



Environmental Evaluation of a Moldy Apartment Complex

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Apartment complex scenario

- ▶ Occurred during COVID-19 uncertainties with lockdowns in the Mid Atlantic region

Apartment complex scenario

- ▶ Worked with tenants vs the landlord with a focus on characterizing the environment vs aiding arguments
- ▶ Old brick buildings with a wood frame partially renovated

Purpose of apartment complex inspection

- ▶ Assess the condition of the property for complaints related to indoor mold
- ▶ Ask for past water damage history if known
- ▶ Ask for musty odor complaints
- ▶ Look for physical signs of past water damage

Measurements

- ▶ Moisture meter measurements
(DOI: 10.1016/j.atmosenv.2005.05.042)
- ▶ Temperature & humidity measurements
(DOI: 10.1128/AEM.07879-11)
- ▶ Particle counts with a laser particle counter
(DOI: 10.1016/j.atmosenv.2007.06.027)

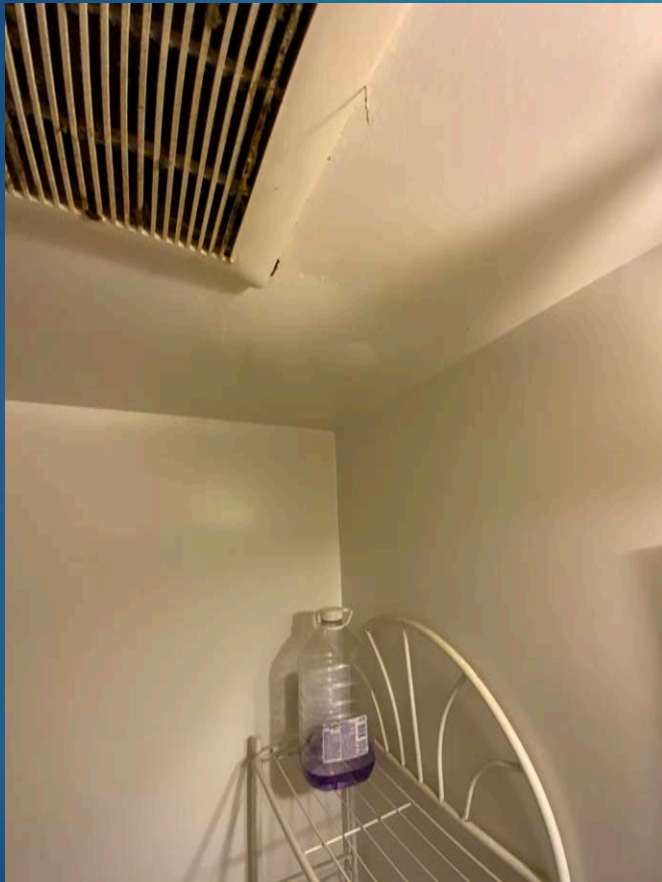
Sample methods not used

- ▶ Spore trap air samples (Settled Science: gravity wins the battle indoors)
- ▶ Surface tape-lifts (growth structures captured at best)
- ▶ Surface swabs analyzed by direct microscopy only (Penicillium/Aspergillus-like is too vague)

