ELSEVIER

Aerobiologia 11 (1995) 27–34

Aerobiologia
International Journal of Aerobiology

Indoor air quality in schools: exposure to fungal allergens

Estelle Levetin*[a], Richard Shaughnessy[b], Eugene Fisher[c], Bryan Ligman[c], Jed Harrison[d], Terry Brennan[e]

[a]*Faculty of Biological Science, University of Tulsa, Tulsa, OK 74104, USA*
[b]*Department of Chemical Engineering, University of Tulsa, Tulsa, OK 74104, USA*
[c]*U.S. Environmental Protection Agency, Office of Radiation and Indoor Air Programs, Washington, DC 20460, USA*
[d]*U.S. Environmental Protection Agency, Office of Radiation and Indoor Air Programs, Las Vegas, Nevada, USA*
[e]*Camroden Associates, Oriskany, New York 13424, USA*

Received 24 June 1994; accepted 11 August 1994

Abstract

This study examined indoor air quality within schools in Kansas City, Spokane, Santa Fe, and Orlando. Air sampling was undertaken with both Andersen Single Stage Samplers and Burkard Personal Air Samplers. The data show a wide range of indoor exposures ranging from less than 100 colony forming units (CFU/m^3) for viable fungi and 100 spores/m^3 for total spores in Spokane and Santa Fe to concentrations over 6000 CFU/m^3 for viable fungi and 15 000 spores/m^3 for total fungi in Orlando and Kansas City, respectively. In the majority of sites the indoor airspora reflected the outdoor taxa with *Cladosporium* the most abundant genus identified; however, several indoor locations had elevated levels of *Penicillium* and *Aspergillus* indicating possible sources of indoor contamination. Airborne basidiospores and smut spores were also fairly abundant in the schools and were among the top five taxa identified. The data also indicated that the airborne concentrations vary significantly during the day and between classrooms within each school. Continued studies in schools are needed to fully assess both the exposure levels and the clinical significance to atopic children allergic to these spores.

Keywords: Aeroallergens; Fungal allergens; Bioaerosols; Indoor aerobiology; Schools; Basidiospores; Smut spores

1. Introduction

Airborne fungal spores have been widely recognized as major allergens capable of causing asthma and allergic rhinitis as well as other allergic diseases (Burge, 1989). The literature on the occurrence of airborne fungi in the home and workplace is extensive including some comprehensive reviews (Lacey and Crook, 1988; Hodgson and Morey, 1989; Burge, 1990; Lacey, 1991; Mishra et al., 1992). However, little is known about potential exposure levels to fungal spores in schools. Although children spend 25% of the day in the classroom, very few studies have specifically examined the air quality in this environment. Dungby et al. (1986) examined 10 elementary schools in Southern California. Fungi were isolated from all indoor sites examined; however, the authors concluded that schools were 'protected environments' for those children sensitive to airborne allergens.

The present study specifically examined school interiors in four separate areas of the United States: Kansas City, KS; Spokane, WA; Santa Fe, NM; and Orlando, FL. It was part of the U.S. Environmental Protection Agency's School Evaluation Project which is a continuing technological development designed to control radon levels in schools. As part of this project, total indoor air quality was assessed in a number of schools. This report focuses only on the bioaerosol measurements from these schools. Results from other parts of this project have been reported elsewhere (Shaughnessy et al., 1993).

2. Materials and methods

Air sampling was conducted in 13 school buildings from September 1991 through April 1992. Four school buildings were investigated in Kansas City (KC) during September 1991; three in Spokane (SP) during December 1991; four in Santa Fe (SF) in February 1992; and two schools in Orlando (OR) in April 1992 (Fig. 1).

* Corresponding author.

0393-5965/95/$09.50
SSDI 0393-5965(95)00109-Q

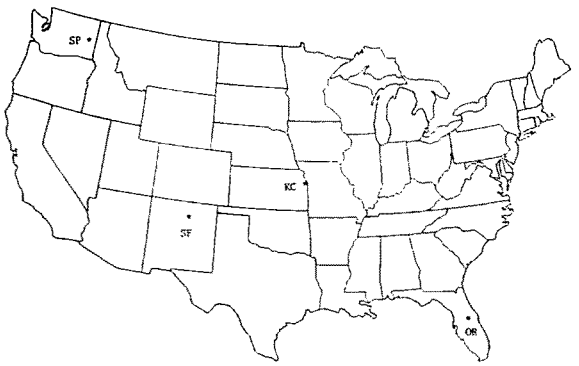

Fig. 1. Location of cities involved in this study.

