A .gov website belongs to an official government organization in the United States. A lock ( ) or https:// means you've safely connected to the .gov website. Share sensitive information only on official, secure websites. Air guidelines from the Guidelines for Environmental Infection Control in Health-Care Facilities (2003). A variety of airborne infections in susceptible hosts can result from exposures to clinically significant microorganisms released into the air when environmental reservoirs (i.e., soil, water, dust, and decaying organic matter) are disturbed. Once these materials are brought indoors into a health-care facility by any of a number of vehicles (e.g., people, air currents, water, construction materials, and equipment), the attendant microorganisms can proliferate in various indoor ecological niches and, if subsequently disbursed into the air, serve as a source for airborne health-care associated infections. Respiratory infections can be acquired from exposure to pathogens contained either in droplets or droplet nuclei. Exposure to microorganisms in droplets (e.g., through aerosolized oral and nasal secretions from infected patients33) constitutes a form of direct contact transmission. When droplets are produced during a sneeze or cough, a cloud of infectious particles >5 µm in size is expelled, resulting in the potential exposure of susceptible persons within 3 feet of the source person.6 Examples of pathogens spread in this manner are influenza virus, rhinoviruses, adenoviruses, and respiratory syncytial virus (RSV). Because these agents primarily are transmitted directly and because the droplets tend to fall out of the air quickly, measures to control air flow in a health-care facility (e.g., use of negative pressure rooms) generally are not indicated for preventing the spread of diseases caused by these agents. Strategies to control the spread of these diseases are outlined in another guideline.3 The spread of airborne infectious diseases via droplet nuclei is a form of indirect transmission.34 Droplet nuclei are the residuals of droplets that, when suspended in air, subsequently dry and produce particles ranging in size from 1–5 µm. These particles can The microorganisms in droplet nuclei persist in favorable conditions (e.g., a dry, cool atmosphere with little or

no direct exposure to sunlight or other sources of radiation). Pathogenic microorganisms that can be spread via droplet nuclei include Mycobacterium tuberculosis, VZV, measles virus (i.e., rubeola), and smallpox virus (i.e., variola major).6 Several environmental pathogens have life-cycle forms that are similar in size to droplet nuclei and may exhibit similar behavior in the air. The spores of Aspergillus fumigatus have a diameter of 2–3.5 µm, with a settling velocity estimated at 0.03 cm/second (or about 1 meter/hour) in still air. With this enhanced buoyancy, the spores, which resist desiccation, can remain airborne indefinitely in air currents and travel far from their source.35 Aspergillosis is caused by molds belonging to the genus Aspergillus. Aspergillus spp. are prototype health-care acquired pathogens associated with dusty or moist environmental conditions. Clinical and epidemiologic aspects of aspergillosis (Table 1) are discussed extensively in another guideline.3 Modes of transmission Airborne transmission of fungal spores; direct inhalation; direct inoculation from environmental sources (rare) 37 Table 8. Strategies to reduce dust and moisture intrusion Causative agents Aspergillus fumigatus (90%–95% of Aspergillus infections among hematopoietic stem cell transplant (HSCT) patients; A. flavus, A. niger, A. terreus, A. nidulans 36–43 Activities associated with infection Construction, renovation, remodeling, repairs, building demolition; rare episodes associated with fomites 44–51 Clinical syndromes and diseases Acute invasive: pneumonia; ulcerative tracheobronchitis; osteomyelitis; abscesses (aspergillomas) of the lungs, brain, liver, spleen, and kidneys; thrombosis of deep blood vessels; necrotizing skin ulcers; endophthalmitis; and sinusitis Chronic invasive: chronic pneumonitis Hypersensity: allergic bronchopulmonary aspergillosis Cutaneous: primary skin and burn-wound infections 44, 45, 52–58 Patient populations at greatest risk Hematopoietic stem cell transplant patients (HSCT): immunocompromised patients (ie, those with underlying disease), patients undergoing chemotherapy, organ transplant recipients, preterm neonates, hemodialysis patients, patients with identifiable immune system deficiencies

who receive care in general intensive care units (ICUs), and cystic fibrosis patients (may be colonized, occasionally become infected) 3 6, 59–78 Factors affecting severity and outcomes The immune status of the patient and the duration of severe neutropenia 79, 80 Occurrence Rare and sporadic, but increasing as proportion of immunocompromised patients increases; 5% of HSCT patients infected, <5% of solid organ transplant recipients infected 36, 37, 81–88 Mortality rate Rate can be as high as 100% if severe neutropenia persists; 13%–80% mortality among leukemia patients 5, 8, 83, 89, 90 + The American Institute of Architects (AIA) standards stipulate that for new or renovated construction Infections due Cryptococcus neoformans, Histoplasma capsulatum, or Coccidioides immitis can occur in health-care settings if nearby ground is disturbed and a malfunction of the facility's air-intake components allows these pathogens to enter the ventilation system. C. neoformans is a yeast usually 4– 8 µm in size. However, viable particles of <2 µm diameter (and thus permissive to alveolar deposition) have been found in soil contaminated with bird droppings, particularly from pigeons.98, 103, 104, 121 H. capsulatum, with the infectious microconidia ranging in size from 2–5 µm, is endemic in the soil of the central river valleys of the United States. Substantial numbers of these infectious particles have been associated with chicken coops and the roosts of blackbirds.98, 103, 104, 122 Several outbreaks of histoplasmosis have been associated with disruption of the environment; construction activities in an endemic area may be a potential risk factor for health-care acquired airborne infection.123, 124 C. immitis, with arthrospores of 3–5 µm diameter, has similar potential, especially in the endemic southwestern United States and during seasons of drought followed by heavy rainfall. After the 1994 earthquake centered near Northridge, California, the incidence of coccidioidomycosis in the surrounding area exceeded the historical norm.125 Emerging evidence suggests that Pneumocystis carinii, now classified as a fungus, may be spread via airborne, person-to-person transmission.126 Controlled studies in animals first demonstrated that P. carinii could be spread through the air.127 More recent

studies in health-care settings have detected nucleic acids of P. carinii in air samples from areas frequented or occupied by P. carinii-infected patients but not in control areas that are not occupied by these patients.128, 129 Clusters of cases have been identified among immunocompromised patients who had contact with a source patient and with each other. Recent studies have examined the presence of P. carinii DNA in oropharyngeal washings and the nares of infected patients, their direct contacts, and persons with no direct contact.130, 131 Molecular analysis of the DNA by polymerase chain reaction (PCR) provides evidence for airborne transmission of P. carinii from infected patients to direct contacts, but immunocompetent contacts tend to become transiently colonized rather than infected.131 The role of colonized persons in the spread of P. carinii pneumonia (PCP) remains to be determined. At present, specific modifications to ventilation systems to control spread of PCP in a health-care facility are not indicated. Current recommendations outline isolation procedures to minimize or eliminate contact of immunocompromised patients not on PCP prophylaxis with PCP-infected patients.6, 132 The bacterium most commonly associated with airborne transmission is Mycobacterium tuberculosis. A comprehensive review of the microbiology and epidemiology of M. tuberculosis and guidelines for tuberculosis (TB) infection control have been published.4, 133, 134 A summary of the clinical and epidemiologic information from these materials is provided in this guideline (Table 3). Modes of transmission Airborne transmission via droplet nuclei 1–5 µm in diameter Causative agents Mycobacterium tuberculosis, M. bovis, M. africanum Patient factors associated with infectivity and transmission Activities associated with infections Clinical syndromes and disease Patient populations at greatest risk Factors affecting severity and outcomes Occurrence Mortality rate Chemoprophylaxis / treatment * Material in this table is compiled from references 4, 133–141. M. tuberculosis is carried by droplet nuclei generated when persons (primarily adults and adolescents) who have pulmonary or laryngeal TB sneeze, cough, speak, or sing;139 normal air currents can keep these

