COMPARISON OF BIOCONTAMINANT LEVELS IN SCHOOLS -THE IMPACT OF CARPET VS. SMOOTH FLOOR COVERING

Final Report

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Executive Summary

A carefully designed study was performed to provide information on the biocontaminant levels associated with carpeted and smooth surface flooring in two schools located in rural North Carolina. The objective of this study was to determine if there was a quantifiable difference in biocontaminant levels between a school with predominantly carpeted flooring and a school with predominantly vinyl composite tile (VCT) smooth surface flooring.

The floor covering of a school is just one of many factors that can vary between schools. To effectively assess the biological contributions of carpet vs. smooth flooring to the school environment and within the cost constraints of the study, it was important to minimize the impact of the other variables.

Two primary criteria were used to select the site: the school management had to be willing to participate and be supportive of the research effort and the schools had to meet our school profile. The school profile focused on the engineering aspects of the school buildings and identifying schools with similar ventilation systems in the zones being sampled, similar student loads, building age, etc. The two schools selected for the study were comparable in age, design, and student load, with the major difference between them being the type of floor covering. Both schools were noncomplaint, nonproblem buildings. The tiled school was a middle school, and the carpeted school an elementary school.

The two schools were paired as closely as possible. Both were from the same school district and situated in rural locations in North Carolina. Both were first occupied in 1996. The HVAC systems were as similar as possible and appeared well maintained. Four basic efficiency fiberglass panel air filters were used in each air handling unit (AHU). The school system has a standard operating procedure for the cleaning and maintenance of all of the schools in the system. As best we could determine, it was followed in the two schools participating in this study.

The smooth surface school had tile floors in all areas with the exception of the administration area and media center. In the carpeted school, the classroom floor area was two-thirds carpet and one-third tile. The halls, kitchen, cafeteria and art room were tiled; the music room, general purpose room, administrative areas and media center were carpeted. In total, approximately 70 to 75 percent of the floor was carpeted. This percentage is typical of a “carpeted” school in North Carolina.

Each school was sampled five times throughout the school year. Sampling at each school took one full day; therefore, the two schools were sampled on sequential days to minimize any short-term climatic or weather differences. One of our primary goals was to collect a sufficient number of samples to perform statistical analyses on each parameter to help elucidate flooring differences and nonflooring differences, such as time of year. Therefore, between three and five replicate samples (depending upon the contaminant) were collected and analyzed each sampling trip.

The sampled contaminants were carefully selected to provide a broad range of information, as well as some internal checks and balances to minimize the possiblility that results from only one contaminant might be misleading. Using multiple markers and different methods allows us to state our conclusions much more strongly. Air and floor dust samples from the two schools were collected. The air samples were analyzed for culturable fungi, total airborne spores, airborne $PM_{2.5}$ dust mass (particulate matter with aerodynamic diameters less than 2.5 μm), allergens (dust mite, cockroach, and cat), endotoxins, and ß-1,3 glucans. The dust mite, cockroach, and cat allergens and endotoxins and ß-1,3 glucans were quantified in the airborne $PM_{2.5}$ dust sample. The floor dust samples were analyzed for culturable fungi, allergens (dust mite, cockroach, and cat), endotoxins, and ß-1,3 glucans.

The total spores, culturable fungi, and ß-1,3 glucans are different parameters, but all are designed to quantify fungal contamination levels. The measurement of total spores quantifies the total number of spores without regard to culturability or viability. This was important because, generally, only 1 to 10 percent of the total spores would be expected to be culturable. ß-1,3 glucans were selected as a biochemical marker for fungal contamination. One of the primary sources of ß-1,3 glucans in the environment is fungi, so a reasonable correlation with total spores and culturable fungi would be expected.

Dust mite, cat, and cockroach antigen were selected because they are commonly associated with allergy and asthma. While dust mites and cockroaches would be expected in schools, cats would not. Generally, cat antigen is thought to be brought into schools on the clothing of cat owners. Endotoxin was selected primarily because inhalation of endotoxins has been shown to increase nonspecific bronchial reactivity in asthmatics and can be used as a biochemical marker for gram negative bacteria.

To assist in the interpretation of the data, a statistical analysis was performed. All of the data from the samples were used in the analyses. Two-way analysis of variance (ANOVA) models were used to analyze the logarithms of the outdoor air, indoor air, and surface concentration data; sources of variation in each model included schools, times, and a school-by-time interaction. Models excluding the interaction effect were also fit. In addition, for analysis of the indoor air, and surface data, locations within schools were treated as random effects. For these data, analysis of covariance (ANOCOVA) models were also employed in which the average outdoor air level at a given time and school was employed as a covariate as a means of controlling for temporal and school differences in outdoor air levels. The SAS© GLM procedure was used for all analyses.

A comparison of the floor contaminant loading, calculated per area of floor, showed that the carpeted flooring had 25 times the concentration of biocontaminants than an equal area of tiled flooring, except for the culturable fungi. There were statistically significant differences in flooring contaminant loading between the two schools. This is not a surprising result because the floor dust samples were collected with a specialized research vacuum cleaner and carpet is known to serve as a sink. One of the properties of carpet is that it holds and prevents tracking of dirt. Regular maintenance of carpet is desirable to prevent excessive loading of contaminants before tracking can occur.

Further comparison of the concentration of each contaminant, calculated per gram of floor dust, showed that there was little difference in the concentration of the contaminants in the floor dust between the two schools.

The airborne sample analyses found no statistically significant difference in the airborne levels between the two schools for the three allergens, but significant differences between the two schools for airborne levels of spores, fungi, ß-1,3 glucan, dust mass, and endotoxins. In all cases, the airborne levels in the tiled school were higher than the carpeted school. The full implication of this finding is not clear. All of the parameters that were significantly different have outdoor sources in this study. Although the schools

were paired as much as realistically possible, there may have been more outdoor air infiltration in the tiled school than the carpeted school. Subtle differences can influence airborne concentration. While there may be reasonable explanations for these differences involving the HVAC systems and outdoor concentrations, the results suggest that floor covering is not the major contributor to airborne levels of biocontaminants in nonproblem schools. One possibility that should be investigated is that smooth surface floors permit a greater quantity of particle reintrainment than soft surfaces such as carpet. However, additional data are needed to support this idea.

Small aerosol particles, as measured in this study (those contributing to $PM_{2.5}$ or fungal spores), tend to remain airborne for long periods. This size fraction, $PM_{2.5}$, is respirable. These aerosols were measured in the air samples collected in the schools. Particles in this size range slowly settle to floor surfaces (in periods of hours) through movement in air currents and diffusion in quiet air layers. Once settled on carpet surfaces, these small particles are difficult to dislodge into the air again.

One class of aerosol particles that was not examined in this study was the coarse particles, those with sizes larger than $PM_{2.5}$ but smaller than PM_{10}, or between 2.5 and 10 μm aerodynamic diameter. These particles come from both indoor and outdoor sources. These size particles settle rather quickly to the floor (in minutes). From there, such particles may be reintrained by people walking across the floor, by machines vibrating the floor, or by strong air currents.

The coarse particles may serve as carriers for biocontaminants that have settled on them or are mixed with them on the floor surfaces. In such cases, the higher airborne concentrations in the tiled floor schools may provide a steady source of fresh biocontaminants onto coarse particles that are rather easily reintrained. On the other hand, the much larger loadings of biocontaminants in carpeted floor materials may represent a larger reservoir of older, coarse particles that can be stirred up, although perhaps not as effectively as on the tiled floors. Measuring coarse particle contaminants is difficult because, without some sort of agitation, the particles remain on the floor.

An excellent start has been made on collecting baseline data for carpeted and smooth surface floored schools. However, care should be taken when extrapolating these data because only two schools were studied. Additional studies including other paired schools are needed.

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COMPARISON OF BIOCONTAMINANT LEVELS IN SCHOOLS -THE IMPACT OF CARPET VS. SMOOTH FLOOR COVERING

INTRODUCTION

Choosing the appropriate floor surface for a school environment is a complex issue. To assist school personnel in determining which flooring is best for their school, we performed a carefully designed study to provide information on the biocontaminant levels associated with carpeted and hard surface flooring. The objective of this study was to determine if there was a quantifiable difference in biocontaminant levels between a school with predominantly carpeted flooring and a school with predominantly smooth surface flooring.

While there have been many studies performed in schools, most focus on schools that have become problem or complaint environments. Very few have considered the type of floor unless it has become a problem. Once a school has become a problem environment, it is no longer possible to adequately assess the influence of flooring choices. Information is needed that provides baseline data regarding the impact of flooring in schools on contaminant levels and air quality.

Although there is limited data on the potential impact of flooring on schools, health care facilities have been studied in depth. The results of research in hospitals on the impact of the type of floor surface are not consistent. There is no concrete evidence associating floor type with transmission of infections to either patients or staff. There have been a number of studies in hospitals demonstrating that recontamination of newly cleaned hard floors may occur rapidly from airborne bacteria and organisms transferred from shoes, equipment, and contaminating substances (Greene, 1969; Spaulding, 1970; Maki et al., 1982).

As with hard floor surfaces, numerous studies in hospitals have demonstrated that carpet contains a diverse microbial population, primarily bacteria and fungi. Carpeting in health care facilities has been popular for over 30 years. Carpeting offers some advantages in these types of environments - reduced noise levels, a “humanizing” effect, and a reduction in the number of falls and related injuries (Lee, 1965). Although studies have demonstrated that bacterial and fungal contamination in carpet tends to increase with time and higher levels of activity, there is no direct evidence relating nonproblem carpets and infection rates in health care environments (Simmons et al., 1982; Shaffer and Key, 1966; Skoutelis et al., 1993; Streifel et al., 1999).

While data from hospitals are useful, data on schools are needed. This study was implemented to help address that need. The goal was to determine if there was a quantifiable difference in biocontaminant levels between one school with predominantly carpeted flooring and another school with predominantly smooth surface flooring. Air and floor dust samples from the two schools were collected for a period of 1 year. The air samples were analyzed for culturable fungi, total airborne spores, airborne dust mass, allergens (dust mite, cockroach, and cat), endotoxins, and ß-1,3 glucans. The floor dust samples were analyzed for culturable fungi, allergens (dust mite, cockroach, and cat), endotoxins, and ß-1,3 glucans.

The contaminants to be sampled were carefully selected to provide a broad range of information as well as some internal checks and balances. This was especially important because the results from only one contaminant may potentially be misleading. Using multiple markers and different methods allows us to

state our conclusions much more strongly. The total spores, culturable fungi, and ß-1,3 glucans are different parameters, but all are designed to quantify fungal contamination levels. The measurement of total spores quantifies the total number of spores without regard to culturability or viability. This was important because, generally, only 1 to 10 percent of the total spores would be expected to be culturable. ß-1,3 glucans were selected as a biochemical marker for fungal contamination. One of the primary sources of ß-1,3 glucans in the environment is fungi, so a reasonable correlation with total spores and culturable fungi would be expected.

Dust mite, cat, and cockroach antigen were selected because they are commonly associated with allergy and asthma. While dust mites and cockroaches would be expected in schools, cats would not. Generally, cat antigen is thought to be brought into schools on the clothing of cat owners. Endotoxin was selected primarily because inhalation of endotoxins has been shown to increase nonspecific bronchial reactivity in asthmatics and can be used as a biochemical marker for gram-negative bacteria.

The airborne dust mass samples that were collected were $PM_{2.5}$, defined as particulate matter with aerodynamic diameters less than 2.5 µm. This size fraction is respirable. In addition, dust mite, cockroach, and cat allergens and endotoxins and ß-1,3 glucans were quantified in the airborne $PM_{2.5}$ airborne dust sample.

IDENTIFICATION OF PARTICIPANT SCHOOLS

The first step of the study was to identify candidate sites for participation. The floor covering of a school is just one of many variables that can differ from school to school. To effectively assess the biological contributions of carpet vs. smooth floor covering to the school environment and limit the cost of the study, it was important to minimize the impact of the other differences. To meet this goal, we developed a school profile to assist in the selection process and collected sufficient replicates to permit a statistical analysis of the data.

Two main criteria were used to select the site: school design and willingness to participate. First, the school management had to be willing to participate and be supportive of the research effort, and, second, the schools had to meet our school profile. The development of the school profile focused on the engineering aspects of the school buildings and identifying schools with similar ventilation systems in the zones being sampled, similar student loads, similar building age, etc. The two schools selected for the study were comparable in age, design, and student load, with the major difference between them being the type of floor covering. Both schools were noncomplaint, nonproblem buildings. The tiled school was a middle school, and the carpeted school was an elementary school.

The two schools were paired as closely as possible. Both were from the same school district and situated in rural locations in North Carolina. Both were first occupied in 1996. The HVAC systems were identical. Comfort air conditioning in both schools was accomplished with zoned air handling units (AHUs). Zones included multiple classrooms and auxiliary rooms. Oil-fired boilers provided steam to the AHU coils for the heating season, and packaged chillers provided chilled water to coils during the cooling season. Humidity was not controlled through reheat. The boilers and chillers were operated together only for a few weeks during the spring and fall when both heating and cooling might be required within a short period. The systems at both schools appeared well maintained. Four air filters were used in each AHU. The filters were basic efficiency fiberglass panel filters.

The tiled school was all tiled, with the exception of the administration area and media center. In the carpeted school, the classroom floor area was two-thirds carpet and one-third tile. The halls, kitchen, cafeteria, and art room were tiled; the music room, general purpose room, administrative areas, and media center were carpeted. In total, approximately 70 to 75 percent of the floor was carpeted. In our initial survey of schools, we determined that this percentage would be typical of a carpeted school.

The school system has a standard operating procedure for the cleaning and maintenance of all of the schools in the system. As best we could determine, it was followed in the two schools participating in the study.

MATERIALS AND METHODS

The assessment of carpet vs. smooth surface flooring in the two schools focused on biocontaminants. Air and floor samples were collected. The air samples were analyzed for culturable fungi, total airborne spores, airborne dust mass ($PM_{2.5}$), allergens (dust mite, cockroach, and cat), endotoxins, and ß-1,3 glucans. The dust samples were analyzed for culturable fungi, allergens (dust mite, cockroach, and cat), endotoxins, and ß-1,3 glucans. The test matrix is shown in Table 1.

Table 1. Test Matrix – Number of Samples

POLLUTANT		SCHOOL #1			SCHOOL #2			TOTAL
		INDOOR		OUTDOOR	INDOOR		OUTDOOR	
		CARPETED			TILE			
		AIR	DUST	AIR	AIR	DUST	AIR	
Culturable Fungi	xerophillic	25	25	15	25	25	15	130
	cellulosic	25	25	15	25	25	15	130
Total airborne spores		20	ND	20	20	ND	20	80
Allergens (dust mites, cockroach, cat)		50	30	20	50	30	20	200
Airborne dust mass		20	ND	20	20	ND	20	80
Endotoxins/ß-1,3 glucans		25	15	25	25	15	25	130
Total		165	95	115	165	95	115	750

ND = Not determined.

