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THE EFFECT OF AIR CONTROL SYSTEMS ON THE INDOOR DISTRIBUTIONS OF VIABLE PARTICLES

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We have investigated the filtering effects of three types of air control systems of enclosed structures on viable particles in the ambient air. *Aspergillus fumigatus* and other thermophilic organisms were used as monitors for viable particles. The indoor concentrations of viable particles were found to be affected by building design and the use of conventional mechanical air systems. Viable particles of approximately 4.0 μm and greater in aerodynamic diameter were filtered from the air while respirable size particles less than 4.0 μm were not filtered as well. There was evidence of growth of viable particles within the mechanical air systems. Conventional air control systems may not be adequate for the control of viable particle contamination of the indoor environment without modifications and proper maintenance.

Introduction

Indoor/outdoor studies of particle distributions generally have found a larger proportion of small particles indoor than out (Hirsch *et al.*, 1978; Yocom *et al.*, 1971; Sterling, 1977; Jacobs *et al.*, 1962; Sterling *et al.*, 1975). These differences in size distributions have been attributed largely to air control systems, filters, and buildings as a whole acting as particle-size selectors (Yocom *et al.*, 1971; Solomon, 1975; Solomon, 1976; Kozak, 1978; McNall, 1975; Graveson, 1978; Millner *et al.*, 1980). Lung respiratory deposition models have shown specific size ranges of small particles to be more easily inspired and deposited in the lung, making the particle size (aerodynamic diameter) an important dimension. Present building standards and recent energy conservation measures have increased the importance of air control systems. The intent of this study was to determine to what extent building characteristics and conventional air conditioning systems have an effect on the influx and recycling of viable particles within a structure.

Methodology

The study was conducted at two wastewater treatment and sludge composting facilities—one in Washington, DC (facility 1) and the other in Camden, NJ (facility 2). Both facilities have been shown to have greater than background levels of *Aspergillus fumigatus* at the composting site (Millner *et al.*, 1980; Clark *et al.*, 1980; Marsh *et al.*, 1979). Samples of viable particles and meteorologic information were collected for two consecutive days at each facility in September of 1980. Three types of air control systems were studied at each facility: (1) natural air control systems using open windows and/or doors, (2) room unit air conditioners and (3) central air conditioners. The central air units used replaceable fiberglass air filters and the room units reusable foam air filters. The mechanical units were in operation at least one hour before air sampling.

Twenty-one paired indoor/outdoor volumetric air samples for viable particles were collected with Andersen six-stage nondisposable cascade impactors using an air flow of 28.3 liters per minute onto glass petri dishes (supplied by Andersen Samplers, Inc.) containing 27 ml of modified Czapek-Dox Bile Agar; 50 μg/ml of streptomycin and chloramphenical and, 20 units/ml of penicillin were added to retard bacterial growth. The paired air samples consisted of simultaneous sampling at the outdoor intakes and room exits of the air control systems for a duration of 5 to 10 min, taken between two to four times daily. One paired air sample at each of the three air control systems was collected within a one-hour period.

Surface swab samples of the mechanical air control

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system filters were taken twice (August and September 1980) with sterile cotton tipped swabs moistened with sterilized distilled water. A 4 cm square area of the filters was swabbed and streaked immediately onto prepared media dishes.

Measurements of temperature and relative humidity at each indoor and outdoor site were collected concurrently with volumetric air samples using a sling psychrometer and a psychrometric chart (ACGIH, 1972). Outdoor meteorologic conditions were obtained from the local weather station in each area.

Exposed cultures were incubated at 45 °C for 48 hours and then refrigerated to inhibit further colony growth. Colony counts, in colony forming units per 28.3 liters of air, were obtained for *Aspergillus fumigatus* and other *Aspergillus species* and thermophilic fungi by direct colony count on the basis of microscopic examination, colony color and colony morphology (Raper *et al.*, 1965).

