APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Aug. 2001, p. 3712–3715 Vol. 67, No. 8
0099-2240/01/$04.00+0 DOI: 10.1128/AEM.67.8.3712–3715.2001

Effectiveness of Germicidal UV Radiation for Reducing Fungal Contamination within Air-Handling Units

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Received 27 October 2000/Accepted 16 May 2001

Levels of fungi growing on insulation within air-handling units (AHUs) in an office building and levels of airborne fungi within AHUs were measured before the use of germicidal UV light and again after 4 months of operation. The fungal levels following UV operation were significantly lower than the levels in control AHUs.

Fungal contamination of air-handling units (AHUs) is a widespread phenomenon in buildings with central heating, ventilation, and air-conditioning (HVAC) systems and is a potential source of contamination for occupied spaces (1, 8, 16, 20). Fungi have been found growing on air filters, insulation, and cooling coils, as well as in ducts. This contamination often contributes to building-related diseases, including both infectious diseases and hypersensitivity diseases, such as allergic rhinitis, asthma, and hypersensitivity pneumonitis (4, 11, 13). In addition, acute toxicosis and cancer have been attributed to respiratory exposure to mycotoxins (5).

Control of fungi in indoor environments has traditionally focused on source control, ventilation, and air cleaning. Source control emphasizes the reduction or elimination of moisture to limit fungal growth. Although this can be effective in many areas, it is not achievable in HVAC systems during cooling. By design, air-conditioning systems cause moisture to condense from air. As a result, other methods are needed to reduce fungal contamination. Ventilation relies on using filtered outdoor and recirculated indoor air. Ventilation is ineffective, however, when unfiltered outdoor air introduces outdoor bioaerosols or when the HVAC system itself is contaminated. Air cleaning has focused on using properly maintained high-quality filters within HVAC systems as well as portable air-cleaning devices. Recently, there has been renewed interest in the use of germicidal UV irradiation to disinfect indoor environments for control of infectious diseases in hospitals, other health care facilities, and public shelters (14, 15, 18, 19).

Although it has been known for many years that UV light has various effects on fungi (3, 9, 10), only a few studies have specifically focused on the effects of germicidal UV light (2, 7, 12, 17, 22, 23). Currently, various manufacturers are marketing germicidal UV lamps for controlling contamination, including fungal contamination in indoor environments, as well as AHUs and ducts. Studies have shown that these measures may be effective for controlling the spread of bacterial diseases (14, 15, 18, 19); however, little is known about the effectiveness of UV-C radiation for controlling fungal contamination. The present investigation was undertaken to determine the effectiveness of germicidal UV radiation for reducing fungal contamination within AHUs.

This investigation was conducted in a 286,000 square-foot office building in Tulsa, Okla. The building was originally constructed in the 1920s and was completely remodeled in 1976. Each floor of this four-story building is equipped with four primary AHUs and two perimeter units; these units were installed when the building was remodeled. Beginning in 1996, the air handlers were retrofitted with germicidal UV lamps. During the fall of 1996 all the AHUs in the building were inspected. At this time UV lamps were installed in AHUs on one floor, and work was progressing to install them on a second floor. Acoustical insulation within many of the AHUs exhibited abundant mold growth, as did drain pans. Preliminary air samples and insulation samples were collected to develop the sampling protocols used in this study.

AHUs on two floors were selected for further investigation; no UV lamps had been installed in these AHUs. The floors were designated the study floor and the control floor. Only the four main AHUs on each of these floors were used for the remainder of the investigation. In May 1997, air samples and insulation samples were collected from the eight AHUs. UV lamps were installed on both floors, but they were activated only in the AHUs on the study floor. Each AHU was retrofitted with 10 lamps, which were installed downstream of the coils. The output of each lamp was 158 $\mu W/cm^2$ at 1 m or 10 $\mu W/cm^2$ for every 2.54 cm of tube length at 1 m (21). The lamps were operated 24 h a day throughout the summer and early fall in the AHUs on the study floor. On the control floor, no UV lights were operated. Throughout the building, air conditioning was in use during this period. In late September, samples were collected from all eight AHUs.

