GUIDANCE ON INDOOR ENVIRONMENTAL QUALITY IN HEALTH CARE FACILITIES

PAHO
Pan American Health Organization
World Health Organization
REGIONAL OFFICE FOR THE Americas

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Contents

Tables

Figures

Acknowledgments

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Abbreviations and Acronyms

%	percentage
°C	degrees Celsius
µg/m³	microgram per cubic meter
AD	aerodynamic diameter
AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Bq/m³	becquerel per cubic meter
CDC	Centers for Disease Control and Prevention
cfm	cubic feet per minute
cfu/m³	colony-forming units per cubic meter
CI	chemical intolerance
CO	carbon monoxide
CO_2	carbon dioxide
CxA	commissioning agent
ECG	electrocardiogram
EPA	Environmental Protection Agency
ff/cc	fibers per cubic centimeter
ff/m³	fibers per cubic meter
h	hour
H_2O	water
HAI	hospital-acquired infection
HEPA	high efficiency particulate air
HVAC	heating, ventilation, and air conditioning
IAQ	indoor air quality
IAQA	Indoor Air Quality Association
ICP	inductively coupled plasma-atomic emission spectrometry
ICP	infection control practitioner
ICRA	infection control risk assessment
ICU	intensive care unit
IEQ	indoor environmental quality
IH	industrial hygienist
IQ	intelligence quotient
ISO	International Organization for Standardization
l/s	liters per second
LEED	Leadership in Energy and Environmental Design

MAD	median aerodynamic diameter
Max.	maximum
MERV	minimum efficiency reporting value
MRI	magnetic resonance imaging
m/s	meters per second
NA	not applicable
NDIR	nondispersive infrared
NIOSH	National Institute for Occupational Safety and Health
nm	nanometer
NO_2	nitrogen dioxide
NR	not required
O_3	ozone
OHS	occupational health and safety
OR	operating room
Pa	Pascal unit
PAC	postanesthesia care unit
PAHO	Pan American Health Organization
PCM	phase contrast microscopy
PID	photoionization detector
PM	particulate matter
ppb	parts per billion
ppm	parts per million
SO_2	sulfur dioxide
TWA	time weighted average
ULPA	ultra-low particulate air
UV	ultraviolet
UVGI	ultraviolet germicidal irradiation
WHO	World Health Organization

Executive Summary

The aim of this guidance is to enhance the capacity of health care facilities to protect and improve the health of their target communities by ensuring access to health care in a healthy and sustainable environment. In order to foster an environmentally responsible and resilient health system, several infrastructural and maintenance aspects of health care facilities need to be ensured, including indoor environmental quality. Indoor environments in health care facilities are highly complex and require special attention to guarantee a healthy environment for patients, the health workforce, visitors, and support personnel. Appropriate and adequate heating, ventilation, and air conditioning systems, ensuring temperature and humidity and indoor air quality pollutants and physical constituents are within approved ranges, and timely maintenance and routine inspection are all fundamental components of environmentally sustainable and climate-resilient health care facilities.

This publication builds upon the World Health Organization (WHO) Operational Framework for Building Climate Resilient Health Systems[1] and the WHO Guidance for climate resilient and environmentally sustainable health care facilities[2] to look specifically at indoor environmental quality aspects of a health care facility that need to be met in order to ensure adequate infrastructure.

[1] World Health Organization. Operational framework for building climate resilient health systems. Geneva: WHO; 2015. Available from: https://www.who.int/publications/i/item/operational-framework-for-buildingclimate-resilient-health-systems, accessed 21 November 2021.

[2] World Health Organization. WHO guidance for climate-resilient and environmentally sustainable health care facilities. Geneva: WHO; 2020. Available from: https://www.who.int/publications/i/item/9789240012226, accessed 21 November 2021.

Introduction

Patients and health care staff remain in health care facilities over extended periods of time. Therefore, ensuring a healthy indoor environmental quality (IEQ) is critical to protect patients, visitors, health care workers, and avoid cross-infection. Furthermore, addressing IEQ is an important component of the environmental sustainability of health care facilities.

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IEQ refers to the quality of a building's environment in relation to the health and well-being of those who occupy space within it. It is determined by many factors, including lighting, air quality, and damp conditions (*1*). Indoor environments are highly complex and occupants may be exposed to a variety of factors, including chemical pollutants, particulate matter and pathogens. Some of the most common emission sources of contaminants include office machines, cleaning products, construction activities, carpets and furnishings, perfumes, cigarette smoke, water-damaged building materials, microbial growth (fungal, mold, and bacterial), insects, and outdoor pollutants. Other factors such as indoor temperatures, relative humidity, and ventilation levels can also affect how individuals respond to the indoor environment.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines acceptable indoor air quality in standard 62.1 as “air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction” (*2*). IAQ is limited to what is in the air inside the building.

Increased energy conservation efforts in the last four decades have led to the construction of more energy-efficient, airtight buildings. Deficient ventilation in such building results in increased exposure to indoor pollutants. Different terms have emerged to describe the conditions affecting occupants of these buildings: sick building syndrome; multiple chemical sensitivity; environmental illness; and idiopathic environmental intolerance. Currently, chemical intolerance and toxicant-induced loss of tolerance are increasingly used instead of multiple chemical sensitivity, environmental illness, and idiopathic environmental intolerance (*3*) to describe chemical intolerances or sensitivity to repeated low-level exposures.

Health care buildings involve complex installations and systems that are sensitive to the environmental conditions. Proper operation of medical devices usually requires controlled environments that may be difficult to maintain in certain climates. The IAQ concept in health care facilities has led to a modern field of specialization among engineers, environmental and occupational hygienists, public health specialists and other related professionals (*4*).

The objective of this publication is to provide guidance to address indoor environmental quality for health care facilities, focused on small island developing countries in the Region of the Americas.

Identification of indoor air pollutants in health care facilities

The airborne chemical and microbiological contaminants of concern for health care facilities have been identified, are well documented, and will be reviewed here. Table 1 lists the most common contaminants found in health care facilities, along with a guidance limit and the health effects on building occupants. Not all contaminants will be present at the same time, but the hospital engineer or environmental hygienist should be aware of their existence when investigating an IAQ problem.

The guidance limits presented in Table 1 may serve as a reference if local regulation is not available.

Table 1. Common indoor air pollutants and physical constituents in health care facilities

PARAMETER/CONTAMINANT	GUIDANCE LIMIT	REFERENCE	HEALTH EFFECTS
Temperature	20–26 °C[a]	ASHRAE 170-2021 (*5*)	Comfort
Relative humidity	Maximum 60%	ASHRAE 170-2021 (*5*)	None
Carbon	700 ppm over exterior concentration	ASHRAE 62.1-2016 (*2*)	Rapid breathing, rapid heart rate, clumsiness, emotional upsets, and fatigue can result (*6*)
Carbon monoxide	9 ppm and no more than 2 ppm above outdoor level	LEED®, 2013 (*7*)	Headache, nausea, dizziness, drowsiness, confusion, and death. May cause permanent damage to organs including the brain and heart (*8*)
Particulate matter PM-10	15 µg/m³	WHO, 2021 (*9*)	Premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat
Particulate matter PM-2.5	5 µg/m³		Aggravated asthma, decreased lung function, increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing (*10*)
Particle counts	Depends on the function of the space	ISO 14644-1: 2015 (*11*)	NA
Total volatile organic compounds	200 µg/m³	LEED® 2013 (*7*)	Eye, nose, and throat irritation, headaches, loss of coordination and nausea, damage to liver, kidney, and central nervous system. Some organics can cause cancer in animals, some are suspected or known to cause cancer in humans (*12*)
Formaldehyde	16.3 ppb	LEED® 2013 (*7*)	Acute (short-term) and chronic (long-term) inhalation exposure to formaldehyde in humans can result in respiratory symptoms, and eye, nose, and throat irritation. Possible human carcinogen (*13*)
Nitrogen dioxide	10 µg/m³	WHO, 2021 (*9*)	A high concentration of NO^2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing, or difficulty breathing), hospital admissions, and visits to emergency rooms. Longer exposures to elevated concentrations of NO^2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. People with asthma, and children and older persons are generally at greater risk for the health effects of NO^2 (*14*)
Radon	1 Bq/m³	WHO-Europe, 2000 (*15*)	Lung cancer (*16*)
Ozone	100 µg/m³	WHO, 2021 (*9*)	Depending on the level of exposure, ozone can: cause coughing and sore or scratchy throat; make it more difficult to breathe deeply and vigorously and cause pain when taking a deep breath; inflame and damage the airways; make the lungs more susceptible to infection; aggravate lung diseases such as asthma, emphysema, and chronic bronchitis; and, increase the frequency of asthma attacks. (*17*)

[a] Will depend on the function of the space.