particles airborne for prolonged periods and spread them throughout a room or building.142 However, transmission of TB has occurred from mycobacteria aerosolized during provision of care (e.g., wound/lesion care or during handling of infectious peritoneal dialysis fluid) for extrapulmonary TB patients.135, 140 Gram-positive cocci (i.e., Staphylococcus aureus, group A beta-hemolytic streptococci), also important health-care associated pathogens, are resistant to inactivation by drying and can persist in the environment and on environmental surfaces for extended periods. These organisms can be shed from heavily colonized persons and discharged into the air. Airborne dispersal of S. aureus is directly associated with the concentration of the bacterium in the anterior nares.143 Approximately 10% of healthy carriers will disseminate S. aureus into the air, and some persons become more effective disseminators of S. aureus than others.144–148 The dispersal of S. aureus into air can be exacerbated by concurrent viral upper respiratory infection, thereby turning a carrier into a "cloud shedder."149 Outbreaks of surgical site infections (SSIs) caused by group A beta-hemolytic streptococci have been traced to airborne transmission from colonized operating-room personnel to patients.150–153 In these situations, the strain causing the outbreak was recovered from the air in the operating room150, 151, 154 or on settle plates in a room in which the carrier exercised.151–153 S. aureus and group A streptococci have not been linked to airborne transmission outside of operating rooms, burn units, and neonatal nurseries.155, 156 Transmission of these agents occurs primarily via contact and droplets. Other gram-positive bacteria linked to airborne transmission include Bacillus spp. which are capable of sporulation as environmental conditions become less favorable to support their growth. Outbreaks and pseudo-outbreaks have been attributed to Bacillus cereus in maternity, pediatric, intensive care, and bronchoscopy units; many of these episodes were secondary to environmental contamination.157–160 Gram-negative bacteria rarely are associated with episodes of airborne transmission because they generally require moist

environments for persistence and growth. The main exception is Acinetobacter spp., which can withstand the inactivating effects of drying. In one epidemiologic investigation of bloodstream infections among pediatric patients, identical Acinetobacter spp. were cultured from the patients, air, and room air conditioners in a nursery.161 Aerosols generated from showers and faucets may potentially contain legionellae and other gram-negative waterborne bacteria (e.g., Pseudomonas aeruginosa). Exposure to these organisms is through direct inhalation. However, because water is the source of the organisms and exposure occurs in the vicinity of the aerosol, the discussion of the diseases associated with such aerosols and the prevention measures used to curtail their spread is discussed in another section of the Guideline (see Part I: Water). Airborne transmission may play a role in the natural spread of hantaviruses and certain hemorrhagic fever viruses (e.g., Ebola, Marburg, and Lassa), but evidence for airborne spread of these agents in health-care facilities is inconclusive.190 Although hantaviruses can be transmitted when aerosolized from rodent excreta,191, 192 person-to-person spread of hantavirus infection from source patients has not occurred in health-care facilities.193–195 Nevertheless, health-care workers are advised to contain potentially infectious aerosols and wear National Institute of Occupational Safety and Health (NIOSH) approved respiratory protection when working with this agent in laboratories or autopsy suites.196 Lassa virus transmission via aerosols has been demonstrated in the laboratory and incriminated in health-care associated infections in Africa,197–199 but airborne spread of this agent in hospitals in developed nations likely is inefficient.200, 201 Yellow fever is considered to be a viral hemorrhagic fever agent with high aerosol infectivity potential, but health-care associated transmission of this virus has not been described.202 Viral hemorrhagic fever diseases primarily occur after direct exposure to infected blood and body fluids, and the use of standard and droplet precautions prevents transmission early in the course of these illnesses.203, 204 However, whether these viruses can

persist in droplet nuclei that might remain after droplet production from coughs or vomiting in the latter stages of illness is unknown.205 Although the use of a negative-pressure room is not required during the early stages of illness, its use might be prudent at the time of hospitalization to avoid the need for subsequent patient transfer. Current CDC guidelines recommend negative-pressure rooms with anterooms for patients with hemorrhagic fever and use of HEPA respirators by persons entering these rooms when the patient has prominent cough, vomiting, diarrhea, or hemorrhage.6, 203 Face shields or goggles will help to prevent mucous-membrane exposure to potentially-aerosolized infectious material in these situations. If an anteroom is not available, portable, industrial-grade high efficiency particulate air (HEPA) filter units can be used to provide the equivalent of additional air changes per hour (ACH). Some human viruses are transmitted from person to person via droplet aerosols, but very few viruses are consistently airborne in transmission (i.e., are routinely suspended in an infective state in air and capable of spreading great distances), and health-care associated outbreaks of airborne viral disease are limited to a few agents. Consequently, infection-control measures used to prevent spread of these viral diseases in health-care facilities primarily involve patient isolation, vaccination of susceptible persons, and antiviral therapy as appropriate rather than measures to control air flow or quality.6 Infections caused by VZV frequently are described in health-care facilities. Health-care associated airborne outbreaks of VZV infections from patients with primary infection and disseminated zoster have been documented; patients with localized zoster have, on rare occasions, also served as source patients for outbreaks in health-care facilities.162–166 VZV infection can be prevented by vaccination, although patients who develop a rash within 6 weeks of receiving varicella vaccine or who develop breakthrough varicella following exposure should be considered contagious.167 Viruses whose major mode of transmission is via droplet contact rarely have caused clusters of infections in group settings through airborne routes. The factors

facilitating airborne distribution of these viruses in an infective state are unknown, but a presumed requirement is a source patient in the early stage of infection who is shedding large numbers of viral particles into the air. Airborne transmission of measles has been documented in health-care facilities.168–171 In addition, institutional outbreaks of influenza virus infections have occurred predominantly in nursing homes,172–176 and less frequently in medical and neonatal intensive care units, chronic-care areas, HSCT units, and pediatric wards.177–180 Some evidence supports airborne transmission of influenza viruses by droplet nuclei,181, 182 and case clusters in pediatric wards suggest that droplet nuclei may play a role in transmitting certain respiratory pathogens (e.g., adenoviruses and respiratory syncytial virus [RSV]).177, 183, 184 Some evidence also supports airborne transmission of enteric viruses. An outbreak of a Norwalk-like virus infection involving more than 600 staff personnel over a 3-week period was investigated in a Toronto, Ontario hospital in 1985; common sources (e.g., food and water) were ruled out during the investigation, leaving airborne spread as the most likely mode of transmission.185 Smallpox virus, a potential agent of bioterrorism, is spread predominantly via direct contact with infectious droplets, but it also can be associated with airborne transmission.186, 187 A German hospital study from 1970 documented the ability of this virus to spread over considerable distances and cause infection at low doses in a well-vaccinated population; factors potentially facilitating transmission in this situation included a patient with cough and an extensive rash, indoor air with low relative humidity, and faulty ventilation patterns resulting from hospital design (e.g., open windows).188 Smallpox patients with extensive rash are more likely to have lesions present on mucous membranes and therefore have greater potential to disseminate virus into the air.188 In addition to the smallpox transmission in Germany, two cases of laboratory-acquired smallpox virus infection in the United Kingdom in 1978 also were thought to be caused by airborne transmission.189 * This list excludes microorganisms transmitted from aerosols derived from water. + Refer to

the text for references for these disease agents. § Airborne transmission of smallpox is infrequent. Potential for airborne transmission increases with patients who are effective disseminators present in facilities with low relative humidity in the air and faulty ventilation. ¶ Documentation of pseudoepidemic during construction. ** Airborne transmission documented in the laboratory but not in patient-care areas. † The recommendations in this guideline for Ebola Virus Disease has been superseded on August 1, 2014. Heating, ventilation, and air conditioning (HVAC) systems in health-care facilities are designed to An HVAC system includes an outside air inlet or intake; filters; humidity modification mechanisms (i.e., humidity control in summer, humidification in winter); heating and cooling equipment; fans; ductwork; air exhaust or out-takes; and registers, diffusers, or grilles for proper distribution of the air (Figure 1).213, 214 Decreased performance of healthcare facility HVAC systems, filter inefficiencies, improper installation, and poor maintenance can contribute to the spread of health-care associated airborne infections. The American Institute of Architects (AIA) has published guidelines for the design and construction of new health-care facilities and for renovation of existing facilities. These AIA guidelines address indoor air-quality standards (e.g., ventilation rates, temperature levels, humidity levels, pressure relationships, and minimum air changes per hour [ACH]) specific to each zone or area in health-care facilities (e.g., operating rooms, laboratories, diagnostic areas, patient-care areas, and support departments).120 These guidelines represent a consensus document among authorities having jurisdiction (AHJ), governmental regulatory agencies (i.e., Department of Health and Human Services [DHHS]; Department of Labor, Occupational Safety and Health Administration [OSHA]), health-care professionals, professional organizations (e.g., American Society of Heating, Refrigeration, and Air-Conditioning Engineers [ASHRAE], American Society for Healthcare Engineering [ASHE]), and accrediting organizations (i.e., Joint Commission on Accreditation of Healthcare Organizations [JCAHO]). More than 40 state agencies that license