Each school was sampled five times throughout the school year, May (the end of school), September (the beginning of school), and November, January, and March. Sampling at each school took one full day; therefore, the two schools were sampled on sequential days. This sampling pattern minimized any short-term climatic or weather differences such as rain. One of our primary goals was to collect a sufficient number of samples to perform statistical analyses on each parameter to help elucidate flooring dif-

ferences and nonflooring differences, such as time of year. Therefore, between three and five replicate samples (depending upon the pollutant) were collected and analyzed each sampling trip.

Collection of Samples

All samples were collected during the school day while the schools were in session. No attempt was made to limit normal student activity. Air samples were collected using a variety of samplers and protocols depending upon the pollutant being measured. The total airborne spores were collected using Air-O-Cells (Zefon Analytical Accessories, Fl). The airborne dust mass ($PM_{2.5}$) was collected on 2 µm pore-size 47 mm PTFE filters using URG's Fine Particle Sampler. The same filters were analyzed for the three allergens, endotoxins, and ß-1,3 glucans.

The culturable fungi were sampled using a Mattson-Garvin slit-to-agar impactor. The Mattson-Garvin draws air at 28.3 L/min through a metal inlet with a 0.006-inch slit, allowing the impaction of an extensive size range of airborne organisms on the surface of a rotating agar plate. Five sampling sites were designated inside each school building, and an outdoor location was sampled in triplicate.

Air-O-Cells are preloaded cassettes containing a glass slide coated with a sticky impaction medium. The base of the cassette is connected to a pump using flexible tubing and air is drawn onto the impaction surface at 28.3 L/min through a slit in the top of the cassette. Five sampling sites were designated inside each school building, and an outdoor location was sampled in triplicate.

The URG Fine Particle Sampler consists of an air pump that maintains constant flow throughout sampling. A 47 mm PTFE filter is loaded into a filter pack containing various stages separated by Teflon-coated mesh screens. The filter is placed on the top stage of the filter pack. Above the filter, a 2.5 µm cut cyclone is screwed into the filter pack. The cyclone is also coated with Teflon to prevent particle loss within the inlet. The entire apparatus is connected with flexible tubing to the pump, and samples are collected at 16.7 L/min for 2 hours each. Two indoor locations were sampled in duplicate, and an outdoor location was sampled twice in duplicate.

All dust samples were collected with the High Volume Surface Sampler or HVS3. The HVS3 was developed through the EPA for the collection of dust sample from carpets and bare floors. The dust can be analyzed for lead, pesticides, or other chemical compounds and elements. The American Society for Testing and Materials (ASTM) standard practice D5438 describes the protocols and its applicablity to a variety of carpeted and bare floor surfaces (ASTM, 1994). It has been tested for level loop and plush pile carpets and bare wood floors. RTI has a procedure for using the HVS3 to collect dusts for microbiological assays (Leese et al., 1993).

The HVS3 uses a 1-horsepower vacuum motor and a specifically designed nozzle and cyclone trap. The unit has magnehelic gauges that are used to manually set the flow rate and pressure drop across the nozzle at the monitored surface. The cyclone effectively collects 99 percent of the dust mass lifted by the vacuum (Roberts et al., 1991).

Upon arrival at the field site, five separate carpeted or smooth flooring areas were designated for sampling. Using a steel template measuring 4'?4' (carpet) or 16'?4' (tile), squares were laid out on the floor,

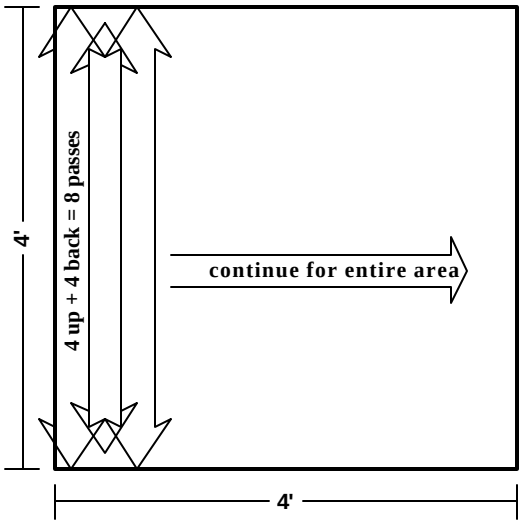

Figure 1. Vacuum pattern used for the HVS3 floor dust sampling

and marked with masking tape. Each square was sampled following the sampling pattern shown in Figure 1.

The sampling pattern consisted of first vacuuming following upward and downward strokes for eight consecutive passes. The operator then moved the sampler to the right of the completed strokes and repeated the series. The series was repeated until the entire sampling area was covered. The sample bottles for the HVS3 were preweighed in the laboratory prior to leaving for the field site. After sampling, the bottles were brought back to RTI, postweighed, and the net weight recorded. On each trip samples were collected from five indoor locations.

Sample Analyses

The culturable fungi were grown on DG18 for the xerophillic organisms and cellulose agar for the cellulosic fungus, *Stachybotrys chartarum*. No *Stachybotrys chartarum* were isolated from either school and these data are not reported in detail. On the DG18, the predominant organisms were enumerated and identified to at least the genus level.

Airborne dust mass was quantified by weighing PTFE air filters. The filters were equilibrated at 30 to 35 percent relative humidity in the weighing chamber for at least 16 hours. The filters were weighed on a seven-place balance following a standardized weighing program, which promotes consistency throughout the weighing process. Pre- and postweighing procedures were the same. The operator who performed the preweighing, also postweighed the filters. The net weight was recorded. After weighing, the filters were extracted for the antigen, endotoxin, and ß-1,3 glucan analyses.

The allergen (dust mite, cat, and cockroach) contents were assayed using a modification of the Food and Drug Administration procedure (FDA, 1994) for the Enzyme Linked ImmunoSorbent Assay (ELISA) inhibition (competition). This assay is a polyclonal assay (detects multiple antigens) designed to be specific for the test antigens (i.e., *Der f*). We selected this assay over the monoclonal (detects one specific antigen) because, like the monoclonal, it is specific for the test antigens but inclusive of more antigens than the monoclonal and results in a lower minimum detection limit. The assay determines the relative potency of the antigen in the test sample compared to a standard antigen preparation.

Endotoxins and ß-1,3 glucans were quantified using endotoxin-specific and ß-1,3 glucan-specific Limulus amebocyte lysate assays, respectively.

Total airborne spores were quantified by analysis of the Air-O-Cells. Each Air-O-Cell cassette was opened, and the internal glass slide containing the impaction medium was removed. The slide was placed onto a microscope slide and stained with lacto-glycerol. Total airborne spores were counted microscopically at 600X magnification.

Statistical Analyses

The primary purpose of the statistical analysis was to determine whether the differences in the levels of the various contaminants quantified in the two schools were statistically significant. All of the data from the samples were used in the analyses.

Two-way analysis of variance (ANOVA) models were used to analyze the logarithms of the outdoor air, indoor air and surface concentration data; sources of variation in each model included schools, times, and a school-by-time interaction. Models excluding the interaction effect were also fit. In addition, for analysis of the indoor air and surface data, locations within schools were treated as random effects. For these data, analysis of covariance (ANOCOVA) models were also employed in which the average outdoor air level at a given time and school was employed as a covariate as a means of controlling for temporal and school differences in outdoor air levels. The SAS[1] GLM procedure was used for all analyses.

RESULTS

The results of the analyses are shown in Tables 2 through 8. Each table presents the summary data for one of the contaminants. The airborne data are separated into indoor and outdoor measurements and expressed in terms of the volume (cubic meter) of air. The flooring data are expressed in terms of area (square meter) of floor. The data are presented as the geometric mean (GM) and geometric standard deviation (GSD) over the full year of sampling. The GSD is a number greater than 1 that describes the breadth of the distribution of values when the geometric mean is used. The GSD is the ratio of the 84th percentile of the distribution to the mean of the distribution. That is, 84 percent of the distribution lies within a value equal to GSD times the mean value. A GSD of 1.4 indicates a narrow range of values in the distribution; the 84th percentile is at only 1.4 times the mean value. A GSD of 6 represents a very broad range of values in the distribution: 6 times the mean value will encompass only 84 percent of all the values.

As discussed above, a statistical analysis was performed to assist in the interpretation of the data. The conventional level of statistical significance that is commonly used is $p < .05$. In other words, a 95 percent likelihood that the difference in the means is not due to chance is required to establish significance. Those results that are statistically significant are bolded in the tables.

The general pattern that emerges for all the contaminants is that there is little or no difference in the airborne levels between the two schools, while there are notable differences in flooring contaminant loading between the two schools. However, a couple of differences in contaminant levels between the two schools require futher discussion. It is important to note that these results cover the entire year. A further breakdown of the data that includes the seasonal differences will help clarify these differences and their importance. Appendix A contains all of the data collected over the course of the study. Each contaminant is presented graphically. The results are plotted by sample measurement over time.

Table 2 shows the airborne $PM_{2.5}$ and floor dust data. These results show that there is a small but statistically significant difference in the indoor airborne dust levels between the two schools and a large, statistically significant difference in the quantity of floor dust. The difference in the outdoor airborne levels between the two schools was not significantly different.

[1]SAS is the registered trademark of SAS Institute, Inc., Cary, NC.

Table 2. Summary of Airborne $PM_{2.5}$ and Floor Dust Data

SCHOOL	AIRBORNE $PM_{2.5}$ (µg dust/m^3)		FLOORING (mg dust/m^2)
	IN GM (GSD)	OUT GM (GSD)	GM (GSD)
Carpeted	**8.0 (1.9)**	9.3 (1.9)	**1,000 (3)**
Tiled	**13.9 (1.4)**	11.8 (1.4)	**40 (2.2)**

Bolded text = statistically significant difference $p < .05$).

Table 3 gives the results of the dust mite analyses. As can be seen in the table, the mite antigen levels in the air samples collected from the tiled school are slightly higher than in the carpeted school, both indoors and outdoors, but there was no significant difference between the two schools. As before, there was a large, statistically significant difference between the two schools in the dust mite antigen loading of the flooring.

Table 3. Summary of Airborne and Floor Dust Mite Antigen Data

SCHOOL	AIRBORNE (ng/m^3)		FLOORING (ng/m^2)
	IN GM (GSD)	OUT GM (GSD)	GM (GSD)
Carpeted	32.3 (2.3)	23.2 (2.2)	**5,900 (5.5)**
Tiled	73.7 (4.4)	55.8 (4.5)	**110 (4.5)**

Bolded text = statistically significant difference ($p < .05$).

The next two tables show the results of the cat and cockroach analyses. In both cases, the outdoor levels are the same but the indoor levels differ. For the cat antigen, the tiled school level is slightly higher, while the carpeted school has slightly higher cockroach antigen levels. Neither result was statistically significant. For both antigens, the carpet dust contained significantly higher loading of antigen than the tiled floor.

Table 4. Summary of Airborne and Floor Cat Antigen Data

SCHOOL	AIRBORNE (ng/m^3)		FLOORING (ng/ m^2)
	IN GM (GSD)	OUT GM (GSD)	GM (GSD)
Carpeted	63.5 (5.4)	22.6 (2.5)	**5,500 (3.2)**
Tiled	96.6 (6.1)	20.2 (3.2)	**180 (3.4)**

Bolded text = statistically significant difference ($p < .05$).

Table 5. Summary of Airborne and Floor Cockroach Antigen Data

SCHOOL	AIRBORNE (ng/m^3)		FLOORING (ng/ m^2)
	IN GM (GSD)	OUT GM (GSD)	GM (GSD)
Carpeted	87.1 (4.2)	35.4 (2.5)	**5,400 (4.4)**
Tiled	49.1 (3.0)	32.1 (2.1)	**50 (3.4)**

Bolded text = statistically significant difference ($p < .05$).

Table 6 presents the results of the endotoxin analysis. The most notable feature of the data is the high standard deviation of the airborne data. This much variability is suggestive of significant seasonal variability and needs to be examined further. These results show that there is a statistically significant difference in both the indoor and outdoor airborne dust levels between the two schools as well as a large, statistically significant difference in the endotoxin loading of the floor dust.

Table 6. Summary of Airborne and Floor Endotoxin Data

SCHOOL	AIRBORNE (EU/m^3)		FLOORING (EU/ m^2)
	IN GM (GSD)	OUT GM (GSD)	GM (GSD)
Carpeted	**0.3 (2.3)**	**0.2 (1.9)**	**48,000 (3.4)**
Tiled	**0.9 (1.3)**	**0.3 (2.0)**	**2,200 (2.8)**

Bolded text = statistically significant difference ($p < .05$).

The final two tables in this group give the results for the airborne and flooring ß-1,3 glucan quantification (Table 7) and total airborne spores and culturable fungi, as well as the fungi isolated from the floor samples (Table 8). As can be seen from these tables, there are small but statistically significant differences between the indoor airborne levels in the two schools, but not the outdoor levels. The outdoor spores and fungal colony-forming units (CFUs) exceed the indoors in all cases, indicating a functioning air filtration system in the HVAC. Interestingly, these are the only contaminants measured in this study whose levels were similar in both schools. This suggests that in a nonproblem, noncomplaint school, the primary source of spores and culturable fungi is the outdoor air.

Table 7. Summary of Airborne and Floor ß-1,3 Glucan Data

SCHOOL	AIRBORNE (ng/m^3)		FLOORING (ng/ m^2)
	IN GM (GSD)	OUT GM (GSD)	GM (GSD)
Carpeted	**0.2 (1.4)**	0.2 (2.1)	**1,200,000 (6.2)**
Tiled	**0.5 (1.3)**	0.2 (2.3)	**50,000 (3.7)**

Bolded text = statistically significant difference ($p < .05$).

Table 8. Summary of Airborne Total Spore and Fungi Data, and Floor Fungi Data

SCHOOL	TOTAL SPORES		CULTURABLE FUNGI		
	AIRBORNE (spores/m^3)		AIRBORNE (CFU/m^3)		FLOORING (CFU/ m^2)
	IN GM (GSD)	OUT GM (GSD)	IN GM (GSD)	OUT GM (GSD)	GM (GSD)
Carpeted	**1,200 (2.8)**	10,000 (4.0)	**50 (2.4)**	550 (3.3)	2,400 (5.7)
Tiled	**2,700 (2.1)**	9,000 (3.0)	**160 (3.1)**	300 (6.5)	3,800 (3.5)

Bolded text = statistically significant difference ($p < .05$).

The main objective of the statistical analyses was to determine if the differences in the indoor airborne contaminant levels between the carpeted school and the tiled school were statistically significant. Additionally, we wanted to evaluate the impact of the outdoor air and seasonality (time of year) on the results. Table 9 summarizes the results of the statistical analyses. The black boxes designate the statistically significant differences. The first column lists the location from which the sample was collected.

The second column lists the components that were tested as the source of variation. The next columns show the various contaminants included in the study.