Table 1. Common indoor air pollutants and physical constituents in health care facilities *(continued)*

PARAMETER/CONTAMINANT	GUIDANCE LIMIT	REFERENCE	HEALTH EFFECTS
Lead in air	0.5 µg/m³	WHO Europe, 2000 (*15*)	Once taken into the body, lead distributes throughout the body in the blood and is accumulated in the bones. Depending on the level of exposure, lead can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems, and the cardiovascular system. Lead exposure also affects the oxygen carrying capacity of the blood. The lead effects most likely to be encountered in current populations are neurological effects in children. Infants and young children are especially sensitive to lead exposures, which may contribute to behavioral problems, learning deficits, and lowered IQ (*18*)
Asbestos fibers in air	500 ff/m³ (5x10-4 ff/cc)	WHO Europe, 2000 (*15*)	Fibrotic lung disease (asbestosis) and changes in the lining of the chest cavity (pleura). These diseases can lead to reduced respiratory function and death. Long-term inhalation of asbestos fibers also increases the risk of lung cancer and mesothelioma (*19*)
Other fibers in air	0.1 ff/cc	Recommendation	Skin, eye, and upper and lower respiratory tract irritation can occur and depend on exposure levels and job duties. Skin irritation has been the most common health effect noted (*20*)
Fungal structures (air) very clean areas	Absent	UNE 171330-2 (*21*)	Keeping the fungal colonies in air low will aid in preventing nosocomial fungal infections in immunocompromised patients
Fungal structures (air) moderately clean areas	< 10 cfu/m³ [b]		
Fungal structures (air) other areas	< 25 cfu/m³		
Bacteria [c] very clean areas	< 10 cfu/m³	UNE 171330-2 (*21*)	Keeping the bacterial colonies in air low will aid in preventing nosocomial bacterial infections in immunocompromised patients.
Bacteria moderately clean area	10—100 cfu/m³		
Bacteria other areas	100—200 cfu/m³		
Nitrous oxide	25 ppm	NIOSH (*22*)	Dyspnea (breathing difficulty); drowsiness, headache; asphyxia; reproductive effects; liquid: frostbite (*22*)
Halothane Enflurane Methoxyflurane	C 2 ppm	NIOSH (*22*)	Irritation eyes; central nervous system depression, analgesia, anaesthesia, convulsions, respiratory depression; liver, kidney injury. In animals: reproductive, teratogenic effects (*22*)
Glutaraldehyde	C 0.2 ppm	NIOSH (*22*)	Irritation of eyes, skin, respiratory system; dermatitis, sensitization of skin; cough, asthma; nausea, vomiting (*22*)
Ethylene oxide	< 0.1 ppm C 5 ppm	NIOSH (*22*)	Irritation of eyes, skin, nose, throat; peculiar taste; headache; nausea, vomiting, diarrhea; dyspnea (breathing difficulty), cyanosis, pulmonary oedema; drowsiness, lassitude (weakness, exhaustion), incoordination; ECG abnormal; eye, skin burns; liquid: frostbite; reproductive effects (*22*)

[b] Nonpathogenic: *Aspergillus, Rhizopus, Mucor, Scedosporium.*
[c] Mesophilic aerobic bacteria.


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Control of indoor air pollutants in health care facilities

There are four factors that contribute to an IAQ problem, according to the United States Environmental Protection Agency (EPA) 1991 publication *Building Air Quality* (*23*): source, pathways, HVAC[1] and occupants.

The source of contamination represents the main threat to IAQ. In a health care facility, there are many sources of particulate matter, chemical and biological pollutants that can affect the occupants. For example, disinfectants, volatile organic compounds[2], mold, anesthetic gases, and medications. Moreover, patients constitute a source of biological contaminants, mainly bacteria and virus. Complete removal of all contaminants from the indoor environment is rarely possible in health care settings. Therefore, health care facilities should also consider more comprehensive interventions.

[1] Heating, ventilation, and air conditioning

[2] Volatile organic compunds are emitted as gases from a wide array of products. Examples include: paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions.

The pathway of a contaminant is the route from the source of contamination to the occupant, passing through the indoor environment. For example, if a surgeon is generating anesthetic gases in an operating room (OR), and there is a pathway connecting the OR and other areas of the operating theater, the gases can migrate to these areas and affect other occupants not directly involved in the surgery procedure. Airflow patterns are one of the most important pathways in buildings. Without a pathway, the contaminant cannot move beyond its source; therefore, controlling the pathway is one of the strategies to reduce occupants exposure to indoor contaminants.

In a health care setting, the HVAC system is the most important pathway and driving force for air movements. Having a source of contamination and pathway is not enough to cause an IAQ problem. There has to be a force driving the contaminant through the pathway. The contaminants can pass through the air ducts moved by pressure differentials throughout the building, affecting occupants in areas not necessarily close to the contaminant source. Mold spores can migrate from adjacent construction and renovation areas to patient wards and other critical areas of a health care facility. Controlling the ventilation rate, airflow direction and air distribution patterns is another way to prevent IAQ problems in the health care environment.

Building occupants are a critical factor for IAQ. There are different levels of exposure and vulnerabilities among building occupants. Health workers, administrative and maintenance personnel and in-patients spend extended periods of time at the health care facility. Visitors and service providers usually have reduced exposure times. Certain occupations within the facility (i.e operators of radiology equipment or cleaning teams) might be exposed to specific contaminants. Groups with certain health conditions can also have increased vulnerability to exposure to contaminants. All these aspects should be taken into consideration when assessing how to reduce exposure of occupants.

To manage the IAQ problem, it is necessary to assess the four factors mentioned above to identify the most suitable interventions. It is necessary either to find the source of IAQ contaminants and control it or completely remove it, or act on the pathway or the force. While removing all building occupants is usually not feasible nor desirable, certain interventions — such as building maintenance — or IAQ issues could require the relocation of building occupants.

Complete removal of the source of contaminant is usually the most effective way to address IAQ. Examples include: using less hazardous disinfectants, using paints with low or no volatile organic compounds, banning smoking in all areas of the health care facility, or removing plants from the building. If removal is not possible, the second option is to act on the pathway and/or the force.

The control techniques for preventing IAQ problems in health care facilities involve acting on the engineering system designs and operations and proper maintenance of mechanical ventilation systems, for effective dilution and removal of the contaminants. Control and mitigation measures include: filtration, differential pressure control, directional airflow control, local exhaust ventilation, and ultraviolet germicidal irradiation (UVGI) disinfection.

Mechanical ventilation

Ventilation is essential for the control of contaminants. Mechanical ventilation through the HVAC systems is an effective way to provide a controlled environment and reduce contaminants inside the building. There are two ways of achieving this: through dilution ventilation, or exhaust ventilation. The former is the most common strategy in health care facilities in the Caribbean and Central American region. Exhaust ventilation, also referred to as "local exhaust ventilation" is used in selected activities that involve more hazardous chemicals, such as histology laboratories, application of sterilants, ionizing radiation, and antineoplastic drugs.

Dilution ventilation is based on introducing fresh outside air to the building and mixing it with the inside air to dilute contaminants. Part of the inside air needs to be exhausted and replaced for fresh outside air. The process of removing indoor air and introducing outside to control air contaminats is known as ventilation. The amount of outside air that is introduced into the building envelope, and exchanged for the inside air, is referred to as "air changes per unit of time" (usually per hour): air changes per hour (ACH). ASHRAE, AIA[3] (*24*), and CDC[4] (*25*) have published recommended air change rates for outdoor air and total air for health care facilities, as summarized in Table 2.

[3] American Institute of Architects.
[4] Centers for Disease Control and Prevention.

Table 2. Summary of ventilation requirements and psychrometric conditions of health care facilities (*5*)

AREA	OUTDOOR ACH[a]	TOTAL ACH	TEMPERATURE	RELATIVE HUMIDITY
Patient wards	2	4	21—24 °C	Max. 60%
Operating theatre	4	20	20—24 °C	20—60%
Intensive care unit	2	6	21—24 °C	30—60%
Infectious isolation room	2	6	21—24 °C	20—60%
Protective isolation room	2	12	21—24 °C	Max. 60%
Laboratory	2	6	21—24 °C	Max. 60%
Emergency room — trauma/ resuscitation room	3	15	21—24 °C	20—60%
Labor/delivery/recovery	2	6	21—24 °C	21—24°C
Dialysis treatment area	2	6	22—26 °C	Max. 60%
Autopsy room	2	12	20—24 °C	Max. 60%
Burn unit	2	6	21—24 °C	40—60%
General examination room	2	4	21—24 °C	Max. 60%
Laundry	2	10	NA	Max. 60%

[a] Air Changes per Hour

The recommended outdoor air change rates are based on the quality of the outdoor air meeting minimal standards, as given in Table 3. If the outdoor air quality is poor, the HVAC system should consider treatment to avoid worsening indoor air quality in the facility. Local exhaust ventilation by means of chemical fume hoods, biological safety cabinets, and extraction systems should be used to control critical point emission sources of contaminants in sterilizing rooms, endoscopy rooms, laboratories, tissue processing rooms, and other similar areas.

