UCSF
University of California
San Francisco

CURRY
INTERNATIONAL
TUBERCULOSIS
CENTER

2

Environmental Controls

Overview

Part 1. Ventilation

Overview

In this manual, the term "environmental controls" refers to the use of engineering and architectural technologies to help prevent the spread of infectious diseases, specifically focusing on reducing the transmission of airborne infectious disease.

Due to limited funding and other restrictions, care facilities such as public health clinics, community health clinics, and homeless shelters frequently make use of locations that were not originally designed for such use. Within hospitals and large healthcare institutions, areas may also be repurposed from other services. As a result, if a location has an existing "office" or "residential" ventilation system, it may not have sufficient safeguards to prevent the spread of TB or other airborne microorganisms. In worst case scenarios, ventilation systems may not be operational or may not be present at all.

Environmental controls are the second line of defense in the TB infection prevention and control program, after basic administrative controls.

Additional risks faced by care facilities are deficiencies in environmental controls for airborne infection prevention and control. When deficiencies occur, persons with potential or known TB are sometimes placed in airborne infection isolation rooms (AIIRs) that have inadequate environmental controls. Poorly designed and/or incorrectly operating AIIRs can place healthcare personnel (HCP), visitors, and patients at risk for TB infection and disease. This chapter outlines the design, implementation, and maintenance of environmental controls at both a facility level and at an AIIR level.

After basic administrative controls, environmental controls are the second line of defense in the TB infection prevention and control program. Effective administrative controls are necessary to ensure the proper operation and maintenance of environmental controls. Environmental controls help to prevent the spread and reduce the concentration of airborne infectious particles (e.g., TB-containing droplet nuclei). A summary of environmental controls and their use in prevention of transmission of *M. tuberculosis* is provided in this chapter's two sections: Part 1: *Ventilation* and Part 2: *Ultraviolet C-Band (UVC)*.

ENVIRONMENTAL CONTROLS FOR TB INCLUDE:		
Ventilation		**Ultraviolet C-Band (UVC)**

MECHANICAL & NATURAL VENTILATION
Mechanical ventilation: heating, ventilating, air-conditioning (HVAC) systems
• Dilution ventilation
• Unidirectional ventilation
• Single-pass ventilation
• Recirculating ventilation
  • No filtration
  • Filtration: low, medium, or high; high efficiency particulate air (HEPA)
  • In-duct UVC (UVGI)
Mixed-mode ventilation
Natural ventilation
	ROOM AIR CLEANERS (RACs)
	• HEPA filtration
	• Minimum efficiency reporting value (MERV) 11-14 filtration
	• UVC
		• Upper-room UVC
		• Whole-room UVC
		• In-duct UVC
		• RACs with UVC

What does "commissioning" mean?

Any project to build or renovate a facility's environmental control systems will involve commissioning. Commissioning (of a building or system [e.g., HVAC, UVC, RAC]) is a process, not a specific task. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) describes commissioning as a series of procedures, methods, and documentation requirements that confirms a building "performs" as desired.[1]

Major stages in the commissioning process

1. **Pre-design stage** ensures the building owner's/operator's needs, requirements, and objectives are well defined.
2. **Design stage** ensures the design meets the owner's/operator's needs, requirements, and objectives. This stage involves not just designers, but also the owner/operator and peers to review and comment on the design.
3. **Construction stage** ensures that the work conforms with the construction design plans.
4. **Occupancy and operation stage** ensures the end product meets the owner's/operator's needs, requirements, and objectives; and staff and management have the necessary skills and/or funds to operate the product.

- During this stage, the contractor provides operation and maintenance manuals to the owner/operator and necessary training to staff. Whether operation and maintenance activities will be contracted out or handled within the owner's/operator's organization, forward all maintenance and operations information to the applicable person(s).
- At the end of the construction stage or the beginning of the occupancy and operation stage, conduct **performance testing** and repeat periodically throughout the operation of the equipment and/or space. Also called **final acceptance testing,** this testing step confirms the equipment meets the design requirements under various conditions, e.g., can the HVAC system provide the design airflow rates with both clean and with loaded (dirty) filters?

What to do

- If the project is small (e.g., installing a RAC or minor modifications to the ventilation system), a person knowledgeable in the technology can oversee the commissioning process.
- Larger projects may require an independent **commissioning agent,** professional engineer, or certified industrial hygienist (someone familiar with the required activities) to "witness" the final acceptance testing. A commissioning agent can make sure the entire commissioning process is executed completely and correctly.

Part 1. Ventilation

Using ventilation to reduce TB transmission

What is ventilation and why do we need it?

Ventilation is the movement of air within a building and replacement of inside air with air from the outside, preferably in a controlled manner. Two general types of ventilation include:

- **Mechanical ventilation,** which usually refers to the use of mechanical equipment that circulates air in a building and may also involve heating and/or cooling. Mechanical ventilation systems may or may not bring in air from the outside.
- **Natural ventilation,** which relies on unrestricted movement of air (doors, windows, ducts/channels, design of building, etc.) to bring in air from the outside. Fans may also assist in this process and distribute the air (mixed-mode ventilation).

Ventilation is needed to:

- Dilute and/or remove infectious aerosols
- Contain and/or prevent the spread of infectious particles to other areas within the facility
- Provide a comfortable environment (temperature, relative humidity, low noise, and no drafts)

How ventilation helps reduce TB transmission

Ventilation can reduce the risk of airborne disease transmission through dilution, removal, and containment.

Dilution (general) ventilation: When clean or fresh air enters a room, by either natural or mechanical means, and is mixed well with the existing air, the concentration of small airborne infectious particles in room air is reduced. An example of using dilution ventilation would be the opening of doors and windows to bring in clean outside air to dilute objectionable odors, reduce carbon dioxide (CO_2), and reduce airborne contaminants. Dilution reduces the likelihood that a person in the room will breathe air that may contain infectious particles.[1]

Removal and containment: Further interventions to remove and direct the air with the infectious particles safely away from others in the facility (containment) help to prevent airborne transmission.

Infectious particles are removed when potentially contaminated room air is:

- Exhausted outdoors to a safe place (i.e., away from persons, ventilation intakes, building openings) and replaced with outside air, or

- Filtered or irradiated to trap or inactivate infectious particles containing *M. tuberculosis* and then recirculated into the facility, or
- A combination of these two methods.

In any ventilated space, air is constantly entering (being supplied) and leaving (being exhausted). When air is introduced into a space, it may mix to a certain extent with the air already in the room. Effective **air mixing** will dilute any airborne pollutants (vapors, odors, infectious particles).

- The more effective the mixing of air, the better the dilution of infectious particles.
- The more efficient the airflow patterns in a room, the better the removal of infectious particles.

Ventilation systems are designed to balance these two properties.

Airflow rate and air changes per hour (ACH)

- **Mechanical airflow rate or volumetric airflow rate** (cubic feet per minute [CFM] or cubic meters per hour [m^3/h]) is the volume of air which passes per unit time. In terms of characterizing a room or space, it might be the air into or out of a room or space through a grille or diffuser, under a door, and through various "openings" in the envelope or boundary of the space.[2]
- **Clean air delivery rate (CADR),** (CFM or m^3/h) is the volume of "clean air" which passes per unit time. For the purpose of this document, "clean air" is defined as the sum of the airflow rate of outside air and treated air (particle-free and/or air in which microbes have been inactivated). Treatment of air may include filtration and/or UVC.[3,4]
- **Air changes per hour (ACH**) or air exchange rate is a function of the **CADR**. This is the amount of clean air added to or existing air removed from a room or space, divided by the volume of the space. If the air in the room or space is perfectly mixed, ACH is a measure of how many times the air within a defined space is replaced with clean air in one hour.[2,5]

For many facilities, indoor air is often recirculated with minimal cleaning and with no addition of outdoor air (approaching zero ACH), or only a small or variable proportion of outdoor air (very little ACH). Some facilities add environmental controls to clean recirculated air using special filters or disinfect with germicidal ultraviolet-C light (UVC, also referred to as Ultraviolet Germicidal Irradiation, UVGI). These controls can be described in terms of relative equivalence of air exchange rate (**equivalent air changes per hour, eACH**) as compared to strictly ACH.[6,7] Note: if $ACH_{OUTDOOR\ AIR}$ equals zero, the space may not meet the minimum ventilation requirements for control of CO_2 and other environmental contaminants.

- Four methods to produce ACH include (and may be used in combination):
  - $ACH_{OUTDOOR\ AIR}$ is based on the clean outside air flowing into a space.
  - $eACH_{CLEAN}$ is the clean air returning to the space (recirculated air) that has been cleaned using filtration or disinfected using UVC. Note that the air returned to the space may not be 100% clean if the filtration/disinfection is not 100% efficient.

- $eACH_{RAC}$ is the clean air returning to the space using a RAC. Note that the air from the RAC returning to the space may not be 100% clean if the filtration/disinfection is not 100% efficient.
- $eACH_{UR\ UVC}$ is the clean air circulated in the space, disinfected with upper-room UVC.
- For any combination of methods, the total equivalent air exchange rate ($eACH_{TOTAL}$) is:

  $$eACH_{TOTAL} = ACH_{OUTDOOR\ AIR} + eACH_{CLEAN} + eACH_{RAC} + eACH_{UR\ UVC}$$

Room clearance

Room clearance (%) is the percentage of initial number or concentration of infectious particles removed after a specified unit of time. Room clearance may be expressed in terms of percent reduction in infectious particles in one hour or in terms of time to achieve a defined clearance rate at a specified ACH.

- If we assume perfect mixing in a room or space with 6 ACH and **no further generation of particles,** 99.75% of the initial particles will have been removed from the room or space in one hour (see Table 1). If the same room or space was ventilated at a rate of 12 ACH, 99.999% of the initial particles will have been removed in one hour.
- If we assume perfect mixing in a room or space with 6 ACH and **no further generation of particles,** it will take 46 minutes to reduce the initial particles by 99% and it would take 69 minutes to reduce the initial particles by 99.9%. In a room or space with 12 ACH, it would take 23 minutes to reduce the initial particles by 99% and it would take 35 minutes to reduce the initial particles by 99.9% (see Table 2).
- In reality, most rooms have less than ideal air mixing, therefore the reduction in particles and times shown in Tables 1 and 2 represent best case scenarios.

Note: Increasing the number of ACH beyond 12 ACH will have diminishing returns and will be of very little benefit at a significant cost for most spaces (Table 1). Exceptions could include small spaces, such as a sputum collection booth, where an ACH or eACH >12 can be achieved at a reasonable cost for the added removal and/or inactivation rate.

TABLE 1. **Air-changes per hour (ACH) and infectious particle removal:** ACH and percent of infectious particles remaining and removed after one hour, assuming no patients/clients or procedures are generating infectious particles and there is “perfect” air mixing.[8]

ACH	Remaining (%)	Removed (%)
1	36.8	63.2
2	13.5	86.5
4	1.8	98.2
6	0.25	99.75
9	0.01	99.99
12	0.001	99.999
18	0.000002	99.999998
24	0.000000004	99.999999996

Source: P.A. Jensen

TABLE 2. **Air-changes per hour (ACH) and clearance times:** ACH and time required for removal efficiencies of 99% and 99.9% of airborne contaminants, assuming there is “perfect” air mixing.[5]

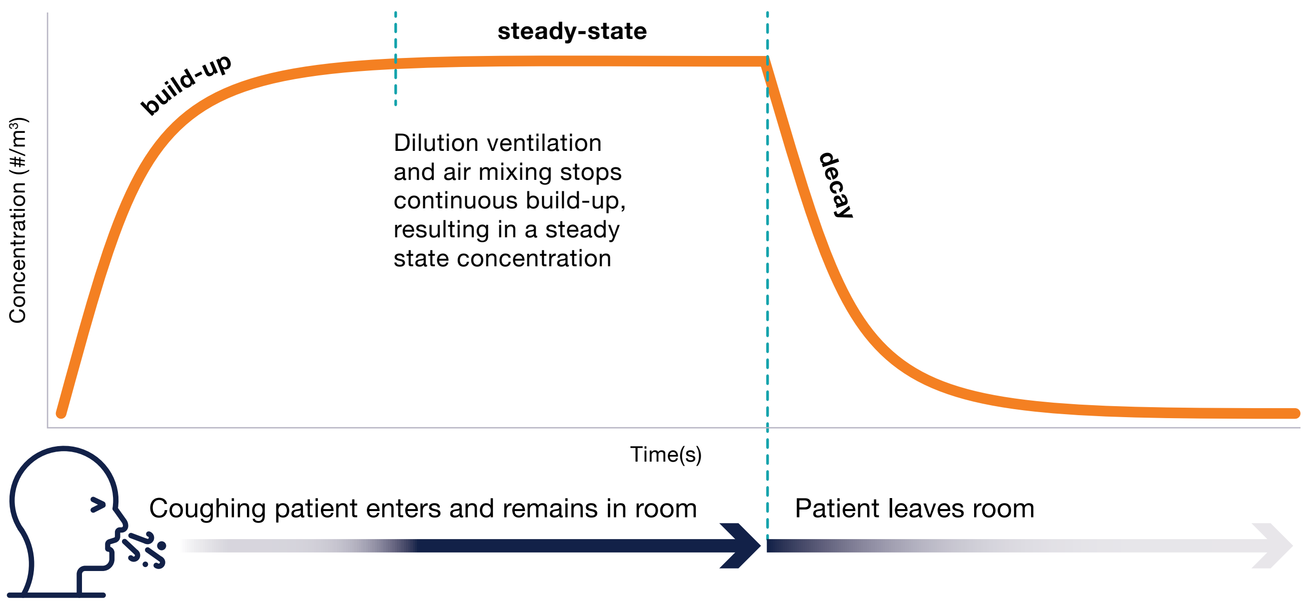
	Minutes required for removal efficiency*	
ACH	**99%**	**99.9%**
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

*Time in minutes to reduce airborne concentration by 99% then 99.9%

Source: CDC *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Settings*, 2005[5]

Note: **If there is ongoing production of infectious particles in a room** (e.g., an untreated, coughing patient with pulmonary TB), a well-designed ventilation system can dilute and reduce the concentration of infectious particles, but the number of infectious particles in the room will eventually reach a steady state between production and removal (Figure 1). The number of infectious particles in the room will not reduce to zero until the source is removed. Increasing the number of ACH can reduce the steady-state concentration of infectious particles in a room. Similar to the infectious particle decay when there is no source of infectious particles, increasing ACH beyond 12 ACH will have diminishing returns. Once the person who is producing the infectious particles leaves the room, continued air exchange can then clear the air within the room completely as seen in the concentration decay curve in Figure 1.[8]

FIGURE 1. **Infectious particle production and clearance:** Schematic of steady-state concentration of infectious particles using dilution ventilation with perfect air mixing then clearance (decay curve) when source of infectious particles is removed.



Source: P.A. Jensen/CITC

For step-by-step instructions on how to calculate the ACH and room clearance time, see Appendix A, *Room Clearance Time Calculation (and ACH) Worksheet*.

Using directional airflow to reduce TB transmission

What is directional airflow?

Ventilation can also help reduce the concentration of infectious particles in specific locations within a room. By directing where clean air enters a space and knowing where potentially infected air is removed from a space, the location of people and activities can be matched to the **directional airflow** to optimize the protective benefits of ventilation.

Simply stated:

- Locate the people you are trying to protect from TB exposure near the clean air supply
- Locate people who may be infectious near a place where air is removed from the space

Directional airflow is also referred to as “airflow currents” in some guidelines and recommendations.