Preliminary data showed that air sampling in the AHUs conducted while the AHUs were running resulted in collection of few or no fungal spores because the high airflow rate produced nonisokinetic conditions. For this reason the supply fan in each AHU was shut off prior to sampling. Although this action caused some mechanical disturbance, it provided a method for estimating the potential load of fungal propagules available for dispersal.

Air samples were collected in duplicate by using paired single-stage Andersen (N-6) samplers with malt extract agar

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TABLE 1. Mean concentrations of fungi isolated from insulation samples in AHUs before and after installation of germicidal UV lamps

Fungal taxon isolated	Concn (10^3 CFU/cm^2)			
	Study floor[a]		Control floor	
	May[b]	September	May[b]	September
Acremonium		0.65 (0.65)	5.81 (5.81)	23.81 (23.68)
Aspergillus versicolor	64.87 (38.56)[c]	0.96 (0.56)[d]	87.58 (32.95)	1,765.46 (1,702.1)[d]
Cladosporium (unknown)	135.28 (50.38)	8.42 (5.22)[d]	22.68 (10.19)	95.31 (37.74)[d]
Cladosporium cladosporioides	0.26 (0.26)	5.04 (5.04)	0.65 (0.39)	228.59 (226.92)
Cladosporium (other)		0.13 (0.13)		1.72 (1.60)
Curvularia		0.05 (0.05)		
Hyalodendron	4.65 (3.84)	13.95 (13.95)	83.96 (83.10)	109.66 (72.09)
Penicillium	8.16 (4.35)	1.05 (0.63)	9.27 (8.11)	16.0 (15.59)
Sporothrix	0.01 (0.01)			
Nonsporulating colonies	0.04 (0.04)		1.94 (1.94)	
Total	213.27 (82.53)	30.51 (24.85)[d]	211.89 (130.80)	2,240.55 (1,622.4)[d]

[a] UV lamps were used only on the study floor.
[b] May concentrations were measured before the UV lamps were turned on.
[c] Mean (standard error).
[d] The concentrations on the control floor and the study floor were significantly different after the use of germicidal UV lamps ($P < 0.05$).

plates for viable fungi and paired Burkard personal samplers for total spores. Two-minute Andersen samples and 5-min Burkard samples were collected approximately 40 cm downstream of the cooling coils 30 s after the supply air fan in each AHU was turned off. All samples were started simultaneously, but the Andersen samplers were switched off after 2 min. Samples were obtained from each AHU at least twice in both the spring and the fall.

Plates from the Andersen samplers were incubated at room temperature for 5 to 7 days. Colonies were counted, fungi were identified, and concentrations were expressed in CFU per cubic meter of air. Burkard slides were made permanent by using a lactophenol-polyvinyl alcohol mounting medium, and the slides were examined microscopically at a magnification of ×1,000. Spores were identified and counted. Counts were converted into atmospheric concentrations and expressed in numbers of spores per cubic meter of air. Data from all samples for each AHU were averaged for each time period.

For each AHU, pieces of fiberglass insulation (approximately 60 cm^2) were cut from the insulation directly opposite the cooling coils, approximately 1 m from the base, 2 m from the end wall, and less than 30 cm from the UV lights. The insulation samples were individually sealed in sterile plastic bags for transport to the laboratory. In the laboratory, a smaller square of each insulation sample (6.5 cm^2) was cut from the center of the larger piece. The small square was soaked in 10 ml of sterile distilled water for 20 min. The suspension was vortexed for 30 s and then dilution plated in triplicate on malt extract agar plates. The plates were incubated at room temperature for 5 to 7 days. Colonies were counted, fungi were identified, and concentrations were expressed in CFU per square centimeter. Data from replicate samples were averaged for each AHU.

For each type of sample collected (viable spores, total spores, and insulation) the concentrations obtained for each AHU were averaged to determine means for the study floor and means for the control floor. Mann-Whitney U tests were used to compare the means in May and in September by using Statistica 5.0 software.