Table 3. World Health Organization air quality guidelines (2021)

CONTAMINANT	AVERAGE CONCENTRATION (*9*)	
	MG/M³	PERIOD
Particles (PM-2.5) *	5	Annual mean
	15	24 hours mean
Particles (PM-10) **	15	Annual mean
	45	24 hours mean
Carbon monoxide	4	8 hours mean (mg/m³)
Nitrogen dioxide	10	Annual mean
Sulfur dioxide	40	24 hours mean
Ozone	100	8 hours mean
Lead	0.5	Annual mean

*Suspended particles having a median aerodynamic diameter (MAD) of 2.5 µm.
**Suspended particles having a median aerodynamic diameter (MAD) of 10 µm.

Filtration

Filters can effectively trap particulate contaminants, including inorganic and organic particles, microbiological pathogens, and the like. Various grades of filter efficiencies can be used to achieve different degrees of cleanliness. In the Americas, the common standard used is ASHRAE 52.2 (*26*), which establishes a scale known as the minimum efficiency reporting value (MERV) of the air cleaner or filter. The ISO 16890 international standard also presents a technical specification, requirements, and classification system based on particulate matter efficiency (*27*). Table 4 shows the equivalent filter rating between the ISO 16890 and the ASHRAE ratings.

The MERV scale was designed by ASHRAE in 1987 to report the effectiveness of air filters. The scale is designed to represent the worst-case performance of a filter when dealing with particles in the range from 0.3 to 10 micrometers. The MERV value is from 1 to 20. Higher MERV values correspond to a greater percentage of particles captured on each pass. Table 5 presents the typical applications for the different MERV ratings.

Another type of filter commonly found in health care facilities is the high-efficiency particulate air (HEPA) filter, which is a type of pleated mechanical air filter. HEPA filters can theoretically remove at least 99.97% of particles with an aerodynamic diameter of 0.3 micrometers (µm). The 0.3-diameter responds to the worst case, or what is called the “most penetrating particle size”. **HEPA filters** can be combined with prefilters to trap larger particles before they come into contact with the main filter, this is important to protect the HEPA filter.

A not-so-common air filter used in health care facilities is the ultra-low particulate air (ULPA) filter, that can trap smaller particles than the HEPA filters. **ULPA filters** are **99.999% effective** at removing submicron particles of 0.12 µm aerodynamic diameter or larger.

The higher efficiency rating of the HEPA, ULPA, and higher MERV filters is due to the increased density of the filter medium. The higher-density filters will cause a decrease in the air flow through the filters and require more power to move the air through the medium. In a critical area such as an OR, a HEPA filter should be used, The recommended cleanliness levels are described in table 7

Figure 2 illustrates a cleanliness assessment in an operating room using a particle counter.

Table 4. Approximate equivalent ratings of filters tested under ASHRAE Standard 52.2 and ISO 16890

ASHRAE MERV (STANDARD 52.2)	ISO 16890 RATING
1—6	ISO Coarse
7—8	ISO Coarse > 95%
9—10	ePM10
11—12	ePM2.5
13—16	ePM1

Table 5. Typical MERV applications

MERV	MINIMUM PARTICLE SIZE	COMMON CONTROLLED CONTAMINANT	APPLICATION
1—4	> 10 µm	Large particles: pollen, sand dust, textile fibers, and the like	Residential applications
5—8	10–3 µm	Mold spores, dust mite debris, animal dander	Better residential, commercial, offices
9—12	3–1 µm	Legionella bacteria, humidifier dust, lead dust, emission particles	Hospital, laboratories, better commercial
13—16	1–0.3 µm	Bacteria, droplet nuclei, cooking oil, smoke, insecticide dust	Hospital and general surgery
17—10	< 0.3 µm	Virus, carbon dust, smoke	Electronics, pharma manufacturing, cleanrooms

Particulate matter prefilters with a minimum MERV rating of should be placed upstream, ahead of the cooling/heating coil (Figure 1) to remove larger particles that combine return air from multiple rooms or introduce outdoor air (*5*). The prefilter can also prolong the life of the final filter placed downstream of the air-handling unit, resulting in a more cost-effective operation.

In health care facilities, the final filter should at least have the efficiencies listed in Table 6, to collect nearly all fungal spores of 2–5 µm diameter and bacteria in colony-forming units of 1 µm diameter or larger. In a critical area such as an OR, a HEPA filter should be used.

Figure 1. Configuration of a filtration system

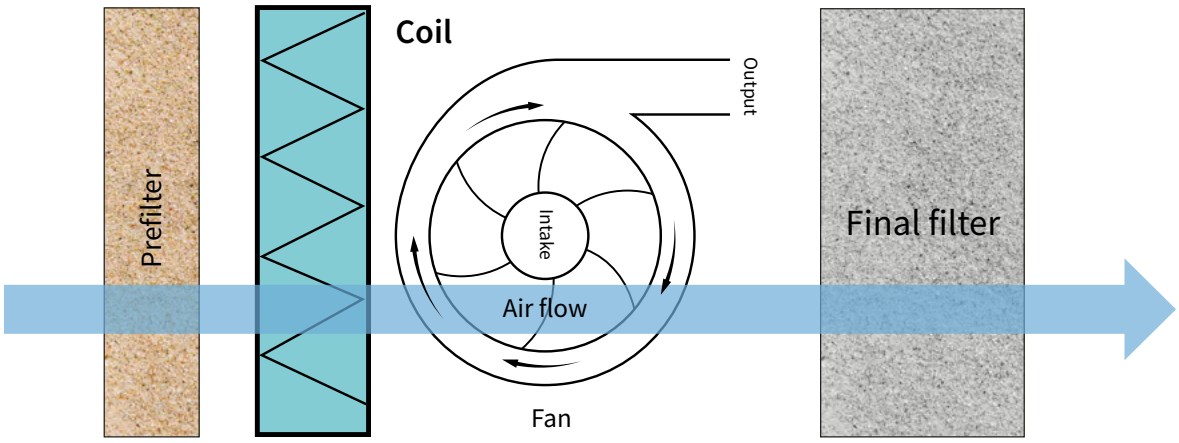

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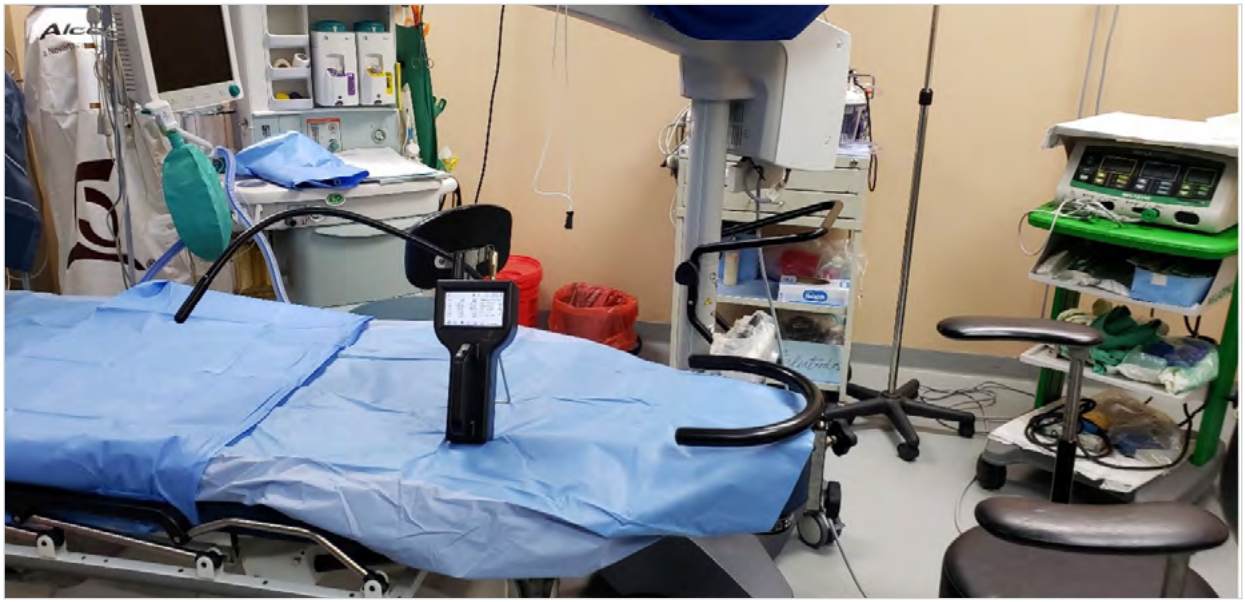
Table 6. Minimum filter efficiencies in health care facilities (*5*)

