

CONTROL OF AIRBORNE FUNGAL SPORES IN A UNIVERSITY HOSPITAL

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EI 87-493 (Received 3 November 1987; Accepted 24 May 1989)

A new university hospital was designed to maximize the air quality protection of severely compromised patients undergoing transplantation or treatment for malignant disorders. The entire hospital was designed as a sealed building with two filter systems having >95% efficiencies for 1.0 μm particles. Controlled airflow and isolation of the most severely compromised patients were also design features. Air quality monitoring of particles and airborne fungi demonstrate effective control in the patient environment. The results show the areas with the greatest control of personnel and air changes have the lowest airborne concentrations of fungi and the smallest particles. Larger indoor airborne particle ranking indicate highest levels depending on local human activity, air change rates, or filtration efficiency.

INTRODUCTION

Indoor air quality is often a controversial subject when relating to personnel and occupant comfort in the indoor environment. Hospital indoor air quality concerns also include contamination control measures to prevent airborne spread of infectious diseases. Control measures for tuberculosis, Varicella zoster (chicken pox), Rubeola and Rubella (measles) and Herpes zoster have typically focused on controlled local ventilation when infectious patients are isolated in a hospital environment. Since the development of transplant technologies, certain ubiquitous airborne fungi of the genus *Aspergillus* have become a menace to certain high risk, severely immune compromised patients (Petersen et al. 1983). These patients are generally being treated for hematological malignancies or are recipients of an organ

or marrow transplant. During a period just after receiving a bone marrow transplant (BMT), patients are extremely susceptible to many infectious diseases. Of particular concern are fungal infections which are not amenable to conventional antibiotic treatment.

Immune suppressed patients cannot be continuously confined to their rooms because some diagnostic and/or therapeutic procedures must be performed elsewhere in the building. Thus, in a dynamic hospital environment these immune compromised patients may be affected by many activities which aerosolize spore clouds. Aisner et al. (1976), Opal et al. (1986), and Lentino et al. (1982) have documented the infection problems associated with construction activity in hospitals. Peterson et al. (1983) and Rhame et al. (1984) suggest that hospital indoor air may be asso-

ciated with nosocomial Aspergillosis. The infections experienced at the University of Minnesota BMT unit were due primarily to *Aspergillus fumigatus* and *Aspergillus flavus*. These organisms are spore forming, filamentous fungi. *A. fumigatus* produces spores ≈ 2.0 to $3.5 \mu\text{m}$ in diameter while *A. flavus* spores are ≈ 3.0 to $6.0 \mu\text{m}$.

The *Aspergillus* organisms are important soil microbes associated with decomposition of organic material. The organisms, unlike most filamentous fungi, are tolerant of temperatures $>37^\circ\text{C}$. The spores are passively aerosolized when accumulated spores are disturbed. The microbes settle slowly once aerosolized. *A. fumigatus* is extremely buoyant and remains airborne for a long period of time depending on local convection air currents and activity. The length of time spores remain suspended in hospital air enhances the probability of patients breathing this infectious agent. Once the spores and other particles are deposited in healthy lung alveoli, specific white blood cells engulf and rid the body of the settled particles. The immune suppressed patient often does not have normal white cell function; hence, the saprophytic *Aspergillus* spores are allowed to germinate and grow. Because this opportunistic infection is not generally treatable, preventive measures must be emphasized.

The University of Minnesota has had an active BMT and organ transplant program since the late 1960s. The BMT infection control concept has evolved from a sterile laminar airflow environment for the treatment of patients (Solberg et al. 1971) to the current program using "normalized" infection control measures which include scrupulous handwashing, exclusion of infectious disease sources (sick individuals), and airflow control. In May 1986 a new hospital was opened to replace 450+ outdated beds. The air handling system for the new hospital was designed in conformance with Health, Education and Welfare Standards for the Construction of Hospitals and Health Care Facilities, American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Applications Handbook, Uniform Building Code, and the most recent state and local code requirements. Design features included a closed/locked window system, a fungal inhibitor in structural steel insulation, dilution transfer fans at all the major entrances, a net positive air supply versus exhaust air for the total building, two filter fan systems for all fan units, and steam humidification after the final filter. In special areas (such as the operating room [OR] and the BMT unit), high efficiency particulate filters (HEPA) (99.97% efficient at $0.3 \mu\text{m}$ particles)

