# 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, 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 1-2 hours after arriving at work and disappear 3-4 hours 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 form 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 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 four 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 seven-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 hyper responsive 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 condition these microorganisms proliferate and colonize interior surfaces.

For example, bacteria play an important role as part of the body's micro flora, and , along with skin, are shed continuously. Given acceptable

growth conditions, they can multiply form one organism to more than one billion organisms in just 18 hours. 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 "make up 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 a 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.

Antimicrobial 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 which are immune to what was once an effective treatment dose.

Conventional (unbound) antimicrobials can often be very effective against specific types of microorganisms, but 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-trimethoxysilylpropyldimethyloctadecyl ammonium chloride (SYLGARD) Antimicrobial Treatment) manufactured by Dow Corning, 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 form 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 be controlled with this type of antimicrobial (10).

**BUILDING EVALUATIONS**

**Residential Study**

Methodology: A total of 19 homes in the metropolitan area of Cincinnati, Ohio were selected for the study, at least 10 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 one year and diagnosed as mold sensitive, (2) the attending allergist was asked to document clinical observations for at least six

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 (a) age, (b) amount, and (c) 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 Sabaurouid'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 one hour, 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 retrieval in the homes prior to antimicrobial treatment of the carpet ranged form 6 Colony Forming Units (CFU's) per plate to 42 CFU's per plate (Figure 1). After antimicrobial treatment, the average total microbial retrievals ranged form 1 CFU per plate to 20 CFU's per plate.

Thirteen of the 19 homes (68%) showed greater than 50% reduction in total aeromicrobiological populations following antimicrobial treatment of the carpeting.

Analysis of the symptomatic responses form the mold-sensitive occupants in the homes revealed that 19 of 24 (79%) people 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, surveys were sent to participants to assess symptom scored, medication patterns, general health and treatment value to allergies. Eighteen participants responded. These data are presented in Table 1.

**Table 1**

**1988 Residential Mold Allergy Study Survey Results 1 Year After Treatment**

**Symptom Scores During Study**

| | Pre-Treatment | 1-Year After |
|---|---|---|
| Mild | 0 | 8 |
| Moderate | 1 | 7 |
| Mod-Severe | 3 | 2 |
| Severe | 5 | 1 |

**Reported Changes in General Health**

| | |
|---|---|
| Improved | 10 |
| Worse | 1 |
| Unchanged | 7 |

**Alterations 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 Allergies**

| | |
|---|---|
| Should be Available to Allergies | 18 |
| Not Beneficial to Allergies | 0 |

## Commercial Building Studies

Methodology: Studies on ten buildings from various geographical locations (See 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 the 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 (11), this retrieval method cannot be used to quantify changes in aerobiological densities. However, the repeated demonstration of statistically significant variances form a sufficiently high number of sampling locations provides confidence in identifying an event as causal and allows for gross comparisons at specific sample sites.

Treatment: An aqueous solution of 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride was applied to dry carpeting in accordance with the manufacturer's specifications (12). 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 on or weekends without their knowledge.

**Table 2**

**Commercial Building Studies**
**- Building Codes -**

| Number | Type | Location |
|---|---|---|
| 1 | School | Alexandria, KY |
| 2 | Print Shop | St. Petersburg, FL |
| 3 | Office Building | Rochester, NY |
| 4 | Condominiums | Keystone, CO |
| 5 | Office Building | Clearwater, FL |
| 6 | Office Complex | Clearwater, FL |
| 7 | Office Building | Clearwater, FL |
| 8 | Office Building | Miami, FL |
| 9 | Office Building | Tampa, FL |
| 10 | Office Building | Cincinnati, OH |

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

Two week 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 one hour, 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 variances and clinical observations of occupant response. Figure 2 shows the percent variance of each building following treatment of carpeting. These averages are derived by dividing the total number of colonies retrieved by the number of plate sites.

**Table 3**

**Follow-Up Sampling in 5 Buildings**
**During 2nd Year After Treatment**
**Average CFU's Retrieved Per Plate**

| Building | Pre-Treatment | Post-Treatment | 2nd Year |
|---|---|---|---|
| No. 1 | 13.4 | 1.7 | 3.6 |
| No. 3 | 54.0 | 1.0 | 1.1 |
| No. 6 | 20.3 | 3.5 | 4.1 |
| No. 9 | 27.4 | 3.3 | 3.5 |
| No. 10 | 17.0 | 2.9 | 2.8 |

The variances between pre-treatment and post-treatment retrieval averages range between 71-98%. Within this group of buildings, 2 (20%) showed greater than 90% change, 9 (90%) greater than 80% change, and 10 (100%) greater than 70% change.