Results

Figures 1, 2, and 3 show the relative distribution of different sizes of *A. fumigatus* and other thermophilic fungi found on each stage of the Andersen sampler, at the indoor and outdoor sampling sites for each air control system. The approximate size range for each stage of the Andersen viable sampler is shown in Table 1. The figures showing the relative distributions indicate a significant transition between the outdoor and indoor distributions of those viable particles found on stages 3 to 4 (approximately 2.1 to 4.7 μm in aerodynamic diameter). In general, a greater percent of the total colony forming unit counts on stage 3 were found outdoors and on stage 4 indoors. This transition is most pronounced with *A. fumigatus* (Fig. 1) which falls into the 2.1 to 4.7 μm range (Raper *et al.*, 1965). The histogram of other thermophilic fungi, which are generally of a larger size, does not show a transition as clearly and not at all at the central air system (Fig. 2).

By combining the other thermophilic fungi and the *A. fumigatus* colony forming unit counts, a more continuous size range may be obtained (Fig. 3). The change in the particle size-range distributions is shown clearly

Table 1. Orifice diameter and aerodynamic size ranges for the six-stage Andersen sampler.[a]

Stage	Orifice Diameter (mm)	Range of Particle Size (μm)
1	1.18	7.0 and above
2	0.91	4.7 -7.0
3	0.71	3.3 -4.7
4	0.53	2.1 -3.3
5	0.34	1.1 -2.1
6	0.25	0.65-1.1

[a] From Andersen Samplers Inc., 1976.

