Developments in Industrial Microbiology, Volume 31
(Journal of Industrial Microbiology, Suppl. No. 5)
Editor: G.E. Pierce

28. Sustained aeromicrobiological reductions utilizing silane-modified quaternary amines applied to carpeting: preliminary data from an observational study of commercial buildings

W. C. White, R. L. Gettings, and R.A. Kemper

Dow Corning Corporation, Midland, MI 48686-0994, USA
and
Kemper Research Foundation, 122 Main Street, Milford, OH 45150-1122, USA

SUMMARY

Microorganisms are increasingly identified as etiologic agents in Building Related Illnesses (BRI). Infectious, allergenic, toxic, and irritational presentations by building occupants are causally liked to microbial infestation of the workplace. In field studies of schools and office buildings where BRI symptoms were manifest, data support the hypothesis that illnesses result from exposure to excessive bioaerosols. The data also confirm that microbial prophylaxis can be achieved by affixing silane-modified quaternary amines to interior surfaces. These agents chemically react with numerous substrates to produce durable antimicrobial surfaces which reduce microbial populations and inhibit recolonization. The functionality of these activated surfaces enables the destruction of microorganisms which contact them, thereby reducing aerobiological presence.

INTRODUCTION

The etiology of Building Related Illness (BRI) is increasingly investigated, revealing an array of airborne allergens, infectives, irritants, and toxicants in the non-industrial workplace. [3]. Historically, volatile organic compounds (VOCs), combustion by-products, respirable suspended particles have been reported as causative agents in numerous investigations of BRI [3]. While these agents have been detected in the indoor environment, frequently they are not present in sufficient concentration to produce the variety and levels of human response observed [16].

Editor's Note: Technology and product references in this article have been updated to current status. The silane quat antimicrobial technology and products were originally developed and commercialized by Dow Corning Corporation. AEGIS Environments was established in 1990 to further develop and commercialize this unique antimicrobial technology and purchased Dow Corning's Antimicrobials Business in 1995. Although the basic chemistry of the active ingredient remains unchanged, AEGIS' patented and/or proprietary advancements in application engineering and surface modification technology have significantly improved the performance, durability and safety of the technology and products.

Investigators are now challenged to elucidate specific human response profiles for the myriad of potential contaminants in order to develop appropriate strategies for proper sourcing, remediation and, if possible, prophylaxis.

Inadequate ventilation has been most frequently reported as the primary problem (52%) affecting workers [11]. But, this convenient grouping is generally used to describe environments where 'no specific sources of environmental contamination and generally low concentrations of contaminants are found in our environmental monitoring [10].

The microbiological contribution to BRI has often been ignored. Yet, microbial contaminants can initiate and/or potentiate each of the symptoms associated with BRI. Microbes were reported as causative in only 5% of BRI outbreaks [11]. This may be an underestimation of microbial influences that results from a narrow focus on more spectacular BRI manifestations that include respiratory illnesses such as humidifier fever, Legionnaires' Disease and hypersensitivity pneumonitis.

The milder, acute discomforts more frequently reported may result from sustained or repeated exposure to moderate levels of microbioaerosols or biogenic metabolites in the workplace. This exposure may prove to be the proximate cause of a large percentage of illnesses that are frequently sourced to 'poor ventilation.' A Working Group of the World Health Organization recently reported that the combined effect of all biological air contaminants in building air is thought to account for a substantial proportion of absenteeism in schools and workplaces. It was of the opinion that through reductions in biological air contaminants in the indoor environment, a significant reduction in acute infections and allergic episodes could be achieved [18].

In a recent report on 30 buildings, all of the

Airborne transmission of respiratory infections has been demonstrated for bacteria, fungi and viruses [8]. In a study of respiratory illnesses at 4 Army training centers, researchers concluded that trainees housed in modern barracks were 50% more likely to contract a respiratory infection than those housed in older, drafty buildings [4].

Hypersensitivity resulting from exposure to airborne fungi is well documented [1]. Although frequently perceived to be outdoor, seasonally-mediated events, elevated levels of airborne mold spores, hyphal fragments and mold metabolites are known to be indoor, perennial phenomena in buildings with contaminated carpeting or HVAC systems. The symptomatic presentation of persons occupying these buildings appears related more to indoor rather than outdoor influences and subside when subjects are away from the office environment.

