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Chapter 6

INTERPRETATION OF BIOLOGICAL DATA ON INDOOR AIR QUALITY: PRESENCE DOESN'T EQUATE TO SIGNIFICANCE

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ABSTRACT

Based on results of residential air tests, homeowners may be advised that a significant mold problem exists in their home, and that extensive cleanup or remediation is required. Those living in such homes may attribute perceived or actual health conditions to reported levels of, or exposure to, molds. Consensus numerical guidelines or agency standards for evaluation of mold exposure do not exist. Toxicological evidence does not support a contention that healthy individuals are at significant health risk from common mold levels. Putative sensitive populations are not well-documented, and the literature is controversial or inconsistent. Factors influencing likelihood that indoor mold exposure contributes to adverse health effects include indoor vs. outdoor mold levels, concentration/types of mold species indoors vs. outdoors, number of samples collected indoors vs. outdoors, and number of sample events. For situations in which prevalence and speciation of indoor mold is indistinguishable from or less than outdoors, adverse health effects cannot be solely or predominantly a result of indoor exposures. Mold concentration data are reviewed from several residences where mold test results were presented as indicating a "mold problem". We conclude, despite the fact that extensive and expensive remediation efforts and protracted litigation occurred, these data do not support allegations of adverse health effects from potential exposure to indoor mold in the observed homes.

Keywords: Mold, air, exposure, home, toxicology, health, litigation

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1. INTRODUCTION

There are numerous human conditions that have been associated with mold and these manifest specific signs, symptoms, and established etiologies. There are, however, many who believe that exposure to mold can also cause multiple, poorly defined syndromes, and these weakly supported beliefs have proven profitable for some (Pettigrew et al., 2010). "Mold related illness" is a highly controversial condition consisting primarily of nonspecific symptoms such as headache, rhinorrhea, fatigue, memory loss, and eye irritation. Although inhalation of high concentrations of mold spores in special cases has been reported to cause respiratory distress such as hypersensitivity pneumonitis, allergic rhinitis, and asthma exacerbation, the relationship between mold exposure and clinical outcomes remains unclear (Edmondson et al., 2009).

Litigation related to mold typically involves bold assertions that exposure to indoor molds has caused a variety of ill-defined illnesses (Bush et al., 2006). The current literature does not provide compelling evidence that exposure at levels expected in most indoor environments where mold is detectable are likely to result in measurable health effects (Gots and Pirages, 2002). Simply stated, the fact that mold is detectably present does not constitute evidence of meaningful exposure. For example, detection of toxigenic fungi in indoor environments does not necessarily indicate the presence of mycotoxins, unless those substances actually are measured (Khalili and Bardana, 2005).

An understanding of the capabilities and limitations of fungal air data is of great importance, given the role that it plays in supporting the opinions of experts who may be involved in claims of environmental damage or health effects (Spicer et al., 2005). Consensus numerical guidelines or agency standards for evaluation of mold exposures with regard to effects on human health do not exist (Srikanth et al., 2008; Storey et al., 2004), although numerous suggested recommendations have been proposed (Rao et al., 1996). Without an established numerical standard which defines “clean”, “acceptable”, or “contaminated”, the characterization of a building with respect to fungi must be conducted on a relative basis. That is, data from a reference environment that an investigator has good reason to believe is “acceptable” can be compared to a building that is suspected of being problematic. For air samples, the comparison most often used is that of outdoor air, under the paradigm that a building is performing adequately if the indoor environment is not significantly different from the general ambient environment in terms of microbiota.

Certain types of fungi have been associated with various health effects in some circumstances. Because of the problem in defining a “significant”

difference between a suspect indoor environment and the reference environment, any detection of air-borne fungal types associated with potential health effects often results in the subjective statement that an indoor environment is "contaminated". As a result, the normal rules of scientific evidence which demand an objective and quantifiable treatment of data often are overlooked (Spicer et al., 2005).

2. OBSERVED RESIDENTIAL MOLD CONCENTRATIONS

Indoor and outdoor mold spore concentration data for five residential buildings (single family houses or apartments) were available for evaluation. Three of the buildings had reported evidence of water intrusion or a plumbing leak and water damage, as determined by a "mold inspector" hired by the building occupants or their representatives. Two of the buildings had evidence of exterior water damage, but no reported evidence of interior water damage (Table 1).

