Nurses' Guide to Improving Indoor Air Quality in Health Care

Health care employers have a legal and moral obligation to provide nurses and other health care workers with a safe work environment, including clean indoor air. Ventilation is an essential part of a multi-layered approach to infection control to combat the spread of aerosol-transmitted pathogens, in combination with personal protective equipment (PPE), screening, testing, isolation, staffing, and other measures. This detailed guide provides information about the importance of ventilation, what employers should do to reduce aerosol-transmitted pathogens, and how nurses can identify whether their employers are compliant or not.

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SECTION 1 » VENTILATION AS PART OF A MULTILAYERED APPROACH TO INFECTION CONTROL IN HEALTH CARE

SWISS CHEESE MODEL OF RISK REDUCTION IN HEALTH CARE

In hospitals and other health care settings, the Swiss cheese model of risk reduction is necessary for the prevention and protection of health care workers and patients from aerosol-transmitted pathogens (*see Image 1*). Akin to a stack of Swiss cheese slices, a single slice on its own contains holes through which hazards may pass but when multiple measures are combined the certainty of preventing the hazard increases. This section outlines the multilayered measures that health care employers should implement in order to proactively anticipate and prevent occupational exposures to aerosol-transmitted infectious diseases, including isolation and source control, ventilation, respiratory protection and other PPE.

Irrespective of vaccination rates or a pathogen's pandemic or endemic classification, workplace protections in health care settings remain vital to protect patient and health care worker health and safety. Safe staffing in health care settings is a fundamental measure that should be implemented as part of a multilayered approach to enable optimal, timely patient care for every patient, adequate breaks for staff, time to don and doff PPE, and appropriate cohorting of infected and non-infected patients. Patient assignments with both infected and non-infected patients increase the potential for transmission of aerosol-transmitted infectious diseases between patients and staff.

Ventilation is an essential part of a multilayered approach to infection control to combat the spread of aerosol-transmitted pathogens, such as SARS-CoV-2/Covid-19, influenza, respiratory syncytial virus (RSV), norovirus, and meningococcal disease, in health care settings.[1,2,3] Research shows that infected individuals emit infectious respiratory aerosol particles in a continuous range of sizes when they breathe, cough, laugh, sneeze, vocalize, or have aerosol-generating procedures performed.[4] These aerosol particles can travel and remain suspended in the air for long periods, depending on environmental factors.[5,6] Without adequate ventilation, suspended infectious aerosols can accumulate in the air in indoor spaces, becoming increasingly concentrated and increasing risk of transmission.

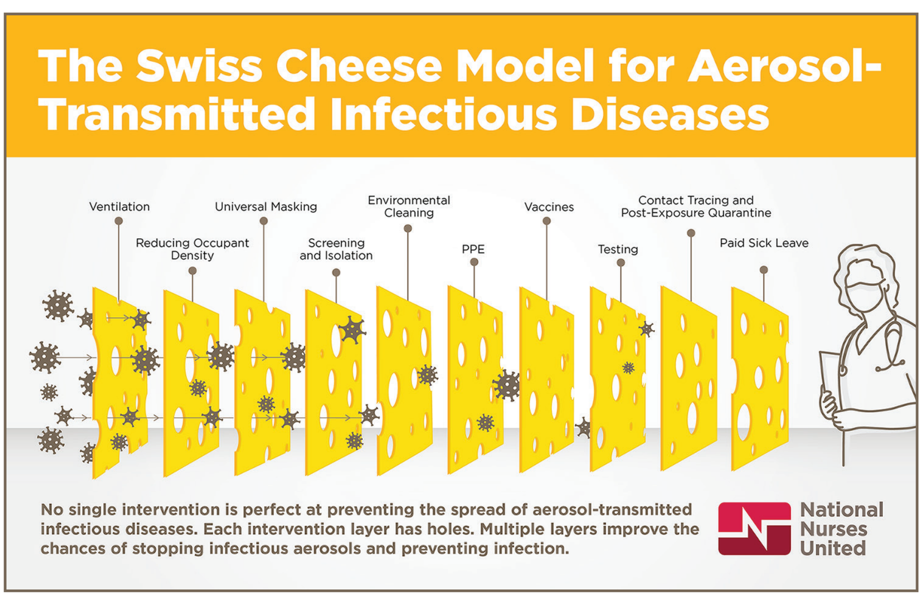


Image 1.

Good ventilation — combined with other mitigation measures — is important for reducing concentration of infectious aerosols in health care settings. The lower the concentration, the less likely aerosol-transmitted pathogens can be inhaled and transmitted to others in hospitals and other health care settings. However, ventilation by itself is insufficient to reduce the risk of transmission, especially when individuals are in close proximity to each other such as during provision of patient care.

Important elements of the Swiss cheese model of risk reduction in health care settings include »

1. Identification and isolation of infectious and potentially infectious patients, combined with source control, is essential to preventing infectious aerosols from being released into and spreading through the air in health care facilities.

    » **Screening** — Health care employers should establish procedures for screening patients and visitors to effectively identify cases of aerosol-transmitted infectious diseases.

    » **Isolation** — Patients with suspected or confirmed aerosol-transmitted diseases must be isolated promptly in airborne infection isolation rooms (AIIRs). AIIRs are rooms with specially designed ventilation systems that reduce the possibility that infectious viral particles will be transported to other areas of the facility. When there are more patients requiring isolation than AIIRs available, health care facilities should convert ventilation systems in additional rooms, units, and on floors to increase availability of space for airborne infection isolation. See section 2 for additional information on AIIRs.

