PREVALENCE AND CONCENTRATIONS OF CULTURABLE AIRBORNE FUNGAL SPORES IN 86 OFFICE BUILDINGS FROM THE BUILDING ASSESSMENT SURVEY AND EVALUATION (BASE) STUDY

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ABSTRACT

Fungi were measured in indoor and outdoor air in 86 randomly selected, public and private office buildings in ten climatic regions in the continental United States as part of the U.S. Environmental Protection Agency's (EPA's) Building Assessment and Survey Evaluation (BASE) study. The purpose of the BASE study is to characterize many of the parameters associated with indoor environmental quality in public and private office buildings. Over 2,000 time-integrated air samples for fungi were collected during winter and summer. The buildings were randomly selected without regard to indoor air quality concerns, except that buildings with high profile indoor air quality issues were excluded. For each building, samples were collected at three indoor locations and one outdoor location. Thirty genera of fungi were detected indoors and 28 outdoors. The five most commonly found fungal groups or taxa were the same for both indoor and outdoor samples. In rank order, based upon the frequency of detection in a building were: Non-sporulating; *Cladosporium*; *Penicillium*; Yeast; and *Aspergillus*. These data can serve as a valuable resource for comparison in other indoor air quality investigations. The data are also available for researchers and other interested parties and for use by health researchers and policy makers.[1]

INTRODUCTION

In 1994, the U.S. EPA initiated the Building Assessment Survey and Evaluation (BASE) study to collect data on a broad cross section of public and private office buildings across the continental United States. The purpose of the BASE study is to characterize parameters most commonly associated with indoor air quality in public and private office buildings and to characterize occupant perceptions of health symptoms and indoor air quality in the same buildings. During a one-week period in each building, data were collected according to a consistent protocol [1]. In addition to the fungal group concentrations, a range of other parameters were measured including: three-day continuous measures of carbon monoxide, carbon dioxide, temperature, and relative humidity. Integrated samples of volatile organic chemicals including aldehydes, particulates, radon, and bacteria were also taken. Building characteristics and the operation of the heating, ventilation, and air-conditioning systems, and occupant perceptions of indoor air quality constituted the other major types of data collected.

The purpose of this paper is to identify the fungi most commonly present in indoor office environments, to report the ranges of concentrations, and to compare indoor to outdoor

[1] Data may be requested from the US EPA by contacting Laureen Burton by fax 202-565-2071 or email burton.laureen@epamail.epa.gov.

results. These data can be used to provide a reference for typical fungi concentrations found in office buildings in the U.S. In the future, they may be useful for determining the relationship of fungi concentrations to other building factors and occupant symptoms and perceptions.

METHODS

During a four-year period beginning in 1994, 2,064 individual bioaerosol samples were collected from 86 randomly selected public and commercial office buildings. Bulk samples were also taken of visible fungal growth in the study space and ventilation system. The buildings represent twenty-three (23) states and thirty-two (32) cities. Cities were randomly selected from ten climatic regions in the U.S. as defined for the BASE study. Cities with populations greater than 100,000 were eligible for inclusion. Within each city, buildings were recruited for participation by randomly calling phone numbers from business listings for each city. The design of this study was intended to randomly select buildings that could include both problem and non-problem buildings in proportion to their existence in the population. Buildings selected for the study had to have agreement of the owner or management and at least one area of the building which met all of the following criteria: (1) occupied by 50 or more employees who could receive the questionnaire; (2) served by no more than two air handling systems; and (3) those occupants were positioned in no more than three floors. In addition, if the building itself had highly publicized indoor air quality concerns, it was excluded.

While the protocol specified a collection of 2,064 samples using both two- and five-minute duration, the data from 681 five-minute samples were used exclusively for the analysis reported in this paper (duplicates and seven voided samples were excluded). In the development of the protocol, it was initially believed that organisms could potentially be underrepresented or overloaded due to sampling time. Analysis later confirmed that five-minute samples rarely resulted in overloaded plates, and generally provided better resolution including lower limits of detection (LOD) than the two-minute samples. Based upon these initial findings and space constraints, only results for the five-minute samples are presented.