health-care facilities have either incorporated or adopted by reference these guidelines into their state standards. JCAHO, through its surveys, ensures that facilities are in compliance with the ventilation guidelines of this standard for new construction and renovation. Engineering controls to contain or prevent the spread of airborne contaminants center on General ventilation encompasses A centralized HVAC system operates as follows. Outdoor air enters the system, where low-efficiency or "roughing" filters remove large particulate matter and many microorganisms. The air enters the distribution system for conditioning to appropriate temperature and humidity levels, passes through an additional bank of filters for further cleaning, and is delivered to each zone of the building. After the conditioned air is distributed to the designated space, it is withdrawn through a return duct system and delivered back to the HVAC unit. A portion of this "return air" is exhausted to the outside while the remainder is mixed with outdoor air for dilution and filtered for removal of contaminants.215 Air from toilet rooms or other soiled areas is usually exhausted directly to the atmosphere through a separate duct exhaust system. Air from rooms housing tuberculosis patients is exhausted to the outside if possible, or passed through a HEPA filter before recirculation. Ultraviolet germicidal irradiation (UVGI) can be used as an adjunct air-cleaning measure, but it cannot replace HEPA filtration. 15 Filtration, the physical removal of particulates from air, is the first step in achieving acceptable indoor air quality. Filtration is the primary means of cleaning the air. Five methods of filtration can be used (Table 5). During filtration, outdoor air passes through two filter beds or banks (with efficiencies of 20%–40% and ≥90%, respectively) for effective removal of particles 1–5 μm in diameter.35, 120 The low-to-medium efficiency filters in the first bank have low resistance to airflow, but this feature allows some small particulates to pass onto heating and air conditioning coils and into the indoor environment.35 Incoming air is mixed with recirculated air and reconditioned for temperature and humidity before being filtered by the second bank of filters. The performance of filters with ≤90%

efficiency is measured using either the dust-spot test or the weight-arrestance test.35, 216 *Material in this table was compiled from information in reference 217. The second filter bank usually consists of high-efficiency filters. This filtration system is adequate for most patient-care areas in ambulatory-care facilities and hospitals, including the operating room environment and areas providing central services.120 Nursing facilities use 90% dust-spot efficient filters as the second bank of filters,120 whereas a HEPA filter bank may be indicated for special-care areas of hospitals. HEPA filters are at least 99.97% efficient for removing particles ≥0.3 µm in diameter. (As a reference, Aspergillus spores are 2.5–3.0 µm in diameter.) Examples of care areas where HEPA filters are used include PE rooms and those operating rooms designated for orthopedic implant procedures.35 Maintenance costs associated with HEPA filters are high compared with other types of filters, but use of in-line disposable prefilters can increase the life of a HEPA filter by approximately 25%. Alternatively, if a disposable prefilter is followed by a filter that is 90% efficient, the life of the HEPA filter can be extended ninefold. This concept, called progressive filtration, allows HEPA filters in special care areas to be used for 10 years.213 Although progressive filtering will extend the mechanical ability of the HEPA filter, these filters may absorb chemicals in the environment and later desorb those chemicals, thereby necessitating a more frequent replacement program. HEPA filter efficiency is monitored with the dioctylphthalate (DOP) particle test using particles that are 0.3 µm in diameter.218 HEPA filters are usually framed with metal, although some older versions have wood frames. A metal frame has no advantage over a properly fitted wood frame with respect to performance, but wood can compromise the air quality if it becomes and remains wet, allowing the growth of fungi and bacteria. Hospitals are therefore advised to phase out water-damaged or spent wood-framed filter units and replace them with metal-framed HEPA filters. HEPA filters are usually fixed into the HVAC system; however, portable, industrial grade HEPA units are available that can filter air at the rate of 300–800 ft3

/min. Portable HEPA filters are used to Portable HEPA units are useful engineering controls that help clean the air when the central HVAC system is undergoing repairs219 but these units do not satisfy fresh-air requirements.214 The effectiveness of the portable unit for particle removal is dependent on If portable, industrial-grade units are used, they should be capable of recirculating all or nearly all of the room air through the HEPA filter, and the unit should be designed to achieve the equivalent of ≥12 ACH.4 (An average room has approximately 1,600 ft3 of airspace.) The hospital engineering department should be contacted to provide ACH information in the event that a portable HEPA filter unit is necessary to augment the existing fixed HVAC system for air cleaning. Efficiency of the filtration system is dependent on the density of the filters, which can create a drop in pressure unless compensated by stronger and more efficient fans, thus maintaining air flow. For optimal performance, filters require monitoring and replacement in accordance with the manufacturer's recommendations and standard preventive maintenance practices.220 Upon removal, spent filters can be bagged and discarded with the routine solid waste, regardless of their patient-care area location.221 Excess accumulation of dust and particulates increases filter efficiency, requiring more pressure to push the air through. The pressure differential across filters is measured by use of manometers or other gauges. A pressure reading that exceeds specifications indicates the need to change the filter. Filters also require regular inspection for other potential causes of decreased performance. Gaps in and around filter banks and heavy soil and debris upstream of poorly maintained filters have been implicated in health-care associated outbreaks of aspergillosis, especially when accompanied by construction activities at the facility.17, 18, 106, 222 As a supplemental air-cleaning measure, UVGI is effective in reducing the transmission of airborne bacterial and viral infections in hospitals, military housing, and classrooms, but it has only a minimal inactivating effect on fungal spores.223–228 UVGI is also used in air handling units to prevent or limit the growth of vegetative bacteria and fungi. Most

commercially available UV lamps used for germicidal purposes are low-pressure mercury vapor lamps that emit radiant energy predominantly at a wave-length of 253.7 nm.229, 230 Two systems of UVGI have been used in health-care settings – duct irradiation and upper-room air irradiation. In duct irradiation systems, UV lamps are placed inside ducts that remove air from rooms to disinfect the air before it is recirculated. When properly designed, installed, and maintained, high levels of UVGI can be attained in the ducts with little or no exposure of persons in the rooms.231, 232 In upper-room air irradiation, UV lamps are either suspended from the ceiling or mounted on the wall.4 Upper air UVGI units have two basic designs: The germicidal effect is dependent on air mixing via convection between the room's irradiated upper zone and the lower patient-care zones.233, 234 Bacterial inactivation studies using BCG mycobacteria and Serratia marcescens have estimated the effect of UVGI as equivalent to 10 ACH–39 ACH.235, 236 Another study, however, suggests that UVGI may result in fewer equivalent ACH in the patient-care zone, especially if the mixing of air between zones is insufficient.234 The use of fans or HVAC systems to generate air movement may increase the effectiveness of UVGI if airborne microorganisms are exposed to the light energy for a sufficient length of time.233, 235, 237–239 The optimal relationship between ventilation and UVGI is not known. Because the clinical effectiveness of UV systems may vary, UVGI is not recommended for air management prior to air recirculation from airborne isolation rooms. It is also not recommended as a substitute for HEPA filtration, local exhaust of air to the outside, or negative pressure.4 The use of UV lamps and HEPA filtration in a single unit offers only minimal infection-control benefits over those provided by the use of a HEPA filter alone.240 Duct systems with UVGI are not recommended as a substitute for HEPA filters if the air from isolation rooms must be recirculated to other areas of the facility.4 Regular maintenance of UVGI systems is crucial and usually consists of keeping the bulbs free of dust and replacing old bulbs as necessary. Safety issues associated with the use of UVGI systems are

described in other guidelines.4 Temperature and humidity are two essential components of conditioned air. After outside air passes through a low- or medium-efficiency filter, the air undergoes conditioning for temperature and humidity control before it passes through high-efficiency or HEPA filtration. HVAC systems in health-care facilities are often single-duct or dual-duct systems.35, 241 A single-duct system distributes cooled air (55°F [12.8°C]) throughout the building and uses thermostatically controlled reheat boxes located in the terminal ductwork to warm the air for individual or multiple rooms. The dual-duct system consists of parallel ducts, one with a cold air stream and the other with a hot air stream. A mixing box in each room or group of rooms mixes the two air streams to achieve the desired temperature. Temperature standards are given as either a single temperature or a range, depending on the specific health-care zone. Cool temperature standards (68°F–73°F [20°C–23°C]) usually are associated with operating rooms, clean workrooms, and endoscopy suites.120 A warmer temperature (75°F [24°C]) is needed in areas requiring greater degrees of patient comfort. Most other zones use a temperature range of 70°F–75°F (21°C–24°C).120 Temperatures outside of these ranges may be needed occasionally in limited areas depending on individual circumstances during patient care (e.g., cooler temperatures in operating rooms during specialized operations). Four measures of humidity are used to quantify different physical properties of the mixture of water vapor and air. The most common of these is relative humidity, which is the ratio of the amount of water vapor in the air to the amount of water vapor air can hold at that temperature.242 The other measures of humidity are specific humidity, dew point, and vapor pressure.242 Relative humidity measures the percentage of saturation. At 100% relative humidity, the air is saturated. For most areas within health-care facilities, the designated comfort range is 30%–60% relative humidity.120, 214 Relative humidity levels >60%, in addition to being perceived as uncomfortable, promote fungal growth.243 Humidity levels can be manipulated by either of two mechanisms.244 In a

