CHAPTER 5

Sustained Reduction of Aerobiological Densities in Buildings by Modification of Interior Surfaces with Silane Modified Quaternary Amines

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INTRODUCTION

Building-related illness (BRI) or sick building syndrome (SBS) continues to stimulate global attention as the scientific community investigates causative factors and the scope of effects. Many deleterious symptoms, including erythema, mental fatigue, high frequency of airway infections, hoarseness, wheezing, itching and nonspecific hypersensitivity, nausea, headaches, lethargy and dizziness affect the health and productivity of workers.[1]

The onset of these symptoms is insidious and usually attributed to factors other than BRI/SBS. After repeated attacks, however, workers recognize a typical pattern: symptoms appear 1 to 2 h after arriving at work and disappear 3 to 4 h after leaving. These symptoms are the classic manifestations of BRI/SBS. Additionally, workers report that the severity of the attacks usually increases with subsequent exposures. Efforts to determine the etiologic factors, sources of the problem, and effective solutions have proven to be formidable.

BRI/SBS was believed to result from occupant exposure to excessive levels of organic vapors, noxious gases, or physical irritants within closed, tightly sealed buildings. Bioaerosols were identified as causal in fewer than 5% of the outbreaks investigated by NIOSH.[2,3]

The importance of bioaerosols and biogenic materials as indoor environmental

pollutants is increasingly recognized. They are implicated as etiologic agents in numerous outbreaks of BRI/SBS and other respiratory illnesses. Inhalation of mycotoxins and aflatoxins has been shown to induce mycotoxicosis (liver cancer) and many are known to be acutely toxic. The long-term exposure hazards to building occupants are not presently known, but currently available data suggest that exposure to mycotoxins could have deleterious effects on health.[4,5]

By design, energy-efficient buildings concentrate the level of airborne microorganisms and their by-products as sourced from environmental surfaces, people, dust, and furnishings, causing them to rise above the threshold at which many occupants will present with a response. Supporting this, Dr. Harriet A. Burge and her research team presented evidence that fungi within tightly sealed buildings can cause hypersensitivity pneumonitis, a condition that may produce permanent lung damage and even death.[6]

Furthermore, researchers at the Walter Reed Army Institute of Research in Washington, D.C., conducted a 4-year study of barracks housing more than 400,000 recruits to examine the incidence of influenza and other respiratory illnesses. The researchers, led by Dr. John F. Brundage, found that trainees housed in modern barracks were about 50% more likely to contract a respiratory infection during the 7-week training period than those housed in older, more drafty buildings.[7]

MICROORGANISMS

Bacteria, fungi, viruses, and algae are all associated with the indoor environment of buildings, and many are capable of producing the symptoms associated with BRI/SBS. Of these, bacteria and fungi are most frequently associated with hyperresponsive illnesses, infections, and toxic response.[8]

Although a building may be infested during construction (particularly with fungi), more typically the organisms are routinely brought into the building by its occupants. Lofted into the air by normal activities in the building, these microorganisms can be transported throughout the building by occupants and the HVAC system. Thus, even the most remote areas of the building become vulnerable to infestation. Under favorable conditions these microorganisms proliferate and colonize interior surfaces.

For example, bacteria play an important role as part of the body's microflora and, along with skin, are shed continuously. Given acceptable growth conditions, they can multiply from one organism to more than one billion organisms in just 18 h. Fungi — typically outdoor organisms known as mold, mildew, and yeasts — enter the building on clothing, are wafted in through open doors, or are pulled in as "makeup air" by the HVAC system.

Inhalation of these microorganisms, their somatic parts, and/or their by-products may produce an immunologic response that triggers the release of specific antibodies. Repeated exposures magnify the antigen-antibody reactions, lowering

tolerance levels and exacerbating clinical symptoms. Other manifestations of excessive microbial presence include odors, discoloration, deterioration, and defacement of contaminated surfaces.

ANTIMICROBIALS

Antimicrobial agents have been used for many years to reduce microbial populations and their associated problems. By definition, an antimicrobial agent is an agent that destroys or inhibits the growth of microorganisms. Bacteria, fungi (mold and mildew), yeasts, and algae are the major classes of microorganisms.