A total of 516 five-minute primary samples were collected from three randomly selected indoor locations in each of 86 buildings during both morning and afternoon sampling rounds. The remaining 172 primary samples were taken outdoors near the outdoor air source of the air handling unit serving the test space, using identical sampling methodology. Field blanks, shipping blanks, and duplicates served as quality assurance measures to assess contamination and analytical precision. Three indoor and four outdoor five-minute samples were voided due to overgrowth. The total number of samples used for this report is 513 indoor samples and 168 outdoor samples.

Airborne fungal samples were collected at a flow rate of 28.3±1.4 liters per minute for five minutes. Pumps were attached to Andersen N6 single-stage inertial impactors. Spores were impacted onto 100 millimeter x 15 millimeter polystyrene petri plates containing 30 milliliters of 2% malt extract agar (MEA). Included in the composition was a 20% dextrose solution, which inhibits the growth of most bacteria.

All samples were shipped via overnight delivery to the Harvard School of Public Health Laboratory, Boston, MA. Immediately upon arrival, samples were incubated at room

temperature with twelve-hour light and dark cycles. Isolates were examined after seven days, whereupon morphological analyses and counts were conducted using standardized light microscopy.

The colony forming units (CFUs) of each organism were quantified in terms of their number per unit volume of air sampled adjusted to standard temperature and pressure. Data obtained were adjusted relative to the positive hole correction factor, and results were tabulated into a standard spreadsheet for the identification of forty isolates (Table 1). The standard spreadsheet was developed based upon fungi identified on at least one plate, either from the aerosol sampling or from the bulk samples collected in buildings with visible fungal growth.

Table 1. Selected Fungal Isolates

Acremonium	*Aspergillus versicolor*	*Monilia*	*Sporobolomyces*
Alternaria	*Aureobasidium*	*Nigrospora*	*Stachybotrys*
Arthrinium	*Botrytis*	Non-Sporulating	*Thysanophora*
Arthrospores (ns)	*Cladosporium*	*Ostrachoderma*	*Trichoderma*
Aspergillus flavus	*Coelomycetes*	*Paecilomyces*	*Ulocladium*
Aspergillus fumigatus	*Cunninghamella*	*Penicillium*	*Verticillium*
Aspergillus glaucus	*Curvularia*	*Periconia*	*Wallemia*
Aspergillus niger	*Drechslera*	*Pestalotia*	Yeast
Aspergillus ochraceus	*Epicoccum*	*Pithomyces*	*Zygomycetes*
Aspergillus Other	*Fusarium*	*Rhinocladiella-like*	Unknown

RESULTS

In the 86 buildings studied, 30 different fungal groups were identified indoors in quantifiable concentrations. Four genera, at low concentration and frequency, were unique to the indoor samples: *Thysanophora*; *Oedocephalum*; *Rhinocladiella*-like; and *Verticillium*. In the outdoor samples, 28 different fungal groups were identified in quantifiable concentrations. Table 2 shows the frequency of the occurrence of specific fungal growth on a plate. In reporting these results, if the number of colony forming units for a specific fungal group was below the limit of detection (ND), the value was set to zero. In addition, all *Aspergillus* species were summed.

Figure 1 shows the number and percent of buildings in which the eight most commonly identified taxa were detected. *Cladosporium* and Non-sporulating were found in over 90% of the buildings. Table 2 shows the distribution parameters of the concentrations in CFU/m^{3}of these same eight taxa.

Table 2. Distribution of the Concentration in CFU/m^{3}of Most Commonly Identified Taxa