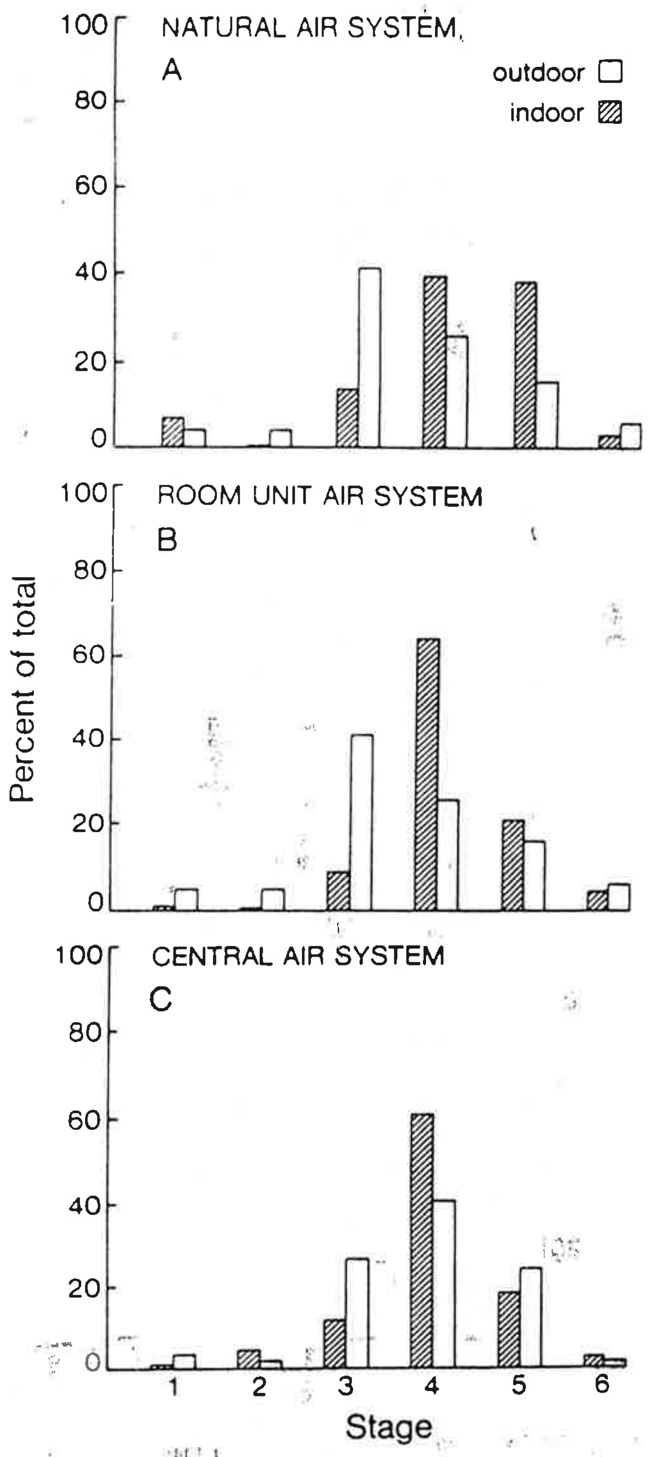

Fig. 1. Percent of *Aspergillus fumigatus* colony-forming units on each stage of the Andersen six-stage viable sampler. (The particle-size range found on each stage decreases as the stage number increases. The aerodynamic size ranges are given in Table 1.)

at the room unit systems. A greater proportion of the larger particles (collected on stages 1 through 3) are found outdoor and the smaller particles (collected on stages 4 and 5) indoor. The natural air system continues to show the distribution found previously for the other thermophilic fungi in stages 1 through 3 (Fig. 2) and for

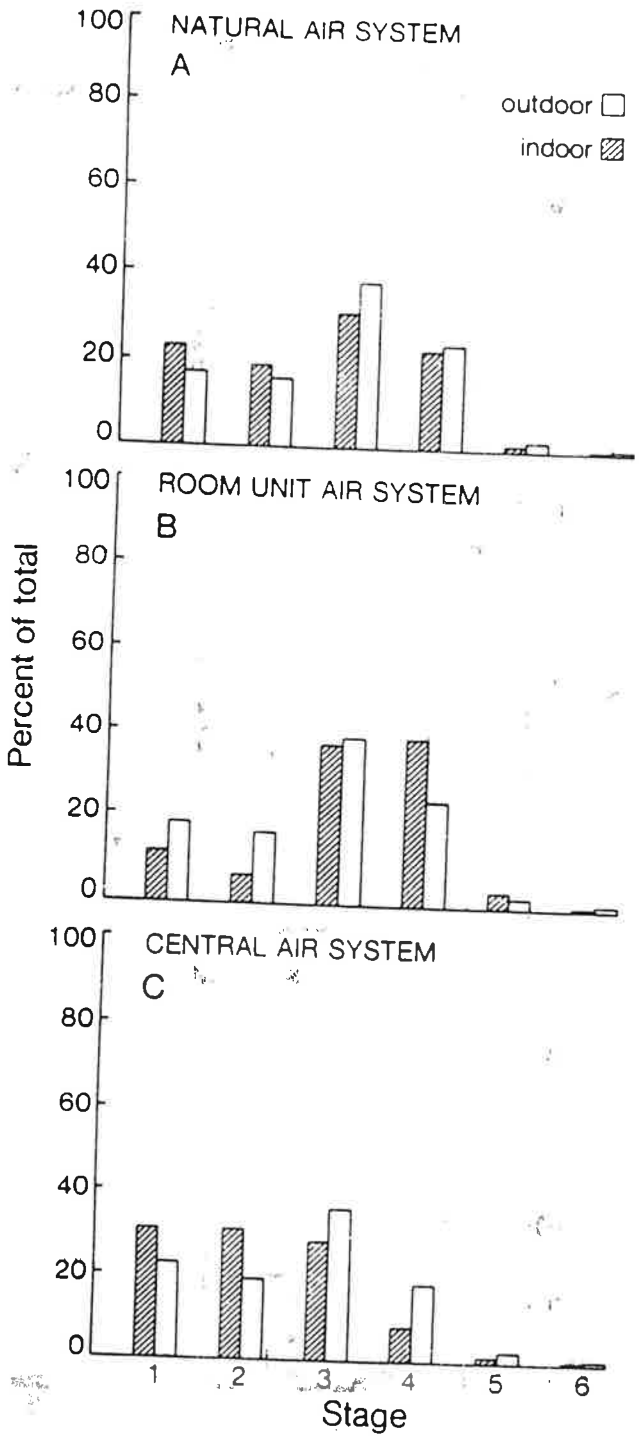

Fig. 2. Percent of thermophilic organisms other than *A. fumigatus* colony-forming units on each stage of the Andersen six-stage viable sampler. (The particle-size range found on each stage decreases as the stage number increases. The aerodynamic size ranges are given in Table 1.)