Three of the SF school buildings were separate structures on one campus and are treated as separate schools in this report. The school facilities in this study ranged from old buildings in which heating was provided by boilers with no mechanical ventilation or cooling to modern buildings with central heating ventilation and air conditioning (HVAC) systems. In the former, open windows provided the only means of cooling or ventilation, while in the latter the windows were sealed, and the HVAC system was the only means of air exchange.

To assure an accurate representation of bioaerosols, data from both Burkard Personal Samplers and Single Stage (N-6) Andersen Samplers were used to analyze for total spores and viable or cultureable fungi, respectively. Burkard samples were collected for 5 or 10 min onto slides that were previously greased with a thin layer of Lubriseal (Thomas Scientific). Outdoor samples were collected for 5 min and indoors for 10 min; however, indoor sampling in the SF schools was decreased to 5 min due to the density of the sampling trace seen on the first few slides. Exposed slides were stained with glycerin-jelly and microscopically examined at $\times 1000$ to enumerate and identify the fungal spores. Counts were converted to concentrations and expressed as spores/m^3.

Air samples for viable fungi were collected for 1 min (outdoor samples) or 2 min (indoor samples) with Andersen Samplers onto Petri dishes containing malt extract agar. Dishes were sealed with Parafilm for transport to the laboratory and incubated for 5–7 days at room temperature (25 ± 1°C) under natural daylight supplemented with fluorescent light. Colonies were counted and identified microscopically. Those colonies which failed to form spores were allowed additional in-

Table 1
Mean concentration of total airborne fungal spores at selected schools in four cities

City and building	Number of indoor samples	Mean indoor concentration (spores/m^3)	Range	Mean outdoor concentration (spores/m^3)
Kansas City — September 1991				
KC #1	18	3133	1444–5470	65 539
KC #2	4[a]	3764	389–8110	26 609
KC #3	2[a]	9999	4888–15 110	31 108
KC #4	20	6061	2666–12 823	25 162
Average for city		5157		39 603
Spokane — December 1991				
SP #1	10	458	0–1778	148
SP #2	14	1287	56–2889	1184
SP #3	12	963	111–2722	296
Average for city		969		543
Santa Fe — February 1992				
SF #1	9	503[b]	59–1882	177
SF #2	9	288[b]	0–588	39
SF #3	9	295[b]	118–588	79
SF #4	9	392	0–706	39
Average for city		369		98
Orlando — April 1992				
OR #1	12	1541	944–2706[c]	4860
OR #2	13	4039	1889–8214	23 627
Average for city		2810		14 244

[a]Additional samples were collected but there was too much dust to count.
[b]The amount of dust present on all indoor Santa Fe samples obscured spores resulting in an underestimate of total spores.
[c]Heavy deposits of dust on several of the slides from OR-1 may have resulted in an underestimate of the total spores.

cubation time and re-examined after 2 and 3 weeks. Results from these cultures were expressed as colony forming units per cubic meter (CFU/m^3).

Generally, each building was sampled on one day with samples collected three times during the day at 3–7 sites within each building as well as outdoors. Both indoor and outdoor samples were collected in the morning, mid-day, and late afternoon. Indoor data from both types of samplers were compared to those from the outdoor reference samples.

3. Results

A total of 183 (145 indoors and 38 outdoors) slides from Burkard Samplers and 195 (154 indoors and 41 outdoors) culture plates from Andersen Samplers were analyzed. The difference between the total Andersen and Burkard samples reflects some duplicate Andersen samples collected in the KC schools. Airborne fungi were present in all locations with the highest concentrations in KC and OR, and the lowest in SP and SF (Tables 1,2). In general, the indoor concentrations and taxa in each city reflected outdoor levels and types; however, specific indoor contamination was found in several locations. Space does not permit enumerating all the fungi found at each school; however, the most abundant taxa or taxonomic groups in each city are listed in Tables 3,4. The average outdoor concentrations of these fungi are also shown. Those fungi responsible for indoor contamination are evident when the indoor and outdoor levels are compared.