    » **Source control** — Source control, including universal masking, is essential because spread from asymptomatic or presymptomatic individuals is a hallmark of SARS-CoV-2 and other common infectious diseases transmitted through the air, including RSV and influenza.[7,8,9] Infections can also occur with fleeting exposures. For example, one study found that exhaled aerosols from a single person can transmit SARS-CoV-2 to others within 6 to 37 minutes in a room at normal indoor conditions.[10] Other studies have shown that Covid-19 infections occurred with less than 15 minutes of exposure, both at short and long-range distances.[11,12,13] Universal masking, preferably with N95 respirators, is critical to limiting the spread of infectious aerosols emitted by the wearer. A study from the National Institute of Occupational Health and Safety (NIOSH) tested aerosol exposures between a source and receptor with and without masks.[14] They found that only when both the source and receptor wore tight-fitting facemasks (universal masking) were aerosol exposure levels significantly reduced (by about 80 percent compared to situations where either the source or the receptor or both were not wearing a mask).[15]

2. Adequate ventilation in both patient care and non-patient care areas is vital to reducing the risk of transmission of infectious diseases and improving air quality.

    » Multiple pathogens transmitted by infectious aerosols are capable of eliciting infection without symptoms. Aerosol particle concentrations are likely to be highest nearest the source but will, over time, increase throughout a shared space if ventilation is not adequate, putting anyone in that space at risk of inhaling an infectious dose, even after the source has left the space. Adequate ventilation is necessary to reduce the risk of exposure to aerosol-transmitted infectious diseases in all health care settings, including inpatient areas, outpatient areas, and other locations.

- Non-patient care areas, such as corridors and employee breakrooms also can present risk for nosocomial infection, even though staff are not directly providing care to infected patients. For example, one study found levels of SARS-CoV-2 in the corridor adjacent to Covid patients' rooms that produced significantly higher exposure than inside Covid patients' rooms.[16] This difference was related to better ventilation systems in patient rooms than corridors. Special attention must be paid to ventilation in nurses' stations, break rooms, cafeterias, corridors, and other locations to reduce the risk of transmission of aerosol-transmitted infections.

- Specifically, ventilation in bathrooms/restrooms is an important consideration, especially for facilities used by multiple individuals. One study found nosocomial Covid transmission between two individuals who used the same, poorly ventilated restroom in a hematologic ward, forty minutes apart.[17] Aerosol-transmitted pathogens, including both respiratory and non-respiratory viruses, can also be aerosolized during production of vomit and diarrhea. One study found a strong association between vomiting and the presence of airborne norovirus in inhalable particle size fractions at levels high enough to cause infection.[18] Toilet flushes aerosolize waste particles, which can include infectious diseases emitted in human waste. The emission of particles into a room resulting from a single 6-liter toilet flush can be equivalent to a person talking loudly for over six and a half minutes.[19] Viruses like SARS-CoV-2 can be shed for weeks to months in feces after respiratory and other symptoms have resolved.[20,21]

3. Respiratory protection and other PPE are necessary parts of a multiple measures approach to protecting health care workers from aerosol-transmitted pathogens.

    - When an employer cannot control hazards through other means and respiratory protection is required, the employer must establish a respiratory protection program in accordance with OSHA's Respiratory Protection Standard.[22]

    - Respiratory protection and other PPE are necessary parts of a multiple measures approach to protecting nurses and other health care workers from aerosol-transmitted diseases — without regard to a pathogen's pandemic or endemic classification. Respirators are designed and engineered to provide filtration efficiency from 95 to 99 percent of airborne particles, depending on filter classification, while allowing air flow.[23] Optimal PPE for aerosol-transmitted pathogens includes a powered air-purifying respirator (PAPR), coveralls that are impervious to viral penetration, head and shoe coverings, and gloves. Under no circumstances should nurses and other health care workers be provided less than a minimum of N95 filtering face piece respiratory protection when caring for patients with suspected or confirmed aerosol-transmitted diseases.

HIERARCHY OF CONTROLS

Workplace protections should be guided by the hierarchy of controls, a framework used in occupational health and safety that prioritizes the most effective control measures for limiting exposures to hazardous agents. Image 2 illustrates the hierarchical order for which control measures should be implemented, starting with measures that eliminate the hazard at its source, followed by engineering controls, including ventilation. At the bottom of the hierarchy is PPE, utilized only when other control measures are insufficient to fully protect workers from exposure.

The hierarchy of controls prioritizes ventilation and filtration — engineering controls that are "built in" to the workplace — over control measures that change work practices and procedures because they can provide a more permanent and reliable means to preventing or reducing exposure to the hazard. While the hierarchy of controls prescribes the order of significance in which to treat a workplace hazard, using a combination of multiple measures is the most effective means to provide the best level of protection. In other words, control measures are best implemented simultaneously rather than in sequential order or individually, as individual measures are effective in different ways but insufficient on their own to prevent the hazard from occurring. Akin to a stack of Swiss cheese slices, a single slice on its own contains holes through which hazards may pass but when multiple measures are combined the certainty of preventing the hazard increases.