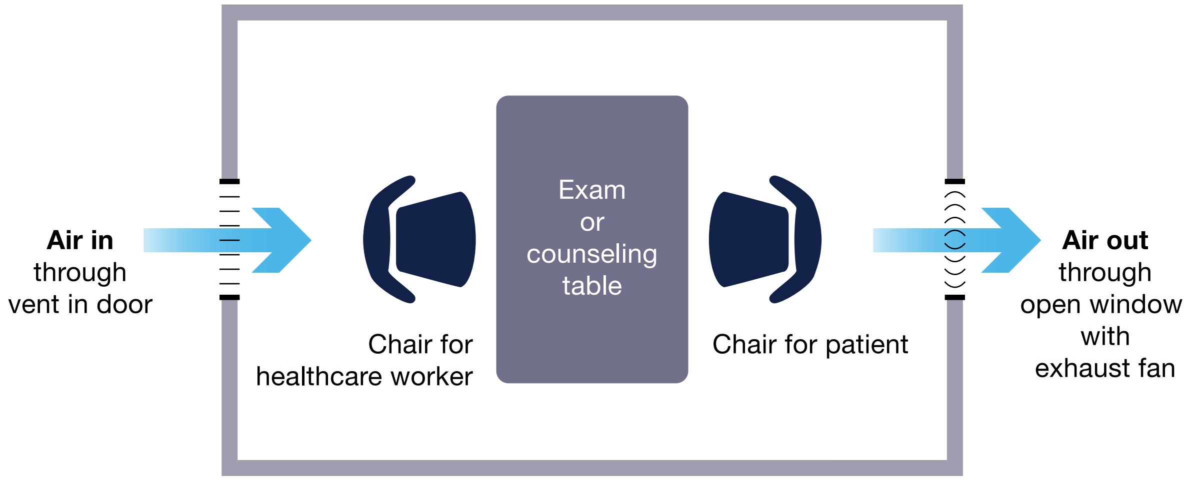
How directional airflow helps reduce TB transmission

Directional airflow principles apply to either mechanical or natural ventilation systems.

Unidirectional airflow (horizontal): If applied appropriately, the strategic use of directional airflow can help protect staff from an unidentified TB patient.[5] For example, horizontal directional airflow can help reduce the chance that TB will spread from a patient/client to a staff member doing intake interviews.

- If the airflow direction is always the same (e.g., a room with a reliable exhaust-only window fan), the staff member should sit near the fresh air supply, and the patients/clients should sit near the exhaust location as shown in Figure 2a.

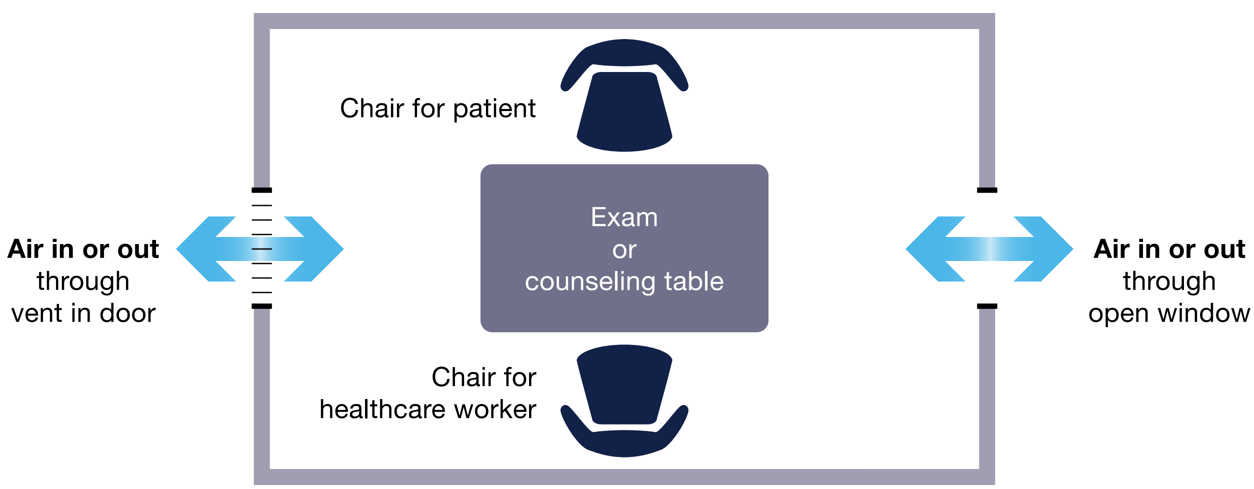
FIGURE 2A. **Room layout with unidirectional airflow:** Example layout in a room with unidirectional airflow using an exhaust-only window fan (TB exam or counseling room)



Adapted from CDC *Core Curriculum on Tuberculosis: What the Clinician Should Know*, Chapter 6: Tuberculosis Infection Control, 2021[9]

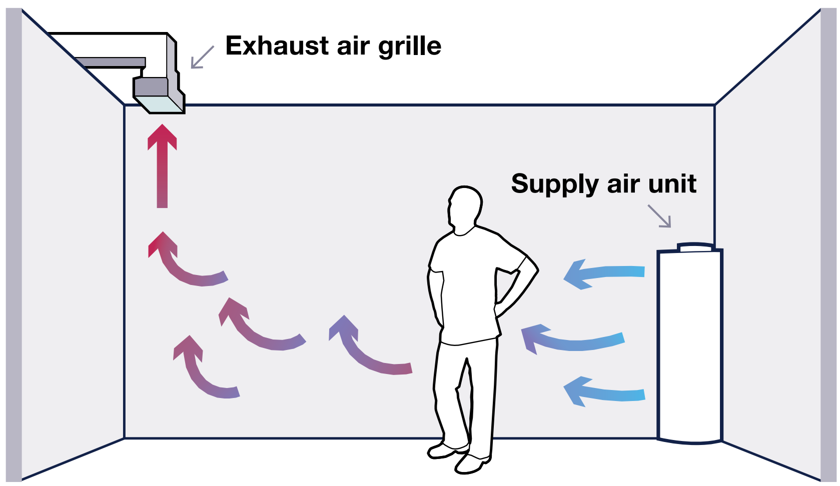
In a naturally ventilated room where the direction of airflow may be less predictable, as shown in Figure 2b, the table is rotated 90 degrees to make the desk orientation optimal for airflow to be in either direction. Note: When an exhaust-only window fan is relatively weak and outside prevailing winds are strong, the unidirectional airflow may not work as intended and this second layout may be preferred.

FIGURE 2B. **Room layout with variable airflow:** Example layout of a room with airflow that may be in either direction, generally a naturally ventilated room (TB exam or counseling room).



Displacement ventilation (vertical): This is a vertical, unidirectional air distribution system that introduces cool air (conditioned "clean" air) at low velocity, usually from air supply diffusers located near the floor and exhausted above the occupied zone, usually in the ceiling (see Figure 3). Occupants and equipment in a space will warm the air, and the warmer air will rise (referred to as "buoyancy forces"). Buoyancy forces ensure that this cooler clean air supply pools near the floor level. As the air warms, any infectious particles being produced by an occupant with TB will be carried up in the thermal plumes that are formed and are exhausted at or near the ceiling. Detailed information on use of displacement ventilation can be found in the 2016 *Price Engineering Guide Displacement Ventilation*.[10]

FIGURE 3: **Example of room with displacement ventilation**

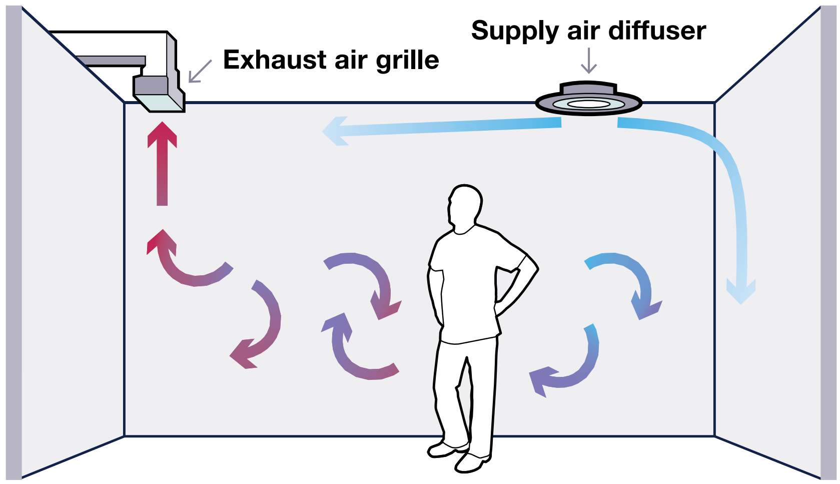


Using directional airflow vs. dilution ventilation methods for congregate settings

In a room in which large numbers of people may congregate, such as a dormitory or a waiting room, anyone could be a source of TB that could spread to others in the room. In general, the direction of air movement to protect one primary location in the space is less critical. A potential exception would be a congregate setting with an adjacent designated staff or healthcare personnel (HCP) area (e.g., receptionist or nursing workstation). In this case, directional airflow from a clean air source going from the staff/HCP area to the congregate patient or client area would be best.

- A dilution-based strategy to provide clean air that is mixed well to dilute the concentration of any infectious particles and then distributes the air throughout the space reduces the average transmission risk for other occupants regardless of where the source may be located (see Figure 4).
- Installing upper-room UVC to disinfect air with a good air mixing system is another example of using a dilution system for a crowded space.[7,11] See *Environmental Controls: UVC*, section, *Upper-room UVC*.
- A displacement ventilation method that supplies cooler, clean air near the floor throughout the space could also work in a crowded situation in which the potential source of infectious particles is not known.

FIGURE 4. **Example of general dilution ventilation.** Note round, louvered supply air diffuser positioned at a distance from the exhaust grille in the ceiling



Checking directional airflow and airflow patterns

People can usually feel or "smell" the presence or absence of air movement in a space. A ventilated space may have a slight draft; however, this is more a function of the diffuser (the air supply inlet) design and not an indication of the effectiveness of the ventilation system. In the absence of adequate ventilation, air may feel stuffy and stale, and odors will linger.

Checklist to assess ventilation in your facility:

- ☐ Check that all occupied rooms have a source of natural or mechanical ventilation (both air supply and air exhaust). When directionality is desired, validate that the airflow moves in the desired direction (e.g., from the supply and through the room to the exhaust, or from the corridor into the room). Air may move to adjacent spaces via open doors or grilles in doors.
- ☐ Check that windows, doors, vents, ductwork, etc., are easy to open and to keep open, that all supply diffusers and air exhaust grilles (exhaust outlets) are open and airflow is unimpeded. Note that most mechanical ventilation systems will not operate properly when combined with natural ventilation (windows and doors open to outdoors).
- ☐ Check air mixing and determine directional air movement in all parts of occupied rooms. A preferred method is to use non-irritating "smoke tubes" or "smoke/fog generators" designed for checking airflow. Acetic acid smoke tubes may be preferred over sulfuric acid tubes due to safety concerns.[12] Inexpensive ways to visualize air movement are to use a thin strip of tissue paper or incense sticks (two lit together may be needed to produce enough visual smoke).

CONTINUED

Checklist to assess ventilation in your facility:

CONTINUED

- [ ] The following is a general description of the procedure:

1. Activate smoke tubes per manufacturer instructions (or hold two incense sticks together and light them, allow to start to burn, then blow out flame, cup one hand over the smoke to allow it to cool and become neutrally buoyant).
2. Observe the direction of the smoke movement. Repeat in various areas of the space (including the opening under the closed room entry door) and record.

   Observe how quickly the smoke dissipates. This is a subjective test that may require some practice. It does not give a definite result but is useful for qualitatively comparing rooms to each other. For example, it may take one minute for smoke to dissipate in one room but 10 minutes in another. Repeat smoke tests for various common conditions at your facility. For example, if doors are kept open during the day but closed at night, the tests should be done under both conditions. If smoke does not move or dissipate over approximately 5 minutes, technically evaluate airflow with an environmental engineer and consider remediation.

For further information on methods for checking airflow (e.g., smoke or tissues tests, use of manometer), see Chapter 4, *Airborne Infection Isolation Rooms*, section, *Monitoring AIIR environmental controls*.

Mechanical ventilation

Mechanical ventilation systems use dilutional strategies, remove contaminated air, and control airflow patterns in a room or setting through mechanical means. This includes a building's heating, ventilation, and air-conditioning (HVAC) system but may also entail specialized systems for a room or workstation. An engineer or other professional with expertise in ventilation (preferably within hospital, healthcare facility, laboratory, and/or protected environments) should be included as part of the staff of the healthcare setting. Otherwise, a consultant with expertise in ventilation engineering specific to healthcare settings should be hired for design, installation, or maintenance issues. Ventilation systems should be designed to meet all applicable federal, state, and local requirements.

- Mechanical ventilation systems may be designed to apply directional airflow methods to supply clean air to specific locations within a space (e.g., unidirectional airflow of clean air towards staff, and removing contaminated air near an infectious source).
- A mechanical system may be designed to use vertical, displacement ventilation methods, where cool air is supplied near the floor and the warm air removed near the ceiling as a primary means of removing airborne infectious particles. A displacement strategy may be a more efficient method than dilution ventilation at removing airborne infectious particles for some settings, particularly in large, congregate settings, and more uniformly reduces the risk of exposure to all occupants in the space.

This section will cover details of mechanical ventilation systems as they apply to infection control for:

- Negative and positive pressure systems
- HVAC systems

More guidance on mechanical ventilation principles and implementation:

- For general TB infection control guidance and specific use of negative or positive pressure: Centers for Disease Control and Prevention (CDC) 2005 *Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings.*[5]
- For airborne infection isolation rooms (AIIRs): CDC 2019 update: *Guidelines for Environmental Infection Control in Health-Care Facilities, Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC)*.[13]
- Guidelines by the Facilities Guideline Institute on the design and construction of hospitals and outpatient facilities, and residential, care, and support facilities.[14,15,16]

Airflow differentials and pressure differentials

To better understand mechanical ventilation strategies and systems, it is useful to understand the concepts of airflow differentials and pressure differentials:

- **Airflow differential** (CFM or m^3/h) is the difference between the total supply airflow rate and the total exhaust airflow rate. If this number is negative and the room or space does not have excessive openings or leakage, the room or space would be depressurized or "negative" pressure relative to the surrounding spaces. If this number is positive and the room or space does not have excessive openings or leakage, the room or space would be pressurized or "positive" relative to the surrounding spaces.
- **Pressure differential** (inch water gauge, "wg; or Pa) is the pressure inside the room or space relative to the pressure outside of the room or space. If the pressure inside is less than the pressure outside, the room or space would be depressurized or "negative" pressure relative to the surrounding rooms or spaces. If the pressure inside is greater than the pressure outside, the room or space would be pressurized or "positive" relative to the surrounding rooms or spaces.

Using specialized equipment (e.g., negative pressure laboratory hood or sputum induction booth) or the facility HVAC system, supply and exhaust airflow rates can be mechanically adjusted to produce the desired negative or positive pressurized spaces relative to the surroundings. Air movement is driven by this pressure differential, i.e., air is always moving from the more "positive" space towards the "negative" space.

How negative pressure helps reduce the risk of TB transmission

Negative pressure is created by setting (or balancing) a ventilation system so that more air is mechanically exhausted from a room than is mechanically supplied, until the pressure differential is >0.01 "wg (2.5 Pa). This creates a ventilation imbalance, called airflow differential, and the room will have a negative pressure relative to surrounding areas, including the corridor. If the room is sufficiently sealed, the room makes up the airflow differential by continually drawing in air from outside the room.