Table 9. Summary of Statistical Analysis of Airborne Data

SAMPLE LOCATION	SOURCE OF VARIATION	CONTAMINANTS							
		Total Spores	Fungi	Cat Antigen	Cockroach Antigen	ß-1,3 Glucan	Mite Antigen	$PM_{2.5}$ Dust Mass	Endo-toxin
INDOOR AIR CONCENTRATION	Schools	■	■			■		■	■
	Times	■	■			■	■	■	
	Times*Schools	■	■	■			■	■	
	Outdoor air		■	■					
OUTDOOR AIR CONCENTRATION	Schools								■
	Times	■	■			■		■	■
	Times*Schools	■	■					■	

Black box = statistically significant difference ($p < .05$).

For the contaminants measured in the outdoor air, there was no overall statistically significant difference between schools for any of the parameters except for endotoxin. There were statistically significant time (seasonal) differences for total spores, fungi, ß-1,3 glucan, endotoxin, and airborne dust mass, with some differences in school*time interaction for the two schools for total spores, fungi, and dust mass. All these contaminants have outdoor sources and are an expected result of seasonal differences. There were no statistically significant differences for cat, cockroach, or mite antigens, which originate primarily from indoor sources. Overall, the outdoor concentrations were similar for the two schools.

For the indoor air concentrations, there were significant differences between the two schools for spores, fungi, and ß-1,3 glucan and for dust mass and endotoxin. In all cases, the tiled school was higher than the carpeted. Care should be used when interpreting this finding. The important fact is that the results for the carpeted school were not higher than the results for the tiled school. There are a number of probable explanations and we have no way of knowing what is the correct one. As all of these parameters have outdoor sources in this study, they probably demonstrate the influence of the HVAC system more than the impact of the flooring. Second, there may have been more outdoor air infiltration in the tiled school than in the carpeted school. One possibility that should be investigated is that there is more reintrainment of small particles from hard surface floors. However, more research is needed before proposing that hypothesis.

There were also seasonal differences for spores, fungi, ß-1,3 glucan, mite antigen, and dust mass. Except for ß-1,3 glucan, these seasonal patterns were somewhat different for the two schools. These seasonal patterns are readily observed in the graphs in Appendix A.

That carpet would have more dust loading than tile floor was not surprising. To further compare the two schools, the concentration of each contaminant was calculated per gram of floor dust. As can be seen from Table 10, there was little difference in the concentration of the contaminants in the floor dust between the two schools.

Table 10. Summary of Floor Contaminant Data Expressed per Gram of Floor Dust.

SCHOOL	CONTAMINANT					
	Mite Antigen (ng/g) GM (GSD)	Cat Antigen (ng/g) GM (GSD)	Cockroach Antigen (ng/g) GM (GSD)	Endotoxin (EU/g) GM (GSD)	ß-1,3 Glucans (ng/g) GM (GSD)	Fungi (CFU/g) GM (GSD)
Carpeted	7,000 (2.5)	6,000 (1.7)	**4,600 (2.7)**	43,000 (2.8)	1,100,000 (2.8)	6,700 (2.3)
Tiled	3,400 (3.5)	4,800 (3.5)	**1,600 (3.5)**	51,000 (2.8)	1,300,000 (6.9)	6,600 (1.9)

Bolded text = statistically significant difference ($p < .05$).

As seen in the summary data in Tables 2 through 8, the differences in the flooring loading data were statistically significant for all of the tested parameters except fungi (see Table 11). This result is reasonable as these were not problem schools and there were no known indoor sources of fungi. The primary sources of fungi were those tracked in on shoes or from the outdoor air. There were seasonal differences for fungi, dust mass, and endotoxin, but these patterns were consistent across schools. Cockroach and ß-1,3 glucan exhibited different school*time interactions for the two schools.

The statistical analysis for the concentration of the contaminants in the floor dust is shown in the bottom rows of Table 11. There were no statistically significant differences in the concentration of any of the contaminants in the dust between the two schools, except for cockroach antigen. There were seasonal differences for fungi ($p<.01$), ß-1,3 glucans ($p<.01$), and endotoxin ($p<.05$), but these patterns were consistent across schools. Cockroach and ß-1,3 glucan exhibited different school*time interactions for the two schools ($p<.01$).

Table 11. Summary of Statistical Analysis of Surface Data

SAMPLE LOCATION	SOURCE OF VARIATION	CONTAMINANTS						
		Fungi	Cat Antigen	Cock Antigen	ß-1,3 Glucan	Mite Antigen	Dust Mass	Endotoxin
SURFACE LOADING	Schools		■	■	■	■	■	■
	Times	■					■	■
	Times*Schools			■	■			
SURFACE DUST CONCENTRATION	Schools			■			n/a	
	Times	■			■		n/a	■
	Times*Schools			■	■		n/a	

Black box = statistically significant difference ($p < .05$).

DISCUSSION

A comparison of the floor concentrations shows that the carpeted flooring has many times the concentration of biocontaminants that an equal area of tiled flooring has. This is not a surprising result, since one of the advantages of carpet is that it keeps dirt from being tracked all over. Unfortunately, unless the

carpet is well-maintained, the loadings of biocontaminants may build up until they do begin to be tracked all over. Regular maintenance is critical.

It is clear from the tables that the airborne biocontaminants have higher concentrations over tiled floors than over carpet, as much as three times higher. There may be reasonable explanations for these differences that involve the HVAC systems and outdoor concentrations, but, in any case, it is unlikely that the flooring plays much role in the differences. This judgment is made based on the aerosol properties of the particles involved.

Small aerosol particles, such as those contributing to $PM_{2.5}$, fungal spores, and biological components such as endotoxins and ß-1,3 glucans, tend to remain airborne for long periods. These are the aerosols that were probably measured in the air samples in the schools. These particles do slowly settle to surfaces (in periods of hours) through movement in air currents and diffusion in quiet air layers. Once attached to surfaces, these small particles are difficult to dislodge into the air again.

One class of aerosol particles that was not examined in this study was the coarse particles, those with sizes larger than $PM_{2.5}$ but smaller than PM_{10}, or between 2.5 and 10 µm by aerodynamic diameter. These particles come from both indoor and outdoor sources. These size particles settle rather quickly to the floor (in minutes). From there, such particles may be stirred up again by people walking across the floor, by machines vibrating the floor, or by strong air currents.

The coarse particles can serve as carriers for the biocontaminants that have settled on them or are mixed with them on the floor surfaces. In such cases, the higher airborne concentrations in the tiled-floor schools may provide a steady source of fresh biocontaminants onto coarse particles that are rather easily stirred up. On the other hand, the much larger loadings of biocontaminants in carpeted floor materials may represent a larger reservoir of older, coarse particles that can be stirred up, although perhaps not as effectively as on the tiled floors.

Measuring coarse particle contaminants is difficult, because without some sort of agitation, the particles remain on the floor. It is also possible that continuous agitation in one area will deplete the area of particles that can be resuspended. Nonetheless, a person walking on a floor and resuspending particles is right in the midst of the cloud and can suffer maximum exposure.

There are some particles near the 2.5 µm diameter that can be resuspended and still be sampled by the devices used in this study that account for the differences in airborne concentration between the two schools. These particles may contribute to the airborne biocontaminant concentrations that were measured. Whether or not more of them have come from tiled floors or from carpeted floors is a question that cannot be answered with this data set. Some careful experiments that use time of day or activity monitors to modify the sampling would probably be required to distinguish between directly airborne and resuspended biocontaminants.

CONCLUSIONS

The objective of this study was to determine if there was a quantifiable difference in biocontaminant levels between a school with predominantly carpeted flooring and a school with predominantly smooth surface flooring. The results showed that there was no difference in the airborne levels between the two

schools for the three allergens, but there were significant differences between these schools for airborne levels of spores, fungi, ß-1,3 glucan, dust mass, and endotoxins. In all cases, the results for the tiled school were higher than those for the carpeted. The full implication of this finding is not clear. All of the parameters that were significantly different have outdoor sources in this study. Furthermore, there may have been more outdoor air infiltration in the tiled school than in the carpeted school. Although the schools were paired as much as realistically possible, subtle differences can influence airborne concentrations. The results suggest that floor covering is not the major contributor to airborne levels of biocontaminants in non-problem schools.

Another possibility that should be investigated is that there is more reintrainment of particles from hard surface floors. However, this idea cannot be answered with this data set. Some careful experiments that use time of day or activity monitors to modify the sampling would probably be required to distinguish between directly airborne and resuspended biocontaminants. However, more research is needed before proposing that hypothesis.

There were statistically significant differences in flooring contaminant loading between the two schools. That carpet would have more dust loading than tile floor was anticipated as carpet is known to serve as a sink. Further comparison of the concentration of each contaminant, calculated per gram of floor dust, showed that there was little difference in the concentration of the contaminants in the floor dust between the two schools.

Care should be taken when extrapolating these data. While we have made an excellent start on collecting baseline data for carpeted and smooth surface floored schools, only two schools were studied. Additional studies are needed that include additional schools.

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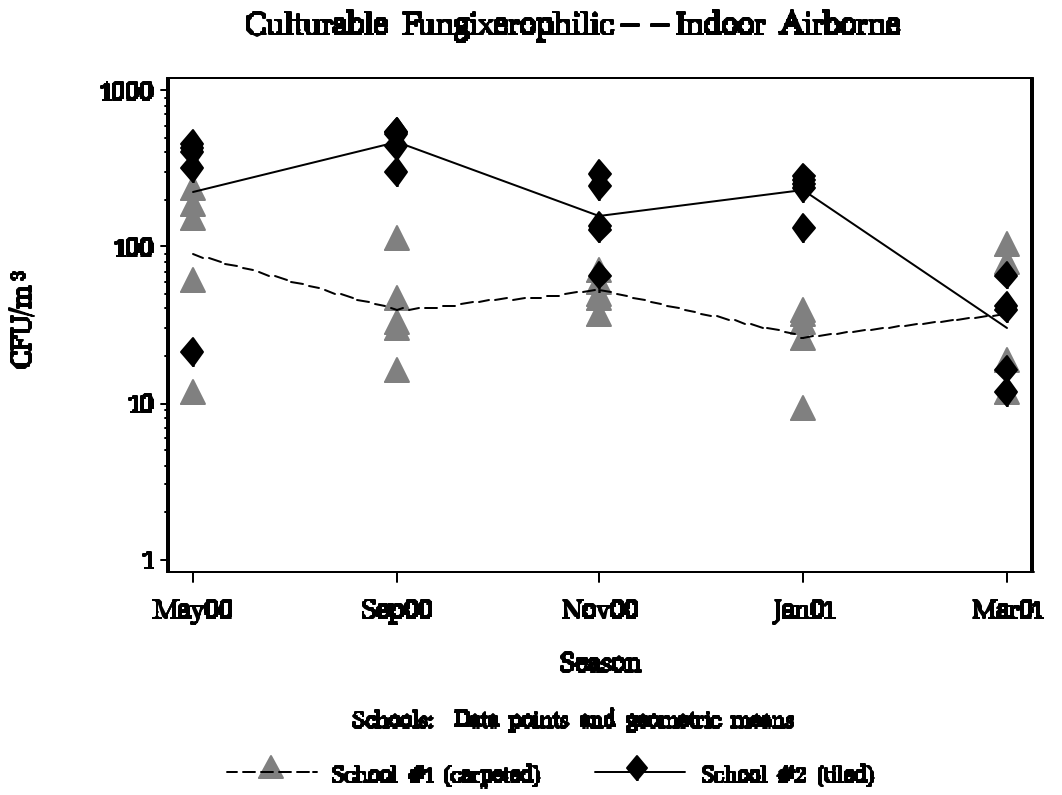
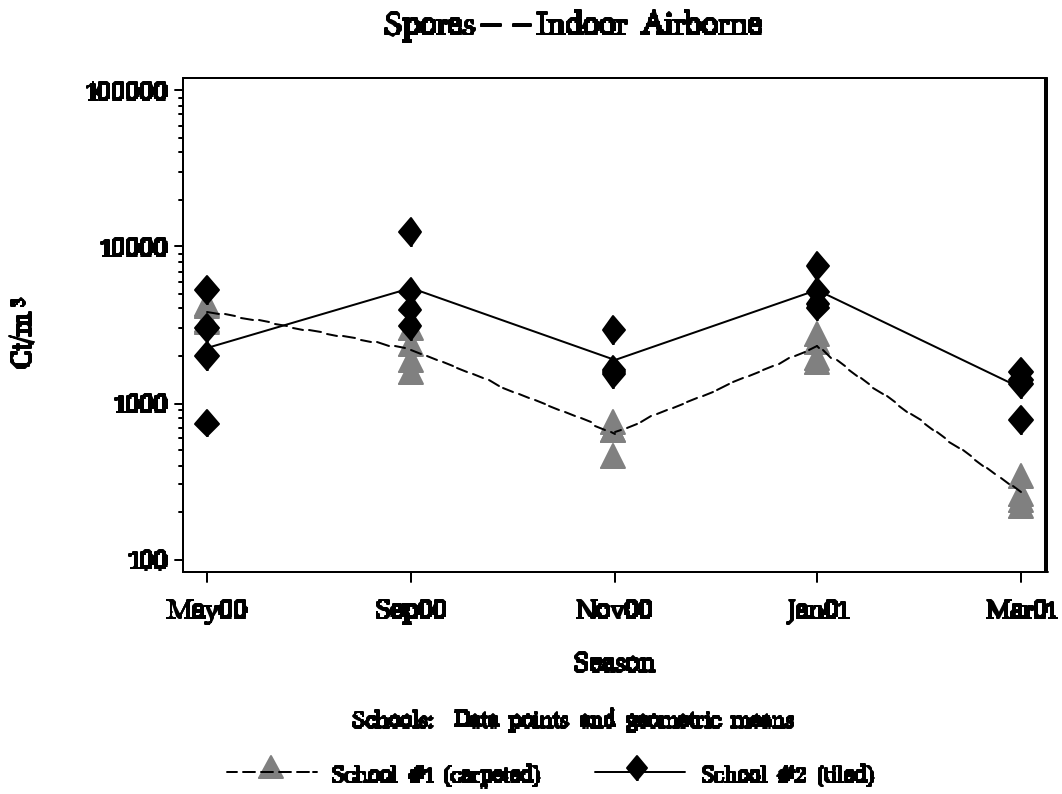
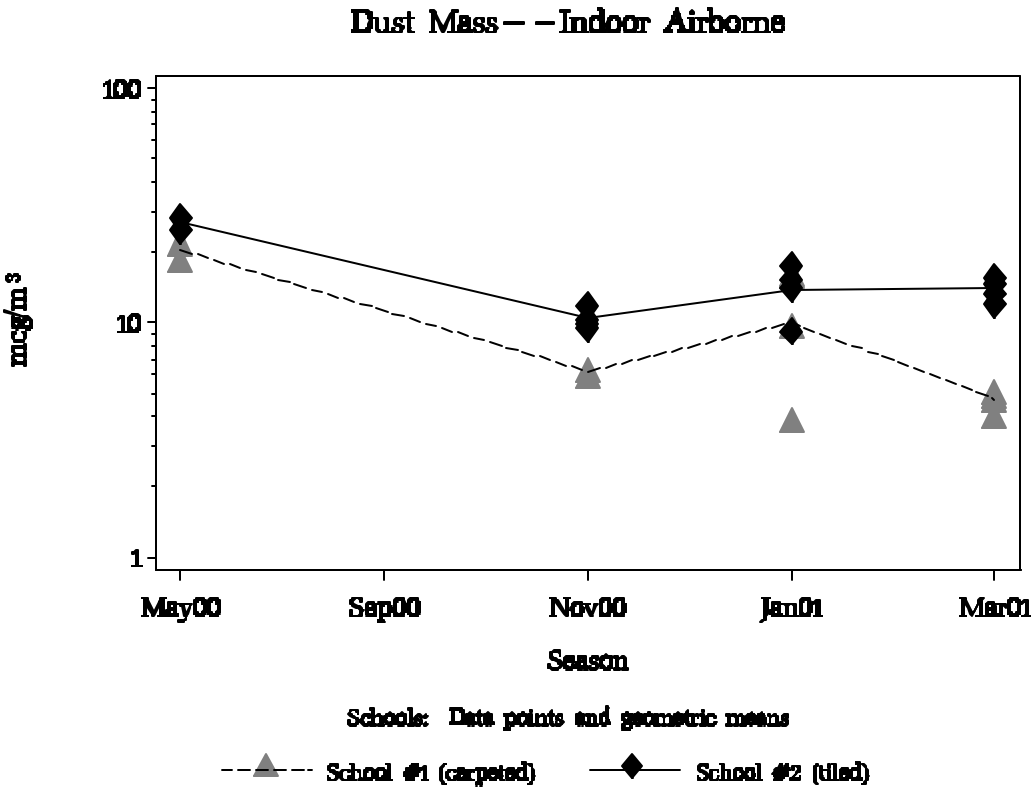
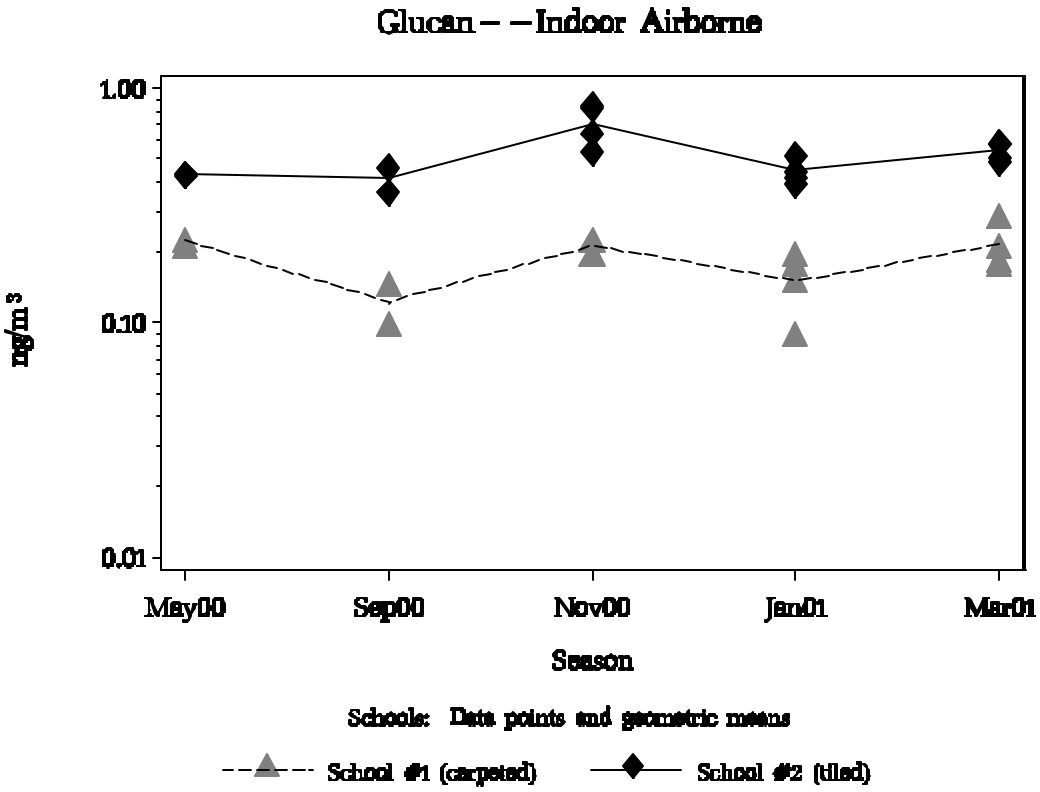
APPENDIX A

