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Cleaning: A Solution to the Sick Building Mystery?

The connection between health and cleanliness is, for most people, a matter of common sense. Office workers report higher rates of discomfort when they perceive a dirty, dusty environment. Research, not surprisingly, shows that certain cleaning methods are effective in reducing dust on surfaces and in reducing the levels of indoor air contaminants. Yet some cleaning practices, like the use of improperly diluted cleaning solutions, are themselves significant threats to good IAQ. As with everything else, there are right and wrong ways to clean. In this article and in the following issue, the ***BULLETIN*** discusses building cleaning and the relationships between cleaning and IAQ.

Office Worker Symptoms and Building Cleanliness

Occurrences of office worker symptoms (also known as sick-building syndrome or SBS symptoms) have often been associated with poorly cleaned buildings. And, many times when we go in to investigate a problem building, we find that the building was poorly cleaned. Offices are often dusty simply because of a low level of cleaning, but at times the clutter around work stations precludes thorough and effective cleaning.

Strong relationships exist between the quality of indoor air and the concentrations of dust and chemicals found on building interior surfaces. The relationships are well-documented in the literature for some pesticides. Several studies reported at Indoor Air '96 in Nagoya showed the cleanliness of filters in ventilation systems directly affected the quality of air downstream from the filters. On the basis of physical principles, none of this is very surprising.

Studies done at the EPA headquarters in Washington "...indicated that the workplace variable affecting the largest number of health symptoms and comfort/odor concerns was dust." Occupant perceptions of dusty environments were strongly associated with SBS symptom prevalence rates, more strongly than any physical factor measured in the study. Researchers identified dust as "...the characteristic contributing most powerfully to a wide variety of health, comfort, and odor concerns" (Wallace *et al.*, 1991).

The Danish Town Hall Study found that dust was the most highly correlated variable with self-reported health symptoms (Skov *et al.*, 1989). A Swedish study found that intensive cleaning of carpets and wet dusting reduced health symptoms in an office building for at least the following two months (Norbäck and Torgen, 1989). A British study by Roys *et al.* (1993) reported that intensive office cleaning was followed by more than a 35% reduction in the average number of office worker symptoms.

IAQ and Surface Contamination

Gases and vapors can adsorb and particles can deposit on surfaces. These gases and vapors are in constant flux, moving from the surfaces to the air and back again. Some of the larger particles (>1 micron dia) can also be dislodged from surfaces and redeposit else-

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where, while smaller particles (<1 micron dia) tend to remain on surfaces until dislodged by deliberate cleaning. Particles (that are heavy enough) can fall to horizontal surfaces due to gravity, or stick to both vertical and horizontal surfaces due to impaction or (in the case of lighter particles) diffusion, electrostatic forces, and thermophoresis.

Dust on floors or wall surfaces can be re-suspended in the air when the surface is disturbed by people walking on or near it, by the vibration caused by many ordinary human activities, or even by cleaning activities themselves. Nearly everyone is familiar with the smell of dust in the air after vacuuming with ordinary household vacuum cleaners. Many studies have shown that airborne dust levels are actually higher after vacuuming with typical equipment. Similarly, the vibration of an earthquake raises dust levels measurably.

The rate of removal of dust from the air by gravity and by deposition on surfaces depends on the size of the particles involved. Thomas Schneider of the Danish National Institute of Occupational Health has reported these removal rates on floor, walls, and ceilings in terms of equivalent air exchange rates for particles of different sizes. The results are shown in Figure 1.

Modern Office Environments

There is an enormous amount of surface area in a typical office building that rarely or never gets cleaned. The largest single surface area in a typical open office environment is on the free-standing partitions separating work stations, which often have a surface area (both sides) of more than 3.5 times the floor area. The second largest surface area exposed to circulating air is the ceiling tile where the concealed space above a suspended ceiling is used as a return air plenum. In this common configuration, the ceiling tile surface area approaches twice that of the floor area (Levin, 1987). Neither the partitions nor the ceiling tile are cleaned routinely, if ever. If there is a relationship between the cleanliness of surfaces and the quality of indoor air, is it any wonder that maintaining good IAQ is such a challenge?

