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

ESTELLE LEVETIN,1* RICHARD SHAUGHNESSY,2 CHRISTINE A. ROGERS,† AND ROBERT SCHEIR3

Faculty of Biological Science1 and Department of Chemical Engineering2 The University of Tulsa, Tulsa, Oklahoma 74104, and Steril-Aire, Inc., Cerritos, California 907033

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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 μW/cm² at 1 m or 10 μW/cm² 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.
of each insulation sample (6.5 cm²) was cut from the center of transport to the laboratory. In the laboratory, a smaller square end wall, and less than 30 cm from the UV lights. The insula-

d
Total 213.27 (82.53) 30.51 (24.85)
Nonsporulating colonies 0.04 (0.04) 1.94 (1.94)
Sporothrix 0.01 (0.01)
Penicillium
Hyalodendron
Acremonium
Aspergillus versicolor
Cladosporium (unknown)
Cladosporium cladosporioides
Cladosporium (other)
Curvularia
Halophyllum
Penicillium
Acremonium
Cladosporium cladosporioides, Cladosporium sphaero-

The dominant fungi found within the AHUs for both the air samples and the insulation samples included Penicillium cory
ter temperature for 5 to 7 days. Colonies were counted, fungi were identified, and concentrations were expressed in CFU per cu
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 Acremo-
nium spp., Cladosporium cladosporioides, Cladosporium sphaer-

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

<table>
<thead>
<tr>
<th>Fungal taxon isolated</th>
<th>Conc (10^3 CFU/m^3)</th>
<th>May</th>
<th>September</th>
<th>May</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Study floor</td>
<td></td>
<td>Control floor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternaria</td>
<td>0.02 (0.01)</td>
<td>0.01</td>
<td>0.10 (0.10)</td>
<td>0.01</td>
<td>0.10 (0.10)</td>
</tr>
<tr>
<td>Aspergillus</td>
<td>3.08 (2.58)</td>
<td>1.89</td>
<td>7.46 (3.37)</td>
<td>1.47</td>
<td>11.87 (1.99)</td>
</tr>
<tr>
<td>Cladosporium</td>
<td>15.64 (8.83)</td>
<td>14.75</td>
<td>9.25 (9.25)</td>
<td>0.04</td>
<td>0.04 (0.04)</td>
</tr>
<tr>
<td>Epicoccum</td>
<td>0.01 (0.01)</td>
<td>0.01</td>
<td>0.01 (0.01)</td>
<td>0.01</td>
<td>0.01 (0.01)</td>
</tr>
<tr>
<td>Humicola</td>
<td>0.07 (0.03)</td>
<td>0.01</td>
<td>0.01 (0.01)</td>
<td>0.01</td>
<td>0.01 (0.01)</td>
</tr>
<tr>
<td>Hyalodendron</td>
<td>2.18 (0.28)</td>
<td>0.59</td>
<td>22.05 (63.06)</td>
<td>0.00</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>Penicillium</td>
<td>0.11 (0.11)</td>
<td>0.25</td>
<td>0.03 (0.03)</td>
<td>0.25</td>
<td>0.03 (0.03)</td>
</tr>
<tr>
<td>Sporothrix</td>
<td>0.10 (0.03)</td>
<td>0.06</td>
<td>0.06 (0.06)</td>
<td>0.06</td>
<td>0.06 (0.06)</td>
</tr>
<tr>
<td>Yeast</td>
<td>0.33 (0.09)</td>
<td>0.25</td>
<td>0.03 (0.03)</td>
<td>0.25</td>
<td>0.03 (0.03)</td>
</tr>
<tr>
<td>Nonsporulating</td>
<td>21.65 (11.27)</td>
<td>2.98</td>
<td>22.55 (11.1)</td>
<td>239.52 (58.55)</td>
<td>239.52 (58.55)</td>
</tr>
</tbody>
</table>

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).

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

<table>
<thead>
<tr>
<th>Fungal taxon isolated</th>
<th>Conc (10^3 spores/m^3)</th>
<th>May</th>
<th>September</th>
<th>May</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Study floor</td>
<td></td>
<td>Control floor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternaria</td>
<td>0.04 (0.03)</td>
<td>0.01</td>
<td>0.01 (0.01)</td>
<td>0.03</td>
<td>0.03 (0.01)</td>
</tr>
<tr>
<td>Cladosporium</td>
<td>29.54 (8.75)</td>
<td>5.63</td>
<td>185.56 (52.51)</td>
<td>0.05</td>
<td>0.05 (0.05)</td>
</tr>
<tr>
<td>Penicillium-Aspergillus</td>
<td>27.49 (20.92)</td>
<td>6.09</td>
<td>185.56 (52.51)</td>
<td>0.05</td>
<td>0.05 (0.05)</td>
</tr>
<tr>
<td>Ascospores</td>
<td>0.12 (0.06)</td>
<td>0.04</td>
<td>0.06 (0.06)</td>
<td>0.06</td>
<td>0.06 (0.06)</td>
</tr>
<tr>
<td>Basidiosporos</td>
<td>0.03 (0.01)</td>
<td>0.01</td>
<td>0.01 (0.01)</td>
<td>0.01</td>
<td>0.01 (0.01)</td>
</tr>
<tr>
<td>Smuts</td>
<td>0.70 (0.25)</td>
<td>0.24</td>
<td>1.46 (1.09)</td>
<td>0.24</td>
<td>1.46 (1.09)</td>
</tr>
<tr>
<td>Total</td>
<td>57.92 (25.09)</td>
<td>12.45</td>
<td>255.54 (52.27)</td>
<td>0.16</td>
<td>0.16 (0.16)</td>
</tr>
</tbody>
</table>

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).