AREA	MERV RATING
Patient wards	14
Operating room	16
Intensive care unit	14
Infectious isolation room	14
Protective isolation room	HEPA
Laboratory	8
Emergency room–trauma/resuscitation room	14
Labor/delivery/recovery	14
Dialysis treatment area	8
Autopsy room	8
Burn unit	HEPA
General examination room	8
Laundry	8

Table 7. Recommended air cleanliness level in selected areas

AREA	ISO 14644-1 RATING (28) IN OPERATION	MAXIMUM NUMBER OF PARTICLES @0.5 MM
Patient wards	ISO 9	35,200,000
Operating room	ISO 8	3,520,000
High-risk operating room	ISO 6	35,200
Conventional operating room	ISO 8	3,520,000
Intensive care unit	ISO 8	3,520,000
Infectious isolation room	ISO 8	3,520,000
Protective isolation room	ISO 8	3,520,000
Laboratory	ISO 9	35,200,000
Emergency room–trauma/resuscitation room	ISO 8	3,520,000
Labor/delivery/recovery	ISO 8	3,520,000
Dialysis treatment area	ISO 9	35,200,000
Autopsy room	ISO 9	35,200,000
Burn unit	ISO 8	3,520,000
General examination room	ISO 9	35,200,000
Laundry	ISO 9	35,200,000

Figure 2. Particle count measurements in an operating room



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Differential pressure control

Maintaining a differential pressure between two adjacent areas, such as an operating room and a corridor, can allow to control the airflow direction. The air pressure differential among various areas of a health care facility should be controlled to ensure clean-to-less-clean airflows. This air pressure differential will aid in the prevention of hospital-acquired infections (HAI). Table 8 shows the recommended air pressure differentials in various areas of a health care facility. It is important to point out that pressure differentials are between adjacent areas.

The differential pressure should be at least 2.5 Pa (0.01 in. of H_2O), so that any interference due to door-opening, wall spaces, elevator movement, and other normal activities will not change the positive or negative nature of the pressure or the airflow direction. Doors should have proper seals to avoid air leaks (see Figure 3 and Figure 4). For a typical hospital facility, a positive pressure of 2.5 Pa can be obtained by regulating the supply air to a level exceeding the exhaust air by 59 l/s (125 cfm). Conversely, a negative pressure of –2.5 Pa can be obtained with the supply air 59 l/s (125 cfm) below the exhaust air (*29*).

Maintaining a differential pressure demands constant attention to air-balancing, and system maintenance. Loading the filters will significantly increase the pressure drop, reduce the air supply, and may cause a change in the pressure differential. For critical areas (such as operating rooms, intensive care units [ICUs], and isolation rooms), a differential pressure monitoring system is recommended for continuous checking of the operating condition.

Figure 3. Air movement due to pressure differentials

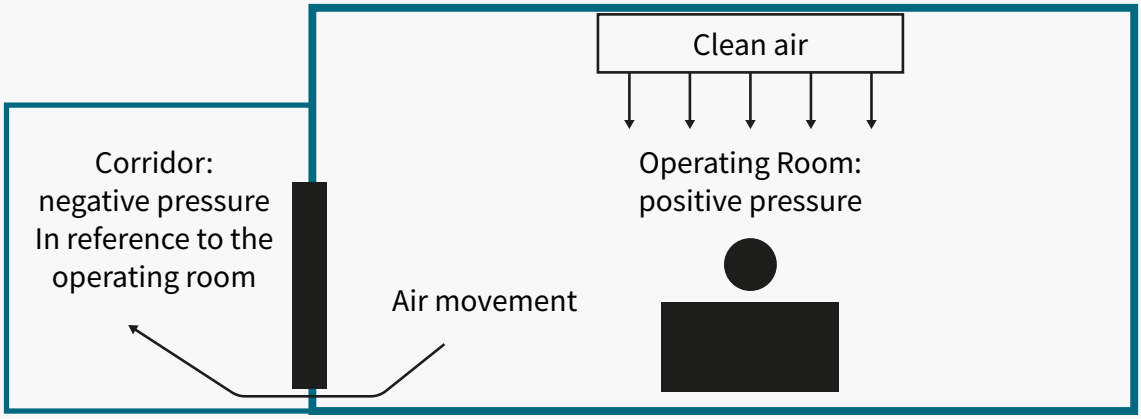

Table 8. Pressure relationship to adjacent areas (*5*)

AREA	PRESSURE RELATIONSHIP
Patient wards	NR
Operating room	Positive
Intensive care unit	Positive
Infectious isolation room	Negative
Protective isolation room	Positive
Laboratory	Negative
Emergency room — trauma/resuscitation room	Positive
Labor/delivery/recovery	NR
Dialysis treatment area	NR
Autopsy room	Negative
Burn unit	Positive
General examination room	NR
Laundry	Negative

Note: NR= not required.

Figure 4. Doors to an operating room that do not seal properly

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Directional airflow control

Airflow in health care facilities is also important to ensure proper IAQ. Air movement from clean zones to less-clean zones or zones of greater contamination will aid in preventing HAIs. The air movement should always be from clean zones to zones of progressively greater contamination. In operating rooms, a unidirectional (laminar) airflow is recommended to avoid turbulence that can resuspend airborne particles. Turbulence can also cause mixing of airborne pathogens and increase the risk of HAIs.

In critical areas like operating rooms, ICU´s, and burn units, the air flow should be vertical from ceiling to floor, or horizontal from wall to wall, as illustrated in Figure 5 and Figure 6. The clean air should only pass one time through the patient area. Return diffusers should be situated in such a way that contaminated air is not passed through the surgical site. Supply diffusers should be of the unidirectional type, and the contaminated air should exhaust through the sides at floor level. Mini split-type units are not recommended in critical areas (e.g. operating rooms, ICUs, burn units), because the system only recycles air, and the flow cannot be controlled. Mini split-type units are not recommended in critical areas (e.g. operating rooms, ICUs, burn units), because the system only recycles air, and the flow cannot be controlled (see figure 7)

It is important that return grilles are not obstructed by equipment in the operating rooms to avoid interfering with the designed air flow pattern (Figure 6). In practice, the actual airflow pattern may be different from the ideal condition, depending on a number of factors, such as HVAC design, ventilation rates, interference by health care workers or surgical equipment.

Figure 5. Recommended airflow pattern in operating rooms:
ceiling to floor (preferred way)

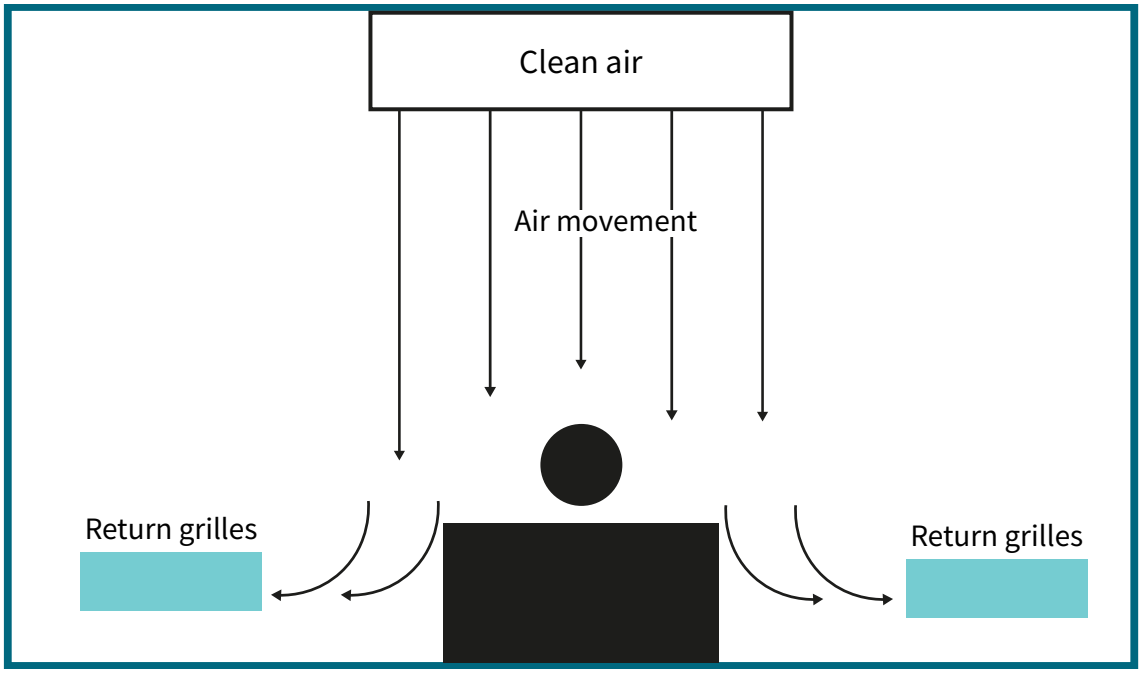

Figure 6. Recommended airflow pattern in operating rooms:
ceiling to floor (option 2)