Antimicrobials treatments differ in chemical nature, mode of operation, durability, effectiveness, toxicity, safety, and cost. They can be divided into two major categories: bound and unbound. These terms refer to whether or not the antimicrobial has the capability to chemically bond to the surface on which it is applied.

Unbound Antimicrobials

An unbound antimicrobial cannot be bonded to a surface in order to function properly. It must diffuse from the treated substrate and be consumed by the microorganism in order to be effective. Once inside the organism, the chemical agent will act like a poison interrupting some key metabolic or life-sustaining process of the cell, causing it to die. Once the antimicrobial is depleted or is washed away during regular maintenance, protection vanishes. Therefore, the degree of durability desired must be considered when choosing an antimicrobial treatment.

After application, an unbound antimicrobial continues to diffuse or leach from the substrate on which it has been applied. As this diffusion continues, the concentration of the active ingredient becomes diluted below effective levels. Under these conditions, microorganisms have the ability to adapt or build up a tolerance to these antimicrobials. Highly resistant strains can develop that are immune to what was once an effective treatment dose.

Conventional (unbound) antimicrobials often can be very effective against specific types of microorganisms, but are generally limited in their ability to offer broad spectrum control. In other words, they may be effective against specific bacteria, but not all, or they may destroy all bacteria, but be ineffective against fungi, yeasts, or algae. The safety and toxicity of "unbound" antibacterial treatments vary considerably depending on the specific chemistry involved.

Bound Antimicrobials

Bound antimicrobial agents, like 3-trimethoxysilylpropyl dimethyloctadecyl ammonium chloride (SYLGARD Antimicrobial Treatment) manufactured by Dow Corning Corporation, remain chemically attached to the surface on which they are applied. They function by interrupting the organism's delicate cell membrane.[9] This prevents microorganisms from carrying on vital life processes. These antimicrobials kill organisms on contact and can do so again and again.

Since a "bound" antimicrobial is covalently and/or ionically bonded to surfaces, it does not diffuse or partition into the surrounding environment. An effective level of the material remains on the surface, and the adaptation process described earlier cannot and does not occur. The unique mechanism by which bound antimicrobials exhibit their activity permits them to effectively control a broad spectrum of microorganisms. Bacteria, molds, mildew, fungi, yeasts, and algae can all be controlled with this type of antimicrobial.[10]

BUILDING EVALUATIONS

Residential Study

Methodology

A total of 19 homes in the metropolitan area of Cincinnati were selected for the study, at least ten of which housed adolescent mold allergy sufferers. The homes were selected in conformance with the following criteria: (1) at least one family member had to be under the care of an allergist for at least 1 year and diagnosed as mold sensitive, (2) the attending allergist was asked to document clinical observations for at least 6 months, and (3) carpet and air conditioning were required in the main living areas of the home.

Prior to initiating the study, the following characteristics of each home were noted: (1) type, size, and age of home; (2) type of air conditioning; (3) presence and type of air filtration devices; (4) presence and type of other allergy control actions used in the home; and (5) characteristics of carpeting in the home as to age, amount, and wall-to-wall or area. The following parameters were recorded about the mold-sensitive occupants in each home: (1) age, (2) sex, (3) relative degree of severity in allergic responses, (4) other allergies, (5) current allergy therapy, and (6) name and length of time under the care of an allergist.

Testing

Two weeks prior to treatment standard plastic petri dishes (BBL) containing Sabauroud's Dextrose Agar were placed at floor level in random arrays (20 plates per home) throughout test zones. Plate locations, time, activity, and ambient conditions within zones were recorded.

Two weeks following treatment, petri dishes were placed at floor level in the pre-treatment locations. Post-treatment samplings were designed to replicate pre-treatment conditions as closely as possible. All plates were exposed for 1 h, sealed, and sent to the laboratory for incubation and enumeration using standard microbiological methods.

Participants were aware that they were part of a study but not informed regarding control or treated homes.

Results

Comparisons of total aeromicrobial gravity plate retrievals and percent changes before and after silane modified quaternary amines treatment can be seen in Figure 1.

Average total microbial retrievals in the homes prior to antimicrobial treatment of the carpet ranged from 6 colony forming units (CFUs) per plate to 42 CFUs per plate (Figure 1). After antimicrobial treatment, the average total microbial retrievals ranged from 1 CFU per plate to 20 CFUs per plate.