In Figure 3 we can see the actual retrieval counts at 33 sites within the test building Number 3. These data are representative of patterns observed in the ten buildings in this study. Note the pre-treatment variances representing a range from 2 CFU/Plate -4 156 CFU/Plate whereas the post-treatment retrieval counts range only form 0 CFU/Plate - 4 CFU/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 twelve 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 5 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 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 room 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 effect that result for exposure to microbiological pollutants in the workplace.

**CONCLUSION**

These studies provide data which 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-trimethoxysilylpropyldimethyloctadecyl ammonium chloride to carpeting and be reflected in agar plate retrievals and in human response. Thus, our investigations present strong evidence of microbial of the 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride.

The durable attachment of 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride to interior building surfaces clearly reduces aeromicrobiological densities. The unique functionality of these activated surfaces enable the extended destruction of microorganisms that 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.

**Acknowledgment**

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**Figure 1.**

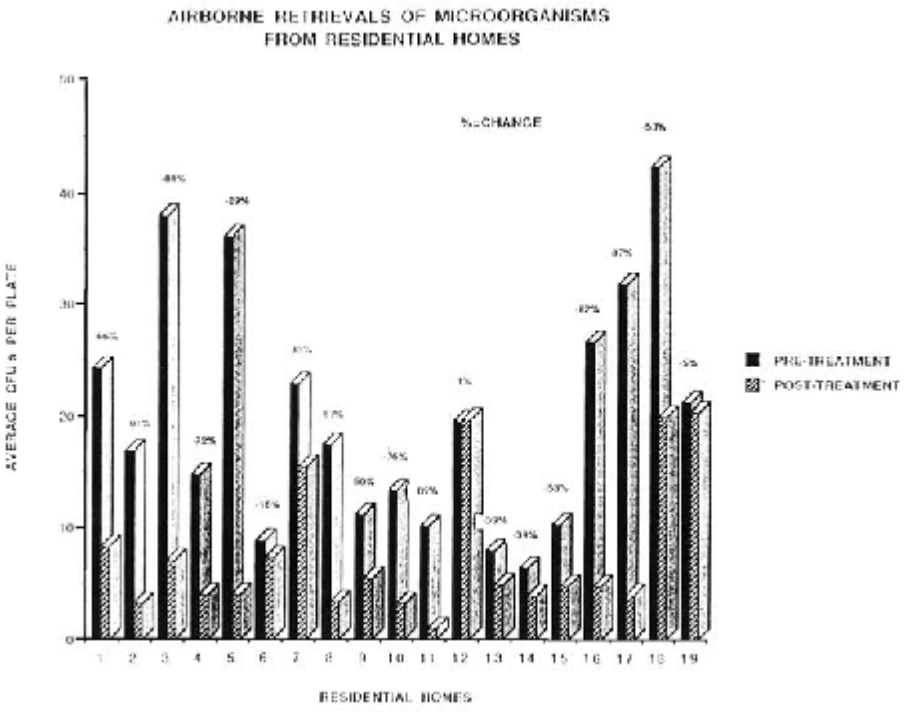

AIRBORNE RETRIEVALS OF MICROORGANISMS
FROM RESIDENTIAL HOMES
% CHANGE
AVERAGE CFU's PER PLATE
RESIDENTIAL HOMES
PRE-TREATMENT
POST-TREATMENT