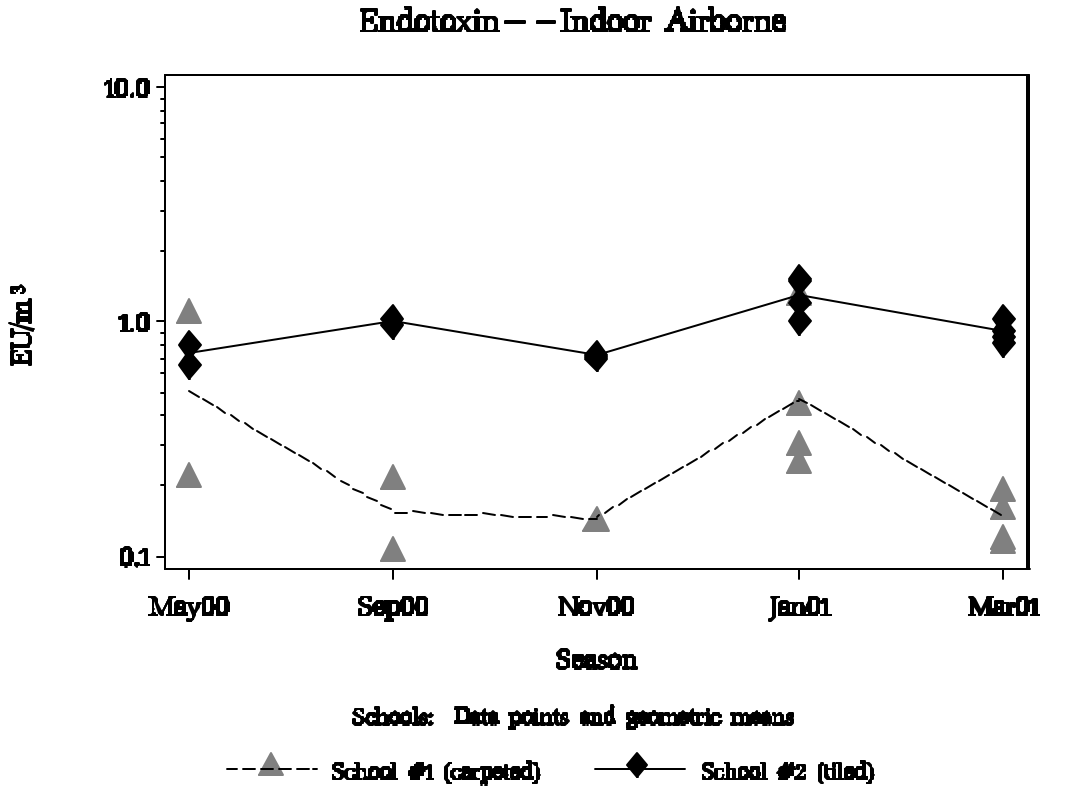
Graphs for the INDOOR Airborne Contaminant Results

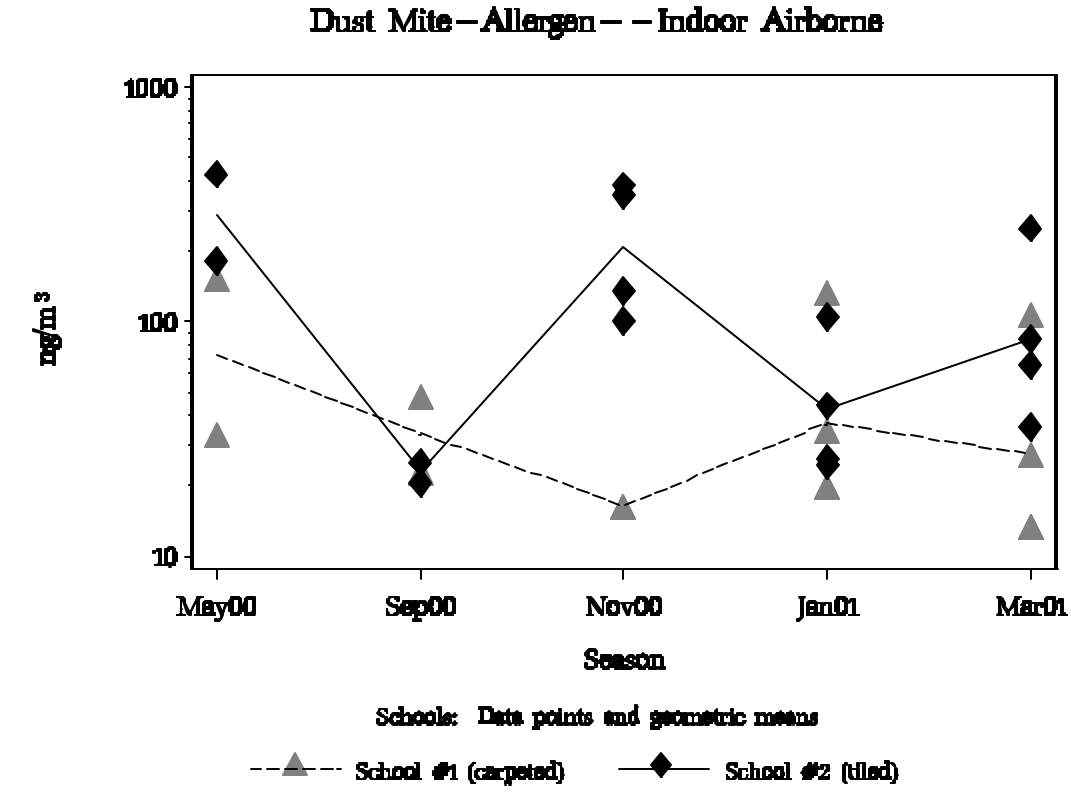


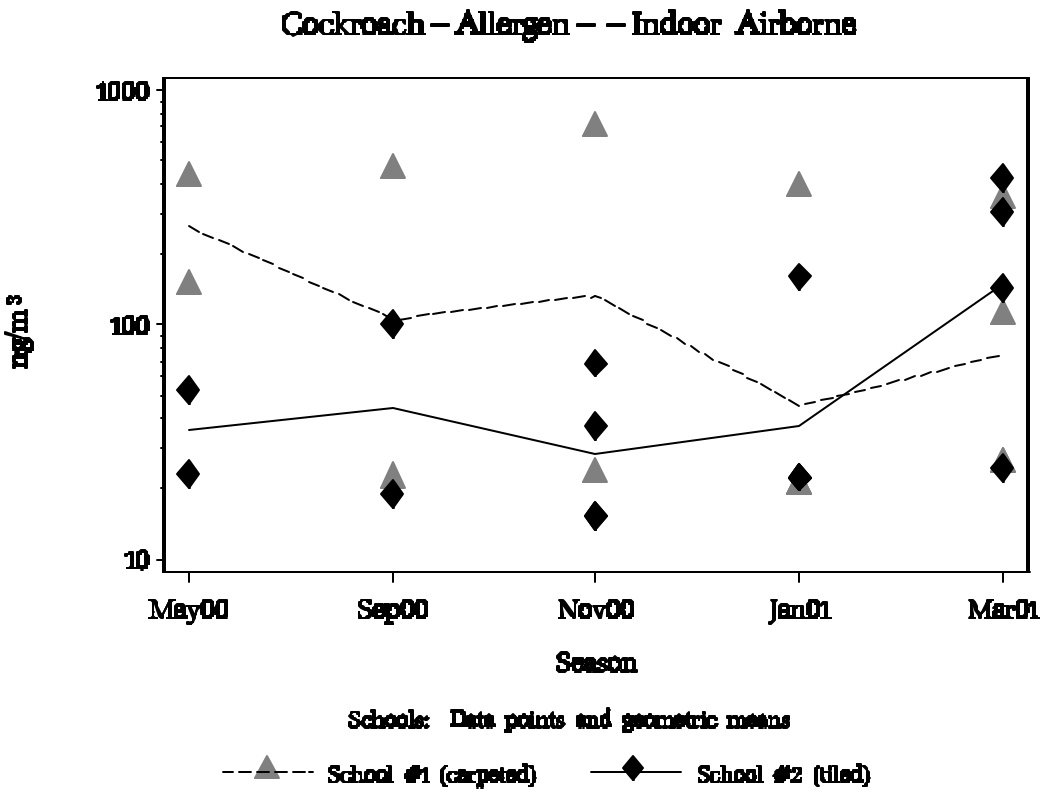


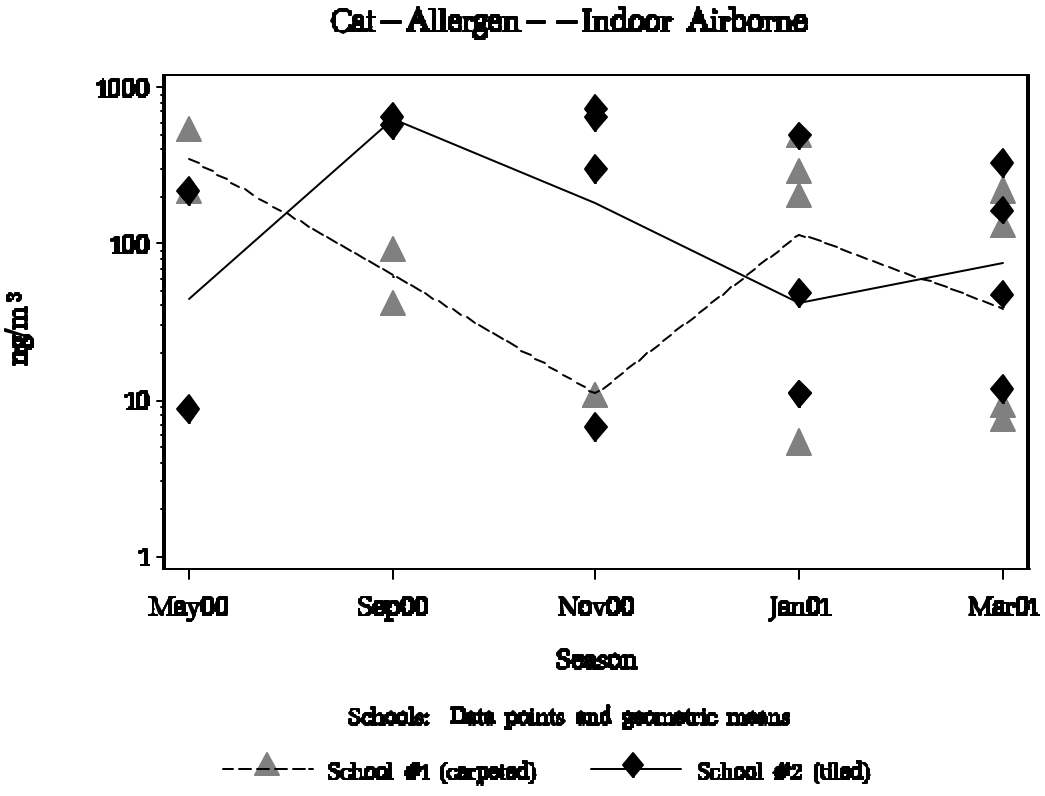

Dust Mass--Indoor Airborne
100
10
1
mcg/m3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)


