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Cleaning and Special Environments — Understanding the Science

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Introduction

Special environments are those that harbor individuals who are considered susceptible to negative health effects associated with the accumulation of indoor contaminants and pollutants, and therefore present a notable challenge. They include schools, daycare, healthcare facilities (e.g., hospitals, rehabilitation centers and long-term care facilities [LTCFs]), and some home environments. Such populations include individuals with severe allergies and hypersensitivities, to include asthma, as well as those who are immune suppressed or immune deficient and therefore at-risk for a variety of potential life-threatening opportunistic infections caused by otherwise innocuous indoor contaminants such as environmental molds.

Children and especially young children have immature immune and organ systems and are therefore at risk during their growth and development, especially from pollutants such as heavy metals and chemical residues that may be present in everyday house dust. Similarly at risk are the elderly, with their waning immune function and susceptibility to drug-resistant bacterial pathogens and respiratory viruses, in conjunction with a variety of chronic illnesses that often renders them even more vulnerable to indoor environmental contaminants.[1] This article draws from the available scientific data necessary for an understanding of the complexities of special environments, in order to provide a basis of guidance for cleaning and restoration professionals.

The Indoor Ecosystem

Each indoor environment is an artificially created ecological system comprised of a nonliving or physical component intertwined with a living or biological one.

About the Author

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SYNOPSIS

Special environments harbor individuals who are considered susceptible to negative health effects associated with the accumulation of indoor contaminants and pollutants. They include schools, daycare, healthcare facilities, long-term care facilities (LTCF) and some home environments.

Children have immature immune and organ systems and are at risk during their growth and development from pollutants such as heavy metals and chemical residues. Also at risk are the elderly, with their waning immune function and susceptibility to bacterial pathogens and respiratory viruses, and those convalescing from medical interventions.

Each indoor environment is a created ecosystem of a nonliving, physical component intertwined with a living, biological one. Within each ecosystem, if the accumulating particulate burden is not regularly reduced through cleaning, it becomes a source of indoor contamination.

Cleaning is a systematic, science-based process of managing unwanted matter. Effective cleaning incorporates practices and procedures necessary for maximum pollutant removal.

School facilities present a particular challenge due to budget constraints, staff shortages, ill-functioning cleaning equipment, poor cleaning products and insufficient staff training. Evidence suggests that poor indoor environmental quality is common and adversely affects the performance and attendance of students.

Recent studies indicate that targeted cleaning of frequent-contact points resulted in reduced illnesses tied to bacterial contamination reservoirs, reduced sick building syndrome symptoms, and reduced absenteeism.

Carpets in schools are usually cleaned by extraction once a year, but the lack of effective routine maintenance with efficient vacuuming permits the carpet dust reservoir to fill and become a contamination source. Children are then exposed to respirable carpet dusts containing a variety of pollutants.

To prevent HVAC-related pollution problems in schools, a combination of proper design, inspection, cleaning and maintenance is needed. The HVAC system must have easy access for inspection, cleaning and maintenance of all components, including filters, cooling coils and ductwork.

Small animals in schools, while valuable to learning, are sources of environmental pollution. The primary exposure in classrooms harboring animals is from airborne allergens. To minimize exposures to allergic and infectious agents, schools should dedicate one room as an animal room, thus taking active pollutant sources from the classrooms and facilitating the cleaning process.

Hospitals and long-term care facilities are especially challenged to prevent the transmission of infectious-disease agents resulting in healthcare-associated infections (HAI). Environmental sources can be managed through an effective building maintenance program as well as through cleaning and disinfection practices that inactivate and remove infectious particles and reduce reservoirs.

Steam cleaning and disinfection has become more common. A study confirmed that steam begins to kill vegetative bacteria on contact, and that inactivation continues rapidly and logarithmically. Another study found that microfiber and steam technology was significantly more effective in controlling a norovirus outbreak than a two-step process involving detergent cleaning followed by hypochlorite solution.