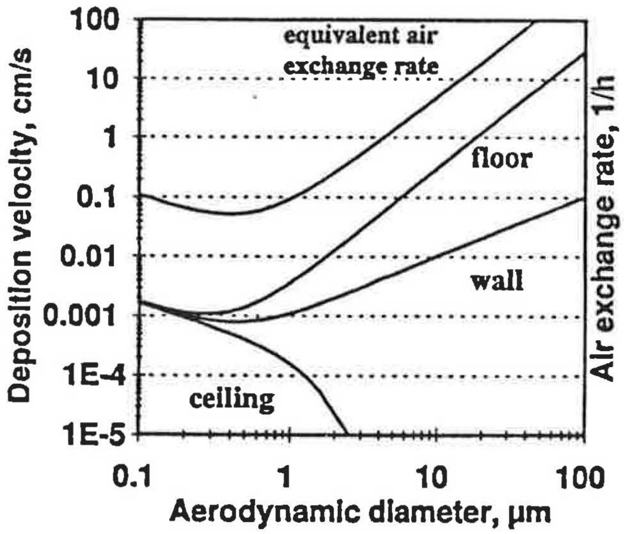

Figure 1 - Deposition velocity onto room surfaces of airborne particles and resulting equivalent air exchange rate . (Schneider, 1995).

Dust and Computers

Schneider *et al.* measured particle deposition velocities on a mannequin in front of a computer and modeled factors determining deposition velocities (1993). They found that both the electromagnetic fields and the air currents associated with computer monitors and computer cooling fans affect the deposition of particles on users' facial skin and eyes — increasing deposition velocities by up to ten-fold.

The weaker the air currents, the greater the influence of the electrostatic fields. The electrical field influences are greatest, according to the model, for particles near 1 µm; air currents are most important for particles near 10 µm. According to Schneider, the results are important for assessing the contribution of particles to "office eye syndrome" attributed to particles and particle-bound surfactants in office environments.

Thus, workers in front of a computer may have much greater exposure to dust and other particulate matter than other workers in nearby areas. Furthermore, dust levels may be more important where skin or eye irritation or even respiratory tract irritation occurs.

Biological Contaminants

Increasing evidence from all over the world indicates that moisture in homes is associated with higher rates of asthma and allergy. It is logically assumed that the presence of moisture signals higher concentrations of microbial contaminants and bioaerosols. Thus, from a health perspective, moisture control is important for reducing biological pollutant exposure in homes, and, presumably, in other environments as well. A number of recent, well-publicized lawsuits in Florida make it clear that moisture control is essential to maintaining low concentrations of microbial contaminants. Very serious health hazards can accompany some microbial pollutants.

Dust is also a reservoir for microbial contaminants. Danish Town Hall researchers (among others) have suggested that the cause of health problems in offices and schools could be physical irritation, allergens, or endotoxins related to dust exposures (Gravesen *et al.*, 1990). Since microbial growth strongly depends on the presence of moisture, the combination of moisture and dust is an obvious one to consider as an indicator of potential IAQ problems. Clearly, then, moisture intrusion should be considered as a major risk factor for IAQ problems. Controlling humidity and moisture in materials and on surfaces is obviously important to reducing risks of microbial contamination.

Indoor Air Pollutants from Cleaning Products and Solvents

The California Healthy Buildings Study (CHBS) and the Bell Communications Research (Bellcore) telephone company administration buildings studies found distinct sets of chemicals that were predominantly either from indoor or from outdoor sources (Ten Brinke, 1995; Shields, Fleischer and Weschler, 1996). Among those found in the CHBS predominantly from indoor sources were compounds used for cleaning and degreasing — dichloromethane, trichloroethene, and 1,1,1-trichloroethane. Their geometric means and ranges of concentrations (ppb) in the CHBS were as follows: dichloromethane, 0.49 ± 6.7 (<0.1 - 41); trichloroethene, 2.0 ± 2.2 (0.31 - 6.9); and, 1,1,1-trichloroethane 4.1 ± 3.8 (0.10 - 41).