water-wash unit, water is sprayed and drops are taken up by the filtered air; additional heating or cooling of this air sets the humidity levels. The second mechanism is by means of water vapor created from steam and added to filtered air in humidifying boxes. Reservoir-type humidifiers are not allowed in health-care facilities as per AIA guidelines and many state codes.120 Cool-mist humidifiers should be avoided, because they can disseminate aerosols containing allergens and microorganisms.245 Additionally, the small, personal-use versions of this equipment can be difficult to clean. The control of air pollutants (e.g., microorganisms, dust, chemicals, and smoke) at the source is the most effective way to maintain clean air. The second most effective means of controlling indoor air pollution is through ventilation. Ventilation rates are voluntary unless a state or local government specifies a standard in health-care licensing or health department requirements. These standards typically apply to only the design of a facility, rather than its operation.220, 246 Health-care facilities without specific ventilation standards should follow the AIA guideline specific to the year in which the building was 120, 214, 241 built or the ANSI/ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality. Ventilation guidelines are defined in terms of air volume per minute per occupant and are based on the assumption that occupants and their activities are responsible for most of the contaminants in the conditioned space.215 Most ventilation rates for health-care facilities are expressed as room ACH. Peak efficiency for particle removal in the air space occurs between 12 ACH–15 ACH.35, 247, 248 Ventilation rates vary among the different patient-care areas of a health-care facility (Appendix B).120 Health-care facilities generally use recirculated air.35, 120, 241, 249, 250 Fans create sufficient positive pressure to force air through the building duct work and adequate negative pressure to evacuate air from the conditioned space into the return duct work and/or exhaust, thereby completing the circuit in a sealed system (Figure 1). However, because gaseous contaminants tend to accumulate as the air recirculates, a percentage of the recirculated air is exhausted to the outside and

replaced by fresh outdoor air. In hospitals, the delivery of filtered air to an occupied space is an engineered system design issue, the full discussion of which is beyond the scope of this document. Hospitals with areas not served by central HVAC systems often use through-the-wall or fan coil air conditioning units as the sole source of room ventilation. AIA guidelines for newly installed systems stipulate that through-the-wall fan-coil units be equipped with permanent (i.e., cleanable) or replaceable filters with a minimum efficiency of 68% weight arrestance.120 These units may be used only as recirculating units; all outdoor air requirements must be met by a separate central air handling system with proper filtration, with a minimum of two outside air changes in general patient rooms (D. Erickson, ASHE, 2000).120 If a patient room is equipped with an individual through-the-wall fan coil unit, the room should not be used as either AII or as PE.120 These requirements, although directed to new HVAC installations also are appropriate for existing settings. Non-central air-handling systems are prone to problems associated with excess condensation accumulating in drip pans and improper filter maintenance; health-care facilities should clean or replace the filters in these units on a regular basis while the patient is out of the room. Laminar airflow ventilation systems are designed to move air in a single pass, usually through a bank of HEPA filters either along a wall or in the ceiling, in a one-way direction through a clean zone with parallel streamlines. Laminar airflow can be directed vertically or horizontally; the unidirectional system optimizes airflow and minimizes air turbulence.63, 241 Delivery of air at a rate of 0.5 meters per second (90 ± 20 ft/min) helps to minimize opportunities for microorganism proliferation.63, 251, 252 Laminar airflow systems have been used in PE to help reduce the risk for health-care associated airborne infections (e.g., aspergillosis) in high-risk patients.63, 93, 253, 254 However, data that demonstrate a survival benefit for patients in PE with laminar airflow are lacking. Given the high cost of installation and apparent lack of benefit, the value of laminar airflow in this setting is questionable.9, 37 Few data support the use of laminar airflow systems

elsewhere in a hospital.255 Positive and negative pressures refer to a pressure differential between two adjacent air spaces (e.g., rooms and hallways). Air flows away from areas or rooms with positive pressure (pressurized), while air flows into areas with negative pressure (depressurized). AII rooms are set at negative pressure to prevent airborne microorganisms in the room from entering hallways and corridors. PE rooms housing severely neutropenic patients are set at positive pressure to keep airborne pathogens in adjacent spaces or corridors from coming into and contaminating the airspace occupied by such high-risk patients. Self-closing doors are mandatory for both of these areas to help maintain the correct pressure differential.4, 6, 120 Older health-care facilities may have variable pressure rooms (i.e., rooms in which the ventilation can be manually switched between positive and negative pressure). These rooms are no longer permitted in the construction of new facilities or in renovated areas of the facility,120 and their use in existing facilities has been discouraged because of difficulties in assuring the proper pressure differential, especially for the negative pressure setting, and because of the potential for error associated with switching the pressure differentials for the room. Continued use of existing variable pressure rooms depends on a partnership between engineering and infection control. Both positive- and negative-pressure rooms should be maintained according to specific engineering specifications (Table 6). *Material in this table was compiled from references 35 and 120. Table adapted from and used with permission of the publisher of reference 35 (Lippincott Williams and Wilkins). Health-care professionals (e.g., infection control, hospital epidemiologists) must perform a risk assessment to determine the appropriate number of AII rooms (negative pressure) and/or PE rooms (positive pressure) to serve the patient population. The AIA guidelines require a certain number of AII rooms as a minimum, and it is important to refer to the edition under which the building was built for appropriate guidance.120 In large health-care facilities with central HVAC systems, sealed windows help to ensure the efficient operation of the system, especially with

respect to creating and maintaining pressure differentials. Sealing the windows in PE areas helps minimize the risk of airborne contamination from the outside. One outbreak of aspergillosis among immunosuppressed patients in a hospital was attributed in part to an open window in the unit during a time when both construction and a fire happened nearby; sealing the window prevented further entry of fungal spores into the unit from the outside air.111 Additionally, all emergency exits (e.g., fire escapes and emergency doors) in PE wards should be kept closed (except during emergencies) and equipped with alarms. A failure or malfunction of any component of the HVAC system may subject patients and staff to discomfort and exposure to airborne contaminants. Only limited information is available from formal studies on the infection-control implications of a complete air-handling system failure or shutdown for maintenance. Most experience has been derived from infectious disease outbreaks and adverse outcomes among high-risk patients when HVAC systems are poorly maintained. (See Table 7 for potential ventilation hazards, consequences, and correction measures.) AIA guidelines prohibit U.S. hospitals and surgical centers from shutting down their HVAC systems for purposes other than required maintenance, filter changes, and construction.120 Airflow can be reduced; however, sufficient supply, return, and exhaust must be provided to maintain required pressure relationships when the space is not occupied. Maintaining these relationships can be accomplished with special drives on the air-handling units (i.e., a variable air ventilation [VAV] system). Microorganisms proliferate in environments wherever air, dust, and water are present, and air-handling systems can be ideal environments for microbial growth.35 Properly engineered HVAC systems require routine maintenance and monitoring to provide acceptable indoor air quality efficiently and to minimize conditions that favor the proliferation of health-care associated pathogens.35, 249 Performance monitoring of the system includes determining pressure differentials across filters, regular inspection of system filters, DOP testing of HEPA filters, testing of low- or medium efficiency filters,

and manometer tests for positive- and negative-pressure areas in accordance with nationally recognized standards, guidelines, and manufacturers' recommendations. The use of hand-held, calibrated equipment that can provide a numerical reading on a daily basis is preferred for engineering purposes (A.Streifel, University of Minnesota, 2000).256 Several methods that provide a visual, qualitative measure of pressure differentials (i.e., airflow direction) include smoke-tube tests or placing flutter strips, ping-pong balls, or tissue in the air stream. Preventive filter and duct maintenance (e.g., cleaning ductwork vents, replacing filters as needed, and properly disposing spent filters into plastic bags immediately upon removal) is important to prevent potential exposures of patients and staff during HVAC system shut-down. The frequency of filter inspection and the parameters of this inspection are established by each facility to meet their unique needs. Ductwork in older health-care facilities may have insulation on the interior surfaces that can trap contaminants. This insulation material tends to break down over time to be discharged from the HVAC system. Additionally, a malfunction of the air-intake system can overburden the filtering system and permit aerosolization of fungal pathogens. Keeping the intakes free from bird droppings, especially those from pigeons, helps to minimize the concentration of fungal spores entering from the outside.98 Accumulation of dust and moisture within HVAC systems increases the risk for spread of health-care– associated environmental fungi and bacteria. Clusters of infections caused by Aspergillus spp., P. aeruginosa, S. aureus, and Acinetobacter spp. have been linked to poorly maintained and/or malfunctioning air conditioning systems.68, 161, 257, 258 Efforts to limit excess humidity and moisture in the infrastructure and on air-stream surfaces in the HVAC system can minimize the proliferation and dispersion of fungal spores and waterborne bacteria throughout indoor air.259–262 Within the HVAC system, water is present in water-wash units, humidifying boxes, or cooling units. The dual-duct system may also create conditions of high humidity and excess moisture that favor fungal growth in drain pans as well as in