Table 1. Water Damage/Elevated Mold Matrix

Residence	Evidence of Interior Water Damage (Y/N)	Evidence of Exterior Water Damage (Y/N)	Heath Effects Reported (Y/N)	Elevated Aspergillus/ Penicillium (Y/N)
1	Y	Y	Y	Y
2	N	Y	Y	Y
3	Y	N	Y	Y
4	N	Y	Y	Y
5	Y	Y	Y	N

A number of air samples for mold analysis were collected from each building, and from outside locations in each instance, for comparison purposes. The results of the mold sampling results for each building are presented in Table 2 through Table 6. Sampling locations indoors included bedrooms, dining rooms, kitchens, living/family rooms, bathrooms, closets, and hallways.

The mold sampling data do not indicate that any significant difference exists between the concentrations in indoor air compared to those in outdoor air. In fact, the geometric means of the total mold spore concentrations in the outdoor air exceed those of the indoor air in Residences 1-5 (Tables 2-6) by two to four-fold (Table 7).

Table 2. Residence 1: Outside/Inside Mold Spore Concentrations

Sample Name	Outside	Outside	Outside	Outside	Kitchen	Kitchen	Dining Room
Date	5/29/08	5/29/08	7/18/08	7/18/08	7/18/08	5/29/08	5/29/08
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria		40					
Ascospores	2720	2160	640	427	27	440	520
Aspergillus/Penicillium	640	720			507	1080	2120
Basidiospores	840	640	3413	2560	67	40	80
Bipolaris/Drechslera	40	40			27		
Chaetomium						80	
Cladosporium	520	360	13	893	80	160	120
Curvularia			13		27	40	
Epicoccum		40			27		40
Myxomycetes	40			133	133		
Nigrospora							
Pithomyces							
Total	4800	4000	4079	4013	895	1840	2880

Sample Name	Family Room	Upstairs Hall	Master Bedroom	Master Bedroom	Master Bathroom	Living Room	Bedroom
Date	5/29/08	5/29/08	5/29/08	7/18/08	5/29/08	7/18/08	7/18/08
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria	40						40
Ascospores	440	560	360	27	320	13	13
Aspergillus/Penicillium	1680	1280	1560	293	2720	533	480
Basidiospores	40	40			80	27	13
Bipolaris/Drechslera				40		27	93
Chaetomium							
Cladosporium	360	160	200	13	480	40	320
Curvularia				93		67	120
Epicoccum	40	40				27	53
Myxomycetes				80		53	67
Nigrospora							13
Pithomyces							13
Total	2600	2080	2120	546	3600	787	1225

Table 3. Residence 2: Outside/Inside Mold Spore Concentrations

Sample Name	Outside	Outside	Outside	Dining Room	Family Room	Bedroom	Bedroom	Bedroom	Bedroom	Front Room
Date	7/25/08	7/25/08	3/18/09	7/25/08	7/25/08	7/25/08	3/18/09	7/25/08	3/18/09	3/18/09
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria	80		53				80		173	40
Ascospores	3120	2880	40	320	480	680	293	600	333	93
Aspergillus/Penicillium	680	840		4280	3080	1640	640	2760	213	880
Basidiospores	840	640	27	80	80	40	93	80	53	27
Bipolaris/Drechslera									147	13
Chaetomium							13			
Cladosporium	680	1120	3627	320	240	440	867	360	267	173
Curvularia	40	80	27	40		240	240	200	213	27
Epicoccum			693				80	40	267	107
Myxomycetes	80	160		40				80	133	67
Nigrospora			27						13	
Pithomyces							13		133	13
Total	5520	5720	4494	5080	3880	3040	2319	4120	1945	1440

Sample Name	Kitchen	Kitchen	Laundry Room	Master B/R	Master Bath	MBR-2nd Floor	Rear Room	Study	Upstairs Bath
Date	3/18/09	7/25/08	7/25/08	7/25/08	7/25/08	3/18/09	3/18/09	7/25/08	7/25/08
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria	27					147	120		
Ascospores	107	320	360	360	280	373	67	360	240
Aspergillus/Penicillium	453	640	520	3000	1120	280	613	3640	2080
Basidiospores	13	40	120		40	27		40	
Bipolaris/Drechslera	27					53	40		
Chaetomium					40				
Cladosporium	160	200	320	280	160	307	360	160	280
Curvularia	40	40	120	160		213	67	40	
Epicoccum	93					107	240		
Myxomycetes	80	40		40		133	27		40
Nigrospora	27					27	40		
Pithomyces	27					107			
Total	1054	1280	1440	3840	1640	1774	1574	4240	2640

