ISIAQ Review

on

Indoor Air Quality in Hospitals and Other Health Care Facilities

October 2003

Indoor Air Quality in Hospitals and Other Health Care Facilities
Authors

Chairmen:

Kalliokoski, Pentti	Finland
Luscuere, Peter	The Netherlands
Streifel, Andrew	USA

Contributors:

Bakke, Jan	Norway
Batterman, Stuart	USA
Flatheim, Gaute	Norway
Haverinen, Ulla	Finland
Holcatova, Ivana	Czech Republic
Nathanson, Ted	Canada

Secretary:

Tarvainen, Kaija	Finland

CONTENTS

PART 1. INTRODUCTION

Hospitals and other health care facilities are complex environments which require ventilation for comfort and to control hazardous emissions for patients, personnel and visitors. Indoor air quality is more critical in health care facilities than in most other indoor environments because of the many dangerous microbial and chemical agents present. Another factor is the increased susceptibility of patients, especially immuno-suppressed persons. Providing ventilation capable of efficiently fulfilling all - even contradictory - needs in hospitals and other health care facilities is a great challenge, and adequate solutions have not yet been found for many indoor air quality problems. In addition, the importance of good indoor climate is not yet universally recognized. Therefore, nosocomial infections due to contaminated air continue to cause unnecessary costs and suffering, and health care personnel remain subject to several occupational exposure risks. Sick building syndrome (SBS) episodes have also been reported in hospital workers. Moreover, indoor climate in these environments often fails to maintain a reasonable comfort level.

No exact airborne nosocomial infection rates are available. An estimate of 10% for their relative contribution among all nosocomial infections has been proposed (Schaal 1991). In recent years, the overall hospital-acquired infection rate has been 5-10% in Europe and North America (Emmerson 1995). Rates vary widely between different wards, ranging from 1% or less in oculistic and psychiatric wards to about 30% in intensive care (CDC 1985). Many nosocomial infections appear at home when patients are discharged early after short periods of hospitalization. This is one reason why reported hospital-acquired infection rates are probably underestimated.

There are several bacteria, viruses, and fungi that can be transmitted through the air. The possibility of airborne infection depends strongly on the type of the microbe.Gram-positive cocci, such as staphylococci, which survive relatively well in a dry environment, are more likely to be transmitted by air than gram-negative bacilli, which can tolerate only a short period without moisture. Medical intervention of certain diseases can cause a patient to become extremely susceptible to common opportunistic environmental microbes.

The development of antibiotic resistant bacterial strains is a serious threat to present hospital care practice. Even though ventilation is not the primary means of controlling multi-resistant bacteria, it is, nevertheless, one link in the chain required to provide comprehensive hygiene. In addition, it should be noted that extensive use of bactericides may produce chemical health risks to personnel.

Infection control practices vary widely. Due to cultural, financial, educational and other differences, various countries have adopted different practices. In addition, differences often exist among different hospitals in the same city or even among different wards in the same hospital. In most countries there are no common recommendations on the prevention of nosocomial infections. Present standards and guidelines originate mainly from the US Centers for Disease Control and Prevention (CDC).

Practical infection control work is usually carried out by the infection control doctor (generally a part-time medical microbiologist) and the infection control nurse. Most hospitals also have infection control committees. Often, these do not have any personnel from the technical department and this causes several problems. Many indoor air problems result simply from the lack of active collaboration between medical and technical personnel:

- Inappropriate air pressure differences may be maintained in critical areas which require a controlled environment.
- Building repair, without adequate control, may adversely affect nearby areas with high cleanliness requirements.
- Many modern hospitals have sophisticated and expensive ventilation systems but too often these have not been properly integrated into the building design, and then maintained, or even used. This is at least partly due to the fact that the importance of maintaining good indoor air quality is not yet unanimously recognized among the medical community.
- Medical staff often have poor knowledge of the intended operational performance of ventilation systems, even with regard to their protective functions. Systems that were originally properly designed can be misused to the extent that the intended functionality is reduced, leading to increased risks (Luscuere *et al*. 1993).

Due to an almost constant need for updating and expanding of medical services, renovation and construction are common occurrences in health care facilities. Fungal spores and bacteria may be released during repair, maintenance, and construction. The spores are small and remain airborne over a lengthy period. Therefore, they may travel long distances. Exposure to fungal spores constitutes a very serious threat to immuno-compromised patients.

Water and moisture damages also occur often in hospitals. These may create microbial reservoirs that lead to adverse health effects among patients as well as personnel.

Health care personnel are occupationally exposed to several potentially harmful gases, vapors, and dusts:

- When the patient is anesthetized during surgery, the released anesthetic gases may affect exposed personnel.
- Adverse health effects may be caused by exposure to disinfectants and sterilants.
- Patients are administrated medications which can cause hazardous exposure to the health care worker. It is essential that this type of exposure is recognized.

Recognition of hazards requires some understanding of the variety of hazardous agents found in health care facilities. Hazards for patients and employees may differ. However, the hospital environment should be safe for both patients, employees, and visitors. The presence of airborne biological and chemical agents and their risk factors must be recognized in order to organize an effective indoor air quality safety program where resources are allocated optimally to reduce risks from airborne hazards.

Even in the richest countries, hospitals are facing huge economic difficulties. Problems are generally more severe in old hospitals that may have large wards and poor or no mechanical ventilation. The situation is even more difficult in poor countries. Therefore, there is always a need for efficient and cost-effective control methods.

The purpose of this review is to provide a comprehensive summary on the airborne health risks in health care facilities and to discuss the various control means.

PART 2. RISK ASSESSMENT AND HEALTH EFFECTS

1. Patient Susceptibility and Health Effects

The most dangerous bacteria that may be transmitted as infective aerosols are *Staphylococcus aureus* and *Mycobacterium tuberculosis*. Staphylococcal infections have occurred frequently in nurseries and operating rooms. The situation is improving in nurseries but *Staphylococcal* post-operative wound infections remain a major problem (Eickhoff 1993):

- It has been estimated that these constitute as much as 29% of the hospital-acquired infections in the Netherlands (Luscuere 1995).
- On the other hand, the relative frequency of deep sternal infections caused by *S. aureus* after open thoracic surgery has been reduced from 17% in 1984-86 to 6% in 1993-95 in a large Swedish hospital. In this hospital the number of surgical site infections caused by coagulase-negative staphylococci (CoNS) has continuously increased, accounting for 14% of surgical site infections in 1990-92 (Tammelin *et al.* 2000).
- Staphylococcus *epidermidis* is the predominant CoNS on the human skin. Even though the risk is influenced by several factors, such as the immuno-competence of the patient and the type of surgery, it is obvious that the risk factors include airborne microbes.
- High *S. aureus* infection risk also exists in the burns units (Mäkelä *et al.* 1979).
- Methicillin resistant *S. aureus* (MRSA) and *S. epidermidis* (MRSE) strains have become worldwide problem. The appearance of vancomycin intermediate- resistant *S. aureus* strains (VISA) have been reported recently in Japan and USA. If totally resistant strains appear, no antibiotic is effective against these strains.
- Multiple drug resistant strains of *M.tuberculosis* have also been developed (see section 2).

Immuno-suppressed patients, such as transplant recipients (Pannuti *et al.*1991) and leukemia and other cancer patients undergoing chemotherapy (Harvey and Hyers 1987; Horn *et al.*1985) are at risk of acquiring infection from the hospital environment. Immuno-suppression caused by human immuno-deficiency-virus (HIV) impairs the ability to defend against TB infection. Persons infected with both TB and HIV have much higher risk of progressing rapidly to active TB than HIV-negative individuals. TB is common among drug abusers and homeless persons. They also run the highest risk of becoming carriers of multidrug-resistant strains because their taking of TB medication is erratic.

In addition to pathogens, several opportunistic bacteria, such as *Pseudomonas aeruginosa* and *Mycobacterium chelonei*, need to be controlled:

- Even though *P.aeruginosa* is a significant human pathogen it usually causes infections only in the context of some serious underlying disease. Nosocomial infections occur, for example, in intensive care units.
- The water systems in hospitals may be contaminated with *Legionella*, which causes pneumonia in susceptible patients. The mortality rate has been reported to be as high as 40% among nosocomialy-acquired legionellosis cases (CDC 1997).

- *Burkholderia* (*Pseudomonas) cepasia* is a respiratory pathogen especially for cystic fibrosis (CF) patients. Antimicrobial treatment is relatively ineffective against this bacterium and colonization may lead to bacteremia.

Bacteria are also often found in moisture damaged building structures. Actinomycetes and some other bacteria (e.g., *Bacillus cereus*) may produce toxins (Roponen *et al*. 1999, Mikkola *et al*. 1999) and it is possible that bacteria have a more important role in the etiology of health problems of the occupants of moisture damaged buildings that has generally been assumed.

The airborne transmission of viruses causing measles (rubella) and chicken pox (varicella) has long been recognized. These cause high mortality among immuno-compromised patients. The varicella-zoster-virus that remains latent in the body may later activate causing a skin disease (shingles).

Bacterial and viral infections still account for most of the fatal infections in immuno-compromised patients, but the incidence of fungal infections is increasing and since antifungal therapy remains rather ineffective, fungal pathogens have become a major risk factor for these patients (Overberger *et al*.1995). Invasive fungal diseases are not easily recognized at an early stage and this makes successful treatment even more difficult (von Eiff *et al*.1996):

- Candidiasis and aspergillosis are the most common fungal infections.
- There are, however, several other fungal pathogens including *Cryptococcus neoformans*, *Alternaria* sp.,*Curvularia* sp., *Drechslera* sp., *Exophiala* sp., and *Fusarium* sp. (Simpson and Nightingale 1994). While *Candida* infections are endogenous in origin in most cases, opportunistic mycoses caused by the other fungi are exogenous.
- *Aspergillus* spores in particular have caused much concern because they are ubiquitous and invasive. Aspergillosis has a 75% fatality rate (Gucalp *et al*. 1991). *Aspergillus* species have also been reported to be the most common cause of pneumonia in bone marrow transplant and aplastic anemia patients (Weinberger *et al*. 1997). Four *Aspergillus* species, *A. fumigatus, A. flavus*, A. niger, and *A. terreus*, are commonly encountered as causes of disease. However, other *Aspergillus* species can also be dangerous for immuno-suppressed patients (Rinaldi 1983).*Aspergillus* spore counts as low as 1-3 cfu/m^3 have been found to cause infections (Goodley *et al*. 1994).
- In addition, infections may occur due to colonization, e.g. of the paranasal sinuses, prior to hospital admission (Hay *et al*. 1995). Asthmatic patients and infants are also risk groups for fungal exposures. If fungal growth takes place in the building, toxic metabolites (mycotoxins) may appear, for example, due to *Stachybotrys chartarum*.

2. Employee Susceptibility and Health Effects

Biology – infectious agents

The rapid increase of tuberculosis in the US and many other countries and the simultaneous development of multiple drug resistant strains of *Mycobacterium tuberculosis* have caused a great deal of concern among health care personnel. The current annual infection rate of TB among US health care workers is 0.5-1% but only 0.15% among the general US population (Nicas 2000). According to data obtained from 210 US hospitals, the mean TB infection rate among high risk employees - bronchoscopists and respiratory therapists - was 1.9% in hospitals that treated at least six TB patients annually, and 0.2% in hospitals that treated fewer than six TB patients annually (Fridkin *et al*. 1995).

A very low dose can cause TB infection. An estimate of one infectious droplet nuclei per 300 m^3 of air has been given as the critical concentration (Rutala *et al.* 1995). This has also been demonstrated with Guinea pigs exposed to air vented from a ward of TB patients.

The animals became infected, indicating that TB may spread via the ventilation system (Riley *et al*. 1959). Therefore, ventilation for control of infectious isolation is an important means to prevent transmission of TB. CDC (1994) and OSHA (1997) have recently issued guidelines for that purpose.

Chemical vapors and gases

The risk of microbial dissemination occurs when contaminated materials are handled. Disposal of clinical waste and the handling of infectious laundry are examples of potentially dangerous operations. New surgical and autopsy procedures also generate potentially infectious aerosols which have been found to cause occupational diseases (see part 3).

Mold, dusts and fumes

Living or working in a moldy building is known to cause irritation and various, mainly respiratory, diseases (e.g., Dales *et al*. 1991, Flannigan and Miller 1994). Mold growth is also a problem in hospitals and may result in adverse health effects among personnel in hospitals if moisture damage remains unrepaired.

Even though aspergillosis is an important nosocomial infection it has not been commonly reported as a work-related disease in hospitals (Melius 1993). There are, however, a few pathogenic fungi, especially *Coccidioides immitis* and *Histoplasma capsulatum*, which may cause infections, especially in microbiology laboratories. The main risk is from the handling of live cultures and biopsy and post-mortem samples. Infections are usually caused by skin contact, but a few airborne infections have also been reported (Campbell 1995).