were used. Additionally, the BMT unit has the HEPA filters located at the air discharge diffuser in the patient room. Each BMT patient room has a positive airflow control device with malfunction alarms at the nurse station. The fan units for the patient care areas are a force-through versus a draw-through filtration type. The whole hospital ($\approx 46,500 \text{ m}^2$) was designed to provide superior air quality filtered ventilation systems and specific controlled environments to provide the susceptible patients an environment with minimal concentrations of airborne fungi.

BASIC HOSPITAL DESIGN

The hospital structure was designed with an engineered smoke evacuation system which allowed for sealing the building. Triple pane windows are locked and sealed with caulk on the opening joints and frame. The major penetrations to the building from the outside are protected by the installation of powered revolving doors. Other major entrances have foyer space to minimize the effects of the wind during egress.

A fungal inhibiting compound (copper-8-quinolinolate) at about 200 mg/kg was incorporated into the structural fibrous steel of the building to obviate concern for potential opportunistic fungal growth during periods of water leakage.

The basic air handling system (AHS) for all patient care and diagnostic areas consists of an air blender for mixing outside and return air, 40% efficient (ASHRAE 52-76 dust spot method) rough filter, heating/cooling coils, fan, 95% efficient (ASHRAE 52-76 dust spot method) push-through final filter, and steam humidification (Fig. 1). The general public, administrative, nutrition, and reprocessing areas have a two filter (40% and 95% efficiency) system. However, these fans are the draw-through type with the fan placed after the filter bank. The draw-through fans require less operational and initial costs; however, the major disadvantage for patient area use involves negative pressure on the fan housing which can draw, depending on fan house penetrations, unfiltered air into the air supply system after the filter. The supply duct system in the hospital is constructed of galvanized steel with exterior fiberglass insulation. Fiber noise insulation is minimized in the supply air ducts. Depending upon the economizer control of the outside air, air recirculation through the filters for reuse varies from a maximum of 70% to 0%.

To exclude air from less filtered buildings connecting the new hospital through a number of passages, transfer fans were installed to recirculate

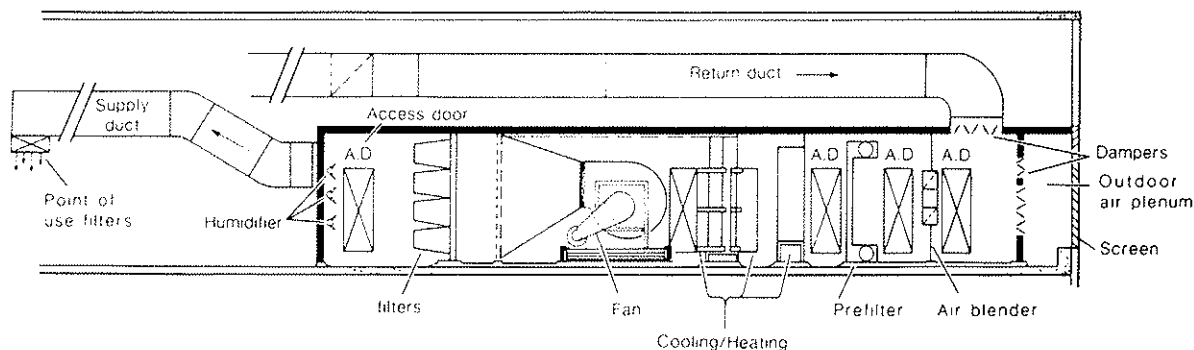


Fig. 1. Hospital high efficiency air handling system with a 95% efficient push-through filtration for all patient areas. Point-of-use filters are located in the bone marrow transplant unit.

ambient air through HEPA filters. The system is set up to provide countercurrent airflow and a dilution ventilation to reduce the concentration of incoming spore aerosols. Due to elevator movement, elevator equipment rooms are supplied with hospital quality air to assure high quality air movement between floors.