Daycare centers and home healthcare environments can present significant infectious, allergic and toxic exposure risks. To decrease exposures, reservoirs must be routinely managed through effective cleaning programs with emphasis on the physical removal of soil and pollutants. This approach significantly decreases microbial pathogens, and minimizes the use of biological and chemical residual germicides.

The indoor environment is a complex ecosystem. Absent an effective and frequent reduction and removal process, contaminant reservoirs can become pollutant sources. To maintain an ecological balance and promote healthfulness, effective cleaning practices must be identified, evaluated and implemented.

The physical environment includes structural, finishing and furnishing materials, and their paints, coatings and sealants, a variety of contents, and a climate as measured by temperature, relative humidity and airflow. The living or biological indoor environment typically includes microorganisms, insects, plants, rodents, pets and humans.

This indoor ecosystem is comprised of an interrelated complex of smaller microenvironments or habitats, each of which has its own mix of physical and biological factors, and can serve as reservoirs for a variety of pollutants that can potentially affect the quality of the air in occupied spaces. Some microenvironments are structural components such as interior and exterior wall cavities, ceiling spaces, air-handling systems, and crawlspaces. Others serve as reservoirs that readily collect particulates as dusts, fibers, soil, and debris that can harbor a variety of chemical and biological pollutants, such as pesticide and lead residues, along with microbial, insect and animal allergens. Examples of such microenvironments include textile floor coverings, upholstered and hard surface furnishings, bathroom surfaces, and food preparation and pet areas.

If the accumulating particulate burden of these reservoirs is not regularly reduced through a removal process known as cleaning, they may quickly become sources of indoor contamination through airborne dissemination resulting from occupant activity and mechanical airflow. Such dissemination can seed previously uncontaminated areas as well as degrade air quality, leading to occupant exposures and adverse health effects in susceptible individuals. The latter, in particular, are considered at-risk in the aforementioned special environments that present significant cleaning challenges.

The general population often incurs health risks in high occupancy indoor environments such as office buildings, hotels, and cruise ships. The focus of this discussion will be on special environments. However, the home, where everyone typically has their highest occupancy time, presents the greatest risk because reservoir reduction through cleaning is often the least well managed. Many of the principles covered here also apply to home cleaning.

Cleaning

Cleaning is a systematic, science-based process of managing unwanted matter, so human activities can take place in a healthy environment.[2] Effective cleaning requires an understanding of the science of particulate deposition and retention on various surfaces. Effective cleaning also chooses those practices and procedures necessary for maximizing pollutant removal while containing the process and minimizing cross-contamination. In all cases, cleaning needs to maintain and preserve the integrity of the surface or material being treated. It is heavily dependent on frequency of implementation and the efficiency of the equipment and cleaning products being used.

Schools

Public school facilities present a particular challenge in regard to cleaning and overall environmental management due to budget constraints and resultant shortages of facilities maintenance and janitorial staff, outdated and ill-functioning cleaning equipment, and poor cleaning products and staff training. Additionally, many schools are poorly designed and constructed, and ageing, making adequate inspection and appropriate subsequent cleaning a significant challenge. Thus, not surprisingly, available evidence suggests that poor indoor environmental quality (IEQ) in schools is common and adversely influences the performance and attendance of students, primarily through health effects resulting from exposure to indoor contaminants and pollutants.[3] Lack of proper cleaning permits dust-collecting reservoirs to become sources of insect, animal, and microbial antigens that can trigger asthma and respiratory allergies, and possibly induce respiratory inflammation, which may predispose students to infectious respiratory illness, especially during the cold and flu season.[4, 5, 6, 7]

Major dust reservoirs/sources in schools that typically lack effective cleaning and maintenance include carpet, animal cages, and HVAC systems. Additionally, inattention to moisture intrusion or accumulation throughout a facility may lead to microbial growth and amplification which can further contribute to poor air quality and greater student exposures to respiratory health risks. On the positive side, the value of effective cleaning has been demonstrated, as increased effort at improved cleaning of floors and desks in schools has actually been demonstrated to reduce upper respiratory symptoms.[8]

