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Indoor Health: Background Levels of Fungi

There is no uniformity in the suggested guidelines for acceptable levels of fungi in indoor ambient air. Thus, health professionals have no way to determine what levels of fungi may pose a threat to human health. The authors reviewed the published literature to identify data reported for noncomplaint structures, that is, structures in which occupants did not have health concerns associated with the quality of the indoor air. For both commercial and residential structures, fungal concentrations detected were often higher than currently suggested guidance values. The average indoor air concentration in 149 noncomplaint commercial buildings was 233 colony forming units (CFU) per cubic meter, whereas outdoor ambient air levels averaged 983 CFU/m³. Total indoor spore counts ranged from 610 to 1040 spores/m³ in three commercial buildings. Outdoor total spore counts associated with these buildings ranged from 400 to 80,000 spores/m³. The average indoor concentration reported for 820 noncomplaint residential structures was 1252 CFU/m³ with an average outdoor level of 1524 CFU/m³. Total spore counts detected indoors at 85 residential structures ranged from 68 to 2307 spores/m³. Outdoor spore levels associated with these structures ranged from 400 to 80,000 spores/m³. A large proportion of both commercial and residential noncomplaint structures have indoor ambient air fungal concentrations above 500 CFU/m³, a level often advocated as requiring remediation in structures when occupants complain of nonspecific adverse health symptoms.

Keywords: fungi, indoor air quality

In the past few years the public and media have given greater attention to indoor health issues associated with exposure to fungi. Fungi are ubiquitous in the environment; they exist naturally in air, soil, and water. They are found in particularly heavy concentrations in gardening materials such as compost and in natural environments such as woodland areas and farms. Fungi can be detected at some low concentrations in indoor ambient air, in dust, or on surfaces in most commercial or residential structures. Without intentionally developing a sterile environment, a mold-free, indoor environment is not possible.

Recommendations for addressing fungal concentrations detected in structures have been developed by a diverse range of organizations, as illustrated in Table I. These recommendations appear to be based on either a consensus reached within a particular organization or on professional field experience.^(1,2) As might be expected, there is little consistency among these recommendations. In contrast to recommendations

presented in Table I, some indoor air quality professionals suggest that any ratio between indoor and outdoor concentrations of less than 1 is acceptable.⁽³⁾ Yet others suggest that an acceptable measure can be a ratio between indoors and outdoors consistently more than 2 and exceeding 1000 spores/m³.⁽⁴⁾

Such a lack of uniformity may be understandable given the ubiquitous nature of fungi in our environment, their diverse physical properties, and seasonal variations associated with wide ranges of climate in which they are found. Other factors influencing differences in indoor ambient air levels include differences in building maintenance, extent of indoor plants, type of ventilation used in a structure, indoor temperatures and relative humidity, and the type of furniture and carpeting present.⁽⁵⁻⁸⁾

Perhaps the most important constraint for establishing uniform standards for indoor ambient air in commercial and residential structures is the limited scientific evidence of an association with adverse health effects at low environmental concentrations. An illustration of the lack of a sound

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TABLE I. Example Quantitative Recommendations for Fungal Concentrations

Organization (Document, Year)	Recommendations
American Conference of Industrial Hygienists (<i>Air Sampling Instruments for Evaluation of Atmospheric Contaminants</i> , 1995)	<p>< 100 CFU/m³—low 100–1000 CFU/m³—intermediate, represents general indoor and outdoor concentrations > 1000 CFU/m³—high, represents animal handling areas</p>
American Industrial Hygiene Association (<i>The Industrial Hygienist's Guide to IAQ Investigations</i> , 1993)	Rank order assessment; indoor/outdoor comparison recommended
Commission of European Committees (<i>Report #12: Biological Particles in Indoor Environment</i> , 1993)	<p>Residential structures: > 10,000 CFU/m³—very high < 10,000 CFU/m³—high < 1000 CFU/m³—intermediate < 200 CFU/m³—low < 500 CFU/m³—low (on DG18 medium) < 50 CFU/m³—very low Commercial, nonindustrial structures: > 2000 CFU/m³—very high < 2000 CFU/m³—high < 500 CFU/m³—intermediate < 100 CFU/m³—low < 25 CFU/m³—very low</p>
Canadian Mortgage and Housing Corporation (<i>Testing of Older Houses for Microbiological Pollutants</i> , 1991)	<p>> 200 CFU/m³ presence of species other than <i>Alternaria</i> and <i>Cladosporium</i>—investigate > 500 CFU/m³ includes <i>Alternaria</i> and <i>Cladosporium</i>—investigate; Indoor/outdoor comparison recommended when ≤ 200 CFU/m³</p>
IAQ Association Inc. (<i>IAQ Standard #95-1 Recommended for Florida</i> , 1995)	<p>< 300 CFU/m³ of common fungi—OK < 150 CFU/m³ mixed species, not pathogenic or toxigenic—OK</p>
National Health and Welfare, Canada (disclaimer/ <i>IAQ in Office Building: A Technical Guide</i> , 1993)	<p>Toxigenic, pathogenic not acceptable in indoor air ≥ 50 CFU/m³ one species—investigate ≤ 150 CFU/m³ if mixed species—OK ≤ 500 CFU/m³ if common tree/leaf fungi—OK in summer</p>
U.S. Occupational Safety and Health Administration (<i>Technical Manual</i> , 1992)	<p>≥ 1000 CFU/m³—contamination ≥ 10⁶ fungi/g dust—contamination ≥ 10⁵ fungi/mL stagnant water or slime—contamination</p>
World Health Organization (<i>IAQ: Biological Contaminants</i> , 1988)	<p>Pathogenic/toxigenic unacceptable in indoor air > 50 CFU/m³, one species—investigate ≤ 150 CFU/m³, mixed species—OK ≤ 500 CFU/m³, if <i>Cladosporium</i> or other common phylloplane—OK</p>