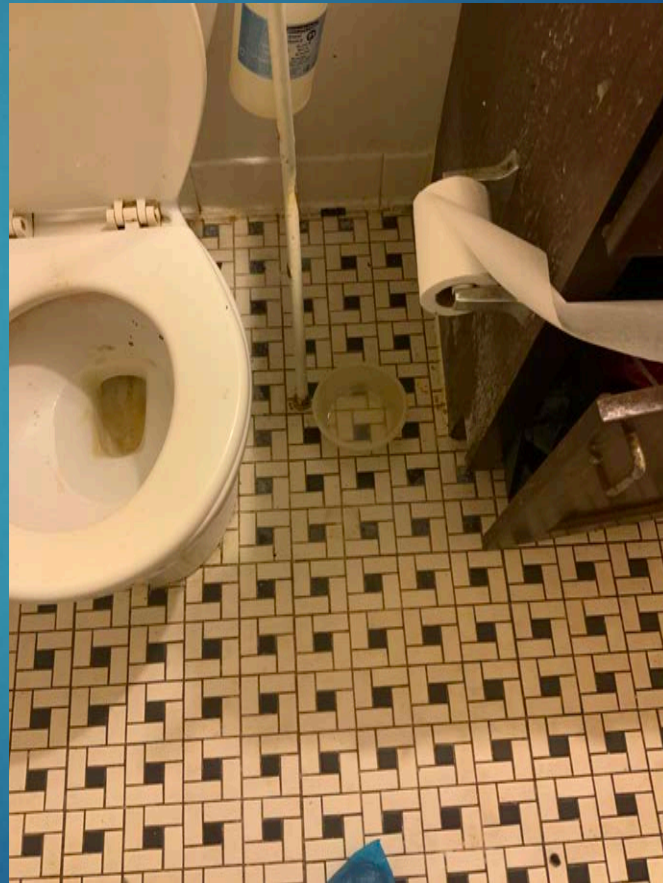
Sampling

- ▶ Culturable with fungal micro-vacuum and surface swab samples (DOI: 10.1289/ehp.10355)
- ▶ Mold specific quantitative polymerase chain reaction (DOI: 10.1080/15459624.2020.1844892)
- ▶ Lipopolysaccharides (endotoxins: LAL) limulus amoebocyte lysate test