The central building automation system (CBAS) continually monitors the following AHS parameters: fan discharge temperature and humidity, differential pressure before and after filters, supply and return fan off alarm, return air temperature, and humidity. The CBAS system regulates the required temperature and humidity adjustment automatically (economizer) by regulating the outside air intake recirculated air ratio. The hospital was designed in accordance with jurisdictional code requirements unless medical staff indicated exceptions in specialty areas such as bone marrow transplant or infection control designed isolation rooms.

STRICT AIR QUALITY CONTROL

The cleanest air filtered environments required in the designed hospital are the OR and to a degree the bone marrow transplant patient room. These two areas must have a net positive air supply relative to adjacent space. A variable speed fan in the OR delivers 25 ac/hr during operating procedures and 5 ac/hr during periods of non-operation. This is accomplished with two fans which supplement the air volume for the ORs. A positive airflow is maintained in an operating room at all times through judicious air balance. The air is filtered at 99.97% efficiency for a 0.3 μm particle in the central fan unit. The AHS is used exclusively for the OR. Each OR was designed to provide a vertical airflow from ceiling to the operating table (Fig. 2). The exhaust ducts are located in each corner of the rooms near the floor. The airflow washes over the operating site and passes to the exhaust ducts.

The BMT patient rooms are designed with cross flow ventilation; that is, the air is supplied from ceiling diffusers on one side of a patient bed allowing air movement over the patient and is exhausted through a low wall return register close to the floor near the room entrance. Besides the main central two-air-filter supply fan, an additional final filter is located in each BMT room supply diffuser and in the corridor diffusers in the bone marrow ward. The BMT room air is supplied through a perforated minimal air aspirating diffuser to prevent air turbulence. A typical BMT room is supplied air at the rate of 15 ac/hr (Fig. 3). Diffuser size depends on the adjusted air flow room size factors necessary to minimize the perception of air movement. The supply air is relieved into the patient room toilet and room return air ducts. About 70% of the room air is returned to the central air handling system and mixed with outside air, filtered, and resupplied to the patient rooms. The bathroom air exhaust is ducted to the roof for outside disposal. To assure airflow out of the rooms, the rooms are maintained at a positive pressure by an air supply volume which is approximately 10% greater than exhausted air. The sealed rooms allow excess air relief through the crack under patient room doors.

Assurance of uninterrupted positive airflow from the patient room is maintained with the use of a mechanical airflow control system (Honeywell, Minneapolis, MN) which monitors airflow direction. A one to two minute delay is built into the system to allow for normal traffic into patient rooms. The air flow control device modulates room return air dampers during low airflow conditions, and if the positive airflow condition is not rectified in the set period, an audible alarm at the nurses station alerts patient care personnel.

Air quality may be affected in a modern hospital by occupant activity and/or the many systems which control the quality of that sensitive environment. A