fibrous insulation material that becomes damp as a result of the humid air passing over the hot stream and condensing. If moisture is present in the HVAC system, periods of stagnation should be avoided. Bursts of organisms can be released upon system start-up, increasing the risk of airborne infection.206 Proper engineering of the HVAC system is critical to preventing dispersal of airborne organisms. In one hospital, endophthalmitis caused by Acremonium kiliense infection following cataract extraction in an ambulatory surgical center was traced to aerosols derived from the humidifier water in the ventilation system.206 The organism proliferated because the ventilation system was turned off routinely when the center was not in operation; the air was filtered before humidification, but not afterwards. Most health-care facilities have contingency plans in case of disruption of HVAC services. These plans include back-up power generators that maintain the ventilation system in high-risk areas (e.g., operating rooms, intensive-care units, negative- and positive-pressure rooms, transplantation units, and oncology units). Alternative generators are required to engage within 10 seconds of a loss of main power. If the ventilation system is out of service, rendering indoor air stagnant, sufficient time must be allowed to clean the air and re-establish the appropriate number of ACH once the HVAC system begins to function again. Air filters may also need to be changed, because reactivation of the system can dislodge substantial amounts of dust and create a transient burst of fungal spores. Duct cleaning in health-care facilities has benefits in terms of system performance, but its usefulness for infection control has not been conclusively determined. Duct cleaning typically involves using specialized tools to dislodge dirt and a high-powered vacuum cleaner to clean out debris.263 Some duct-cleaning services also apply chemical biocides or sealants to the inside surfaces of ducts to minimize fungal growth and prevent the release of particulate matter. The U.S. Environmental Protection Agency (EPA), however, has concerns with the use of sanitizers and/or disinfectants to treat the surfaces of ductwork, because the label indications for most of

these products may not specifically include the use of the product in HVAC systems.264 Further, EPA has not evaluated the potency of disinfectants in such applications, nor has the agency examined the potential attendant health and safety risks. The EPA recommends that companies use only those chemical biocides that are registered for use in HVAC systems.264 Although infrequent cleaning of the exhaust ducts in AII areas has been documented as a cause of diminishing negative pressure and a decrease in the air exchange rates,214 no data indicate that duct cleaning, beyond what is recommended for optimal performance, improves indoor air quality or reduces the risk of infection. Exhaust return systems should be cleaned as part of routine system maintenance. Duct cleaning has not been shown to prevent any health problems,265 and EPA studies indicate that airborne particulate levels do not increase as a result of dirty air ducts, nor do they diminish after cleaning, presumably because much of the dirt inside air ducts adheres to duct surfaces and does not enter the conditioned space.265 Additional research is needed to determine if air-duct contamination can significantly increase the airborne infection risk in general areas of health-care facilities. Environmental disturbances caused by construction and/or renovation and repair activities (e.g., disruption of the above-ceiling area, running cables through the ceiling, and structural repairs) in and near health-care facilities markedly increase the airborne Aspergillus spp. spore counts in the indoor air of such facilities, thereby increasing the risk for health-care associated aspergillosis among high-risk patients. Although one case of health-care associated aspergillosis is often difficult to link to a specific environmental exposure, the occurrence of temporarily clustered cases increase the likelihood that an environmental source within the facility may be identified and corrected. * Reprinted with permission of the publisher of reference 35 (Lippincott Williams and Wilkins). Construction, renovation, repair, and demolition activities in health-care facilities require substantial planning and coordination to minimize the risk for airborne infection both during projects and after their completion. Several

organizations and experts have endorsed a multi-disciplinary team approach (Box 4) to coordinate the various stages of construction activities (e.g., project inception, project implementation, final walk-through, and completion).120, 249, 250, 273–276 Environmental services, employee health, engineering, and infection control must be represented in construction planning and design meetings should be convened with architects and design engineers. The number of members and disciplines represented is a function of the complexity of a project. Smaller, less complex projects and maintenance may require a minimal number of members beyond the core representation from engineering, infection control, environmental services, and the directors of the specialized departments. Members Functions and responsibilities Education of maintenance and construction workers, health-care staff caring for high-risk patients, and persons responsible for controlling indoor air quality heightens awareness that minimizing dust and moisture intrusion from construction sites into high-risk patient-care areas helps to maintain a safe environment.120, 250, 271, 275–278 Visual and printed educational materials should be provided in the language spoken by the workers. Staff and construction workers also need to be aware of the potentially catastrophic consequences of dust and moisture intrusion when an HVAC system or water system fails during construction or repair; action plans to deal quickly with these emergencies should be developed in advance and kept on file. Incorporation of specific standards into construction contracts may help to prevent departures from recommended practices as projects progress. Establishing specific lines of communication is important to address problems (e.g., dust control, indoor air quality, noise levels, and vibrations), resolve complaints, and keep projects moving toward completion. Health-care facility staff should develop a mechanism to monitor worker adherence to infection-control guidelines on a daily basis in and around the construction site for the duration of the project. The three major topics to consider before initiating any construction or repair activity are as follows: A checklist of design

and function considerations can help to ensure that a planned structure or area can be easily serviced and maintained for environmental infection control (Box 5) .17, 250, 273, 275–277 Specifications for the construction, renovation, remodeling, and maintenance of health-care facilities are outlined in the AIA document, Guidelines for Design and Construction of Hospitals and Health Care Facilities. 120, 275 * Use of carpet cleaning methods (e.g., "bonneting") that disperse microorganisms into the air may increase the risk of airborne infection among at-risk patients, especially if they are in the vicinity of the cleaning activity.111 Proactive strategies can help prevent environmentally mediated airborne infections in health-care facilities during demolition, construction, and renovation. The potential presence of dust and moisture and their contribution to health-care associated infections must be critically evaluated early in the planning of any demolition, construction, renovation, and repairs.120, 250, 251, 273, 274, 276–279 Consideration must extend beyond dust generated by major projects to include dust that can become airborne if disturbed during routine maintenance and minor renovation activities (e.g., exposure of ceiling spaces for inspection; installation of conduits, cable, or sprinkler systems; rewiring; and structural repairs or replacement).273, 276, 277 Other projects that can compromise indoor air quality include construction and repair jobs that inadvertently allow substantial amounts of raw, unfiltered outdoor air to enter the facility (e.g., repair of elevators and elevator shafts) and activities that dampen any structure, area, or item made of porous materials or characterized by cracks and crevices (e.g., sink cabinets in need of repair, carpets, ceilings, floors, walls, vinyl wall coverings, upholstery, drapes, and countertops).18, 273, 277 Molds grow and proliferate on these surfaces when they become and remain wet.21, 120, 250, 266, 270, 272, 280 Scrubbable materials are preferred for use in patient-care areas. Containment measures for dust and/or moisture control are dictated by the location of the construction site. Outdoor demolition and construction require actions to keep dust and moisture out of the facility (e.g., sealing

windows and vents and keeping doors closed or sealed). Containment of dust and moisture generated from construction inside a facility requires barrier structures (either pre-fabricated or constructed of more durable materials as needed) and engineering controls to clean the air in and around the construction or repair site. An infection-control risk assessment (ICRA) conducted before initiating repairs, demolition, construction, or renovation activities can identify potential exposures of susceptible patients to dust and moisture and determine the need for dust and moisture containment measures. This assessment centers on the type and extent of the construction or repairs in the work area but may also need to include adjacent patient-care areas, supply storage, and areas on levels above and below the proposed project. An example of designing an ICRA as a matrix, the policy for performing an ICRA and implementing its results, and a sample permit form that streamlines the communication process are available.281 Knowledge of the air flow patterns and pressure differentials helps minimize or eliminate the inadvertent dispersion of dust that could contaminate air space, patient-care items, and surfaces.57, 282, 283 A recent aspergillosis outbreak among oncology patients was attributed to depressurization of the building housing the HSCT unit while construction was underway in an adjacent building. Pressure readings in the affected building (including 12 of 25 HSCT-patient rooms) ranged from 0.1 Pa–5.8 Pa. Unfiltered outdoor air flowed into the building through doors and windows, exposing patients in the HSCT unit to fungal spores.283 During long-term projects, providing temporary essential services (e.g., toilet facilities) and conveniences (e.g., vending machines) to construction workers within the site will help to minimize traffic in and out of the area. The type of barrier systems necessary for the scope of the project must be defined.12, 120, 250, 279, 284 Depending on the location and extent of the construction, patients may need to be relocated to other areas in the facility not affected by construction dust.51, 285 Such relocation might be especially prudent when construction takes place within units