- Infectious particles that are generated within a room will be contained there by a continuous flow of air being pulled into the room from under the door or through openings in the walls, ceilings, or floors. Therefore, when a negative pressure room is used as designed, infectious particles cannot escape to the corridor or other areas of the facility.

The most common examples of negative pressure are residential bathrooms. Often a bathroom will have an exhaust fan but no mechanical air supply. The most common application within healthcare facilities is the use of negative pressure to create AIIRs or localized negative pressure use in laboratory safety hoods.

Room pressurization should be monitored in accordance with an Infection Prevention and Control (IPC) plan. Even if the AIIRs are equipped with electronic pressure monitors, the Centers for Disease Control and Prevention (CDC) recommends AIIRs be checked for negative pressure by using smoke tubes or other visual checks before occupancy. In addition, these rooms should be checked daily when occupied by a patient with presumptive or confirmed TB disease. See Appendix B, *Airborne Infection Isolation Room Pressure Monitor Checklist* as a template for recording verification results. For further information on methods for checking airflow (e.g., smoke or tissues tests, use of manometer), see Chapter 4, *Airborne Infection Isolation Rooms,* section, *Monitoring AIIR environmental controls*.

Negative pressure is created by exhausting more air from a room than is supplied to the room by the HVAC system.

Infectious particles are contained within a room by a continuous air current being pulled into the room under the door or through openings in the walls, ceilings, or floors.

Negative pressure: Airborne infection isolation rooms (AIIRs)

AIIRs use dilution ventilation principles to reduce the concentration of airborne infectious particles within them, but also use mechanical containment methods to keep contaminated air in the room from potentially moving into shared corridors or other adjacent indoor spaces. To achieve this, a negative pressure differential is created relative to adjacent spaces by exhausting more air from the room than the amount supplied, as described in the preceding section. These are sometimes referred to as “negative pressure” rooms.

CDC 2005 recommendations specify:[5]

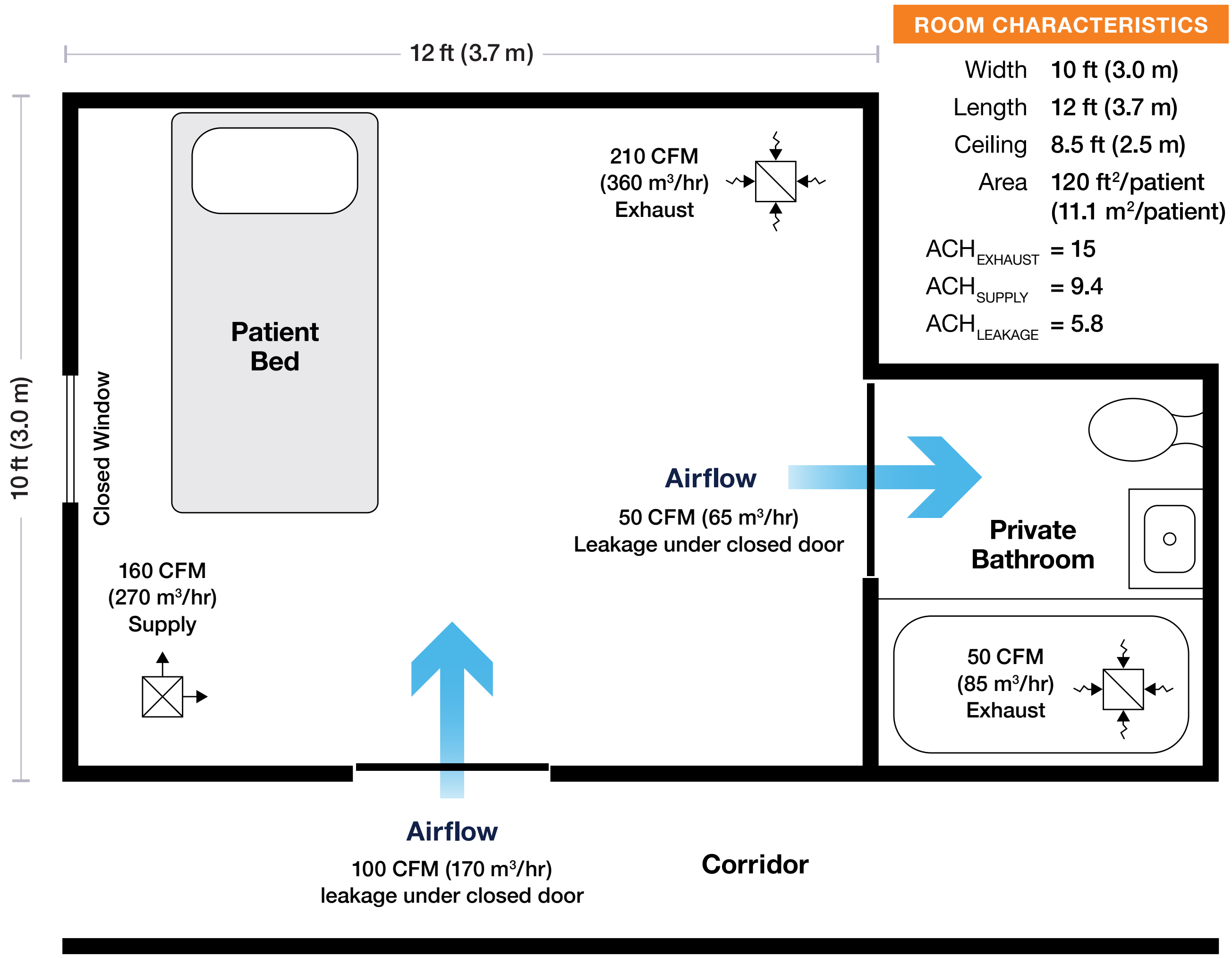
- To dilute airborne TB or microorganisms, AIIRs should have a **minimum of 12 ACH.**
- To contain airborne TB or microorganisms, AIIRs should have a **minimum pressure differential, relative to surrounding areas, of at least 0.01 "wg (2.5 Pa)** such that air flows into the AIIR. AIIRs are generally set for a minimum of 0.05 "wg (12.5 Pa) to maintain containment during small fluctuations in the HVAC system airflow rates.
- To maintain a negative pressure differential relative to surrounding areas, the **exhaust airflow rate should be ≥10% or ≥100 CFM (≥170 m^3/h), whichever is greater, than supply airflow rate.** This is called airflow differential or differential airflow.
- Variable air volume (VAV) systems that are often used to adjust "zones" of temperature should not be used for AIIRs. The primary purpose of VAV systems is to vary the airflow rate based on room temperature and they may not reliably meet the requirements for contaminant control.

Note that higher pressure differentials of up to 0.1 "wg (25 Pa) have been used; however, this is difficult to maintain and requires more powerful ventilation equipment, stronger ductwork, and a tightly sealed room.

For more in-depth information on AIIRs, including considerations for upgrading or converting an existing room into an AIIR, see Chapter 4, *Airborne Infection Isolation Rooms*.

An example of an AIIR is illustrated in Figure 5.

FIGURE 5. **Sample ventilation scheme for an AIIR used for a TB patient**



Source: Adapted from *CDC Core Curriculum*, Chapter 6[9]

- The mechanical exhaust airflow rate of 210 CFM in the AIIR is set higher than the room's HVAC air supply rate of 160 CFM. The mechanical exhaust airflow rate in the bathroom is 50 CFM. The total airflow differential of 100 CFM meets the recommendations of CDC. In addition, the ACH of 15 exceeds the recommendation of CDC for an AIIR. Assuming this AIIR does not have a large opening to the surrounding areas (except slot under the door), the pressure of this room should be at least 0.01 "wg (2.5 Pa) lower than the corridor and adjacent areas.
- The pressure differential will cause additional air to flow into the room, mainly from the more positive pressure space of the corridor through the space under the entry door into the room (100 CFM). The continuous flow of air inward prevents the spread of any infectious particles generated by an individual within the room from spreading through the corridors to other areas of the facility.
- Note the positioning of the clean air supply is at a distance from the exhaust grille. This avoids "short-circuiting" of clean air so that it is not inadvertently pulled immediately out through the exhaust system without having a chance to mix and dilute the concentration of any infectious particles in the room.

- The exhaust grille is located closer to the patient (potential source of infectious particles). Exhaust air should be released outdoors away from other windows or areas of air entry into the building and away from where people may congregate outside.

AIIR leakage and sealing

The magnitude of the required airflow differential to achieve a pressure differential of ≥0.01 "wg (2.5 Pa) is a function of the leakage area and the airflow differential of a room. Poorly sealed rooms are susceptible to losing their intended pressure differential and allowing contaminated air to flow into adjacent spaces. One might think that the only leakage area is the slot under a door. There may be additional leakage around windows and doors as well as through holes in surfaces for electrical outlets or other utilities, false ceilings, and other openings in walls, ceiling, or floor.

- Sealing a room may be required to make it as airtight as possible to prevent air from being pulled in through cracks and other gaps and preserve the desired degree of negative pressure.
- If the leaks allow in a greater amount of air than the negative pressure offset, this excess air will flow out of the room under the door and through any other openings. This can cause a room to operate under positive pressure even though the mechanical system is designed to create negative pressure.
- If the envelope (i.e., all outdoor-facing aspects: exterior walls, foundation, roof, windows, and doors) of a building is not sealed, wind can adversely affect room pressurization.
- False ceilings (i.e., a ceiling with 2'x2' or 2'x4' "tiles") are major areas of air infiltration and a huge airflow differential may be needed to maintain an adequate pressure differential.[13-15] The Facility Guidelines Institute (FGI) recommends ceilings in AIIRs be solid, with no seams, to provide a pressure barrier (additional technical details may be found in references).[14-16]

As the opening under the door gets smaller, the velocity of the air entering the room will increase and the pressure differential will increase.

- As a general rule of thumb, the velocity of air under the door should be at least 100 fpm (0.5 m/s).

Whenever the door is open, directional air movement at the doorway is uncertain. Although more air is being drawn into the room than is leaving because of the airflow differential, the large door opening results in a free exchange of air occurring at the door. Air is coming into the room, but air is also leaving. Negative pressure spaces may be designed with an anteroom to reduce the counterproductive effects used by entry and exit into the room.[17]

The greater the offset and the tighter the room is sealed, the better the containment of infectious particles.

Positive pressure: Protective environment

At times, it is desirable to reinforce the safety of an area (e.g., a nursing station next to a crowded ward). This can be accomplished by creating a positive pressure environment, **supplying higher amounts of clean air to a space relative to the adjacent surrounding areas.** This works to discourage flow of potentially contaminated air from the adjacent areas into the protected areas.

- To create a protective environment, the recommendation for air exchange rate remains 12 ACH and the differential pressure remains the same ($\geq$0.01 "wg, 2.5 Pa); however, air should flow out of the room. This is sometimes called "positive pressure."
- To achieve a positive pressure relative to surrounding areas, the supply airflow rate should be $\geq$10% or 100 CFM (170 m^3/h), whichever is greater, than the exhaust airflow rate.
- The principles for designing and maintaining a protective environment are similar to those discussed for AIIRs, with the primary exception being that the driving force behind the airflow and pressure differentials is the higher supply of clean air relative to exhaust or return air creating a positive pressure space. Operating rooms, bone-marrow transplant rooms, and burn-patient rooms are other examples of protective environments.

In specialized circumstances, a combination of positive and negative pressure strategies for adjacent spaces or combination AIIR and protective environment rooms may be desired. An example for application would be a special care unit for highly immunocompromised persons being treated for a transmissible airborne infectious disease.

Local ventilation methods: Booths, tents, hoods

Local ventilation is a ventilation method in which airborne contaminants (e.g., infectious droplet nuclei or other infectious particles) are collected and/or removed before they are dispersed into the general environment.

- **Enclosing devices contain the source of aerosolization as well as remove the aerosolized infectious particles.**
- The most common examples of local ventilation methods include sputum collection booths, isolation tents, enclosing hoods, and biological safety cabinets (BSCs).
- Enclosing booths or tents, such as those used for sputum collection/induction or isolation of an infectious patient, are available in many different designs.
- Ventilated external exhaust hoods are generally not very efficient unless they have a high capture velocity and are placed very close to the point of aerosol generation. Use caution and properly vet the hoods with an environmental engineer or contractor if considering for use during high-risk aerosol generating procedures such as sputum induction (generally not recommended for this use).
- Ventilated workstations and BSCs are used in clinical, microbiological, and research laboratories. These two technologies will not be discussed further in this manual. For a useful CDC-collaborative resource, see *Ventilated Workstation Manual for AFB Smear Microscopy* (Angra, 2011).[18]

Sputum booths

A sputum collection booth is an enclosing device functioning as a mini AIIR. The aerosol-generating procedure is conducted within the booth (the patient is inside the booth and the HCP outside the booth). See Figure 6.

- In general, the sputum booth should be located within a room that meets the ventilation requirements of an AIIR. This is recommended so that the HCP is protected if the exhaust high efficiency particulate air (HEPA) filter and/or exhaust UVC lamp(s) are not working properly.
- The sputum booth should be at a lower pressure than the surrounding area to prevent contamination of the room.
- Generally, sputum booths should be operated at 20-24 ACH or greater and a pressure differential of at least 0.1 "wg (25 Pa).
- Some units have HEPA filters that recirculate air back into the same room or duct air outside, while others simply duct all air outdoors, away from people, open windows, and ventilation air intakes.

FIGURE 6.

Sputum booth (installed within an AIIR)

Source: CITC/San Francisco Department of Public Health, TB Prevention and Control Clinic

Isolation tents

"Tents" may come in different configurations. Figure 7 depicts a tent that encloses the patient as well as all necessary medical equipment.

- Tents may provide temporary isolation when no AIIRs are available.
- A negative pressure environment may be created inside the tent to reduce transmission risks from an infectious source to HCP within a "normal" neutral pressure room.
- A negative pressure environment inside a tent may also be located within a positive pressure environment (outside the tent) for a combination AIIR and protective environment solution.
- Tents should provide both inward airflow as well as a minimum of 12 ACH and a pressure differential of at least 0.01 "wg (2.5 Pa).
- The air may be recirculated if HEPA filters are properly maintained and tested; otherwise, the air should be safely exhausted to the outdoors.

FIGURE 7.

Example of a tent isolation room

Source: UCSF/Barbara Ries

HVAC systems

Facilities that do not already have an HVAC system (central ventilation system) can improve air circulation and reduce TB transmission risk by adding one. Facilities that have existing HVAC systems should make any necessary improvements to make sure the systems have adequate components in place and meet the applicable regulatory requirements. In all cases, environmental controls must be in place and followed to prevent the spread of contaminants.

This section describes HVAC systems and methods to assess and improve a system. It should be useful to those responsible for an existing facility served by a mechanical system and to those considering the design of an HVAC system for a new or an existing building.

About mechanical ventilation systems

HVAC systems, also called forced-air systems, are mechanical ventilation systems that circulate air in a building. By providing a combination of outdoor air and cleaned air (filtration and/or UVC disinfected) to support dilution, a mechanical ventilation system can help prevent the spread of TB.[19]

However, the same system can inadvertently spread particles containing *M. tuberculosis* beyond the room occupied by the TB patient because it recirculates air throughout a building. **Recirculating ventilation systems have been responsible for TB transmission** among people who were never in the same room but shared air through a ventilation system.[20]

Using a mechanical system to improve TB IPC

There are four general ways in which an HVAC system can help interrupt the path of TB transmission:

- It can introduce fresh outside air to dilute and replace room air.
- It can use filters to remove infectious particles from recirculated air.
- It can use UVC lamps to disinfect recirculated air.
- It can be designed to support the pressure differentials for AIIR and protective environments.

These features can be incorporated into the design of a new system or can be added to an existing system.