These chlorinated hydrocarbons are usually found in indoor air, although, perhaps, more frequently in the US than in Europe. Individually, these chemicals can cause health and comfort problems at higher concentrations than those usually found indoors. Too little is known about their combined effects at the lower concentrations typically found indoors. The 1,1,1- trichloroethane geometric mean concentration for all the buildings in the CHBS study was second-highest of all the 40 compounds quantified; it was second only to ethanol with a geometric mean of 22 ± 1.8 ppb and a range of 8.7 - 130 ppb.

Current Cleaning Trends

Accumulating evidence shows the importance of cleaning for IAQ and for the significance of IAQ for occupant health, comfort, and productivity. However, the amount of cleaning routinely done in many North American buildings appears to be declining, according to a survey of their members by the Building Owners and Managers Association (BOMA).

Comparisons of 1990 and 1996 study results show that most property managers have maintained their level of service while some property managers reduced the frequency of some activities (see Table 1). Two notable examples are the vacuuming of low-traffic carpet areas and the dusting of desks and shelves. Half of the survey respondents still provide both activities on a daily basis; however, it appears that the trend is to shift low-traffic carpet vacuuming to two to three times a week and dusting of desks and shelves to once a week. On the other hand, the frequencies of other essential activities such as high-traffic carpet vacuuming and trash removal remain virtually the same.

BOMA reports the average cleaning cost for US private-sector office buildings was $1.09/ft^2 in 1995 (CAN $1.06/ft^2 for Canadian private-sector buildings, about US $.79). Cleaning expenses consist of payroll/contract expenses for both daytime and evening routine cleaning, specialized contract cleaning, supplies and equipment replacements, and trash removal and recycling (in the form of either expenses or revenues that offset trash removal). (Source: 1996 Experience Exchange Report, a publication that "reports the

Table 1 - High-frequency cleaning activities 1990 data (in parentheses) vs. 1996 data (BOMA).

Service	*No. of Responses*	*Daily*	*2-3x week*	*1x week*	*1-2x month*	*1-2x yr.*	*3-4x yr.*	*as needed*	*not done*	*other*
Dust/damp mop high traffic hard floors	845	91% (91%)	4% (4%)	2% (3%)	1% (1%)	0%	0%	2%	0% (1%)	0%
Dust/damp mop low traffic hard floors	833	54% (58%)	22% (20%)	18% (19%)	3% (3%)	0%	0%	3%	1%	0%
Vacuum high traffic carpets	847	94% (97%)	4% (3%)	2%	0%	0%	0%	0.3%	0.2%	0%
Vacuum low traffic carpets	842	52% (61%)	25% (20%)	19.3% (18%)	1.2% (1%)	0%	0%	2.2%	0.2%	0.1%
Dust desks/shelves	833	47% (60%)	17% (19%)	26%	4%	0%	0%	5%	0.4%	0.6%
Trash removal from interior space	845	98% (98%)	1% (1%)	1% (1%)	0%	0%	0%	0%	0%	0%

actual rental income and operating expenses for office buildings in North America.")

Cleaning expenses (adjusted for inflation) have steadily dropped for the past 10 years, BOMA says. What accounts for the decrease in costs, more efficient cleaning or less frequency? The answer, according to BOMA, appears to be that some decrease in frequency contributes to the cost savings. According to the report, cleaning expenses accounted for 13% in the US and 10% in Canada of the total operational plus fixed expenses (see Figure 2). Overall, property managers do well in controlling cleaning costs, according to BOMA.