It has been reported that rooms with carpeting have significantly higher levels of dust than rooms with bare floors, that microfungal counts were found to be significantly higher in dust from carpets than from bare floors, and that the level of organic macromolecular components was found to be higher in dust from carpets than in dust from bare floors [7].

Such work provides sufficient data to suspect microbial contaminants in a majority of BRI outbreaks. Confirmational data, however, has been elusive due to its ubiquitous nature and the lack of availability of remediation strategies. Previously, it has been impossible to substantially alter the microbiological profile of a building unless sources of gross microbial contamination could be identified and removed. Consequently, much of the previous data reflect on microbial contribution from humidifiers and HVAC components. Ambient

microbioaerosols contaminants sourced to carpeting and other textiles are rarely studied or linked to illness unless mold hypersensitivity among occupants is known or suspected or studies are directed at nosocomial infections.

Although antimicrobial agents were available to reduce microbial reservoirs, they were incapable of producing substantive and sustained aeromicrobiological control. Also, toxic or irritational response to these agents can obscure observation of symptomatic variances concomitant with fluctuations of microbioaerosol presence and density.

Selection of an appropriate material was critical to the execution of the experimental design of this work. Antimicrobial agents vary greatly in chemical type, mode of action, durability and a variety of other properties. The properties of one of the classes of immobilized silane quaternary amines, 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride, AEGIS Antimicrobial, led us to choose it. This agent has been used successfully to provide durable, long-lasting, broad-spectrum antimicrobial activity [6, 9, 15]. It was EPA registered for our intended use and known to produce antimicrobial surfaces on key building substrates. Its chemical reactivity to surfaces and to itself reduces the ability for this material to partition into the environment. Unlike most other antimicrobials, this property greatly reduces the risks of the material becoming involved as a reactant with people [13]. As a membrane interrupter [14], risks of adaptation by inductive or mutational mechanisms are eliminated. This provides investigators an opportunity to study clinical effects of ambient micro flora on building occupants. When microbial reservoirs are destroyed to reduce biological contribution to the air and antimicrobial activation of the surfaces continuously decreases airborne microbial densities, we should be able to observe variations in clinical response profiles of persons reporting BRIs secondary to reduced exposure to airborne microbes.

During the past 3 years, we have investigated BRI complaints in more than 30 buildings throughout the US. During our first investigation at a school where more than 200 students and staff complained of illness, we observed a substantial reduction of microbioaerosol presence resulting from application of a surface-bonded antimicrobial agent to the school's carpeting. Within 2 weeks of the treatment, complaints ceased [2].

In the present investigation, we report on the first attempts to determine whether ambient microbioaerosols within buildings can be regulated by the application of silane-modified quaternary amines to carpeting. We further attempt to observe whether or not clinical complaint profiles can be linked to and positively influenced by reduced exposure to microbial pollutants in the workplace.

MATERIALS AND METHODS

Antimicrobial Treatment of Carpeting

An aqueous solution of 3-trimethoxysilylpropyldimethyloctadecyl ammonium chloride was applied to dry carpeting in accordance with the manufacturer's specifications.[5] Carpeting was not cleaned prior to antimicrobial applications.

Building occupants in 6 of the buildings were not aware of any remediation activities. Although samples were performed during normal work hours, application of the treatment was performed at night or on weekends without their knowledge.

Aerobiological Sampling Methods

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 [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.

Two week prior to treatment, standard plastic petri dishes containing Sabauroud Dextrose Agar (SDA: BBL) were placed at floor level in random arrays (40-90 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 same locations. Post-treatment samples 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.

Culturing and Enumeration

Plates were incubated at 30˚C and counted after 48 h and again after 72 h. Final counts were reported as those observed at the 72 h count with confirmatory readings after 7 days. Care was taken to avoid secondary seeding of the plates by primary isolates of dry-spored types.

Colony counts were performed on all retrieval plates and differentiated into two groups: filamentous fungi and all others. Identification of the isolates was not performed.

RESULTS

Data and observations of 10 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.

The pre and post treatment retrieval averages are reported in Table 1.

These averages are derived by dividing the total number of colonies retrieved by the number of plate sites.

The variances between pre-treatment and post-treatment retrieval averages range between 71 and 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.