housing immunocompromised patients (e.g., severely neutropenic patients and patients on corticosteroid therapy). Advance assessment of high-risk locations and planning for the possible transport of patients to other departments can minimize delays and waiting time in hallways.51 Although hospitals have provided immunocompromised patients with some form of respiratory protection for use outside their rooms, the issue is complex and remains unresolved until more research can be done. Previous guidance on this issue has been inconsistent.9 Protective respirators (i.e., N95) were well tolerated by patients when used to prevent further cases of construction-related aspergillosis in a recent outbreak.283 The routine use of the N95 respirator by patients, however, has not been evaluated for preventing exposure to fungal spores during periods of non-construction. Although health-care workers who would be using the N95 respirator for personal respiratory protect must be fit-tested, there is no indication that either patients or visitors should undergo fit-testing. Surveillance activities should augment preventive strategies during construction projects.3, 4, 20, 110, 286, 287 By determining baseline levels of health-care acquired airborne and waterborne infections, infection-control staff can monitor changes in infection rates and patterns during and immediately after construction, renovations, or repairs.3 Air sampling in health-care facilities may be conducted both during periods of construction and on a periodic basis to determine indoor air quality, efficacy of dust-control measures, or air-handling system performance via parametric monitoring. Parametric monitoring consists of measuring the physical periodic assessment of the system (e.g., air flow direction and pressure, ACH, and filter efficiency) can give assurance of proper ventilation, especially for special care areas and operating rooms.288 Air sampling is used to detect aerosols (i.e., particles or microorganisms). Particulate sampling (i.e., total numbers and size range of particulates) is a practical method for evaluating the infection-control performance of the HVAC system, with an emphasis on filter efficiency in removing respirable particles (<5 μm in diameter) or larger particles from the air. Particle size is

reported in terms of the mass median aerodynamic diameter (MMAD), whereas count median aerodynamic diameter (CMAD) is useful with respect to particle concentrations. Particle counts in a given air space within the health-care facility should be evaluated against counts obtained in a comparison area. Particle counts indoors are commonly compared with the particulate levels of the outdoor air. This approach determines the "rank order" air quality from "dirty" (i.e., the outdoor air) to "clean" (i.e., air filtered through high-efficiency filters [90%–95% filtration]) to "cleanest" (i.e., HEPA-filtered air).288 Comparisons from one indoor area to another may also provide useful information about the magnitude of an indoor air-quality problem. Making rank-order comparisons between clean, highly-filtered areas and dirty areas and/or outdoors is one way to interpret sampling results in the absence of air quality and action level standards.35, 289 In addition to verifying filter performance, particle counts can help determine if barriers and efforts to control dust dispersion from construction are effective. This type of monitoring is helpful when performed at various times and barrier perimeter locations during the project. Gaps or breaks in the barriers' joints or seals can then be identified and repaired. The American Conference of Governmental Industrial Hygienists (ACGIH) has set a threshold limit value-time weighted average (TLV®-TWA) of 10 mg/m3 for nuisance dust that contains no asbestos and <1% crystalline silica.290 Alternatively, OSHA has set permissible exposure limits (PELs) for inert or nuisance dust as follows: respirable fraction at 5 mg/m3 and total dust at 15 mg/m3 . 291 Although these standards are not measures of a bioaerosol, they are used for indoor air quality assessment in occupational settings and may be useful criteria in construction areas. Application of ACGIH guidance to health-care settings has not been standardized, but particulate counts in health-care facilities are likely to be well below this threshold value and approaching clean-room standards in certain care areas (e.g., operating rooms).100 Particle counters and anemometers are used in particulate evaluation. The anemometer measures air flow velocity, which can be used to determine sample

volumes. Particulate sampling usually does not require microbiology laboratory services for the reporting of results. Microbiologic sampling of air in health-care facilities remains controversial because of currently unresolved technical limitations and the need for substantial laboratory support (Box 6). Infection-control professionals, laboratorians, and engineers should determine if microbiologic and/or particle sampling is warranted and assess proposed methods for sampling. The most significant technical limitation of air sampling for airborne fungal agents is the lack of standards linking fungal spore levels with infection rates. Despite this limitation, several health-care institutions have opted to use microbiologic sampling when construction projects are anticipated and/or underway in efforts to assess the safety of the environment for immunocompromised patients.35, 289 Microbiologic air sampling should be limited to assays for airborne fungi; of those, the thermotolerant fungi (i.e., those capable of growing at 95°F–98.6°F [35°C–37°C]) are of particular concern because of their pathogenicity in immunocompromised hosts.35 Use of selective media (e.g., Sabouraud dextrose agar and inhibitory mold agar) helps with the initial identification of recovered organisms. Microbiologic sampling for fungal spores performed as part of various airborne disease outbreak investigations has also been problematic.18, 49, 106, 111, 112, 289 The precise source of a fungus is often difficult to trace with certainty, and sampling conducted after exposure may neither reflect the circumstances that were linked to infection nor distinguish between health-care acquired and community-acquired infections. Because fungal strains may fluctuate rapidly in the environment, health-care acquired Aspergillus spp. infection cannot be confirmed or excluded if the infecting strain is not found in the health-care setting.287 Sensitive molecular typing methods (e.g., randomly amplified polymorphic DNA (RAPD) techniques and a more recent DNA fingerprinting technique that detects restriction fragment length polymorphisms in fungal genomic DNA) to identify strain differences among Aspergillus spp., however, are becoming increasingly used in epidemiologic investigations of health-care acquired

fungal infection (A. Streifel, University of Minnesota, 2000).68, 110, 286, 287, 292–296 During case cluster evaluation, microbiologic sampling may provide an isolate from the environment for molecular typing and comparison with patient isolates. Therefore, it may be prudent for the clinical laboratory to save Aspergillus spp. isolated from colonizations and invasive disease cases among patients in PE, oncology, and transplant services for these purposes. *Material in this box is compiled from references 35, 100, 222, 289, 297. Sedimentation methods using settle plates and volumetric sampling methods using solid impactors are commonly employed when sampling air for bacteria and fungi. Settle plates have been used by numerous investigators to detect airborne bacteria or to measure air quality during medical procedures (e.g., surgery).17, 60, 97, 151, 161, 287 Settle plates, because they rely on gravity during sampling, tend to select for larger particles and lack sensitivity for respirable particles (e.g., individual fungal spores), especially in highly-filtered environments. Therefore, they are considered impractical for general use.35, 289, 298–301 Settle plates, however, may detect fungi aerosolized during medical procedures (e.g., during wound dressing changes), as described in a recent outbreak of aspergillosis among liver transplant patients.302 The use of slit or sieve impactor samplers capable of collecting large volumes of air in short periods of time are needed to detect low numbers of fungal spores in highly filtered areas.35, 289 In some outbreaks, aspergillosis cases have occurred when fungal spore concentrations in PE ambient air ranged as low as 0.9–2.2 colony-forming units per cubic meter (CFU/m3) of air.18, 94 On the basis of the expected spore counts in the ambient air and the performance parameters of various types of volumetric air samplers, investigators of a recent aspergillosis outbreak have suggested that an air volume of at least 1000 L (1 m3) should be considered when sampling highly filtered areas.283 Investigators have also suggested limits of 15 CFU/m3 for gross colony counts of fungal organisms and <0.1 CFU/m3 for Aspergillus fumigatus and other potentially opportunistic fungi in heavily filtered areas (≥12 ACH