Commercial Carpet Cleaning

A major issue in indoor air has been the impact of carpets on IAQ and carpet's role in reports of occupant health symptoms and discomfort. While emissions of VOCs from new carpets has been a major focus in the past, cleaning and maintenance throughout a carpet's useful life is probably a far more relevant issue for determining total occupant exposure. Cleaning carpets is a challenge, as it is with any permanently installed textile material.

Various factors determine the accumulation, binding, and re-suspension of dust. These factors include activity, quality of cleaning, type of carpet, humidity, and size of particles among others. Dybendal *et al.* (1991) found that the daily vacuuming of carpets in schools was ineffective in preventing the build-up of allergen deposits. Only prolonged, vigorous vacuuming was effective in removing lead from carpets, and only 20 - 40% of the dust was removed from one m^2 of carpet after one minute. Five minutes of repeated cleaning resulted in removal of 60 - 90% of the dust (Ewers *et al.*, 1989). Roberts *et al.* found that normal residential vacuum cleaners were extremely ineffective in removing dust from carpets or the lead contained in the dust (1991).

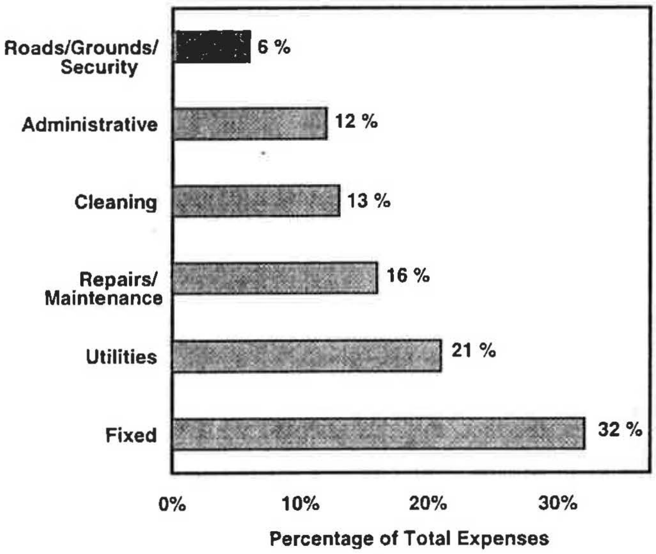

Figure 2 - Ratio of major expenses to total expenses: US private sector (BOMA).

We discuss a significant cleaning study performed by the Research Triangle Institute (RTI) in North Carolina in the following section. One of the improved cleaning methods the RTI used involved a more effective, commercially-available carpet cleaning system, "The Big Green Clean Machine." The recommended cleaning procedure is to first dry-vacuum with the unit, then wet-extract the carpet. This procedure was tested in a portion of the day-care area comprising about 58 m^2 (~620 ft^2). Researchers recorded the initial and final water plus carpet cleaner volumes and the total volume of water extracted from the carpet. Before the initial carpet cleaning, the dust loading was 0.68g/m^2. After cleaning, it was 0.38 g/m^2. The dry vacuuming with the "Clean Machine" extracted 0.19 g/m^2.

The initial volume in the unit was 8270 ml (8000 ml of water and 270 ml of cleaner). The final volume of clean water remaining in the unit was 2440 ml and the volume of extracted water was 2400 ml. By calculation, the unit applied 5830 ml of water. It extracted only 41% of the water that was put on the carpet and 60 ml of water per square meter remained on the carpet after cleaning. This appears to be a significant amount of moisture to leave in the carpets.

Thomas Schneider on Cleaning and the Indoor Environment

Schneider has focused a considerable amount of attention on the control of dust in indoor air. He is an expert in aerosol science and, together with his colleagues, has elevated the study of dust and particles in indoor air to a fine art.

Schneider reports that airborne dust concentrations of 0.1 mg/m^2 are typical for Danish offices. This concentration results in deposition of dust on the floor at a rate of about 0.02 g/m^2 per day. This rate compares to the rate at which track-in dust is deposited far away from the entrance to a building.