The actual retrieval counts at 33 sites within a test building are representative of patterns observed in the 10 buildings in this study. The pre-treatment variances range from 2 CFU/plate to 156 CFU/plate whereas the post-treatment retrieval counts range only from 0 CFU/plate to 4 CFU/plate. This stabilization of the aeromicrobiological retrievals is noteworthy along with the consistently effective reduction in numbers retrieved.

Table 1

Fungal Retrievals in 10 Buildings Pre-and Post-AEGIS Antimicrobial Treatment

	1	2	3	4	5	6	7	8	9	Building 10	
Pre-Tr., CFU/Plate	13.4	28.0	54.0	40.2	32.0	20.3	36.0	26.0	27.4	17.0	
Post-Tr., CFU/Plate		1.7	8.0	1.0	1.4	4.8	3.5	4.1	4.0	3.3	2.9
Variance	87%	71%	98%	95.5%	85%	83%	89%	85%	88%	83%	
No. of Sites	50	29	33	45	20	47	14	30	20	15	

Following are descriptive accounts of the observations made at each of the test building sites:

Field Study 1: February 1986
Facility: Campbell County
Location: Alexandria, KY

Retrieval Data
Pre: 13.4 CFU/Plate
Post: 1.7 CFU/Plate
Reduction: 87.3%
Sample Sites: 50

This two-story building, constructed in 1979, houses approximately 4,560 students and 45 staff members. Within 1 year of the school opening, a small number of teachers and students complained of allergies and respiratory problems they linked to the school.

By 1985, problems affected more than half of the student and staff population. NIOSH, OSHA, the Kentucky Labor Cabinet, and private consultants were brought in to investigate. They found excessive levels of CO_2 and fungi which they believed resulted from improperly functioning HVAC units that permitted excessive levels to accumulate in the air, producing an allergic response.

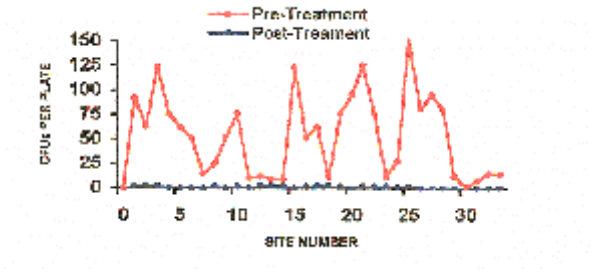

Figure 1. Fungal Retrievals Per Site Pre-and Post-Treatment with AEGIS Antimicrobial Treatment at 33 Sites in One Building.

They recommended extensive structural repairs and modifications of the HVAC systems.

A microaerobiologic survey of the school on February 4, 1986, produced an average of 13.4 fungal CFUs per plate, even though HVAC units had been modified to permit greater air exchange and carpets had been cleaned and disinfected 8 times with a conventional biocide. The complaints persisted. The school was treated with AEGIS Antimicrobial on February 15. Post-treatment analysis revealed that fungal levels had dropped to 1.7 CFUs per plate, a reduction of 87.3%. Within 7 days of the treatment, complaints had ceased. There have been no reports of additional complaints to date.

Field Study 2: October 1986
Facility: Withheld at Owner's Request
Location: St. Petersburg, FL

Retrieval Data
Pre: 28.0 CFU/Plate
Post: 8.0 CFU/Plate
Reduction: 71.4%
Sample Sites: 29

This 9-year-old building contains offices and a large printing shop area. Numerous employees within both sections complained of respiratory ailments, dizziness and flu-like symptoms. Organic volatiles were suspected, but vapor analysis showed levels to be well below threshold limit values.

An aeromicrobiological survey was conducted in October, producing an average of 28 CFUs per plate. AEGIS Antimicrobial was applied to carpeting and walls in January, 1987. Post-treatment analysis in February produced an average of 8.0 CFUs per plate, a 71.5% reduction in fungal aerosols.

All workers who had previously complained of respiratory ailments reported feeling much better after the treatment. No complaints have been reported by any workers to date.