Cleaning for Health. Recent studies have collectively indicated that enhanced hygiene in schools, and targeted cleaning of biological residual contamination related to frequent-contact points, resulted in reduced illnesses tied to bacterial contamination reservoirs (MRSA, shigella outbreaks), reduced sick building syndrome symptoms, and reduced absenteeism due to infectious illnesses.[9, 10, 11, 12]

And while school hygiene programs such as handwashing promotion are admirable and well-intentioned, they typically neglect the rapid recontamination of hands via high contact touch points that are usually poorly cleaned. Thus, student illness and absenteeism rates fail to change.[13, 14]

While classrooms and hallways remain major dust reservoirs in school buildings, other subcompartments of the ecosystem (e.g. food preparation areas, restrooms, locker rooms, gyms) require similar attention to cleaning, with an additional targeted focus on reducing the infectious disease potential. School kitchens and related areas, as obligated by public health code, must be cleaned and sanitized to prevent environmental contamination and transmission of bacterial pathogens such as *E. coli, Listeria,* and *Salmonella*.

Similarly, restrooms must be effectively cleaned and monitored for effectiveness to prevent exposure and resultant student illnesses from a variety of pathogens, both enteric (e.g. noroviruses, *E. coli*) and respiratory (e.g. cold, flu viruses). This is emphasized by results of a study in two daycare centers where 19% of surfaces tested were positive for rotavirus.[15] Rotavirus contamination was found on drinking fountains, water play tables, toilet handles, and telephone receivers. There can also be other consequences associated with poor cleaning of school restrooms, with students describing them as "unpleasant," "dirty," "smelly," and "frightening," and refusing to use them while at school, thus suffering consequences such as constipation, urinary tract infections, and incontinence.[16, 17]

Likewise, school locker rooms and gymnasium surfaces and materials, if improperly cleaned and sanitized, can increase transmission of infectious agents such as athlete's foot fungi, *Staphylococcus aureus,* and Herpes viruses. Absent effective cleaning, there is the potential for widespread outbreaks among students, as occurred with methicillin-resistant *S. aureus* (MRSA) in a college football team.[18] A recent extensive review of the significance of fomites (inanimate surfaces) in the spread of respiratory and enteric viral disease, stated that "the rapid spread of viral disease in crowded indoor establishments, including schools, day care facilities, nursing homes, business offices, and hospitals, consistently facilitates disease morbidity and mortality." Further, it concluded that "level of cleanliness" is one of a number of factors involved.[19]

Carpet. Although carpets in schools are usually cleaned by an extraction process once each year, the lack of effective maintenance with efficient vacuuming throughout the year permits the carpet dust reservoir or "sink" to fill and become a source. Carpeted classrooms are typically crowded with student desks and other furniture, and manpower is usually lacking to rearrange it to effectively vacuum the carpet even once per week. Additionally, some vacuum cleaners are inefficient at dust capture and lack appropriate exhaust filtration. Thus they serve as aerosol generators, collecting carpet dust and its pollutants, and aerosolizing them back into the environment.

As carpet becomes a source, children can be exposed to very fine or respirable particles (<5.0 μm) which may contain a variety of allergens from dust mites, cockroaches, and cats (as antigens are brought to school on clothing and shoes), as well as spores from allergenic molds such as *Cladosporium, Penicillium,* and *Aspergillus.* Research has shown that even dust from well-maintained carpet can harbor in excess of 1.5×10^5 mold spores and 1.0×10^7 bacteria per gram of carpet dust.[20] Thus, if carpet has been water damaged from moisture intrusion or damp from inefficient cleaning methods for more than 24 hours, the fungi and bacteria will grow and amplify rapidly. In this situation, the carpet's burden of fungal contamination, primarily as mold allergens, along with potential toxic metabolites (mycotoxins) increases significantly, as does the bacterial burden and its source of endotoxins (bacterial cell wall components that react with lung tissue and are associated with respiratory illness). The latter can induce fever, increase reactivity of the airways, and induce bronchoconstriction and chest tightness. Endotoxins also have the potential to boost responses to inhaled antigens.[21]

Chemical pollutant exposures may occur as children are exposed to respirable carpet dusts containing residues of pollutants such as pesticides, cleaning products, lead, and various volatile organic compounds (VOCs) produced by microbial contamination. A "musty," "moldy," "mildewy" odor is definitive for microbial contamination of carpet. Additionally, carpet may serve as a fomite or mechanical means of transmission of agents such as head lice or fungi that cause skin infections, such as ringworm. These are significant risks for children in the lower grades who might sit or lie on carpet for most of the school day.