PART 3. BIOLOGICAL SOURCES

3. Patient Sources

The presence of an infectious patient is potentially hazardous not only to other patients but also to the health care employees. Patients with infectious diseases, e.g., tuberculosis, chicken pox , measles , and German measles (Rubella), which spread easily via air, must be contained in special ventilated care areas.

TB is transmitted as small mucusal particles carrying viable bacteria, called droplet nuclei. These particles, having diameters from 1 to 5 µm, are generated by the coughing and sneezing of patients with active TB. Due to their small size, the particles can stay airborne for lengthy periods. Bacteria are also dispersed into the air during many routine patient care activities, such as bedmaking (ASHRAE 1995). TB infection may occur after deposition of a single infectious particle in the lungs. Infected persons have about a 10% lifetime risk of developing active TB. As mentioned before, the risk is clearly higher among HIV-infected persons (CDC 1994).

Airborne transmission is possible for many bacteria. *Pseudomonas aeruginosa* can become airborne during certain procedures, e.g., removal of dressings from leg ulcers or the puncturing of an abscess. A recent study (Ensor *et al*. 1996) indicated that cystic fibrosis patients disseminate *B(?). cepacia* into the environment. The risk of airborne transmission escalates during physiotherapy. It has been suggested that widespread environmental contamination on carpets and soft furnishing with Group A *streptococci* contributed to an outbreak in a nursery home (Sarangi and Rowsell 1995).

The common respiratory viruses, rhinoviruses, influenza and parainfluenza viruses, which are mainly spread by large droplets, may also be spread by the airborne route. Respiratory syncytial virus and adenoviruses have been shown to have airborne transmission in pediatric wards (Hall 1981). Varicella-zoster virus, measles and rubella may also spread via the airborne route (Eickhoff 1993). Certain enteric viruses may be transmitted through the air (Sawyer 1988).

Many health care workers risk exposure to bloodborne pathogens, especially hepatitis B virus (HBV). Operating room personnel have the highest risk (Pattison *et al.* 1975). In addition to exposure via the skin, exposure may occur due to aerosols generated by surgical power tools, such as oscillating bone saws, bone drills, and electrocautery (Heinsohn *et al*. 1991). Most of the particles generated are in the respirable range (less than 4 µm). Laser plumes are considered a possible microbial source, especially during removal of human papilloma virus tumors, vaginal warts, or extrapulmonary tuberculosis lesions.

4. Employee and Environmental Sources

<u>Staphylococci and other pathogenic bacteria</u>

Employees may become sources of airborne infections among patients. A person releases about 10 million particles within a day. The release rate is roughly 10,000 particles/min while walking. About 5-10% of the particles (size range 2.5-20 μm) carry bacteria (Noble 1976). Among these, *Staphylococcus aureus*, *S. epidermidis* and gram-negative rods are common causes of post-operative wound infections (Tarvainen 1990). Carriers of staphylococci are common. Noble (1962) classified a person to be a disperser of a particular organism if its proportion exceeds 1% of the total disseminated bacteria. Dispersers of *S. aureus* are more common in men (9-13) than in women (1-1.5%) (Tammelin *et al.* 2000).

Staphylococcus aureus is the most important cause of surgical site infections in the USA (Casewell 1998). The development of methicillin- and even vancomycin-resistant strains of *Staphylococcus aureus* has caused great concern. MRSA is spread mainly by direct contact from the hands of health care personnel. In the revised British guidelines for the control of MRSA infections in hospitals (Ayliffe *et al*. 1998), isolation in a single room with a negative pressure is mentioned as an important control measure because MRSA carriers contaminate their environment by releasing staphylococci-containing particles. Ventilation systems have also been found to be sources for MRSA outbreaks. Kumari *et al.* (1998) described a case where ventilation was operated on an intermittent cycle in an orthopedic ward. When the system was shut down, a negative pressure was created that sucked air from the ward and contaminated the outlet grilles. Contaminated air was blown back when ventilation was started again.

As mentioned earlier, the relative importance of surgical site infections by *S. epidermidis* has been increasing in Sweden since the early 1980s. One reason is the develoment of methicillin-resistant strains (MRSE). A recent Swedish study (Tammelin *et al.* 2000) indicated that as many as 43% of male and 25% of female operating room staff members were dispersers of MRSE (based on the definition given by Noble (1962)). MRSE was also detected in the air of the operating room in spite of high ventilation rate (80 ACH). The authors concluded that because the percentage of the dispersers was so large, the best way to reduce the risk of airborne MRSE transmission was to ask the personnel to wear special scrub suits.

Opportunistic bacteria

Streptococcus pyogenes is a rare, but serious, cause of surgery complications. Its carriers often remain asymptomatic. Sites from which its airborne dissemination has occurred include pharynx, anus, hair and skin (Eickhoff 1993). The importance of airborne transmission has been demonstrated by investigating post-operative wound infections caused by *S. pyogenes*. Contrary to expectations, assisting staff members, not surgeons, were the most common sources. The carrier could even be working in an adjacent room (Kolmos *et al*. 1997).

According to an Italian study, bacteria detected in intensive care and surgery wards were mostly Gram positive and probably derived from human sources. However, more hazardous species, including *Staphylococcus aureus, Acynetobacter lwoffi,* and *Pseudomonas aeruginosa,* were also frequently encountered in air (Alcini *et al*. 1995). Such microbes can be associated with local sources:

- *P. aeruginosa* is ubiquitous in the environment.
- *Burkholderia cepacia*, which resembles *P. aeruginosa*, is another common environmental bacterium.

Many infectious diseases, e.g., tuberculosis, are spread as droplet nuclei. The sources mentioned earlier as occupational health risks may also cause infections among patients.

Legionella

The preferred environments for *Legionella* bacteria include warm water systems, such as faucets and showers, cooling towers and humidifiers. Dead ends in piping that cause stagnation of water also provide amplification sites for *Legionella.* Legionellosis outbreaks have occurred in several hospitals. Elderly males, especially those suffering from respiratory and renal diseases, seem to be at risk (Barbaree *et al*. 1993). Highly immuno-compromised patients, of course, require extremely strict control measures. It is also probable that many cases of nosocomial legionnellosis are not detected because routine culturing of respiratory tract secretions is rarely carried out.

Fungi

Outdoor air generally contains a high concentration of fungal spores. The concentration of viable spores often exceeds 1000 cfu/m^3 during the summer. Only during winter months in areas where ground has snow cover do the fungal spore counts become low in outdoor air. Pathogenic *Aspergilli* belong to the normal outdoor fungal flora. Mold spores may enter hospitals through windows or inadequate air filtration system. Surfaces, such as carpets (Gerson *et al.*1994) and multiple-hole false ceilings (Damiani *et al*. 1994) where dust can accumulate, as well as potted plants (Staib *et al*, 1981), are potential fungal sources. Spores may enter the patient's room even as contamination on personnel's clothing. Several studies (e.g., Overberger *et al*. 1995) have shown that dust generated during construction and renovation in health care facilities contains *Aspergillus* and other fungal spores. An association between airborne mold spore contamination due to construction work and incidence of *aspergillosis* in immuno-compromised patients has also been documented (Dewhurst *et al.* 1990). Even air filters, which should prevent the entry of fungal spores into the building, may become colonized with fungi. This is a risk especially in HVAC systems with excessive cooling capacity in humid climate (Simmons *et al*. 1997). An outbreak of *aspergillosis* has been reported due to fungal growth on the frames of air filters in a hospital (Arnow *et al*. 1991).

Hospitals suffering from moisture damages become moldy, as other buildings, if immediate and effective measures are not taken. In addition to the risk of development of fungal infections among patients with suppressed immune systems, long term exposure to fungi may cause other adverse health effects among personnel and patients. As stated earlier, moisture damage may also lead to bacterial growth in building materials.

An outbreak of postoperative endophthalmitis was caused by the fungus *Acremonium kiliense* which grew in a reservoir-type evaporative humidifier. No further cases appeared after the humidifier was removed (Fridkin *et al*. 1996).

PART 4. CHEMICAL EXPOSURES

Because several chemical hazards are evident in health care facilities, an occupational hygiene plan should be developed and implemented that includes measures for safe handling and storing of chemicals.

5. Disinfectants and Sterilants

Health care personnel are commonly exposed to disinfection and sterilization agents, such as ethylene oxide, glutaraldehyde, Chloramin T, and formaldehyde. The US OSHA occupational exposure limits (OEL) are 1 ppm for ethylene oxide and 0.2 ppm for glutaraldehyde. A lower (ceiling) limit of 0.05 ppm has been proposed by ACGIH for glutaraldehyde. The ACGIH threshold limit value (TLV) for formaldehyde is 0.3 ppm (a ceiling value).

Ethylene oxide is a commonly used sterilizing agent for medical equipment. It is a directly acting mutagen and a suspected carcinogen (Hogstedt *et al*. 1986). In addition, ethylene oxide seems to have sensitizing properties to the airways causing occupational asthma and inducing positive specific immune response. This has been documented by Prick-tests and IgE-reactions (Deschamps *et al*. 1992), Dugue *et al*. 1991, Rumpf *et al*. 1985, Verreas and Michel 1995). Long term ethylene oxide exposure levels averaging 0.07 ppm have been detected in a US hospital (LaMontagne 1993). Short-term peak exposures to ethylene oxide often occur during the unloading of sterilizers (Angerer *et al.* 1998). Ethylene oxide peak levels above 400 ppm have been reported after opening the sterilizers (Popp *et al*. 1994).

Glutaraldehyde is used especially for cold disinfection of endoscopes usually as a 2.0-3.4% water solution. It is also used in the processing of x-ray films and to disinfect whirlpool tanks and impellers in physical therapy (Wellons *et al.* 1998). Glutaraldehyde is a strong irritant. The irritation threshold is about 0.3 ppm and the odor detection limit 0.04 ppm (Wellons *et al*. 1998). Glutaraldehyde is probably the main cause of occupational asthma among health care workers (Corrado *et al*. 1986, Curran *et al*. 1996, Di Stefano *et al*. 1999, Stenton *et al*. 1994). Glutaraldehyde is also a skin sensitizer. The use of automatic disinfection machines has reduced exposure to glutaraldehyde. However, spills have been reported to occur commonly (Niven *et al*. 1997).During floor spills, the airborne concentrations of glutaraldehyde up to close to 1 ppm were detected (Niven *et al*. 1997). Exposure to glutaraldehyde can be maintained below the 0.05 ppm level by following careful work practices and by using automated equipment in well-ventilated rooms.

Chloramin T (sodium salt of N-chloro-p-toluene sulphonamide) is used in cleaning floors and other surfaces. It is also used to disinfect equipment. It has sensitizing properties and has caused asthma in exposed hospital staff (Dijkman *et al*. 1981, Schoneich and Wallenstein 1985). Allergic contact urticaria has also been reported in connection with exposure in hospitals (Beck 1983, Dooms-Goosens *et al.* 1983).

Formaldehyde is used in disinfection and in the processing of x-ray films. It is a strong irritant and can also act as a sensitizer (Burge *et al.* 1985, Degorce-Hecquet *et al.* 1987). However, asthma and other airway symptoms probably occur more frequently as a result of its irritative effects than from specific sensitization (Nordman *et al.* 1985). It is also a possible carcinogen.

6. Anesthetic Gases

Nitrous oxide, halothane, sevoflurane, enflurane, and isofurane are the most commonly used anesthetic gases. Halogenated gases are also used mixed with oxygen-nitrous oxide. Embryotoxic and teratogenic effects have been detected in rats exposed to high concentrations of halothane (Baeder and Albrecht 1990) and nitrous oxide (Fujinaga *et al.* 1989). The early epidemiological studies indicated an elevated risk of miscarriage among women exposed occupationally to anesthetic gases (Edling 1980). Even though this has not been detected consistently in recent studies (Tannenbaum and Goldberg 1985), similar findings have still been reported (Guirguis 1990). There is some evidence to suggest an elevated risk among wives of exposed male anesthetics. No clear conclusions can be made according to experimental animal tests done for enflurane and isoflurane (Tannenbaum and Goldberg 1985). Besides being a health risk to the staff, exposure to anesthetic gases during surgery may impair job performance during critical procedures.

Halothane has the highest acute toxicity, especially to the central nervous system. Exposure levels exceeding 10 ppm may cause headache and fatigue. Prolonged exposure may lead to liver damage. Halothane has quite low OEL, ranging from 0.5 ppm (Australia) to 5 ppm (Sweden and Germany). In the US, NIOSH recommends a limit of 2 ppm for all halogenated anesthetic gases. If the halogenated gases are used together with nitrous oxide, a lower limit of 0.5 ppm is recommended by NIOSH. The exposure limit recommended by NIOSH for nitrous oxide is 25 ppm.The Swedish and Finnish OELs for enflurane and isoflurane are 10 ppm and 100 ppm for nitrous oxide.