HVAC configurations

HVAC systems come in many different configurations. A ventilation unit can be in a utility room, a rooftop, an attic, a basement, or a closet, or it can be suspended from the ceiling in the room itself. The basic components of the system are usually the same and may include some or all of the following:

- Filters to remove particles from outside air
- Filters to remove particles from recirculated air
- In-duct UVC lights to inactivate microbes

- A fan to move the air through the unit
- A section for heating
- A section for cooling and/or dehumidifying

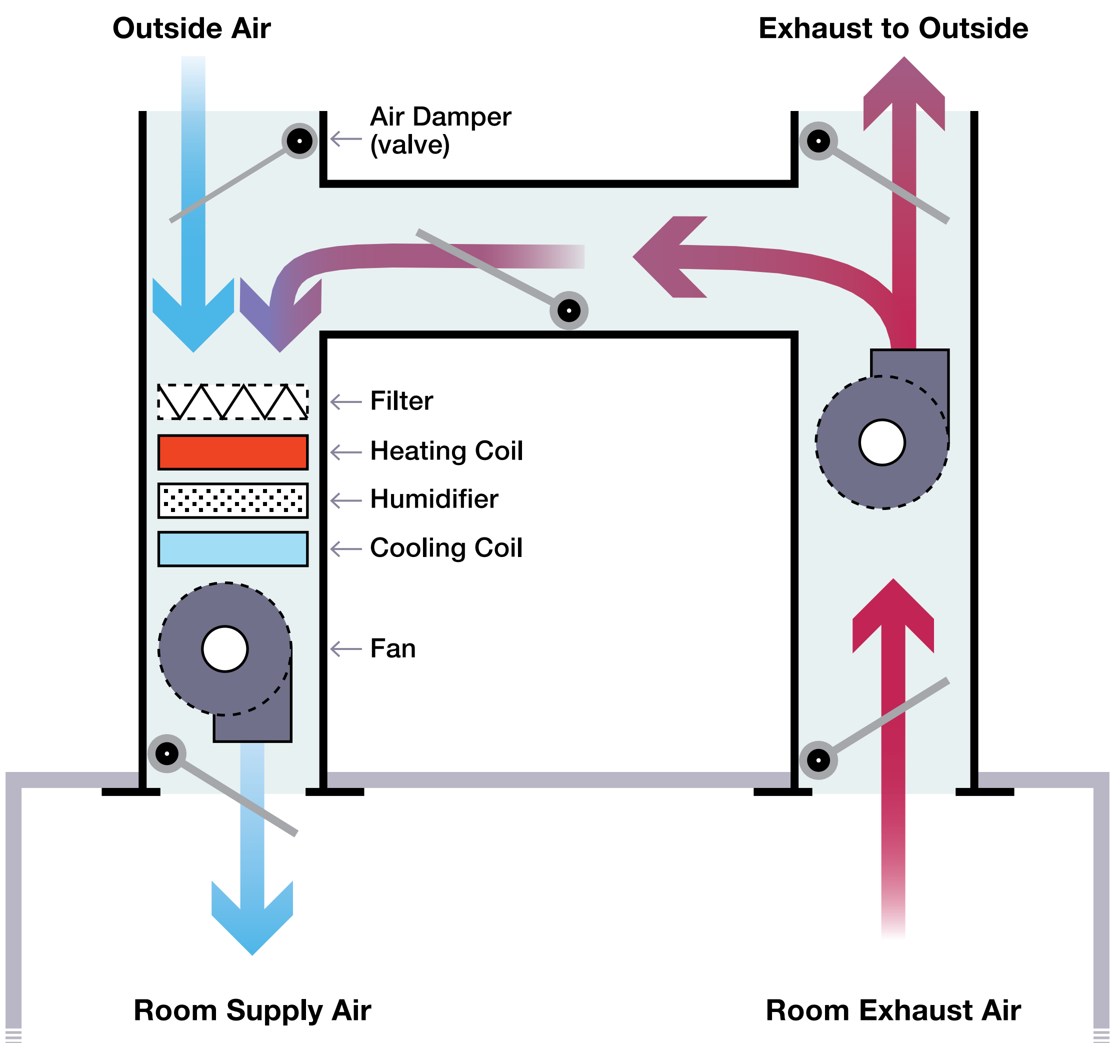
These components can be installed in a single unit or can be housed in separate sections. A system may also include other parts, such as:

- A thermostat and controls
- Ductwork, diffusers, and/or grilles to distribute and collect air

Figure 8 shows an example of a recirculating HVAC configuration.

A more detailed introduction to engineering HVAC principles can be found in the Price Industries *Engineer's HVAC Handbook* (2011).[21]

FIGURE 8. **Example HVAC recirculating system (partial outside air intake)**



Recirculating HVAC systems

Some buildings have an HVAC system that recirculates all air returned to the system, i.e., 100% recirculation and 0% outside air.

In a 100% recirculating HVAC system, air is supplied to a room to provide ventilation and/or heating or air conditioning. This air mixes with room air and then is drawn back (returned) to the HVAC system, where it is filtered and/or irradiated as well as heated and/or cooled before being sent back to the room.

Even in a building with a recirculating HVAC system, some rooms will exhaust rather than return air. Typically, bathrooms, shower rooms, institutional kitchens, and similar spaces will have a separate fan to exhaust air directly outdoors. Care must be taken so that exhaust air to outdoors does not inadvertently re-enter the facility through leakage points around nearby doors, windows and even ceilings, walls, or fresh-air intakes.

For TB control, the best type of HVAC system is one without recirculation—that is, a 100% outside air (single-pass or once-through) arrangement. In this case, all supply air is fresh outside air, which is filtered and then heated or cooled before it is supplied to the AIIR. All potentially contaminated room air is exhausted directly outside the building.

However, once-through HVAC systems are uncommon in smaller healthcare settings because it is expensive to continuously heat or cool air from outside to a comfortable room temperature and relative humidity. For example, if it is 40 degrees Fahrenheit (°F) outdoors and 70°F indoors, recirculating 70°F air is cheaper than heating outdoor air from 40° to 70°F. To maintain comfort and minimize mold growth, relative humidity should range from 40-60%.

Most commercial HVAC systems, such as those that serve office buildings, are a compromise between 100% recirculation and 100% outside air. They recirculate most, but not all, of the air returned by the system. The portion of outside air is usually somewhere between 10 to 30% of the total quantity of supply air. If not properly treated, recirculated air may increase risk of infection. Many larger HVAC systems also have some kind of energy recovery. See ASHRAE COVID Recommendations[22] as well as the *ASHRAE Handbook: HVAC Systems and Equipment*, 2020.[23]

Air supply and exhaust

A ventilation system introduces and removes air by means of air diffusers and grilles. In most healthcare applications, diffusers and grilles are usually mounted on a ceiling or on a wall.

- Supply air inlets are called **diffusers**. Exhaust air outlets (or return) outlets are generally called **grilles** or registers.
- The neck of the inlet or outlet is the point at which the outlet connects to the air duct. The neck size is selected to match the desired airflow rate and air velocity.

- The pattern or style of an inlet or outlet is the physical configuration of its face as seen from the room. For example, many supply air diffusers (inlets) can have a louvered pattern while many exhaust air grilles have a perforated metal pattern

Air provided to a room is called *supply* air. Air removed from a room, however, is either *return* air or *exhaust* air, depending on the path it takes after it leaves the room.

- **Return air** is "returned" to the HVAC unit for up to 100% recirculation
- **Exhaust air** is discharged outdoors for up to 100% exhaust (no recirculation)

The effectiveness of any given ventilation rate in clearing a space of air contaminants depends on how well the air is mixed. In turn, air mixing depends largely on how and where air enters and leaves the space. Consequences of poor air mixing are stagnation, temperature stratification, and short-circuiting. Avoid these situations because they reduce the benefits of dilution ventilation.

- **Stagnation** occurs when part of the room does not benefit from the fresh supply air. It also occurs in a room that does not have any ventilation, or has poorly designed diffusers and/or poor installation. People in a stagnant location would probably feel that the air is stuffy. Infectious particles in a stagnant area can remain concentrated and will dissipate slowly.
- **Stratification** occurs when there is an increase in temperature from the lower level of the room to the ceiling. A poorly designed room, with incorrect supply air diffusers at or near the ceiling, may provide warm, fresh air during the heating season that unfortunately remains in the upper portion of the room without significantly mixing, diluting, or warming the air in the occupied lower part of the room.
- **Short-circuiting** occurs when clean air is removed before it has mixed well with room air, such as when the exhaust air grille is located right next to the supply of incoming air. A room must not only have a satisfactory amount of clean air supplied to it, but this air must also mix with the air already in the room.

Proper selection and location of the supply air diffusers and exhaust air grilles will help avoid stagnation, temperature stratification, and short-circuiting.

More detailed engineering considerations for HVAC principles and mixing ventilation can be found in the Price Industries *Engineer's HVAC Handbook* (2011).[21,24]

HVAC components

Diffusers and grilles

Supply air diffusers provide tempered air for comfort (temperature and relative humidity) as well as outside and/or clean recirculated air to reduce the airborne concentration of CO_2, odors, chemical vapors, and infectious particles. Clean supply air also reduces the concentration of infectious particles in a room.

- For example, an HVAC system provides heating to two separate dormitory rooms in a homeless shelter. Each dormitory room has three small supply-air diffusers in the ceiling, directing air into the occupied space, to ensure that the heated air reaches everyone in both rooms. A single large grille in the hallway returns air to the HVAC system. In this building, the general direction of air will be from the dormitory rooms to the hallway, then the air is returned to the HVAC system. In this case, 90% of the air is recirculated back to the dormitories and 10% is replaced with outside air. With proper diffuser design, the air will be well-mixed in the dormitories.

Choosing a proper type of diffuser and its placement can impact how well the supply air moves and mixes in a space to reach all areas, avoiding stagnation, and how well heated or cooled air is mixed and distributed to avoid counterproductive temperature stratification. The design of a diffuser can determine the direction and influence the velocity of entering air.

Placement of **exhaust grilles** in relationship to supply diffusers is also important. Short-circuiting, as described in the previous section, may occur if the source of supplied air is located too close to the exhaust grille and does not allow the desired mixing and dilution of air in the room. Hence, a ceiling exhaust grille is generally placed far from the supply air diffuser.

An HVAC specialist can assist in the proper selection and placement of supply air diffusers and exhaust grilles.

Figure 9A shows the ideal (but rarely applied) supply air diffuser and exhaust air grille locations. Note that this is similar to an industrial "clean room" and is generally not feasible in most healthcare settings. Figure 9B shows alternate placement of diffusers and grilles as a compromise to the ideal locations. This is seen in a large number of operating theaters and in a few AIIRs.

FIGURE 9A.

Example of HVAC design where air moves from one wall to the opposite wall (most efficient design)

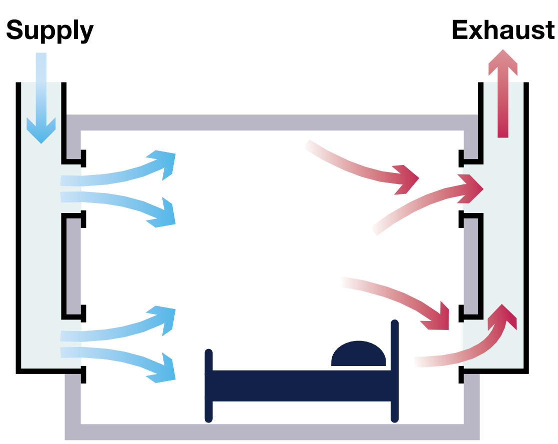
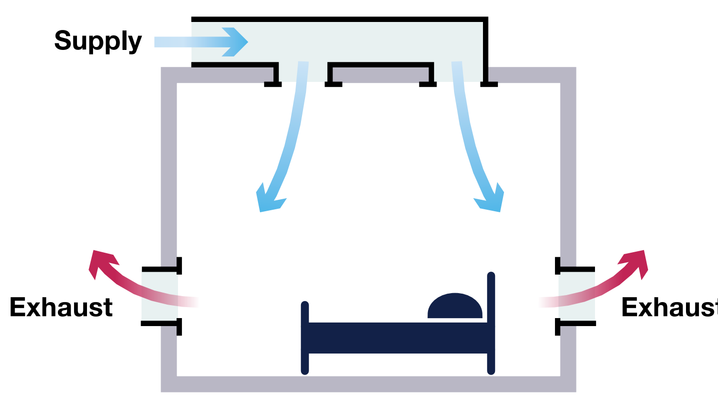


FIGURE 9B.

Example of HVAC design with air supplied from ceiling and exhausted lower in room through walls



Source: Figures 9A and 9B. Adapted from CDC: *Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Settings, 2005*[5]

Figure 10A depicts another reasonable example of diffuser and grille placement. Here, the desired airflow is pushed from a diffuser across the ceiling then down the walls to mix in the occupied space. The exhaust is in the corridor so the airflow patterns (i.e., air mixing) is acceptable. This HVAC setup could be used to support a protective environment.

FIGURE 10A.

Supply air source in room with exhaust in corridor: A louvered supply air diffuser in the ceiling with the exhaust grille located outside of the room

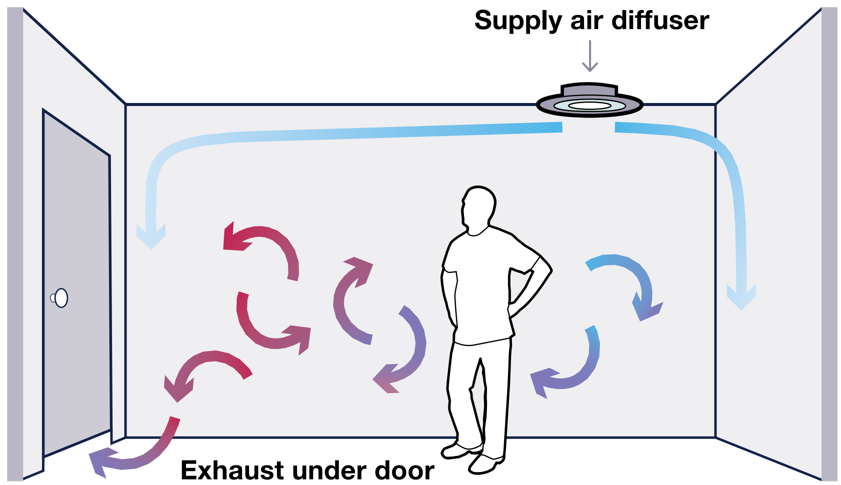


Figure 10B depicts the problem of short-circuiting due to the close proximity of the supply air diffuser and the exhaust air grille. Short-circuiting occurs when a portion of the supply air is quickly exhausted, limiting the desired air dilution and mixing.

- With both air supply and exhaust located in the ceiling, short-circuiting may increase when heating systems are in use, since warm air rises (buoyancy factors). Proper mixing to adequately move the warm supply air downward can reduce short-circuiting.

FIGURE 10B.