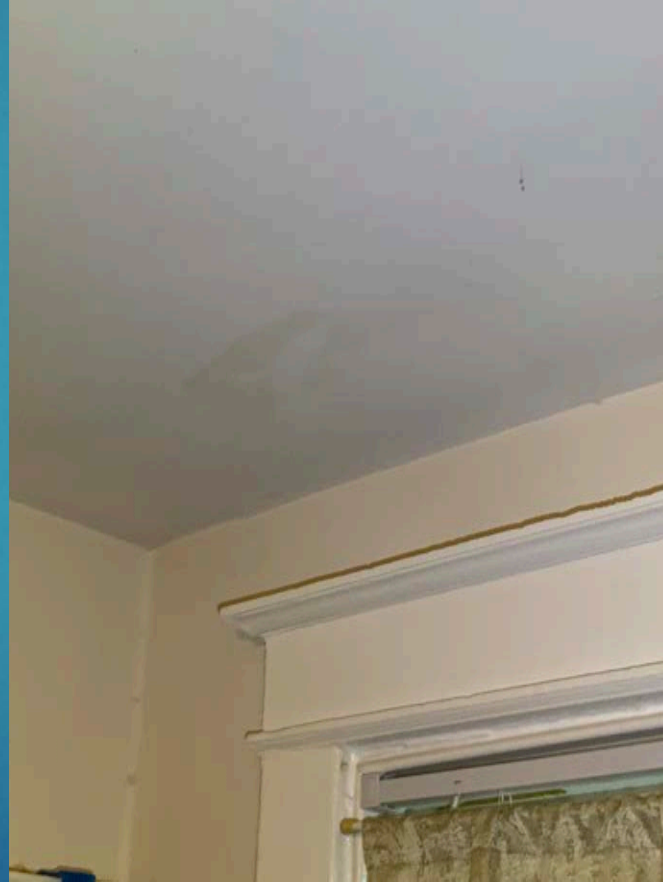
Moisture Sources



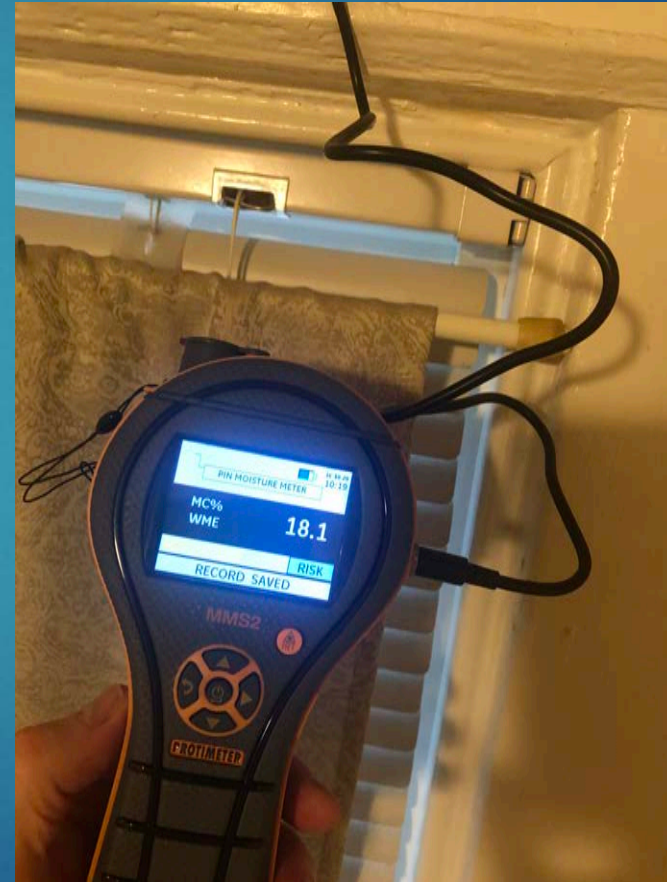
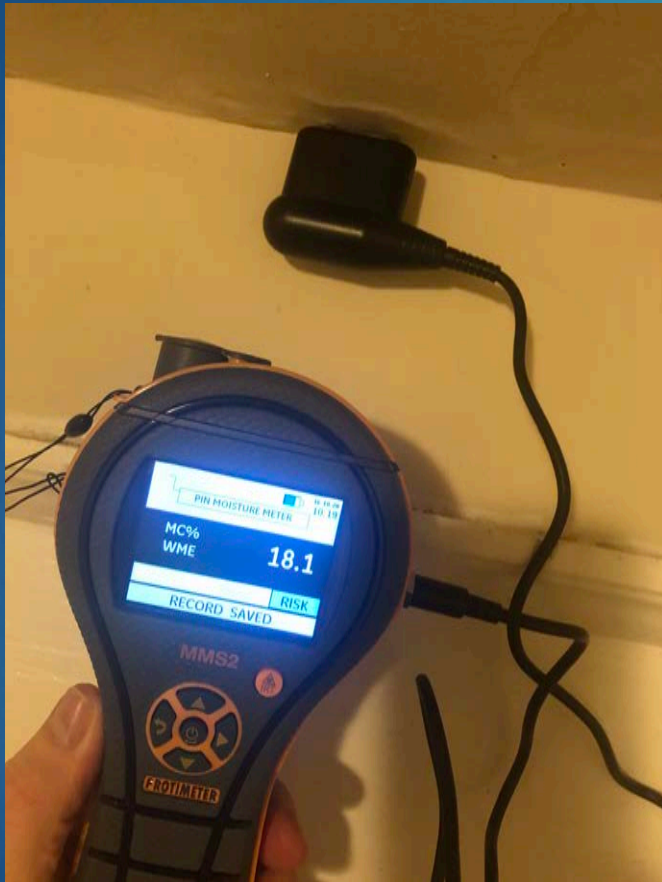
Moisture sources



