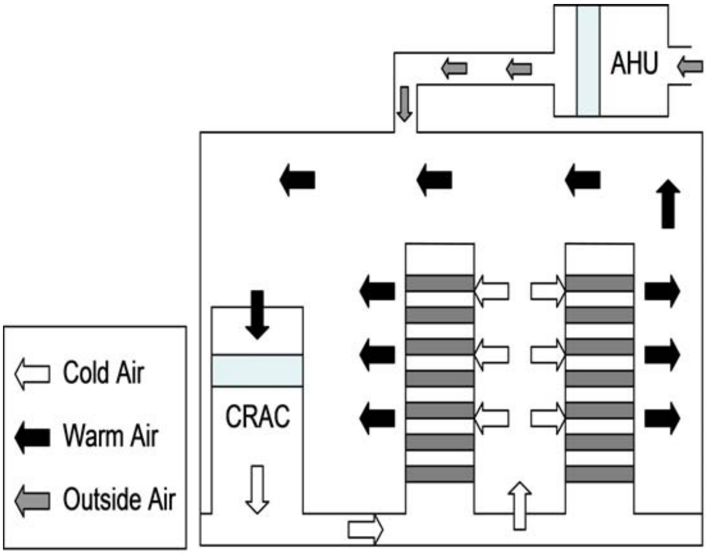

Figure 1.3 Airflow in a raised-access floor data center.

cabinets. The warmed air eventually makes its way back to the intake of the CRAC unit or the AHU return (not shown in Figure 1.3). Most air circulation in datacom centers is internal to the datacom center zone. The majority of datacom centers are designed to have only a small portion of outside air enter the datacom center for positive pressurization. Some datacom centers provide no ductwork for outside air to directly enter the datacom center area. Rather, outside air is only provided by infiltration from adjacent zones, such as office spaces or hallways. However, a growing number of datacom centers use air handlers designed with air-side economizers (similar to those used in commercial buildings) to take advantage of the energy- efficiency benefit of using a high volume of outside air for cooling. It should be noted that the traditional closed-flow layout results in the same air circulating through filters repeatedly. The intake of large volumes of external air and its subsequent exhaust from the datacom equipment center results in fewer passes through the filtration system for any given volume of air.

PM deviates from airflow paths and settles onto interior surfaces primarily through three different mechanisms:

- gravitational settling
- diffusional movement
- electrostatic attraction

Gravitational settling is a function of particle mass and has the greatest influence on large particles. Gravitational settling becomes insignificant for particles smaller than approximately 1 μm (3.93701×10^{-5} in.) in diameter, while particles greater than 10 μm (0.000393701 in.) have short airborne residence times due to the strong gravitation forces that cause particles to quickly settle onto horizontal surfaces. Strong air currents can prolong airborne residence times, even for large particulates.

The diffusional movement of PM is caused by random collision of air molecules against airborne particles. The result of these collisions allows particles to migrate from higher particle concentrations to lower particle concentrations. Diffusion is significant only with very small particles and has minimal influence on particles greater than 0.1 μm (3.93701×10^{-6} in.) in diameter. Diffusion affects particles equally in all directions. While larger particles primarily deposit onto horizontal surfaces, smaller particles have an equal tendency to deposit on either horizontal or vertical surfaces.

Electrostatic attraction is the force between opposite charges that pulls particles together or causes them to settle on surfaces. The simplest example is static electricity, the same force which may cause clothes to cling together.

Once a particle comes into contact with a surface, either by gravitational settling, diffusional movement, or electrostatic attraction, it is generally expected to remain deposited. Resuspension of particles in the air is expected to be minimal because of the cohesive forces between the particles and surface. Mechanical processes such as floor sweeping, movement of floor or ceiling tiles, or equipment maintenance often cause resuspension.

Gaseous contaminants diffuse in the air to occupy the entire volume, but differences in air density may cause stratification. The movement of the contaminants is relative to the air movement.

1.5 DIFFERENCES BETWEEN HUMAN HEALTH AND DATACOM EQUIPMENT CONCERNS

PM vulnerabilities in humans are very different than those in datacom equipment. Most studies of PM in the workplace are focused on the range of particulates harmful to humans. Two frequently tracked values are PM2.5 and PM10. These are the airborne particle sizes of PM < 2.5 μm (PM < 9.84252×10^{-5} in.) and PM < 10 μm (PM < 0.000393701 in.) in diameter. These values roughly relate to material sizes remaining after various stages of the human filter. Human physiology provides multiple filtration stages as PM-laden air is drawn into the respiratory system. Filtration in the nose and throat removes most large airborne particulates.

Many electronic assemblies are vulnerable to much larger airborne material. Long fibers can be particularly problematic for electronic equipment. Fibers in excess of 5 mm (0.196850394 in.) in length have been found within IT equipment.

1.6 OVERVIEW OF CHAPTERS

Chapter 1—The introduction states the purpose/objective of the publication as well as some background information about the importance, sources, and nature of PM and gaseous contamination. This chapter also includes a brief overview of the remaining chapters and their relationships to each other.

Chapter 2—This chapter discusses PM and gaseous contaminants and how their interaction can impact the reliable operation of datacom equipment. The chapter examines the datacom equipment components, devices, and subsystems vulnerable to PM and gaseous contaminants and describes their mechanical, chemical, and electrical effects. Some of the more pronounced effects are overheating, corrosion, and arcing. These effects can have serious consequences on the long-term health of the datacom equipment.

Chapter 3—There are several test methods, guidelines, and limits available for consideration and use in datacom environments. This chapter examines pertinent documents but does not recommend a single set of limits. Because of the complexity of PM and gaseous impacts on datacom equipment, individual datacom manufacturers may choose to either adopt a single industry work, adopt a combination of industry works, or establish their own set of design requirements. Establishing individual test methods and limits is done to address specific materials, electrical design characteristics, and/or thermal design characteristics necessary to meet performance or other critical design objectives.

Chapter 4—Best practices for facility level prevention and controls are documented in detail in this chapter. PM and gaseous exposure risks and hazards need to be identified so that datacom equipment centers can be designed and constructed to keep contamination out. Contaminant prevention is a very important consideration with respect to facility location, design, construction, and the cooling system. Even with contamination mitigation through prevention, potential PM and gaseous contamination sources are unavoidable and must be controlled. Actionable recommendations, aimed at controlling PM and gaseous contamination, are provided in this chapter to be incorporated into general business processes and procedures. Implementing facility prevention and control techniques can diminish PM and gaseous contamination to levels below those that most manufacturers would be concerned about in a typical datacom equipment center. One important aspect of control is monitoring to evaluate the condition of the datacom equipment center. Some monitoring is as simple as visual inspection, but at times, testing and analysis is necessary. Examples are documented in Chapter 5.

Chapter 5—Testing and analysis can be used to conclusively determine the presence and quantity of PM and gaseous contaminants. This chapter presents methodical, comprehensive surveys that can be used to determine the presence of contaminants. Some of the site surveys can be done visually, but typically instruments are required to collect data and professional analysis is necessary to interpret the results and identify sources for remediation.

Chapter 6—Air-side economizers represent a significant opportunity for datacom equipment centers to save energy. This chapter offers a set of considerations for implementing air-side economizers successfully. It also identifies potential threats to datacom equipment centers.

Chapter 7—This chapter offers a short summary of key ideas presented in this book.

Appendix A—This appendix discusses proposed datacom environment contamination levels.

Appendix B—This appendix examines field contamination occurrences.

Appendix C—This appendix presents future work in PM and gaseous contaminants.