Glucan--Indoor Airborne
1.00
0.10
0.01
ng/m3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)


Endotoxin – –Indoor Airborne
10.0
1.0
0.1
EU/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

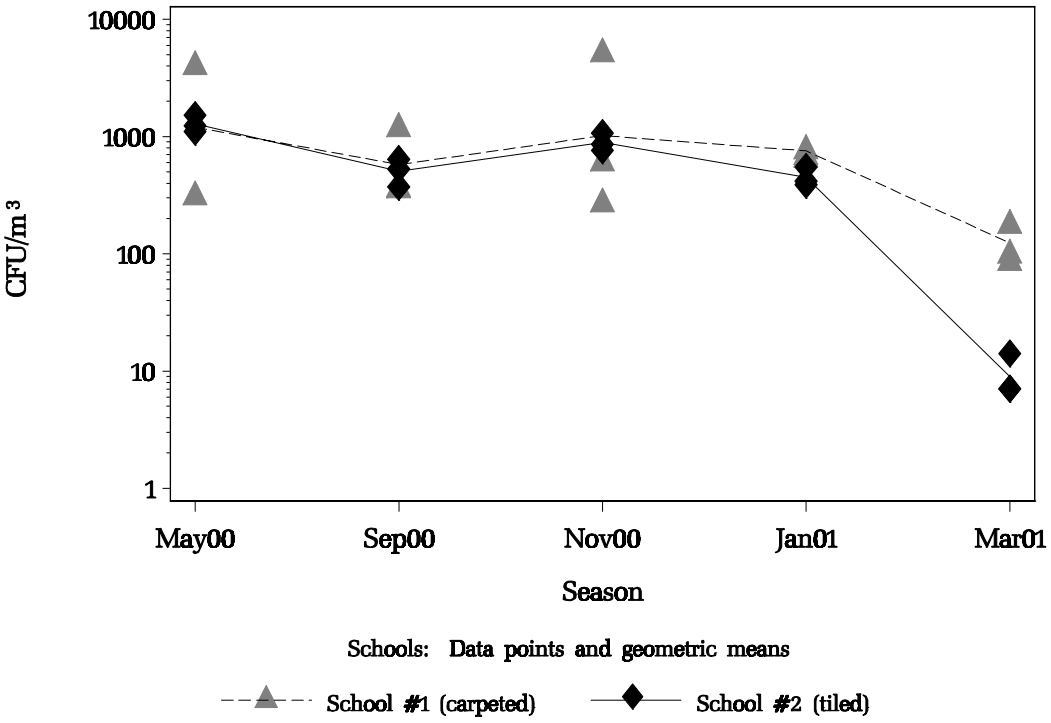

Dust Mite–Allergen – –Indoor Airborne
1000
100
10
ng/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)


Cockroach – Allergen – – Indoor Airborne
1000
100
10
ng/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

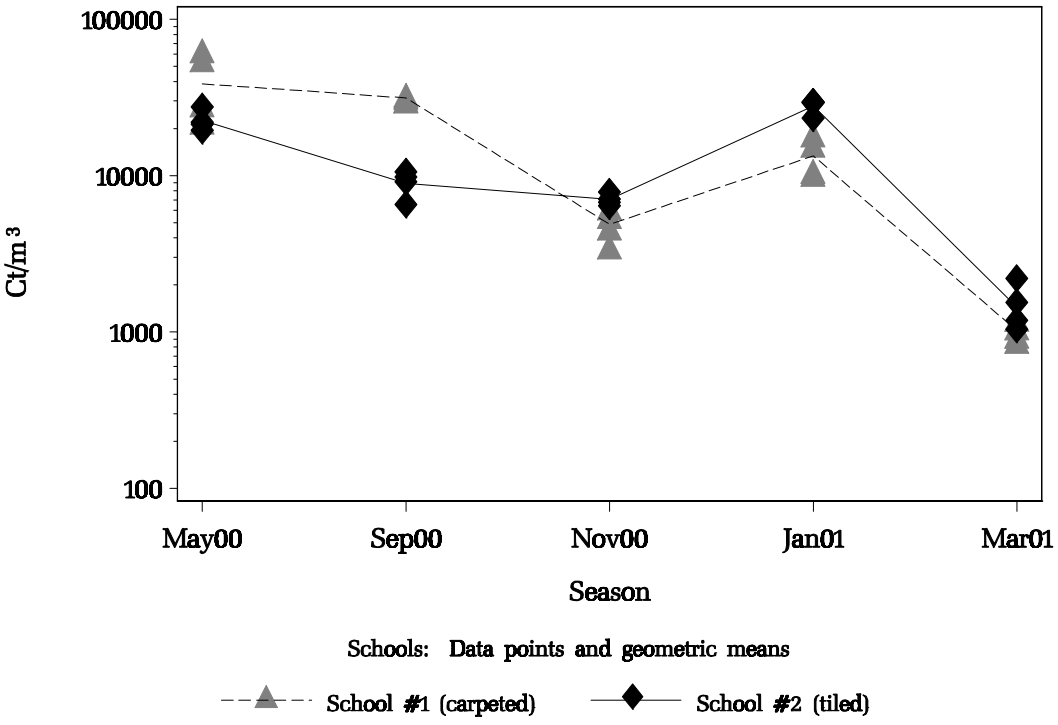

Cat – Allergen – – Indoor Airborne
1000
100
10
1
ng/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

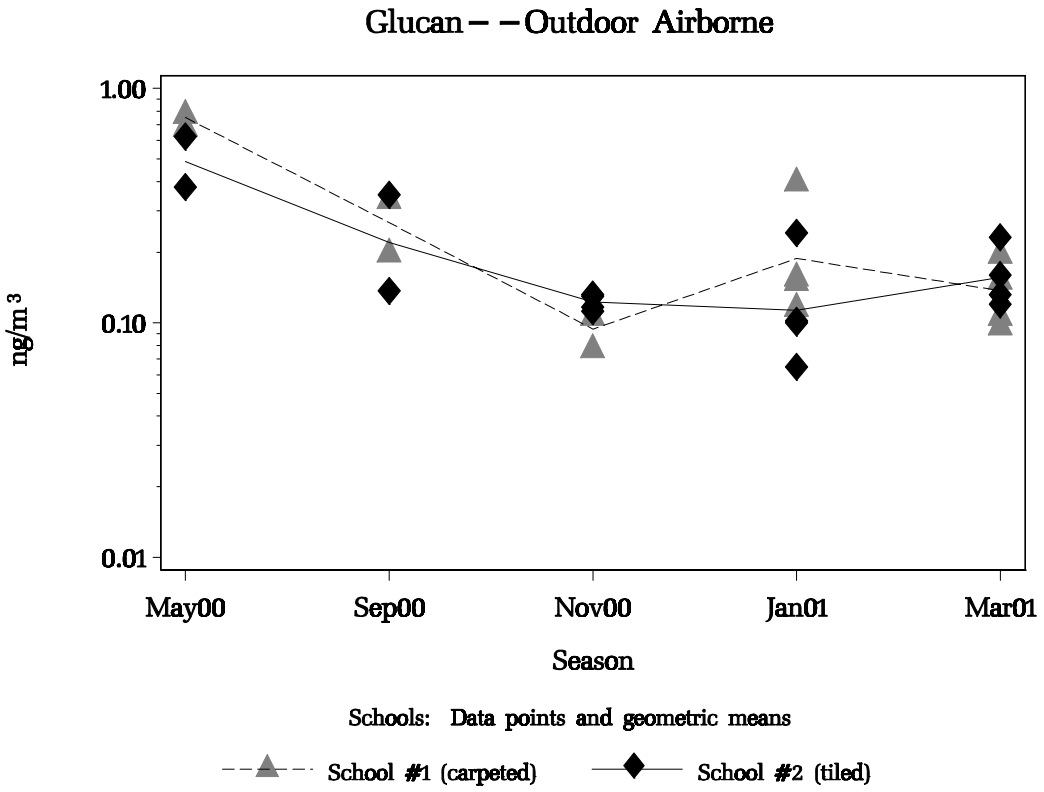
Graphs of OUTDOOR Airborne Contaminant Results

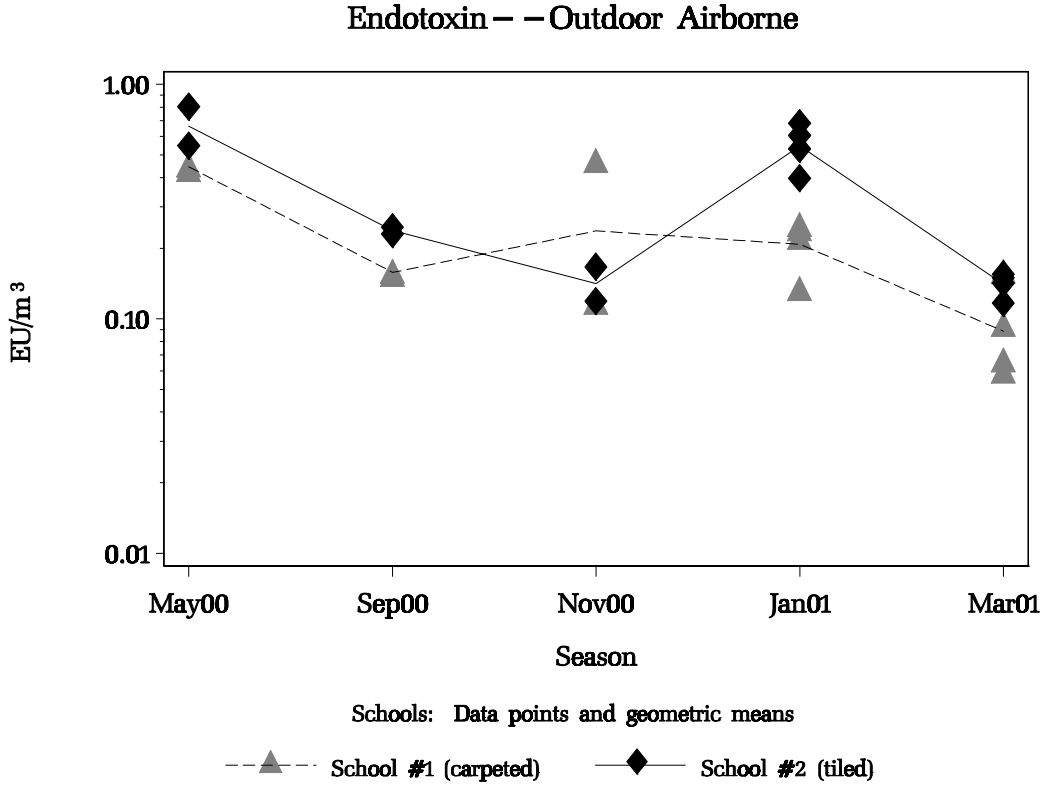
Culturable Fungixerophilic – –Outdoor Airborne