Field Study 3: March 1987
Facility:1 City Center Building
Location: Rochester, New York, NY

Retrieval Data
Pre: 54.0 CFU/Plate
Post: 1.0 CFU/Plate
Reduction: 98.2%
Sample Sites: 33

Several areas within this 5-story structure were subjected to serious water damage from a ruptured standpipe. A significant amount of carpeting was replaced. Shortly after installation, workers complained of odors and hyper-responsive ailments that included headaches, burning eyes and upper respiratory infections. These symptoms disappeared when away from the work environment.

An aeromicrobiological survey was conducted in February, 1987 and revealed excessive fungal levels. An average of 54.0 CFUs per plate were retrieved, although no visible growth was found in the building or its HVAC system. In March 1987, AEGIS Antimicrobial was applied to 3 of the 5 floors. Aeromicrobiological analysis in May showed the microbioaerosol level had dropped to an average of 1 CFU per plate at the 33 sample sites. Although some odor complaints have been reported, no office-related health complaints have been received from persons in treated areas.

Field Study 4: April 1987
Facility: Withheld at Owner's Request
Location: Keystone, CO

Retrieval Data
Pre: 40.2 CFU/Plate
Post: 1.4 CFU/Plate
Reduction: 96.5%
Sample Sites: 45

Guests occupying 4 of the condominiums within this resort complex frequently complained of musty odors and mold allergies during their stay. In April 1987, the condominiums were sampled prior to application of AEGIS Antimicrobial. Pre-treatment sampling produced an average of 40.2 CFUs per plate within the 4 units.

Aeromicrobiological sampling performed 4 h after treatment showed a 61% reduction, producing an average of 15.7 CFUs per plate. Sampling performed in December 1987, produced an average of 1.4 CFUs per plate, a reduction of 96.5% of the original level. No odor or allergic complaints have been reported since the units were treated.

Field Study 5: July 1987
Facility: Withheld at Owner's Request
Location: Clearwater, FL

Retrieval Data
Pre: 32.0 CFU/Plate
Post: 4.8 CFU/Plate
Reduction: 85.2%
Sample Sites: 20

Owners of this 2-year-old building had received numerous health complaints from 12 workers located within 2 office areas. High humidity levels and moisture incursion were linked to high fungal concentrations within the air. Major design modifications of the HVAC system were proposed.

In June 1987, aeromicrobiological surveys revealed fungal levels averaging 32.0 CFUs per plate. Carpeting was treated with AEGIS Antimicrobial in July. Post-treatment sampling produced an average of 4.75 CFUs per plate, a reduction of 85.2% in airborne fungi. All workers showed improvement within 5 days of

treatment, and no BRI symptoms have been reported.

Field Study 6: August 1987
Facility: US Homes Building
Location: Clearwater, FL

Retrieval Data
Pre: 20.3 CFU/Plate
Post: 3.5 CFU/Plate
Reduction: 82.7%
Sample Sites: 47

Numerous employees on the 2nd and 4th floors of this building presented with BRI complaints. Although modifications were made to the HVAC system to ensure efficient performance and increased make-up air, the complaints continued.

In January 1987, aeromicrobiological sampling was performed to determine the level of microorganisms. Test sites (47) revealed an average catch of 20.28 CFUs per plate, with a high count of 107. Plating included the air handlers on each floor. However, counts on plates exposed to exhaust air from HVAC plenums were much lower than anticipated.

Application of the AEGIS Antimicrobial was completed in July. Post-treatment sampling produced an average of 3.5 CFUs per plate, an 82.7% reduction in airborne microorganisms. Management has not received complaints from workers on treated floors since July.

Field Study 7: August 1987
Facility: Withheld
Location: Clearwater, FL

Retrieval Data
Pre: 36.0 CFU/Plate
Post: 4.1 CFU/Plate
Reduction: 88.6%
Sample Sites: 14

Three workers who experienced moderate to severe symptoms only while at work occupy offices located within this complex. These symptoms developed within 2-3 months after moving into the building. They complained of sinus congestion, itchy eyes and ocular infections, blurred vision and headaches. Absenteeism was high.

Pre-treatment analysis of the air revealed an average of 36.0 fungal CFUs per plate. AEGIS Antimicrobial was applied in August. Post-treatment sampling produced 4.1 fungal CFUs per plate, a reduction of 88.6%. Although 2 of the 3 workers reported feeling improved during the week following the treatment, no medical or complaint data are available after that time.