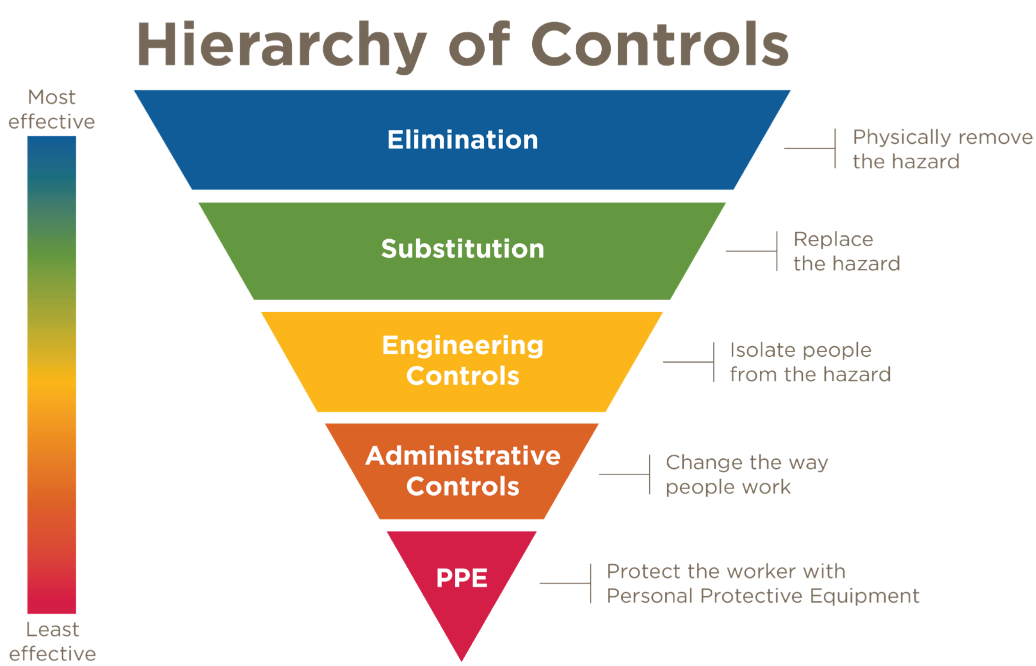


Image 2. **NIOSH**

SECTION 2 » BASIC PRINCIPLES FOR VENTILATION OF INDOOR SPACES

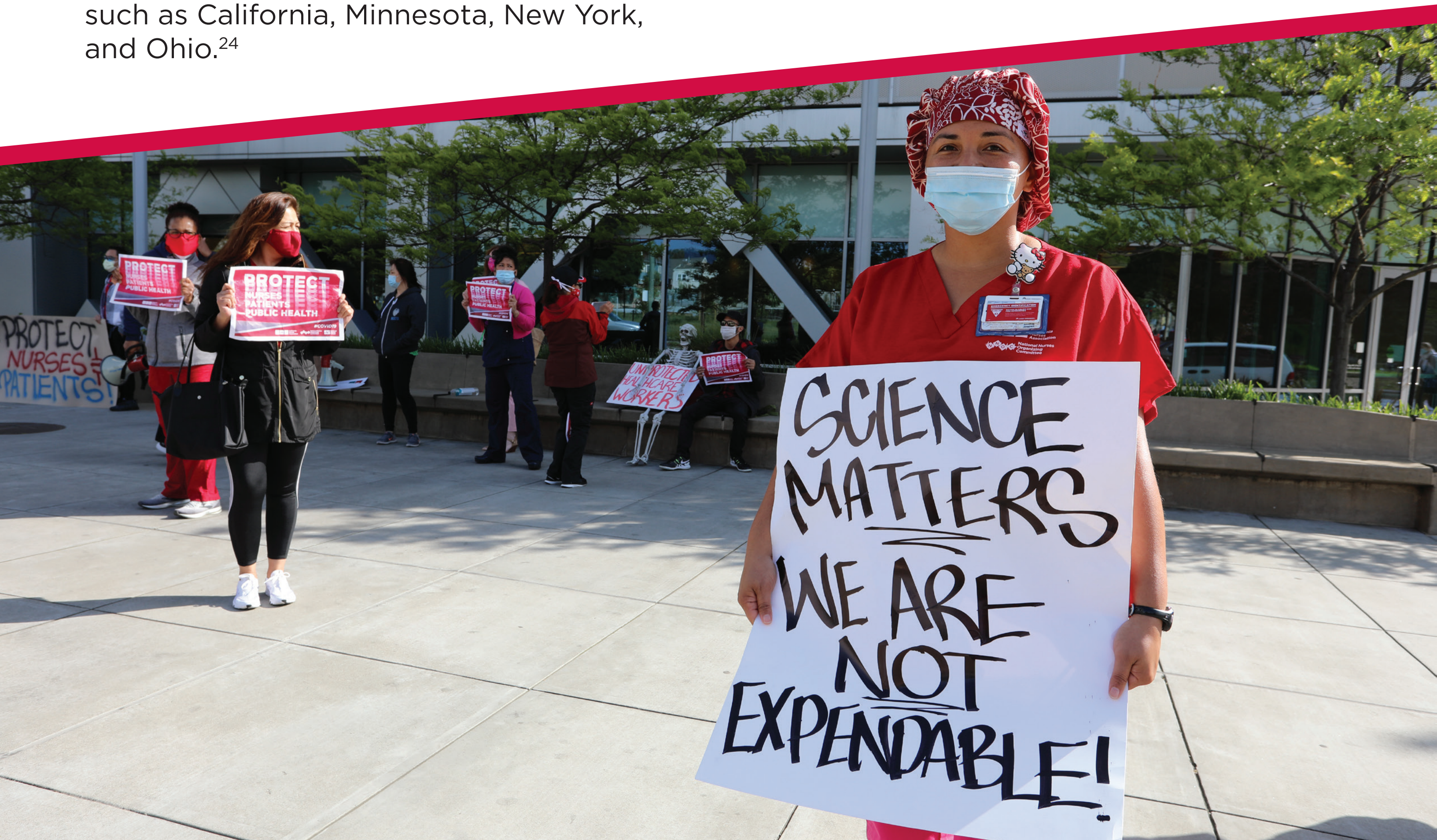
Ventilation is the process of replacing indoor air that may contain pathogens and other contaminants with clean air into a building, through natural or mechanical means, thus diluting the concentration of infectious aerosol particles. Clean air can be comprised of fresh outdoor air, by filtration of indoor air, or by a combination of both outdoor and filtered air.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) establishes minimum engineering design criteria for indoor air quality and ventilation systems in health care settings, including recommended ventilation rates, filter performance, air distribution strategies, and more. ASHRAE consensus standards and other guidance do not have regulatory authority unless incorporated into state and local building codes. Some states have incorporated ASHRAE consensus standards into their requirements for health care facilities, such as California, Minnesota, New York, and Ohio.[24]