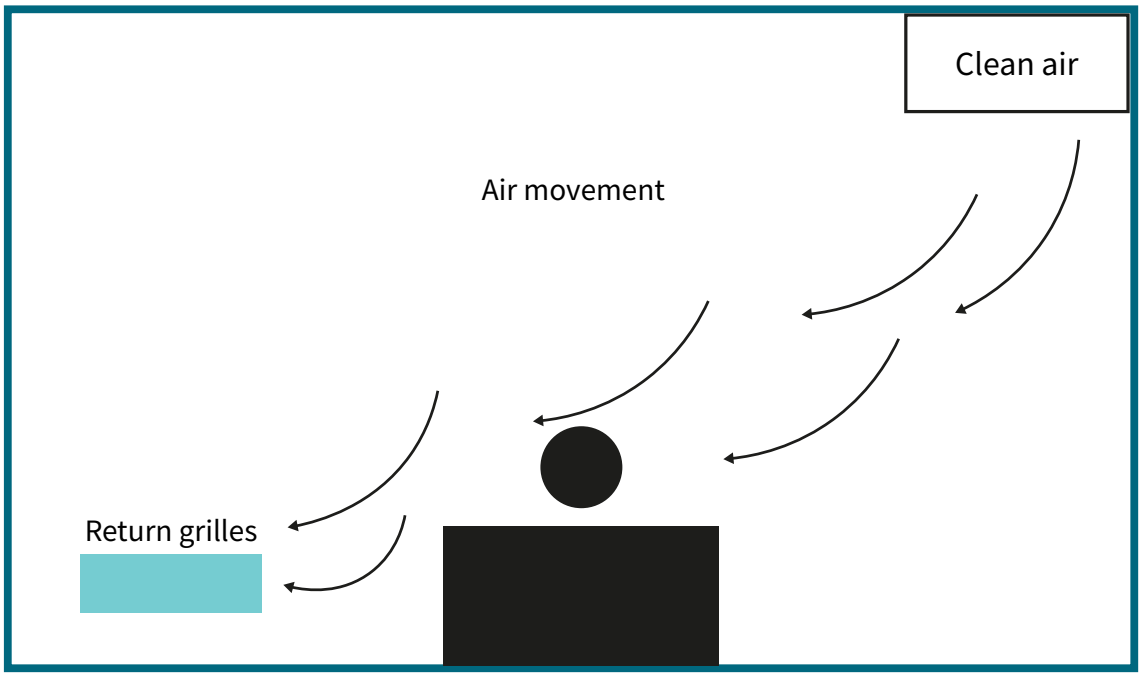

Figure 7. Mini split systems in operating rooms are not recommended

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Figure 8. Return grilles should be free of obstructions

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Ultraviolet germicidal irradiation disinfection

The effectiveness of a UVGI system to inactivate microorganisms in the air and/or on surfaces has been amply demonstrated (*30*). UVGI disinfection (UV radiation of wavelength 220–300 nm) can penetrate cell walls, and inactivate airborne droplet nuclei by damaging their DNA/RNA and disrupting their reproductive mechanisms. Airborne pathogens, such as multidrug-resistant mycobacterium tuberculosis bacteria, legionella bacteria, and measles viruses, can be killed by UVGI. However, UVGI is less effective against fungal spores (*25*).

Inactivation rates of 90% or higher can be achieved, but this depends on the type of microbial contaminant, specific species, physical or mechanical factors such as UV irradiation intensity, exposure/dwell time, lamp distance, and placement, as well as lamp life cycle and cleanliness, air movement and patterns, temperature, relative humidity, and air mixing. A UVGI lamp perpendicular to a moving airstream does not provide a favorable killing rate, because of the short dwell time. Airborne removal is best applied in conjunction with filtration of particles with prefiltration, in order to protect lamps and mechanical filtration downstream for microbial particles. The HVAC system should maintain an air speed not exceeding the limit for optimal disinfection performance. This can be accomplished by computer modeling methods. A typical installation configuration is shown in Figure 9. Again, this configuration is appropriate for maintaining the coils clean, but not appropiate for air cleaning.

Figure 9. UVGI lamps installed upstream of the cooling coil

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The CDC (*25*) recommends that UVGI be used to supplement the engineering control methods, including mechanical ventilation, filtration, and differential pressure control, but should not be used as a substitute for any of these methods.

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Methods for analysis and measurement of indoor environmental parameters in health care facilities

The Indoor Air Quality Association (IAQA) lays out a five-step systematic approach to assessing indoor air quality (*31*):

1. **INFORMATION-GATHERING**
2. **WALK-THROUGH INSPECTION**
3. **INDICATOR MEASUREMENTS**
4. **SAMPLING**
5. **CONCLUSIONS AND RECOMMENDATIONS**

The assessment method starts with gathering information and trying to understand the problem. A lot of information can be gathered by asking questions to the affected occupants, and reviewing related documentation, such as plans, inspections records, maintenance records, environmental assessments, hospital infection control committee meeting minutes, etc. The second step involves a walk-through inspection of the affected occupied space, outdoors, and the HVAC systems.

Sampling is divided into two parts: indicator measurements and other samples. The first includes general ambient measurements that will give a broad picture of the psychrometric conditions of the building envelope. These include: temperature, relative humidity, ventilation, pressurization, and particle counts for health care facilities. As mentioned before, these parameters are important to ensure a healthy indoor environment. Indicator measurements are always recommended in health care facility assessments. Table 2 shows the recommended psychrometric conditions for health care facilities. If an indicator measurement is out of the recommended range, a more specific problem could be present. For example, if the relative humidity is 70%, microbial growth could be a possibility; and surface moisture could indicate that hot humid air is entering the building envelope.

With information from the first three steps, a tentative explanation of the problem (hypothesis) can be formulated. It might be necessary to do additional sampling to test the hypothesis and reach a conclusion. This is step four of the process. At this point, it is possible to create a sampling plan, and then collect samples. Nevertheless, many times, IAQ problems can be identified just by going through the first three steps of the process. It is important to emphasize that sampling is not always necessary to reach a conclusion.

The term “sampling” can mean many things, so it should be defined as it applies to the health care facility assessment. “Sampling” in this context means collecting a representative amount of a contaminant in the field to be analyzed in a laboratory. Some contaminants can be measured with direct reading instruments in the field, while others will need to be sent to the laboratory for analysis. It is of utmost importance that the measuring technique or sampling method used be an accepted one, preferably validated, so that measurements can be replicated. Table 9 mentioned the recommended sampling methods and the suggested measuring times for IAQ parameters in health care facilities assessments.

The next question is “what to measure?” There are two approaches to this question: there can be sampling for as many contaminants as possible, or a narrower focused sampling based on the findings of the first three steps. The idea in the first approach is to test for as many contaminants as possible, and hope to find one that explains the IAQ problem. This can be very expensive, and will not necessarily help reach a conclusion.

By analyzing the information gathered in the first three steps of the assessment, it is possible to select the most plausible explanation for the problem (the hypothesis), and test it by performing field measurements of selected contaminants. After critically reviewing all the information, indicator measurements results, and sampling results, it will then be possible to formulate an explanation of the problem (conclusion), and provide recommendations.

The hard part in formulating a sampling strategy is maximizing the statistical confidence in the data, because the number of samples can easily exceed the allotted budget. There is no easy answer to the question: “how many samples should be taken?”. The answer will depend on the available resources, the local conditions, the expertise of the public health practitioner, and other available evidence. A balance between good data and the available resources should be the aim.