In 13 of the 19 homes (68%), greater than 50% reduction in total aeromicrobiological populations was shown following antimicrobial treatment of the carpeting.

Analysis of the symptomatic responses from the mold-sensitive occupants in the homes revealed that 19 of 24 (79%) recorded intermediate to significant improvement in their conditions. The improvements noted were fewer headaches, decreased congestion, better balance, decreased sinus problems, required medicine reduced or stopped, and an overall better feeling. The remaining five allergy sufferers recorded essentially no changes in their allergic symptoms. Three of the original study participants reported being ill with colds or other infections during the evaluation period, and the allergy-sufferer in the control house (#19) reported no change of condition. These four original participants are not included in the calculation above.

One year after the treatment was applied, participants were sent surveys to assess symptom scores, medication patterns, general health, and treatment value to allergics. Eighteen participants responded. These data are presented in Table 1.

Commercial Building Studies

Methodology

Studies on ten buildings from various geographical locations (Table 2) are reported in this paper. These buildings represent a wide array of structures and geographies. The common thread is the widespread reporting of SBS symptoms from the building occupants. Suspecting microbial involvement sourced from the environmental surfaces, microbial retrievals and mediation was undertaken.

This study was designed to determine gross variances of bioaerosol presence within large test areas. Gravitational sampling was utilized to provide broad aeromicrobiological profiles of test zones, thereby enabling a quantification of retrievals prior to and following treatment. Although the recovery of airborne agents, often in patterns that roughly parallel clinical events, has fostered widespread confidence in the validity of fallout techniques,[12] this retrieval method cannot be used to quantify changes in aerobiological densities. However, the repeated demonstration of statistically significant variances from a sufficiently high number of sampling locations provides confidence in identifying an event as causal and allows for gross comparisons at specific sample sites.

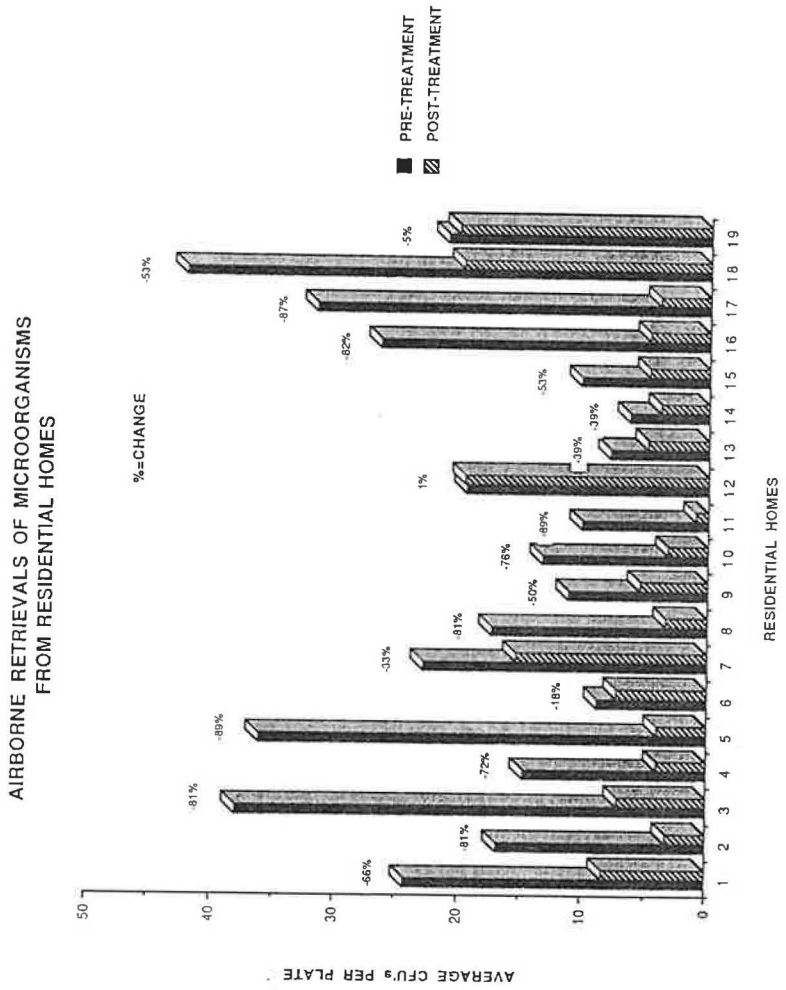

Figure 1. Comparison of total aeromicrobial retrievals and percent changes before and after antimicrobial treatment in residential homes.