Field Study 8: October 1987
Facility: Withheld at Owner's Request
Location: Miami, FL

Retrieval Data
Pre: 26.0 CFU/Plate
Post: 4.0 CFU/Plate
Reduction: 84.6%
Sample Sites: 30

Numerous workers within 5 isolated areas within the building complained of mildew odors, burning eyes, tight chest and abnormally high infection rates. Workers in other sections of the building were not affected.

Aeromicrobiological analysis of these areas was conducted in September 1987, producing an average of 26.0 CFUs per plate. AEGIS Antimicrobial was applied to carpeting in these areas during October. Post-treatment analysis produced an average of 4.0 CFUs per plate, a reduction of 84.6%. All but 2 workers reported alleviation of symptoms within 10 days of treatment. No additional complaints have been received.

Field Study 9: November 1987
Facility: Withheld at Owner's Request
Location: Tampa, FL

Retrieval Data
Pre: 27.4 CFU/Plate
Post: 3.3 CFU/Plate
Reduction: 87.9%
Sample Sites: 20

Discussions with employees revealed widespread complaints of stale, musty odors and respiratory ailments. Analysis of the HVAC system revealed operational status exceeded ASHRAE standards.

An aeromicrobiological survey of the building demonstrated high fungal prevalence, showing an average of 27.4 CFUs per plate. In November 1987, AEGIS Antimicrobial was applied throughout the building. Post-treatment analysis produced 3.3 fungal CFUs per plate, a reduction of 87.9%. Although most employees reported significant improvements, persons within one office continued to report discomforts. This office was re-treated in January 1988. We have received no complaints of office-related illness since that time.

Field Study 10: April 1988	Retrieval Data
Facility: Withheld at Owner's Request	Pre: 17.0 CFU/Plate
	Post: 2.9 CFU/Plate
Location: Cincinnnati, OH	Reduction:82.9%
	Sample Sites: 15

In 1987, new offices were constructed to house the Accounting Department workers. Within 3 months of completion, workers complained of heavy odors and symptoms including headaches and burning eyes. The receptionist for this area is mold-sensitive and most affected. Workers from other parts of the building also complained whenever they entered these offices. OSHA conducted vapor analyses of the area but found only trace levels consistent with the rest of the building.

An aeromicrobiological survey produced an average of 17 CFUs per plate. Application of AEGIS Antimicrobial significantly reduced odor and complaints in all but the reception area. Further examination revealed heavy fungal infestation on carpeting beneath the chair mat of the receptionist. Re-treatment of this small area eliminated the odors and allergic discomforts. Post-treatment sampling produced an average of 2.9 CFUs per plate, a reduction of 82.9%. There have been no reports of odors or office-related illnesses since the treatment.

DISCUSSION

The data and observation reflect upon the real-world environment of building occupants, demonstrating the ability to effectively reduce aeromicrobiological pollutants in the workplace and to relieve discomforts and morbidity that can be associated with microorganisms. When we first began to study BRI, our perceptions were conditioned by traditional beliefs that persist today; microorganisms play only a minor role in the development of symptoms caused by poor indoor air quality. Organic vapors, physical irritants and "stale air" were considered primary causative factors in as high as 90% of worker health complaints.

The small percentage of problems that were linked to microbial pollutants was believed to result only from gross fungal infestation of HVAC systems or carpets that were contaminated from flooding.

As our research continued, real-world experiences forced us to re-evaluate conventional theory. The data consistently showed that air in buildings with high worker complaint profiles contained excessive levels of microbial pollutants.

In the 10 investigations in this report of SBS/BRI within a large diversity of building designs and geographies, symptomatic improvement was uniformly reported by workers, and reduction of microbioaerosols levels were observed after treatment of the carpeting with the silane-modified quaternary amine. While these data are not conclusive, it forces 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.

This study provides 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 silane-modified quaternary amines to carpeting and be reflected in agar place retrievals and in human response.

Thus, our investigations present strong evidence of microbial involvement in the acquisition of SBS/BRI and reveal an effective remediation tool in the form of the silane-modified quaternary amines. The results, while anecdotal from a statistical sense, present strong evidence of a causal linkage between environmental surfaces, such as carpeting, as microbial reservoirs and human response. We believe this presents significant insight into the complex issues relating to the role of microorganisms in indoor air quality and offers a new base for experimental design and hypothesis.

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