Source: Adapted from Reference 1.

scientific basis for current recommendations is the extent of fungal exposure observed in occupational settings. Such occupational exposures, via handling materials of natural origin, can be extremely high. At sawmills maximum airborne concentrations have been reported as 1,500,000 colony forming units (CFU) per cubic meter, with *Penicillium* as the predominant genus.⁽⁹⁾ Concentrations measured at honeybee overwintering facilities are reported as 2200 to 13,931 CFU/m³ while workers are sweeping up dead bees, from 300 to 54,700 CFU/m³ when equipment is being cleaned, and from 238 to 1442 CFU/m³ before disturbance by workers.⁽¹⁰⁾ A study of differences in air concentrations on farms with and without disease revealed an average exposure concentration of 120,000,000 spores/m³ on the control farms.⁽¹¹⁾ Daily spore levels associated with adverse health effects were at least 10 times greater. Air concentrations in spawning sheds on mushroom farms have been reported as high as 100,000 spores/m³; even greater concentrations are detected at other areas on these farms.⁽¹²⁾ Fungi detected in the breathing zone of workers in a municipal waste composting facility reach levels of 8,200,000 CFU/m³.⁽¹²⁾

Because a major question facing indoor health professionals is

what levels of fungi in ambient indoor air represent a threat to health, a review of the literature was conducted. The purpose of the review was to identify (1) a range of indoor ambient air concentrations in structures without health complaints associated with indoor air quality, (2) the diversity of fungal species detected, (3) differences noted among geographical areas and across seasons, and (4) the influence of different sampling equipment on reported concentrations.

VARIABILITY IN REPORTED CONCENTRATIONS

Fungi are eukaryotic organisms belonging to a kingdom that is distinct from plants and animals.⁽⁷⁾ Fungi reproduce via the formation of spores from sexual or asexual processes. These spores differ in number of cells, size (from 2 to 100 μm), shape, and color.^(7,13) Most spores are adapted for airborne dispersal, although some can be dispersed by insects, water, animals, and humans. All fungi depend on an external source of organic material for growth.

TABLE II. Seasonal Variability in Outdoor Spore Counts per Cubic Meter

Location	March 2001– June 2001	September 2001–December 2001
Northeast		
Albany, N.Y.	9–1534	1075–18,005
Washington, D.C.	90–3690	787–13,678
Pittsburgh, Pa.	70–18,863	472–15,894
Waterbury, Conn.	8–6764	1882–25,118
South Atlantic		
Charlotte, N.C.	686	543–5423
Miami, Fla.	611–9711	667–18,183
Tampa, Fla.	800–8500	990–5990
South Central		
College Station, Tex.	1821–33,999	1640–27,953
Oklahoma City, Okla., Station 1	262–17,055	1901–39,370
Fort Smith, Ark.	3524–14,012	7815–14,800
Midwest		
Milwaukee, Wisc.	65–13,627	0
Grand Rapids, Mich.	497–2749	6182–6693
Indianapolis, Ind.	45–15,256	1925–21,439
St. Louis, Mo.	395–24,500	5266–68,855
West		
Las Vegas, Nev.	8–673	15–186
Santa Barbara, Calif.	544–33,090	767–555,833
San Jose, Calif., Station 1	351–17,090	636–17,276
Vancouver, Wash.	481–4865	1951–28,411

Source: National Allergy Board, American Academy of Allergy, Asthma and Immunology, Reference 18.