Airborne anesthetic gases originate partly in the waste anesthetic gas exhaled by the patient and partly in the fugitive anesthetic gas leaked from the anesthesis administration devices. The removal of the anesthetic gases from the body occurs slowly. Nitrous oxide and isofurane concentrations as high as 900 ppm and 800 ppm, respectively, have been detected in the exhaled air one hour after the operation (Moore 1997). The total recovery room emissions of nitrous oxide and sevoflurane were 10 g and 4.2 g for a 13 year old boy (Christiansen *et al.* 1999). Often, concentrations of anesthetic gases have clearly exceeded the OELs in operating rooms if no local exhaust has been used. In such situations, concentrations of nitrous oxide averaged 930 ppm and reached 2750 ppm in Finland in the 70s. The corresponding values were 14 ppm and 57 ppm for halothane. The mean concentrations were 135 ppm for nitrous oxide and 0.9 ppm for halothane when controlled with exhausts. The corresponding maximum values were 380 ppm and 1.9 ppm (Nikki *et al.* 1972). Somewhat lower nitrous oxide levels were detected by the British Health and Safety Executive while surveying 40 operating rooms and 18 recovery rooms in 1980-84 (Gardner 1989). The median airborne concentrations were 131 ppm among anesthesiologists, 94 ppm for surgeons, 47 for other operating room personnel, and 23 for recovery room personnel. However, some very high exposure levels were also detected in this study, especially among anesthesiologists (up to 1440 ppm). If a separate exhaust is used, it must be located very close to the face (within 10 cm). Therefore, a combination of the traditional exhaust tube and two-sided pillow exhausts has been recommended. (Christiansen *et al.* 1999). Scavenging exhaust systems have been found to be a quite effective, decreasing the median exposure levels to below 100 ppm for all the personnel groups studied. Nevertheless, a few high airborne concentrations (above 300 ppm) were also measured. The exposure levels were clearly reduced with an increased rate of general ventilation among personnel other than the anesthesiologists who worked closest to the emission source (Gardner 1989).

The new studies conducted in the 90s indicate that the concentrations of anesthetic gases may still be high:

- Concentrations as high as 3970 mg/m^3 of nitrous oxide and 721 mg/m^3 of halothane were detected in Czechland in poorly ventilated operating rooms (Hartlova and Lebenhart 1995).
- The mean concentration of nitrous oxide was 150 ppm in measurements conducted in operation rooms of 33 Finnish hospitals in the early 90s. The nitrous oxide concentration often exceeded 1000 ppm when a scavenging exhaust system was not applied. Even with an exhaust the mean level of nitrous oxide was as high as 116 ppm. The exposure levels were generally higher among nurses than among anesthesiologists. The mean levels of halothane, isoflurane, and enflurane were 1.6 ppm, 2.7 ppm, and 1.4 ppm, respectively. The levels were clearly lower in the recovery rooms; however, nitrous oxide levels exceeding 150 ppm were occasionally detected. The highest levels of halogenated anesthetic gases were about 2 ppm (Rantala *et al*. 1993).
- In another large study conducted in 28 German hospitals in 1989-91 (Bohne-Matusall and Rasmussen 1991), 26% of anesthesiologists' TWA (Time Weighed Average) exposure levels were above 50 ppm for nitrous oxide (madian 19 ppm, max. 1800 ppm) and 8% above 5 ppm for halothane (median 0.2 ppm, max. 13 ppm). In this case, exposure levels were clearly lower among nurses (median 10 ppm for nitrous oxide and 0.1 ppm for halothane). At recovery rooms, the median exposure levels were 9 ppm (max. 81 ppm) for nitrous oxide and 0.1 ppm (max. 1.1 ppm) for halothane.

High nitrous oxide concentrations have been observed in dental facilities both in Finland (Rantala *et al*. 1993) and in the USA (Mc Glothlin *et al*. 1997) despite using the scavenging mask exhaust. High exposure levels were also detected in a recent Finnish study conducted in a pediatric hospital (Christiansen *et al*. 1999). The observed ranges for airborne concentrations of nitrous oxide and sevoflurane were 4-230 ppm and 0.5-32 ppm respectively in the breathing zone of the anesthesiologists during ordinary operations. The corresponding ranges for the nurses were 4-63 ppm and 0.3-5 ppm. Tube exhausts were used during these operations. Concentrations were quite low in the recovery room (air exchange rate 5 h^{-1}). The mean breathing zone concentrations for nitrous oxide and sevoflurane were 4 and 0.4 ppm, respectively. Very high concentrations of sevoflurane (mean concentration 93 ppm) appeared during the operation of a small baby when a warm air (38^{o}C) blow hood (Bair-hugger) was used besides the anesthetic mask. Similarly, high airborne concentrations of nitrous oxide were detected in a recent Italian study. The average concentrations ranged from 8 to 445 ppm with a maximum value of 1345 ppm (Moscato *et al*. 2000).

The concentration limits recommended by NIOSH are difficult to achieve even when the scavenging mask exhausts are used in an operating room provided with effective laminar flow ventilation. The TWA exposures of the personnel varied from 16 to 29 ppm for nitrous oxide and from 0.7 to 0.9 ppm for sevoflurane in an operating room with a ventilation rate of

$20\ h^{-1}$ (Hoerauf *et al*. 1997). Anyhow, the recommendations given based on the above mentioned German study (Bohne-Matusall and Rasmussen 1991) provide useful guidelines for exposure minimization. It is necessary to use an anesthetic apparatus with low leakage and meticulous working practices to avoid spillage of gas. In addition, effective room ventilation is essential and local exhaust is needed during certain procedures, such as children's anesthesia.

7. Latex and other Allergens

Health care workers who wear natural rubber gloves regularly are at high risk of sensitization to latex. Gloves are often powdered with starch. When gloves are used latex allergens are adsorbed to the powder, and when gloves are donned or discarded, starch particles with the adsorbed latex allergens become airborne. The concentration of latex allergen may exceed 200 ng/m^3 in the air (Baur *et al*. 1998). This aerosol can evoke symptoms among sensitized persons and may be able even to sensitize some individuals by inhalation (Bubak *et al.* 1992). A considerable decrease in airborne latex allergen levels can be achieved by using powder-free or low allergen containing gloves (Swanson *et al*. 1995). In addition to latex, the corn starch powder used as lubricant in gloves has shown to cause IgE-mediated allergic reactions among hospital personnel (Crippa and Pasolini 1997).

Acrylic resins are used as denture base material in dental clinics and as bone cement in orthopedic surgery. Methylmethacrylate, which is mixed with a powdered polymer immediately before its use for both applications, is an irritant and sensitizing agent. It has caused skin problems, especially among dental technicians and dentists (Murer *et al*. 1995) but also among surgeons (Kassis *et al*. 1984). Disposable latex gloves do not provide sufficient protection because acrylic monomer rapidly penetrates them. Either encapsulated systems or impermeable gloves should be used (Murer *et al*. 1995). Some evaporation of the monomer also takes place. However, exposure levels were well below the OEL (410 mg/m^3 in the UK) during measurements performed in a British operating room (Williams and Syderham 1996).

Common aeroallergens are also often present in hospitals and may induce symptoms in asthmatics. Soft furnishings and carpets have been found to provide a habitat for the house dust mite to survive and areas for cat and dog allergens to build up (Fletcher *et al*. 1995).

8. Other Factors

Exhaust Fumes

A common indoor air complaint in many health care facilities is the intake of exhaust fumes. Air intakes are often located without taking into consideration traffic, loading docks, and emergency generators. Even if the original design for preventing exhaust gas problems was effective, later developments, such as a large construction project or the addition of a heliport, may cause nuisance and more serious problems. Air quality impacts in operating rooms due to exhaust fumes from the helicopters may cause delays in surgery and raise concern for the safety of the employees and patients.

Laboratory and Pharmacy Chemicals and Drugs

Chemicals and drugs that may become airborne are generally contained in fume hoods. However, laboratory and pharmacy workers may be exposed to the chemicals and drugs they handle. For example, small amounts of cyclophospamide (a chemotherapeutic drug) were detected in the urine of two German hospital pharmacists, although they handled the drug in a vertical laminar flow cabinet and used gloves and protective clothing (Ensslin *et al.* 1997). Trace amounts of this drug have also been found in the air and surfaces of hospital pharmacies (McDevitt *et al.* 1993). Many chemotherapeutic drugs are carcinogenic. The health risks caused by exposure to trace amounts of chemotherapeutic drugs are not known. Increased chromosomal aberration frequencies have, however, been observed in some studies (e.g., Grummt *et al*. 1993).

Medicated aerosols

Medicated aerosols used to treat pulmonary hypersensitivity and pneumonia or for infection prophylaxis have been found to increase airway sensitivity among therapy personnel. Ribavirin, used as an aerosolized medication for respiratory synicitial virus infections, has been found to be teratogenic in animal tests

Odors and Other Factors

Several reports on SBS in hospital workers have been published (e.g. Muzi *et al.* 1995). Many of them have occurred in new hospitals. A too brief airing period before occupation might have contributed to the situation. The intake of exhaust air originating from kitchens can lead to odor problems in patient care areas. Environmental tobacco smoke (ETS) still remains a problem in some hospitals (Kralikova *et al*. 1995). Roofing has also been the source of many complaints. These complaints are transient but nonetheless problematic.

Exposure to film processing and other photochemicals may cause irritative and possible sensitizing effects in the x-ray department. These problems are not widely recognized (Bakke and Eldoen 1996, Smedley *et al*. 1996).

PART 5. CONTROL MEASURES

9. Local Exhausts

Local exhausts are extensively used in industry to control hazardous emission sources. Local source control also provides a cost-effective means to improve indoor air quality in hospitals. Local exhausts should be used always when there is an obvious emission source, such as a high-speed oscillating saw or laser plume.

Scavenging exhaust systems should be used to control occupational exposure to anesthetic gases during surgery. Unfortunately, these do not always provide enough protection (see section 6). Therefore, exposure levels should be monitored.

Cytostatic drugs should be handled inside horizontal laminar flow hoods. In addition, the use of nitrile gloves is important.

Exhaust booths and tents can be used to contain TB droplet nuclei released from TB patients during sputum induction, bronchoscopy, and administration of aerosolized drugs, such as pentamidine. Containment hoods have been developed for bone saws and postmortem examination tables. Local capture devices can also be adopted for transport or enclosure of infectious patients (Streifel 1995).

Negatively pressurized evacuated gowns can be used to prevent shedding of potentially infectious particles by the surgery team during operations where ultraclean air is required.

It has been claimed that glove box autopsy chambers are too difficult to use, but this may be due to improper design or inexperience.

Dust control during renovation of occupied space requires barrier separation (see section 17).

10. Ventilation

<u>Ventilation</u>

The design of proper ventilation systems plays an important role in the prevention of the spread of nosocomial infections. Ventilation is also important for comfort and to minimize exposure to airborne chemical pollution (Streifel 1995). For effective contaminant control ventilation airflow should be reliable. Health care related ventilation standards exist in several countries. The most extensive standards are provided by Centers for Disease Control (CDC) and American Institute of Architects (AIA) in the USA. These include guidelines for preventing the transmission of *Mycobacterium tuberculosis* (CDC 1994), for the prevention of nosocomial pneumonia (CDC 1994), and for construction and equipment in general (AIA 1993). The ASHRAE handbook on HVAC applications also contains a chapter on health care facilities (ASHRAE 1995).

The US guidelines are based on air exchanges per hour (ACH), ie. the volume of air delivered to a space divided by the volume of the space. Ventilation recommendations for patient rooms range from 2 (AIA 1996) to 4 ACH (ASHRAE 1995). A minimum ventilation for intensive care is 6 ACH (ASHRAE 1995). However, this practice has been questioned because contamination is usually not related to room size, instead standards based on volumetric flow rates per patient have been recommended (Marshall 1996). Such standards are used in some countries. For example, 10 L/s/patient for rooms of chronic patients and 8 L/s/patient for other patient rooms have been specified in Finland (Tarvainen 1990).

Relative humidity should be kept below 60% (preferably below 50%) to avoid mold and mite problems. In particular the condensation of moisture on walls and other surfaces should be prevented because moist surfaces allow microbial colonization and growth with potentially hazardous outcomes. On the other hand, there aare indications of that RH should not be less than 30%,in departments for patients with chronic respiratory diseases (Holcatoca and Holcat 1994, Holcatova *et al* 1995).

Air Conditioning

In hospitals, air conditioning has a more important function than merely to promote comfort. Certain patient groups, such as cardiac patients, do not tolerate heat load well. On the other hand, some other patient groups, such as burn patients, need a warm and humid environment (ASHRAE 1995).

A central air conditioning system, in which a mixture of fresh outdoor air and recirculated air is filtered and conditioned for temperature and humidity, is often used in hospitals for its low cost and simplicity. It is, however a risk to use recirculated air, and difficult to adapt for the specific requirements of local areas. This is a particular problem in cold climates in which rooms along the exterior parts of the building require warmer air than rooms in the central core.

The use of variable air volume (VAV) systems, where room temperature is adjusted by regulating the supply airflow, has increased in health care facilities. Air quality may suffer due to lower ventilation rates. In addition, a shift from positive to negative pressure may occur in individual spaces causing infiltration of contaminated air. If corridor and nursing support areas are provided with VAV systems while the patient rooms have constant volume systems, the pressure differentials between the spaces become difficult to maintain due to the air flow variation in the corridor and nursing support areas.