Table 1. 1988 Residential Mold Allergy Study Survey Results 1 Year After Treatment

	Pre-Treatment	1 Year After
Symptom Scores During Study		
Mild	0	8
Moderate	10	7
Mod-Severe	3	2
Severe	5	1
Reported Changes in General Health 1 Year After Treatment		
Improved	10	
Worse	1	
Unchanged	7	
Alteration of Medications During Study		
Increased dosage or frequency	0	
Decreased dosage	1	
Decreased frequency	1	
Decreased dose and frequency	1	
Decreased dose, frequency and type	4	
Unchanged	11	
Reported Usefulness of Treatment to Allergics		
Should be available to allergics	18	
Not beneficial to allergics	0	

Table 2. Commercial Building Studies — Building Codes

Number	Type	Location
1	School	Alexandria, KY
2	Office building/print shop	St. Petersburg, FL
3	Office building	Rochester, NY
4	Condominiums	Keystone, CO
5	Office building	Clearwater, FL
6	Office building	Clearwater, FL
7	Office complex	Clearwater, FL
8	Office building	Miami, FL
9	Office building	Tampa, FL
10	Office building	Cincinnati, OH

Treatment

An aqueous solution of 3-trimethoxysilylpropyl dimethyloctadecyl ammonium chloride was applied to dry carpeting in accordance with the manufacturer's specifications.[11] Carpeting was not cleaned prior to antimicrobial applications. Building occupants in six of the buildings were not aware of any remediation activities. Although samplings were performed during normal work hours, application of the treatment was performed at night or on weekends without their knowledge.

Testing

Two weeks prior to treatment, standard plastic petri dishes (BBL) containing Sabauroud's Dextrose Agar were placed at floor level in random arrays (14 to 50 sites per building) throughout test zones. Plate locations, time, activity, and ambient conditions within zones were recorded.

Two weeks following treatment, petri dishes were placed at floor level in the pre-treatment locations. Post-treatment samplings were designed to replicate pre-treatment conditions as closely as possible. All plates were exposed for 1 h, sealed and sent to the laboratory for incubation and enumeration using standard microbiological methods.

Results

Data and observations of ten buildings are reported in this paper. These are representative of all buildings we have investigated, both in quantification of variation and clinical observations of occupant response. The percent variation of each building following treatment of carpeting is shown in Figure 2. These averages are derived by dividing the total number of colonies retrieved by the number of plate sites.

The variation between pre-treatment and post-treatment retrieval averages range between 71 and 98%. Within this group of buildings, two showed greater than 90% change, nine showed greater than 80% change, and all showed greater than 70% change.

The data in Figure 3 are representative of patterns observed in the ten buildings in this study. Note the pre-treatment variances representing a range of from 2 CFUs per plate to 156 CFUs per plate whereas the post-treatment retrieval counts range only from 0 CFUs per plate to 4 CFUs per plate. This stabilization of the aeromicrobiological retrievals is noteworthy along with the consistently effective reduction in numbers retrieved.

The clinical profiles of building occupants within the commercial buildings were evaluated during the 12 months following treatment. No changes were reported or observed in any of the buildings. During the second year following treatment, aerobiological samplings were performed at five of the buildings in conformance with the initial and post-treatment sampling criteria. The retrieval averages are presented in Table 3 and reveal aeromicrobiological profiles in ranges consistent with post-treatment averages.

In the ten investigations in this report of BRI/SBS within a large diversity of building designs and geographies, symptomatic improvement was uniformly reported from workers and reduction of microbioaerosol levels were observed after treatment of the carpeting with the silane modified quaternary amine. While these data are not conclusive, it challenges us to dislodge traditional perceptions and expand our research efforts to better understand the short- and long-term health effects that result from exposure to microbiological pollutants in the workplace.