Water sources



Water sources



Water sources and air movement



Water sources and air movement

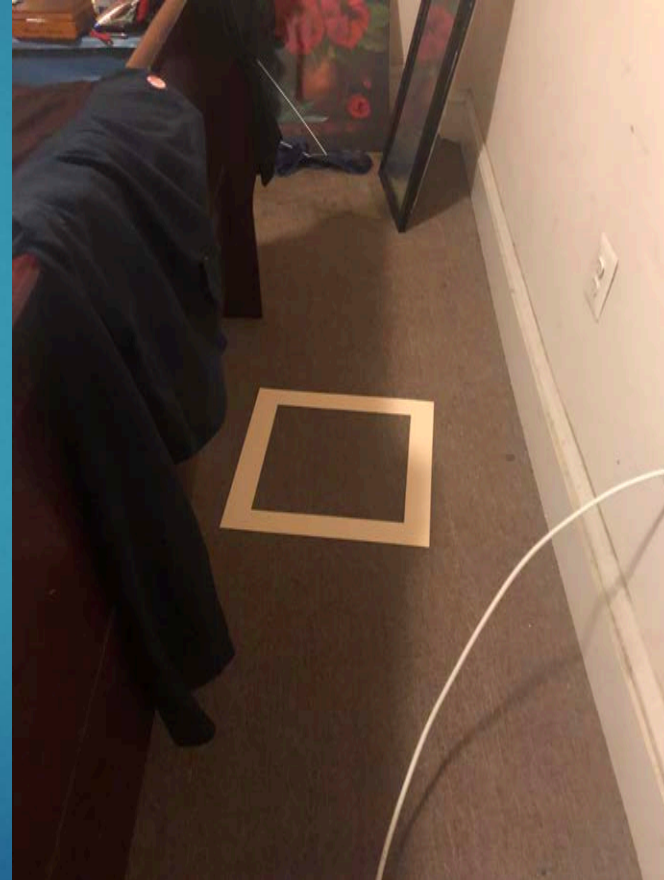


Test the theory

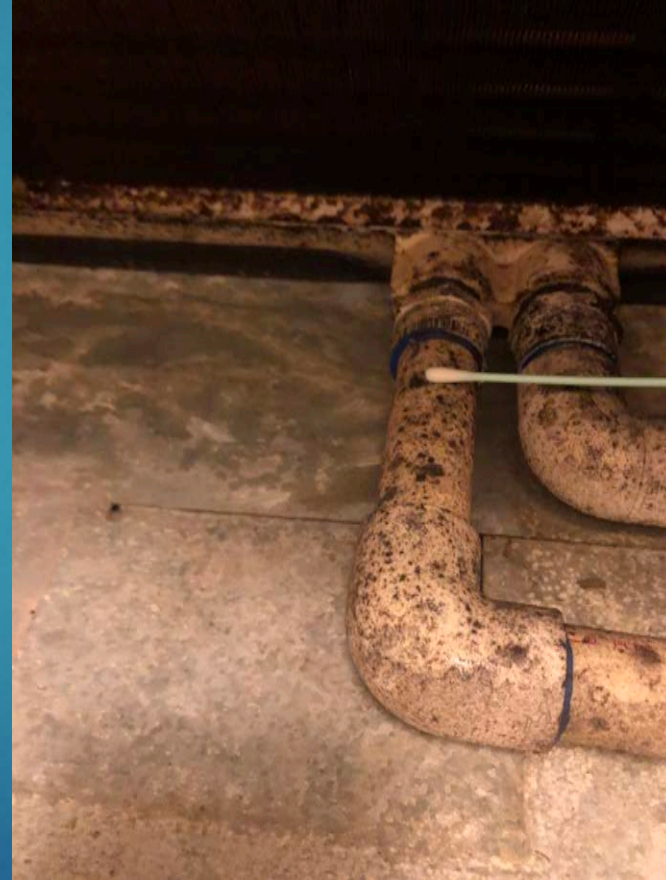


- ▶ Endotoxins are cell wall material from gram negative bacteria that desiccate into smaller fragments
- ▶ These smaller fragments can behave like smoke
- ▶ Betaproteobacteria and Gammaproteobacteria can produce the highest concentrations of endotoxins

Representative screening samples help show trends



Lawyers unlock closets: water sources & air movement

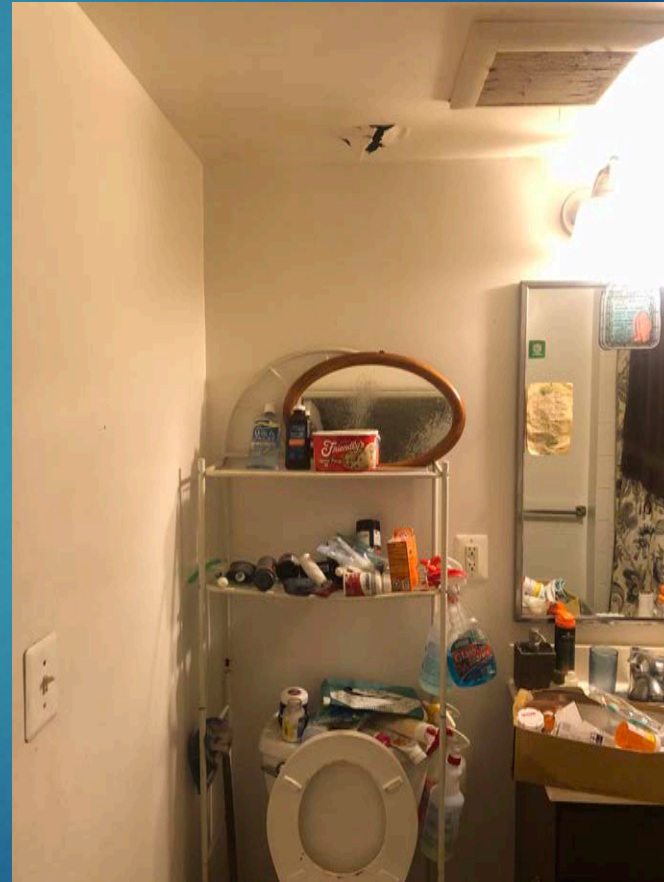


HVAC closet surface swabs

- ▶ 1 square inch of the upper left corner of the cooling coil where filter bypass occurs leading to accumulation. (top)
- ▶ 1 square inch on the top of the condensate pipe where return air may dislodge growth into the coil assembly and beyond. (bottom)