In the majority of viable and total spore samples, *Cladosporium* was the most abundant genus identified during this study. On the slides from Burkard Samplers used for assessing total spore concentrations, both basidiospores and smut spores were fairly abundant in the indoor samples. Although all basidiospores were counted as a group, the genera identified include *Coprinus, Ganoderma, Scleroderma*, and *Agaricus*. No attempt was made to identify the smut spores to genus level. The concentrations of both spore types were greatest in KC and OR; however, they were present in all schools and ranked among the top five taxa or taxonomic groups identified in each city (Table 3). The mean concentrations of these spores in the individual schools are shown in Table 5.

Among the major taxa identified during viable sampling were *Penicillium* and *Aspergillus*. *Penicillium* was among the top five fungi in all the cities, while *Aspergillus* was among the top in Santa Fe and Orlando. The average concentrations of these taxa in each building are shown in Table 6.

Because of the geographic and climatic differences and the differences in the ventilation systems employed, there are major distinctions in the indoor air spora at the schools. Even within each school, variations were found among the different classrooms and also within one room at different times of the day.

Table 2
Mean concentrations of viable airborne fungi at selected schools in four cities

City and building	Number of indoor samples	Mean indoor concentration (CFU/m^3)	Range	Mean outdoor concentration (CFU/m^3)
Kansas City — September 1991				
KC #1	18	494	152–1409	6267
KC #2	12	2100	136–4969	10 196
KC #3	4	2087	1667–2712	5545
KC #4	24	1009	197–2166	8186
Average for city		1124		7700
Spokane — December 1991				
SP #1	10	56	16–109	234
SP #2	14	189	16–531	406
SP #3	12	123	16–281	188
Average for city		130		276
Santa Fe — February 1992				
SF #1	9	119	50–350	178
SF #2	9	624	17–4134	83
SF #3	9	419	150–1069	44
SF #4	9	244	27–884	83
Average for city		352		104
Orlando — April 1992				
OR #1	12	628	76–2970	3192
OR #2	12	1756	515–6454	15 761
Average for city		1119		9476

Table 3
Mean concentrations of fungal taxa or taxonomic groups most frequently isolated during total spore sampling at schools in four cities

Taxa	Mean indoor concentration (spores/m^3)	Range	Mean outdoor concentration (spores/m^3)
Kansas City			
Cladosporium	2839	222–10 443	24 736
Basidiospores	246	0–944	2094
Penicillium/Aspergillus	211	0–765	398
Smut spores	195	0–706	2816
Alternaria	157	0–889	1622
Spokane			
Cladosporium	344	0–1555	321
Penicillium/Aspergillus	73	0–556	37
Smut spores	56	0–500	25
Basidiospores	43	0–333	49
Periconia	28	0–444	0
Santa Fe[a]			
Cladosporium	92	0–588	25
Aureobasidium	45	0–823	0
Basidiospores	38	0–470	5
Smut spores	32	0–118	0
Penicillium/Aspergillus	14	0–118	0
Orlando			
Cladosporium	1152	111–4444	7385
Basidiospores	201	0–667	393
Smut spores	108	0–444	297
Penicillium/Aspergillus	105	0–556	298
Curvularia	89	0–333	353

[a]Indoor Santa Fe samples were overloaded with dust such that the concentrations underestimate the spore load.

3.1. Kansas City

Outdoor bioaerosol concentrations were high when the sampling was undertaken in the KC schools. The maximum outdoor concentration of total spores was 81 172 spores/m^3 while the maximum outdoor concentration for viable airborne fungi was 19 968 CFU/m^3. Indoors, concentrations varied considerably from a low of 389 spores/m^3 to a high of 15 110 spores/m^3 for total airborne spores and from 136 to 4969 CFU/m^3 for viable airborne fungi levels (Tables 1,2). The concentrations depended, in part, on the type of heating and ventilation systems present.

At KC-1, a tight building with a central HVAC system, indoor concentrations of airborne fungi had the lowest average for the buildings sampled in Kansas City and were generally less than 25% of outdoor levels. KC-2 was equipped with separate air handlers for each floor, and sampling data indicated far greater bioaerosol concentrations in the basement. Morning concentrations of viable fungi were approximately nine times greater in the basement than the first floor, and total spores were 17 times more abundant in the basement although most of the taxa were outdoor types. In KC-3, there was no central HVAC system, and the windows were operable but mainly closed on the day the building was sampled. Bioaerosols were up to 50% of outdoor levels. KC-4 was equipped with central heating and mechanical ventilation but no air conditioning. Windows were operable but the majority were closed when the investigators were in the building. Some sites had bioaerosol levels up to 33% of outdoor levels (Tables 1,2).