These organic materials are digested by fungal enzymes and subsequently absorbed. There are thousands of genera of fungi and numerous species within each genus.^(7,14) Nearly 69,000 species of fungi have been described, and it is estimated that the total may be greater than 1.5 million.⁽⁷⁾

Outdoor concentrations vary widely by geographic location. Within a geographic location additional variations occur in response to seasons; daily temperature changes; humidity; wind velocity and direction; extent of vegetation; time of day; and amount of precipitation.^(7,13,15) The literature reports fungal concentrations outdoors ranging from as low as 20 to over 100,000 CFU/m³ depending on the location and season.^(13,16,17) The National Allergy Board of the American Academy of Allergy, Asthma, and Immunology regularly reports on total spore counts throughout the United States.⁽¹⁸⁾ Table II illustrates the outdoor concentrations reported at different times during the same year and among different geographic locations. Within a single species such seasonal variation can be extreme; e.g., *Cladosporium* levels have been reported as 26 CFU/m³ in winter and more than 11,000 CFU/m³ in summer at a single location.⁽¹⁹⁾

Most fungi detected indoors have an outdoor source.^(7,20–23) *Cladosporium* and *Alternaria* species are the most commonly detected fungal genera in outdoor air, originating on the surfaces of plant leaves; but they have been detected indoors also. Other commonly detected indoor fungi include multiple species of *Penicillium* and *Aspergillus*, species which grow readily in topsoil and decay litter. A diverse range of species are commonly detected in both outdoor and indoor ambient air.^(7,13,20–23)

Fungi are introduced into the indoor environment through

natural (open windows and doors) and mechanical ventilation systems. They also are brought indoors on an individual's shoes and clothing and by pets. Indoor ambient concentrations are influenced by several factors including temperature, humidity, water intrusion into building structures, and the extent of movement of outdoor air into a building.^(5,24,25) General household and building maintenance activities have been reported to influence changes in fungal concentrations. Such activities include cleaning, dusting, vacuuming, vegetable peeling, and presence of plants and pets.⁽⁶⁾ The five most common fungal genera detected in indoor air include *Cladosporium*, *Penicillium*, *Aspergillus*, *Alternaria*, and *Aureobasidium*.^(6,26–28)

In addition to the above factors influencing variability in fungal concentrations, present day sampling and analytical approaches also contribute to our inability to establish guidelines for acceptable levels in an indoor environment. It has been only during the past decade that new approaches have been adopted.⁽²⁹⁾ Even with these new approaches, there is limited uniformity in how fungal concentrations are reported—some report only viable fungi in colony-forming units per cubic meter, whereas others report total spore counts per cubic meter. Studies of comparative recoveries suggest a potential for underreporting when only viable counts are provided.⁽³⁰⁾ This problem is compounded by the use of different culture media and associated differences in growth rates among species.⁽³¹⁾ Past and current practices of characterizing fungi via gross microscopic features is unsuitable when attempting to find cause and effect relationships between the presence of specific species and adverse health effects. Spores of different species often are insufficiently distinctive to permit accurate identification with these methods.⁽²⁹⁾

Despite a lack of uniformity in reporting units (i.e., total spores or CFU), many health professionals suggest that if the indoor ambient concentration is less than concentrations observed in outdoor air and if the fungi detected in both are similar, then no health risk should be expected.^(15,22) However, similarities or differences observed between indoor and outdoor air depend on the quality of monitoring design and the number of samples collected in each environment during the same time period.^(29,32) Normal variation in concentrations observed (e.g., minute-to-minute and day-to-day) both within and between the two environments makes interpretation of such a comparison difficult. This is particularly true when fungal concentrations are low and sample numbers are small. Take for example, mixed species concentrations reported as 100 CFU/m³ indoors and 50 CFU/m³ outdoors; if samples from indoors are collected at a different time during the day from outdoor samples, and if the sample size is limited (e.g., three indoor samples and one outdoor sample), even a 2:1 ratio may be meaningless.

Too often investigators rely on fungal concentrations detected in bulk samples of materials not exposed to indoor ambient air, for instance, insulation materials in interstitial spaces. They rely heavily on levels detected in dust and on structural surfaces. However, the mere presence in such instances does not mean that occupants actually are inhaling fungal components. Unless spores can be transferred from these materials into the indoor ambient air and thus are available for intake into an individual's respiratory system, on foods being ingested, or are in direct contact with skin, there is no risk to human health. Moreover, the amount present must be sufficient to produce an adverse, albeit generally transient, health effect. Once exposure ceases, these transient effects almost invariably abate.