TYPES OF VENTILATION

There are two primary means to provide ventilation to indoor spaces:

- Natural ventilation brings in outdoor air via open windows, doors, and/or openings in the building envelope. However, natural ventilation is not recommended in health care settings as its effectiveness can vary based on wind speed and direction, air change rates, and other factors.
- Mechanical ventilation systems or heating, ventilation, and air conditioning (HVAC) systems dilute contaminated air in a space by delivering a continuous supply of fresh outdoor air while removing indoor air, filtering contaminated air, or through a combination of the two.[25]



FILTRATION

Filtration is an essential part of HVAC systems. Filtration of recirculated air captures aerosol particles that are or could be infectious as well as other contaminants. A filter's collection efficiency is a function of particle size. The majority of infectious aerosol particles are in the smallest inhalable particle size (< 5 µm) and travel farthest and stay aloft longest.[26] Speech produces 100 to 1,000 times the number of aerosols less than 100 µm in size for every droplet that is greater than 100 µm.[27] Thus, higher-rated filters remove a greater fraction of aerosol particles each time the air passes through them, resulting in higher levels of protection.

There are different types of filters that provide different levels of filtration. The most commonly used filter ratings for HVAC systems are Minimum Efficiency Reporting Values or MERV ratings, derived from a test method developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE).[28] MERV, which ranges from 1 to 16, describes a filter's ability to capture differently sized particles in the air.[29] For example, a MERV 13 rated filter means that the filter can capture at least 90 percent of particles between 3 and 10 microns (µm) but is only 50 percent efficient at removing particles around 0.3 µm. Table 1 summarizes removal efficiencies of MERV-rated filters for particles between 0.3 and 10 µm in diameter at a specified flow rate of air. The higher the MERV rating, the better the filter is at capturing specific types of particles. High efficiency particulate air (HEPA) filters are the highest rated filters and most effective for removing aerosolized viruses as they are designed to remove at least 99.97 percent of aerosol particles that are 0.3 µm.[30]

Table 1. **Minimum Efficiency Reporting Values or MERV Ratings** (Source: EPA)

MERV rating	Average Particle Size Efficiency in Microns		
	0.3 – 1.0 microns	1.0 – 3.0 microns	3.0 – 10.0 microns
MERV 1 – 4	–	–	<20%
MERV 5	–	–	≥20%
MERV 6	–	–	≥35%
MERV 7	–	–	≥50%
MERV 8	–	≥20%	≥70%
MERV 9	–	≥35%	≥75%
MERV 10	–	≥50%	≥80%
MERV 11	≥20%	≥65%	≥85%
MERV 12	≥35%	≥80%	≥90%
MERV 13	≥50%	≥85%	≥90%
MERV 14	≥75%	≥90%	≥95%
MERV 15	≥85%	≥90%	≥95%
MERV 16	≥95%	≥95%	≥95%
High Efficiency Particulate Air (HEPA) Filter	99.97%	99.97%	99.97%

FACTORS THAT IMPACT VENTILATION EFFECTIVENESS

How well-ventilated a space is depends on a range of factors, including room size and layout; how effective duct systems are in exhausting contaminated indoor air and bringing in fresh outdoor air into a room; directional airflow; and the number of people occupying a space. Occupant density — especially in high-traffic areas like waiting rooms, cafeterias, and break-rooms — plays an important factor in the amount of ventilation needed in a space. In other words, the greater the number of people that occupy a space, the higher the risk of exposure, the greater the need for higher ventilation airflow rates. Ventilation rate is defined as the rate at which fresh outdoor air replaces indoor air in a given space, often expressed in air changes per hour (*see section 3 for how to calculate ventilation rates*).

It is important to remember that ventilation and filtration, by themselves, are insufficient to stop transmission of aerosol-transmitted pathogens. Adequate ventilation and filtration should be combined with source control measures to prevent potential sources from being in indoor spaces and PPE for health care workers in the same airspace as patients with aerosol-transmitted diseases. See Section 1 for more information about the multilayered approach required to reduce risk of transmission of aerosol-transmitted diseases in health care settings.