1	CMA	10,000x	<i>Aureobasidium pullulans</i>	2	20,000	1%	
			<i>Cladosporium</i> spp.	11	110,000	5%	
			<i>Rhodotorula glutinis</i>	132	1,300,000	55%	
			<i>Rhodotorula minuta</i>	31	310,000	13%	
			<i>Rhodotorula mucilaginosa</i>	18	180,000	7%	
			yeasts	47	470,000	20%	
	Total					2,400,000	
	DG18	10,000x	<i>Aureobasidium pullulans</i>	2	20,000	1%	
			<i>Cladosporium</i> spp.	4	40,000	2%	
			<i>Rhodotorula glutinis</i>	118	1,200,000	58%	
			<i>Rhodotorula minuta</i>	34	340,000	17%	
			yeasts	45	450,000	22%	
Total					2,100,000		
MEA	10,000x	<i>Cladosporium sphaerospermum</i>	7	70,000	4%		
		<i>Rhodotorula glutinis</i>	94	940,000	53%		
		<i>Rhodotorula minuta</i>	9	90,000	5%		
		<i>Rhodotorula mucilaginosa</i>	11	110,000	6%		
		<i>Sporobolomyces salmonicolor</i>	5	50,000	3%		
		yeasts	52	520,000	29%		
Total					1,800,000		
1	CMA	10,000x	<i>Cladosporium</i> spp.	39	390,000	100%	
	Total					390,000	
	DG18	10,000x	<i>Cladosporium</i> spp.	27	270,000	100%	
Total					270,000		
1	MEA	10,000x	<i>Aureobasidium pullulans</i>	1	10,000	3%	
			<i>Cladosporium sphaerospermum</i>	28	280,000	97%	
Total					290,000		

Water management?



Comparison of AHHS1 2006 vs AHHS 2019

Note: HERTSMI-2 was not developed by EPA or HUD

► Based on single family homes in every state in the mainland except CO in the AHHS2 from 2019 with data released in late 2020 and published in 2021

ERMI (reference data from published studies in 2007 & 2021)	AHHS 1 GM CE/mg	AHHS 1 GM Log 10	AHHS 2 GM CE/mg	AHHS 2 GM Log 10
<i>Aspergillus penicillioides</i>	91 (4)	1.96	140 (6)	2.15
<i>Aspergillus versicolor</i>	2 (0)	0.3	14 (4)	1.15
<i>Chaetomium globosum</i>	2 (0)	0.3	3 (0)	0.3
<i>Stachybotrys chartarum</i>	2 (0)	0.3	1 (0)	0
<i>Wallemia sebi</i>	18 (0)	1.26	155 (4)	2.19
HERTSMI-2 score	4		14	
Relevance	Low		Moderate	
Other Group 1 Organisms				
<i>Aspergillus flavus</i> (a)	2	0.3	1	0
<i>Aspergillus fumigatus</i> (b)	3	0.48	2	0.3
<i>Aspergillus niger</i> (c)	4	0.6	18	1.26
<i>Aspergillus ochraceus</i> (d)	2	0.3	3	0.48
<i>Aspergillus restrictus</i> (e)	2	0.3	6	0.78
<i>Aspergillus sclerotiorum</i>	2	0.3	2	0.3
<i>Aspergillus sydowii</i>	3	0.48	6	0.78
<i>Aspergillus unguis</i>	2	0.3	1	0
<i>Aureobasidium pullulans</i>	263	2.42	335	2.53
<i>Cladosporium sphaerospermum</i>	13	1.11	47	1.67
<i>Eurotium amstelodami</i> (f)	155	2.19	71	1.85
<i>Paecilomyces variotii</i>	2	0.3	2	0.3
<i>Penicillium brevicompactum</i>	5	0.7	6	0.78
<i>Penicillium corylophilum</i>	2	0.3	4	0.6
<i>Penicillium crustosum</i> (g)	1	0	6	0.78
<i>Penicillium purpurogenum</i>	1	0	1	0
<i>Penicillium spinulosum</i> (h)	1	0	1	0
<i>Penicillium variable</i>	3	0.48	6	0.78
<i>Scopulariopsis breviculvis/fusca</i>	2	0.3	2	0.3
<i>Scopulariopsis chartarum</i>	2	0.3	3	0.48
<i>Trichoderma viride</i> (i)	2	0.3	2	0.48
Group 1 Score		15.58		20.24
Group 2 Organisms				
<i>Acremonium strictum</i>	4	0.6	7	0.85
<i>Alternaria alternata</i>	35	1.54	75	1.86
<i>Aspergillus ustus</i>	2	0.3	2	0.3
<i>Cladosporium cladosporioides</i> 1	331	2.52	892	2.95
<i>Cladosporium cladosporioides</i> 2	4	0.6	13	1.11
<i>Cladosporium herbarum</i>	31	1.49	180	2.26
<i>Epicoccum nigrum</i>	117	2.07	59	1.77
<i>Mucor amphibiorum</i> (j)	15	1.18	17	1.23
<i>Penicillium chrysogenum</i>	5	0.7	24	1.38
<i>Rhizopus stolonifer</i>	1	0	2	0.3
Group 2 Score (normal is ≥7 & ≤14)		11.00		14.01
ERMI Score (Gp 1 – Gp 2)		4.58		6.23