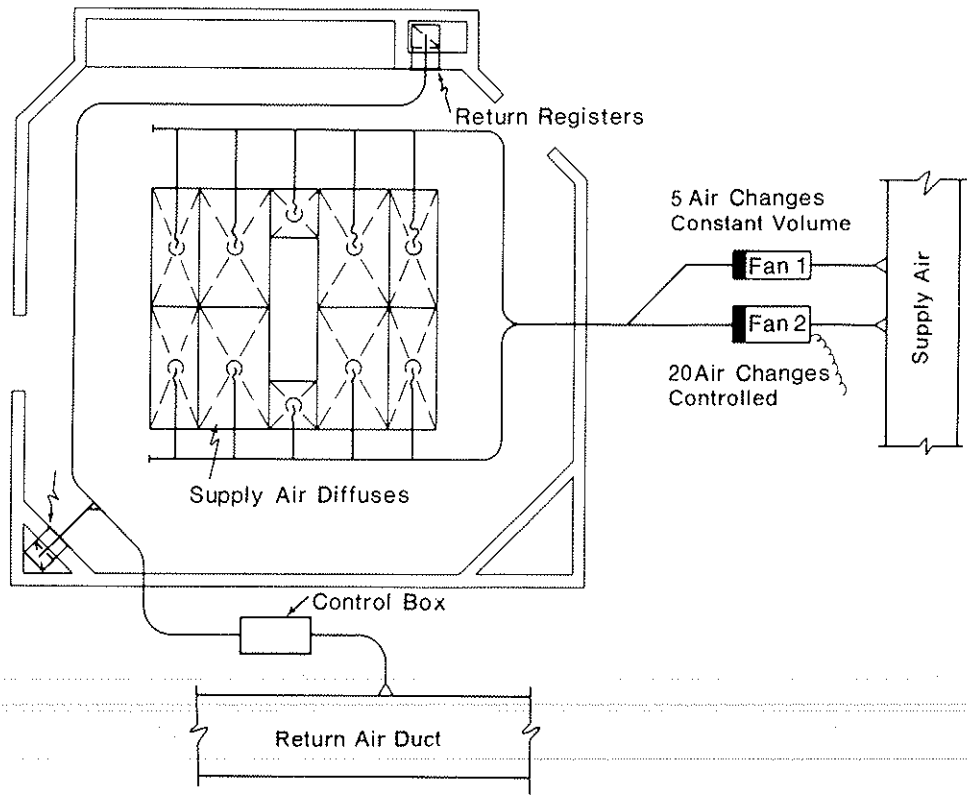


Fig. 2. Typical operating room air system including vertical airflow from non-aspirating diffusers directly over operation site. Control of air changes per hour allows for higher airflow adjustment when rooms are occupied.