In KC-1 and KC-4, two schools with very different ventilation systems, basidiospores and smut spores were a remarkably consistent feature of the air spora occurring on 85–100% of the indoor samples. Concentrations up to 944 basidiospores/m^3 occurred in KC-1, a building with sealed windows, while in KC-4 with operable windows the peak was 765 basidiospores/m^3. In general, smut spore concentrations were not as high in KC-1, but they occurred in all the samples from KC-4 with a peak of 706 spores/m^3.

One unusual event occurred in KC-2 during the day samples were collected. A construction accident within the building resulted in the massive release of dust from a vacuum bag. Both Burkard and Andersen samples were collected following the mishap. The resulting Burkard slides were overloaded with dust and unreadable. On the Andersen plates, the *Penicillium* concentration averaged 1500 CFU/m^3, and constituted approximately 50–60% of the total number of colonies.

Table 4
Mean concentrations of fungal taxa or groups most frequently isolated during viable sampling at schools in four cities

Taxa	Mean indoor concentration (CFU/m^3)	Range	Mean outdoor concentration (CFU/m^3)
Kansas City			
Cladosporium	787	61–2354	7185
Penicillium	189	0–2931	15
Alternaria	70	0–266	678
Non-sporulating	22	0–112	27
Yeast	14	0–125	66
Spokane			
Cladosporium	47	0–243	149
Yeast	40	0–187	60
Non-sporulating	13	0–78	10
Aureobasidium	9	0–62	11
Penicillium	8	0–47	10
Santa Fe			
Yeast	102	0–896	32
Penicillium	94	0–2273	0
Aspergillus	83	0–1695	0
Cladosporium	27	0–350	7
Non-sporulating	26	0–102	18
Orlando			
Cladosporium	838	15–5809	8355
Aspergillus	115	0–2390	0
Penicillium	74	0–436	431
Non-sporulating	67	0–174	208
Yeast	66	0–323	321

3.2. Spokane

During the period of the investigation, the outdoor bioaerosol concentrations were low. The average outdoor value for viable airborne fungi was 276 CFU/m^3 and the maximum 750 CFU/m^3, while the average for total airborne spores was 543 spores/m^3 and the maximum 2664. Indoor concentrations were also relatively low, although several indoor locations had higher concentrations than outdoors. Mean levels were 130

Table 5
Mean concentrations of airborne basidiospores and smut teliospores at selected schools in four cities

City and building	Mean basidiospore concentration (spores/m^3)		Mean smut teliospore concentration (spores/m^3)	
	Indoor	Outdoor	Indoor	Outdoor
KC #1	325	5204	102	3576
KC #2	14	778	278	2111
KC #3	84	778	334	778
KC #4	238	450	276	3207
SP #1	17	0	45	0
SP #2	20	37	76	0
SP #3	93	111	46	74
SF #1	13[a]	0	13[a]	0
SF #2	39[a]	0	39[a]	0
SF #3	26[a]	0	46[a]	0
SF #4	74[a]	0	30[a]	0
OR #1	124	379	53	150
OR #2	273	407	158	444

[a]The amount of dust present on all indoor Santa Fe samples obscured spores resulting in an underestimate of total spores.

Table 6
Mean concentrations of airborne *Penicillium* and *Aspergillus* spp. at selected schools in four cities

City and building	Mean *Penicillium* concentration (CFU/m^3)		Mean *Aspergillus* concentration (CFU/m^3)	
	Indoor	Outdoor	Indoor	Outdoor
KC #1	45	12	10	16
KC #2	748	0	8	38
KC #3	44	0	4	0
KC #4	49	59	4	12
SP #1	0	10	0	0
SP #2	18	31	8	0
SP #3	3	0	0	0
SF #1	12	0	6	0
SF #2	260	0	199	0
SF #3	50	0	106	0
SF #4	55	0	19	0
OR #1	49	861	214	0
OR #2	99	0	15	0

CFU/m^3 for viable fungi and 969 spores/m^3 for total airborne spores. The maximum concentration indoors was 531 CFU/m^3 for viable fungi and 2889 spores/m^3 for total spores (Tables 1,2).