Short-circuiting: A louvered supply air diffuser in the ceiling with an exhaust grille located nearby (too close together)

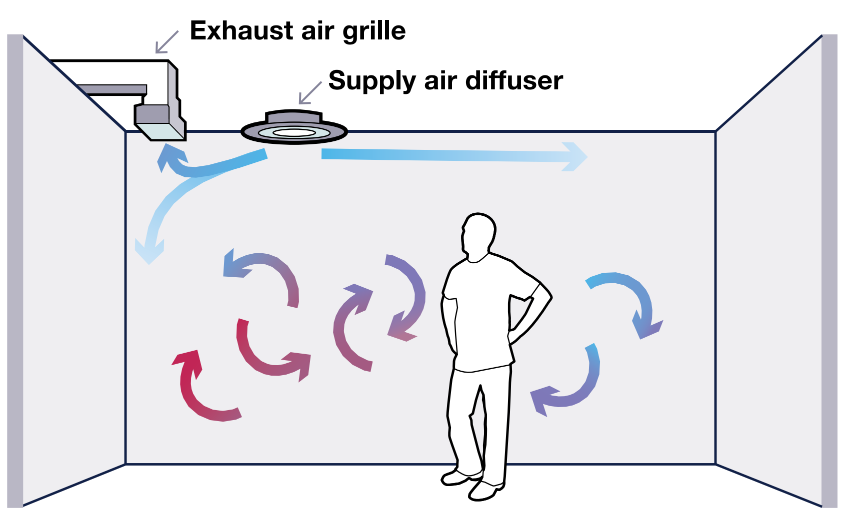
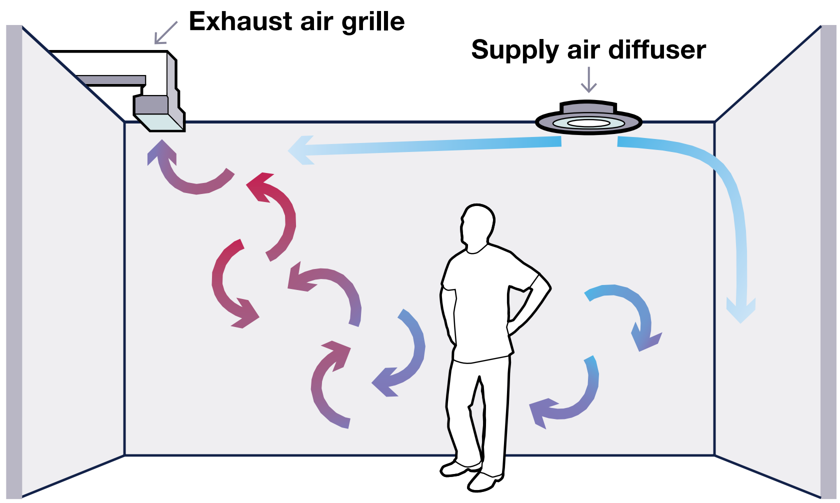


Figure 10C depicts the best compromise when both the supply air diffuser and the exhaust air grille are located in the ceiling. In addition, some vertical air movement is created as air is warmed from the presence of occupants in a room. Therefore, the diffuser design should take into account not only the geometry of the room, but also the equipment, activities, and occupants in the room.

FIGURE 10C.

Supply air source separated from exhaust within the same room:
A louvered supply air diffuser in the ceiling with an exhaust grille located as far from the supply air diffuser as possible



For images of different types of supply air diffusers and exhaust grilles, see section on *Air distribution* and Figure 11.

Outside air intake

The **outside air intake** is where fresh air enters the HVAC system on the roof or an outside wall. It can be a duct opening or part of the unit, and it usually includes an adjustable damper. A damper is a device that can be adjusted to increase or decrease the amount of outside air drawn into the unit.

If possible, existing 100% recirculating HVAC systems should be modified to include an outside air intake. A facility engineer or a mechanical contractor should do this work.

As air is drawn in, dirt and debris, such as bird feathers, pollen, mold, and dust may accumulate around the opening. For this reason, intakes are usually easy to find. A wire mesh screen and low-efficiency filters (minimum emission reporting value [MERV] 1-7) are often used to trap dirt and debris. Note that some filters are “loose fitting” while others are “tight fitting.” Loose-fitting filters are generally lower efficiency and may have significant leakage around the filter. Tight-fitting filters generally have a neoprene or synthetic gasket to seal the filter onto the HVAC system, thus preventing leakage of particles around the filter.

When feasible, outside air intakes should be kept fully open and routinely cleaned to allow in as much fresh outside air as possible.

Air filters

Filters are used to clean air. They are rated based on their efficiency to remove particles from air that is passed through them, assuming a secure seal of the filter to the HVAC system. ASHRAE MERV rates the filtering efficiency of an air filter on a scale of 1 to 16. The higher the MERV rating, the more efficient a filter is. In general, as filter efficiency increases, the resistance (pressure drop) of the sealed filter increases. Physical/non-electrostatic filters rely on physical filtration properties to remove airborne particles. The pressure drop across a non-electrostatic filter will increase with loading and potentially lead to a decrease in the actual airflow rate.[25]

An electrostatic filter relies on a "permanent charge" to increase its filtration efficiency. As the electric charge is lost or shielded, the filter may become less efficient. In general, an electrostatic filter will have a lesser pressure drop than a physical filter of the same reported filtration efficiency. The pressure drop across an electrostatic filter and the actual filtration efficiency may decrease as the electrostatic charge is dissipated and/or masked by airborne particles. Therefore, depending on the type of filter used, the pressure drop may or may not be the most useful indicator of ongoing filter efficiency or when the filter should be changed. In addition to ASHRAE, other trade or standardization organizations offer rating systems for filters that may be listed under specifications, including the International Organization for Standardization (ISO).

- Appendix C contains a table of MERV filter efficiencies for three different particle size ranges (0.3-1.0 μm, 1.0-3.0 μm, and 3.0-10.0 μm).
- HEPA filters are specialized filters that remove 99.97% of particles 0.3 μm in size (U.S. Department of Energy standards). HEPA filters are rated separately from MERV filters.

Infectious particles (droplet nuclei) generated by TB patients are believed to have a broad size distribution. These droplets may contain one or more bacilli. Because only **1–5 μm sized infectious particles** can reach deep into the lung and infect a susceptible host, systems should target filtration for particles of this size.

Filters are a standard component within recirculated air systems as well as individual room air cleaners. Ventilation systems may have just one filter, or they may have two or more. More than one filter is referred to as a filter bank.

What type of filter should be used?

The most suitable type of filter for many recirculating air systems is a pleated filter, named because the filter inside the filter frame is folded into pleats. Lint filters are commonly flat.

Table 3 compares three different rated filters:

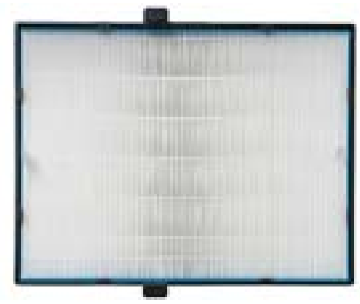
- **Coarse or lint filter (MERV 4):** A common lint filter will remove few particles in the size range of infectious particles containing *M. tuberculosis* (note: MERV 1-7 filters are only tested with 3.0-10 µm to determine their rating).
- **Pleated filter (MERV 13):** Pleated filters can remove more than 85% of all particles in the size range of infectious particles containing *M. tuberculosis*. Pleated filters are most commonly supplied as "box/frame"-style filters. "Bag/pocket"-style filters may have similar (or greater) filter surface area and similar performance as compared to pleated filters.
- **HEPA filter:** A HEPA filter will remove virtually all particles in the size range of infectious particles containing *M. tuberculosis*. Note that a HEPA filter is a densely pleated, specialized device that will not fit in most standard HVAC systems.

Lint or coarse filters (MERV 1-4) as well as pleated filters (MERV 5-13) are generally available from hardware stores in sizes that fit most small HVAC systems.

Pleated filters are slightly more expensive than lint filters. They also cause more of an obstruction, which may reduce airflow.

More detailed engineering considerations for use of filters within HVAC systems for healthcare settings can be found in the Price Industries *Engineer's HVAC Handbook* (2011).[21,26,27]

TABLE 3. **Examples of selected ventilation filters and their filtration efficiencies**

Coarse or Lint Filter	Pleated Filter	HEPA Filter
MERV 4	**MERV 13**	**HEPA**
		
Particle Size Efficiency / **Filtration** 0.3-1.0 µm: Not evaluated 1.0-3.0 µm: Not evaluated 3.0-10.0 µm: <20%	**Particle Size Efficiency** / **Filtration** 0.3-1.0 µm: ≥50% 1.0-3.0 µm: ≥85% 3.0-10.0 µm: <90%	**Particle Size Efficiency** / **Filtration** 0.3 µm: ≥99.97%
A MERV 4 filter will not remove small infectious particles containing *M. tuberculosis*. They will remove very large, visible particles such as some pollens, molds, and lint. There is very little initial resistance across a filter such as this upon initial installation. Generally, these filters are changed on a monthly or quarterly basis. They are designed to extend the life of more expensive, more efficient filters.	A MERV 13 filter will remove at least 85% of small infectious particles containing *M. tuberculosis*. An N95 respirator filter is more efficient at small particle removal than a MERV 13 filter. There is moderate initial resistance across a filter such as this upon initial installation. Generally, these filters are changed on a quarterly, semi-annual, or annual basis. They are designed to extend the life of very expensive, more efficient, HEPA filters.	A HEPA filter will remove nearly 100% of small infectious particles containing *M. tuberculosis*. An N100 respirator filter is of equivalent filtration efficiency. There is a significant initial resistance across a filter such as this upon initial installation. Generally, these filters are changed based on a combination of resistance (pressure drop across the filter) and system airflow rate.
Reference: ASHRAE 52.2-2017[25]	**Reference:** ASHRAE 52.2-2017[25]	**References:** ASHRAE Handbook: HVAC Systems and Equipment, Chapter 29;[28] and IEST RP-CC 001.7[29]

Sources: CITC, Adobe/Sakuramos, Adobe/Vchaulup

How often should filters be changed?

In the absence of a pressure gauge to measure the pressure drop across a filter, **there should be a set schedule to change filters. In addition, filters should be checked visually every month** and replaced if a decrease in airflow is noticed or per manufacturer's instructions, whichever is more frequent.[30]

It is important to replace filters before they obstruct or reduce the airflow rate below the minimum acceptable airflow rate. As mentioned in Table 3, there are often two or three filters in a system. When used in combination, the lint or course filter helps extend the life of a pleated filter, and a pleated filter helps extend the life of a higher MERV or HEPA filter. **In general, lint or course filters are changed monthly or quarterly. Pleated filters, if protected by a lint or coarse filter are changed quarterly or annually.** HEPA filters, if protected by both a lint or coarse filter and a pleated filter, and based on acceptable pressure drop, may be changed every few years. The amount of time it takes for a filter bank to load up depends on:

- How many particles there are in the air (the dustier the room air, the quicker the filter will load up); and
- How often the ventilation system is operated (the more frequently the ventilation system is used, the quicker the filters will become dirty)

Fan energy is used to push or pull air through filters. This is because filters cause an obstruction in the air's path. Over time, as dust accumulates, the obstruction increases. Consequently, the amount of air that the fan can move through the filter may decrease. Less airflow means less removal of infectious particles and less clean air supplied back to a space to support dilution.

Pressure drop and filter gauge

The relative amount of obstruction caused by filters is called the **pressure drop or resistance.** It is measured in inches of water gauge ("wg).

A pressure gauge installed across a filter bank shows the pressure drop across the filter. This is the most effective way to monitor filter loading and to determine when it is time to change the filter.

A filter gauge assembly consists of:

- The gauge
- Two measurement ports that are installed inside the duct, one on each side of the filter
- Copper or rubber air tubing

Generally, tubing connects each sampling port to a pressure gauge or manometer. The gauge reads the pressure difference between the front (upstream) and the back (downstream) of the filter.

The observed pressure drop when new filters are installed is called the **clean pressure drop.** For pleated filters, this is usually about 0.25 "wg (62 Pa). As the filter loads up, the pressure drop will increase. The filter is usually replaced when the pressure drop increases by roughly 0.20 "wg to 0.45 "wg (50-110 Pa). This is called the **changeout pressure drop.** HEPA filters start with a clean pressure drop of approximately 1"wg (250 Pa). Follow filter, HVAC system, and RAC manufacturer's instructions for actual changeout pressure drop recommendations. This is critical as airflow generally decreases with an increase in pressure drop.[30]

Some filter banks in HVAC systems (and most RACs) do not include a filter gauge, and many smaller ventilation systems are not constructed to accommodate one; e.g., most residential-type recirculating HVAC systems do not have an obvious location for a filter gauge. As a rule of thumb, consider installing a filter gauge if the system has a filter bank, as opposed to just a single filter. A facility engineer or mechanical contractor can assist with the system evaluation and installation.

Replacing existing filters with higher-efficiency filters

On occasion, a **low-cost improvement to an existing HVAC system can be done by upgrading the existing filter with a replacement filter that has a higher filtration efficiency.** General issues to consider include:

- Potential added airflow resistance of a higher efficiency filter
- Increased load on the fan/motor combination with a new filter (as well as effect of loaded filter)
- Possible shortening of the life of the fan/motor combination
- Increased cost due to increased frequency of changing/replacing the filter
- Reduction in airflow rate and reduction in ACH of room or setting

If higher efficiency filtration is deemed important based on the facility risk assessment, consider consulting with a facility engineer to ensure the system can support replacement with an upgraded filter.

- A standard residential or small office system is generally a recirculating system. Often, they are fitted with a MERV-5 (1"- or 4"-thick) filter.
- Do **not** jump immediately from a MERV-5 to a MERV-13 filter (often recommended for COVID-19 prevention and for clean air to obtain Leadership in Energy and Environmental Design [LEED®] certification). The best solution is to test by slowly increasing the filtration efficiency (MERV rating) until a significant reduction in airflow rate is detected.
  - A simple, qualitative way to test for a drop in airflow involves taping a thin strip of tissue paper to the supply air diffusers in several rooms to see if they flutter the same using the higher efficiency filter compared to the airflow (strip flutter) using the original MERV-5 filter.
  - Once you observe a change, remember this change is with a clean filter (rather than the performance expected over the filter life). Install a filter two MERV ratings lower than the one that showed a significant reduction in airflow.
- Follow the manufacturer's recommendations with respect to when and how to change a filter. Before changing the filter, look at the flutter strip on the supply air grilles.
  - Is there an observed reduction in the flutter observed and/or extension of the strip after the filter change?
    - **If yes,** see if the filter manufacturer makes a different model filter (at the same desired rating) which has a lower resistance (pressure drop across the filter). If not, you should use a new/replacement filter with a lower MERV rating.
    - **If no,** was there a significant increase in airflow as indicated by the flutter strip? If yes, continue to use this MERV-rated filter.

- Note: **Filters with the same MERV rating may have different resistances (pressure drops) between different brands and models.** Do not jump from one filter manufacturer to another without following the steps previously mentioned.
- Aim to have sufficient airflow when the filter is loaded (dirty), not just when it is clean. As such, the filter may need to be changed more frequently than the manufacturer's recommended interval.
- While not intuitive, a thicker filter assembly, such as a 4", has greater filter surface area which results in a lower resistance relative to a standard 1" filter with the same MERV rating. Some HVAC systems may be retrofitted to handle 4" filters. Follow the same routine previously described to check airflow.

Thermostats

In small HVAC systems, similar to residential or small clinic systems, thermostats are usually mounted on a wall near a return air grille. In larger HVAC systems, there may be a network of temperature and relative humidity sensors throughout the systems and a computerized HVAC control system (building management system [BMS]) may serve to control temperature and humidity for the areas served by the HVAC system.

Many different types of thermostats are available for small HVAC systems, ranging from the very simple to programmable units with many functions. Most designs include three basic components:

- A switch that allows the thermostat to control the unit (on/off, fan on/cycle with heating or cooling)
- A thermometer that measures and displays room temperature and often relative humidity
- An adjustable set point that allows the user to input the desired room temperature and often relative humidity

More expensive thermostats allow the user to program the fan, heating, and air conditioning parameters by zone and to have different set points for weekdays and weekends.