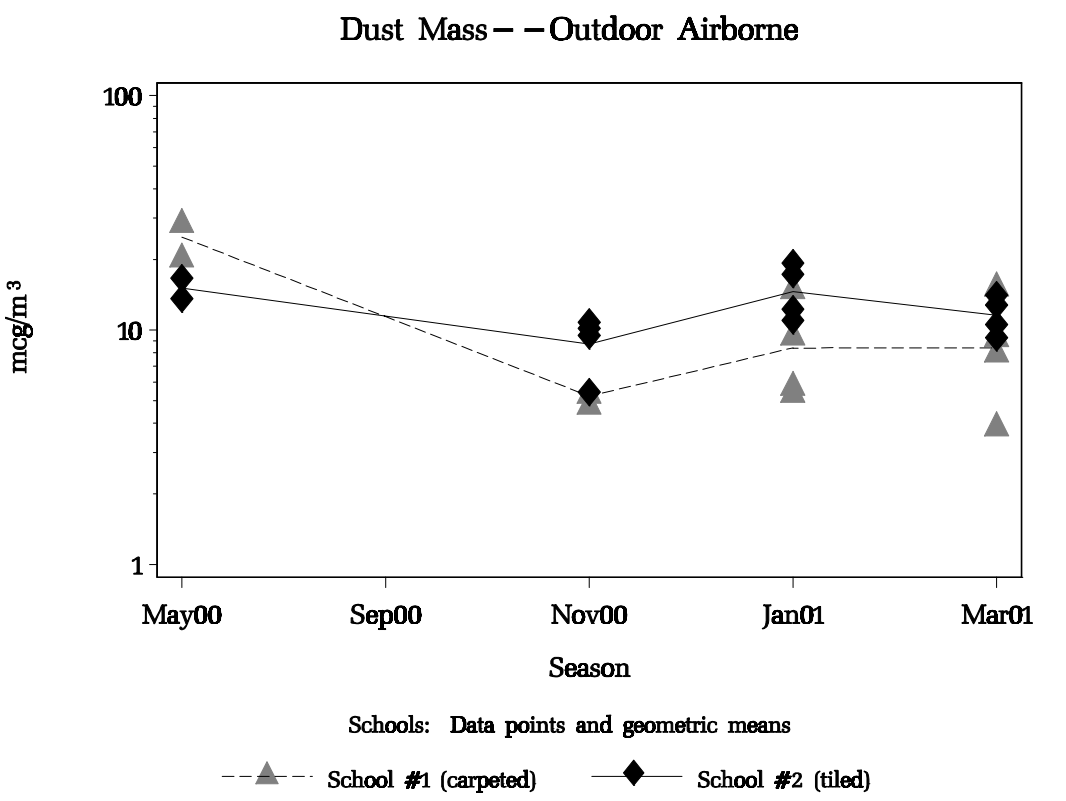


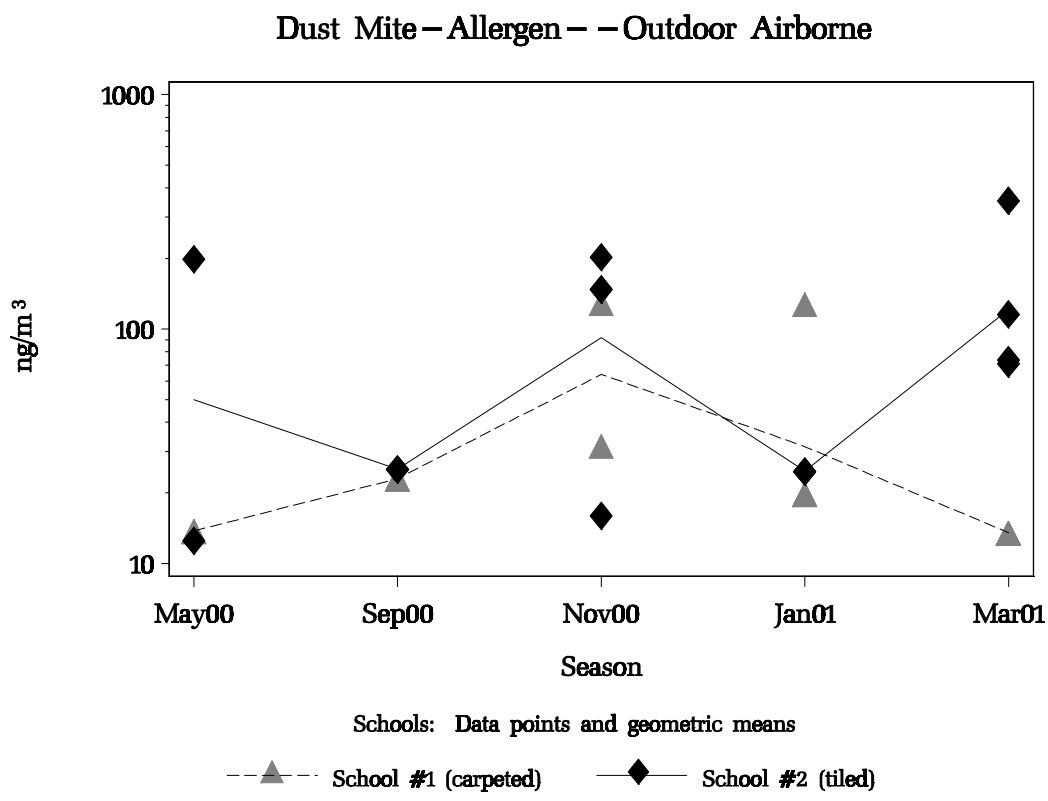
Spores – –Outdoor Airborne

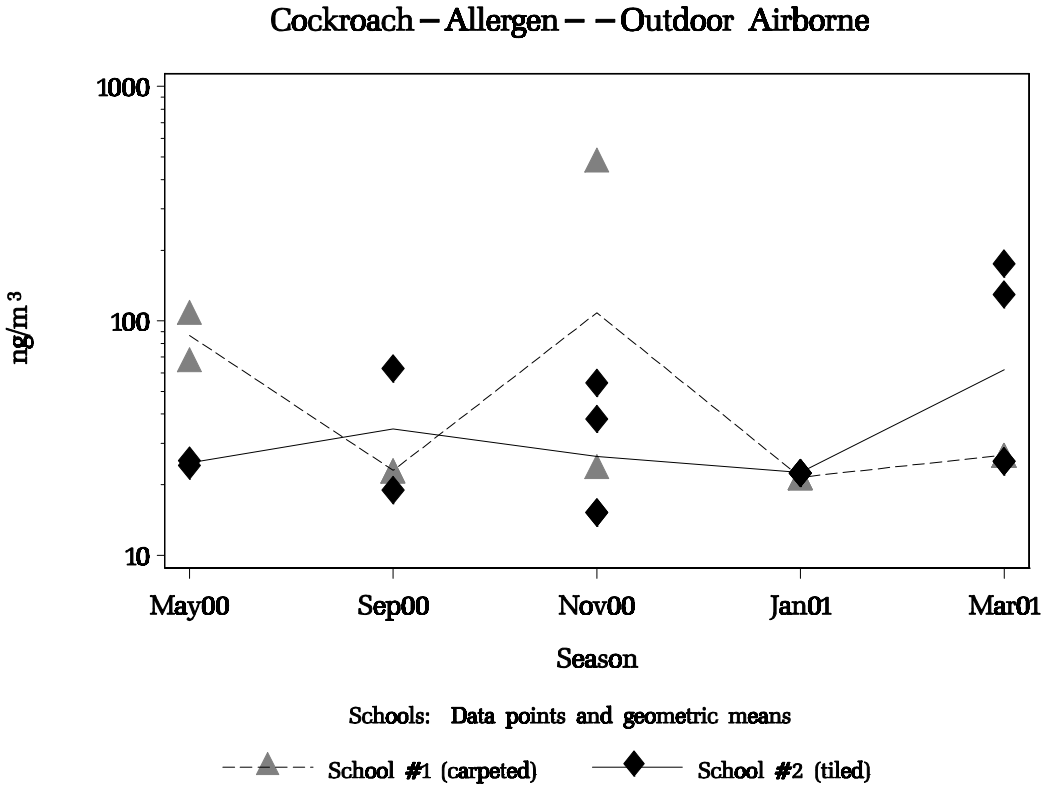


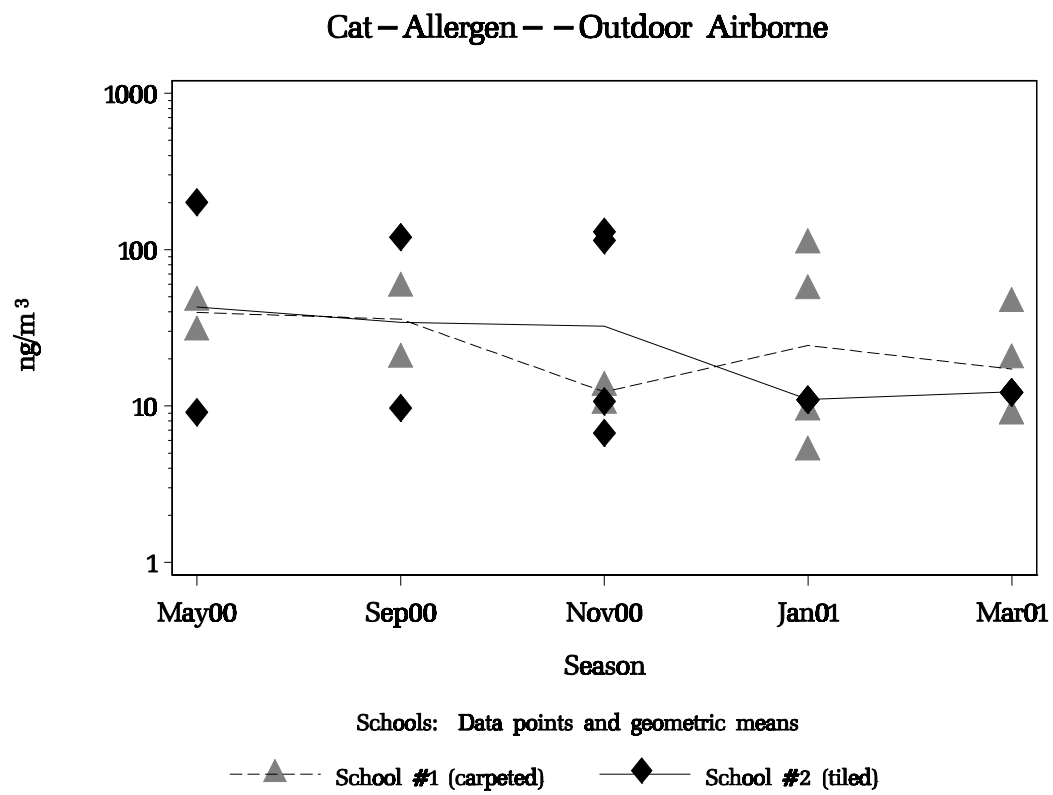

Glucan – –Outdoor Airborne
1.00
0.10
0.01
ng/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)


Endotoxin – –Outdoor Airborne
1.00
0.10
0.01
EU/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

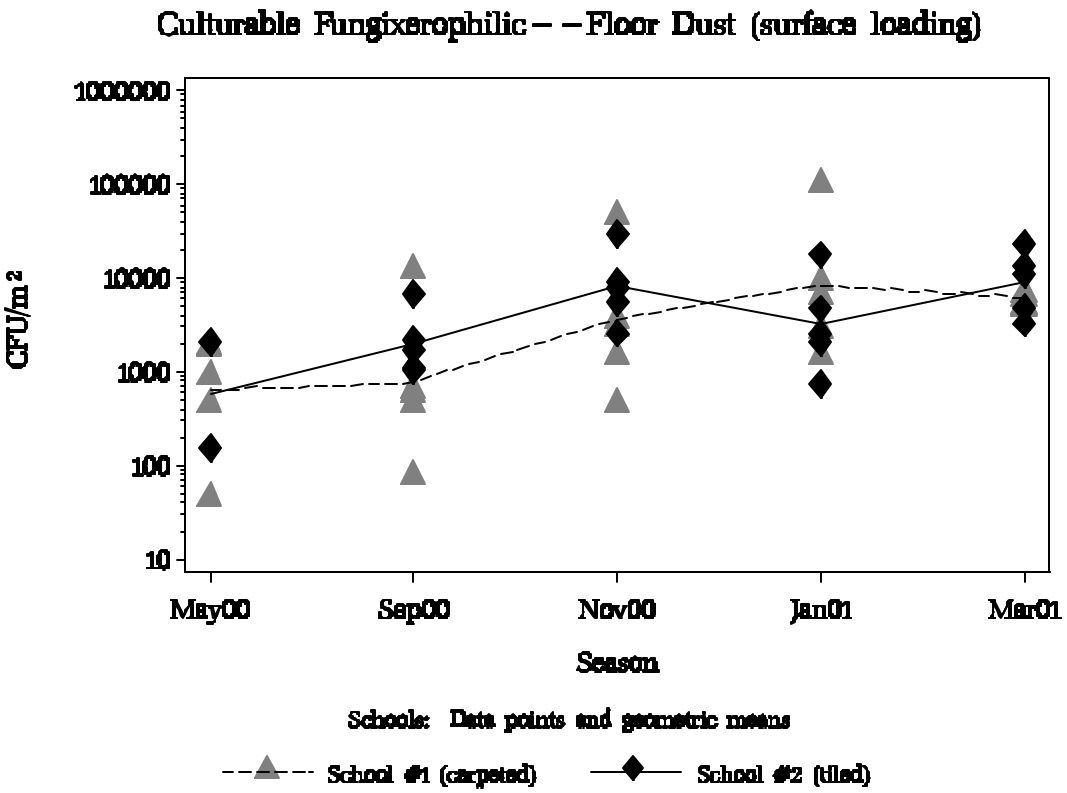

Dust Mass – –Outdoor Airborne
100
10
1
mcg/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

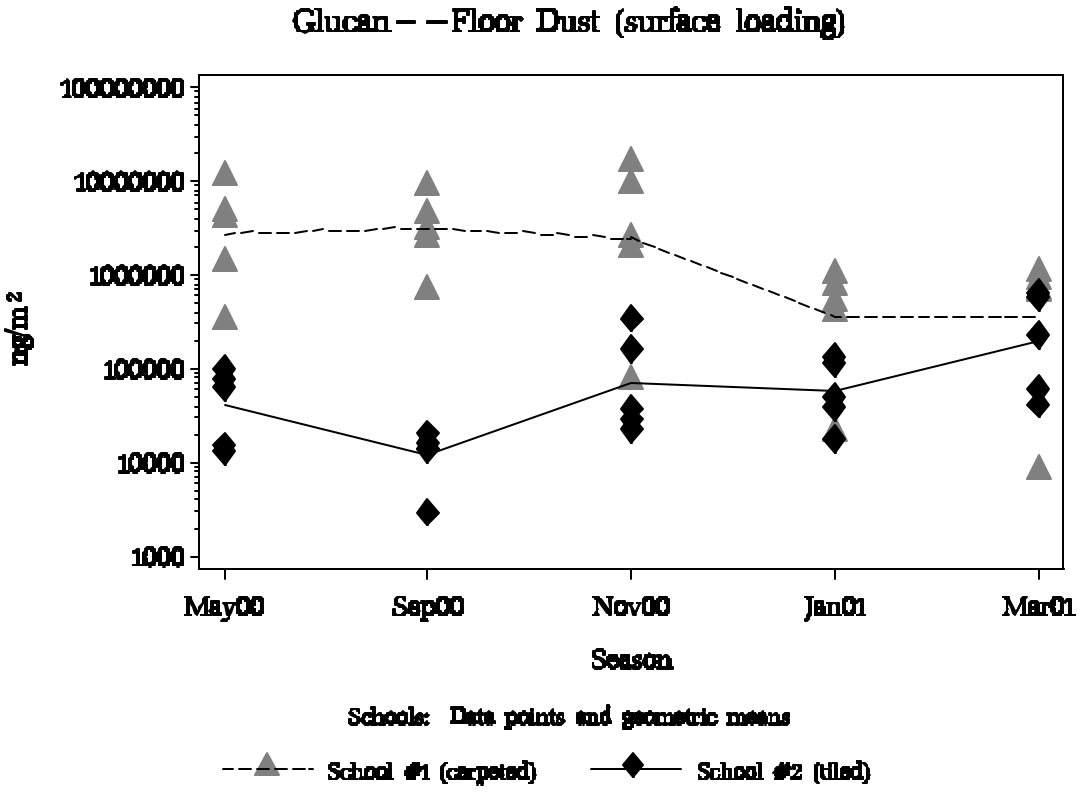

Dust Mite – Allergen – –Outdoor Airborne
1000
100
10
ng/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

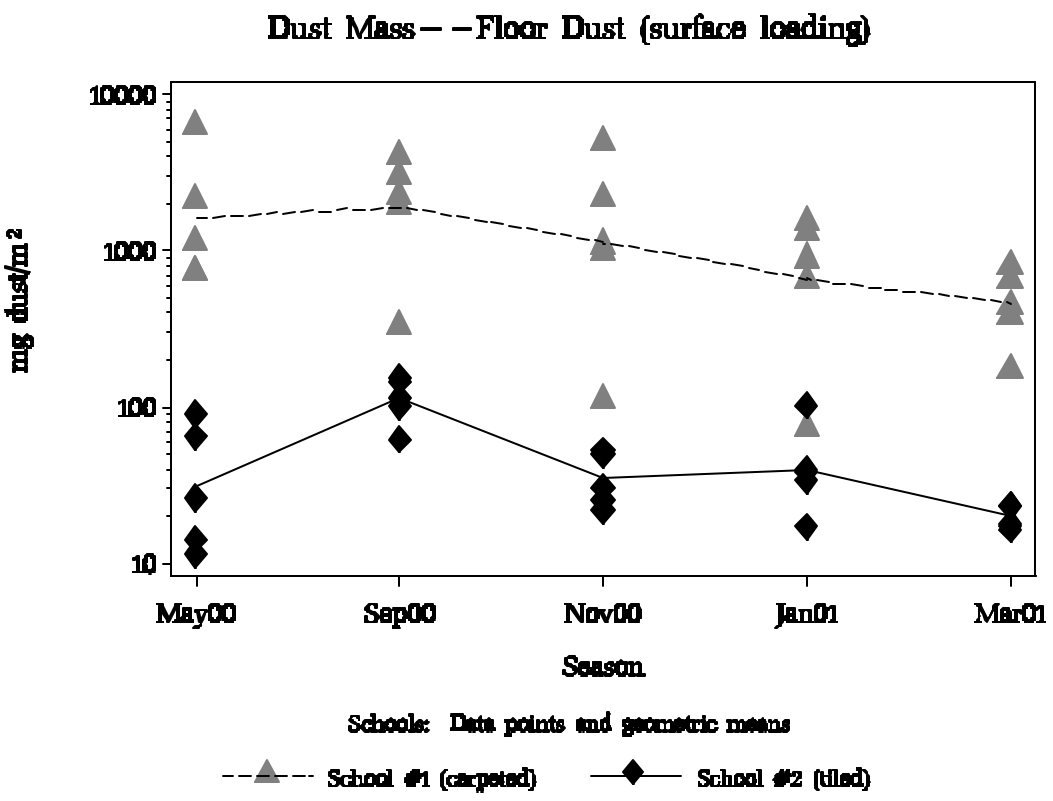

Cockroach – Allergen – – Outdoor Airborne
1000
100
10
ng/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