3.3. Santa Fe

The outdoor bioaerosol concentrations of both viable and total airborne fungi were negligible in most samples. The maximum outdoor concentration of total spores was 353 spores/m^3 and the maximum for viable fungi was 467 CFU/m^3. Although all the indoor sites had concentrations higher than outdoors, overall the indoor concentrations were relatively low. The elevated concentration of airborne fungi at a few sites showed evidence of indoor contamination.

Sampling data from SF building #2 showed the average concentration of viable fungi at 624 CFU/m^3 with a range of 17–4134 CFU/m^3. Specific data for individual classrooms in this building indicate that site 2 was the source of the contamination. The peak concentration, 4134 CFU/m^3, was recorded during the late afternoon sampling following class dismissal. This was 14 times higher than the early afternoon sample and 41 times higher than the morning sample. Colonies of *Aspergillus* and *Penicillium* species dominated this sample at concentrations of 2273 and 1695 CFU/m^3, respectively. During a follow-up visit to this classroom 3 months later, similar results were obtained. Data from sampling for viable fungi showed a morning concentration of 242 CFU/m^3 but a mid-day concentration of 2113 CFU/m^3. Anecdotal evidence recorded by the investigators indicated that students in the classroom were dancing immediately before the mid-day air sample was collected on this second visit.

It should be noted that particulates (dust, skin scales, lint, etc.) were so abundant on all the indoor Burkard samples from Santa Fe that the data for total spores are questionable. Particulates may have obscured spores resulting in concentrations that probably underestimated the total spore load. Also, the overloaded slides may have prevented spores from adhering to the slides.

3.4. Orlando

When the Orlando schools were sampled, the outdoor bioaerosol levels varied considerably on the 2 days of the investigation. Concentrations were five times higher on the second day than the first. When school building OR-1 was investigated, the outdoor concentration of total spores averaged 4860 spores/m^3 and viable fungi averaged 3191 CFU/m^3. When sampling was conducted at building #2, the average outdoor concentration of total spores was 23 627 spores/m^3 and the average for viable fungi was 15 761 CFU/m^3. Indoor concentrations in both schools appeared to reflect the outdoor levels with the concentrations in OR-2 approximately three times greater than OR-1. Although several indoor sites showed elevated concentrations of bioaerosols, these were generally outdoor genera. Basidiospores and smut teliospores occurred on 68% of the indoor samples in Orlando with the maximum concentration of 667 basidiospores/m^3 in one room of OR-2.

A few sites had elevated levels of *Penicillium* or *Aspergillus* colonies, especially site 3 in OR-1. The late afternoon concentration of airborne viable fungi was 2970 CFU/m^3; nine times greater than the early afternoon sample and 39 times greater than the morning. Eighty percent of the late sample consisted of *Aspergillus* colonies at 2390 CFU/m^3.

4. Discussion

The data presented here represent multiple samples collected at various schools in the United States. The locations represent a wide geographic range but, more importantly, they were collected during different seasons representing a broad climatic diversity. Kansas City schools were sampled in September, a period when outdoor allergens are often at peak concentrations in the central U.S. The Orlando samples were collected in April; however, in this humid, sub-tropical city, airborne allergens are generally present year round. By contrast, the Spokane and Santa Fe schools were studied during winter when outdoor bioaerosol concentrations were at a minimum (Tables 1,2). Clearly, the indoor bioaerosol concentrations in these two cities were least influenced by outdoor levels. Although seasonal influences are evident in the higher bioaerosol concentrations in KC and OR schools, this study was not an attempt to examine seasonal climatic or weather effects. A long-term investigation over all four seasons is needed to evaluate the effect of seasonal weather patterns on indoor bioaerosol levels in these schools. In the same manner, this study was not designed to examine specific city-to-city or school-to-school differences; it was an attempt to determine some baseline data on the range of bioaerosol levels that exist in schools.