Table 9. Recommended measuring techniques for selected IAQ contaminants

PARAMETER/CONTAMINANT	GUIDANCE LIMIT	REFERENCE	RECOMMENDED MEASUREMENT TECHNIQUE	SUGGESTED MEASUREMENT TIME	COMMENTS
Temperature	20—26 °C[a]	ASHRAE 170-2021 (*5*)	Direct reading instrumentation	Average 24 hours	
Relative humidity	Maximum 60%	ASHRAE 170-2021 (*5*)	Direct reading instrumentation	Average 24 hours	To avoid microbial growth.
Carbon dioxide	700 ppm over exterior concentration	ASHRAE 62.1-2016 (*2*)	Direct reading instrumentation — NDIR sensor	Average 24 hours	At higher concentrations not common in indoor spaces: nausea and vomiting, collapse, convulsions, coma and death.
Carbon monoxide	9 ppm and no more than 2 ppm above outdoor level	LEED®, 2013 (*7*)	Direct reading — electrochemical sensor	Average 24 hours	Usually not a contaminant of concern in indoor spaces in health care facilities.
Particulate matter PM10	15 µg/m³	WHO, 2021 (*9*)	Direct reading	Average 24 hours	PM2.5 is the preferred indicator.
Particulate matter PM2.5	5 µg/m³				
Particle counts	Depends on the function of the space	ISO 14644-1: 2015	Discrete particle counter	See method	Particle counts indicate the level of cleanliness in controlled areas.
Total volatile organic compounds	200 µg/m³	LEED® 2013 (*7*)	Direct reading – photoionization detector (PID)	Varies	Measurements in toluene units.
Formaldehyde	16.3 ppb	LEED® 2013 (*7*)	Direct reading	30 minutes	Formaldehyde can also be measured using laboratory analysis.
Nitrogen dioxide	10 µg/m³	WHO, 2021 (*9*)	Direct reading	24 hours	Nitrogen dioxide can also be measured using laboratory analysis.
Radon	1 Bq/m³	WHO-Europe, 2000 (*15*)	Direct reading	≥ 48 hours	The measuring equipment can sometimes require more than 24 hours to stabilize.
Ozone	100 µg/m³	WHO, 2005 (*9*)	Direct reading	8-hour average	
Lead in air	0.5 µg/m³	WHO-Europe, 2000 (*15*)	NIOSH 7300 — ICP[b]	See method	Other laboratory standard methods are acceptable.
Asbestos fibers in air	500 ff/m³ (5x10-4 ff/cc)	WHO-Europe, 2000 (*15*)	NIOSH 7400 PCM[c]	See method	Other equivalent methods using optical microscopy and phase contrast are acceptable.
Other fibers in air	0.1 ff/cc	Recommendation	NIOSH 7400 PCM	See method	1/10 of the maximum limit.

[a] Will depend on the function of the space.
[b] Inductively coupled plasma-atomic emission spectrometry.
[c] Phase contrast microscopy.

Table 9. Recommended measuring techniques for selected IAQ contaminants *(continued)*

PARAMETER/CONTAMINANT	GUIDANCE LIMIT	REFERENCE	RECOMMENDED MEASUREMENT TECHNIQUE	SUGGESTED MEASUREMENT TIME	COMMENTS
Fungal structures (air) very clean areas	Absent	UNE 171330-2 (*21*)	NIOSH 0800	3—5 minutes	Other equivalent laboratory methods are acceptable.
Fungal structures (air) moderately clean areas	< 10 cfu/m³ [d]				
Fungal structures (air) other areas	< 25 cfu/m³				
Bacteria[e] **very clean areas**	< 10 cfu/m³	UNE 171330-2 (*21*)	NIOSH 0800	3—5 minutes	Other equivalent laboratory methods are acceptable.
Bacteria moderately clean areas	10—100 cfu/m³				
Bacteria other areas	100—200 cfu/m³				
Nitrous oxide	25 ppm	NIOSH (*22*)	NIOSH 6600	TWA[f] over the time exposed	For exposure to waste anesthetic gas.
Halothane **Enflurane** **Methoxyflurane**	C 2 ppm	NIOSH (*22*)	OSHA 103	60 minutes	For exposure to waste anesthetic gas.
Glutaraldehyde	C 0.2 ppm	NIOSH (*22*)	NIOSH 2531	TWA over the time exposed	Glutaraldehyde is a strong sensitizer; replacement for another disinfectant should be considered.
Ethylene oxide	< 0.1 ppm C 5 ppm	NIOSH (*22*)	NIOSH 1614	TWA over the time exposed	Potential occupational carcinogen.

[d] Nonpathogenic: *Aspergillus, Rhizopus, Mucor, Scedosporium.*
[e] Mesophilic aerobic bacteria.
[f] TWA: time weighted average.

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Maintenance to ensure a healthy environment in health care facilities

Health care facilities contain equipment that can have important repercussions on IAQ, especially the HVAC system. Although the origin of IAQ problems is not necessarily always related to the HVAC system, it is one of the main sources of problems in health care facilities (*28*). For this reason, the maintenance of the HVAC systems is of importance, and should be carefully planned and monitored. A detailed maintenance plan should be in place to ensure the ventilation and filtration systems are working according to specifications. Maintenance records should be maintained and analyzed. This is a team effort between hospital engineers, and indoor environmental professionals. Table 10 shows the minimum recommended parameters that should be included in a maintenance plan to control IAQ.

Figures 10-14 illustrate the hospital staff taking measurements to assess the HVAC system. It is recommended that these assessments be done every six months.

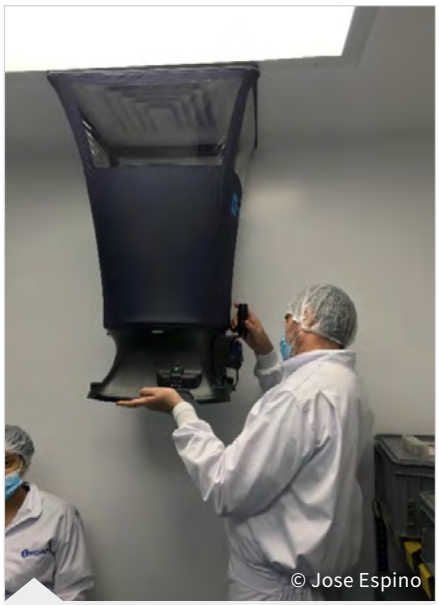

Figure 10. Measurements of airflow hood meter

Figure 11. Particle counts in an operating room

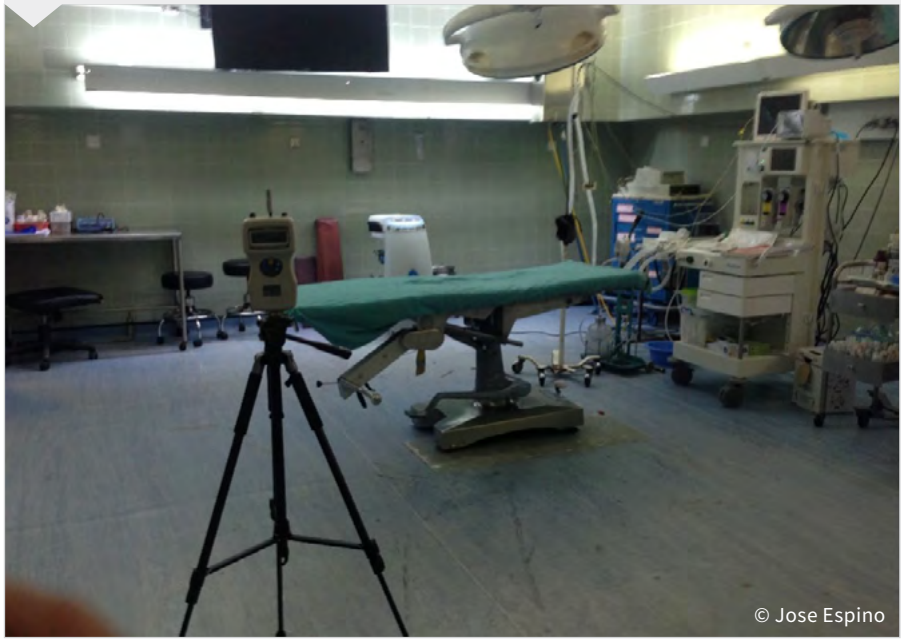

Figure 12. Filter integrity assessments for HEPA filters

Figure 13. Assessment of cleanliness level with a particle counter in a clinical laboratory