SECTION 3 » AIRBORNE INFECTION ISOLATION ROOMS AND LOCAL EXHAUST VENTILATION SYSTEMS

Certain areas in hospitals and other health care settings require special ventilation and filtration systems, such as positive pressure and airborne infection isolation rooms (AIIRs). The contents herein are based on relevant literature as well as standards and guidance from ASHRAE and others. ASHRAE establishes minimum engineering design criteria for indoor air quality and ventilation systems in health care settings, including recommended ventilation rates, filter performance, air distribution strategies, and more. ASHRAE consensus standards and other guidance do not have regulatory authority unless incorporated into state and local building codes. Some states have incorporated ASHRAE consensus standards into their requirements for health care facilities, such as California, Minnesota, New York, and Ohio.[31]

AIRBORNE INFECTION ISOLATION ROOMS (AIIRS)

Isolating patients with confirmed or suspected aerosol-transmitted diseases in AIIRs reduces the possibility that infectious viral particles will be transported to other areas of the facility in the air (e.g., hallways, nurses' stations). AIIRs have ventilation systems specially designed to provide negative pressure relative to other parts of the health care facility. This means that AIIRs are protective for health care workers and patients in the facility because air is always flowing from hallways into the AIIR (*see image 3*). Contaminated air from the AIIR either gets exhausted directly outside or is sent through a HEPA filter before being recirculated. This means that escape of contaminated air into the hallway is limited, and that contaminated air does not get recirculated throughout the building. This decreases the potential for exposure of other patients, visitors, nurses, and health care workers to the aerosol-transmitted disease. AIIR doors must be closed at all times, except during entry and exit to avoid disruption of airflow and isolation.

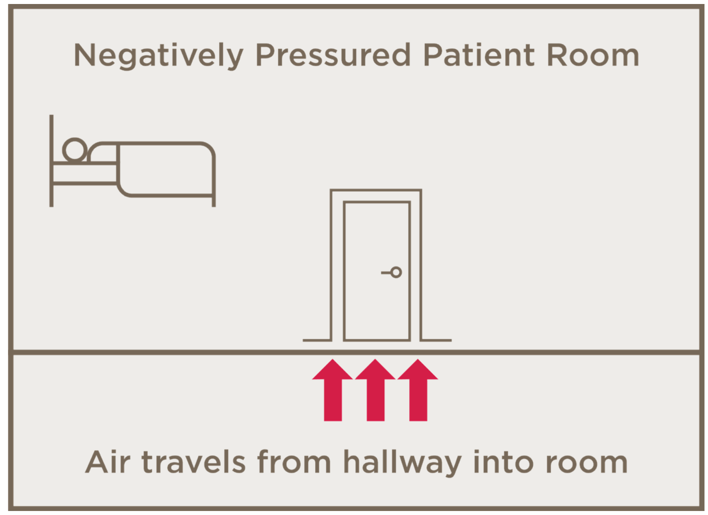


Image 3. **Directional airflow into negatively pressured rooms (Source: CDPH)**

There are multiple design requirements for AIIRs. AIIRs must maintain at least -0.01 inches of water column (or −2.5 Pa) negative-pressure differential to adjacent areas.[32] AIIRs should also continuously provide an air flow rate of at least 12 air changes of exhaust per hour (ACH) and must be exhausted directly outdoors away from intake vents, employees, and the public to constantly dilute contaminated room air.[33] The higher the rate of air changes — or the higher the amount of clean air delivered to the room — the lower the risk of disease spreading through the air within the room. If air exhausted from the AIIR is recirculated, then HEPA filtration must first be used to capture any infectious aerosol particles in the air. When an anteroom is provided, the airborne infection isolation room should be operated under constant negative pressure to the anteroom and the corridor.[34]

In situations where demand for AIIRs may exceed their availability, health care employers should convert additional rooms, units, and floors to negative pressure ventilation to facilitate isolation of patients with suspected and confirmed aerosol-transmitted diseases. Such temporary structures require careful planning and implementation as well as engagement with frontline registered nurses to avoid inadvertently compromising the ventilation or air balance in other parts of the facility. Converting additional spaces to negative pressure should be included in employers' emergency preparedness plan — both for surges in patients requiring AIIRs and for future pandemics.

One method of achieving temporary isolation is by installing a HEPA filtered negative air machine[35, 36] in a single patient care room with a dedicated bathroom to exhaust room air outside through the window (*see image 4*). A HEPA filtered negative air machine (also known as an air scrubber) provides HEPA filtration while inducing negative pressure in the room. The room exhaust/return air grille should be sealed with tape to prevent pulling air from the return air system. The room must be closed at all times except during entry and exit to avoid disruption of airflow and isolation. The negative air machine should have a pressure differential of -0.01 inches of water column (or −2.5 Pa) and must be kept running once installed to avoid the room becoming positively pressurized.

» A patient care unit exclusively served by a single air handling unit or HVAC system can also be temporarily converted into negative pressure (*see Image 5*).[37] The HVAC system can be modified to provide 100 percent exhaust to the outside, creating negative pressure for the entire unit. HEPA filters also should be installed in the system prior to service and all doors must be kept closed except for entry and exit. This method allows facilities to establish a dedicated unit to care for patients infected with the same aerosol-transmitted disease. This ensures there are no mixed assignments to reduce transmission both through the air and through health care workers moving around the unit and caring for multiple patients.

Similar to permanent AIIRs, health care employers should ensure continuous monitoring in spaces converted to negative pressure ventilation to verify that clean air is drawn into the room or unit and that contaminated air does not escape into the hallway or other areas. This should be conducted on a daily basis or more often if conditions change that may alter airflow and room pressure (*see Section 3 for how to verify negative pressure*). Nurses and other health care workers caring for patients in temporary isolation should be provided with optimal PPE, including respiratory protection at least as protective as an N95 respirator.