Surface MSqPCR samples (ERMI) taken from walls with EDC of the LA and BR separately

- ▶ *Fusarium solani**
- ▶ 90 SE/mg
- ▶ *Streptomyces griseus**
- ▶ 33 SE/mg
- ▶ Endotoxins
- ▶ 4,273 EU/mg

ERMI (reference data from a published study in 2021 for Pre-1978)	AHHS 2 GM CE/mg	AHHS 2 GM Log 10	B-1025 LA CE/mg	B-1025 LA Log 10
<i>Aspergillus penicillioides</i>	140 (6)	2.15	1,600 (10)	3.20
<i>Aspergillus versicolor</i>	14 (4)	1.15	29 (4)	1.46
<i>Chaetomium globosum</i>	3 (0)	0.30	44 (6)	1.64
<i>Stachybotrys chartarum</i>	1 (0)	0.00	1 (0)	
<i>Wallemia sebi</i>	155 (4)	2.19	120 (4)	2.08
HERTSMI-2 score	4		24	
Relevance	Low		High	
Other Group 1 Organisms				
<i>Aspergillus flavus</i> (a)	1	0.00	5	
<i>Aspergillus fumigatus</i> (b)	2	0.48	4	
<i>Aspergillus niger</i> (c)	18	0.60	1,700	3.23
<i>Aspergillus ochraceous</i> (d)	3	0.30	2	
<i>Aspergillus restrictus</i> (e)	6	0.30	9	
<i>Aspergillus sclerotiorum</i>	2	0.30	ND	
<i>Aspergillus sydowii</i>	6	0.48	130	2.11
<i>Aspergillus unguis</i>	1	0.30	25	1.40
<i>Aureobasidium pullulans</i>	335	2.42	100	
<i>Cladosporium sphaerospermum</i>	47	1.11	110	
<i>Eurotium amstelodami</i> (f)	71	2.19	6,500	3.81
<i>Paecilomyces variotii</i>	2	0.30	800	2.90
<i>Penicillium brevicompactum</i>	6	0.70	74	1.87
<i>Penicillium corylophilum</i>	4	0.30	7	
<i>Penicillium crustosum</i> (g)	6	0.00	640	2.81
<i>Penicillium purpurogenum</i>	1	0.00	4	
<i>Penicillium spinulosum</i> (h)	1	0.00	ND	
<i>Penicillium variable</i>	6	0.48	97	1.99
<i>Scopulariopsis brevicaulis/fusca</i>	2	0.30	23	1.36
<i>Scopulariopsis chartarum</i>	3	0.30	1	
<i>Trichoderma viride</i> (i)	3	0.30	6	
Group 1 Score		20.24		38.69
Group 2 Organisms				
<i>Acremonium strictum</i>	7	0.85	2	
<i>Alternaria alternata</i>	75	1.86	17	
<i>Aspergillus ustus</i>	2	0.30	410	2.61
<i>Cladosporium cladosporioides</i> 1	892	2.95	260	
<i>Cladosporium cladosporioides</i> 2	13	1.11	6	
<i>Cladosporium herbarum</i>	180	2.26	59	
<i>Epicoccum nigrum</i>	59	1.77	17	
<i>Mucor amphibiorum</i> (j)	17	1.23	1,400	3.15
<i>Penicillium chrysogenum</i>	24	1.38	2,900	3.46
<i>Rhizopus stolonifer</i>	2	0.30	99	2.00
Group 2 Score (normal is ≥7 & ≤14)		14.01		18.94
ERMI Score (Gp 1 – Gp 2)		6.23		19.75