According to Schneider, surface contamination by dust must exceed 0.2% in order to be seen by a person, and contamination levels must differ by more than 0.45% to be perceived as different. Thus, he asserts, it is not possible to assess the amount of dust by visual inspection alone and objective methods are needed. Among his contributions are a small device, about the size and shape of a home microscope, that can characterize the amount of dust on surfaces. A sticky, transparent tape applied by a roller to standardize pressure collects dust from a surface. It is then inserted in the measuring device where the amount of light passing through the tape results in a reading of the percent of blocked light and, thus, the fraction of the surface covered by dust.

This measuring device is useful in studies but also useful in establishing standards for cleaning-contractor performance. Schneider and his colleagues have established standards based on their work in Denmark and other parts of Scandinavia. Objective measures for assessing cleanliness are essential for evaluating cleaning worker performance. Cleaning is a multibillion ECU per year business in Scandinavian countries. In the US, using BOMA cleaning cost data cited above — cleaning costs in excess of $1.00 per square foot per year or more — the figure is more than $13 billion in commercial office space alone in the US.

Schneider asks the following questions about building cleaning:

1. Do customers get what they are paying for and how would they know?
2. Would IAQ improve from spending more?
3. Is it necessary to spend so much?
4. Which of the many cleaning methods are most effective?

Recommended Surface Contamination Levels

Schneider suggests three levels of quality to use as standards: a baseline level, an improved level, and an indoor environmental level. He shows proposed norms in Table 2.

Baseline quality: The potential dust sources can readily be controlled to this level by using appropriate cleaning methods.

Improved quality and indoor environmental quality: The degree of surface cleanliness is maintained by using the best currently available cleaning methods and programs. Control of secondary dust sources to this level does not imply that SBS will not occur. "The suggested quality guidelines are a first attempt to quantify the quality of cleaning in relation to the indoor environment. As more measurements are taken and more experience is gained, the recommended values may have to be adjusted."

Schneider says these limits do not specify how clean surfaces should become after cleaning, but, rather, the levels that should not be exceeded during the time between cleanings. He suggests that it is the task of the cleaning company to select appropriate cleaning methods and frequencies. We believe that only a very sophisticated company might be able to do this, but that a sophisticated facility manager along with the cleaning company might, over time, be able to observe the dust levels and jointly determine the appropriate cleaning frequency to maintain dust coverage below the recommended maximum levels.

A different set of values is necessary for carpets, since the sample collection will not provide the same sort of index for carpets as for hard surfaces. A separate set of recommendations by Schneider for carpets is based on the dust sampling instrument.

Recommendations for Cleaning

An overview of recommendations for cleaning from Michael Berry's book, "Protecting the Built Environment: Cleaning for Health," is presented below.

I. Cleaning should be organized, scheduled, and focused on achieving specific objectives, especially those related to health protection and maintenance or restoration of valuable property.

II. The cleaning process should be coordinated with other basic environmental management strategies: source control, activity management, dilution, and design intervention.

III. Cleaning should always follow fundamental environmental protection guidelines:

- safety
- cleaning for health first and appearance second
- maximum extraction for pollutants (particles, gas, and biopollutants) from the occupied space

Table 2 - Proposed norms for non-textile surfaces.

		Percent area covered by dust		
Cleaning object	*Location*	*Indoor Environmental Quality*	*Improved Quality*	*Baseline Quality*
Hard surface furniture	Close to person	1	2	4
	Easily accessible	1.5	3	6
	Other	5	10	15
Hard floors	Walk area	3	7	12
	Other	5	10	18

- minimize chemical, particle, and moisture residue
- minimize human exposure to pollutants
- clean in relation to improving the total environment, and
- proper disposal of cleaning wastes.

BOMA Survey Respondents on Cleaning and IAQ

The BOMA cleaning study revealed that 49% of the respondents consider IAQ programs to be part of their day-to-day cleaning operations. Their IAQ programs tend to incorporate both mandatory and optional requirements of applicable federal, state, and local regulations as well as guidance materials. An operations and maintenance (O&M) program usually consists of the following:

- The operation and maintenance of HVAC equipment.
- The oversight of activities that impact IAQ (for example, painting, construction/renovation, cleaning personnel, and pest-control practices).
- Tenant relations.