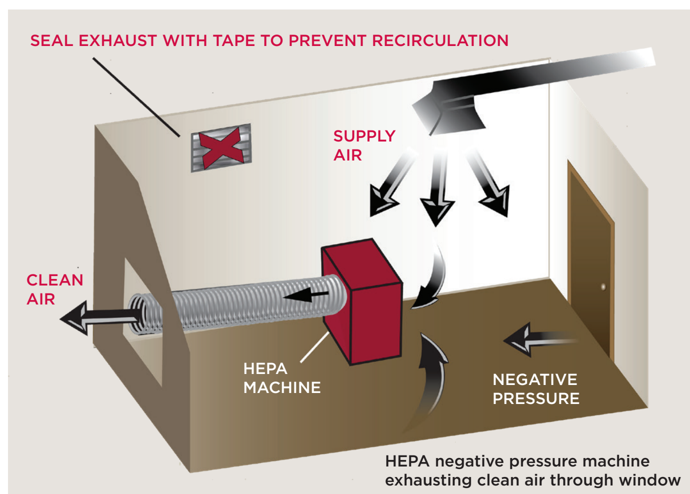


Image 4. **Single patient room temporary isolation (Source: Minnesota Department of Health)**

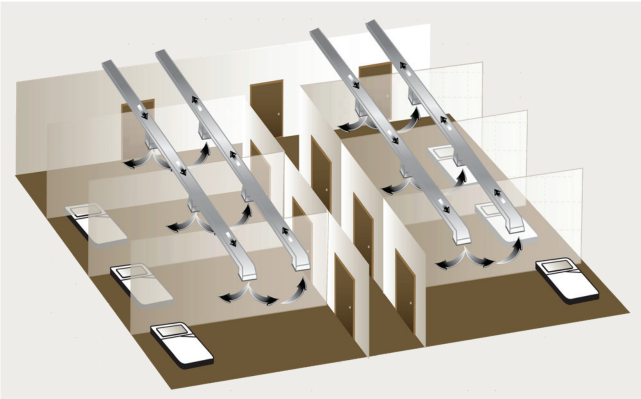


Image 5. **Unit-wide temporary isolation. (Source: Minnesota Department of Health)**

SPECIAL CONSIDERATIONS FOR OPERATING ROOMS

Operating room ventilation systems play an important role in preventing surgical site infections (SSI) from aerosol-transmitted contaminants and maintaining a sterile environment around the surgical site. According to the CDC, SSIs account for 20 percent of all health care-associated infections and are associated with a 2- to 11-fold increase in the risk of mortality.[38] Of SSI-associated deaths, 75 percent are directly attributable to the site infection.[39] Because of this, operating rooms require positive pressure and additional air changes per hour. Positive pressure rooms maintain a higher pressure inside than that of the surrounding environment, pushing the air out and keeping aerosol-transmitted contaminants from entering. In other words, the air should flow from the operating room to the hallway. Operating rooms should have a minimum total of 20 air changes per hour supplied with a minimum of four ACH outside air.[40]

Screening and testing of all patients prior to surgical procedures is necessary to inform decisions about delaying procedures to protect patient and health care worker safety. For example, studies have found that surgical procedures while a patient is SARS-CoV-2-positive or has recently had Covid-19 can lead to increased mortality rates and negative outcomes for patients, including asymptomatic infected patients.[41,42] Nurses and other health care workers should be provided with optimal PPE, including respiratory protection at least as protective as an N95 respirator, during patient transport or situations in which patient infection status cannot be confirmed until during or after a case.

LOCAL EXHAUST VENTILATION

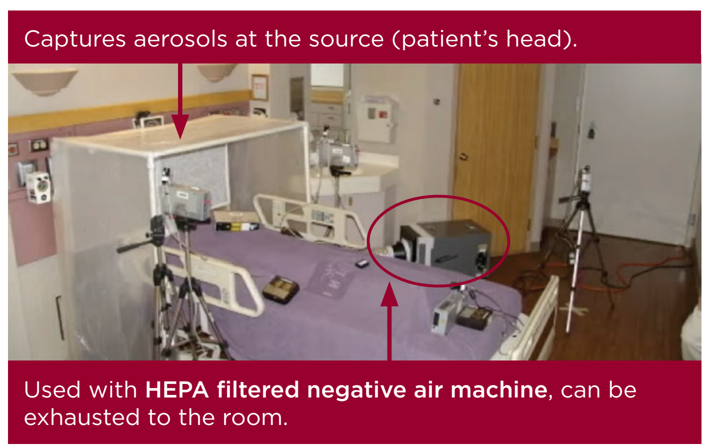
While health care employers work to convert more spaces to negative pressure in situations where there are more patients who need isolation than AIIRs are available, local exhaust ventilation near the patient's bed can be used to capture infectious aerosol pathogens. However, using portable air filtration units or ventilated headboards should only be a temporary measure until an AIIR or negative pressure room is available, especially where ongoing aerosol-transmitted pathogen exposures are likely to occur.

Portable air filtration HEPA units — Portable air filtration HEPA units that are properly sized for the room can effectively remove infectious diseases from the air and protect staff, patients, and visitors. Patients should be isolated in single exam rooms with the doors closed. One study found that portable HEPA filtration units effectively removed aerosol particles in a single bed hospital room in 20 minutes.[43] Another study found that the use of two portable HEPA filtration units in a single patient room could clear 99 percent of aerosol particles within 5.5 minutes.[44]

» There are different types of portable air filtration HEPA units, so the length of time a HEPA filter can be used depends on the type of HEPA filter, how many air changes per hour it performs (ventilation rate of the room), the size of the room, and the maintenance requirements for the model. The employer should provide information about the HEPA filter unit to nurses so that they know how to check if it is working, who to contact for maintenance, how to disinfect its surface for infection prevention, and other important aspects.