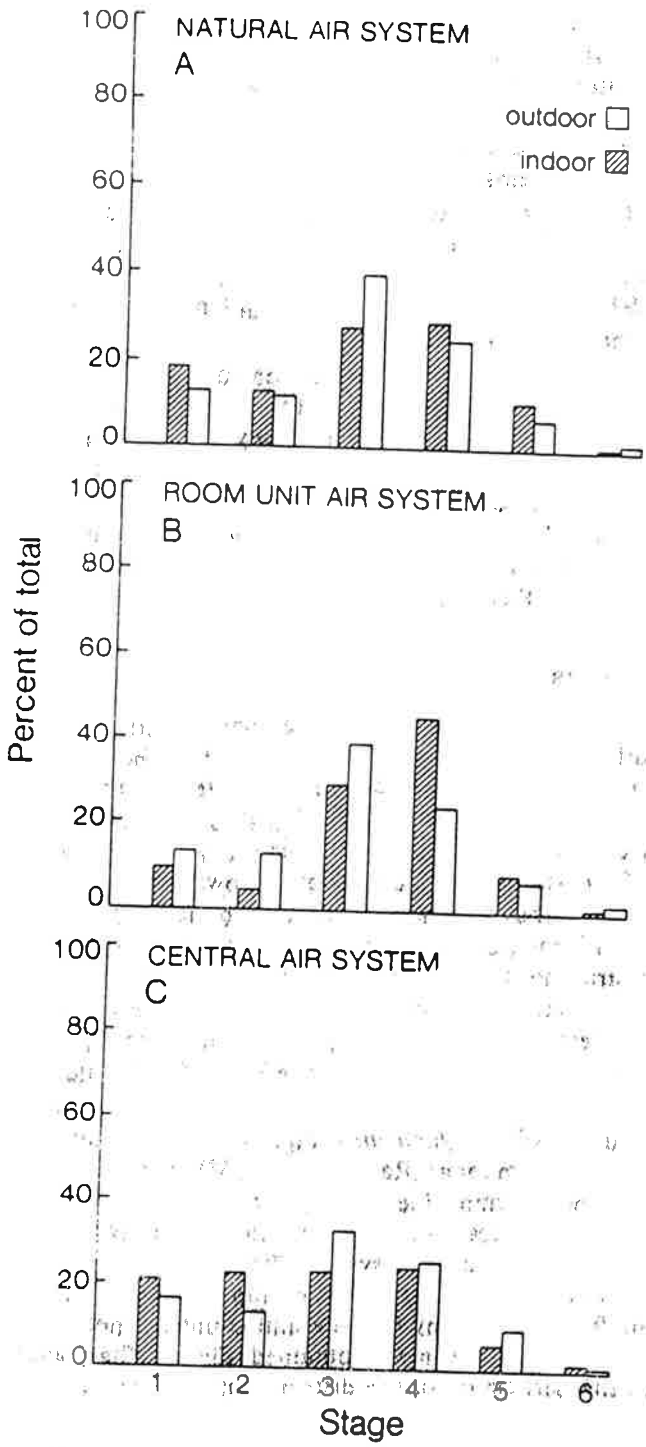

Fig. 3. Percent of all thermophilic organisms colony-forming units on each stage of the Andersen six-stage viable sampler. (The particle-size range found on each stage decreases as the stage number increases. The aerodynamic size ranges are given in Table 1.)

A. fumigatus in stages 5 and 6 (Fig. 1), with stage 4 being a transition range.

On the basis of the observations made from the size distributions shown in Figs. 1, 2, and 3, the colony forming unit counts found on stages 1 through 3 and on stages 4 through 6 were combined (Table 2 and Fig. 4).