"Of particular importance in the above O&M list is the cleaning function. Cleaning practices can directly affect the air quality within your building. Property managers can help to ensure that their cleaning practices do not have a negative IAQ effect on their buildings by taking into account some of the following suggestions:

- Poor housekeeping that fails to remove dust and other dirt can contribute to IAQ complaints.
- Cleaning materials can contribute to poor IAQ as a result of the odors they may produce or emit." [Note that the problem is identified only as an odor emission problem and not as the emission of irritating or even toxic chemicals.]

Since janitorial staff or contractors may be the first to recognize and respond to potential IAQ problems, they should be educated on the following topics:

Cleaning schedules. Janitorial staff or contractors need to be aware of when cleaning activities are scheduled. If possible, cleaning should be performed during off-peak hours with the air-handling units still on the "occupied" cycle.

Purchasing cleaning products. Janitorial staff or contractors need to learn about the chemicals in cleaning and maintenance products and their potential toxicity. They should review material safety data sheets and obtain information from the supplier about chemical emissions of materials being considered for purchase. Currently, there are no general systems for verifying or labeling low-emission products. Nor are there any standard procedures that building managers can use in gathering emissions data on products they are considering buying. Limited information on some materials, such as pressed-wood products, is available, and more may be expected in the future. Public- and private-sector organizations are working to develop product testing procedures for acceptance by such organizations as the American Society for Testing and Materials (ASTM).

Materials handling and storage. Janitorial staff or contractors should review the use of cleaning materials to ensure proper use and storage.

Trash disposal. Proper trash disposal procedures should be followed. For example, containers should be covered, pest control should be effective, and the trash collection area should be cleaned every day.

Ducts

If cleaning carpets, desks, and shelves is so effective, then shouldn't duct cleaning be effective as well? We asked some leading IAQ experts, and their responses were mixed. Yet, a series of studies reported at Indoor Air '96 in Nagoya showed definitively that the HVAC system in many buildings is an important source of indoor air pollution. Several studies using Ole Fanger's trained panels had found that ventilation systems are often the source of sensory pollution in buildings. This seemed surprising at first because we tend to look to ventilation systems as the source of clean air.

The final report of a recent study by the EPA on duct cleaning in residences will be released soon. But research in the US to date has not demonstrated that air coming out of cleaned ducts is any cleaner than air coming out of just-plain-old-dirty ducts. There is no question, however, that good hygiene practices related to HVAC system cleanliness is warranted. This includes filters, coils, drain pans, dampers, baffles, insulation, and duct surfaces themselves. Even dust from metal ducts can be cultured — that is, it is viable microbial material with the potential to create IAQ problems.

RTI Office/Day Care Center Cleaning Study

Never satisfied with even the most obvious and logical conclusions without empirical evidence, scientists have once again conducted research to prove what was previously assumed. There is now well-documented evidence that proper and adequate cleaning of building interiors has a significant (measurable) impact on IAQ.

Researchers at Research Triangle Institute studied the efficacy of improved cleaning practices for one year in an office/day care center. During the study's first five-months, the previous "normal" cleaning practices were followed. Then, improved practices were instituted for the last seven months of the study. Many typical IAQ parameters were measured, and most showed convincingly that improved cleaning results in better IAQ. The improved cleaning measures applied in the study are listed in Table 3.

Table 4 shows a comparison of the results from IAQ measurements during the first and second phases of the study. It is apparent from the data that considerable improvement was made in virtually every parameter that was monitored.

Conclusions

We have discussed many of the issues and technical details related to the cleanliness of the indoor environment and IAQ. In the next ***BULLETIN***, we will present a comprehensive set of building cleaning recommendations from various authorities including those whose work is described in this article.