A risk model to examine potential toxin exposure via inhalation has been suggested by Burge and clearly illustrates fungal exposure.⁽³³⁾ The model assumes an adult inhalation rate of 1.0 m³ of

TABLE III. Fungal Concentrations Reported in Nonproblem, Noncomplaint Commercial Buildings

Outdoor Spore Count (no./m ³)	Indoor Spore Count (no./m ³)	Outdoor (CFU/m ³)	Indoor (CFU/m ³)	Species Detected	Geographic Location	Season	Number of Buildings	Reference
400–80,000 ^A	610			<i>Alternaria</i> <i>Aspergillus</i> <i>Penicillium</i> <i>Ascospores</i> <i>Basidiospores</i> <i>Botrytis</i> <i>Cladosporium</i> <i>Curvularia</i> <i>Drechslera</i> <i>Epicoccum</i> <i>Fusarium</i> <i>Odeium</i> <i>Peronospora</i> <i>Pithomyces</i> Rusts Smuts <i>Stemphylium</i> <i>Torula</i> <i>Stachybotrys</i> <i>Zygomycetes</i>	Southern California		37	34
1728 (Roto-rod)	655			<i>Alternaria</i> Rust <i>Cladosporium</i> Mycelial <i>Epicoccum</i> Smut	Southern California	late spring	10	35
1306 (Andersen)	1040			<i>Cladosporium</i> <i>Alternaria</i> <i>Penicillium</i> <i>Mycelia</i> <i>Epicoccum</i> <i>Aureobasidium</i> <i>Aspergillus</i> <i>Phoma</i> <i>Drechslera</i> <i>Cephalosporium</i> <i>Streptomyces</i> <i>Pithomyces</i> <i>Ulocladium</i> <i>Acremonium</i> <i>Mucor</i> <i>Rhinocladiella</i> <i>Botrytis</i> <i>Chaetomium</i> <i>Stemphylium</i> <i>Rhizopus</i>	Southern California	late spring	10	35
		127 (68–234)			North Carolina	July–December	1	36
		171 (95–247)			North Carolina	December (during and after cleaning)	1	36
		50 (15–105)			North Carolina	January–July (with improved housekeeping)	1	36
		82 (10–247)			North Carolina	year-round	1	36
		277 (35–978)		<i>Alternaria</i> <i>Aspergillus fumigatus</i> <i>A. versicolor</i>	Great Britain		4	39

TABLE III. Continued.

Outdoor Spore Count (no./m ³)	Indoor Spore Count (no./m ³)	Outdoor (CFU/m ³)	Indoor (CFU/m ³)	Species Detected	Geographic Location	Season	Number of Buildings	Reference
				<i>Aureobasidium</i> <i>Botrytis</i> <i>Cladosporium</i> <i>Phoma</i> <i>Penicillium</i> <i>Stachybotrys</i> <i>Stysanus</i> <i>Mucor</i> <i>Stereum</i>				
		785		<i>Cladosporium</i> <i>Penicillium</i> <i>Chrysosporium</i> <i>Alternaria</i> <i>Aspergillus</i>	Gulf of Mexico and Atlantic Seaboard	year-round	48	21
		1027	854	<i>Aspergillus</i> <i>Cladosporium</i> <i>Penicillium</i> <i>Alternaria</i> <i>Basidiomycetes</i>	14 mid-Atlantic States and Washington DC	year-round		28
		1032	1212	<i>Aspergillus</i> <i>Penicillium</i> <i>Cladosporium</i> <i>Alternaria</i> <i>Paecilomyces</i> <i>Curvularia</i> <i>Fusarium</i> <i>Trichoderma</i>	Taipei, Taiwan		28	25
		474 (99-2195)	83 (14-372)		Houston-Galveston, Texas	year-round	1	26
		92 (3-675)	17 (0-170)		Paris, France	year-round	112	37
		Reuter centrifugal						
		1268 (7-8229)	159 (0-686)		Southern USA	year-round	3	38
		2061 (87-8229)	159 (2-400)		Muscle Shoals, Alabama	year-round	1	38
		944 (43-8229)	164 (26-686)		Chattanooga, Tennessee	year-round	1	38
		753 (7-1504)	83 (1-509)		Knoxville, Tennessee	year-round	1	38
		1977 (87-8229)	160 (2-686)		Southern USA	spring	3	38
		1034 (322-2816)	176 (45-400)		Southern USA	summer	3	38
		1186 (292-4366)	138 (9-378)		Southern USA	fall	3	38
		141 (7-377)	46 (1-117)		Southern USA	winter	3	38

^aRange of outdoor concentrations measured at a single outdoor monitoring station.

air in an 8-hour period and an exposure concentration of 1000 spores/m. With these assumptions Burge estimated that a total of 110 days (at an exposure frequency of 24 hours/day) would be required to accumulate 1.0 ng of toxin in the respiratory tract. Unfortunately, there is limited scientific information that allows a determination of whether such an amount of toxin would result in an adverse health consequence.