Local fan coil systems are often used in hospital areas that require supplemental cooling. Fan coil systems can, however, become reservoirs for opportunistic pathogens. The presence of water and lint can create conditions for mold proliferation. Often such systems are not accessible for maintenance and cleaning, and this allows microbial growth. Maintenance and cleaning are essential for assuring minimal accumulation of opportunistic environmental microbes. Therefore, such systems should not be used for areas in which sensitive patients are hospitalized.

Filtration

By appropriate utilization of air filtration, a hospital air handling system can deliver relatively particle and microbe free air to areas where such high level of protection is needed. High-efficiency particulate air (HEPA) filters, which can arrest 99.97% of 0.3 µm particles, are commonly used in hospitals. The problem presented by filtration is the energy cost involved. The pressure drop across the filter increases with the efficiency of the filter. One of the requirements for filtration is its capability to remove fungal spores. Filters with a 90% dust spot efficiency can provide nearly 100% efficiency against fungal spores (diameter 2-5 µm) and bacteria (usually present in particles larger than 1 µm) and have lower pressure drop than HEPA filters. However, new HEPA filters having large surface areas cause only relatively low pressure drop compared to the previous HEPA filter versions. Therefore, the additional cost is minimal, especially when the very high degree of protection is considered (Streifel 1996). On the other hand, in applications where air flow rate is crucial, such as in-room air filtration and dilution ventilation for TB infection control, the use of HEPA filters may not be appropriate (Miller-Leiden *et al*. 1996).

When filters are installed, care must be taken to prevent leakage between the filter segments and between the filter bed and its frame. Filters are usually replaced after achieving a certain pressure drop; however, mold growth is possible on the filters, especially in hot and humid areas. Therefore, regular visual inspection is also needed. The filters should also be changed if they emit odors.

Portable filtration units are used as a supplemental control measure in TB isolation rooms. Commercially available units have flow rates from 100 to 700 m^3/h and are often provided with HEPA filters. However, the additional air exchange rate obtained with these devices is more critical than the filtration efficiency for particles in the size of droplet nuclei (1-5 µm). The use of a 90% efficient filter instead of a HEPA filter reduces the removal efficiency only marginally (Miller-Leiden *et al*. 1996). When the portable unit provided 13 ACH in a hospital room it removed 90% of particles larger than 0.3 µm within 5 to 8 minutes (Rutala *et al.* 1995). The effectiveness is highest when the filtration unit is positioned close to the patient in order to capture droplet nuclei before these are dispersed throughout the room (Miller-Leiden *et al.* 1996). The efficiency can be estimated reasonably well using a completely-mixed room model (Miller-Leiden *et al.* 1996).

Operating Rooms

Micro-organisms carrying particles originating from a surgical team are difficult to control with the principle of conventional ventilation. The effect of the ventilation rate was negligible in conventional rooms (wall diffuser panel with turbulent diagonal flow and HEPA filtration) within the range of 7.5 - 20 ACH (Kruppa and Ruder 1996).

In order to reduce microbial exposure during surgery, the use of laminar flow ventilation has become general practice in operating rooms. It is designed both to remove bacteria dispersed by the surgical team and to prevent entry of bioaerosols from adjacent spaces and outdoors. The air supply should be directed vertically toward the surgical site and positive pressure should be maintained. Vertical flow is preferred over horizontal airflow for space management and because personnel and equipment cause turbulence in the latter situation. Higher levels of both bacteria and particles are also found under crossflow conditions using the same amount of air (Whyte and Shaw 1973). Windows should be sealed and the doors self-closing. Ventilation rates from 12 to 25 ACH have been recommended for operating rooms (Woods 1986, Rhodes 1988, ASHRAE 1995, Streifel 1995).

This concept of vertical laminar flow was introduced in the early 60s. Fox published an extensive summary of this concept in 1969. It was concluded that a laminar flow system is far superior to conventional or dilution ventilation in attaining a high level of environmental control. When the operating room is provided with laminar flow ventilation exceeding 60 ACH and HEPA filtration, and the surgical team is wearing special laminated protective clothing ,very low microbial (ca. 2 cfu/m^3) and particle levels ($<10^5$ particles larger than 0.5 μm and 5000 particles larger than 5 μm/m^3) can be achieved (Tarvainen *et al.* 1994). The microbial level of 100 cfu/m^3 has been obtained with ventilation rates of 15 - 17 ACH (Tarvainen *et al*. 1994, Streifel 1995).

In downflow ventilation, obstacles and heat dissipation (people, lamps, equipment) can easily disturb the clean protective flow field. Opening of doors, which eliminates over-pressure and can disturb the flow field, often takes place with reported frequencies over 60 times per hour. In addition, thermally driven air flow around the human body can raise particles that can carry bacteria onto the critical wound area, even from persons standing in the downflow areas. According to computational fluid dynamics models, the wound area in the traditional downflow operating room with a large lamp just beneath the filter area may be the most contaminated area in the room. In this case, the physical obstruction of the lamp seemed to be far more important than its heat dissipative disturbance of the downflow (Lemaire *et al.* 1993). Thus, comprehensive planning that takes into consideration all major factors - including ventilation flowfield, positions of lamps and instrument tables, and door openings - is important.

Several ventilation concepts that combine laminar and turbulent flow have been presented:

- In the Allander-system (flow rate ca. 1 m^3/s), the laminar flow region is confined within a surrounding air curtain.
- The anesthetic team is separated by a partial wall in the Allo-Pro-system in which the local ventilation rate may be 500 ACH (flow rate ca. 2.8 m^3/s).
- A displacement flow pattern is the aim of the Charnley-Howorth-system where supply air, which is introduced above the operation table, is partially recirculated (flow rate ca. 2.8 m^3/s).
- In the Weiss-system (flow rate ca. 0.7 m^3/s), supply air flow is blown with two supporting flows and exhausted from one wall (Schmidt 1987).
- The upward displacement ventilation that was put to use in Sweden and Norway - mainly to provide comfortable climatic conditions in the operation rooms - was found to result in higher counts of bacteria both in the air and on surfaces than the conventional mixing system (Friberg *et al*. 1996). It was concluded that upward displacement ventilation

should not be used for ordinary surgical procedures, but that it might be suitable for open laser surgery.

Isolation

The same architectural and ventilation design has been largely applied for both infectious and protective isolation. The pressure conditions are simply reversed (Hermans and Streifel 1993). The laminar air flow (LAF) principle with HEPA filtration is commonly applied in isolation rooms. This kind of system has proved to be useful in the control of invasive aspergillosis but it seems to be less efficient in reducing the incidence of gram-negative bacteremia (Fenelon 1995).

The basic ventilation principle in protective isolation is to provide positive pressure ventilation. Conventionally, the filtered supply air flow has been designed to exceed the exhaust flow by at least 10%. However, the pressure difference between the protective isolation room and the adjacent space is the critical parameter. It should be at least 2.5 Pa. The airflow differential required to fulfill this criterium depends on the leakage area. A ventilation rate higher than 12-15 ACH is recommended (AIA 1995, ASHRAE 1995). Supply air diffusers should be located in the ceiling and designed to deliver air far enough into the room to ensure effective mixing (Streifel 1996).

Mere positive pressure may, however, not provide sufficient protection for the most sensitive patients, especially patients requiring bone marrow transplants. They are often housed in laminar air flow (LAF) rooms where one entire wall is provided with HEPA filters. Air is blown through the filters at high velocity (about 0.5 m/s) and exhausted through high-capacity return ducts located on the opposite wall to provide piston flow across the room. To enhance patient protection, personnel should work downstream from the patient. Such rooms provide a ventilation rate higher than 100 ACH (Streifel 1996). To ensure effective infection control, anterooms are helpful. The LAF environment provides effective protection against aspergillosis. However, bone marrow transplant patients may acquire the infection after discontinuation of LAF (Wald *et al.* 1997).

Negative pressure isolation rooms are needed for patients who have infectious diseases that spread by the airborne route. Negative pressure is achieved with exhaust exceeding supply by about 15%. The exhaust air is blown to the outdoors or filtered through a HEPA filter if it is to be returned for reuse. CDC (1994) recommends 12 ACH as the minimum ventilation rate for new and renovated facilities and 6 ACH for existing facilities. The room must be well sealed to prevent air infiltration. It is difficult to obtain unidirectional air flow field with exhaust, however, and respiratory protection for personnel is also necessary. Surgical masks do not provide adequate protection, therefore particulate or powered air purifying respirators are recommended. Source control measures: surgical masks for patients and the use of local exhausts near the patient's head are recommended (Streifel 1996). In addition, UV lights and portable filters can be used to reduce airborne bacterial levels.

Procedure rooms

Special procedure rooms used to assure effective infection control of the administration of medicated aerosols, or for bronchoscopy, should be ventilated to contain the release of problematic aerosols. The rooms should be negatively pressurized with 6-12 ACH. Tents and booths provided with negative pressure can be used as temporary alternatives. Released particles should be removed with HEPA filtration (Streifel 1995).

Autopsy is also a high-risk procedure. Post-mortem examinations of known cases of TB should be performed in a room capable of containing released infectious agents. In addition, the use of ventilated examination tables and containment hoods is recommended, especially during bone sawing (Streifel 1995), to assure effective infection control.

11. Disinfection

Ultraviolet germicidal irradiation (UVGI) is used to decrease the risk of the spread of TB in isolation and treatment rooms and in other areas where patients with active TB are likely to be present, such as waiting rooms and radiology areas. It is known that short wavelength ultraviolet (254 nm) irradiation kills *Mycobacterium tuberculosis*. Its sensitivity is an intermediate relative to other bacteria (Riley 1988). The efficiency of UVGI is expressed either as a reduction percentage or as equivalent removal by ventilation (equivalent ACH). Due to practical difficulties, only surrogates have been used to assess the efficiency of UVGI treatment. In an experimental study with a single release of *Mycobacterium bovis*, good removal efficiency corresponding to 20 ACH was observed (Riley and Nardell 1989). On the other hand, only moderate effectiveness corresponding to 1.5-2 ACH (reduction of 14-19 %) was achieved for total culturable airborne bacteria in a real waiting room study where bacteria were introduced continuously (Macher *et al.* 1992). Therefore, the efficiency of UV light fixtures under actual conditions remains unknown. For example, CDC (1994) recommends UV germicidal irradiation (UVGI) only to supplement other engineering controls (ventilation, negative pressure, and HEPA filtration). It should also be noted that UV does not protect effectively against fungal spores.

The UVGI should be arranged either as duct or upper-room air irradiation to protect human exposure (the main risk is inflammation of the cornea of the eye). In the former, UV lamps are installed inside the exhaust ducts of recirculating air handling system. A recent Italian study showed that the best control of *Aspergillus* was achieved when the UV lamps were directed to irradiate the surface of the ventilation filters after humidification (Grossi 2000). In the latter system, UV lamps are mounted on the ceiling or on the upper parts of walls. The lamps must be shielded to direct radiation only upward. The ceiling and wall should be painted with non-reflecting coatings. The UVGI has an inherent problem: as the ventilation rate is increased, the length of air irradiation time is decreased. Unfortunately, the optimal relationship between them is not known.

Calcium hypochlorite is commonly used to disinfect cooling towers for *Legionella* (Tablan *et al*. 1994). Maintaining all warm water heaters at 60^{o} C and protecting water outlets used by sensitive patients with bacterial filters are effective means of controlling legionellosis (Köhler *et al*. 1999; Mathys *et al*. 1999). If the hot-water system has been identified as the source of *Legionella*, the system can be decontaminated by pulse thermal disinfection or by flushing with superheated water (65 ^{o}C). In addition, physical cleaning of water tanks, water heaters, faucets, and shower heads may be required (CDC 1997). Other methods available for controlling the proliferation of *Legionella* in hospital water systems include ozone, hyperchlorination, and electrically produced copper and silver ions. It has been found that chlorine is unreliable in the control of *Legionella*. Chlorine dioxide is more effective but even it does not ensure complete eradiction, probably because *Legionella* live in a protozoonotic relationship with free-living amebas and can remain viable within their resistant cysts (Kilvington and Price 1990, Hamilton *et al*. 1996). Electric showers where cold water is heated immediately before leaving the shower head have also been found to be an effective method of controlling *Legionella* in a Brazilean renal transplant unit (Levin *et al.* 1995). Epidemic disease can be controlled by these methods, but sporadic cases may continue to occur. Very low concentrations of *Legionella* (1 cfu/mL) have been found to be able to cause infections among immuno-compromised patients (Mathys *et al.* 1999). It is possible that legionellosis can be completely prevented among the most sensitive patients only by exclusive use of sterile water, even for drinking and oral hygiene (Mathys *et al*. 1999).