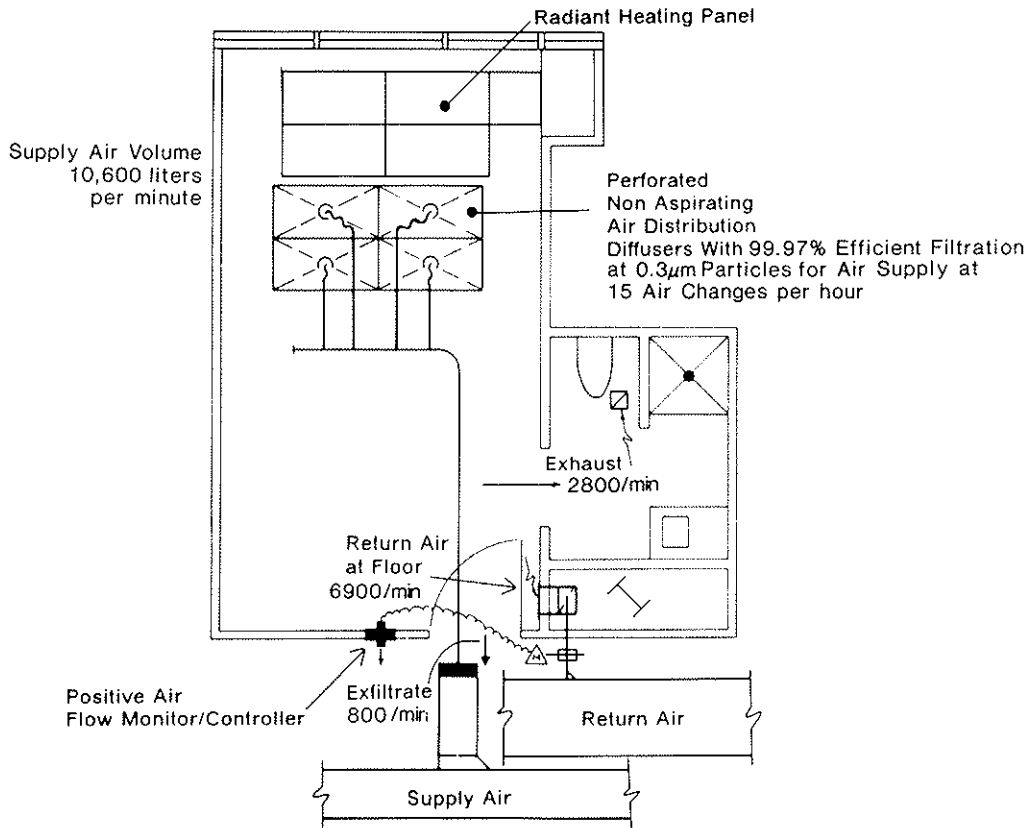


Fig. 3. Typical bone marrow transplant room with approximately 15 air changes per hour and positive pressure room. Airflow is monitored with a mechanical device which controls exhaust and activates alarm if airflow is interrupted.

fire protection system to specifically control smoke will provide safety by allowing sealing of the BMT room windows but may cause interrupted airflow during alarm conditions. Understanding how life safety requirements affect normal airflow is essential to assure minimal effect on the air quality of the critical patient care ward.

METHODS

After occupancy, the new hospital building was evaluated to compare airborne concentrations of particles and fungi from 15 different areas inside and outside of the new building. Eight patient care wards were averaged as one location. Non-viable airborne particles were sampled using an optical particle counter (Climet, model 8060, Redlands, CA). Ambient air particles were counted in the following sizes: 0.3 to 0.5 μm ; 1 to 5 μm ; and $>5 \mu\text{m}$; in HEPA filtered OR and BMT areas, 99.97% efficient at 0.3 μm particles; in non-HEPA filtered areas, 40% efficient pre and 95% efficient after filters; in the old hospital with minimal filtration, 40% efficient; and outside. Counts were recorded as particles per ft^3 and were subsequently converted to particles per meter³. Airborne molds were also compared in the respective

areas. The air was evaluated for viable mold using high volume (700 L/min.) Casella/London slit air samplers. Dual 3.5 m³ air samples were collected at each site. The viable mold particles were collected on Inhibitory Mold Agar and incubated at room temperature ($\approx 25^\circ\text{C}$) and at 37°C . The plates were evaluated after 72 hours incubation according to identification keys found in the Laboratory Handbook of Medical Mycology. Results were converted to colony forming units per meter cubed (cfu/m^3).

RESULTS

The respective areas in this evaluation did not demonstrate expected rank order. The areas with the highest filtration had the lowest concentration rank order only in the smallest particle sizes (Table 1). The x-ray area and ORs demonstrate lowest rank order with respect to larger particles. X-ray has 95% at 1.0 μm particle efficiency filtration while ORs have 99.97% at 0.3 μm particles. Operating rooms have restricted entrance, special clothing, and protective covering along with high air change rates (25 ac/hr) while x-ray has minimal human activity and higher ac/hr (9/hour) to accommodate heat gain

Table 1. Differential rank order of airborne particle concentrations in various size ranges from different hospital locations.

	<u>0.3-0.5 μm^*</u>	<u>Rank**</u>	<u>1.0-5.0 μm^*</u>	<u>Rank**</u>	<u>$>5.0 \mu\text{m}^*$</u>	<u>Rank**</u>
Operating Room	3.7×10^3	1	8.4×10^2	1	1.2×10^2	2
Bone Marrow Transplant	3.4×10^4	2	2.1×10^3	3	2.8×10^2	6
Radiation Therapy	6.8×10^4	3	3.5×10^3	4	2.6×10^2	5
X-Ray	9.3×10^4	4	9.0×10^2	2	9.9×10^1	1
Patient Wards (8 averaged)	1.0×10^5	5	4.1×10^3	6	2.4×10^2	4
Main Lobby	2.0×10^5	6	7.6×10^3	7	3.8×10^2	7
Old Hospital	3.4×10^5	7	3.4×10^3	5	2.3×10^2	3
Outside	4.5×10^5	8	1.4×10^4	8	5.0×10^2	8