CONCENTRATIONS OBSERVED IN "NONCOMPLAINT" STRUCTURES

A review of a total of 144 publications reveals 31 studies that include indoor and outdoor ambient air concentrations collected from noncomplaint commercial and residential buildings.

TABLE IV. Fungal Concentrations Reported in Noncomplaint Residential Buildings

Outdoor Spore Count (no./m ³)	Indoor Spore Count (no./m ³)	Outdoor (CFU/m ³)	Indoor (CFU/m ³)	Species Detected (both outdoors and indoors)	Geographic Location	Season	Number of Buildings	Reference
400–80,000 ^a	1333			<i>Alternaria</i> <i>Aspergillus</i> <i>Penicillium</i> <i>Ascospores</i> <i>Basidiospores</i> <i>Botrytis</i> <i>Cladosporium</i> <i>Curvularia</i> <i>Drechslera</i> <i>Odaium</i> <i>Peronospora</i> <i>Pithomyces</i> <i>Rusts</i> <i>Smuts</i> <i>Stemphylium</i> <i>Stachybotrys</i>	Southern California		19	34
		1297 (657–3785)	1776 (612–2610)	<i>Cladosporium</i> <i>Penicillium</i> <i>Aspergillus</i> <i>Alternaria</i>	New Haven, Connecticut	October	10	40
		505	801	<i>Alternaria</i> <i>Aspergillus</i> <i>Cladosporium</i> <i>Penicillium</i> <i>Wallemia</i>	New Haven, Connecticut	winter	11	17
		830	930	<i>Alternaria</i> <i>Aspergillus</i> <i>Cladosporium</i> <i>Penicillium</i> <i>Botrytis</i> <i>Wallemia</i>	New Haven, Connecticut	spring	11	17
		1198	998	<i>Alternaria</i> <i>Aspergillus</i> <i>Cladosporium</i> <i>Penicillium</i> <i>Botrytis</i> <i>Epicoccum</i> <i>Fusarium</i> <i>Wallemia</i>	New Haven, Connecticut	summer	11	17
		607	884	<i>Alternaria</i> <i>Aspergillus</i> <i>Cladosporium</i> <i>Penicillium</i> <i>Botrytis</i> <i>Epicoccum</i> <i>Fusarium</i> <i>Wallemia</i>	New Haven, Connecticut	fall	11	17
		4100	1200	<i>Cladosporium</i> <i>Penicillium</i> <i>Alternaria</i> <i>Aspergillus</i> <i>Fusarium</i>	Midwest USA	April–December	27	41
		941	669	<i>Aspergillus</i> <i>Aureobasidium</i> <i>Botrytis</i> <i>Cladosporium</i> <i>Eurotium</i> <i>Penicillium</i> <i>Ramularia</i> <i>Wallemia</i>	Netherlands	May	18	14

TABLE IV. Continued

Outdoor Spore Count (no./m ³)	Indoor Spore Count (no./m ³)	Outdoor (CFU/m ³)	Indoor (CFU/m ³)	Species Detected (both outdoors and indoors)	Geographic Location	Season	Number of Buildings	Reference
		557	566	<i>Aspergillus</i> <i>Penicillium</i> <i>Cladosporium</i> <i>Alternaria</i> <i>Paecilomyces</i> <i>Curvularia</i> <i>Fusarium</i> <i>Trichoderma</i>	Taipei, Taiwan	summer	92	42
		411	388	<i>Aspergillus</i> <i>Penicillium</i> <i>Cladosporium</i> <i>Alternaria</i> <i>Paecilomyces</i> <i>Curvularia</i> <i>Fusarium</i> <i>Trichoderma</i>	Taipei, Taiwan	winter	87	42
		114	89 (AC) ^a 128 (no AC) ^b	<i>Aspergillus</i> <i>Cephalosporium</i> <i>Chrysosporium</i> <i>Cladosporium</i> <i>Curvularia</i> <i>Fusarium</i> <i>Monilia</i> <i>Mucor</i> <i>Penicillium</i> <i>Rhizopus</i> <i>Mycelia</i> <i>Streptomyces</i> <i>Trichophyton</i>	Honolulu, Hawaii	July–December	50	24
1283 (212–3884)	660 (11–3708)			<i>Acremonium</i> <i>Alternarium</i> <i>Aspergillus</i> <i>Aureobasidium</i> <i>Beauveria</i> <i>Botrytis</i> <i>Cephalosporium</i> <i>Cladosporium</i> <i>Curvularia</i> <i>Drechslera</i> <i>Epicoccum</i> <i>Fusarium</i> <i>Geotrichum</i> <i>Mucor</i> <i>Mycelia</i> <i>Nigrospora</i> <i>Paecilomyces</i> <i>Phoma</i> <i>Penicillium</i> <i>Pithomyces</i> <i>Planozythia</i> <i>Rhinocladiella</i> <i>Rhizopus</i> <i>Rhodotorula</i> <i>Sporobolomyces</i> <i>Stachybotrys</i> ^c <i>Streptomyces</i> <i>Ulocladium</i> <i>Zygopodium</i>	Southern California		32	53
635	277			<i>Alternaria</i> <i>Aspergillus</i> <i>Cladosporium</i>	Southern California	July	1	5