» Using a portable air filtration HEPA unit should only be a temporary measure until an AIIR is available. All patients with suspected or confirmed aerosol-transmitted disease should be placed in AIIRs or units that have been converted to negative pressure.

Ventilated headboards — Ventilated headboards, developed by NIOSH, can also provide effective source control. Used in conjunction with a HEPA filter unit (*see Images 6 and 7*), ventilated headboards provide an enclosure over the head of a supine patient that captures infectious aerosols at the source and returns clean air to the room.[45] Laboratory tests, conducted by NIOSH, showed that ventilated headboards successfully captured/removed over 99 percent of infectious aerosol particles.[46]



Images 6 and 7**. Ventilated headboards (Source: NIOSH)**

SECTION 4 » INSPECTION, MAINTENANCE, AND USE OF VENTILATION SYSTEMS

Ventilation and filtration engineering controls must be maintained, inspected, and monitored for exhaust or recirculation filter loading and leakage at least annually, whenever filters are changed, and more often, if necessary, to maintain effectiveness. Like water flowing downhill, air naturally flows from areas of high pressure towards low pressure. Airflow will always take the path of least resistance. This means that air will move through any leaks or gaps in the ventilation system that offer the least resistance, allowing infectious aerosol particles to go around the filter rather than through it. Blocked or obstructed vents can also disrupt air flow patterns and prevent fresh, outdoor air from reaching the breathing zone of building occupants, resulting in insufficient removal of aerosol-transmitted pathogens. This is why proper operation and maintenance of ventilation systems in hospitals and other health care settings are critical to preventing the spread of aerosol-transmitted diseases.

HOW DO YOU ENSURE VENTILATION SYSTEMS ARE PROPERLY MAINTAINED?

Health care employers are responsible for the work environment, including the operation, maintenance, and inspection of ventilation systems. To determine whether ventilation systems are working properly, nurses and their union can request a copy of their employers' HVAC maintenance records. Health care employers should make all records available upon request and include information about ventilation airflow rates, filtration, and pressure relationships among rooms.

Additional questions can also include »

- Who is the designated person responsible for maintaining and investigating HVAC systems and overseeing and addressing employee complaints about indoor air quality?
- What number of air changes per hour does the HVAC system supply to the lobby, employee breakrooms, and other areas?
- What proportion of outdoor air does the HVAC system supply? If less than 100 percent outdoor air, what level of filter is used for recirculated air? How often are filters changed so that airflow is sufficiently maintained?
- Is the HVAC system checked, inspected, cleaned, and maintained on a regularly scheduled basis? If problems are found during inspections, are they corrected within a reasonable time?
- Are employee or employee representative complaints about indoor air quality promptly and thoroughly investigated?
- In clinics and other outpatient settings, does the HVAC system operate continuously prior to and during working hours?
- How often are air ducts cleaned?
- Are restrooms under negative pressure? Is the exhaust fan ON at all times and is air exhausted to the outside?

HOW DO YOU ENSURE NEGATIVE PRESSURE IS FUNCTIONING IN AN AIIR OR CONVERTED SPACE?

Negative pressure or the direction of airflow in each AIIR should be monitored and recorded on a daily basis, when occupied by a patient who requires isolation. AIIRs should have a built-in room pressure monitor to provide a continuous readout of pressure differential between the patient room and the corridor, including both visual and audible alarms to alert staff when room pressurization is lost (*see Images 8 and 9*). AIIRs must maintain at least -0.01 inches of water column negative-pressure differential to adjacent areas.[47] Nurses and other health care workers should be trained in the use and functionality of room pressure monitors, including what to look for on a pressure monitor, how to read and interpret differential pressure values and what to do when pressurization is lost.

Negative pressure or proper directional airflow can also be visually demonstrated by smoke trails while an AIIR is in use (*see Images 10 and 11*). Smoke tube testing can determine the direction of airflow into and out of a patient's room. If the smoke flows under the door into the room, then the room is under negative pressure. However, if the smoke is blown outward or remains stationary, then negative pressure has not been achieved. Placing a strip of tissue paper at the bottom of the closed door can also be performed for rapid verification of negative pressure (*see Image 12*). If the room is negatively pressurized, the tissue is pulled towards the room. However, both smoke and tissue tests only indicate directional airflow at the point of testing, in contrast to built-in room pressure monitors that provide quantitative, continuous measurement.

Images 8 and 9. **Negative pressure room monitors (left: Cal/OSHA; right: SETRA)**

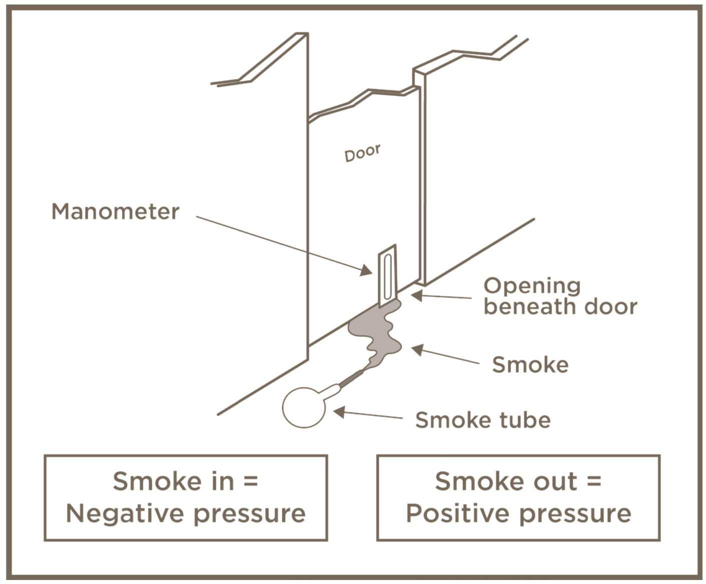


Image 10. **Smoke tube testing (Source: MMWR, 2005)**

Image 11. **Smoke tube testing (Source: Elon Ullman, OHB)**

Image 12. **Example of a health care worker using a tissue paper to verify negative pressure (Source: Southeastern TB Center)**