In a study sponsored by the U.S. Environmental Protection Agency (EPA), indoor air quality monitoring for biological pollutants was conducted before and then during professional carpet cleaning in 16 commercial, public and residential environments.[22] The sites included six clerical offices in high-rise buildings, four service-based business offices at ground level, five single-family homes, and one elementary school classroom. The data showed a strong relationship between the routine cleaning and maintenance of carpets and resultant low levels of airborne fungi. The lowest levels of airborne fungi were in the clerical offices, and the highest were in the homes and the school. The clerical offices were rigorously maintained by daily vacuuming, monthly shampoo or bonnet cleaning, and regular (every 12–18 months) hot water extraction. The offices also had reduced track-in contamination by being above ground level, without animals or children. Conversely, the homes and school classroom were at ground level, had multiple pollutant sources, and perhaps most importantly, were infrequently cleaned and vacuumed.

Those results dramatically demonstrated the effort required to maintain carpet in a healthy state and prevent it from becoming a pollutant source. Extraction cleaning should be done periodically according to the industry standard for professional cleaning of textile floor coverings.[23] The standard calls for ensuring that carpet is dried as quickly as possible to prevent microbial amplification. After cleaning, carpet should be maintained by frequent vacuuming with high efficiency vacuum cleaners that provide maximum dust extraction and minimum dust resuspension to the air. Careful attention to carpet cleaning, maintenance, and moisture control provides the preventive care necessary to keep the carpet sink from becoming a pollutant source. Unfortunately, as mentioned previously, the monetary and personnel resources needed to implement such a program in a school environment are usually lacking. Therefore, serious consideration must be given to the question of whether or not to install carpeting in school buildings. While hard surface flooring will still require routine cleaning and maintenance to reduce pollutants at comparable costs, it will often reduce the potential for an often neglected source in the classroom.

Heating, ventilating, and air-conditioning system (HVAC). In a 15-year-old school building, 50% of the occupants complained of a building-associated illness characterized by eye, nose, and throat irritation, skin rash, headache, and fatigue.[24] Complaints included a musty odor during the air-conditioning season. Air-handling unit plenums and major air supply ducts were lined with a porous insulation. Due to deficiencies in air filtration, the insulation had become permeated with organic dusts after many years. Insulation downstream of the cooling coils became amplification sites for fungi, such as *Penicillium,* and bacteria such as thermophilic actinomycetes. Both produce spores that can be deposited in the upper and lower airways and result in a variety of respiratory illnesses. Airborne concentrations of those microorganisms in classrooms and offices were up to 100 times those found in the outdoor air. The acoustical insulation inside air-handling units and air supply ducts functioned as amplification sites for microorganisms.

The key to preventing air duct-related pollution problems in school buildings is a combination of proper design and dedicated inspection, cleaning and maintenance. First and foremost, internal porous insulation should be precluded from use in ductwork. Even if sealed liner is used internally, it still maintains the possibility of entrapping dust and debris, and it also complicates the commercial duct cleaning process. Ducts can be insulated externally using fiberglass wrap. If internal porous insulation is determined to be a source of microbial contamination, it should be removed or the ductwork replaced, as opposed to the use of antimicrobials, biocides, sealants/encapsulants — although the latter may be beneficial in unique circumstances.

Additionally, components of the HVAC system must be designed and constructed to provide access for easy inspection, cleaning and maintenance of all components, to include filters, cooling coils and ductwork. Access doors should be large and easy to open to facilitate thorough and regular maintenance. Hinged access doors are preferable to bolted access panels, and condensate drain pans must be designed to completely drain. Many pans are still designed and manufactured with the bottom of the drain hole above the bottom of the pan, always ensuring enough of a water reservoir to produce a microbial soup whose contaminants can be entrained into the building airflow.