The percentage of smaller particles of *A. fumigatus* was always greater indoor than outdoor. The amount of difference in the indoor/outdoor percentages varied with the type of air control system. The room unit and natural air systems showed variations between the indoor and outdoor colony forming unit counts of the

Table 2. Percent of colony-forming units on stages 4-6 combined[a] of the Andersen six-stage viable sampler.

Organism	Type of Air System	Percent Indoor	Percent Outdoor	Probability of Difference by Chance[b]
A. fumigatus:				
	Natural	79.9 (52.5)[c]	48.7 (18.7)	<0.01
	Room Unit	90.5 (41.1)	48.7 (18.7)	<0.01
	Central	81.3 (32.5)	66.4 (37.3)	>0.1
Fungi Other than *A. fumigatus*:				
	Natural	26.6 (40.7)	27.7 (24.2)	>0.1
	Room Unit	42.6 (49.9)	27.7 (24.2)	<0.05
	Central	9.7 (8.6)	21.1 (23.6)	<0.05
A. fumigatus and Other Fungi Combined:				
	Natural	40.8 (93.2)	34.3 (42.9)	>0.1
	Room Unit	55.9 (91.0)	34.1 (42.9)	<0.01
	Central	32.0 (41.1)	36.2 (60.9)	>0.1

[a] The aerodynamic size range of the particles found on stages 4-6 is approximately 4.0 to 0.6 μm.
[b] Determined by chi-square test, 1 df.
[c] Actual colony forming units per 28.3 l of sampled air.

smaller size particles (stages 4 through 6) of 41.8% and 31.2%, respectively, greater than would be expected by chance ($p < 0.01$) with the room unit showing the greatest difference (Table 2). The central air system showed only a 16% difference between the indoor and outdoor colony forming unit counts, a difference that could be expected by chance. In comparison with the natural air system, the difference in the percent of smaller particles found indoors and outdoors was increased for the room unit system and for the central air systems.

The findings for the other thermophilic fungi were not consistent with those for *A. fumigatus* (Table 2). The smaller and larger particle indoor/outdoor distributions for other thermophilic fungi were significantly different for the room unit and central air systems. Use of the central air system resulted in a substantial decrease in the percent of smaller particles indoors (9.7%) compared with outdoors (21.1%) and the use of room units resulted in an increase in the percent of smaller particles indoors (42.6%) compared to outdoors (27.7%). The indoor and outdoor distribution of particles for the natural air systems were the same. Again, when the mechanical systems are compared with the natural air systems the percentage of smaller particles indoors compared to outdoors was increased when using room units but clearly decreased when using central air systems.

When the *A. fumigatus* and other thermophilic fungi colony forming unit counts were combined (Table 2), no indoor/outdoor difference was shown for the natural air and central air systems. Use of the room unit systems showed a significant increase in the percent of smaller particles found indoors as compared to outdoors.

Swab sample results for the mechanical air system filters are shown in Table 3. During the first survey at facility 1 positive results for *A. fumigatus* and other

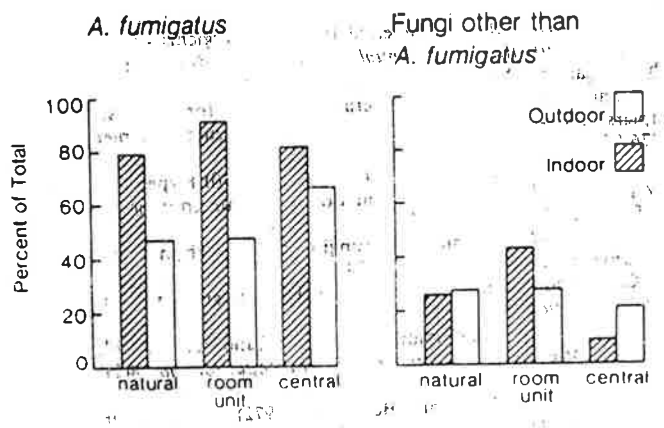

Fig. 4. Percent of colony-forming units on stages 4-6 combined. (The aerodynamic size range of the particles found on stages 4-6 is approximately 4.0-0.6 μm.)