Table 4. Residence 3: Outside/Inside Mold Spore Concentrations

Sample Name Date	Outside 6/9/08	Outside 11/ 11/ 08	Outside 6/9/08	Master Bath 6/9/08	Master BR 11/ 11/ 08	Master BR 6/9/08	Master BR 6/9/08
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria	40	13					40
Ascospores		120	120			40	40
Aspergillus/Penicillium	240	40	40		507	120	960
Basidiospores	760	733	440	80	53		
Bipolaris/Drechslera					13		40
Chaetomium							
Cladosporium	200	213	880	40	13	120	40
Curvularia							
Epicoccum					40		
Myxomycetes/Smuts		13					40
Nigrospora							
Pithomyces					13		
Total	1240	1132	1480	120	639	280	1160

Sample Name Date	Master BR 6/9/08	Guest BR 6/9/08	Kitchen 6/9/08	Corridor Bath 6/9/08	2nd BR 11/ 11/ 08	Living Room 11/ 11/ 08
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria						13
Ascospores		40			40	27
Aspergillus/Penicillium					4320	440
Basidiospores				40	40	13
Bipolaris/Drechslera					13	
Chaetomium						13
Cladosporium	80	40	120	40	27	120
Curvularia						27
Epicoccum						
Myxomycetes/Smuts			120			13
Nigrospora						
Pithomyces						
Total	80	80	240	80	4440	666

Table 5. Residence 4: Outside/Inside Mold Spore Concentrations

Sample Name Date	Outside 7/1/08	Outside 7/1/08	Outside 7/19/08	Outside 7/19/08	Den 7/1/08	Den 7/19/08	Kitchen 7/1/08
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria		40	27		40	93	
Ascospores	3680	3120	1120	560	840	133	520
Aspergillus/Penicillium	320	520		53	240	520	760
Basidiospores	480	920	1840	893	120	107	80
Bipolaris/Drechslera						27	
Chaetomium							
Cladosporium	1280	1080	120	200	320	120	200
Curvularia	160	40				147	
Epicoccum				13		93	
Myxomycetes	120	80	67	80		413	40
Nigrospora							
Pithomyces							
Total	6040	5800	3174	1799	1560	1653	1600

Sample Name Date	Kitchen 7/19/08	Front BR 7/1/08	Master BR 7/19/08	Front BR 7/1/08	Front BR 7/19/08	Garage BR 7/19/08
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria	13		13			
Ascospores	107	960	133	600	53	267
Aspergillus/Penicillium	1187	1240	333	720	320	93
Basidiospores	133	160	53		27	173
Bipolaris/Drechslera		40	53	40	120	107
Chaetomium						
Cladosporium	13	280	27	160	53	67
Curvularia	53	40	27		27	80
Epicoccum	13				13	13
Myxomycetes	93		93	40	27	80
Nigrospora						13
Pithomyces					13	13
Total	1612	2720	732	1560	653	906

Table 6. Residence 5: Outside/Inside Mold Spore Concentrations

Sample ID	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor
Date	8/15/03	10/22/03	2/3/05	2/3/05	9/17/03	9/25/03	9/30/03	10/6/03	8/9/04	8/9/04	8/9/04	12/3/03	12/3/03	12/3/03	2/15/07
Organisms	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria								46	26	13	34	7			
Ascospores	53	213			91		46		1322	2737	863	27		60	173
Aspergillus/Penicillium	2773	213		53	46	46			1293	501	324	20			
Basidiospores			107	67		46	91		3140	3456	1745	7		140	640
Bipolaris									7		27				
Chaetomium											7				
Cladosporium				53		91	46	46	475	587	148	107	337610	67	493
Curvularia									92	132	27		19581		107
Epicoccum															27
Myxomycetes		53			91	46	46		145	66	40	7		20	27
Nigrospora						46			20	26	34	7	39163		13
Pithomyces											7				
Total	2826	479	107	173	228	275	229	92	6520	7518	3256	182	396354	287	1480