Living area micro-vacuum floor sample

112.3 mg/2 sq ft

Chaetomium globosum

Eurotium amstelodami

Aureobasidium pullulans

Multiple species of Rhodotorula

Phoma herbarum

Fusarium graminearum

Fusarium sporothrichioides

Mucor hiemalis

0.1123	CMA	1,000x	<i>Chaetomium globosum</i>	1	8,900	5%	
			<i>Cladosporium</i> spp.	3	27,000	15%	
			<i>Curvularia lunata</i>	3	27,000	15%	
			<i>Mucor</i> spp.	3	27,000	15%	
			<i>Penicillium</i> sp.	1	8,900	5%	
			<i>Phoma</i> spp.	2	18,000	10%	
			<i>Rhodotorula minuta</i>	4	36,000	20%	
	yeasts	3	27,000	15%			
						Total	180,000
	DG18	1,000x	<i>Cladosporium</i> sp.	1	8,900	6%	
			<i>Eurotium amstelodami</i>	5	45,000	31%	
			<i>Phoma</i> spp.	4	36,000	25%	
			<i>Rhodotorula minuta</i>	2	18,000	13%	
			yeasts	4	36,000	25%	
					Total	140,000	
MEA	1,000x	<i>Acremonium strictum</i>	1	8,900	5%		
		<i>Aureobasidium pullulans</i>	1	8,900	5%		
		<i>Chaetomium globosum</i>	1	8,900	5%		
		<i>Cladosporium cladosporioides</i>	1	8,900	5%		
		<i>Curvularia lunata</i>	1	8,900	5%		
		<i>Fusarium graminearum</i>	1	8,900	5%		
		<i>Fusarium sporotrichioides</i>	1	8,900	5%		
		<i>Mucor hiemalis</i>	1	8,900	5%		
		<i>Phoma herbarum</i>	1	8,900	5%		
		<i>Pithomyces chartarum</i>	1	8,900	5%		
		<i>Rhodotorula glutinis</i>	1	8,900	5%		
		<i>Rhodotorula minuta</i>	1	8,900	5%		
		<i>Rhodotorula mucilaginosa</i>	1	8,900	5%		
yeasts	8	71,000	38%				
					Total	190,000	

Surface MSqPCR samples (ERMI) taken from walls with EDC of the LA and BR separately

- ▶ *Fusarium solani**
- ▶ 8 SE/mg
- ▶ *Streptomyces griseus**
- ▶ 42 SE/mg
- ▶ Endotoxin sample taken at HVAC closet door in the LA