PART 6. MONITORING

12. Pressure Control

An outbreak of nosocomial multidrug-resistant tuberculosis occurred in a US hospital even though patient isolation protocols recommended by the CDC guidelines were strictly followed. The investigation revealed that some of the isolation rooms, which should have been under negative pressure, were actually under positive pressure with respect to corridors (Ikeda *et al.* 1995). This case graphically demonstrates the importance of regular checks of pressure conditions. This can be easily accomplished using smoke tubes or tissue paper. Continuous room pressure monitors with alarm system are available but those may require labor-intensive maintenance and cause false alarms. In addition, those devices must be checked periodically with smoke to ensure that they are still working (Streifel 1995).

13. Sampling

Although only few definitive relationships between airborne microbial levels and nosocomial infections have been established, it is natural that maintaining pure air is an important part of infection control. The need is obvious during surgery (Hambraeus 1988). The total microbial level of 10 cfu/m^3 is often used as the recommended limit for joint replacement surgery and the level of 100 cfu/m^3 for general surgery. When the results of several studies were combined, the correlation coefficient was -0.94 between ventilation rate and post-operative infection rate, -0.79 between ventilation rate and microbial concentration, and 0.78 between infection rate and airborne microbial level (Intag 1975). This suggests that effective ventilation limits nosocomial infections.

Fungal sampling is recommended in the rooms of immuno-compromised patients. It should also be carried out at intervals in operating rooms. A limit of 15 cfu/m^3 for total viable spore concentration and a limit of 0.1 cfu/m^3 for *Aspergillus* has been recommended to protect immuno-suppressed patients (Streifel 1994). Systematic monitoring allows early detection of fungal contamination and subsequent protective measures. No nosocomial aspergilloses occurred during a two-year monitoring and control program in a French hospital (Bex *et al.* 2000).

Sampling of both viable and non-viable microbes is essential during and after any major building renovation to ensure safe conditions. When air quality is evaluated before occupancy, these data also serve as background for comparison purposes.

Bioaerosol monitoring is laborious and the results cannot be obtained immediately. Therefore, monitoring of airborne particle counts, instead of traditional microbial counting, has been proposed for isolation rooms with very high hygiene requirements, such as bone marrow transplant patient rooms (Salvigni *et al.* 1995) and laminar flow operating rooms (Fox and Whyte 1996). Abnormally high particle counts indicate at least the presence of abnormal and potentially hazardous conditions. This approach would also allow the adoption of airborne particulate cleanroom classes for critical hospital environments. Research concerning particle transport routes also helps to identify possible exposure pathways (Luscuere 1995).

Occupational exposure to disinfectants, sterilants, and anesthetic gases can be assessed by monitoring their concentrations in the air. Direct-reading analyzers are useful. Such devices are available, for example, for glutaraldehyde. Their detection limit may, however, be too high and accuracy poorer than in methods that separate sampling and analysis phases. Thus, sampling into silica gel tube, 2,4-dinitrophenylhydrazine impregnated passive diffusion badge or filter cassette and subsequent gas chromatographic or high performance liquid chromatographic analysis provides a more accurate determination of airborne glutaraldehyde concentration (Wellons *et al*. 1998; Niven *et al*. 1997).

Special care should be taken to avoid exposure to carcinogenic agents, such as ethylene oxide and cytostatic drugs. The use of proper respirators is highly recommended while working with these in situations where the exposure cannot be excluded with certainty. Biological monitoring can be used to make sure that the exposure prevention has succeeded. N-2-hydroxyethylvaline, the reaction product of ethylene oxide and the N-terminal amino acid of globin, can be used as a biomarker for ethylene oxide exposure. A level of 4 nmol of N-2-hydroxyethylvaline corresponds approximately to the exposure on the OEL level of 1 ppm (Angerer *et al.* 1997). Urine tests are available for some cytostatic drugs, including cyclophoshamide and ifosamide (Ensslin *et al*. 1997).

The airborne concentration of latex allergens can be determined with immunoassay. An association between latex aeroallergen level and frequency of latex sensitization and respiratory complaints was observed in a German hospital. A level of 0.6 ng/m^3 was suggested as critical airborne concentration for latex allergen (Baur *et al*. 1998).

Areas where large amounts of gases are used or stored should have some monitoring device available for the detection of air quality. For example, chiller areas with chlorofluorocarbons should have oxygen detectors for spill conditions, and ethylene oxide detectors should be available in sterile processing to detect leaks or malfunction. Areas where acute hazards are possible should be provided with continuous monitoring devices, especially if dangerous conditions do not alert with strong odor. Other areas need only to be monitored periodically and in abnormal situations to help assure the safety of the employees.

Occupational exposure to some cytostatic drugs can be followed with biological monitoring. Urine tests are available for cyclophosphamide, ifosamide, and platinium-containing drugs (Ensslin *et al*. 1997).

Two strategies have been presented in the CDC guidelines (1997) for prevention of nosocomial legionellosis. The first approach is based on periodic routine culturing of *Legionella* from the water system. When 30% or more of the samples become cultur-positive, the water system is decontaminated and active surveillance for cases is instituted. In the second approach, cooling towers are routinely maintained and only sterile water is used for nebulization devices. Patients with nosocomial pneumonia are tested for legionellosis, and when a case has been confirmed, an investigation for *Legionella* sources is initiated.

Both approaches have their drawbacks. The first approach is problematic because no definite relationship between the percentage of positive cultures and the risk of legionellosis has been established. The second approach has the disadvantage that contamination is observed only after the appearance of cases. In order to ensure the detection of all cases of nosocomial legionellosis, routine culturing of respiratory tract secretions of pneumonia patients for *Legionella*, irrespective of clinical diagnosis, is needed. If cases of legionellosis are detected, then warm water systems should be investigated for *Legionella*. It is recommended that the *Legionella* strains found in patients and water systems should be subtyped and compared beyond the serogroup level to confirm that the infection is hospital-acquired (Köhler *et al.* 1999).

PART 7. MAINTENANCE AND CONSTRUCTION

14. Maintenance and investigation

Sophisticated hospital ventilation systems do not always perform as designed due to inadequate installation or poor maintenance. For example, increased pressure drop due to ventilation system loadings may cause the air balance to change. Rooms that should be negatively pressurized may become positively pressurized, or vice versa. Monitoring devices that follow the pressure drop across filters and in other critical applications should be installed.

If suspended ceilings are used, dirt will accumulate on their upper surface. Uncontrolled air flows that are contaminated by impurities released from this dirt layer may occur from room to room via the space above the suspended ceiling if duct holes between the rooms are not well sealed. Therefore, suspended ceilings need to be investigated. Preferably, completely enclosed ceiling structures should be used.

Improperly installed or poorly maintained humidification or cooling systems may allow moisture build-up and growth of molds. It is necessary that all the components of the air handling system are easily accessible for routine inspection and maintenance. Microbial growth was detected in the sound attenuator located close down-stream to the humidifier in the ventilation system of an operation room in Poland. Water was probably condensated onto the sound attenuator (Charkowska 2000).

Checklists are available to help establish surveillance and infection control programs in health care facilities (e.g., Hansen 1997). Many problems can already be detected with regular visual inspection. The presence of surface moisture, rust, visible mold, slime, bird droppings, and standing water in drain pans are indicators of unacceptable conditions.

Ventilation systems need periodic cleaning. High concentrations of hemolytic bacteria and *Streptococcus viridans* were detected in the air and dust in the ventilation system of a Polish hospital (Charkowska 2000). The ventilation system was never cleaned.

Painstaking maintenance of the anesthesia equipment, including tightening of fittings and changing of poor seals, is needed to control fugitive anesthetic gases. High pressure conditions should be checked for leaks.

The total quality management, which includes the concept of continuous quality improvement, is finding its way to health care facilities. This development is most welcome. It would also inherently produce better working collaboration among all important partners in the prevention of nosocomial and occupational diseases.

It should be recognized that for practical purposes it is difficult to create workplace conditions that satisfy everybody. According to studies conducted among Scandinavian office workers, as many as 25-35% of women and 10-20% of men reported symptoms which they considered to be work-related (Kukkonen *et al*. 1993). Complaints are also common among health care workers. Causes of the complaints are often complex and may include, besides poor indoor air climate, psychosocial problems. Nevertheless, it is vital that the complaint situation should be monitored and acted upon before complaint situation has escalated to the level of a workplace crisis (see ISIAQ Task Force II report). The process starts with a description of the problem. Complaint and interview forms are available for this purpose (e.g., Hansen 1997). If complaints appear periodically, then a follow-up program using daily diaries should be established. The problems should be resolved in co-operation with the complainants. Additional measuring programs can be established to objectively identify IAQ problems and their physical, chemical, and biological origin.

A comprehensive system to manage indoor work environment has been prepared for the hospitals in Halifax (Anon. 1995). As many as forty recommendations were developed including, among others, recommendations to establish a team to deal proactively with indoor air quality concerns and to carry out a standardized audit of physical plant systems at regular intervals.

15. Training

It is essential that maintenance personnel should be trained so that they understand the importance of ventilation. Otherwise, they may shut down critical fan systems without notifying the medical staff in the affected areas. Fan shutdowns must be carefully planned. Furthermore, medical staff should be educated, and understand, that a protective flow of clean air is not obtained if it is disturbed by a poorly placed lamp or other action.

Training in indoor air quality issues is needed on several levels among both technical and medical staff. However, without a comprehensive overview of indoor air quality in health care facilities, it is difficult to establish specific needs. Appropriate training can be initiated once problems are described and evaluated according to health risks.

Training is also urgently needed to improve the safety of construction operations. Design engineers and other technical personnel do not always understand the impact the project may have on occupied wards and the patients' sensitivities to environmental exposures.

16. Remodelling and Renovation

Renovation of health care facilities is common and often disrupts the indoor environment. The frequent upgrading of utilities and patient service facilities means that the hospitals are in an almost continuous state of remodelling and construction. As mentioned earlier, hazardous emissions are released during renovation. The release of accumulated *Aspergillus* spores during renovation is a major cause of nosocomial invasive aspergillosis (Bex *et al* 2000). In addition, ventilation conditions may change, even in critical areas. Therefore, careful planning of renovation activities is very important. This has been recognized in the recent AIA (1996) and CDC (1997) guidelines which also include practical guidance for construction management.

The planning of a hospital renovation project must begin with the initiation of a conceptual design that ensures understanding of possible impacts of all relevant aspects on occupant safety. Risk assessments should locate the most sensitive patient populations, and a defined protocol for maintaining and maximizing infection control measures should be developed.

The plan should include airflow and traffic controls, demolition procedures and barriers, phasing, quality assurance measures and commissioning of the space to be affected. Asbestos abatement techniques should be used for containment of the renovation area. Negative pressure isolation should be achieved with HEPA fan units that discharge to the outside. Solid drywall partitions are preferable to plastic barriers. Demolition materials should be removed via a totally closed chute.

Effective control has been proven to be possible. For example, Overberger *et al.* (1995) reported successful containment of dust and fungal spores within the construction area during a hospital renovation. The construction area was located close to rooms housing bone marrow transplant patients. A barrier was installed to separate the construction area from the rest of the hospital. The work area was maintained at negative pressure, and all air intakes and exhausts were covered. Workers entered and left the construction area through an anteroom, and their traffic was planned to avoid passing patient rooms. One of the elevators was designated to their use only. Sticky mats were placed outside the anteroom to trap dust from the workers' shoes.

During renovation, concentrations of airborne fungal spores remained close to the low background level in the patient area. Following construction, spore counts in the renovated area fell to preconstruction levels.

17. Water Damage Control

Water and moisture damages occur often in hospitals and may create potentially dangerous reservoirs that allow rapid microbial growth. To ensure the safety of the occupants, water damages should be repaired promptly and thoroughly. As mentioned earlier, several studies have demonstrated that fungal spores can be released during repair, maintenance, and construction. Due to their small size (most spores have aerodynamic diameters less than 5 μm), spores remain airborne for long periods and thus can spread throughout the building.

- When water damage has been observed, an inventory of the damaged area should be taken. Building physisists should determine the extent of the damaged area. Negative pressure should be created in the water-damaged area. If the damaged area is large, portable filters used outside this area may help to control the contaminants during repairs.
- Detachable moist building materials, such as ceiling tiles, furniture, and paper files should be removed immediately and preferably discarded.
- Intact hard surface furniture can be cleaned with a bleach solution and air dried (this must be performed in a well ventilated area).
- Essential wet paper can be dried and photocopied before discarding.
- All water damaged drywall and insulation should be removed and replaced (preferably within 24 hours).
- Small electrical components should be replaced. Large components, such as electric motors and light fixtures, should be opened, cleaned and air-dried by qualified personnel.
- It is recommended that wet carpets are removed and discarded. If the moist carpet area is

small and the carpet has been wet less than 48 hours, it may be possible to clean and dry the carpet without the onset of mold growth (Additional information is available, e.g., from University of Minnesota, Environmental Health and Safety Division, www.dehs.umn.edu). However, carpets should, for many reasons, not be used in hospitals. If mold has had time to develop, wet materials should be removed and discarded under strictly controlled conditions. Because it is essential to remove moisture as soon as possible the plan of action must be prepared in advance. HEPA filtered vacuum cleaner should be used for post-repair clean-up.