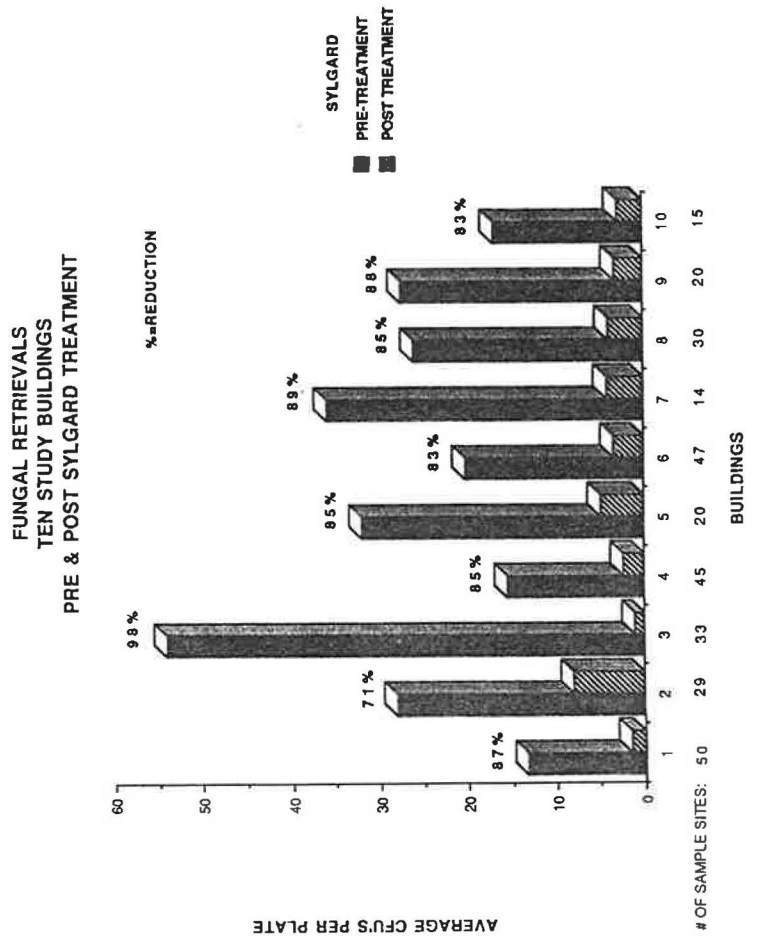

Figure 2. Fungal retrievals in ten study buildings pre- and post-SYLGARD treatment.

Table 3. Follow-Up Sampling in Five Buildings During 2nd Year After Treatment

Building	Average CFUs Retrieved per Plate		
	Pre-Treatment	Post-Treatment	2nd Year
1	13.4	1.7	3.6
3	54.0	1.0	1.1
6	20.3	3.5	4.1
9	27.4	3.3	3.5
10	17.0	2.9	2.8

CONCLUSIONS

These studies provide data that support previous claims that carpeting contributes substantively to aeromicrobiological presence within buildings. It is the first attempt to determine whether or not microbioaerosol presence can be regulated by the application of 3-trimethoxysilylpropyl dimethyloctadecyl ammonium chloride to carpeting and be reflected in agar plate retrievals and in human response. Thus, our investigations present strong evidence of microbial involvement in the acquisition of BRI/SBS and reveals an effective remediation tool in the form of the 3-trimethoxysilylpropyl dimethyloctadecyl ammonium chloride.

The durable attachment of 3-trimethoxysilylpropyl dimethyloctadecyl ammonium chloride to interior building surfaces clearly reduces aeromicrobiological densities. The unique functionality of these activated surfaces enable the extended destruction of microorganisms which contact them. This technology provides a useful tool for dealing with microbial problems on surfaces and for mediating the morbidity, odors, and defacement associated with microorganisms.