Nurses can request a copy of their employers' ventilation test records to determine whether each isolation room is under negative pressure, what the calculated air change rate is and whether air is exhausted directly to the outdoors. Additional questions can also include:

» Do AIIRs meet the recommended pressure differential of -0.01 inches of water column (or -2.5 Pa) negative to adjacent areas?

» How often are AIIR rooms tested to ensure negative pressure?

» How often are negative pressure visualizations performed? Who is designated to perform negative pressure visualizations daily when the AIIR is in use?

» If air cannot be exhausted directly to the outdoors or if it must be recirculated, are local exhaust ventilation systems readily available?

» What procedures are in place if an AIIR is not negative?

HOW DO YOU CALCULATE THE VENTILATION RATE OF A ROOM/UNIT?

The ventilation rate for each ventilation system should be provided by employers. Table 2 provides minimum ventilation rates for select patient care areas as recommended by ASHRAE Standard 170-2021. Ventilation rates can be measured using a balometer (*see image 13*), in cubic feet per minute, at the air diffuser where the air is supplied.

Image 13. **Alnor Balometer capture hood measures the flow rate of air (in CFM) leaving or entering the room in a given time (Source: Tan et al., 2021)**

Ventilation rates are typically expressed in air changes per hour. Air change rates can be calculated using the following formula if the air flow rate is known. Cubic feet per minute (CFM) is a measure of air flow into or out of a room.

$$\text{ACH} = \frac{\text{CFM x 60 minutes/hour}}{\text{Room volume in cubic feet}}$$

Table 2. **Minimum ventilation recommendations for patient care areas based on ASHRAE Standard 170-2021**

Function of space	Pressure relationship to adjacent areas	Minimum total air change per hour (ACH)
Airborne infection isolation room (AIIR)	Negative	12
Operating room	Positive	20
Emergency department waiting room	Negative	12
Patient toilet room	Negative	10
Triage	Negative	12
Trauma room	Positive	15

Table 3. **Air changes per hour and time required for airborne contaminant removal by efficiency (Source: CDC)**

Air Change per Hour (ACH)	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
8	35	52
10	28	41
12	23	35
15	18	28
20	14	21
50	6	8

AFTER A PATIENT WITH SUSPECTED OR CONFIRMED AEROSOL-TRANSMITTED DISEASE VACATES AN AIIR OR ANY ROOM, HOW MUCH TIME SHOULD ELAPSE BEFORE ALLOWING ENTRY BY STAFF OR ANOTHER PATIENT WITHOUT PPE?

Infectious aerosol particles like SARS-CoV-2 can linger in the air even after a person has left the room.[48,49] Table 3 can be used to estimate the length of time, in minutes, necessary to clear the air of 99.9 percent of aerosol-transmitted pathogens after the source (infected) patient leaves the room. The fewer the air changes, the longer the ventilation time required. For example, a room with 12 ACH must be ventilated for 35 minutes. However, if the ventilation rate is unknown, then waiting for at least one hour for the room to be ventilated is a general rule of thumb.

SECTION 5 » DEFINITIONS

- **Air changes per hour (ACH) —** an important metric that measures how often the air in a space is completely replaced with new air, in one hour.
- **Airborne infection isolation room (AIIR) —** a patient care room that is maintained under negative pressure to adjacent areas so that air contaminated with infectious aerosol particles does not escape the room.
- **Cubic feet per minute (CFM) —** a measure of air flow into or out of a room.
- **Directional airflow —** direction of airflow from clean to potentially more contaminated areas.
- **High-efficiency particulate air (HEPA) filter —** air filter that is at least 99.97 percent efficient in capturing dust, pollen, mold, bacteria, and any airborne particles that are 0.3 microns or larger in diameter, at a specified flow rate of air.
- **Infectious dose —** amount of virus needed to establish an infection.
- **Positive pressure —** a room that is maintained under a higher pressure inside than that of the surrounding environment, pushing the air out and keeping airborne contaminants from entering.

SECTION 6 » ADDITIONAL RESOURCES

- American Industrial Hygiene Association (AIHA) » **Reducing the Risk of COVID-19 Using Engineering Controls**
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) » **ASHRAE Standard 241, Control of Infectious Aerosols**
- Association of Home Appliance Manufacturers (AHAM) » **HEPA Filtration – Discussion on Test Methods and Ratings**
- 29 CFR 1910.134 » Federal OSHA's **Respiratory Protection**
- CCR Title 8, Section 5199 » Cal/OSHA's **Aerosol Transmissible Diseases**
- CCR Title 8, Section 5142 » Cal/OSHA's **Mechanically Driven Heating, Ventilating and Air Conditioning (HVAC) Systems to Provide Minimum Building Ventilation**
- CCR Title 8, Section 5143 » Cal/OSHA's **General Requirements of Mechanical Ventilation Systems**
- CCR Title 8, Section 5144 » Cal/OSHA's **Respiratory Protection**
- National Institute for Occupational Safety and Health (NIOSH) » **Expedient Patient Isolation Rooms**

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