The simplest type of thermostat, as used in small HVAC systems, is a three-position switch that operates in response to room temperature. The two positions are **OFF**, **ON**, and **AUTO**.

- When set to **OFF**, the unit will not run, no matter how cold or hot the room becomes.
- When set to **AUTO**, the thermostat will turn on the fan and the heating/cooling component when the room temperature, as measured by the thermostat, drops below the heating set point or rises above the cooling set point.
- When set to **ON**, the fan will operate continuously and the thermostat will turn on the heating/cooling component when the room temperature, as measured by the thermostat, drops below the heating set point or rises above the cooling set point. There are many benefits to leaving the thermostat in the "ON" position:

- The supply air will provide dilution with “clean air” (some portion will be filtered and/or irradiated and some portion may be outdoor air).
- Continuous airflow allows for better airflow patterns and mixing as required for upper-room UVC systems.

For TB control, central control of the HVAC system is recommended.

Checking an HVAC system

To improve TB control and general indoor air quality, make regular checks of all ventilation systems serving the facility. An N95 respirator may need to be worn in the area in the AIIR, within the HVAC system, and where AIIR air is exhausted (in case the air filtration system is not operating properly). Choose a staff person to be the in-house monitor for the ventilation system and follow standard operating procedures for personal protection approved by IPC professionals.

- Develop and maintain a list of basic information for all HVAC systems in the building as a useful IPC tool. The list should include information such as HVAC system location, rooms (including room function) served by the unit, the thermostat location, and the number and size of filters. See Appendix D, *Summary of HVAC Systems Worksheet* for a sample checklist.

If engineering drawings are unavailable, it may be necessary to have a facility engineer or contractor “trace” the HVAC systems to see where all the ducts lead and document the details of the HVAC system. For this task, the facility engineer or contractor will need a rough floor plan of the facility to map and draw the HVAC system. Ducts removing air from AIIRs should be noted and specifically labeled.

Labeling

Maintenance personnel and contractors often re-route ducts to accommodate new services, change-out filters, or perform other maintenance that may require turning off exhaust fans. To help protect these workers, exhaust ducts, fans, and filter housings should be permanently labeled clearly with the words “Caution – TB Contaminated Air,” or “TB-Contaminated Air – Contact Infection Control Coordinator before turning off fan or performing maintenance,” or other similar warnings. The labels should be attached, at most, 20 ft (6.1 m) apart, and at all floor and wall penetrations. Additional signage located on the fans and filters should include the telephone number of the infection control coordinator and the room number(s) of the AIIR(s) exhausted by the fan or through the filter.[5]

Performing checks of HVAC unit

Check operational status of unit:

- Does the unit have the proper filters? Are the filters clean? In a recirculating HVAC system, the lowest efficiency filter is often located at the return grille in the return ductwork (remove grille to check and replace the filters). Larger systems will have the filter bank located immediately before the HVAC unit.
- Check whether an outside air intake is provided at or near the HVAC unit. If

yes, check that the damper is set to the fully open position and that the intake grille and ductwork are clean. While not necessary in all situations, ensuring the damper is set to the fully open position allows for maximizing outside air and reducing the dependency on filtration/disinfection systems for recirculated air.

- Note: "Fully open" does not mean 100% outside air. If there is an outside air intake on a larger HVAC system, it will generally be on the roof or an outside wall. For small systems (i.e., individual room HVAC systems), the damper is generally located in the back of the unit. If there is no damper, then the air is 100% recirculated back into the areas served by the HVAC unit.

Performing checks of AIIRs

- Check that each HVAC system is working by turning on the fan at the thermostat or BMS and observing airflow at all supply diffusers and return grilles. Hold a tissue or generate visible smoke/fog against each outlet to check the direction and "strength" of airflow.
  - At the supply diffuser, the tissue or smoke/fog will be blown away from the diffuser and into the room.
  - At the exhaust or return-air grille, the tissue or smoke/fog will be drawn into the grille and out of the room. Note that dirty or blocked diffusers may impede both airflow rate and airflow patterns.
- CDC (2005) states: "All rooms should be checked for negative pressure by using smoke tubes or other **visual checks before occupancy,** and these rooms should be **checked daily when occupied by a patient** with suspected or confirmed TB disease."[5] This policy statement was originally developed because of the poor performance of physical and electronic pressure monitors.

  At the gap under the door:
  - The tissue or smoke/fog will be drawn into the room for an AIIR.
  - The tissue or smoke/fog will be pushed out of the room for a protective environment.
  - If the tissue or smoke/fog does not move in the proper direction, the cause should be investigated, and the problem remedied before using the room as an AIIR.
  - See Appendix B, *Airborne Infection Isolation Room Pressure Monitor Checklist* for a template to record results.

  Note: Generally, a facilities engineer or trained personnel should also verify the accuracy of the AIIR electronic pressure monitors monthly with a micromanometer (handheld tool to measure pressure).
- Check that the thermostat has a FAN ON or similar setting that allows continuous operation of the fan.
- Check that the HVAC system serves all occupied rooms.
- Check air mixing and determine directional air movement in all parts of occupied rooms.
  - An inexpensive and reliable way to perform these tests is to use incense

sticks to visualize air movement. Smoke tubes or simple smoke generators are other options.

- Check that all diffusers and grilles are clean.
- Check that all exhaust fans in bathrooms and shower rooms are operating properly.

Additional guidance on the evaluation of AIIRs can be found in a review article by Int-Hout (2015).[31]

For further information on methods for checking airflow (e.g., smoke or tissues tests, use of manometer), see Chapter 4, *Airborne Infection Isolation Rooms*, section, *Monitoring AIIR environmental controls*.

Optimizing existing HVAC systems

- Use highest MERV filter that allows adequate airflow rate and ACH
- Maximize exhaust airflow rate
- Maximize outside air (adjustment of outside air dampers) and treatment air (filtration and/or UVC)
- Use thermostats and BMS that allow continuous fan operation
- Run HVAC systems continuously whenever the building is occupied
- Install, if one doesn't already exist, a pressure gauge in HVAC units to monitor filter loading
- Provide natural ventilation to occupied rooms not served by ventilation systems and to all occupied spaces at times when ventilation systems are broken or otherwise not operating
- Consider the use of in-duct UVC as a supplement to filtration and outside air dilution (see Chapter 2: *Environmental Controls, Part 2: UVC*)

Routine upkeep of existing HVAC systems

- Check filters per standard operating procedures and replace when required (see section, *Air filters,* for additional details).
  - Ensure filters are installed correctly in the filter track (not jammed into position).
  - When a new set of filters is installed, write the replacement date on the frame of the filter and/or affix a label to the outside of the filter housing (so the filter change information may be checked without opening the filter housing). Tracking the average life of the filters will help in planning maintenance.
- Clean diffusers, grilles, and in-duct UVC lamps every month.
- Check ventilation units and thermostats every year. Make sure that thermostats operate as designed.

If in-duct UVC is used:

- Check that lamps are operating (ideally, monitor with a calibrated UVC meter)
- Clean lamps every month
- Replace lamps at least once a year or as recommended by the manufacturer
- Dispose of used lamps per local or state regulations or per the manufacturer's recommendations (similar to the disposal of fluorescent lamps)
- Keep records of all routine maintenance activities and dates as well as all episodic maintenance events

Design of new HVAC systems

Architects, engineers, and others designing mechanical systems for new or renovated facilities should consider the following recommendations:

Ventilation rate

- Provide sufficient **airflow rate within the range of 6-12 total ACH** based on the function of the room and the TB risk of those using the room (2 ACH may be appropriate for rooms not used by HCP, patients, or clients). Note that ASHRAE[1,32] and CDC 2019[13] define ACH as CADR divided by room volume. ACH is a measure of how many times the air within a defined space is replaced with clean air in one hour.
- Because loading of filters may result in a decreased airflow rate, the designers should select fans that can still provide an airflow rate in the target range even if the filter is fully loaded.
- Dilution ventilation is an effective environmental control against TB transmission. When installing a new ventilation system, it is generally worth the investment to increase ventilation capacity; the incremental cost is insignificant compared to the total cost of the installation's design and construction.
- If the HVAC system will be supporting an AIIR or protective environment designs, other considerations will need to be included (see sections, *Negative pressure: AIIRs* and *Positive pressure: Protective environments*, or see Chapter 4, *Airborne Infection Isolation Rooms*.

Supply air: Minimum required from outside source

- If a recirculating system is used, a fixed minimum proportion of the supply air should be fresh outside air. This value is usually called the **minimum outside air set point.**
  - **CDC 2005 guidelines recommend a minimum outside air supply rate of 25 CFM per person for homeless shelters.**[5]
  - **ASHRAE** (Standard 170-2021) **recommends a minimum 2 outdoor ACH (out of a total of 12 ACH) in AIIRs and emergency departments, with 100% of the air exhausted to the outdoors.** With 100% of the air being exhausted, the supply must either be: 1) partially recirculated air and/or disinfected air (via filtration or UVC) from other areas of the facility, or 2) 100% outdoor air.[1]
  - Appendix E contains ACH and other ventilation recommendations for selected settings within a healthcare facility.

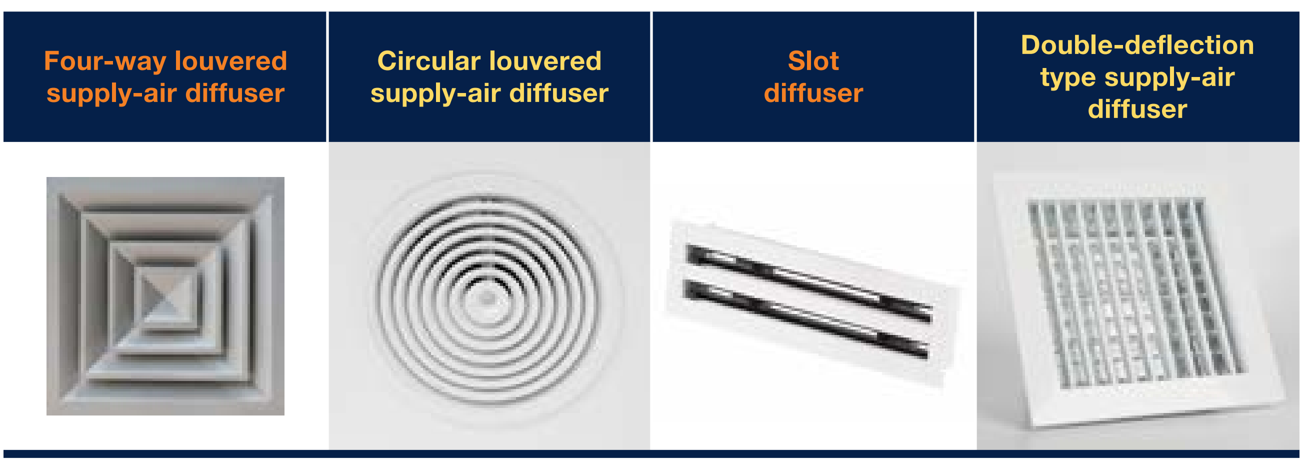
Once-through system or variable recirculating system

- Consider using a single-pass or once-through ventilation system for TB control. This type of system exhausts all air to the outside, rather than recirculating a portion of the air.
- If the operation of this type of system would be too expensive, consider providing a recirculating ventilation system that allows adjustment of the amount of outside air mixed with the recirculated air. Such systems automatically adjust the amount of return air to be recirculated depending on the temperature outdoors. If it is temperate outdoors (e.g., 65°F, 18°C), outdoor air will be continuously brought in to provide what is often referred to as “free cooling,” effectively serving as a single-pass system (with all exhaust air directed to the outdoors).

Air distribution

- **Whenever possible, provide supply air and exhaust locations in each room, rather than collecting exhaust air from several rooms at a single location.** This will reduce the possibility of air currents carrying infectious particles to other areas.
    - Return-air grilles should be located in the same room and as far away as possible from supply-air diffusers so that supply air can fully mix with room air.
- Select the supply air diffusers and exhaust air grilles of the HVAC system to ensure good air mixing. Adequate air supply, air exhaust, and air mixing will greatly reduce the risk of TB transmission by diluting and removing infectious particles. Select diffuser characteristics, such as size and air diffusion pattern, to suit the room characteristics and the individual diffuser location within the room.
    - If the system includes ceiling diffusers, air mixing can be enhanced by using the louvered face type or slot diffusers, rather than the perforated face type of diffusers. Perforated designs are better suited to be used as exhaust grilles. See Figures 11 and 12.

FIGURE 11. **Examples of diffusers**



Sources: Adobe/AliaksandroBS, Adobe/Evannovostro, Adobe/29612992, Adobe/Grispb

- If sidewall air supply diffusers are used, the diffusers should be the double deflection type, with two sets of air deflection blades. The front set of blades is vertical; the second set behind these is horizontal. The louvers should be adjusted to provide even airflow patterns in each room.

In-duct UVC in HVAC systems

- In-duct (or return-duct) UVC may be used in an HVAC system to disinfect air removed from a group setting before recirculation. In-duct UVC is discussed in more detail, see Chapter 2: *Environmental Controls, Part 2: UVC, section, Irradiation of air in an HVAC system (in-duct UVC)*

FIGURE 12.

Exhaust grille (perforated)

Source: CITC

Advantages and disadvantages of HVAC systems

ADVANTAGES	DISADVANTAGES
› Can be effective 24 hours a day, year-round › Controllable, adjustable, and predictable › Help prevent transmission of airborne infectious diseases, including TB › Help control temperature, relative humidity, odor, and indoor air pollutants	› Expensive to plan, install, operate, and maintain › May be drafty and/or noisy if poorly designed and/or installed › Like all environmental controls, maintenance required

HVAC system

Dan has been running an inner-city homeless shelter called *You're Welcome Here* for the last 4 years. The shelter is in the converted basement of a church. When he started working there, Dan noticed that it felt stuffy most of the time.

CASE STUDY

The public health department recently issued a notice alerting shelters of an increase in TB cases among the community's marginally housed population. The shelter screens clients for TB symptoms at intake. The notice prompted Dan to implement some environmental control improvements, something he had been thinking about since his first day on the job. He decided to start by looking at the ventilation system.

Dan made the following assessments and improvements in a few hours, without having to call in the service company, and equipped only with incense sticks, a screwdriver, and a tape measure.

- The existing forced-air HVAC system consisted of a furnace in a janitor's closet, a single return-air grille on the wall outside the closet, six supply-air diffusers in the ceiling of the basement, and a thermostat.
- The return-air grille and duct were extremely dusty. Dan removed the grille and cleaned out the dust with a vacuum cleaner.
- He opened the filter section. The filter was a flat lint-type (MERV-3). It was also extremely dusty and was incorrectly installed in the filter track. Dan measured the lint filter (20" x 25" x 1") and discarded it. He bought three replacement pleated filters (MERV-11) of the same size from a nearby hardware store. They cost about $15 each. He wrote the date on one of the filters, placed it in the furnace, and saved the other two as spares.
- The thermostat had an adjustable temperature setting and three fan settings: OFF, AUTO, and FAN ON. It was set to AUTO so the fan would come on only when the temperature dropped below 68°F. Dan set the controls to FAN ON, and the fan in the unit came on immediately. The improvement in ventilation was obvious (more air moving into room) and less dust was observed on surfaces over time.
- The furnace had no outside air intake and there was no obvious way to connect one because the unit was not close to an outside wall. To let in natural ventilation, Dan decided to keep at least two windows partially open whenever the building was occupied.
- Dan used some incense sticks to evaluate air movement. In addition, he noticed the tissue paper strips taped to the supply-air diffusers fluttered the same as with the lower-efficiency filter. He was happy to see that air movement was visible throughout the shelter. He also confirmed the direction of airflow at each diffuser and at the grille.