As research is still incomplete regarding efficacy of the variety of commercial duct cleaning practices available to mitigate duct-related problems, emphasis for ensuring a healthy school building should focus instead on prevention of pollutant problems through attention to design intervention and subsequent routine inspection, cleaning and maintenance.

Animals in school environments. Small animals in schools are recognized as valuable to the learning process. They are aids to children learning principles of various disciplines including among others, biology, ecology, environmental science, behavior, geography and even mathematics. They are also sources of environmental pollution that must be addressed. Historically, teacher classrooms in elementary and middle schools harbor a variety of small animals such as hamsters, mice, guinea pigs, chinchillas, ferrets, rabbits, snakes, lizards, turtles, chicks, ducklings and others. Children are afforded opportunities to observe, feed, weigh, pet and otherwise handle and care for these animals in order to have meaningful life and educational experiences. While teachers must assume responsibility for providing an optimum environment for the animals, and preventing their mistreatment, they must also realize the potential for adverse health effects to the children in terms of allergic and infectious diseases.

The most insidious exposure affecting children in classrooms harboring animals, especially mammals, is from allergens by the airborne route. Dander from the animals as well as fungal and bacterial spores and toxins from fecal and bedding materials may induce or exacerbate allergic sensitivities. Asthma in elementary school children is the leading cause of school absences, and a major public health concern. Inflammation and irritation of the upper airways as a result of allergen exposure may increase susceptibility to infectious respiratory agents such as cold, influenza and other viruses, as well as bacterial infection such as streptococcal sore throat. Animals also have the potential to transmit infectious agents through direct contact, such as those causing salmonellosis and fungal infections of the skin.

In order to minimize day-long exposures to allergic and infectious agents, it is recommended that schools dedicate one room to be an animal room, thus taking active pollutant sources from the classrooms and facilitating the cleaning process. The room will have adequate cage racks, as well as mechanisms for convenient feeding, watering and cleaning chores. Most importantly, the room will have a dedicated system of exhaust ventilation to carry dusts, dander, allergens, and odors directly out of the building. Teachers can periodically bring students to the animal room for the required observation or experimentation, rather than having the students exposed continually in the classroom. Rather than face difficulties later in attempting to retrofit an area as an animal room, the concept should be addressed in the design phase of a new building or planned renovation, when the determination of the required heating, cooling, ventilation, and cleaning and maintenance is simplified.

Design for a healthy school building. First and foremost, the entire question of cleaning the school building, to include decisions on floor coverings, animals, and access to the HVAC system, must be addressed in the building's design phase. Design intervention is a useful strategy for controlling pollution indoors when it becomes necessary to match the built environment with the activities that take place inside. Design intervention is important when designing new buildings as well as when remodeling an old structure for new use. Buildings and their furnishings need to be designed in a way so they can be cleaned, with cleaning defined as maximizing the removal of pollutants while minimizing chemical, biological, particle and moisture residues.[24,25]

Healthcare Facilities

Hospitals and long-term care. A major challenge for hospitals and long-term care facilities (LTCFs) is prevention of transmission of infectious disease agents resulting in healthcare-associated (or nosocomial) infections. This requires attention to human and environmental source control, activity management, design and dilution intervention, and cleaning.[26]

Sources of infection can be managed either through removal, such as in the case of mold-contaminated building materials, or modification, such as by purging hot water systems to eliminate *Legionella* species. Patients with active tuberculosis can be housed in negative-pressure rooms, required to wear respiratory protection, or placed in laminar-flow beds until shown to be non-infectious. Environmental sources can be managed through a program of building maintenance that ensures appropriate and routine inspection of potential sources, such as HVAC air intakes and filter banks, air ducts, cooling towers, and hot water systems. Sources can also be managed through efficient and routine cleaning and disinfection practices that inactivate and remove potentially infectious particles and reduce reservoirs such as carpet and other dust-contaminated surfaces. The use of detergents in the wet cleaning of surfaces and materials provides for the emulsification of organic residues and thus the removal of associated microbial pathogens. And as most detergent products are formulations of quaternary ammonium compounds, they typically have a disinfection or sanitization effect resulting in the inactivation of microbial contamination as well. Physical removal is crucial in the reduction of bacterial-spore contamination, which may not be eliminated merely by the application of a sporicidal germicide. One study of hospital floor cleaning methods concluded that wet scrub cleaning using detergent solution with "hand hot water" was the most efficient, followed by spray cleaning, and then mopping and vacuuming [27], while another study showed that wet wiping with a detergent cleaner resulted in the physical removal of approximately 3 $\log_{10}$ of *Clostridium difficile* spores from environmental surfaces.[28]