and filtration of ≥99.97% efficiency).120 No correlation of these values with the incidence of health-care– associated fungal infection rates has been reported. Air sampling in health-care facilities, whether used to monitor air quality during construction, to verify filter efficiency, or to commission new space prior to occupancy, requires careful notation of the circumstances of sampling. Most air sampling is performed under undisturbed conditions. However, when the air is sampled during or after human activity (e.g., walking and vacuuming), a higher number of airborne microorganisms likely is detected.297 The contribution of human activity to the significance of air sampling and its impact on health-care associated infection rates remain to be defined. Comparing microbiologic sampling results from a target area (e.g., an area of construction) to those from an unaffected location in the facility can provide information about distribution and concentration of potential airborne pathogens. A comparison of microbial species densities in outdoor air versus indoor air has been used to help pinpoint fungal spore bursts. Fungal spore densities in outdoor air are variable, although the degree of variation with the seasons appears to be more dramatic in the United States than in Europe.92, 287, 303 Particulate and microbiologic air sampling have been used when commissioning new HVAC system installations; however, such sampling is particularly important for newly constructed or renovated PE or operating rooms. Particulate sampling is used as part of a battery of tests to determine if a new HVAC system is performing to specifications for filtration and the proper number of ACH.268, 288, 304 Microbiologic air sampling, however, remains controversial in this application, because no standards for comparison purposes have been determined. If performed, sampling should be limited to determining the density of fungal spores per unit volume of air space. High numbers of spores may indicate contamination of air-handling system components prior to installation or a system deficiency when culture results are compared with known filter efficiencies and rates of air exchange. External demolition, planned building implosions, and dirt excavation

generate considerable dust and debris that can contain airborne microorganisms. In one study, peak concentrations in outdoor air at grade level and HVAC intakes during site excavation averaged 20,000 CFU/m3 for all fungi and 500 CFU/m3 for Aspergillus fumigatus, compared with 19 CFU/m3 and 4 CFU/m3 , respectively, in the absence of construction.280 Many health-care institutions are located in large, urban areas; building implosions are becoming a more frequent concern. Infection-control risk assessment teams, particularly those in facilities located in urban renewal areas, would benefit by developing risk management strategies for external demolition and construction as a standing policy. In light of the events of 11 September 2001, it may be necessary for the team to identify those dust exclusion measures that can be implemented rapidly in response to emergency situations (Table 8). Issues to be reviewed prior to demolition include +When health-care facilities have immunosuppressed patients in their census, telephoning the city building department each month to find out if buildings are scheduled for demolition is prudent. Minimizing the entry of outside dust into the HVAC system is crucial in reducing the risk for airborne contaminants. Facility engineers should be consulted about the potential impact of shutting down the system or increasing the filtration. Selected air handlers, especially those located close to excavation sites, may have to be shut off temporarily to keep from overloading the system with dust and debris. Care is needed to avoid significant facility-wide reductions in pressure differentials that may cause the building to become negatively pressured relative to the outside. To prevent excessive particulate overload and subsequent reductions in effectiveness of intake air systems that cannot be shut off temporarily, air filters must be inspected frequently for proper installation and function. Excessive dust penetration can be avoided if recirculated air is maximally utilized while outdoor air intakes are shut down. Scheduling demolition and excavation during the winter, when Aspergillus spp. spores may be present in lower numbers, can help, although seasonal variations in spore density differ around the

world.92, 287, 303 Dust control can be managed by misting the dirt and debris during heavy dust-generating activities. To decrease the amount of aerosols from excavation and demolition projects, nearby windows, especially in areas housing immunocompromised patients, can be sealed and window and door frames caulked or weather-stripped to prevent dust intrusion.50, 301, 306 Monitoring for adherence to these control measures throughout demolition or excavation is crucial. Diverting pedestrian traffic away from the construction sites decreases the amount of dust tracked back into the health-care facility and minimizes exposure of high-risk patients to environmental pathogens. Additionally, closing entrances near construction or demolition sites might be beneficial; if this is not practical, creating an air lock (i.e., pressurizing the entry way) is another option. The focus of a properly implemented infection-control program during interior construction and repairs is containment of dust and moisture. This objective is achieved by These activities should be coordinated with engineering staff and infection-control professionals. Physical barriers capable of containing smoke and dust will confine dispersed fungal spores to the construction zone.279, 284, 307, 308 The specific type of physical barrier required depends on the project's scope and duration and on local fire codes. Short-term projects that result in minimal dust dispersion (e.g., installation of new cables or wiring above ceiling tiles) require only portable plastic enclosures with negative pressure and HEPA filtration of the exhaust air from the enclosed work area. The placement of a portable industrial-grade HEPA filter device capable of filtration rate of 300–800 ft3 /min. adjacent to the work area will help to remove fungal spores, but its efficacy is dependent on the supplied ACH and size of the area. If the project is extensive but short-term, dust-abatement, fire-resistant plastic curtains (e.g., Visqueen®) may be adequate. These should be completely airtight and sealed from ceiling to floor with overlapping curtains;276, 277, 309 holes, tears, or other perforations should be repaired promptly with tape. A portable, industrial-grade HEPA filter unit on continuous

operation is needed within the contained area, with the filtered air exhausted to the outside of the work zone. Patients should not remain in the room when dust-generating activities are performed. Tools to assist the decision-making process regarding selection of barriers based on an ICRA approach are available.281 More elaborate barriers are indicated for long-term projects that generate moderate to large amounts of dust. These barrier structures typically consist of rigid, noncombustible walls constructed from sheet rock, drywall, plywood, or plaster board and covered with sheet plastic (e.g., Visqueen®). Barrier requirements to prevent the intrusion of dust into patient-care areas include *Material for this box was compiled from references 120, 250, 273, 276, 277. Dust and moisture abatement and control rely primarily on the impermeable barrier containment approach; as construction continues, numerous opportunities can lead to dispersion of dust to other areas of the health-care facility. Infection-control measures that augment the use of barrier containment should be undertaken (Table 9). Dust-control measures for clinical laboratories are an essential part of the infection-control strategy during hospital construction or renovation. Use of plastic or solid barriers may be needed if the ICRA determines that air flow from construction areas may introduce airborne contaminants into the laboratory space. In one facility, pseudofungemia clusters attributed to Aspergillus spp. and Penicillium spp. were linked to improper air flow patterns and construction projects adjacent to the laboratory; intrusion of dust and spores into a biological safety cabinet from construction activity immediately next to the cabinet resulted in a cluster of cultures contaminated with Aspergillus niger. 310, 311 Reportedly, no barrier containment was used and the HEPA filtration system was overloaded with dust. In addition, an outbreak of pseudobacteremia caused by Bacillus spp. occurred in another hospital during construction above a storage area for blood culture bottles.207 Airborne spread of Bacillus spp. spores resulted in contamination of the bottles' plastic lids, which were not disinfected or handled with proper aseptic technique prior to collection of blood

samples. *Material in this table includes information from D. Erickson, ASHE, 2000. +Material in this table was compiled from references 19, 51, 67, 80, 106, 120, 250, 266, 273, 276–278, 280, 285, 309, 312–315. Areas in health-care facilities that require special ventilation include The number of rooms required for PE and AII are determined by a risk assessment of the health-care facility.6 Continuous, visual monitoring of air flow direction is required for new or renovated pressurized rooms. 120, 256 Although the exact configuration and specifications of PEs might differ among hospitals, these care areas for high-risk, immunocompromised patients are designed to minimize fungal spore counts in air by maintaining Air flow rates must be adjusted accordingly to ensure sufficient ACH, and these rates vary depending on certain factors (e.g., room air leakage area). For example, to provide ≥12 ACH in a typical patient room with 0.5 sq. ft. air leakage, the air flow rate will be minimally 125 cubic feet/min (cfm).320, 321 Higher air flow rates may be needed. A general ventilation diagram for a positive-pressure room is given in Figure 2. Directed room air flow in PE rooms is not laminar; parallel air streams are not generated. Studies attempting to demonstrate patient benefit from laminar air flow in a PE setting are equivocal.316, 318, 319, 322 – 327 Air flow direction at the entrances to these areas should be maintained and verified, preferably on a daily basis, using either a visual means of indication (e.g., smoke tubes and flutter strips) or manometers. Permanent installation of a visual monitoring device is indicated for new PE construction and renovation.120 Facility service structures can interfere with the proper unidirectional air flow from the patients' rooms to the adjacent corridor. In one outbreak investigation, Aspergillus spp. infections in a critical care unit may have been associated with a pneumatic specimen transport system, a textile disposal duct system, and central vacuum lines for housekeeping, all of which disrupted proper air flow from the patients' rooms to the outside and allowed entry of fungal spores into the unit (M.McNeil, CDC, 2000). The use of surface fungicide treatments is becoming more common, especially for building materials.329