ASK:

What steps should Dan take to ensure that routine maintenance is done for the HVAC system?

Include annual budget for maintenance and set-up routine checks as part of the IPC plan (see Chapter 1, *Administrative Controls*).

Natural ventilation

Natural ventilation refers to fresh dilution air that enters and leaves a building through openings such as windows, doors, rooftop "whirlybirds", vertical ducting, and skylights. Natural ventilation is the use of natural forces to introduce and distribute outdoor air into or out of a building. These natural forces can be wind (horizontal) or buoyancy generated by the density difference (vertical, warm air rising over cooler air) between indoor and outdoor air.

While natural ventilation may be appropriate in some healthcare settings, it is not an option in many settings where airborne infectious particles need to be controlled. In buildings without operational mechanical ventilation systems, natural ventilation may be used to provide fresh outdoor air to all occupied rooms in the building. However, this may not be practical in extremely hot or cold climates.

Note: Use of natural ventilation methods may not apply to certain settings, such as AIIRs where well-defined airflow rates and pressure differentials are required. Natural ventilation should be implemented only when in compliance with applicable local, state, and industry regulations for your facility.

Wind-driven, buoyancy-driven, and mixed-mode natural ventilation

Wind-driven natural ventilation is sometimes called *horizontal natural ventilation* because winds are generally in a horizontal direction. To optimize wind-driven natural ventilation, good cross-ventilation is needed. To achieve this, one needs openings on opposing sides of a room such that the air may freely flow through the room or space. There is much more to this than simply opening windows. Openings on each opposing side should be approximately 10% of the area of the room (ft^2 or m^2). Ideally, the building should be aligned perpendicular to the prevailing winds.

FIGURE 13.

Wind-driven ventilation

Source: Adobe/Fokke Baarssen

Next to wind speed and direction, the area of the smallest opening is the limiting factor in maximizing air exchange.

Buoyancy-driven natural ventilation is sometimes called vertical natural ventilation or temperature-driven natural ventilation. In this case, if there are vertical stacks (or ducts) from a room or space to the outdoors, and the air temperature in the room is greater than the air outdoors, air will flow from the room or space to the outdoors. In addition, people and equipment generate heat which enhances the movement of air vertically.

Mixed-mode or hybrid natural ventilation is natural ventilation that is "combined" with some type of mechanical ventilation system. Because the effectiveness of wind-driven natural ventilation alone may wane to near zero levels when the wind is minimal or non-existent, a mechanical means of ensuring a minimum air exchange rate is needed. In this case, you may supplement the natural ventilation with a well-designed exhaust-only or dilution mechanical ventilation system. One must ensure good air-mixing or movement across the room.

FIGURE 14. **Buoyancy-driven ventilation**

Source: Adobe/James

FIGURE 15. **Whirlybird**

Source: Shutterstock

Clinics or shelters that do not have a central heating and/or air conditioning system often have **exhaust fans** serving certain areas. Two common examples of exhaust-only mechanical ventilation are bathroom exhaust fans and range hoods used over kitchen stoves. These fans increase ventilation by directly exhausting room air to the outdoors. The "make-up air" or air entering the room is generally leaked in from the outside. There is a wide variety of exhaust fan systems. A system can be as simple as a propeller fan installed in the wall, or it could include a ceiling grille, with a fan and a duct, discharging air through an outside wall or the roof. Over time, dust and lint accumulate on all fans. The fans will become less efficient, and less air is exhausted. For this reason, these systems should be cleaned regularly.

"Whirlybirds," or wind turbines, provide a means to convert wind energy into an exhaust fan by causing the spherical top of a duct to rotate and cause suction; hence, exhausting air from a room. If there is no wind but the temperature inside the room is warmer than the outside temperature, air will move vertically and exhaust to the outside. See Figure 15.

In general, natural ventilation strategies can range from very simple to very complex designs. See WHO *Natural Ventilation for Infection Control in Health-Care Settings*, 2009.[33] for a more detailed discussion for natural ventilation applications.

Using fans with natural ventilation

Propeller fans

Propeller fans can be an inexpensive way to **increase the movement and mixing of air in a room;** however, unless they are sealed and pulling air directly from a window or other opening and pushing it inwards, they provide very little air exchange. They are often added to support both natural and mechanical ventilation systems and induce airflow patterns and air mixing.

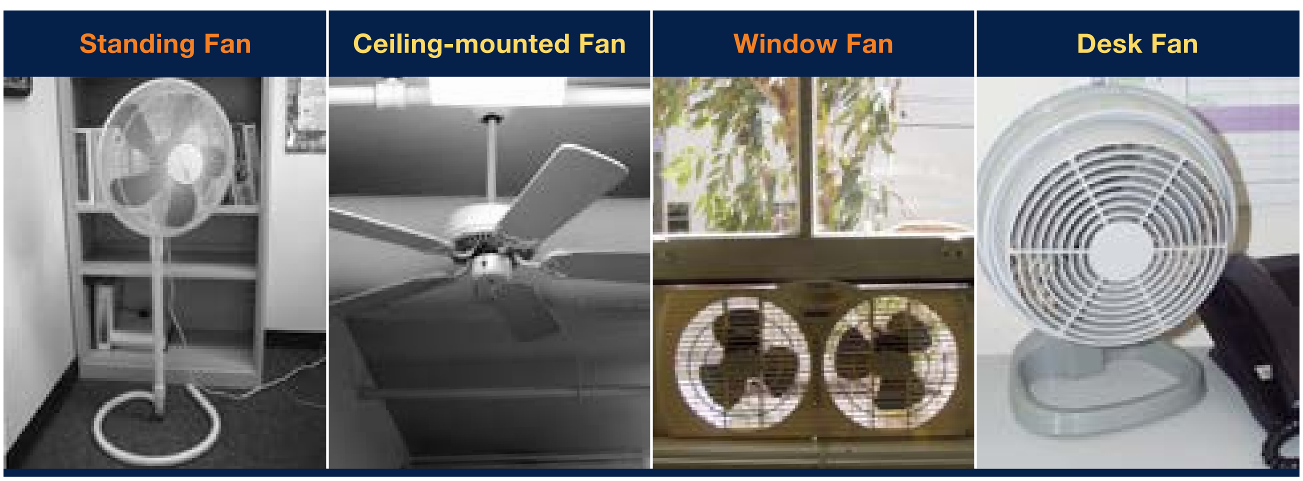
Types of propeller fans

Ceiling fans are propeller fans that are suspended from the ceiling and move air vertically. They circulate air throughout a room but do not remove or inactivate microorganisms. In general, vertical air movement is more efficient at air mixing compared to horizontal air movement only. **Wall and oscillating fans** move air both horizontally and vertically. **Stationary propeller fans** move air mostly horizontally in a room and are less efficient at air mixing than ceiling or oscillating fans.

Types of propeller fans include:

- Fixed fans that pedestal (stand) on the floor
- Ceiling-mounted fans
- Window fans
- Small fans that sit on a desk or other surface

FIGURE 16. **Examples of propeller fans**



Source: CITC

Considerations for natural ventilation

As previously noted, natural ventilation with horizonal airflow using cross-ventilation may work well in some settings. A room with good cross-ventilation (open windows and/or doors with a mixing fan; good mixing, dilution, and removal) will have less TB-transmission risk than a room that may have a mixing fan but openings only on one side with only modest exchange of air in and out (good mixing, modest dilution and removal). The highest TB-transmission risk would be an enclosed room with windows only on one side and no fan and/or no mechanical ventilation (poor mixing, dilution, and removal).

When relying on natural ventilation (with or without fans), consider the following:

- **Natural ventilation can be unpredictable** and may not be practical in very cold or very hot climates. If this is the case, you should consider adding an HVAC system. See section, *HVAC systems*.
- Check that doors, windows, and skylights are easy to open and that any screens or grilles are clear of obstructions. **Keep them open as often as possible** to provide fresh outside air to all occupied rooms (especially if there is no HVAC system).
- Provide extra blankets to occupants who complain of drafts so that ventilation can be used when the space is occupied.
- If fans cause objectionable noise or drafts and cannot be used when the space is occupied, look first for simple solutions that preserve ventilation.
  - Clean the fan blades
  - Adjust direction and/or speed of air movement
  - Replace fan with quieter equipment
- If appropriate for the space and how it is utilized, **consider increasing ventilation at times when the space is unoccupied.** For example, many settings (e.g., shelters) are closed during part of the day, providing an opportunity to open windows and doors while running fans at high speed to "air out" the space.
- If natural ventilation or addition of an HVAC system is not feasible, consider the use of room air cleaners or upper-air UVC to provide clean air on a room-by-room basis. See sections, *Upper-air UVC* and *Room air cleaners*.

Supply and exhaust fans

- A **supply fan** in a window or other opening may be added to augment airflow into the facility. Use the manufacturer's stated airflow rates to select the proper size fan to obtain desired ACH. Window screens or other objects overlying the unit will result in airflow rates lower than those stated by the manufacturer and must be considered.
- When possible, room fans should be placed in locations where they will add to horizontal natural ventilation currents.
  - **Place staff near fresh air sources.**
  - It is always easier and more efficient to blow/push air than to suck/pull air (e.g., it is easier and more efficient to blow out a candle than to suck in air near a candle to extinguish the flame). Therefore, **a well-placed supply fan may be a more efficient way to bring in fresh air for air exchange than using an exhaust fan.**

- Place exhaust fans so that air flows from clean to less clean areas. Fan selection criteria are the same as those stated for supply fans.

Mixing fans

- **Add ceiling or wall fans to increase air mixing.**
- Air mixing can be verified using a simple smoke test to ensure all areas of the room have appropriate air movement. Adequate air movement for mixing is technically at least $\geq$ 20 ft/min (0.1 m/sec) which visually would be a slow drift during the smoke test of $\geq$ 4 in/sec.
- Keep fans running as much as possible when the space is occupied.

Routine upkeep for natural ventilation and exhaust fans

- Ensure all windows, doors (and grilles in doors), and other openings are clean and airflow is unimpeded by furniture, curtains, equipment, or other items.
- **Clean exhaust fan outlets and fans about once a month.** Use a damp cloth or vacuum cleaner to remove dust and lint from fans and grilles. Do not perform this task when patients or clients are in the room.
- The effectiveness of natural ventilation will vary. **Check the appropriateness of natural ventilation in different seasons, times of day, and environmental conditions.** This will give the building management an understanding of whether supplemental mechanical ventilation might be needed due to lack of airflow or unacceptable environmental conditions for natural ventilation.
- **Keep records** of all routine upkeep activities and dates.

Advantages and disadvantages of natural ventilation and fans

ADVANTAGES	DISADVANTAGES
› Natural ventilation can be implemented easily by opening doors and any operable windows and skylights. Unfortunately, not all modern buildings are suited for natural ventilation. › Bringing fresh air into a space reduces the risk of TB transmission and may improve overall indoor air quality. Unwanted indoor pollutants and odors are reduced. › Exhaust fans are generally inexpensive. › Good natural ventilation can be easily added to a building in the design stage.	› Natural ventilation can be uncontrollable and unpredictable depending on wind conditions and other microenvironmental factors. For example, people may close windows and doors, or the wind direction outside may change. › Air that is introduced directly from the outdoors, without the benefit of filters or other air-cleaning devices, may bring in unwanted elements, such as traffic exhaust and noise, rain, dust, odors, pollen, and insects. › Keeping windows and doors open may adversely affect security, comfort (temperature and humidity), and privacy. This is especially true at night and in the winter. › It is difficult to modify a building originally designed with an HVAC system to ensure adequate natural ventilation. › If a building has an operable HVAC system, opening windows may adversely affect room pressurization as well as result in damage to both the HVAC system and building if not properly implemented.

Natural ventilation and exhaust fans

Lynn is the director of *Welcome Home*, a homeless shelter that serves approximately 100 people each night.

The building is a converted warehouse with a high ceiling. It is divided into men's and women's dormitories, each with a shower and toilet room, and a small office area.

CASE STUDY

Lynn is concerned about the spread of TB because of the high incidence of TB among the urban homeless population. Her facility does not screen clients for TB. Because it operates on a first-come, first-served basis, it generally houses a different group of clients each night, thereby possibly increasing the risk of TB transmission. While her facility has not had a TB outbreak, Lynn knows it could happen at any time.

There is no HVAC system. Each shower and toilet room has an exhaust fan.

Check ventilation

After adding a TB screening program for her clients, staff, and volunteers, Lynn wanted to improve ventilation in her building. Her first step was to check the existing ventilation.

Using incense, she noted that air mixing seemed satisfactory near doors and open windows as smoke seemed to disperse quickly. In the corners, away from doors and open windows, however, air movement seemed slow or nonexistent.

To match nighttime conditions, Lynn closed the doors and windows and repeated the tests. Air movement was slow or nonexistent throughout the facility.

Lynn looked at the two exhaust fans in the shower and toilet rooms. Both had a considerable buildup of lint and dust. She turned them on and held a piece of paper against each grille. In the men's room the paper was pulled against the grille. But in the women's room there was no pulling effect, and Lynn noticed that she could not hear the fan running.

Based on these simple checks, Lynn now had a good idea of the ventilation in her building:

- **During the day, when doors and windows were kept open, air movement was good except in the corners of the rooms.**
- **At night, when doors and most windows were closed, air movement was slow to non-existent.**
- **Both exhaust fans needed cleaning.**
- **The exhaust fan in the women's room was not operating.**

ASK: How could Lynn improve the situation with her limited budget?

With a vacuum cleaner, she thoroughly cleaned the two exhaust grilles. She noticed an immediate improvement in airflow at the grille in the men's room, but the fan in the women's room still was not working.

CONTINUED ON NEXT PAGE

CASE STUDY

CONTINUED FROM PREVIOUS PAGE

Improvements

The very first step taken by Lynn was to ensure there was some minimal opening at the top of **all** windows, including windows above any doors. Near the corners on the back wall were two blocked-up windows. It occurred to Lynn that if she were to install an exhaust fan in each of these windows, it should produce an air current throughout the stagnant area near each fan, regardless of whether the doors and windows were open. Air would be drawn from the "permanent" openings added by Lynn. When additional funds are available, Lynn will purchase and install a few ceiling fans to increase air mixing in the room.

The very first step taken by Lynn was to ensure there was some minimal opening at the top of all windows

She measured the window openings and the room volume. She then bought through-the-wall fans at her local hardware store for each window to improve the ACH. Commercially available kitchen and bathroom fans generally come in different sizes and airflow rates (50-200 CFM). Staff from an affiliated job-training program installed the fans in the windows as part of a training exercise. Lynn made sure that the window fans exhausted air out the back of the building.

While the crew was at her building, Lynn asked them to look at the exhaust fan in the women's room. They found the problem, a loose connection, and repaired it.

The results

Lynn did some final incense tests that night, with the fans on and the doors closed. Air movement was greatly improved throughout the facility. However, some clients complained about a slight draft and were provided with extra blankets.

She repeated the tests the next morning with the windows and doors open and was pleased to see that airflow was now satisfactory, even in the corners.

Feeling very proud of herself, Lynn wrote and posted a one-page policy summarizing her environmental control efforts:

- **Keep doors and windows open during the day.**
- **Always keep all fans (toilet exhaust and through-the-wall exhaust fans) ON.**
- **Clean fans on the first of every month.**

The next month, Lynn was happy to share her experience and her policies with her peers at a meeting of the local homeless shelter directors' organization. The members agreed that, while TB transmission at *Welcome Home* could still occur, the risk had been reduced. Furthermore, the increased fresh air had improved the indoor environment for her staff and clients.