It should be pointed out that no standards exist for indoor air quality regarding bioaerosols. Health hazards evaluations, conducted by the National Institute for Occupational Safety and Health (NIOSH) in the United States at office buildings where hypersensitivity pneumonitis and other respiratory diseases were reported, have suggested that buildings with viable spore counts above 1000 CFU/m^3 could be a causative agent and/or a contributing factor to the illnesses (NIOSH, 1987). This guideline was not intended to imply that a concentration of 1000 CFU/m^3 is a safe exposure or threshold value. In general, bioaerosol concentrations cannot be used to assess whether the air is safe or hazardous. Indoor bioaerosol concentrations and types should be evaluated in relation to the outdoor levels. Bioaerosols from outdoors will naturally be in-

troduced with fresh air. In facilities with natural ventilation, i.e. operable windows, the indoor bioaerosols will closely parallel outdoor levels and taxa as was seen in the KC-3 and KC-4 samples. In facilities where the fresh air is filtered within a central HVAC system, the reduction from outdoor levels will depend on the filter efficiency of the system and the tightness of the building, but should still parallel the taxa present outdoors.

The influence of the ventilation system is most apparent when the data from KC-4 with no air conditioning is compared to those from KC-1 which was a tight building with a central HVAC system. In KC-1, the mean indoor concentration of total spores represented only 4.7% of outdoor levels and viable spores were 7.8% of outdoors. This represents indoor/outdoor ratios of 1:21 and 1:13, respectively. By contrast, in KC-4 the mean total spore concentration indoors was 24% of outdoor levels and the mean for viable fungi was 12.3% of outdoors with much higher indoor/outdoor ratios of 1:4 and 1:8.

The magnitude of the outdoor bioaerosol concentrations is also a factor influencing indoor levels. This can easily be seen when the two Orlando schools are compared. Mean indoor concentrations of both total spores and viable fungi were much greater in OR-2 than OR-1. When the outdoor concentrations are also considered this comparison changes. The indoor concentrations of total spores and viable fungi in OR-1 were 31% and 20% of the outdoor levels, respectively. This represents indoor/outdoor ratios of 1:3 for total spores and 1:5 for viable fungi. In OR-2, by contrast, the indoor concentrations of total spores and viable fungi represent 17% and 11% of the outdoor levels. The indoor ratios are also lower at 1:6 for total spores and 1:9 for viable fungi. In addition, OR-1 had evidence of indoor contamination with elevated *Aspergillus* levels.

The American Conference of Government Industrial Hygienists (ACGIH) Bioaerosol Committee indicated that in most buildings concentrations of saprophytic fungi range from 10 to 25% of outdoor levels (Morey, 1990). It should be recognized, however, that both the NIOSH and ACGIH findings relate to large multi-story office buildings with central HVAC systems. No guidelines, recommendations or extensive databases exist for school buildings, many of which lack central HVAC systems.

Higher indoor levels of individual taxa may indicate an indoor source. Taxa that are normally not abundant outdoors and commonly associated with indoor contamination include *Aspergillus* and *Penicillium* species (Burge, 1989; Lacey, 1991; Gutman and Bush, 1993). Indoor locations in KC, SF, and OR showed elevated concentrations of these genera, suggesting sources of contamination were present. These fungi were especially abundant when activities disturbed reservoirs of these spores.

The indoor abundance of basidiospores and smut spores was particularly surprising. Both spore types are produced by basidiomycetes (members of the division Basidiomycota). Basidiospores are the sexual spores of mushrooms, bracket fungi, and puffballs. Many basidiospores are actively discharged from fruiting bodies during periods of high humidity and dispersed by prevailing winds. Smut teliospores are asexual spores formed by members of the Ustilaginales, a group of obligate plant pathogens that are especially important on cereal crops. These are passively dispersed by wind and are common components of the 'dry air spora.' Detection of these spores is not possible in culture. Basidiospores, if they will grow at all, will produce a non-sporulating colony that cannot be identified. Smut spores will generally not grow in culture unless a specialized medium is provided on which a yeast stage develops. The abundance of these spores in the samples collected during this study, points out the value of obtaining total spore concentrations along with the viable samples.

Both basidiospores and smut spores are important components of the atmosphere and are known to be allergenic (Burge, 1985; Levetin, 1991). Recent studies have shown substantial cross reactivity among different basidiomycete species (Reese et al., 1994). However, the significance of these fungi as indoor allergens is still unknown. The data presented here suggest further efforts should be made to determine their importance in indoor environments.

Since both spores types are of outdoor origin, their presence in indoor air indicates the penetration of outdoor bioaerosols. In KC-1 and KC-4, two schools with very different ventilation systems, basidiospores and smut spores were a remarkably consistent feature of the air spora occurring on 85–100% of the indoor samples. They were also fairly abundant in OR-1 and OR-2, even though both the outdoor and indoor concentrations in Orlando were lower than those in Kansas City. Low levels of these spores were even present in the SF schools in February when none were detected in the atmospheric samples. Their presence in these samples may be due to the re-entrainment of previously settled spores within the building.