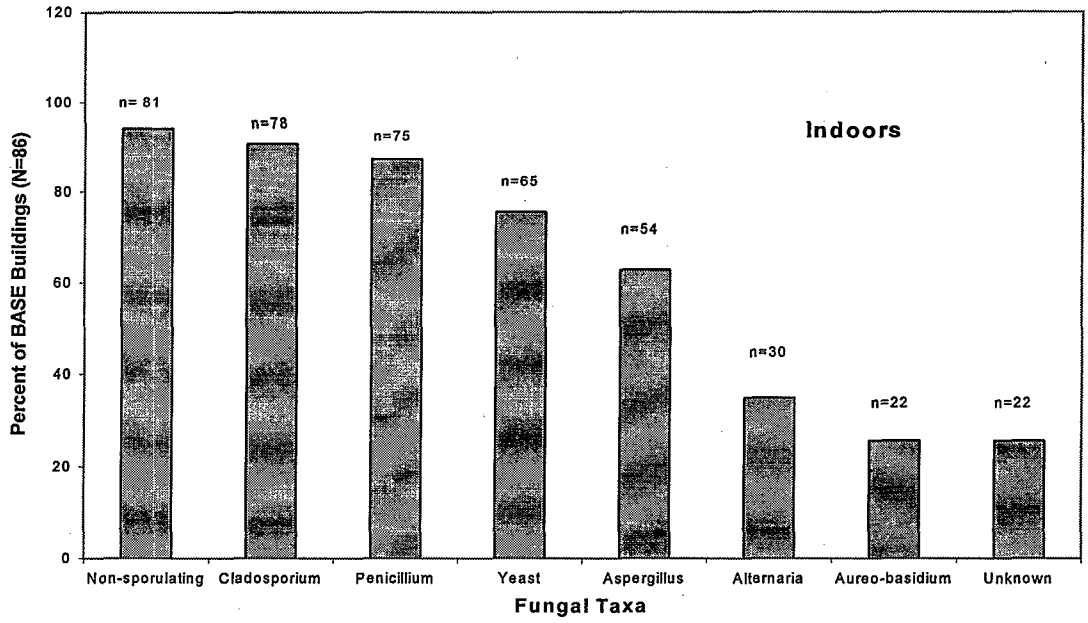
Taxa	Indoor Percentiles				Outdoor Percentiles			
	50	75	95	100	50	75	95	100
Cladosporium	7	28	106	3490	125	446	1410	5370
Non-sporulating	7	14	64	593	28	71	325	6040
Penicillium	ND	8	44	763	16	42	166	1130
Yeast	ND	7	22	160	ND	14	88	1270
Aspergillus	ND	ND	14	63	ND	14	64	1130
Alternaria	ND	ND	7	21	ND	50	16	212
Unknown	ND	ND	7	57	ND	ND	64	627
Aureo-basidium	ND	ND	7	21	ND	ND	14	51

As suggested by Table 3, the distribution of concentrations of these compounds was neither normal nor log normal. The five taxa most commonly found indoors, were also commonly found outdoors, and were all present in at least 25% of the buildings.

Table 3 Frequency* of Presence at Quantifiable Concentrations in Indoor and Outdoor Air for all Fungal Genera Identified

Taxa	Indoor Range of Detectable Conc., CFU/m^3	Taxa	Outdoor Range of Detectable Conc., CFU/m^3
75 - 95% frequency		75- 95% frequency	
None		*Cladosporium*	7 - 5370
50 – 75% frequency		Non-sporulating	7 - 6040
Cladosporium	7 - 3490	50 – 75% frequency	
Non-sporulating	7 - 593	*Penicillium*	7 - 1130
25 – 50% frequency		25 – 50% frequency	
Penicillium	7 - 763	*Aspergillus*	7 - 1130
Yeast	7 - 160	Yeast	7 - 1270
5 – 25% frequency		*Alternaria*	7 - 212
Aspergillus	7 - 63	5 – 25% frequency	
Alternaria	7 - 21	*Aureo-basidium*	7 - 51
Unknown	7 - 57	Unknown	7 - 627
Aureo-basidium	7 - 21	*Epicoccum*	7 - 94
<5% frequency		*Zygomycetes*	7 - 37
Coelomycetes	7 - 15	*Fusarium*	7 - 42
Fusarium	7 - 21	*Botrytis*	7 - 125
Sporobolomyces	7 - 155	*Coelomycetes*	7 - 50
Epicoccum	7 - 14	*Pithomyces*	7 - 28
Zygomycetes	7 - 38	*Curvularia*	7 - 21
Trichoderma	7 - 14	*Ulocladium*	7 - 30
Ulocladium	7 - 7	<5% frequency	
Botrytis	7 - 30	*Trichoderma*	7 - 37
Drechslera	7 - 8	*Drechslera*	7 - 15
Paecilomyces	7 - 7	*Paocilomyces*	7 - 8
Pithomyces	7 - 7	*Acremonium*	15 - 33
Curvularia	7 - 7	*Arthrinium*	7 - 9
Thysanophora	7 - 21	*Beauveria*	7 - 7
Acremonium	7 - 7	*Cunninghamella*	7 - 7
Botyosporium	7 - 7	*Monilia*	7 - 7
Monilia	7 - 7	*Nigrospora*	7 - 7
Nigrospora	7 - 7	*Nodulisporium*	7 - 7
Nodulisporium	7 - 7	*Sporobolomyces*	10 -10
Oedocephalum	7 - 7	*Wallemia*	7 - 7
Rhinocladiella-like	7 - 7		
Verticillium	7 - 7		
Wallemia	7 - 7		