* mean particles/ m^3

** rank order of particles from lowest to highest concentration

from equipment. The lobby proves to have the highest in-hospital levels of smallest particles while the minimal filtered old hospital achieved a lower rank order than the lobby due to minimal occupant activity. Patient care activity levels on the intensive care BMT ward lessen the effectiveness of the three filter system which culminates in a 99.97% at 0.3 μm terminal filter in the BMT area. Of note is the relative low rank order of the old hospital reference point which had minimal human activity and 40% efficient filtration. Outside air ranked last with respect to all particle sizes.

Airborne fungal rank order (Table 2) also favored the ORs and the x-ray rooms. The differences between the patient care areas and the BMT area were not significantly different. Radiation therapy had higher than desirable levels of airborne fungi which was due to the ongoing presence of renovation/construction in that area. Outside hospital sites ranked with the

highest levels of airborne fungi at both incubation temperatures.

The lobby consistently had the highest in-hospital results from the sampling data. The proximity to the outdoors and the high volume of pedestrian traffic affect the air quality. Difficulty in providing meaningful data during transfer fan evaluations has prevented the benefit of local airwash systems located in the lobby and major entrances of the hospital from being fully revealed.

DISCUSSION

Hospitals treating severely immune compromised patients should offer protective environments for patient safety. This report demonstrates that filtration capability of >95% provides adequate particle removal from incoming air. The particles which are 1-5 μm should be removed because that size represents the spore size of opportunistic *Aspergillus*

Table 2: Rank order of total airborne fungal concentration at two different temperatures from various hospital locations.

	Incubation Temperatures			
	<u>37°C*</u>	<u>Rank**</u>	<u>25°C*</u>	<u>Rank**</u>
Operating Room	0	1	2.7	2
Bone Marrow Transplant	0.9	4	4.3	3
Radiation Therapy	2.2	5	7.8	5
X-Ray	0.4	2	2.3	1
Patient Wards (8 averaged)	0.8	3	4.3	4
Main Lobby	3.2	6	40.7	6
Old Hospital	7.4	7	83	7
Outside	121	8	745	8

*colony forming units/m³

** rank order with respect to increasing fungal concentrations (lowest to highest)

fumigatus. In special environments, assurance of uninterrupted positive airflow from the patient room is maintained with the use of a mechanical control system which monitors airflow direction. The higher air changes per hour should remove human shed microbes (especially airborne fungi) from the local patient care environment.

Additional procedures for patient care involving cleaning and maintenance should be established to minimize the aerosolization of potentially harmful fungi. During procedural fan maintenance, we have demonstrated a 600% (30 to 180 cfu/m³) increase in airborne fungal concentrations after fan startup due to filter dust disruption. The increase was noted in an area without terminal filters. Fan maintenance is an ongoing requirement. But if the susceptible individual is exposed to the dose of potentially infectious particles, infection may follow. Environmental cleaning and human behavior modification are both necessary to minimize the aerosolization of harmful microbes. The increase in air change is expedient while maximizing the benefits of intimate patient care.

The laminar flow clean room concept has disadvantages which include high cost, difficult comfort control, and noise. The advantage, if the patient is continually confined, is an airborne particle-free environment. In addition, if transplant technology, especially bone marrow transplant, is to benefit the oncology patient the patient care environment should be protective without the high cost and discomfort associated with the laminar flow situation.

Airborne fungal spores can be controlled with conscientious planning of the physical environment from the filtration system to the direct care of the patient. Efforts should also be made to minimize the presence

of airborne fungal aerosols generated during construction and normal maintenance procedures in the susceptible patient environment. A hospital should provide a protected environment for susceptible patients. This paper should expedite planning concepts for the critical care patient environment.

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