TABLE IV. Continued

Outdoor Spore Count (no./m ³)	Indoor Spore Count (no./m ³)	Outdoor (CFU/m ³)	Indoor (CFU/m ³)	Species Detected (both outdoors and indoors)	Geographic Location	Season	Number of Buildings	Reference
		65	215	<i>Epicoccum</i> <i>Mycelia</i> <i>Penicillium</i> <i>Penicillium</i> <i>Aspergillus</i> <i>Mucor</i> <i>Fusarium</i> <i>Candida</i>	East Tennessee	winter	120	43
		1640	1490	<i>Penicillium</i> <i>Aspergillus</i> <i>Mucor</i> <i>Fusarium</i> <i>Candida</i>	East Tennessee	summer	220	43
1393	538				Milwaukee	summer (with AC) ^a	6	54
1425	1206				Milwaukee	summer (without AC) ^a	6	54
3480	2307			<i>Alternaria</i> <i>Aspergillus</i> <i>Basidiosporium</i> <i>Ascospores</i> <i>Penicillium</i> <i>Cladosporium</i> <i>Coprinus</i> <i>Epicoccum</i> <i>Ganoderma</i> <i>Leptosphaeria</i>	Ontario, Canada	year-round	15	55
		230	150		Finland	year-round	71	44
		950	410		Finland	summer	71	44
		20	40		Finland	winter	71	44
		394 (geometric mean=362)	231 (geometric mean=198)	<i>Dematiaceous</i> <i>Moniliaceous</i> <i>Basidiomycetes</i> <i>Zygomycetes</i>	San Francisco, California	year-round	1	45
		539	165		San Francisco, California	March	1	45
		184	148		San Francisco, California	June	1	45
		480	376		San Francisco, California	September	1	45
		376	351		San Francisco, California	December	1	45
		1131	742	<i>Cladosporium</i> <i>Alternaria</i> <i>Epicoccum</i> <i>Candida</i> <i>Penicillium</i> <i>Aspergillus</i>	Toronto, Canada	July–August	27	46
		45	17		Houston, Texas	winter	41	47
		880	123		Houston, Texas	spring	41	47
		837	268		Houston, Texas	summer	10	47
		196	99		Houston, Texas	year-round	41	47
		86	36		El Paso, Texas	spring	40	47
		60	38		El Paso, Texas	summer	25	47
		72	37		El Paso, Texas	year-round	40	47
		1314 (760-1404)	1589 (951-1760)		Taipei, Taiwan	May–June	6	48

TABLE IV. Continued

Outdoor Spore Count (no./m ³)	Indoor Spore Count (no./m ³)	Outdoor (CFU/m ³)	Indoor (CFU/m ³)	Species Detected (both outdoors and indoors)	Geographic Location	Season	Number of Buildings	Reference
		2081 (1225–2435)	2151 (1508–2502)		Tai-Chi, Taiwan	May–June	12	48
		555	552	<i>Aspergillus</i> <i>Penicillium</i> <i>Cladosporium</i> <i>Alternaria</i> <i>Paecilomyces</i> <i>Curvularia</i> <i>Fusarium</i> <i>Trichoderma</i>	Taipei, Taiwan	July–September	92	49
510	68				Houston, Texas	June–October	12	56
		750	308	<i>Aspergillus</i> <i>Cladosporium</i> <i>Penicillium</i>	Finland	year-round	18	50
		11,885 (urban)	9100 (urban)	<i>Penicillium</i> <i>Aspergillus</i>	Southern Taiwan	winter	76	51
		9173 (suburban)	8333 (suburban)	<i>Alternaria</i> <i>Cladosporium</i>				
		4134 (urban)	3608 (urban)	<i>Penicillium</i> <i>Aspergillus</i>	Southern Taiwan	summer	76	51
		6242 (suburban)	7303 (suburban)	<i>Cladosporium</i> <i>Alternaria</i>				
		0–15,643	0–12,514		Netherlands	year-round	8	52

^aRange of outdoor concentrations measured at a single outdoor monitoring station.

^bAC = air conditioning.

^cOD = detected only outdoors.

Noncomplaint is defined as a structure without adverse health complaints associated with indoor air quality. As illustrated in Tables III and IV, the ambient air concentrations of viable fungi and total spores in these noncomplaint buildings vary widely.