* Frequency detected is calculated by dividing the number of plates with quantifiable fungal counts by the total number of plates



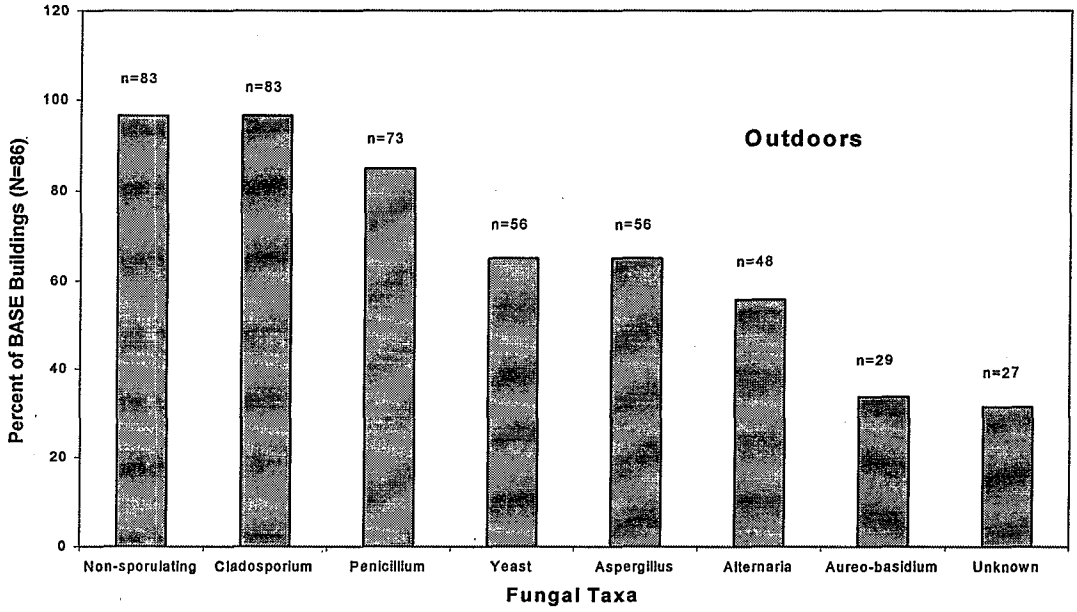


Figure 1: Number and Percent of 86 BASE Buildings with the Eight Most Commonly Detected Taxa (A) Indoors and (B) Outdoors.

DISCUSSION

These results show a range of fungi present inside office buildings; 30 different fungi were identified in indoor environments. Fewer fungi, 28, were identified outdoors. Although the summary data indicate that for each fungal group, indoor concentrations were lower than those outdoors, in several buildings some indoor fungal concentrations were found to be higher than those outdoors indicating the presence of fungal sources in these buildings. The five major fungal groups identified both indoors and outdoors were *Cladosporium,* Non-sporulating, *Penicillium, Aspergillus,* and Yeast. An earlier study in non-residential buildings by Yang [3] showed similar results. Although four fungi were identified exclusively in indoor samples, *Thysanophora*, *Oedocephalum*, *Rhinocladiella*-like and *Verticillium*, the sparse frequency of detection and low concentrations may only indicate potential relevance to the individual buildings.

Elevated fungal counts were found in approximately five percent of the study buildings. Future analyses of these data with the associated occupant questionnaire responses on health symptoms may provide insight into the significance of these findings. Data are available upon request from the U.S. Environmental Protection Agency.

The results from this study provide normative data on fungi in U.S. office buildings that can be used by building diagnosticians for comparison to data from complaint buildings, and by researchers examining the relationships of fungi with other building factors and occupant perceptions collected in this study. These data can also be examined to determine the suitability of this protocol for collecting bioaerosol data in future studies.

ACKNOWLEDGMENTS

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