ERMI (reference data from a published study in 2021 for Pre-1978)	AHHS 2 GM CE/mg	AHHS 2 GM Log 10	B-1025 BR CE/mg	B-1025 BR Log 10
<i>Aspergillus penicillioides</i>	140 (6)	2.15	18,000 (10)	4.26
<i>Aspergillus versicolor</i>	14 (4)	1.15	240 (6)	2.38
<i>Chaetomium globosum</i>	3 (0)	0.30	77 (6)	1.89
<i>Stachybotrys chartarum</i>	1 (0)	0.00	1 (0)	
<i>Wallemia sebi</i>	155 (4)	2.19	360 (4)	2.56
HERTSMI-2 score	4		26	
Relevance	Low		High	
Other Group 1 Organisms				
<i>Aspergillus flavus</i> (a)	1	0.00	3	
<i>Aspergillus fumigatus</i> (b)	2	0.48	11	
<i>Aspergillus niger</i> (c)	18	0.60	8,100	3.91
<i>Aspergillus ochraceus</i> (d)	3	0.30	2	
<i>Aspergillus restrictus</i> (e)	6	0.30	14	
<i>Aspergillus sclerotiorum</i>	2	0.30	ND	
<i>Aspergillus sydowii</i>	6	0.48	340	2.53
<i>Aspergillus unguis</i>	1	0.30	17	1.23
<i>Aureobasidium pullulans</i>	335	2.42	130	
<i>Cladosporium sphaerospermum</i>	47	1.11	120	
<i>Eurotium amstelodami</i> (f)	71	2.19	88,000	4.94
<i>Paecilomyces variotii</i>	2	0.30	1,900	3.28
<i>Penicillium brevicompactum</i>	6	0.70	250	2.40
<i>Penicillium corylophilum</i>	4	0.30	9	
<i>Penicillium crustosum</i> (g)	6	0.00	910	2.96
<i>Penicillium purpurogenum</i>	1	0.00	29	1.46
<i>Penicillium spinulosum</i> (h)	1	0.00	ND	
<i>Penicillium variabile</i>	6	0.48	140	2.15
<i>Scopulariopsis brevicaulis/fusca</i>	2	0.30	16	1.20
<i>Scopulariopsis chartarum</i>	3	0.30	1	
<i>Trichoderma viride</i> (i)	3	0.30	11	
Group 1 Score		20.24		46.30
Group 2 Organisms				
<i>Acremonium strictum</i>	7	0.85	1	
<i>Alternaria alternata</i>	75	1.86	37	
<i>Aspergillus ustus</i>	2	0.30	91	1.57
<i>Cladosporium cladosporioides</i> 1	892	2.95	390	
<i>Cladosporium cladosporioides</i> 2	13	1.11	6	
<i>Cladosporium herbarum</i>	180	2.26	83	
<i>Epicoecum nigrum</i>	59	1.77	57	
<i>Mucor amphibiorum</i> (j)	17	1.23	440	2.64
<i>Penicillium chrysogenum</i>	24	1.38	2,500	3.40
<i>Rhizopus stolonifer</i>	2	0.30	130	2.11
Group 2 Score (normal is ≥7 & ≤14)		14.01		18.73
ERMI Score (Gp 1 – Gp 2)		6.23		27.57

Bedroom micro-vacuum floor sample

121.3 mg/2 sq ft

Aspergillus fumigatus

Aspergillus sydowii

Aureobasidium pullulans

Eurotium spp

Fusarium solani

Penicillium aurantiogriseum

Phoma herbarum

Rhodotorula spp.

0.1213	CMA	1,000x	<i>Aspergillus fumigatus</i>	1	8,200	6%
			<i>Aspergillus sydowii</i>	2	16,000	12%
			<i>Aureobasidium pullulans</i>	1	8,200	6%
			<i>Curvularia lunata</i>	1	8,200	6%
			<i>Penicillium sp.</i>	1	8,200	6%
			<i>Phoma sp.</i>	1	8,200	6%
			<i>Rhodotorula minuta</i>	8	66,000	47%
			yeasts	2	16,000	12%
						Total 140,000
	DG18	1,000x	<i>Aspergillus sydowii</i>	1	8,200	5%
			<i>Eurotium amstelodami</i>	8	66,000	38%
			<i>Eurotium herbariorum</i>	3	25,000	14%
			<i>Penicillium sp.</i>	1	8,200	5%
			<i>Rhodotorula minuta</i>	6	49,000	29%
			yeasts	2	16,000	10%
				Total 170,000		
	MEA	1,000x	<i>Aspergillus sydowii</i>	1	8,200	6%
			<i>Aureobasidium pullulans</i>	4	33,000	22%
			<i>Cladosporium cladosporioides</i>	1	8,200	6%
<i>Eurotium amstelodami</i>			1	8,200	6%	
<i>Eurotium herbariorum</i>			3	25,000	17%	
<i>Fusarium solani</i>			1	8,200	6%	
<i>Penicillium aurantiogriseum</i>			1	8,200	6%	
<i>Phoma herbarum</i>			1	8,200	6%	
<i>Rhodotorula minuta</i>			4	33,000	22%	
<i>Rhodotorula mucilaginosa</i>			1	8,200	6%	
			Total 150,000			

Environmental Evaluation of a Moldy Apartment Complex

- ▶ 40 plus apartments with most having 2 ERMI, 1 endotoxin, 2 micro-vacuum floor samples & 2 HVAC samples
- ▶ 20% field blanks submitted
- ▶ Outdoor samples
- ▶ 3 sets of samples (ERMI & micro-vacuum by culture) for each hallway floor except where there was no electricity
- ▶ Samples in other common areas



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