Table III presents data from 47 noncomplaint commercial buildings with total indoor and outdoor spore counts.^(34,35) The indoor average was 768 spores/m³, ranging from 610 to 1040 spores/m³. Associated outdoor total spore counts ranged from 400 to 80,000 spores/m³. Ambient concentrations of viable fungi detected in commercial buildings were reported for 149 structures.^(21,25,26,28,36–39) The outdoor ambient air averaged 983 CFU/m³ with a range reported as 92 to 2061 CFU/m³. Total viable fungi detected in the indoor ambient air averaged 233 CFU/m³ with a range from 17 to 1212 CFU/m³.

Table IV provides the available data for noncomplaint residences.^(14,17,24,34,40–50) The outdoor ambient air average is 1524 CFU/m³ ranging from 20 to 11,883 CFU/m³. Indoor ambient air concentrations of viable fungi reported for 820 structures range from 17 to 9100 CFU/m³ with an average value of 1252 CFU/m³. Total spore counts detected in 85 residential structures were reported in five studies.^(5,34,51–56) The outdoor count ranged from 400 to 80,000 spores/m³. Indoor concentrations averaged 913 spores/m³, ranging from 68 to 2307 spores/m³.

As many as 29 different genera of fungi have been detected in both indoor and outdoor air at a single residence (see Table IV). *Cladosporium*, *Penicillium*, *Aspergillus*, *Ascospores*, *Curvularia*, *Fusarium*, *Aureobasidium*, *Streptomyces*, *Epicoccum*, *Phoma*, and *Alternaria* are among the most commonly identified. *Stachybotrys* has been reported in recent literature as a fungus of particular concern because of its potential toxigenic properties. Yet, almost all fungi may produce mycotoxins, and our review of the literature

finds that *Stachybotrys* has been detected in both outdoor ambient air and indoor air of noncomplaint structures, that is, those without reported adverse health effects.^(34,39,43)

DISCUSSION

Some interesting points are illustrated by the data compiled in this review. First, the concentrations and variety of species detected may vary substantially when different sampling techniques are used. As noted in Table III, Dungy et al. have used two different types of samplers, Anderson and Roto-rod.⁽³⁵⁾ Total outdoor spores detected were 1306 and 1728 spores/m³, respectively. Total indoor spore counts were reported as 1040 and 655 spores/m³, respectively.

Second, the extent of variability among seasonal concentrations can be affected by the general overall climatic conditions of a geographic location. Table V illustrates seasonal differences at a variety of locations. Also, among geographic locations there is wide variability in concentrations detected both indoors and outdoors. Table VI further demonstrates a similar variability in ratios of indoor and outdoor concentrations with ratios ranging from 8 to 330%.

Third, the concentrations detected in noncomplaint residential buildings are much higher than those detected in noncomplaint commercial buildings. This finding is not unexpected. Traffic between outdoors and indoors would be much greater in residential structures than similar movements in commercial office buildings. Also the presence of pets, potential differences in cleaning schedules (e.g., offices may have daily cleaning schedules, whereas residents may have a less frequent cleaning schedule), and extent of

TABLE V. Seasonal Changes Within a Geographical Location

Location	Season	Concentration (indoor/ outdoor) ^a
<i>Commercial</i>		
North Carolina ⁽³⁶⁾	January–July	50/NR
	July–December	127/NR
Southern USA ⁽³⁸⁾	winter	46/141
	spring	160/1977
	summer	176/1034
	fall	138/1186
<i>Residential</i>		
New Haven, Connecticut ⁽¹⁷⁾	winter	801/505
	spring	930/830
	summer	998/1198
	fall	884/607
Taipei, Taiwan ⁽⁴²⁾	winter	388/411
	summer	566/557
East Tennessee ⁽⁴³⁾	winter	215/65
	summer	1490/1640
Finland ⁽⁴⁴⁾	winter	40/20
	summer	410/950
Houston, Texas ⁽⁴⁷⁾	winter	17/45
	spring	123/880
	summer	268/837
El Paso, Texas ⁽⁴⁷⁾	spring	36/86
	summer	38/60
San Francisco, California ⁽⁴⁵⁾	winter	351/376
	spring	165/539
	summer	148/184
	fall	376/480

^aNR = not reported.

natural ventilation via open windows could explain the greater concentrations detected in residential structures.