Also, the use of steam as a cleaning and disinfection method has become more popularized with the availability of a number of commercial equipment products. A most definitive study of the capability of steam to inactivate a broad spectrum of human pathogenic bacterial challenges dried on a hard surface showed complete kill by exposure to steam vapor within 5.0 seconds.[33] In the study, the use of bacterial challenges (4 $\log_{10}$-8 $\log_{10}$) of MRSA, vancomycin-resistant *Enterococcus faecalis, Salmonella enterica, Pseudomonas aeruginosa, Escherichia coli,* and *Shigella flexneri* exposed to a steam device with its head covered with a cotton-terry material, showed initial kill beginning at 0.5 seconds and continuing through 1.0 and 2.0 seconds, with complete kill of all challenges by 5.0 seconds.[29] Such results confirmed the fact that steam begins to kill vegetative bacteria on contact, and that inactivation continues rapidly and logarithmically. And in-use effectiveness of microfiber and steam technology was confirmed to be significantly more effective in controlling a norovirus gastroenteritis outbreak than a two-step process involving detergent cleaning followed by hypochlorite solution (1,000 ppm) with a 10 minute contact time.[30]

Activity management is the process of ensuring that the building is used for the activities that it was designed to accommodate. Sometimes when indoor air pollutants are encountered, it is the result of the building or section of the building being used for some other purpose than that for which it was originally designed. Examples include laboratories in structures that were designed to be offices or living quarters, or offices in areas that were formerly laboratories. Use of a building in the way that was originally intended also facilitates and promotes a routine program of inspection, maintenance and cleaning. Such a program can become an afterthought when a hospital is continually renovating the existing structure, constructing additions, or otherwise modifying the built environment.

As with schools, design intervention can be crucial to healthcare facilities, and may include special exhaust ventilation or other airflow requirements or the removal and exclusion of certain building or furnishing materials that are particularly susceptible to microbial contamination, such as ceiling tile and carpet. Design intervention might make use of the dilution process to lower airborne concentrations of pollutants through the introduction of more clean air. Very small infectious airborne particles, typically referred to as droplet nuclei, can be moved by air and captured by air filters. For example, a study was conducted to investigate the effectiveness of in-room air filtration with dilution ventilation for control of TB infection.[31] Results showed that ventilation plus recirculating air filtration could reduce average room particle concentrations by 30% to 90%. This, in combination with source-management approaches such as treatment booths and respiratory protection, could significantly lower transmission potential in high-risk settings. Similarly, in controlling nosocomial aspergillosis, high air-exchange rates are the most effective, particularly in combination with point-of-use filtration.[32]

Daycare and Home Healthcare Environments.

As with schools and LTCF facilities, daycare centers and home healthcare environments can present significant infectious, allergic and toxic exposure risks to susceptible occupants. Therefore, requiring routine attention to environmental management through effective cleaning practices is essential.

Pre-school children are not just small adults. They have higher respiratory and heart rates than adults, plus unique oral behaviors, immature livers, kidneys, and immune functions that render them at high risk for adverse health effects from indoor exposures. And as mentioned previously, the elderly suffer from naturally waning immune function, as well as that which is treatment-induced, often in conjunction with the effects of a variety of chronic diseases. Similarly, individuals convalescing at home from chemotherapy, transplantation, AIDS, or other conditions, are rendered especially susceptible to infectious and toxic effects from accumulating indoor pollutants.