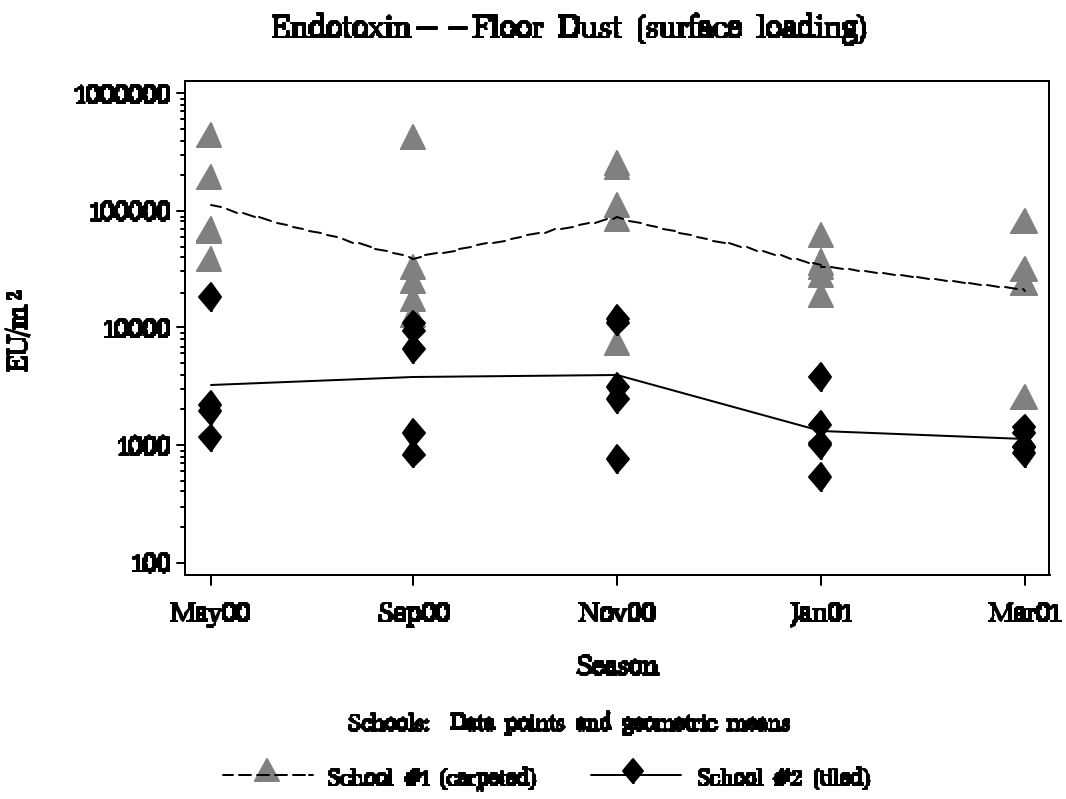

Cat – Allergen – – Outdoor Airborne
1000
100
10
1
ng/m 3
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

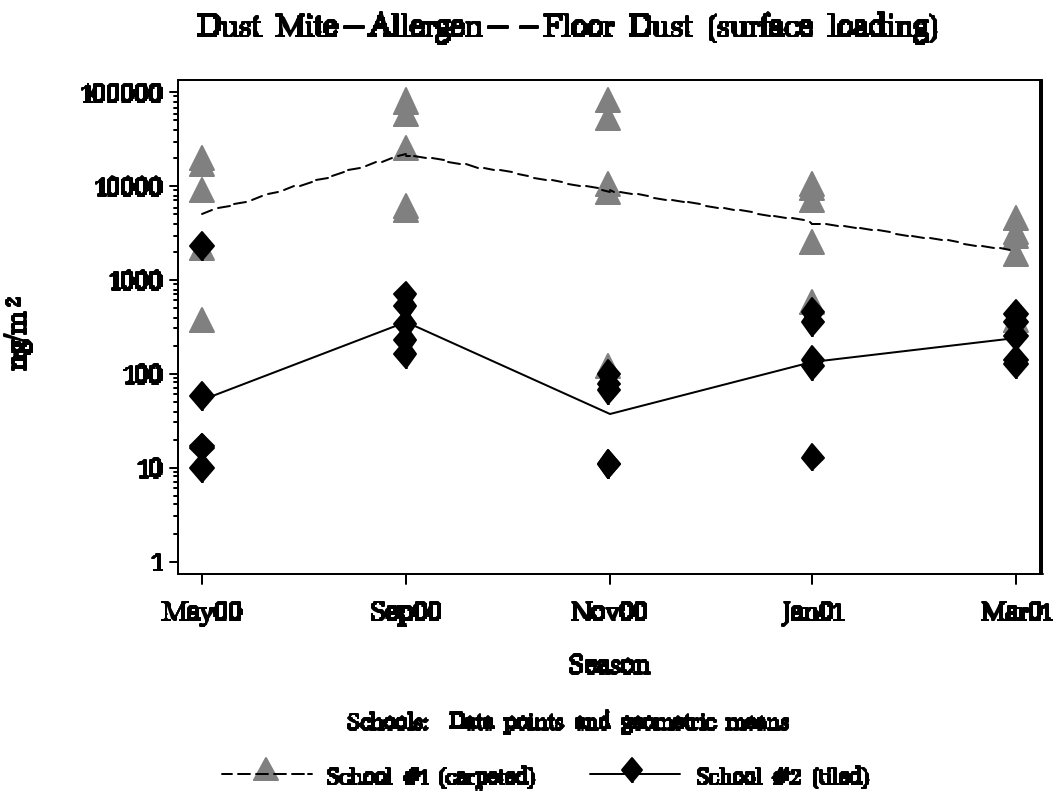
Graphs for Floor Dust (SURFACE LOADING)

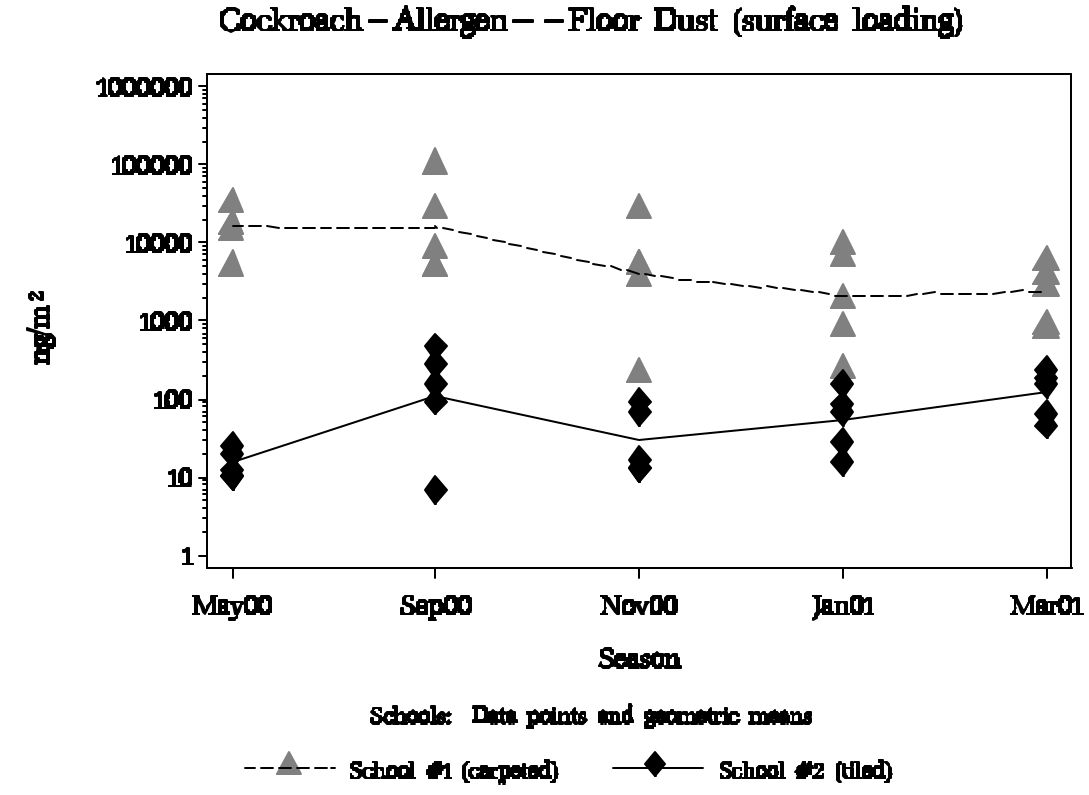


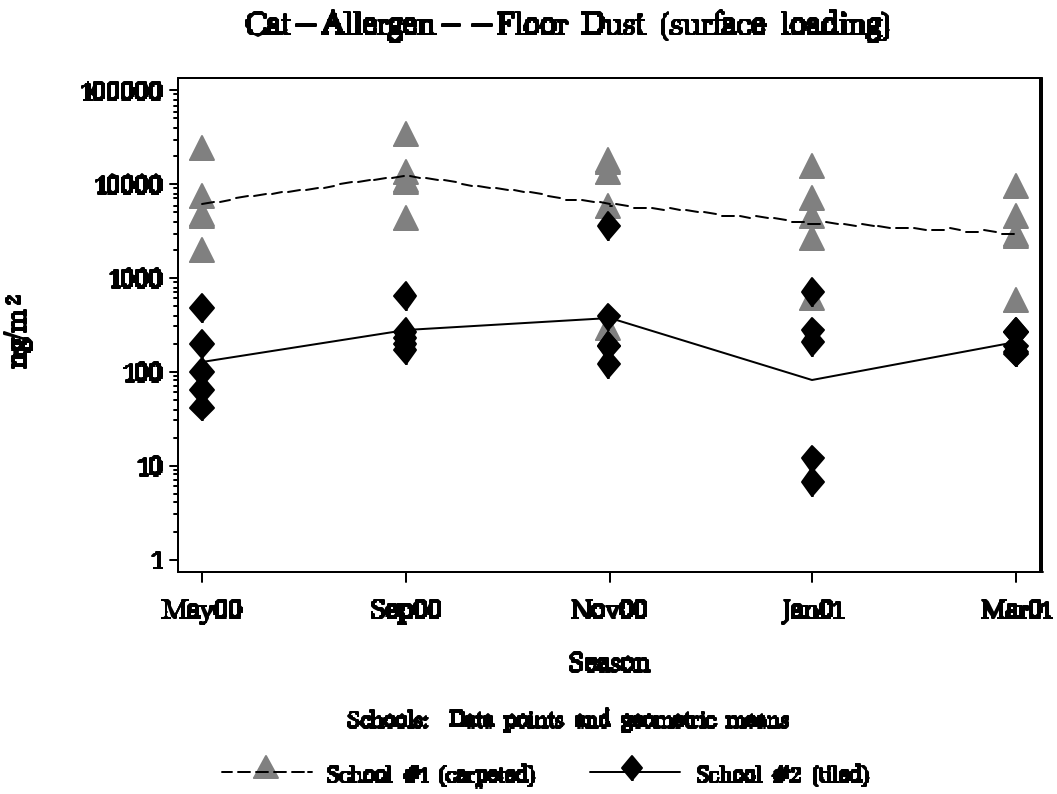



Dust Mass--Floor Dust (surface loading)
10000
1000
100
10
mg dust/m²
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

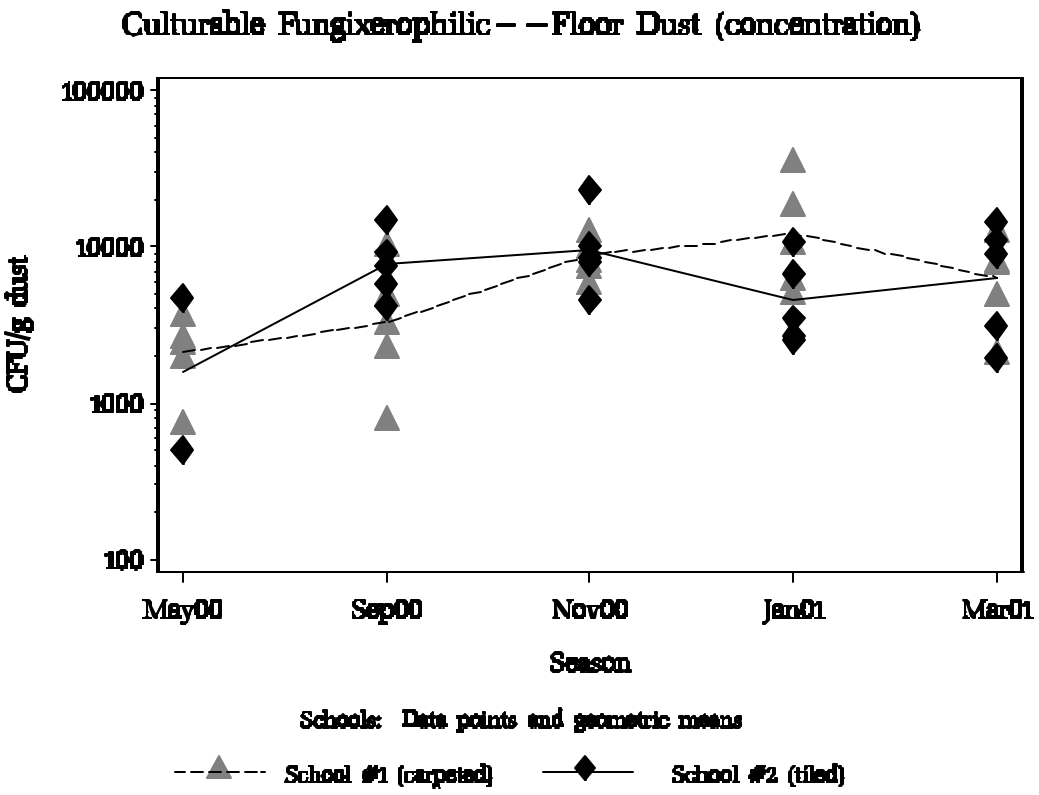

Endotoxin--Floor Dust (surface loading)
1000000
100000
10000
1000
100
EU/m²
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