It is generally believed that there is a cause and effect relationship between exposure to airborne allergens and allergy symptoms; however, threshold concentrations are largely unknown. It has been suggested that concentrations of 100 *Alternaria* conidia/m^3 and 3000 *Cladosporium* conidia/m^3 are reasonable estimates for these widespread taxa (Dhillon, 1991). No estimates have been suggested for basidiospores or smut spores or other taxa described here. While there may actually be threshold concentrations below which no symptoms are experienced, this is probably not an absolute value but a broad gradient based upon individual sensitivities. In-

door concentrations of total spores up to 15 000 spores/m^3 and concentrations of viable fungi up to 6000 CFU/m^3 were observed in this study. These levels may exceed the threshold concentrations for atopic individuals.

5. Conclusions

In conclusion, the current study indicates that concentrations of airborne fungi in schools are quite variable depending on the type of ventilation systems as well as outdoor concentrations. Indoor concentrations vary considerably between schools within the same city. Within a single building concentrations also vary greatly between classrooms and vary during the day. The data presented here suggest that atopic children sensitive to fungal spores may be at risk in some schools. Further aerobiological studies in classroom settings need to be undertaken to fully assess the exposure risk.

References

Burge, H.A. (1985) Fungus allergens. Clin. Rev. Allergy 3, 319–329.

Burge, H.A. (1989) Airborne allergenic fungi: classification, nomenclature, and distribution. Immunol. Allergy Clin. North Am. 9, 307–319.

Burge, H.A. (1990) Bioaerosols: prevalence and health effects in the indoor environment. J. Allergy Clin. Immunol. 86, 687–701.

Dhillon, M. (1991) Current status of mold immunotherapy. Ann. Allergy 66, 385–392.

Dungby, C.I., Kozak P., Gallup J. and Galant, S. (1986) Aeroallergen exposure in the elementary school setting. Ann. Allergy 56, 218–221.

Gutman, A.A. and Bush, R.K. (1993) Allergens and other factors important in atopic disease. In: R. Patterson, C.R. Zeiss, L.C. Grammer and P.A. Grenberger (Eds.), Allergic Diseases. Diagnosis and Management, 4th edn. Lippincott, Philadelphia, PA.

Hodgson, M.J. and Morey, P.R. (1989) Allergic and infectious agents in the indoor air. Immunol. Allergy Clin. North Am. 9, 399–412.

Lacey, J. (1991) Aerobiology and health: the role of airborne fungal spores in respiratory disease. In: D.L. Hawksworth (Ed.), Frontiers in Mycology. C.A.B. International, Kew, UK.

Lacey, J. and Crook, B. (1988) Fungal and actinomycete spores as pollutants of the workplace and occupational allergens. Ann. Occup. Hyg. 32(4), 515–533.

Levetin, E. (1991) Identification and concentration of airborne basidiospores. Grana 30, 123–128.

Mishra, S.K., Ajello L., Ahearn D.G., Burge H.A., Kurup V.P., Pierson D.L., Price D.L., Sampson R.A., Sandhu R.S., Shelton B., Simmons R.B. and Switzer K.F. (1992) Environmental mycology and its importance to public health. J. Med. Vet. Mycol. 30, Suppl. 1, 287–305.

Morey, P. (1990) Bioaerosols in the indoor environment: current practices and approaches. In: Practioners Approach to Indoor Air Quality Investigations. Proceedings of the Indoor Air Quality International Symposium, St. Louis, May 1989: AIHA.

NIOSH (1987) Guidance for Indoor Air Quality Investigations. NIOSH, Cincinnati, OH.

Reese, G., Levetin, E., Horner, W.E. and Lehrer, S.B. (1994) Basidiomycete spore allergen cross reactivity: by monoclonal antibodies and patients' IgE. J. Allergy Clin. Immunol. 93, 232.

Shaughnessy, R., Turk B.H., Levetin E., Fisher E., Ligman B. and Brennan T. (1993) Impact of ventilation/pressurization on indoor air contaminants in schools. Indoor Air '93, Proceedings of the International Conference on Indoor Air Quality and Climate, Helsinki.