Hospitals have several spaces where large quantities of water are used; for example kitchens and washrooms. Such spaces are vulnerable to microbial damage. Metal-frame partition walls with gypsum board covering are commonly used in hospital washrooms. These structures are usually protected against moisture by a moisture barrier or coating and finished with glazed tiles. An extensive inspection conducted in a Finnish hospital revealed that hidden microbial growth occurred quite frequently in the cavity space of the wall, mainly due to faults in tiling and poorly sealed discontinuities in the water barriers that occurred at ducts and joints. Special chairs and grips installed near showers were found to pose a special moisture damage risk. Holes made for ducts and fastenings were often covered only with a plate, allowing penetration of water into the wall cavity. Microbial growth was usually observed behind damp barriers, on the wet side of the wall. The damage could rarely be detected by visual observation or by measurement of the surface dampness. However, this kind of partition wall can be used if the structure is ventilated and provided with electric heating inside the cavity. Even though gypsum has high capillarity and thus wets fast, it also has a small vapor resistance that allows fast drying (Niemi *et al*. 2000). Airborne concentrations of fungal spores were not especially high in the kitchen of a Canadian hospital (Marchant *et al*. 1990). On the other hand, investigations in the school kitchens suggest that bacterial growth constitutes a larger problem than fungi in institutional kitchens where the surfaces are frequently washed (Kalliokoski *et al*. 2000). In general, washing with water should be limited to areas that have moisture barriers. In all cases, excessive water should be removed immediately, and all wet spaces should have effective ventilation.

Hospitals consist generally of large and complex buildings, and moisture damage can easily remain unnoticed. Therefore, a special inspection program should be established. Special attention should be paid to the areas that are most vulnerable to external water, such as roofs, window frames, and foundations. In addition, wet spaces need special follow-up (Haverinen *et al.* 1999).

PART 8. SUMMARY AND CONCLUSIONS

Adequate indoor air quality is especially important in health care facilities in order to ensure the safety of the patients, personnel, and visitors. There is an urgent need to control the airborne spread of infectious agents. In addition to pathogens, opportunistic bacteria and fungi should be controlled due to the extreme sensitivity of immuno-suppressed patients. Health care personnel who are occupationally exposed to several potentially harmful agents also require protection

After a long hiatus, the TB situation has begun to worsen. The increased incidence and the simultaneous emergence of multidrug-resistant strains have greatly increased concern among health care workers. This has become a serious occupational health risk, especially in the USA. Source control is the primary and most effective way of reducing or preventing indoor air quality problems. This is also true for TB control. The droplet nuclei should be captured at the source before they become widely dispersed. This can be achieved by positioning the inlet of a filter unit or the ventilation exhaust close to the infectious patient. Tents and booths provided with negative pressure can be used during short-term procedures. However, TB patients cannot be totally confined to their beds or other known places. In addition, there are patients with unrecognized TB. Airborne concentrations of aerosols carrying viable *M. tuberculosis* can be reduced by effective ventilation, portable air filters, and UVGI. Airborne concentrations can be estimated reasonably well using the completely-mixed room model. The efficiency of such auxiliary measures can be expressed as equivalent ACH and thus their relative benefit can easily be roughly assessed.

Staphylococci are other dangerous bacteria that are transmitted as infective aerosols. Staphyloccal infections have ocurred in nurseries, wound units, and operating rooms. In addition to *S. aureus* coagulase-negative staphylococci, such as *S. epidermidis*, are common causes of surgical site infections. Methicillin resistant strains of *S.aureus* (MRSA) and *S.epidermidis* (MRSE) have become a worldwide problem. Even quite vancomycin resistant *S. aureus* strains have appeared. Carriers of staphylococci are common and many staphylococcal carriers remain asymptomatic. A high percentage of operating room staff members was found to be dispersers of MRSE. MRSE has also been detected in operating room air despite effective ventilation. In such situations, the best way to reduce the infection risk is the use of special protective clothing. The control of staphylococci in burns units where the patients often need to remain for long periods has been studied surprisingly little, and this shortcoming should be rectified.

Airborne transmission is also possible for other potentially pathogenic bacteria, such as *Pseudomonas aeruginosa*. Large numbers of immuno-suppressed patients, who are extremely sensitive to microbial infections, stay in hospitals nowadays. Therefore the control of opportunistic bacteria and especially fungi is particularly urgent. Antifungal therapy is costly and remains relatively ineffective. Invasive aspergillosis has high fatality rate. Laminar air flow rooms provide the most effective protection against aspergillosis. Windows should be tightly sealed and potential fungal sources, such as flowers, should be eliminated. The pressure difference between the protective isolation rooms and the adjacent space should be at least 2.5 Pa. In high infection risk areas, especially in operating rooms and in bone marrow transplant patient rooms, airborne particle counts should be monitored - rather than relying on traditional microbial counting - in order to immediately detect abnormal and potentially hazardous conditions. Critical areas should also be provided with continuous pressure difference indicators, and alarms should be used to indicate personnel of system failures that may lead to hazardous conditions.

Actions should be taken to prevent uncontrolled air flows between rooms via spaces above suspended ceilings through the openings made for ducts and other interstitial spaces. Completely enclosed ceilings are preferable structures for hospitals.

Water and moisture damage often creates microbial reservoirs. Fungal exposure has been recognized as a serious risk to sensitive patient groups, especially immuno-compromised patients. However, microbial growth in the moisture-damaged parts of buildings may also constitute a health risk to personnel and other long-term occupants, such as chronic patients. Therefore, water damage should be repaired immediately. It is important not only to renew the damaged structures but also to eliminate the causes of the damage. If fungal growth has had time to develop, repairs should be made under strictly controlled conditions. Hospitals are often very large and moisture damage can easily remain unnoticed. Therefore, a special inspection program should be established. Areas that are most vulnerable to external water and wet spaces require special attention. The large quantities of water used in hospitals constitute a moisture risk to internal building structures. For example, hidden microbial growth is common in the wall cavities of hospital washrooms. Such cavities should be ventilated and provided with heating.

Legionella are causing a serious pneumonia risk in hospitals. These bacteria are found especially in the warm water systems. Stagnant water in the dead ends of piping can provide amplification sites for *Legionella*. Maintaining the temperature of warm water at 60 ^{o}C prevents the growth of *Legionella*. Highly immuno-compromised patients require extremely strict control measures. Their water outlets should be provided with bacterial filters. If the hot water system has been identified as the source of *Legionella*, the system can be decontaminated by pulse thermal disinfection or flushing with superheated water. In addition, physical cleaning of the most critical parts of the system is recommended. Other methods available for *Legionella* control include ozonation, hyperchlorination, and electrically produced copper and silver ions. However, the efficiency of these methods has not been reliably demonstrated.

Many health care workers have a risk of exposure to blood borne pathogens, especially hepatitis B virus. In addition to exposure via the skin, inhalation exposures may occur due to fine aerosols generated by surgical power tools. There is an obvious need to develop local exhaust systems for these tools. In general, local exhausts, which are extensively used in industry to control hazardous emission sources, could also be used much more widely in the hospitals. They should always be used when there is an obvious emission source. Several other examples have been mentioned in this review.

Disinfectants, sterilants, and anesthetic gases are the most common chemical exposures among health care personnel. Their adverse health effects have been demonstrated and, exposures should therefore be minimized. The airborne concentrations of disinfectants and sterilants can be maintained at low levels by following careful working practices and by using automated equipment in well-ventilated rooms. The control of anesthetic gases has been proved to be more difficult. Concentration limits recommended by NIOSH are difficult to achieve even when the scavenging mask exhaust is used in an operating room provided with effective laminar flow ventilation. The exposure can be minimized, however, by using an anesthetic apparatus with low leakage and meticulous working practices that avoid spillage of gas. In addition, effective room ventilation is essential and local exhausts are required during certain procedures, such as children's anesthesia.

Laminar flow ventilation is the most effective way to provide clean air to the operating rooms. The air supply should be directed vertically toward the surgical site and positive pressure should be maintained. Very low airborne microbial levels can be achieved if the ventilation exceeds 60 ACH in such a room and if the surgical team is wearing special protective clothing. The position of lamps, instrumentation tables, and door openings should be taken into consideration in the planning and use of operating rooms.

Health care workers who use natural rubber gloves regularly are at high risk of sensitization to latex. This risk can be reduced most effectively by using powder-free or low allergen-containing gloves. Acrylic resins are also strong sensitizers. Exposure to them, however, occurs mainly via the skin. It can be minimized by using encapsulated systems and impermeable gloves.

This review indicates that a large amount of reference literature on nosocomial diseases and occupational health risks in hospitals and other health care facilities is needed. However, practical and effective solutions to many problems have not yet been found. The link between the needs and solutions remains surprisingly weak. The effectiveness of many proposed methods has not been demonstrated or adequately documented and, therefore, their usefulness remains controversial. Even where the linkage between needs and solutions does exist, one must decide what level of protection is desired and which approaches are feasible. This requires consideration of all relevant costs (fixed costs, operational costs, costs of hospitalization, and the consequential costs for society). It should be recognized that those involved in decision-making (facility management, administration, insurance companies, and government) often differ from those exposed to the risks, and have different objectives and preferences.

A major problem in improving indoor air quality in health care facilities is the fact that its importance is not yet unanimously recognized. In addition to the lack of recognization, unwarranted disregard and even a belittling attitude, persist, especially in regard to the prevention of nosocomial infections. In many recent comprehensive reviews on this topic, indoor air quality issues remain completely ignored. Fortunately, increasing concerns regarding occupational health risks are resulting in a higher valuation of safe indoor air. This gives hope for an increasing positive stance on the patient safety issues as well. Targetted and high quality research is the best way to guarantee progress in the endeavor to provide safe indoor air for all occupants of health care facilities.

REFERENCES

American Institute of Architects (1996). 1996-1997 Guidelines for Design and Construction of Hospitals and Health Care Facilities, Washington DC: The American Institute of Architects Press.

Alcini, D., Cavallo, D., Bersani, M., Visigalli, F. et al. (1995) Evaluation of airborne microbial contamination in two hospital wards. In Proceedings of Healthy Buildings '95, ed. Maroni, M., Milan: 1061-1066.

Anon. (1995) Metro Hospitals' Committee on Environmental Management, Final Report, Halifax, Nova Scotia.

Angerer, J., Bader, M., Krämer, A. (1998) 'Ambient and biochemical monitoring of workers exposed to ethylene oxide'. Int. Arch. Occup. Environ. Health 71: 14-18.

Arnow, P.M., Andersen, R.L., Mainons, P.D. et al. (1978) 'Pulmonary aspergillosis during hopital renovation.' Am. Rev. Respir. Dis. 118: 49-53.

Arnow, P.M., Sadigh, M., Costas, C. (1991) 'Endemic and epidemic aspergillosis associated with in-hospital replication of Aspergillus organisms.' J. Infect. Dis. 164: 998-1002.

ASHRAE. (1995) 'Health care facilities.' In 1995 ASHRAE Handbook, Heating, Ventilating and Air-conditioning Applications, Atlanta, GA.:7.1-13

Ayliffe, G.A.J., Buckles, A., Casewell, M.W. et al. (1998) 'Revised guidelines for the control of methicillin-resistant Staphylococcus aureus infection in hospitals' J. Hosp. Infect. 39: 253-290.

Baeder, C., Albrecht, M. (1990) 'Embryotoxic/teratogenic potential of halotane.' Int. Arch. Occup. Environ. Health 62: 263-271.

Bakke, J.V., Eldoen, G. (1996) 'Occupational diseases caused by indoor pollution in a X-ray department of a hospital.' Indoor Air 1: 605-610.

Barbaree, J.M., Breiman, R.F., Dufourt, A.P. (1993) Legionella: Current Status and Engineering Perspectives, Washington, D.C.: American Society for Microbiology

Baur, X., Chen, Z., Allmers, H. (1998) 'Can a threshold limit value for natural rubber latex allergen be defined?' J. Allergy Clin. Immunol. 101: 24-27.

Beck, H.I. (1983) 'Type 1 reaction to chloramine.' Contact Dermatitis 9: 155-156.

Bex, V., Mouilleseaux, A., Causse, R. et al. (2000) 'A survey of Aspergillus contamination in a hospital during renovation.' In Proceedings of HB 2000, Espoo, Finland, Vol. 1: 359-364.

Bohne-Matusall, R., Rasmussen, H.U. (1991) Anesthetic Gases in Hospitals – Exposure, Protective Measures. Wirtschaftsverlag NW, Bremerhafen (in German, English summary).

Bubak, M.E., Reed, C.E., Fransway, A.F. et al. (1992) 'Allergic reactions to latex among health-care workers.' Mayo Clinic Proceedings 67: 1075.

Burge, P.S., Harries, M.G., Lam, W.K. et al. (1985) 'Occupational asthma due to formaldehyde.' Thorax 40: 255-260.

Campbell, C.K. (1995) 'Hazards to laboratory staff posed by fungal pathogens.' Journal of Hospital Infection 30: 358-363.