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Table 3 - Fundamental environmental protection guidelines applied to the study.

Guideline	*Examples found in study*
Provide for safety	Cleaning was conducted in unoccupied environments. All toxic materials were kept away from adult occupants and children. All observed physical hazards were removed. Blood-borne pathogens were treated separately from other managed wastes in the building.
Clean for health first and appearance second	Effective disinfectants were used regardless of their bleaching effect on fabrics. When fungi were observed on an interior wall surface, the entire wall was removed to effectively control biopollutants. The primary objective of all cleaning conducted in the building was to guard the health of the occupants.
Maximize the extraction of pollutants from the building envelope	Maintenance staff were re-equipped with state-of-the-art vacuums for removal of particles. Vacuum bags with high collection efficiencies were used. High-temperature hot-water extraction cleaning was used to clean all carpets in the building. Routine dust collection was done with damp dust cloth. Teachers were equipped with special wet-process cleaning machines to immediately clean after accidents.
Minimize chemical, particle, and moisture residue	Rapid drying was achieved through improved ventilation and, in some cases, fans. Many VOC-based cleaning agents were replaced with water-based solutions. Extraction was improved with more efficient equipment and cleaning systems. Moisture-damaged ceiling tiles were removed and replaced.
Minimize human exposure to pollutants	Non-toxic cleaning agents were used. Walk-off mats were placed at all entrances to trap pollutants. High-efficiency filters in vacuums reduced human exposure during cleaning operations. Accidents in child-care areas were cleaned immediately.
Clean in relation to improving the total environment	The ventilation system was balanced to improve air circulation through the building. Pests were controlled through the removal and proper storage of food in the building. Water-damaged areas of the building were identified and repaired. Cleaning was done in proportion to the level of human activity in the building.
Properly dispose of cleaning wastes	All cleaning wastes were properly disposed of in the sewage treatment or solid-waste management system. Human wastes were managed separately from other wastes.

Table 4 - The effects of the cleaning on IAQ (Cole *et al.*, 1994).

Air Pollutant Category	*Routine Housekeeping (5 months)*	*Improved Housekeeping (7 months)*	*% Change*	*Most probable contribution to improved air quality*
Airborne Dust Burdens (Building means)	119 μg/m^3 (4.4-24.2)	5.7 μg/m^3 (1.4-11.9)	-52%	• Efficient vacuum cleaners and bags • Walk off mats • Damp dust cloths • Frequent vacuuming and dusting • Deep cleaning entire building Dust control on hard surfaces
Total VOC (Building means)	324 μg/m^3 (88-530) (3 months)	166 μg/m^3 (29-309)	-49%	• Cleaning chemicals with less VOC • Extraction from carpets • Balanced ventilation system
Biopollutants* (Building means)				• Rapid use of disinfectants after accidents • Control of food and perishables • New extraction equipment • Hot water extraction of carpets • Moisture control • Removal of contaminated sources (wall, rotten tree stump) • Walk-off mats
Total Bacteria	395 CFU/m^3 (71-855)	237 CFU/m^3 (34-868)	-40%	
Gram-negative bacteria	17 CFU/m^3 (1-171)	2 CFU/m^3 (0-9)	-88%	
Endotoxin (surface)	352 (3-1800)	100 (4-260)	-72%	
Bacillus	22 CFU/m^3 (1-85)	18 CFU/m^3 (2-71)	-18%	
Actinomycetes	36 CFU/m^3 (0-312)	2 CFU/m^3 (0-4)	-94%	
Total Fungi	127 CFU/m^3 (22-406)	50 CFU/m^3 (2-219)	-61%	
Penicillum	38 CFU/m^3 (4-284)	5 CFU/m^3 (1-39)	-87%	
Aspergillus	4 CFU/m^3 (0-17)	1 CFU/m^3 (0-11)	-75%	
Cladosporium	35 CFU/m^3 (8-102)	27 CFU/m^3 (0-175)	-23%	

* Anderson sampler data only

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