Thus, to decrease exposures in all of these special environments, their indoor environmental reservoirs must be routinely managed through effective cleaning programs. In this regard, emphasis should be placed on the physical removal of soil and associated pollutants through the use of effective cleaning practices, such as the use of detergent products on hard surfaces. This cleaning approach can significantly decrease pollutants, to include microbial pathogens, and thus minimize the use of germicides, which may leave both biological and chemical residuals as contaminants. In this regard, one study confirmed the effectiveness of vacuuming plus wet washing with detergent on various hard surfaces for the removal of lead-contaminated dust in home environments.[33] And a study looking to control mold and mildew in home environments showed the effectiveness of an approach combining moisture control, cleaning, and the targeted use of disinfectant in reducing potentially allergenic and opportunistic molds.[34]

Cleaning remains the final defense in managing indoor environmental contamination. Even if source management, activity management, design intervention, and dilution ventilation have all been optimally used to control infectious aerosols, cleaning is still necessary, although it should become easier as each strategy is improved.

The importance of cleaning was demonstrated in a year-long study of cleaning effectiveness in a non-complaint multiuse building with laboratories, offices, medical examination rooms, and a daycare unit with 62 children.[35, 36, 20] The routine use of high-efficiency vacuum cleaners, damp dusting, and the use of efficient and less polluting cleaning products on hard surfaces, particularly in high-traffic areas, along with installation of entryway mats to reduce track-in, and rapid attention to events such as leaks and spills, resulted in meaningful decreases in particulate and microbial contamination on surfaces and in air, as well as overall reduction of total volatile organic compounds (TVOCs). After seven months of improved cleaning practices and environmental monitoring, the data showed meaningful decreases in airborne dust mass (50%), airborne fungi (61%), airborne bacteria (40%), carpet dust fungi (40%), and carpet dust bacteria (84%), and endotoxin (72%) over the previous five months before attention to cleaning was implemented.

Perhaps most importantly, the data revealed intricate information about the indoor ecosystem and how source management and cleaning together can stabilize microenvironments and help prevent pollutant buildups that can compromise human health and valuable materials. For example, quantitative measurements of airborne dust mass and carpet dust mass showed an inverse relationship between the two, i.e. as carpet dust is disturbed and resuspended, dust levels in the carpet decrease and airborne dust levels increase. Conversely, as airborne dust settles onto carpet, total airborne dust mass decreases and carpet dust mass increases.[36] And airborne biopollutant monitoring showed occasional spikes of *Penicillium, Aspergillus,* and gram-negative and actinomycete bacteria, thus demonstrating that the indoor environment is indeed an ecosystem with normal fluctuations, yet with attention to source management through routine cleaning and immediate attention to unexpected occurrences, those fluctuations can be controlled.[20]

Public Transport Environments

Current threats of pandemic respiratory disease and bioterror incidents bring a focus of concern to the need for effective cleaning and decontamination protocols addressing public transport vehicles (e.g. airplanes, trains, buses, subways, cruise ships, etc.). In those situations, the decontamination approach must again place an emphasis first on the physical removal of the pollutants, which in itself is a sanitization process. This can involve the use of HEPA vacuuming in combination with a practical wet cleaning/sanitizing method that effectively reduces the pathogen burden to a level below an infective threshold, while minimizing the introduction of chemical pollutants into the environment being addressed. This type of approach presents a practical and feasible alternative to the massive use of chemical germicide sprays and gases which can present a major hazard to remediators and occupants, as well as valuable finishing and furnishing materials.[37]

Conclusion

The indoor environment is recognized as a delicate yet complex ecosystem wherein contaminant reservoirs can easily become pollutant sources through the lack of an effective and frequent reduction and removal process called cleaning. In order to maintain an ecological balance and promote the health of the indoor environment and its occupants, effective cleaning practices for both the prevention and remediation of biological, chemical, and particulate pollution in special indoor environments must be identified and evaluated and then implemented on a routine basis. And the only successful approach toward the accomplishment of this goal is through a dedicated and sustainable cooperative industry effort in the area of cleaning science research.

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