Casewell, M.W. (1995) 'New threats to the control of methillin-resistant Staphylococcus aureus.' J.Hosp. Infect. 30: 465-471.

Casewell, M.W. (1998) 'The nose: an underestimated source of Staphylococcus aureus causing wound infection.' J. Hosp. Infect. 40: S3-S11.

Centers for Disease Control. (1985) National Nosocomial Infection Study.

Centers for Disease Control. (1994a). 'Guideline for prevention of nosocomial pneumonia.' Am. J. Infect. Control 22: 247-292.

Centers for Disease Control. (1994b) 'Guidelines for preventing the transmission of Mycobacterium tuberculosis in health care facilities'. Fed. Reg. 59 (208): 54242-54303.

Charkowska, A. (2000) Contamination in hospital air-conditioning systems. In Proceedings of Healthy Buildings 2000, Espoo, Vol. 2: 193-198.

Christiansen, V., Kulmala, I., Niemeläinen, M. (1999) 'Anesthetic gases and their control in the operating and recovery rooms of a pediatric hospital.' Report TURB 009, State Research Centre, Tampere (in Finnish).

Corrado, O.J., Osman, J., Davies, R.J. (1986) 'Asthma and rhinitis after exposure to glutaraldehyde in endoscopy units.' Hum. Toxicol. 5: 325-328.

Crippa, M., Pasolini, G. (1997) 'Allergic reactions due to glove-lubricant powder in health-care workers.' Int. Arch. Occup. Environ. Health 70: 399-402.

Culver, D.H., Horan, T.C., Gaynes, R.P. et al. (1991) 'Surgical wound infection rates by wound class, operative procedures and patient risk index.' Am. J. Med. Suppl. 3B: 152-157.

Curran, A.D., Burge, P.S., Wiley, K. (1996) 'Clinical and immunologic evaluation of workers exposed to glutaraldehyde.' Allergy 51: 826-832.

Degorce-Hecquet, I., Gacouin, J.C., Sauvaget, J. (1987) 'L'asthme professionel du au formol en milieu hospitalier. A propos de 3 observations.' Rev. Pneumol. Clin. 43: 91-94.

Demiani, L.P., Capelli, O., Vanini, G.C. (1994) Environmental pollution by saprophytic hyalinen hyphomycetes in a hospital high risk department. In Healthy Buildings 94, eds. Banhidi, L., Farkas, B., Magyar, Z., Rudnai, P., Budapest, Vol. 2: 223-228.

Deschamps, D., Rosenberg, N., Soler, P. et al. (1992) 'Persistent asthma after accidental exposure to ethylene oxide.' Br. J. Ind. med. 49: 523-525.

Dijkman, J.H., Vooren, P.H., Kramps, J.A. et al. (1981) 'Occupational asthma due to inhalation of chloramine-T: Clinical observations and inhalation-provocation studies. II. Demonstration of specific IgE antibodies.' Int. Archs. Allergy Appl. Immunol. 64: 422-438.

Dewhurst, A.G., Cooper, M.J., Khan, S.M. Pallett, A.P. et al. (1990) 'Invasive aspergillosis in immunosuppressed patients: potential hazard of building work.' Brit. Med. J. 301: 802-804.

DiStefano, F., Siriruttanapruk, S., McCoach, J.S. et at. (1999) 'Glutaraldehyde: An occupational hazard in the hospital setting.' Allergy 54: 1105-1109.

Dooms-Goosens, A., Gevers, D., Martens, A. et al. (1983) 'Allergic contact urticaria due to chloramine.' Contact Dermatitis 9: 319-320.

Dugue, P., Faraut, C., Figueredo, M. et al. (1991) 'Asthme professionel a l'oxyde d'ethylene chez une infirmiere.' Presse Med. 20: 1455.

Edling, C. (1980) 'Anesthetic gases as an occupational hazard - a review.' Scand. J. Work Environ. Health 6: 85-93.

Eickhoff, T.C. (1993).' Perspectives on airborne infection in health care facilities.' In Proceedings of the Workshop on Engineering Controls for Preventing Airborne Infections in Workers in Health Care and Related Facilities, eds. Bierbaum, P.J. and Lippmann, M.:Cincinnati, Ohio.

Ensslin, A.S., Huber, R., Pethran, A., et al. (1997) 'Biological monitoring of hospital pharmacy personnel occupationally exposed to cytostatic drugs: urinary excretion and cytogenetics studies.' Int. Arch. Occup. Environ. Health 70: 205-208.

Emmerson, A.M. (1995) 'The impact of surveys on hospital infection.' J. Hosp. Infect. 30: 421-440.

Ensor, E., Humphreys, H., Peckham, D., Webster, C., et al. (1996) 'Is Burkholderia (Pseudomonas) cepacia disseminated from cystic fibrosis patients during physiotherapy?' J.Hosp. Infect. 32: 9-15.

Fenelon, L.E. (1995). 'Protective isolation: who needs it?' J.Hosp. Infect. 30: 218-222.

Flannigan, B., Miller, J.D. (1994) 'Health implications of fungi in indoor environments - an overview.' In Health Implications of Fungi in Indoor Environments, eds. Samson, R.A., Flannigan, B., Flannigan, M.E., et al. Amsterdam: Elsevier: 3-28.

Fletcher, A.M., Custovic, A., Pickering, A.C., et al. (1995) In Proceedings of Healthy Buildings 95, ed. Maroni, M., Milan: 1011-1015

Fox, D.G. (1969) 'A study of the application of laminar flow ventilation to operation rooms.' Public Health Monograph Nr. 78, US Dept. Health, Education and Welfare, Public Health Service.

Fox, C., Whyte, A.S. (1996) 'Theatre air sampling – once a year is not enough.' J. Hosp. Infect. 32: 319-322.

Friberg,B., Friberg, S., Burman, L.G. et al. (1996) 'Inefficiency of upward displacement operating theatre ventilation.' J. Hosp. Infect. 33: 263-272.

Fridkin, S.K., Manangan, L., Bolyard, E. et al. (1995) 'SHEA-CDC TB survey, part II: status of TB infection control programs at member hospitals, 1989-1992.' Infect. Control Hosp. Epidemiol. 16: 129-134.

Fridkin, S.K., Kremer, F.B., Bland, L.A. et al. (1996) 'Acremonium kiliense endophthalmitis that occurred after cataract extraction in an ambulatory surgical center and was traced to an environmental reservoir.' CID 22: 222-227.

Fujinaga, M., Baden, M.J., Mazze, R.I. (1989) 'Susceptible period of nitrous oxide teratogenicity in Sprague-Dawley rats.' Teratology 40: 439-444.

Gardner, R.J. (1989) 'Inhalation anaestetics-exposure and control: A statistical comparison of personal exposures in operating theatres with and without anaesthetic gas scavenging.' Ann. Occup. Hyg. 33: 159-173.

Gerson, S.L., Parker, P., Jacobs, M.R. et al. (1994) 'Aspergillosis due to carpet contamination.' Infect. Control Hosp. Epidemiol. 15: 221-223.

Goodley, J.M., Clayton, Y.M., Hay, R.J. (1994) 'Environmental sampling for aspergilli during construction on a hospital site.' J. Hosp. Infect. 26: 27-35.

Grossi, L. (2000) 'Control of the biologically active particulate by means of filters UV irradiation.' In Proceedings of HB 2000, Espoo, Finland, Vol. 2: 107-112.

Grummt, T., Grummt, H.J., Schott, G. (1993) 'Chromosomal aberrations in peripheral lymphocytes of nurses and physicians handling antineoplastic drugs.' Mutat. Res. 320: 19-24.

Gucalp, R., Ciobanu, N., Spoarano, J., et al. (1991) 'Disseminated aspergillosis after fungemia in a patient with extragonadal germ cell tumor undergoing autologous bone marrow transplantation.' Cancer 68: 1842-1844.

Guirguis, S.S., Pelmear, P.L., Roy, M.L., et al. (1990) 'Health effects associated with exposure to anaesthetic gases in Ontario hospital personnel.' Br. J. Ind. Med. 47: 490-497.

Hall, C.B. (1981) 'Nosocomial viral reaspiratory infections.' In Nosocomial Infections, ed.

Dixon, R.E. , Yorke Medical Books: New York: 227-233

Hambraeous, A. (1988) 'Aerobiology in the operating room' J. Hosp. Infect. 11(A): 68-76.

Hamilton, E., Seal, D.V., Hay, J. (1996) 'Comparison of chlorine and chlorine dioxide disinfection for control of Legionella in a hospital potable water supply.' J. Hosp. Infect. 32: 156-160.

Hansen, W. (1997) 'Developing the IAQ program.' In A Guide to Managing Indoor Air Quality in Health Care Organizations, ed. Hansen, W. Oakbrook Terrace, IL: the Joint Commision on Accreditation of Healthcare Organizations: 65-73

Hartlova, D., Lebenhart, P. (1996) 'The measurement of gaseous anesthetics at the operating theatres by Bruel & Kjaer multi gas monitor', In International Conference of Buildings for Healthy Living, Prague.

Harvey, R.L., Hyers, J.P. (1987) 'Nosocomial fungemia in a large community teaching hospital.' Arch. Intern. Med. 147: 2117-2120.

Haverinen, U., Hoffren, H., Husman, T. et al. (1999) 'Moisture and mould problems in hospital buildings – An administrative - and technical -, microbial and health effect studies. Report B 20.' National Public Health Institute, Kuopio (in Finnish, English summary).

Hay, R.J., Clayton, Y.M., Goodley, J.M. (1995) 'Fungal aerobiology:how, when and where?' J. Hosp. Infect. 30: 352-357.

Heinsohn, P., Jewett, D.L., Balzer, L. et al. (1991) 'Aerosols created by some surgical power tools: Particle size distribution and qualitative hemoglobin content.' Appl. Occup. Environ. Hyg. 6: 773-776.

Hermans, R.D., Streifel, A.J. (1993) 'Ventilation designs.' In Proceedings of the Workshop on Engineering Controls for Preventing Airborne Infections in Workers in Health Care and Related Facilities, Cincinnati, Ohio: 107-146.

Hoerauf K. (1997) 'Occupational exposure to sevoflurane and nitrous oxide in operating room personnel.' Int. Arch. Occup. Environ. Health 69: 134-138.

Hogstedt, C., Aringer, L., Gustavsson, A. (1986) Epidemiologic support for ethylene oxide as a cancer-causing agent. JAMA 261: 1575-1578.

Holcatova, I., Holcat, M. (1994) 'Indoor air quality and respiratory diseases.' In Proceedings of Healthy Buildings '94, Budapest: 683-688.

Holcatova, I., Holcat, M., Rames, J. (1995) 'Effect of dry air during the heating period on people with chronic respiratory diseases.' In Proceedings of Healthy Buildings '95, Milan Vol. 1: 443-448.

Horn, R., Wong.B., Kiehn, T.E., et al.(1985) 'Fungemia in a cancer hospital: changing frequency, earlier onset, and results of therapy.' Rev. Infect. Dis. 7: 646-655.

Huskins, C.W. 'Infection control in countries with limited resources.' In Hospital Epidemiology and Infection Control, ed. Mayhall, C.G., Baltimore: Williams and Wilkins: 1176-1200

Ikeda, R.M., Birkhead, G.S., DiFernandino, G.T. et al. (1995) 'Nosocomial tuberculosis: An outbreak of a strain resistant to seven drugs.' Infect. Control Hosp.Epidemiol. 16: 152-159.

Intag, C.E., Wiebe, H.A., Partain, C.L. (1975) 'Investigations of the importance of air-flow of post-operative infections.' ASHRAE Journal 17: 27-33.

Kalliokoski, P., Lignell, U., Meklin, T. et al. (2000) 'Fungal growth and indoor air quality and climate in school kitchens.' In Proceedings of Healthy Buildings 2000, Espoo.

Kassis, V., Vedel, P., Darre, E. (1984) 'Contact dermatitis to methyl methacrylate', Contact Dermatitis 11: 26-28.

Kilvington, S., Price, J. (1990) 'Survival of Legionella pneumophila within cysts of Acanthamoeba polyphaga following chlorine exposure.' J. Appl. Bacteriol. 68: 519-525.

Kolmos, H.J., Svendsen, R.N., Nielsen, S.V. (1997) 'The surgical team as a source of postoperative wound infections caused by Streptococcus pyogenes.' J. Hosp. Infect. 35: 207-214.

Kralikova, E., Rames, J., Lifkova, K., et al. (1995) In Proceedings of Healthy Buildings '95, ed. Maroni, M., Milan: 1073-1075

Kruppa, B., Ruden, H. (1996) 'The influence of various air exchange rates on airborne particles and microorganisms in conventionally ventilated operation rooms.' Indoor Air 6: 93-100.

Kukkonen, E., Skret, E., Sundell, J. et al. (1993) 'Indoor Climate Problems. Nordtest Report', Espoo, Finland 204.