**Figure 2.**

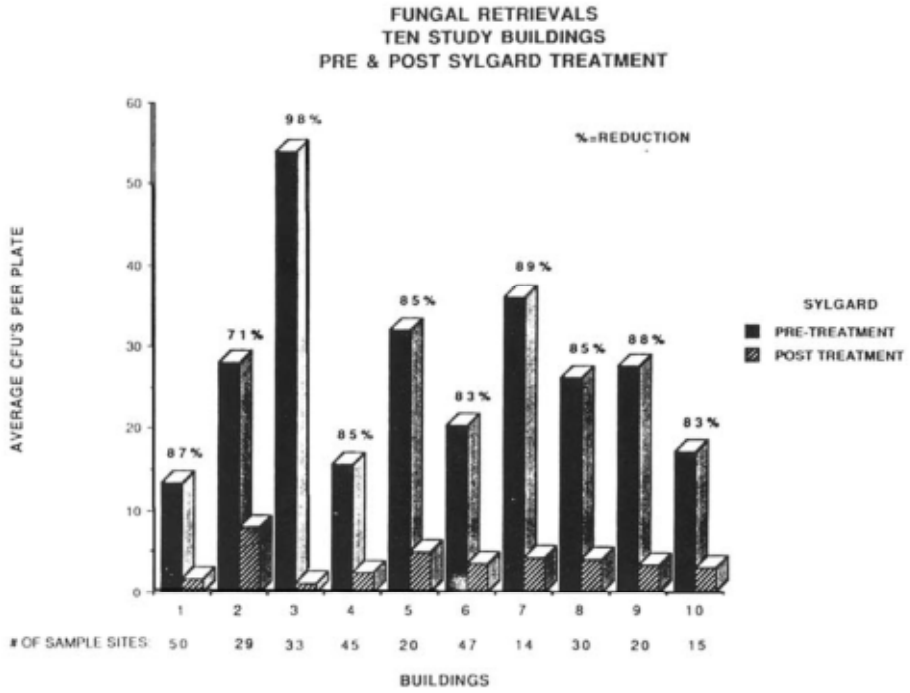
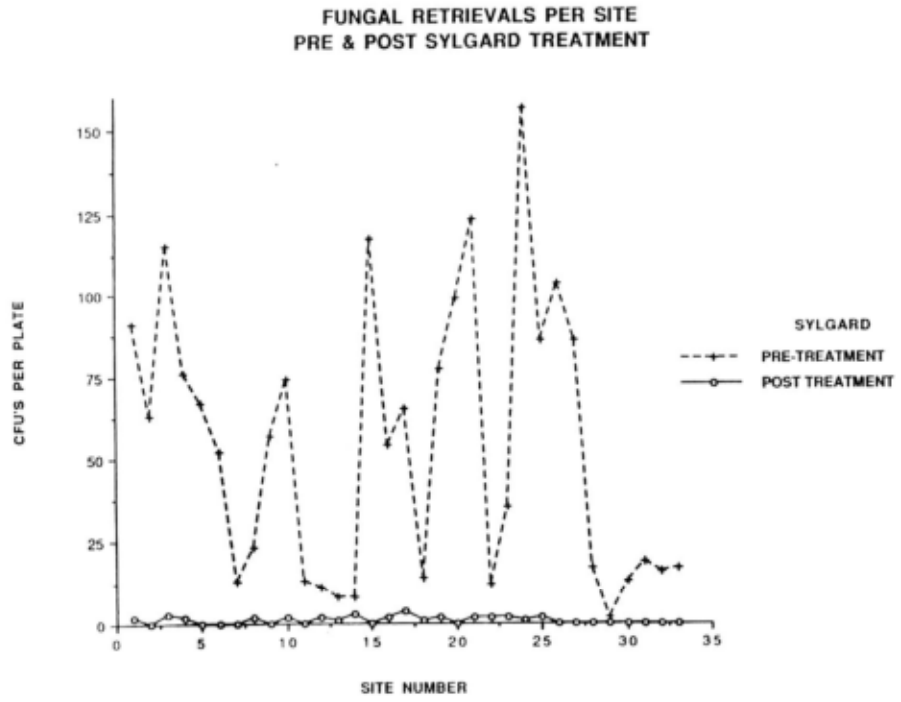

FUNGAL RETRIEVALS
TEN STUDY BUILDINGS
PRE & POST SYLGARD TREATMENT
AVERAGE CFU'S PER PLATE
60
50
40
30
20
10
0
%=REDUCTION
98%
87%
71%
85%
85%
83%
89%
85%
88%
83%
SYLGARD
PRE-TREATMENT
POST TREATMENT
1 2 3 4 5 6 7 8 9 10
# OF SAMPLE SITES: 50 29 33 45 20 47 14 30 20 15
BUILDINGS

**Figure 3.**


FUNGAL RETRIEVALS PER SITE
PRE & POST SYLGARD TREATMENT
CFU'S PER PLATE
150
125
100
75
50
25
0
0
5
10
15
20
25
30
35
SITE NUMBER
SYLGARD
PRE-TREATMENT
POST TREATMENT