The dominant fungi found within the AHUs for both the air samples and the insulation samples included *Penicillium corylophyllum, Aspergillus versicolor*, and a strain of an unidentified *Cladosporium* species which was somewhat similar to *Cladosporium sphaerospermum* (6) and may be a strain of this species. These three taxa accounted for more than 90% of all viable fungi isolated. Other fungi identified included *Acremonium* spp., *Cladosporium cladosporioides, Cladosporium sphaerospermum, Cladosporium elatum*, and *Hyalodendron* sp. Occasionally other *Aspergillus* and *Penicillium* species also occurred in the samples.

In May before the UV lights were turned on, the mean concentrations of the total fungi isolated from the insulation samples on the two floors were similar (Table 1), and there was no significant difference ($P > 0.05$). In the fall the mean concentration on the study floor had decreased, while on the control floor the concentrations had increased and were significantly greater than the concentrations on the study floor ($P < 0.05$). In September the mean concentrations of both *A. versicolor* and the unknown *Cladosporium* species were significantly lower in the AHUs on the study floor ($P < 0.05$).

Similar results were obtained with the air samples (Table 2). In the spring before the UV lights were turned on, the mean concentrations of total viable airborne fungi in the AHUs on the two floors were not significantly different ($P > 0.05$). In the fall, the mean concentration of viable fungi in the AHUs on study floor was an order of magnitude lower, while on the control floor the concentration of viable fungi in the AHUs had increased. The total concentrations of viable fungi in the AHUs on the study floor and the control floor in the fall were significantly different ($P < 0.05$). Because many of the AHUs contained high concentrations of viable fungi, there were frequently multiple impactions and multiple colonies at each impaction point on a culture plate. As a result, it was not always possible to identify each colony to the species level. Therefore, the concentration data in Table 2 are only genus level data. The concentrations of *Penicillium, Aspergillus*, and *Cladosporium* were significantly lower in the AHUs on the study floor than in the AHUs on the control floor after the use of UV lights ($P < 0.05$).

The total spore levels obtained with the Burkard samplers

TABLE 2. Mean concentrations of viable airborne fungi during disturbance sampling within AHUs before and after installation of germicidal UV lamps

Fungal taxon isolated	Concn (10^2 CFU/m^3)			
	Study floor[a]		Control floor	
	May[b]	September	May[b]	September
Acremonium	0.11 (0.10)[c]		0.16 (0.10)	0.10 (0.10)
Alternaria	0.02 (0.01)	0.01 (0.01)	0.02 (0.01)	
Aspergillus	3.08 (2.58)	0.91 (0.48)[d]	1.89 (0.27)	7.46 (3.37)[d]
Cladosporium	15.64 (8.83)	1.28 (0.5)[d]	14.75 (9.25)	11.87 (1.99)[d]
Epicoccum				0.04 (0.04)
Humicola			0.01 (0.01)	
Hyalodendron	0.07 (0.03)		0.02 (0.02)	
Penicillium	2.18 (0.28)	0.68 (0.28)[d]	5.39 (2.36)	220.05 (63.06)[d]
Sporothrix	0.11 (0.11)			
Yeast	0.10 (0.03)	0.05 (0.02)	0.06 (0.03)	
Nonsporulating	0.33 (0.09)	0.06 (0.02)	0.25 (0.03)	
Total	21.65 (11.27)	2.98 (1.06)[d]	22.55 (11.1)	239.52 (58.55)[d]

[a] UV lamps were used only on the study floor.
[b] May concentrations were measured before the UV lamps were turned on.
[c] Mean (standard error).
[d] Concentrations on the control floor and the study floor were significantly different after the use of germicidal UV lamps ($P < 0.05$).

were far greater than the viable spore levels (Table 3). Prior to the use of UV lights, there was not a significant difference ($P > 0.05$) between the mean levels of total spores in the AHUs on the two floors. In September, the total concentrations on the study floor were significantly lower than the total concentrations on the control floor ($P < 0.05$). The fungal taxa identified were consistent with the data obtained with the Andersen sampler and also with the insulation data. However, because it is not possible to differentiate *Penicillium* and *Aspergillus* conidia without conidiophores, the two genera are combined as *Penicillium-Aspergillus* in Table 3. The concentrations of *Cladosporium* and *Penicillium-Aspergillus* on the two floors were significantly different in September ($P < 0.05$).