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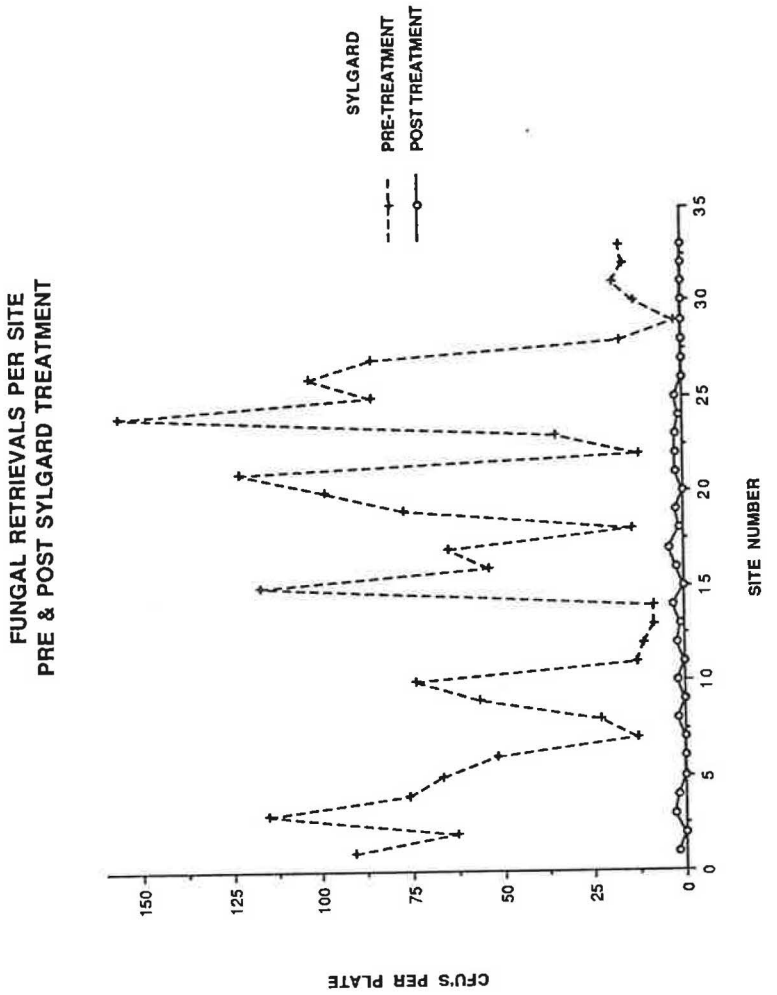

Figure 3. Fungal retrievals per site pre- and post-SYLGARD treatment.

REFERENCES

1. WHO Reports, *Indoor Air Pollutants: Exposure and Health Effects*, WHO Meeting in Nordlingen 1982. Eur. Report No. 78, (1983).
2. American Society of Heating, Refrigeration, and Air Conditioning Engineers, *Indoor Air Quality Position Paper*, (Atlanta: ASHRAE, August 11, 1987).
3. National Institute for Occupational Safety and Health (NIOSH), *Guidance for Indoor Air Quality Investigations*, (January 1987).
4. WHO Reports, *Biological Contaminants in Indoor Air*. WHO Meeting in Rautavaara 1988. Eur. Report
5. Sorenson, W.G., "Mycotoxins as Potential Occupational Hazards," Annual Meeting of the Society for Industrial Microbiology, (Seattle, WA: August 1989).
6. Burge, H.A., Annual meeting of the Academy of Allergy and Immunology, (Anaheim, CA: March 16, 1988).
7. Brundage, J.F., "Building Associated Risk of Febrile Acute Respiratory Diseases and Army Trainees," *JAMA*, 259:14 (1988).
8. White, W.C. and Gettings, R.L., "Evaluating the Antimicrobial Properties of Silane Modified Surfaces." in *Silanes, Surfaces, and Interfaces*, Leyden, D.E., (Ed.), (New York: Gordon and Breach Science Publishers, 1986).
9. White, W.C. and Gettings, R.L., "Evaluating the Antimicrobial Properties of Silane Modified Surfaces." in *Silanes, Surfaces, and Interfaces*, Leyden, D.E., (Ed.), (New York: Gordon and Breach Science Publishers, 1986).
10. Speier, J.L. and Malek, J.R., "Destruction of Microorganisms by Contact with Solid Surfaces," *J. Colloid Interface Sci.*, 89(1):68–76 (1982).
11. Dow Corning Corporation, *SYLGARD Treatment Manual*, Form No. 24-264a-88, (1988).
12. Soloman, W.R., "Sampling Techniques for Airborne Fungi," in *Mould Allergy*. (Philadelphia: Lea and Febiger, 1984) p. 46.