Sample ID	Den	Dining Rm	Dining Rm	Dining Rm	Dining Rm	Dining Rm	East BR	Guest BR	Guest BR	Hall	Kitchen	Kitchen	Kitchen	Kitchen	Kitchen
Date	11/19/04	10/22/03	9/2/03	12/3/03	11/19/04	2/15/07	9/2/03	2/3/05	12/3/03	8/9/04	10/22/03	2/3/05	9/25/03	9/30/03	10/6/03
Organisms	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria										47					
Ascospores	13	213				53		27	41		107	40			
Aspergillus/Penicillium	67	373		54	53	13		53	61	27	213	53		46	
Basidiospores	13			34		213		387	74	94		80			
Bipolaris				7					14						
Chaetomium															
Cladosporium				34		680		53	108	47		53			46
Curvularia	13	53	46	14	13		46	13		40	53	27	46		
Epicoccum															
Myxomycetes				27	53			13	7						
Nigrospora				7				13		7	53				
Pithomyces									7						
Total	106	639	46	177	119	959	46	559	312	262	426	253	46	46	46

Sample ID	Kitchen	Living Rm	Living Rm	Living Rm	Living Rm	Living Rm	LR Chase	Master Bath	Master BR	Master BR	Master BR	Master BR	Master BR	Master BR	Master BR
Date	11/19/04	10/22/03	2/3/05	9/25/03	12/3/03	11/19/04	8/9/04	11/19/04	10/22/03	2/3/05	9/17/03	8/9/04	8/9/04	12/3/03	11/19/04
Organisms	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria												7			
Ascospores		160			74	13			107		46	40	59	14	
Aspergillus/Penicillium	627	213	53	46	209	307		120	160	53		34	40	14	573
Basidiospores	27		107		88		101		53	160		81	53	47	
Bipolaris															
Chaetomium					7										
Cladosporium			53	46	74				267	160		67	165	20	80
Curvularia		53			7				53			20	46	14	
Epicoccum															
Myxomycetes	13	53			27	13			53				7	20	
Nigrospora														7	
Pithomyces	13				7							7		7	
Total	680	479	213	92	493	333	101	120	693	373	46	256	370	143	653

Table 7. Mold Measurement Summary

	Residence 1		Residence 2		Residence 3		Residence 4		Residence 5	
	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outdoor	Indoor
	Geometric Mean	Geometric Mean	Geometric Mean	Geometric Mean	Geometric Mean	Geometric Mean	Geometric Mean	Geometric Mean	Geometric Mean	Geometric Mean
Organism	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3	Spores/m3
Alternaria	40	40	65	80	23	23	33	28	21	18
Ascospores	1,126	123	711	281	120	37	1,638	266	183	48
Aspergillus/Penicillium	679	977	756	1,102	73	644	207	464	187	82
Basidiospores	1,472	42	244	48	626	39	923	93	227	74
Bipolaris/Drechslera	40	41	NA	41	NA	19	NA	56	14	10
Chaetomium	NA	80	NA	23	NA	13	NA	NA	7	7
Cladosporium	216	130	1,403	276	335	51	427	91	268	78
Curvularia	13	60	44	94	NA	27	80	51	233	27
Epicoccum	40	37	693	112	NA	40	13	21	27	NA
Myxomycetes	73	78	113	59	13	40	85	74	41	20
Nigrospora	NA	13	27	25	NA	NA	NA	13	60	12
Pithomyces	NA	13	NA	37	NA	13	NA	13	7	8
Total	4,210	1,590	5,216	2,300	1,276	313	3,761	1,321	886	204

The geometric means for a number of common indoor mold genera such as *Ascospores*, *Basidiospores*, *Cladosporium*, *Epicoccum*, and *Myxomycetes* are typically less than the concentrations detected in outdoor air. Indeed, the only mold type for which the indoor air concentrations were regularly greater than the outdoor concentrations was the *Aspergillus/Penicillium* category. *Aspergillu*s and *Penicillium* grow mainly indoors (Ren et al., 2001) so their presence at a higher indoor concentration is not unexpected. Even for these molds, however, the indoor concentration was less than the outdoor concentration in one residence that had clear evidence of water intrusion and visible mold (Table 1).

Among the plaintiffs occupying each of the buildings a wide variety of adverse health effects were alleged to have been caused by exposure to molds in the indoor environment. These effects included multiple sclerosis, asthma, brain lesions, immune effects, celiac disease, ear infections, and lung cancer. Litigation regarding these health effects was initiated by occupants of each of these buildings, or their representatives. Although exposure to mold has been reported to be associated with exacerbations of some of these health effects (e.g., asthma), none of these have been demonstrated to be caused by indoor air mold exposure.