Fourth, a diverse range of fungi is detected in the indoor ambient air of noncomplaint structures. Too often investigators of complaint buildings argue that genera or species differences detected between indoors and outdoors are critical health variables. However, as illustrated in Tables III and IV, the listed genera in these studies are detected in both environments. The amounts detected between indoor and outdoor concentrations, however, can vary substantially. For example, Ren and Leaderer's data on concentrations of *Penicillium* reveal that the levels outdoors varied between 44 and 348 CFU/m³ and those detected indoors ranged from 0 to 653 CFU/m³.⁽⁴⁰⁾ Similarly, *Aspergillus* concentrations ranged from 44 to 306 CFU/m³ in indoor samples, but that genus was not detected in the outdoor ambient air. Although it may be true, as has been argued, that clear-cut and persistent indoor/outdoor differences in genera suggest an indoor source of growth and possible water damage, little evidence exists that such differences connote a health risk.

Finally, but perhaps the most important observation from these data, is the fact that the concentrations detected in noncomplaint residential and commercial buildings belie suggested guidelines established by various organizations. Seventy-five percent of the noncomplaint residences included in Table IV had average indoor concentrations exceeding 500 CFU/m³. Yet the various suggested guidelines illustrated in Table I consider such levels to require investigation and remediation when occupants have nonspecific

TABLE VI. Ratios of Indoor and Outdoor Fungal Concentrations (CFU/m³)

Reference	Indoor/Outdoor Ratio
<i>Commercial Structures:</i>	
Atlantic states ⁽²⁸⁾	0.83
Taipei, Taiwan ⁽²⁵⁾	1.17
Houston-Galveston, Texas ⁽²⁶⁾	0.18
Paris, France ⁽³⁷⁾	0.18
Southern USA ⁽³⁸⁾	0.08 (spring)
	0.17 (summer)
	0.12 (fall)
	0.33 (winter)
Muscle Shoals, Alabama ⁽³⁹⁾	0.08
Chattanooga, Tennessee ⁽³⁸⁾	0.17
Knoxville, Tennessee ⁽³⁸⁾	0.11
<i>Noncomplaint Residential Structures:</i>	
New Haven, Connecticut ⁽⁴⁰⁾	1.37 (October)
New Haven, Connecticut ⁽¹⁷⁾	1.59 (winter)
	1.12 (spring)
	0.83 (summer)
	1.46 (fall)
Midwest USA ⁽⁴¹⁾	0.29 (April–December)
Netherlands ⁽¹⁴⁾	0.71 (May)
Taipei, Taiwan ⁽⁴²⁾	1.02 (summer)
	0.94 (winter)
Honolulu, Hawaii ⁽²⁴⁾	0.78 (with air conditioning)
	1.12 (no air conditioning)
East Tennessee ⁽⁴³⁾	3.30 (winter)
	0.91 (summer)
Finland ⁽⁴⁴⁾	0.43 (summer)
	2.00 (winter)
San Francisco, California ⁽⁴⁵⁾	0.31 (March)
	0.80 (June)
	0.78 (September)
	0.93 (December)
Toronto, Canada ⁽⁴⁶⁾	0.66 (July–August)
Houston, Texas ⁽⁴⁷⁾	0.14 (spring)
	0.32 (summer)
	0.38 (winter)
	0.42 (spring)
El Paso, Texas ⁽⁴⁷⁾	0.63 (summer)
Taipei, Taiwan ⁽⁴⁸⁾	1.21 (May–June)
Tai Chi, Taiwan ⁽⁴⁸⁾	1.03 (May–June)
Finland ⁽⁵⁰⁾	0.41
Southern Taiwan ⁽⁵¹⁾	0.76 (winter)
	0.91 (winter)
	0.87 (summer)
	1.17 (summer)
Netherlands ⁽⁵²⁾	0.80
Taipei, Taiwan ⁽⁴⁹⁾	0.99 (July–September)

health complaints (e.g., headaches, fatigue, cough). The Occupational Safety and Health Administration guideline indicates that levels greater than 1000 CFU/m³ are unacceptable.⁽⁵⁷⁾ However, 43% of the residential structures in the present data set had concentrations above that level. Additionally, occupational exposures to fungi are orders of magnitude above these levels. The data gathered in this review of the literature strongly suggest that current recommendations do not reflect concentrations reported in non-complaint structures or those detected in outdoor environments, nor do they reflect levels that reasonably could be associated with adverse health outcomes.

SUMMARY

Fungal concentrations reported for commercial and residential structures without associated health complaints are much higher than levels often detected in buildings with complaints of nonspecific health symptoms. The range of genera detected in noncomplaint structures is broad and generally similar to that identified in outdoor air samples. The reported concentrations vary within a geographic location depending on the season and also vary among geographic locations. Therefore, a scientifically sound evaluation of indoor fungal concentrations in complaint structures should require comparison with levels in noncomplaint buildings collected at the same time. Additionally, it is necessary to reconsider the validity of current recommendations for acceptable indoor fungal concentrations. As illustrated in this review, these recommendations do not reflect concentrations observed in noncomplaint structures, and thus, their use can lead to remediation that may not be necessary from a health perspective.

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