Kumari, D.N.P., Haji, T.C., Keer, V. (1998) 'Ventilation grilles as a potential source of methicillin-resistant Staphylococcus aureus causing an outbreak in an orthopaedic ward at a district general hospital.' J. Hosp. Infect. 39: 127-133.

Köhler, J.R., Maiwald, M., Luck, P.C. et al. (1999) 'Detecting legionellosis by unselected culure of respiratory tract secretions and leveloping links to hospital strains.' J. Hosp. Infect. 41: 301-311.

LaMontagne, A.D. 'Utility of the complete blood count in routine medical surveillance for ethylene oxide.' Am. J.Ind.Med. 24: 191-206.

Levin, A.S.S., Gobabra, S., Scarpitta, C.M., et al. (1995) 'Electric showers as a control measure for legionella spp. in a renal transplant unit in Sao Paulo, Brazil.' J. Hosp. Infect. 30:

133-137.

Luscuere, P.G. (1995) 'Bacterial control through contamination control in operating theatres.' In Proceedings of the International Conference on Healthy Buildings '95, ed. Maroni, M., Milan: 135-142

Luscuere, P.G., Lemaire, T.D., Ham, P.J. (1993) 'Improvement capabilities of operating thetres with the help of computer flow modelling.' In Proceedings of Indoor Air '93, Helsinki: 575-580.

Macher, J.M., Alevantis, L.E., Chang, Y-L, et al. (1992) 'Effect of ultraviolet germicidal lamps to airborne microorganisms in an outpatient waiting room.' Appl. Occup. Environ. Hyg. 7: 505-513.

Marshall, J.W. (1996) 'Health care ventilation standard: Air changes per hour or CFM/patient?' ASHRAE J. Sept.: 27-30.

Mathys, W., Deng, M.C., Meyer, J. et al. (1999) 'Fatal nosocomial Legionnaires' disease after heart transplantation: clinical course, epidemiology and prevention strategies for the highly immunocompromized host.' J. Hosp. Inf. 34: 242-246.

McDevitt, J.J., Lees, P.S.J., McDiarmid, M.A. (1993) 'Exposure to hospital pharmacists and nurses to antineoplastic agents.' J. Occup. Med. 35: 57-60.

McGlothin, J., Crouch, K.G. (1997) 'Longitudinal industrial hygiene study of N_20 controls at a pediatric dental facility.' American Industrial Hygiene Conference & Exposition, Dallas: 40-41.

Melius, J. (1993) 'Source characterization and control.' In Proceedings of the Workshop on Engineering Controls for Preventing Airborne Infections in Workers in Health Care and Related Facilities, Cincinnati, Ohio: 73-92.

Mikkola, R., Andersson, M., Peltola, J. et al. (1999) 'Purification and properties of toxins isolated from Streptomyces griseus and Bacillus cereus found in construction materials of buildings.' In Proceedings of Indoor Air '99, Edinburgh, Vol. 4: 1110-1111.

Miller-Leiden, S., Lobascio, C., Nazaroff, W.W. et al. (1996) 'Effectiveness of in-room air filtration and dilution ventilation for tuberculosis infection control.' J. Air & Waste Manage. Assoc. 46: 869-882.

Moscato, U., Esposito, T., Vanini, G. (2000) 'Nitrous oxide pollution: A geostatistical method to assess spatial distribution of anaesthetical gases and hospital staff exposure.' In Proceedings of Healthy Buildings 2000, Espoo, Vol. 1: 487-492.

Nicas, M. (2000) 'Regulating the risk of tuberculosis transmission among health care workers.' AIHAJ 61: 334-339.

Niemi, H., Haverinen, U., Koivisto, J. et al. (2000) 'Moisture pronblems in hospital washrooms – improving durability of gypsum board-covered wall structure.' In Proceedings of Healthy Buildings 2000, Espoo.

Nikki, P., Pfoffli, P., Ahlman, K., et al. 'Chronic exposure to anaesthetic gases in the operating theatre and recovery room.' Ann. Clin. Res. 4: 266-272.

Niven, K.J.M., Cherrie, J.W., Spencer, J. (1997) 'Estimation of exposure from spilled glutaraldehyde solutions in a hospital setting.' Ann. Occup. Hyg. 41: 691-698.

Noble, W.C. (1976) 'Dispersal of bacteria from human skin.' Proceedings of the International Symposium of Contamination Control, Copenhagen: 16-24.

Nordman, H., Keskinen, H., Tuppurainen, K. (1985) 'Formaldehyde asthma – rare or overlooked?' J. Allergy Clin. Immunol. 75: 91-99.

Notarianni, G.L. (1992) 'Glutaraldehyde overexposure: Myth or reality?' J. Healthcare Mat. Manag.: 10: 6.

Occupational Health and Safety Administration. (1997) 'Occupational exposure to tuberculosis;' Proposed rule. Federal Register 62: 54159-54308.

Overberger, P.A., Wadowsky, R.M., Schaper, M.M. (1995) 'Evaluation of airborne particulates and fungi during hospital renovation.' Am. Ind. Hyg. Ass. J. 56: 706-712.

Pannuti, C.S., Ginrich, R.D., Pfaller, H.A.,et al. (1991) 'Nosocomial pneumonia in adult patients undergoing bone marrow transplantation: a 9 year study.' J.Clin.Oncol. 9: 77-84.

Pattison, C.P., Maynard, J.E., Berquist, K.R. et al. (1975) 'Epidemiology of Hepatitis B in hospital personnel.' Am. J. Epidemiol. 101: 59

Pisaniello, D.L. (1997) 'Gluteraldehyde exposures and symptoms among endoscopy nurses in South Australia.' Appl. Occup. Environ. Hyg. 12: 171.177.

Popp, W. (1994) 'DNA-protein cross-links and sister chromatid exchange frequencies in lymphocytes and hydroxyethyl mercapturic acid in urine of ethylene oxide exposured hospital workers.' Int. Arch. Occup. Environ. Health 66: 325-332.

Rhodes, W.W. (1988) 'Control of microbioaerosol contamination in critical areas in the hospital environment.' ASHRAE Trans.94 Pt 1: 1171-1184.

Riley, R.L., Mills, C.C., Nyka, W.,et al. (1959) 'Aerial dissemination of pulmonary tuberculosis. A two-year study of contagion in a tuberculosis ward.' Am. J.Hyg. 70: 185-196.

Riley, R.L. (1988) 'Ultraviolet air disinfection for control of respiratory contagion.' In Architectural Design and Indoor Microbial Pollution, ed. Kundsin, R.B., New York: Oxford University Press: 174-197.

Riley, R.L., Nardell, E.A. (1989) 'The theory and application of ultraviolet air disinfection.' Am. Rev. Respir. Dis. 139: 1286-1294.

Rinaldi, M.G. (1983) 'Invasive aspergillosis.' Rev. Infect. Dis.5: 1061-1077.

Roponen, M., Toivola, M., Meklin, T. et al. (1999) 'Differences in inflammatory responses and cytotoxicity in raw 264.7 macrophages induced by Streptomyces anulatus grown on different building materials.' In Proceedings of Indoor Air '99, Edinburgh,Vol. 4: 1146-1147

Rumpf, K.W., Seubert, S., Seubert, A. et al. (1985) 'Association of ethylene-oxide.induced IgE antibodies with symptoms in dialysis patients.' Br. J. Ind. Med. 49: 523-525.

Rutala, W.A., Jones, S.M., Worthington, J.M. et al. (1995) 'Efficacy of portable filtration units in reducing aerosolized particles in the size range of Mycobacterium tuberculosis.' Infect. Control Hosp. Epidemiol. 16: 391-398.

Rurer, A.J.L., Poulsen, O.M., Roed-Petersen, J. et al. (1995) 'Skin problems among Danish dental technicians.' Contact Dermatitis 33: 42-47.

Salvigni, S., Piva, S., Mazzacane, S. (1995) 'Design parameters and economical aspects in ventilation systems for bone morrow transplant patients.' In Proceedings of Healthy Buildings '95, ed. Maroni, M., Milan: 1111-1116.

Sarangi, J., Rowsell, R. (1995) 'A nursing home outbreak of Group A streptococcal infection: case control study of environmental contamination.' J.Hosp.Infect. 30: 162-164.

Sawyer, L.A.,, Murphy, J.J., Kaplan, JE. (1988) '25-30-nm virus particle associated with a hospital outbreak of acute gastroenteritis with evidence of airborne transmission.' Am.J. Epidem.127: 1261-1271.

Schaal, K.P. (1991) 'Medical and microbiological problems arising from airborne infection in hospitals.' J.Hosp.Infect.18 (A): 451-459.

Schoneich, R., Wallenstein, G. (1985) 'Chloramine as a cause of allergic diseases of the respiratory tract.' Zeitschrift fur Klinische Medizin 40: 1127-1130.

Simmons, R.B., Price, D.L., Noble, J.A. et al. (1997) 'Fungal colonization of air filters from hospitals.' Am. Ind. Hyg. Assoc. J. 58: 900-904.

Simpson, A.J.H., Nightingale, J.M.D. (1994) 'Intravascular line infection with Exophila dermatitidis.' Lancet 345: 67.

Smedley, J., Inskip, H., Wield, G. et al. (1996) 'Work related respiratory symptoms in radiographers.' Occup. Environ, med. 53: 450-454.

Staib, F., Mishra, S.K., Blisse, A. (1981) 'Interaction between Aspergilli and Streptomycetes in the soil of potted indoor plants.' Mycopathologia 70: 9-12.

Stenton, S.C., Beach, J.R., Dennis, J.H, et al. (1994) 'Glutaraldehyde, asthma and work – a cautionary tale.' Occup. Med. 44: 95-98.

Streifel, A.J. (1994) 'Air cultures for fungi.' In Clinical Microbiology Procedures Handbook. University of Minnesota: Minneapolis, MN.

Streifel, A.J. (1995) 'Ventilation design for control of airborne infectious agents.' Infection Control & Sterilization Technology, (5): 18-22.

Streifel, A.J. (1996) 'Hospital ventilation systems and the prevention of airborne nosocomial infections.' In Hospital Epidemiology and Infection Control, ed. Mayhall, C.G., Baltimore: Williams and Wilkins: 955-964.

Swanson, M.C., Yungiger, J.W., Reed, C.E. (1995) 'Immunochemical quantification of airborne natural rubber allergens in medical and dental office buildings.' In Proceedings of healthy Buildings '95, ed. Maroni, M., Milan: 1017-1022.

Tablan, O.C., Anderson, L.J., Arden, N.H. (1994) 'Guidelines for prevention of nosocomial pneumonia.' Infect. Control Hosp. Epidem.15: 587-627.

Tammelin, A., Domicel, P., Hambraeus, A, et al. (2000) 'Dispersal of mehicillin-resistant Staphylococcus epidermis by staff in an operating suite for thoracic and cardiovascular surgery: relation to skin carriage and clothing,' J. Hosp. Infect. 44: 119-126.

Tarvainen, K. (1990) 'The effects of energy saving measures on hospital hygiene.' Finnish Hospital League, Helsinki (in Finnish, English summary).

Tarvainen, K., Wirtanen, G., Mattila-Sundholm, T. (1995) 'Preventing airborne microbial risks in rooms with special hygiene requirements.' In Healthy Buildings '94, eds. Banhidi, L., Farkas, I., Magyar, Z., et al., Budapest, Vol. 2: 217-222..

Varraes, S., Michel, O. (1995) 'Occupational asthma induced by ethylene oxide.' Lancet 346 (8987): 1434-1435.

von Eiff, M., Roos, N., Fegeler, W., et al. (1996) 'Hospital-acquired candida and aspergillus pneumonia - diagnostic approaches and clinical findings.' J.Hosp.Infect .32 : 17-28.

Wald, A., Leisenringen, W., van Burik, J-A. et al. 'Increasing fungal isolation from clinical specimens: Experience in a university hospital over a decade.' J. Hosp. Infect. 35: 185-195.

Weinberger, M., Sacs, T., Sulkes, J.,et al. 'Increasing fungal isolation from clinical specimens: Experience in a university hospital over a decade.' J. Hosp. Infect. 35: 185-195.
Wellons, S.L., Travick, E.G., Stowers, M.F. et al. (1998) 'Laboratory and hospital evaluation of four personal monitoring methods for glutaraldehyde in ambient air.' J.Am.Ind. Hyg. Assoc. 59: 96-103.

Wheeler, A.E. (1993) 'A perspective of ventilation for health care and related facilities.' In Proceedings of the Workshop on Engineering Control for Preventing Airborne Infections in Workers in Health Care and Related Facilities, eds. Bierbaum, P.J., Lippmann, M., Cinicinnati, Ohio: 35-47.

Williams, S., Syderham, N. (1996) 'Exposure to methylmethacrylate in an orthopaedic operating theatre.' Occup. Med. 46: 322-323.

Woods, J.E., Braymen, D.T., Rasmussen, R.W., et al. (1986) 'Ventilation requirements in hospital operation rooms. Part I: Control of airborne particles.' ASHRAE Trans. 92 Pt 2 A: 396-426.