Table 3. Filter swab sample results for room unit and central air systems.

Location	*A. fumigatus*	Other Fungi
Facility 1 – August:		
Room Unit System	positive	positive
Central Air System	positive	positive
Facility 2 – August:		
Room Unit System	positive	positive
Central Air System	——[a]	——
Facility 1 – September:		
Room Unit System	negative	negative
Central Air System	positive	positive
Facility 2 – September:		
Room Unit System	positive	negative
Central Air System	——	——

[a] No result, due to contamination of media plate or no sample obtained.

Table 4. Meteorologic measurements mean values.

Air System		Temp (°C)	p^a	rH	p^a
Natural	In	26.4	>0.1	68.7	<0.01
	Out	26.4		72.0	
Room Unit	In	22.8	<0.001	73.5	>0.1
	Out	26.4		72.0	
Central	In	23.6	<0.001	77.2	<0.01
	Out	27.6		68.4	

[a]Probability of indoor/outdoor differences being due to chance (Students *t*-test).

thermophilic fungi were found for both the room unit and central air system filters. The second survey showed positive results for *A. fumigatus* and negative for other thermophilic fungi. On further inquiry into the maintenance of the units it was found that the room unit filters had been cleaned between the first and second sampling survey and the central air system filter had not, resulting in none or fewer fungal types at the room unit.

Meteorologic data for temperature and relative humidity are briefly summarized in Table 4. In general the indoor and outdoor temperature measurements at the natural air systems were the same and the indoor relative humidity was lower. Statistically significant differences between indoor and outdoor temperature were seen as expected at the room unit and central air systems where the indoor temperature was lower, but the relative humidity was significantly higher indoors than outdoors at the central air systems.

Conclusions

The physical characteristics of buildings interacting with the properties of particles enable a natural filtering and sizing process to take place which usually seems to select the smaller and more easily dispersed particles to be found indoors. The use of filters and mechanical air systems seems to support even more the selection toward smaller particles indoors. Viable particles approximately 4.0 μm in aerodynamic diameter were found to be filtered from the air stream of mechanical air systems while respirable size particles of less than 4.0 μm were not filtered out as well.

Although viable and nonviable particles have physically the same characteristics and may behave similarly, viable particles have the potential for growth and may represent a wide variety of potential irritants and disease antecedents. Filters may act as a collection device for viable particles and other material which can serve as nutrients. The particles may grow and extend through the filter to act as a contaminant source. Excessive recirculation could aggravate this by reintroducing viable particles already selected as being favorable for growth in this environment. The growth of deleterious viable particles within an air system has been reported in residences, office and public buildings and of much concern, in hospitals (Burge *et al.*, 1972; Gage *et al.*, 1970; Petheram *et al.*, 1976; Rose *et al.*, 1972; Millner *et al.*, 1977; Broome *et al.*, 1979). Our data suggest that there could be fungal growth on air filters of mechanical systems and cleaning of the filters has an effect on the fungi present and on subsequent indoor distributions.

The increase in larger particles found indoors at the central air systems may be attributable to a number of factors. The other thermophilic fungi are generally of a larger size than the *A. fumigatus* and were more likely to settle or impact on the central air duct system or filters. The extensive duct work and larger filter area of a central air system increase the potential for collection within the system. The higher humidity measured indoors may also help create a favorable environment and encourage growth of these organisms (Brockett, 1978). The growth of the other thermophilic fungi within the air system will act as a source for the indoor distribution of these particles.

The same size-range of viable particles was present indoors and outdoors for the three types of air control systems. However, the proportion of sizes and their distribution indoors varied depending on the type of air control systems and whether there were possible sources of viable particle generation within the air control systems. The use of a "conventional" size separation by combining total respirable particles (less than 5 or 10 μm aerodynamic diameter) without considering the complete size-range distribution may be misleading in assessing the overall effects of building design and air control systems on viable particles.

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