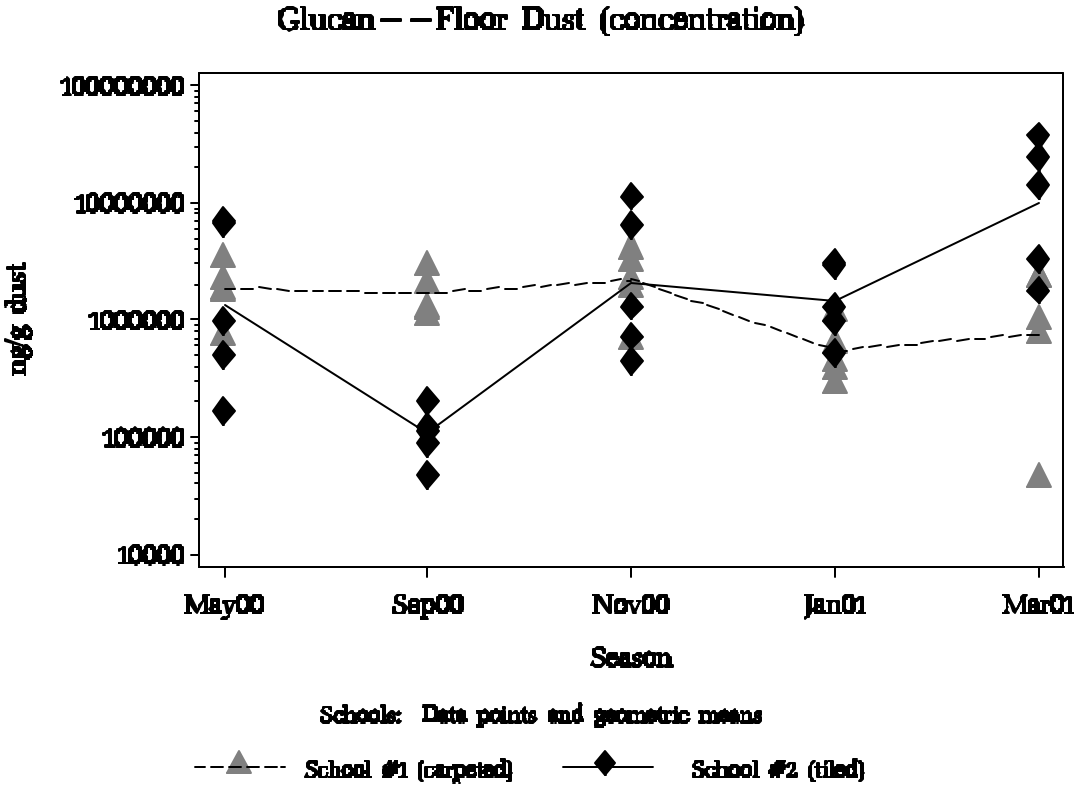

Dust Mite – Allergen – – Floor Dust (surface loading)
100000
10000
1000
100
10
1
ng/m 2
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

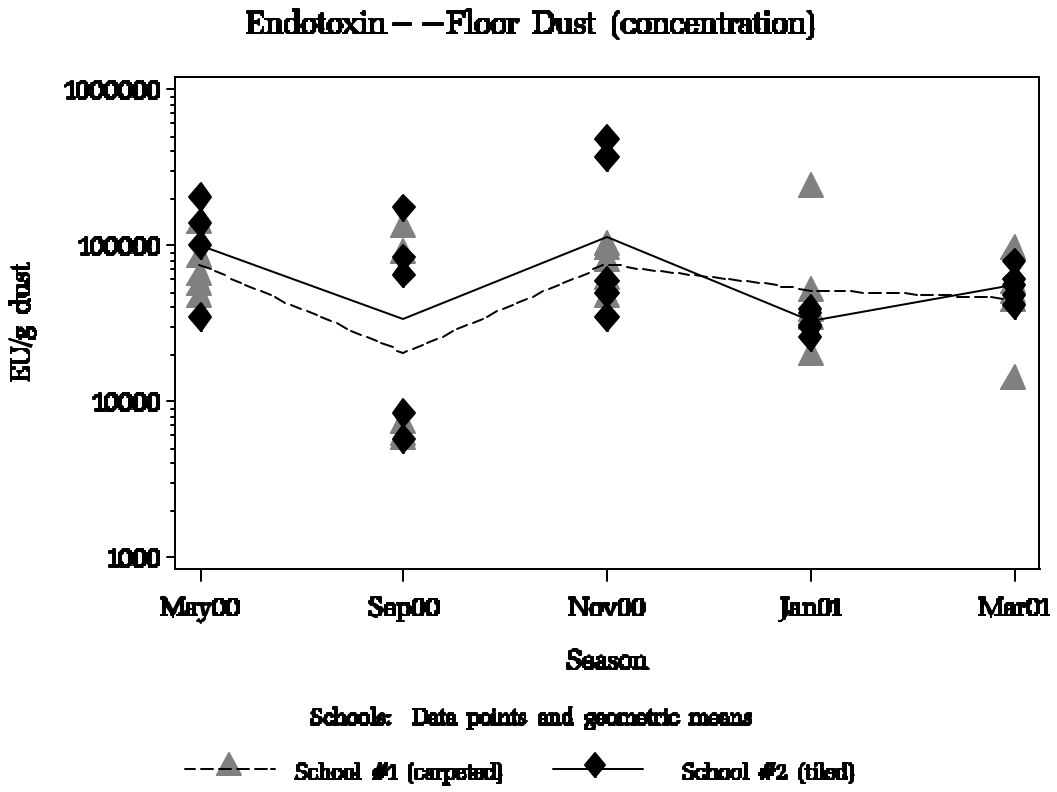

Cockroach – Allergen – – Floor Dust (surface loading)
1000000
100000
10000
1000
100
10
1
ng/m 2
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

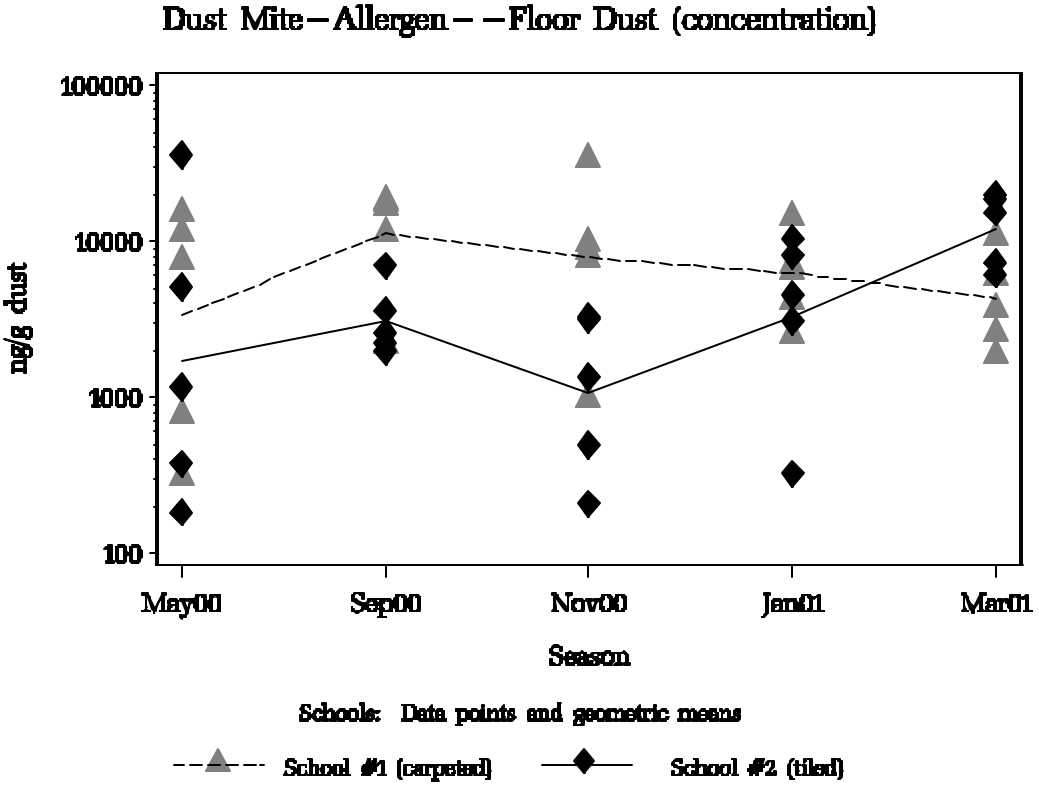

Cat−Allergen− −Floor Dust (surface loading)
100000
10000
1000
100
10
1
ng/m 2
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)

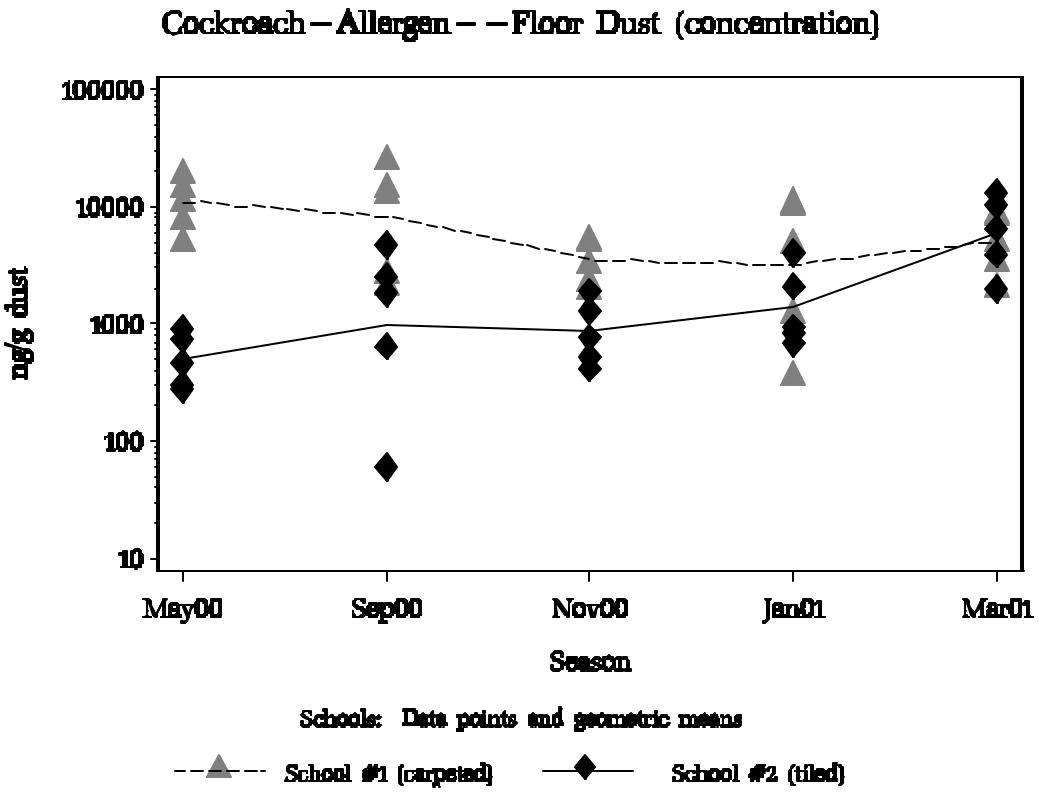
Graphs For Floors Dust (CONCENTRATION)

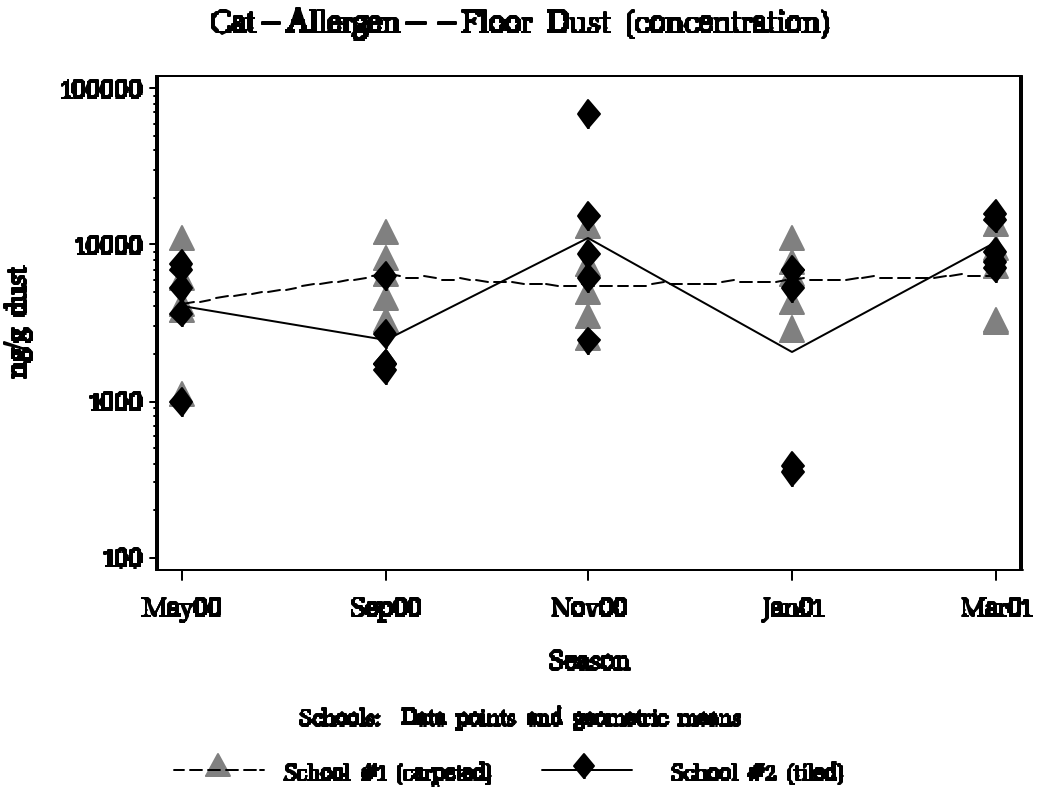





Endotoxin--Floor Dust (concentration)
1000000
100000
10000
1000
EU/g dust
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)


Dust Mite-Allergen--Floor Dust (concentration)
100000
10000
1000
100
ng/g dust
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)


Cockroach – Allergen – – Floor Dust (concentration)
100000
10000
1000
100
10
ng/g dust
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)


Cat – Allergen – – Floor Dust (concentration)
100000
10000
1000
100
ng/g dust
May00
Sep00
Nov00
Jan01
Mar01
Season
Schools: Data points and geometric means
School #1 (carpeted)
School #2 (tiled)