3. DISCUSSION

Although exposure to mold has been reported to be associated with a variety of health effects in humans, whether these effects can be attributed solely or even to a greater degree from indoor exposures depends on the relative magnitude of the potential exposures between indoor air and outdoor air. In the cases presented here, it is apparent that the potential risks for adverse health effects from exposure to mold indoors are not significantly different than those from mold exposure in outdoor air.

Although consensus numerical guidelines or agency standards for evaluation of mold exposures with regard to effects on human health are not available (Srikanth et al., 2008; Storey et al., 2004), there have been suggestions for "acceptance" or "post-remedial clearance" criteria for Aspergillus/Penicillium spore concentrations at less than 750 counts/m^3 (Baxter et al., 2005) or less than 666 counts/m^3 (Robertson and Horner, 2004). Highly sensitive individuals would be expected to react to relatively low concentrations regardless of whether these are present indoors or in the outside air. The point at which mold contamination becomes a threat to health is not known with precision (Robbins et al., 2000). From the perspective of reports of health effects caused by indoor mold exposure, the question is whether the indoor air concentration of mold spores represents a significantly elevated risk above that of concomitant outdoor environments so that any suggested health effects can be clearly attributed to those indoor exposures.

To support an allegation of adverse health effects, the indoor mold air concentrations must exceed those found outdoors and the concentrations of individual mold species or genera found indoors should also exceed those found outdoors. Typical clean building total mold spore concentrations have been reported to be less than 4,000 spores/m^3 in approximately 90% of buildings sampled. Even so, results of airborne fungal analyses alone may not be sufficient to classify a building as "clean" or "moldy" without a thorough evaluation (Baxter et al., 2005).

Concentrations of *Aspergillus/Penicillium* in "clean" buildings have been reported in a number of instances. Codina et al. (2008) reported an indoor concentration range for *Aspergillus/Penicillium* of 0-656 spores/m^3 compared to an outdoor range of 0-3,250 spores/m^3. Barnes et al. (2007) reported a maximum post-remediation *Aspergillus/Penicillium* concentration of 10,912 spores/m^3. MacIntosh et al. (2006) reported a maximum indoor *Aspergillus/Penicillium* concentration of 667 spores/m^3 compared to a maximum outdoor concentration of 5,200 spores/m^3. Finally, Kozak et al. (1985) reported an indoor concentration range for *Penicillium* species of 0-4,737 spores/m^3 and a concentration range for *Aspergillus* species of 0-306 spores/m^3 in Southern California homes. The ranges of *Aspergillus/Penicillium* concentrations measured in the evaluated residences are well within those reported in the literature.

4. CONCLUSION

For each of the residences that have been evaluated, the building occupants or their representatives have alleged a variety of adverse health effects and have initiated litigation on the basis of health concerns and building damage. In each instance, the mold air concentrations were represented to the building occupants

as elevated, although for two of the buildings, competing "experts" disagreed regarding whether the mold concentrations were, in fact, elevated sufficiently to represent a "mold problem".

In four of the five buildings, remediation to reduce mold concentrations was recommended. In the fifth building, there was a recommendation to dispose of porous household items even though there was no evidence of water intrusion or inside water leakage.

Despite reports of adverse health effects, the concentrations of mold spores detected in the indoor air samples in each of these residences do not support a conclusion that indoor mold exposure would have contributed to any health effects to a greater extent than that from outdoor exposures.

The subjective judgments of mold experts must be addressed by an objective evaluation of the mold data. For instances where litigation has alleged that adverse health effects resulted from exposure to mold, a demonstration that indoor mold concentrations significantly exceed those outdoors can provide essential support. Careful evaluation of the data in cases such as those presented here can indicate that there is little, if any, support for the common suggestion that the presence of mold in the indoor environment is the cause of adverse health effects. The first step in countering the subjective claims of some mold evaluators regarding the presence of a “mold problem” and the subsequent recommendation for expensive remediation, therefore, is a rigorous evaluation of the mold concentration data.

Comparison of mold spores in indoor vs. outdoor air is the first, limited, step in a rigorous evaluation. More detailed analysis of other airborne components (e.g., volatiles, mycotoxins) is essential if their presence is being included in suggestions concerning adverse health effects.

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