Figure 14. Particle counts assessment in a dialysis area

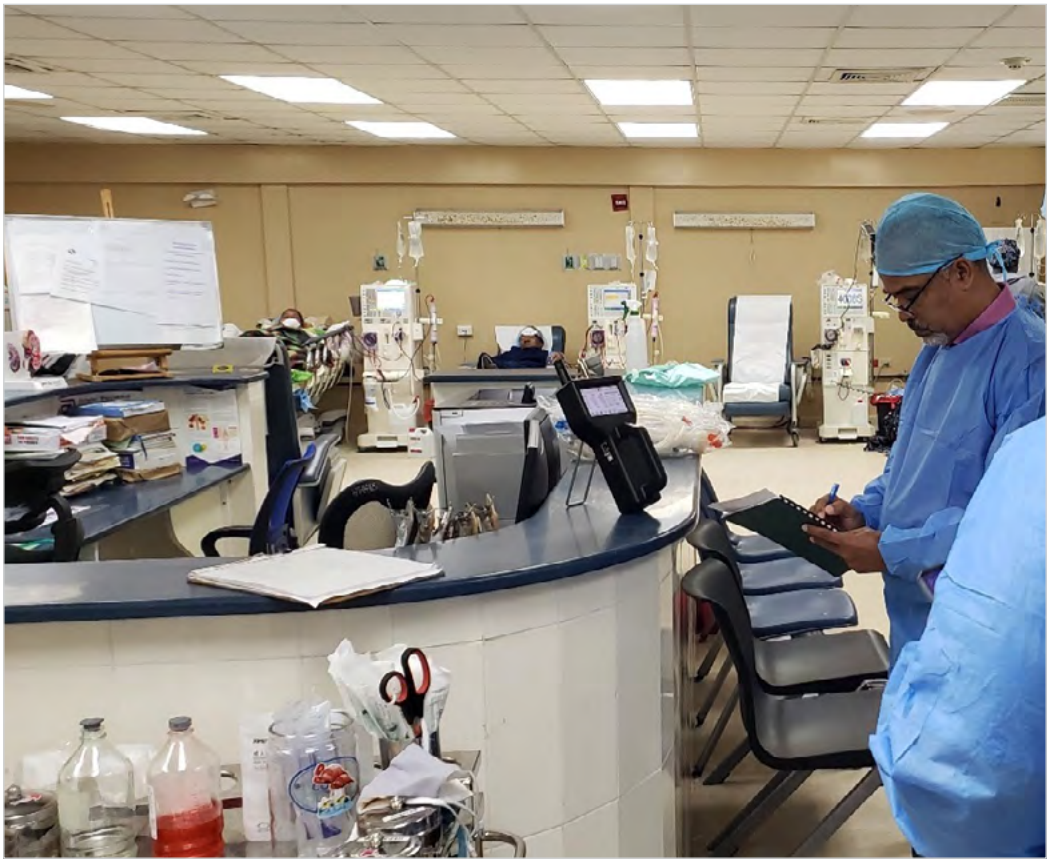

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Table 10. Recommended maintenance plan for health care facilities

PARAMETER	MEASURING RANGE	INSTRUMENT	CALIBRATION INTERVAL	RECOMMENDED MEASUREMENT INTERVAL	COMPLIANCE CRITERIA
Differential pressure	0—50 Pa	Differential pressure monitor (1% max. error)	1 year or per manufacturer's recommendation	Maximum 6 months; after each HVAC maintenance; after any alteration	Minimum 2.5 Pa pressure differential between areas (see Table 8)
Particle counts	0 to more than 35,200,000 particles of 0.5 µm	Particle counter that complies with ISO 21501-4 or equivalent	1 year or per manufacturer's recommendation	Maximum 6 months; after each HVAC maintenance; after any alteration	See Table 7
HEPA filter integrity	0—100%	Aerosol generator and particle counter	1 year or per manufacturer's recommendation	Maximum 12 months; after each HEPA filter replacement; after any alteration	No more than 0.03% the number of particles of 0.3 µm generated before the filter
Air flow	50—4,000 m^3/h or better	Air flow hood meter	1 year or per manufacturer's recommendation	Maximum 12 months; after any alteration	See Table 2
	0.01—50 m/s or better	Anemometer (hot-wire or rotating vane)			
Directional air flow	NA	Smoke tubes	NA	Maximum 12 months; after any alteration	Unidirectional ceiling to floor or wall to wall

Management strategies for a successful IAQ in a health care facility

The success of IAQ control in a hospital strongly relies on the joint efforts of the engineers, industrial hygienists, and health care, administrative, and support staff. The following strategies will aid in maintaining a proper IAQ in the health care facility:

1

Always follow internationally accepted guidelines such as WHO, PAHO, ASHRAE, AIA, or CDC for the design and maintenance of the facilities.

2

Regularly check and correct the HVAC system performance to ensure it is working according to design.

3

Do regular inspection and testing for contaminants such as gases, particles, and microbiological infectious organisms, and take immediate action to rectify the problems if necessary. Develop and implement a sampling plan.

4

Continuously monitor indoor conditions, pressure devices, regular filter, coil and drain cleaning, regular water testing, and regular component replacement.

5

Depending on the size of the health care facility, consider having an environmental specialist (such as an industrial hygienist) on staff, to support the IAQ program.

6

Provide local hooding with exhaust for areas where contaminants are generated, such as laundry, laboratories, sterilization areas, bathrooms, and kitchens. Apply techniques of elimination of contaminants at the source; this is the most effective strategy.

7

The hospital infection control team should be involved in all stages, from predesign to the opening of the hospital areas. Operating rooms and other critical areas should be commissioned before operations.

8

Continuously monitor indoor lights in various areas of the hospital. These should ideally be of a type that offer minimal interruption to the airflow pattern.

9

Humidifier and cooling coils in HVAC units should be disinfected at least every six months.

10

The infection control committee should review the sampling data routinely to identify/detect problems with regard to inherent potentials for IAQ problems.

11

Create awareness among the staff and the public of the importance of IAQ, and encourage participation in IAQ preventive efforts.

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Guidance on best practices for renovation, remodeling, and construction for building contractors

Current construction practices can impact on patient well-being by disseminating bacteria and filamentous fungi that can cause HAIs. To prevent HAIs during construction and renovation activities in health care facilities, a formal approach to risk management should be considered.

The risk assessment is an important step in identifying potential hazards and the type of containment measures necessary for a safe environment. The assessment is the responsibility of a multidisciplinary team that usually involves the hospital representative, contractor representative, architect/designer, infection control practitioner, hospital engineer, project manager representative, occupational health and safety specialist, hospital industrial hygienist, other specialized personnel concerned with or impacted upon by the project (if needed), and a consultant.

An infection control risk assessment (ICRA) is a determination of the potential risk of transmission of infectious agents in the health care facility. This process is an essential

component of a facility functional or master program, to provide a safe environment of care (*24*). The ICRA plan should be developed by a multidisciplinary team with expertise in infection control, risk management, facility design, construction, ventilation, safety, and epidemiology. The ICRA shall only address building areas anticipated to be affected by the construction.

The purpose of the ICRA plan is to minimize HAIs in patients that may arise as a result of exposure to organisms released into the environment during construction and renovation activities; also, to ensure that all personnel involved in the project recognize the importance of infection control as a major priority in the design, construction, and commissioning of the project. The plan outlines the procedures for identifying infection control risks, and the measures required to address and control the risks associated with the construction works.

The level of risk associated with each project is dependent upon the complexity of the project, location of the works, the type of work being undertaken, and the proximity to patients with varying degrees of risk of infection. The ICRA plan should be implemented by the contractor in conjunction with any infection control guidelines or specific project conditions that the hospital deems applicable to the project. The project team must regularly review and revise the plan to identify new risks and infection control measures required in the execution of the construction works. Early planning and implementation of controls will minimize the risk of infection, but may not completely eliminate the risk of infection for groups of vulnerable patients.

Risk identification and control measures

Initially, during the planning stage, a general risk assessment is prepared following a standard methodology. A sample ICRA Matrix of Precautions for Construction and Renovation can found on the Joint Commission website (*32*). The matrices are included in the Appendix. The steps for developing the ICRA plan are as follows:

1. **Identification:** The technical team identifies conditions and activities that may pose a health risk due to infections in the renovation/construction process. This is done in the planning stage, and will depend on where the project is taking place.

2. **Assessment:** An ICRA is developed by qualified personnel and approved by the client for each construction and renovation phase. The ICRA developers should consider the limitations in the area where the project is taking place. These limitations include, for example, access to specialized equipment and staff, laboratory services, shortage of personal protection equipment, and cultural issues.

3. **Training:** The contractor provides training to its staff to ensure that the purpose of the ICRA plan is understood. Training must be completed before the construction staff enter the construction area, and should be provided in the local language.

4. **Permit:** After receiving the ICRA training, the project manager issues a permit that must be displayed at the work site at all times. The permit states the project scope and required precautions.

5. **Verification:** The commissioning agent (CxA) checks progress and compliance with the ICRA plan. If the project scope or conditions change, the ICRA plan should be updated, and a new permit with adjusted recommendations issued.

Implementation

1. Before construction

a. The hospital infection control team identifies areas of concern, and develops a coordinated plan to manage these risks. It also provides input for infection prevention and control in the planning, pre-construction, construction, and post-construction phases.

b. The responsibilities of the contractor and subcontractors are outlined in the terms of reference, taking into consideration the limitations in the area.

c. Training should be provided to all contractors. The controlling contractor is responsible for training the subcontractors and construction staff. Workers should not be allowed to enter the construction area without receiving the infection control training. Participation in the infection control training should be documented.

d. The project manager and the CxA are responsible for ensuring compliance with the ICRA.

e. Essential services that could be disrupted should be identified and communicated to appropriate individuals.

f. Patient and medical staff exposure to construction dust that might contain fungal spores should be minimized.

g. Exposure of the patients in the wards should be minimized by using the appropriate controls outlined in the ICRA plan. The plan should address any modifications to the HVAC system.

h. Construction traffic routes, including designated entrance, elevator, routes for transportation of clean supplies/equipment, and routes for removal of debris, should be established for each contractor, in each renovation phase.