The types of fungi found in the air samples were the same as the types found in the insulation. Outdoor fungal taxa were rarely found in either the control floor AHUs or the study floor AHUs. This suggests that few outdoor spores passed through the filters in the units and also that the source of the airborne spores was the contaminated insulation in the units when disturbance occurred, such as the disturbance caused when the supply fans were shut off. As a result, we cannot say that the UV-C radiation had a direct effect on spores in the air stream. In addition, the effectiveness of UV lamps seemed to be localized, because visual inspection indicated that there was conspicuous fungal growth in the downstream duct insulation lining. Nevertheless, the significant decrease in the insulation certainly had an impact on the resultant air stream and also had an impact on downstream concentrations. Further studies are needed to examine downstream effects and the resultant air quality in occupied spaces, especially in problem buildings.

TABLE 3. Concentrations of total airborne fungal spores during disturbance sampling within AHUs before and after installation of germicidal UV lamps

Fungal taxon isolated	Concn (10^3 spores/m^3)			
	Study floor[a]		Control floor	
	May[b]	September	May[b]	September
Alternaria	0.04 (0.03)[c]			
Cladosporium	29.54 (8.75)	5.43 (3.35)[d]	19.00 (14.16)	68.42 (30.91)[d]
Penicillium-Aspergillus	27.49 (20.92)	6.69 (2.09)[d]	5.63 (2.55)	185.56 (52.51)[d]
Ascospores	0.01 (0.01)	0.01 (0.01)	0.03 (0.01)	
Basidiospores	0.12 (0.06)	0.04 (0.02)	0.05 (0.03)	0.06 (0.04)
Smuts	0.03 (0.01)		0.01 (0.01)	0.04 (0.02)
Other	0.70 (0.25)	0.24 (0.06)	0.47 (0.2)	1.46 (1.09)
Total	57.92 (25.09)	12.41 (4.47)[d]	25.19 (16.73)	255.54 (82.27)[d]

[a] UV lamps were used only on the study floor.
[b] May concentrations were measured before the UV lamps were turned on.
[c] Mean (standard error).
[d] Concentrations on the control floor and the study floor were significantly different after the use of germicidal UV lamps ($P < 0.05$).

The results of this study were similar to the results of a pilot study performed by Menzies et al. (17). These authors found that using germicidal UV lamps resulted in elimination of bacterial and fungal growth on surfaces within an AHU. However, the study of Menzies et al. was performed from October to December in Montreal, Canada, when operation of the HVAC system in the heating mode would normally result in reduced contamination. During the preliminary phase of this study in 1996, we found that once the units were switched from the air-conditioning mode to the heating mode, fungal contamination dramatically decreased.

While the present investigation indicated that concentrations of fungi were significantly lower when UV lamps were in use, the study did not show what stages of fungal growth were most susceptible, nor did it show whether there was a reduction in spore viability. Also, we were not able to show if all the fungi obtained from the AHUs were susceptible to the UV light. In addition, this study was limited to the species found in the building investigated. Asthana and Tuveson (2) showed that germicidal effects were highly selective for certain species. Clearly, more work is needed to determine the direct effects of UV-C radiation on fungi capable of growing in HVAC systems.

In summary, this study indicated that germicidal UV irradiation may be an effective approach for reducing fungal contamination within AHUs. The use of germicidal UV lamps in AHUs resulted in significantly lower levels of fungal contamination in the fiberglass insulation lining of study floor AHUs than in the insulation of control floor units. Also, there were significantly lower levels of viable and total airborne fungi than in the study floor units than in the control floor units when samples were taken during periods of disturbance.

Partial support for this project was provided by a grant from Steril-Aire, Inc., Cerritos, Calif.

We thank Melinda Sterling Sullivan, Jodi Keller, and Mary Pettyjohn for assisting with sampling and/or culturing activities. We also acknowledge the unending support and accommodations provided by Tom McKain, Building Supervisor, and Argel Johnson, Maintenance Director, throughout this study.

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