Copper-based compounds have demonstrated anti-fungal activity and are often applied to wood or paint. Copper-8-quinolinolate was used on environmental surfaces contaminated with Aspergillus spp. to control one reported outbreak of aspergillosis.310 The compound was also incorporated into the fireproofing material of a newly constructed hospital to help decrease the environmental spore burden.316 Acute-care inpatient facilities need at least one room equipped to house patients with airborne infectious disease. Every health-care facility, including ambulatory and long-term care facilities, should undertake an ICRA to identify the need for AII areas. Once the need is established, the appropriate ventilation equipment can be identified. Air handling systems for this purpose need not be restricted to central systems. Guidelines for the prevention of health-care acquired TB have been published in response to multiple reports of health-care associated transmission of multi-drug resistant strains.4, 330 In reports documenting health-care acquired TB, investigators have noted a failure to comply fully with prevention measures in established guidelines.331 – 345 These gaps highlight the importance of prompt recognition of the disease, isolation of patients, proper treatment, and engineering controls. AII rooms are also appropriate for the care and management of smallpox patients.6 Environmental infection control with respect to smallpox is currently being revisited (see Appendix E). Salient features of engineering controls for AII areas include As with PE, airflow rates need to be determined to ensure the proper numbers of ACH.320, 321 AII rooms can be constructed either with (Figure 3) or without (Figure 4) an anteroom. When the recirculation of air from AII rooms is unavoidable, HEPA filters should be installed in the exhaust duct leading from the room to the general ventilation system. In addition to UVGI fixtures in the room, UVGI can be placed in the ducts as an adjunct measure to HEPA filtration, but it can not replace the HEPA filter.4, 346 A UVGI fixture placed in the upper room, coupled with a minimum of 6 ACH, also provides adequate air cleaning.248 One of the components of airborne infection isolation is respiratory protection for health-care workers and visitors when

entering AII rooms.4, 6, 347 Recommendations of the type of respiratory protection are dependent on the patient's airborne infection (indicating the need for AII) and the risk of infection to persons entering the AII room. A more in-depth discussion of respiratory protection in this instance is presented in the current isolation guideline;6 a revision of this guideline is in development. Cough-inducing procedures (e.g., endotracheal intubation and suctioning of known or suspected TB patients, diagnostic sputum induction, aerosol treatments, and bronchoscopy) require similar precautions.348–350 Additional engineering measures are necessary for the management of patients requiring PE (i.e., allogeneic HSCT patients) who concurrently have airborne infection. For this type of patient treatment, an anteroom (Figure 4) is required in new construction and renovation as per AIA guidelines.120 The pressure differential of an anteroom can be positive or negative relative to the patient in the room.120 An anteroom can act as an airlock (Figure 4). If the anteroom is positive relative to the air space in the patient's room, staff members do not have to mask prior to entry into the anteroom if air is directly exhausted to the outside and a minimum of 10 ACH (Figure 4, top diagram).120 When an anteroom is negative relative to both the AII room and the corridor, health-care workers must mask prior to entering the anteroom (Figure 4, bottom diagram). If an AII room with an anteroom is not available, use of a portable, industrial-grade HEPA filter unit may help to increase the number of ACHs while facilitating the removal of fungal spores; however, a fresh air source must be present to achieve the proper air exchange rate. Incoming ambient air should receive HEPA filtration. Operating room air may contain microorganisms, dust, aerosol, lint, skin squamous epithelial cells, and respiratory droplets. The microbial level in operating room air is directly proportional to the number of people moving in the room.351 One study documented lower infection rates with coagulase-negative staphylococci among patients when operating room traffic during the surgical procedure was limited.352 Therefore, efforts should be made to minimize personnel traffic during operations.

Outbreaks of SSIs caused by group A beta-hemolytic streptococci have been traced to airborne transmission from colonized operating-room personnel to patients.150–154 Several potential health-care associated pathogens (e.g., Staphylococcus aureus and Staphylococcus epidermidis) and drug-resistant organisms have also been recovered from areas adjacent to the surgical field,353 but the extent to which the presence of bacteria near the surgical field influences the development of postoperative SSIs is not clear.354 Proper ventilation, humidity (<68%), and temperature control in the operating room is important for the comfort of surgical personnel and patients, but also in preventing environmental conditions that encourage growth and transmission of microorganisms.355 Operating rooms should be maintained at positive pressure with respect to corridors and adjacent areas.356 Operating rooms typically do not have a variable air handling system. Variable air handling systems are permitted for use in operating rooms only if they continue to provide a positive pressure with respect to the corridors and adjacent areas and the proper ACHs are maintained when the room is occupied. Conventional operating-room ventilation systems produce a minimum of about 15 ACH of filtered air for thermal control, three (20%) of which must be fresh air.120, 357, 358 Air should be introduced at the ceiling and exhausted near the floor.357, 359 Laminar airflow and UVGI have been suggested as adjunct measures to reduce SSI risk for certain operations. Laminar airflow is designed to move particle-free air over the aseptic operating field at a uniform velocity (0.3–0.5 m/sec), sweeping away particles in its path. This air flow can be directed vertically or horizontally, and recirculated air is passed through a HEPA filter.360–363 Neither laminar airflow nor UV light, however, has been conclusively shown to decrease overall SSI risk.356, 364–370 Elective surgery on infectious TB patients should be postponed until such patients have received adequate drug therapy. The use of general anesthesia in TB patients poses infection-control challenges because intubation can induce coughing, and the anesthesia breathing circuit apparatus potentially can become contaminated.371

Although operating room suites at 15 ACH exceed the air exchanges required transmission of TB to operating-room personnel. If feasible, intubation and extubation of the TB surgical patient should be performed in AII. AIA currently does not recommend changing pressure from positive to negative or setting it to neutral; most facilities lack the capability to do so.120 When emergency surgery is indicated for a suspected/diagnosed infectious TB patient, taking specific infection-control measures is prudent (Box 8). *Material in this table was compiled from references 4, 347, and 372–374. +The placement of portable HEPA filter units in the operating room must be carefully evaluated for potential disruptions in normal air flow. The portable unit should be turned off while the surgical procedure is underway and turned on following extubation. Portable HEPA filter units previously placed in construction areas may be used in subsequent patient care, provided that all internal and external surfaces are cleaned and the filter's performance is verified with appropriate particle testing and is changed, if needed. * Material in this table is compiled from references 35 and 120. § Positive pressure and HEPA filters may be preferred in some rooms in intensive care units (ICUs) caring for large numbers of immunocompromised patients. ¶ Clean-to-dirty: negative to an infectious patient, positive away from an immunocompromised patient. ** Minimized infiltration for ventilation control; pertains to windows, closed doors, and surface joints. ¶¶ Table used with permission of the publisher of reference 35 (Lippincott Williams and Wilkins). In addition to infectious bioaerosols, several crucial non-infectious, indoor air-quality issues must be addressed by health-care facilities. The presence of sensitizing and allergenic agents and irritants in the workplace (e.g., ethylene oxide, glutaraldehyde, formaldehyde, hexachlorophene, and latex allergens375) is increasing. Asthma and dermatologic and systemic reactions often result with exposure to these chemicals. Anesthetic gases and aerosolized medications (e.g., ribavirin, pentamidine, and aminoglycosides) represent some of the emerging potentially hazardous exposures to health-care workers. Containment of the aerosol at

the source is the first level of engineering control, but personal protective equipment (e.g., masks, respirators, and glove liners) that distances the worker from the hazard also may be needed. Laser plumes and surgical smoke represent another potential risk for health-care workers.376–378 Lasers transfer electromagnetic energy into tissues, resulting in the release of a heated plume that includes particles, gases, tissue debris, and offensive smells. One concern is that aerosolized infectious material in the laser plume might reach the nasal mucosa of surgeons and adjacent personnel. Although some viruses (i.e., varicella-zoster virus, pseudorabies virus, and herpes simplex virus) do not aerosolize efficiently,379, 380 other viruses and bacteria (e.g., human papilloma virus [HPV], HIV, coagulasenegative Staphylococcus, Corynebacterium spp., and Neisseria spp.) have been detected in laser plumes.381–387 The presence of an infectious agent in a laser plume may not, however, be sufficient to cause disease from airborne exposure, especially if the normal mode of transmission for the agent is not airborne. No evidence indicated that HIV or hepatitis B virus (HBV) has been transmitted via aerosolization and inhalation.388 Although continuing studies are needed to fully evaluate the risk of laser plumes to surgical personnel, the prevention measures in these other guidelines should be followed: These guidelines recommend the use of Although transmission of TB has occurred as a result of abscess management practices that lacked airborne particulate control measures and respiratory protection, use of a smoke evacuator or needle aspirator and a high degree of clinical awareness can help protect healthcare workers when excising and draining an extrapulmonary TB abscess.137 CDC provides information on infection control and clinical safety to help reduce the risk of infections among healthcare workers, patients, and visitors. Languages Language Assistance Languages Language Assistance

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