2. During construction

a. Barriers should be constructed to prevent dust from entering adjacent areas, especially in naturally ventilated areas of the facility.

b. If patients and/or staff are working in adjacent areas, negative pressure (~5 Pa) of the encapsulation of the work area, in relationship with the adjacent area, is mandatory.

c. The negative pressure areas and ventilators should be checked daily.

d. Mechanisms for dealing with breaches of the ICRA plan should be established and communicated to the contractor.

e. The project manager, in consultation with the CxA, has the authority to resolve any issues related to breaches of the ICRA plan with the contractor, and to identify solutions.

f. Infection control issues that cannot be resolved by the project manager or CxA may result in a stop work order until these can be settled.

g. The contractor should ensure that hospital equipment and supplies are protected from dust and water exposure.

h. Water leaks or discolored water must be reported immediately to the project manager.

i. Waste and potable water treatment systems should not be affected by the construction activities. Alternate systems should be in place if these systems are part of the construction or renovation works.

j. If patients are moved to other parts of the hospital during renovation, increased surveillance for HAIs due to *Aspergillus* spp., *Histoplasma Capsulatum,* or *Legionella DB* should be maintained.

k. The contractor should maintain the immediate areas adjacent to the construction clean, to minimize dust and debris that may be generated.

l. Work areas should be cleaned daily with HEPA filter equipped vacuum cleaners.

m. Access to waste storage should not be interrupted. Construction waste and debris should not be mixed with the health care facility wastes.

3. After construction

The project manager and CxA should:

a. Review preventive measures that were initiated.

b. Assess the effectiveness of preventive measures.

c. Document and communicate any improvements for future reference.

d. Check the cleanliness of the areas as stated in the terms of reference.

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Appendix

Appendix
ICRA Matrices

Step 1

Use the table to identify the construction activity type	
Type A	**Inspection and noninvasive activities** Includes, but is not limited to, the following: removal of ceiling tiles for visual inspection only; painting (no sanding); wall covering, electrical trim work, minor plumbing; and activities that do not generate dust or require cutting of walls or accessing ceilings other than for visual inspection.
Type B	**Small-scale, short-duration activities that create minimal dust** Includes, but is not limited to, the following: Installation of telephone and computer cabling; access to close spaces; cutting of walls or ceilings where dust migration can be controlled.
Type C	**Work generating moderate to high level of dust, requiring demolition, and removal of any fixed building components or assemblies** Includes, but is not limited to, the following: sanding of walls for painting or wall covering; removal of floor coverings, ceiling tiles and casework; new wall construction; minor duct work or electrical work above ceilings; major cabling activities; any activity that cannot be completed within a single work shift.
Type D	**Major demolition and construction projects** Includes, but is not limited to, the following: activities that require consecutive work shifts; activities that require heavy demolition or removal of a complete cabling system; new construction.

Step 2

Use the table to identify the patient risk groups affected by the activity.
If two groups are affected, select the highest risk group.

LOW RISK	MEDIUM RISK	HIGH RISK	HIGHEST RISK
• Public areas • Workshops • Plantrooms • Office areas	• Cardiology • Echocardiography • Endoscopy • Nuclear medicine • Physical therapy • Radiology/MRI • Respiratory therapy	• Critical care unit • Emergency room • Labor and delivery • Laboratories (specimen) • Medical units • New-born nursery • Outpatient surgery • Pediatrics • Pharmacy • Postanesthesia care unit • Surgical units	• Any area caring for immunocompromised patients • Burn unit • Cardiac catheterization laboratory • Central sterile supply • Intensive care unit • Negative pressure isolation rooms • Oncology • Operating rooms, including C-section rooms

Step 3

Match the construction activity type with the patient risk group number on the construction class matrix to establish the construction class.

Patient risk group	Type A	Type B	Type C	Type D
Low	I	II	II	III/IV
Medium	I	II	III	IV
High	I	III	III / IV	IV
Highest	III	III / IV	III / IV	IV

Notes:

Patient risk group (Low, Medium, High, Highest).
Construction project type (A, B, C, D).
Class of precautions (I, II, III or IV) or level of infection control activities required.
Class I–IV precautions are delineated on the following page.

Infection prevention and control approval will be required when the construction project type and patient risk group indicate that **Class III** or **Class IV** control procedures are necessary.

During construction project

CLASS I

- Execute work using methods to minimize raising dust from construction operations (e.g., wet methods, HEPA vacuuming).
- Immediately replace parts removed for visual inspection.

CLASS II

- Provide active means to prevent airborne dust from dispersing into the air.
- Water mist work or vacuum surfaces to control dust while cutting.
- Seal unused doors with duct tape.
- Block off and seal air vents.
- Place dust mat at entrance and exit of work area.
- Remove or isolate the heating, ventilation, and air conditioning (HVAC) system in areas where work is being performed.

CLASS III

- Remove or isolate HVAC system in areas where work is being done to prevent contamination of duct system.
- Complete all critical barriers (e.g., sheetrock, plywood, plastic) to seal work area from nonwork area or implement control cube method (cart with plastic covering and sealed connection to work site with HEPA vacuum for vacuuming prior to exit) before construction begins.
- Maintain negative air pressure within work site, utilizing HEPA-equipped air filtration units.
- Contain construction waste before transport in tightly covered containers.
- Cover transport receptacles or carts. Tape covering unless lid is solid.

CLASS IV

- Isolate HVAC system in area where work is being done to prevent contamination of duct system.
- Complete all critical barriers (e.g., sheetrock, plywood, plastic) to seal work area from nonwork area or implement control cube method before construction begins.
- Maintain negative air pressure within work site, utilizing HEPA-equipped air filtration units. Seal holes, pipes, conduits, and punctures appropriately.
- Construct anteroom and require all personnel to pass through this room so they can be vacuumed using a HEPA vacuum cleaner before leaving work site, or they can wear cloth or paper coveralls that are removed each time they leave the work site.
- All personnel entering work site are required to wear shoe covers. Shoe covers must be changed each time a worker exits the work area.

Upon completion of project

CLASS I	• Clean work area upon completion of the task. • Area shall be cleaned to an ISO class 9.
CLASS II	• Wipe work surfaces with disinfectant. • Contain construction waste before transport in tightly covered containers. • Wet mop and/or vacuum with HEPA-filtered vacuum before leaving work area. • Upon completion, restore HVAC system where work was performed. • Area shall be cleaned to an ISO class 9.
CLASS III	• Do not remove barriers from work area until completed project is inspected by the project manage / commissioning agent (CxA) and complies with the required cleanliness level. • Remove barrier materials carefully to minimize spreading of dirt and debris associated with construction. • Vacuum work area with HEPA-filtered vacuums. • Wet mop area with disinfectant. • Upon completion, restore HVAC system where work was performed. • Area should be cleaned to the proper ISO class as determined by the CxA.
CLASS IV	• Do not remove barriers from work area until completed project is inspected by the project manager and CxA, and complies with the required cleanliness level. • Remove barrier material carefully to minimize spreading of dirt and debris. • Contain construction waste before transport in tightly covered containers. • Cover transport receptacles or carts. Tape covering unless lid is solid. • Vacuum work area with HEPA-filtered vacuums. • Wet mop area with disinfectant. • Upon completion, restore HVAC system where work was performed. • Area should be cleaned to the proper ISO class as determined by the CxA.

GUIDANCE ON
INDOOR ENVIRONMENTAL QUALITY IN HEALTH CARE FACILITIES

This publication presents guidance to support the Member States of the Pan American Health Organization (PAHO) in making sure that health care facilities provide adequate care for ensuring healthy people and a healthy environment. It builds on the World Health Organization's guidance for climate resilient and environmentally sustainable health care facilities, focusing specifically on indoor environmental quality. It provides illustrations from the Region of the Americas and specific steps for ensuring adequate and appropriate heating, ventilation, and air conditioning systems, and that temperature and humidity and indoor air quality variables are within approved ranges. Best practices for renovation, remodeling, and construction of health care facilities are also included.

The publication is part of an effort coordinated by PAHO to support Member States in fostering an environmentally responsible and resilient health system. It engages different building blocks of health systems to ensure healthy people and healthy environments in health care facilities. It aims to bring awareness of the impacts of indoor environmental quality on the health of patients, the health workforce, as well as maintenance and construction workers in the Americas.

PAHO
Pan American Health Organization
World Health Organization
REGIONAL OFFICE FOR THE Americas