ASK:

What else could be done to prevent the transmission of TB in homeless shelters?

See Chapter 1, *Administrative Controls*, and Chapter 6, *Homeless Shelters*, for more ideas.

Using fans within a room with an HVAC system

Propellor fans may be used in conjunction with some HVAC systems:

- When using upper-room UVC fixtures, air mixing (from the occupied space to and from the upper portion of the room) is critical. Propeller fans and ventilation diffusers will enhance the effectiveness of this application.

Adequate **air mixing** is also an important component for dilution ventilation strategies. Propellor fans may be useful **to minimize stagnation, temperature stratification, and short-circuiting.**

If placed in or near a wall opening, fans can also be used to encourage air movement into and out of a room; however, a **facility engineer should be consulted** to determine if such an intervention will adversely affect the performance of the existing mechanical ventilation system. For example, if someone opens a window and blows warm air into an air-conditioned space, three things may happen:

- At or near the supply air diffusers, water will condense. This will cause water to “drip” into the space as well as wet the ceiling, creating an environment perfect for mold growth.
- Because the air-conditioning system was not designed to cool the additional heat load of the warm outside air, it will run much longer to reach a set temperature, possibly running continuously. The air conditioning system may not be able to maintain the desired temperature and humidity.
- The life of the air conditioning system will be shortened

Windows and doors should not be left open in AIIRs (this will disrupt the desired pressure balance).

Room air cleaners (RACs)

Room air cleaners (RACs) are readily available equipment that can be used anywhere to **provide clean air.** RACs allow improvement to air quality in any room. No detailed engineering knowledge is required to install or maintain RACs. These units are especially **useful in settings that may have inadequate or no mechanical ventilation and limited funds for upgrades.**

RACs with filter(s) are available in a variety of sizes and configurations, but all consist primarily of:

- A primary filter to remove small particles from the air
- A prefilter to remove larger particles and thereby prolong the life of the higher-efficiency filter
- A fan to pull the air through the filter and recirculate the filtered air into the room
- Controls, such as an on/off switch, timer, and fan speed (airflow rate) control

Portable, freestanding devices are the most common type of units. Ceiling-mounted and wall-mounted units are also available. Portable units have the advantage of greater flexibility and ease of installation and service. Permanent units are less vulnerable to tampering and theft, less likely to be in the way, and cannot be easily moved to a location where they will be less effective. RAC selection is based on the amount of “clean” air they deliver, usually expressed in CFM or m^3/h.

The critical performance factors or characteristics of an acceptable RAC include:

- **Clean air delivery rate** (CADR) necessary to provide the needed ACH in the room or setting
- Relatively quiet operation (<55 dBA), even at the highest airflow rate
- Standard US 110-120V outlet or circuit compatibility
- Portable (floor or tabletop) or fixed (wall- or ceiling-mounted) capability to match setting needs
- Ability to induce airflow patterns and/or work in synergy with the existing HVAC system to ensure good air mixing in the room without causing drafts

For additional, detailed discussions on the use of RAC, see references 3, 4, and 5.

RAC filters

A RAC with filter will provide cleaned air to dilute infectious particles and can also remove infectious and other airborne particles. **HEPA filters** remove 99.97% of particles 0.3 μm in size (essentially all infectious particles in the size range of concern for TB) and are used in many available RAC units. However, it takes a powerful, possibly noisy fan to pull air through them. Other less efficient filters, such as a **MERV-13 or higher,** may be used at a higher airflow rate to provide a similar or greater CADR than a RAC with a HEPA filter. TB infectious particles are significantly larger than particles used to test HEPA filters, so RACs that use "near-HEPA" filters (like MERV-13 or higher) can remove the majority of particles of concern for TB and may be appropriate for use in healthcare settings. See ASHRAE (Standard 52.2-2017)[25] for further details.

Other technologies to remove or disinfect infectious particles include:

- UVC
- Electrostatic plates
- Ion generators

Clean air delivery rate (CADR)

CADR is the rate at which an air cleaning device or equipment, including RACs, delivers clean or disinfected air to a room or space. The CADR is measured in CFM or m^3/h.

For a **RAC with filter, the CADR is approximately the product of the actual airflow rate (CFM or m^3/h) and the filtration efficiency of the filter for the particle size of interest,** assuming no leakage around the filter.

- For a RAC with UVC, the CADR is approximately the product of the actual airflow rate (CFM or m^3/h) and the efficiency of UVC to inactivate a select microorganism in a single pass through the RAC. If a test microorganism other than *Mycobacterium tuberculosis* is reported, one must ensure the microorganisms selected is at least as susceptible to inactivation by UVC as *Mycobacterium tuberculosis.* If the RAC has a filter, other than a coarse filter to keep the UVC lamp clean, the CADR is a function of both inactivation by UVC and removal by filtration.

- When choosing a RAC (CADR ≤450 CFM for particulate and/or CADR ≤600 CFM for microorganisms), **look for an Association of Home Appliance Manufacturers (AHAM) Verifide® certificate* or other independent testing certificate** (see *Steps for selecting a RAC* for an example certificate). The U.S. Environmental Protection Agency (EPA) also provides guidance on smaller RACs.[34]
- Larger RACs (CADR >450 CFM for particulates and/or CADR >600 CFM for microorganisms) are not tested to any American National Standards Institute (ANSI)/AHAM standard and will not have an AHAM Verifide® certificate (must rely on an independent testing certificate).
- AHAM testing includes challenges against pollen (5 µm to 11 µm), dust (0.5 µm to 3.0 µm), and tobacco smoke (0.10 µm to 1.0 µm); HEPA filters are tested with 0.3 µm particles (noting that TB infectious particles of interest are 1-5µm). **Generally look at the tobacco smoke or dust results when considering use for TB IC** purposes.

Small RACs

Small RACs deliver 10 to 450 CFM (17-765 m^3/h) of "clean air." Most units include a two- or three-position fan speed (airflow rate) control but no other controls. Small RACs are useful for individual offices, on-site clinic rooms, and other smaller areas.

Small RACs are light enough to be easily carried around and placed on a desktop or other surface. These units are readily available from hardware stores and similar retail outlets.

Small RACs may use MERV-13 or higher efficiency filters, up to and including HEPA filters.

- The **key performance parameter of interest should be the CADR** of the RAC and not the filter classification used.

FIGURE 17.

RAC (low airflow rate)

Source: CITC

* AHAM Verifide® certificate requires one of these two standards is met: ANSI/AHAM Standard AC-1-2020: *Method for Measuring Performance of Portable Household Electric Room Air Cleaners*[3] and ANSI/AHAM Standard AC-5-2022: *Method for Assessing the Reduction Rate of Key Bioaerosols by Portable Air Cleaners Using an Aerobiology Test Chamber*.[4]

Large RACs

Large RACs can deliver from 450 to 1,000 CFM (765-1,700 m^3/h) of clean air and can be used in larger rooms in which groups of people may spend time, such as TV lounges or waiting rooms. **Since these RACs are generally not certified to meet AHAM requirements, independent test reports should be reviewed.**

These units usually have wheels so they can be moved from room to room. Like small RACs, large RACs include a two- or three-position fan speed (airflow rate) control and often a warning light to indicate when filter replacement is recommended.

Options may include a lockable cover for the controls to prevent tampering and an internal UVC lamp. Because the RAC removes most infectious particles in the TB size range, UVC offers minimal added benefit when combined with appropriate filtration.

Some large RACs are designed to exhaust all or a portion of the air to outdoors, creating a room that meets the negative pressure requirements of an AIIR.

Larger units are available from specialized medical equipment suppliers and industrial suppliers.

FIGURE 18.

RAC (high airflow rate)

Source: AeroMed/B. Palmer

Considerations for placement and use of RAC

- Provide portable RACs for all unventilated or poorly ventilated rooms frequented by patients or clients unless the rooms have an operable window or door that is usually kept open when the rooms are occupied.
- **Place small RACs off the floor and near staff so that the clean air generated by the RACs is delivered close to the breathing zone of the people that they are intended to protect.** Consider the HEPA filter unit primarily as a source of clean air and secondly as a removal device for contaminated air.
- Place units evenly throughout crowded rooms so that air movement can be observed in all parts of the room.
- **Select each RAC based on the CADR it produces when it is running at or near the low-speed setting.** RACs with HEPA filters can be noisy when running at higher speed settings. For this reason, people tend to operate them at low or medium speeds in small rooms during interviews. However, at lower fan speeds (airflow rates), the dilution effect is reduced because the RACs do not provide as much purified air as at higher fan speeds (airflow rates).
- Operate RACs continuously while rooms are occupied by patients or clients and for approximately 1 hour after they leave.

RAC selection

- Select RACs with a **CADR that provides an air exchange rate of at least 6 ACH for most general settings.**
  - ASHRAE recommends the minimum air change rate of **6 ACH for exam rooms and 12 ACH in selected areas of healthcare facilities** (e.g., emergency department waiting rooms, aerosol producing/generating procedure rooms, and AIIRs). Given the rate of TB among people who are unstably housed, a congregate group room is comparable to a hospital waiting room, and an interview room is comparable to an exam room.
  - While not ideal, if an existing HVAC system provides some of the necessary ACH, a RAC can be added to increase the total ACH for the space (e.g., HVAC provides 6 ACH + RAC provides 6 ACH = 12 ACH). A better solution would be an upgrade to the HVAC system.
- Note: The CADR listed for a unit is generally based on a clean filter. As the filter loads over time, airflow rate and the actual CADR will decrease.
  - To compensate for this, **add a safety factor of 50% to the required CADR.** The additional cost of buying a RAC with more capacity is usually not significant compared to the total cost of the RAC.
- Make RAC selection based on RAC's AHAM Verifide® certificate or other independent verification of CADR. Note that the reported CADR is based on the RAC operating at the highest airflow setting, if adjustable.
  - Unvalidated RACs may deliver less than the manufacturers' listed CADR and generally are not recommended.

Steps for selecting a RAC:

(See Table 4, *Selection of RAC based on room volume and CADR*)

1. Measure room then calculate the room volume (length x width x ceiling height). For example, a room that is 10 ft wide by 10 ft long with an 8 ft ceiling will have a volume of 800 ft^3 (or 22.7 m^3).
2. Determine the CADR needed for the room based on the room size. Six ACH is the minimum recommended for general room use for healthcare settings. The required CADR in CFM or (m^3/h) to achieve this air exchange rate is calculated as follows:
   - (Room volume x 6 ACH) / (60 minutes per hour) = airflow in CFM; or (Room volume x 6 ACH) = airflow in m^3/h
   - Add a safety factor to the desired CADR that takes into consideration the gradual loading of a filter over time. The recommended CADR that includes a 50% safety factor is listed as "Minimum CADR with 50% Safety Factor" in Table 4.
     - Example: Assume an 800 ft^3 room volume, to achieve 6 ACH and have a 50% safety factor, choose a RAC with a CADR of at least 120 CFM (204 m^3/h).

TABLE 4. **Selection of RAC based on room volume and CADR**

ROOM VOLUME	CADR FOR 6 ACH	MINIMUM CADR WITH 50% SAFETY FACTOR
800 ft^3 (22.7 m^3)	80 CFM (136 m^3/h)	120 CFM (204 m^3/h)
1,000 ft^3 (28.3 m^3)	100 CFM (70 m^3/h)	150 CFM (255 m^3/h)
1,500 ft^3 (42.5 m^3)	150 CFM (255 m^3/h)	225 CFM (382 m^3/h)
2,000 ft^3 (56.6 m^3)	200 CFM (340 m^3/h)	300 CFM (510 m^3/h)
4,000 ft^3 (113 m^3)	400 CFM (680 m^3/h)	600 CFM (1,020 m^3/h)
8,000 ft^3 (227 m^3)	800 CFM (1,360 m^3/h)	1,200 CFM (2,040 m^3/h)

3. Select RACs in which CADR has been independently verified or with an AHAM Verified® certificate.

- Caution: Units with CADR values listed may in reality not match the advertised efficiency, and additional calculations to determine ACH may be required. Read labeling carefully and **do not** automatically use the "room size" information given by manufacturers or the AHAM Verifide® certificate as they assume an 8 ft (2.4 m) ceiling height (see example below).
- If CADR values are given for tests against tobacco smoke, dust, and pollen, **use the CADR values given for tobacco smoke or dust** when choosing a unit for TB IC purposes. Particle ranges tested for tobacco smoke and dust both cover the size range of concern for infectious TB particles.
- See Figure 19 for an example of how an AHAM Verifide® certificate label may appear on a unit.

The AHAM site explains that the room size in square feet on the certificate **assumes a ceiling height of 8 ft.**

- If the room in which the RAC will be placed in has an 8 ft ceiling height, then comparing the square footage on the certificate works directly.
- If the room has different dimensions, multiply the square feet value given for the RAC x 8 ft height to **calculate comparable volume** that AHAM used (360 ft^2 x 8 ft = 2,880 ft^3 for room volume). The CADR performance listed for this unit will apply to a room of this volume.
- If the intended room measures: 18 ft long x 15 ft wide x 10 ft high = 2,700 ft^3 volume, the CADR needed for 6 ACH for a 2,700 ft^3 room is approximately 300 CFM. If a 50% safety factor is added, the desired CADR would be 450 CFM. Using the CADR performance for tobacco smoke of 240 CFM, two of these RACs would easily fulfill the needs or consider finding a different single unit with a higher CADR performance.

FIGURE 19.

Example AHAM Verifide® certificate label

Source: AHAM Verifide®

Note: Most RACs include a control switch that adjusts the airflow from a fixed minimum (low setting) to a fixed maximum (high setting). Because of the increased noise, people tend to use the units at the low setting. Therefore, if CADR values are given for the low setting, consider selecting a unit based on the CADR for lower airflow setting (e.g., for a unit with low/medium/high settings the CADR values may be listed as 100/150/200 CFM [170/255/340 m^3/h]). Many units only list the CADR achieved using the highest airflow setting.

Routine upkeep of RAC filters

- **Designate a staff person to be the in-house monitor of the RACs.** This person should be aware of the basic principles of RAC operation, including effective placement and maintenance. This person should also implement a written schedule for changing the prefilters and primary filters.

Maintenance consists of replacing the prefilter and the primary filter at regular intervals. The manufacturer's instructions should explain how this is done. **In general, replace the prefilters every 3-6 months, and replace the primary filters every 1 or 2 years.** Actual replacement time will depend mainly on how often the units are used and how dusty the room air is.

Advantages and disadvantages of RACs

ADVANTAGES	DISADVANTAGES
Can be implemented almost immediately	Unpredictable because, if controls are accessible, patients, clients, or staff members may: turn them down or off; move or unplug the units; place books or other items on top that may impede airflow; or even place under the bed to reduce noise
Can be implemented room by room	Can be drafty and noisy
Relatively inexpensive to plan, install, and maintain	Do not bring in outside air
Have adjustable airflow rate	Do not filter out odors
Can be portable	CADR/airflow rate decreases as the filter gets loaded with airborne particles
Remove other indoor air particles, such as dust and allergens	
Do not require costly equipment to evaluate	

Room air cleaner (RAC)

Catherine is a case manager in an inner-city homeless shelter. As part of her work, she interviews about six new clients every week. Her office has no ventilation and no window to the outdoors. Because clients have not been medically screened and because of the lack of ventilation, she is concerned about TB transmission. The clinic manager has set aside $150 to buy a RAC for the office once Catherine can tell her what size unit she would like.

CASE STUDY

Catherine wants a unit that will provide an air change rate of at least 6 ACH. She uses a tape measure and a calculator to estimate a suitable HEPA filter unit airflow based on the room's volume.

Room volume	=	width x length x height
	=	8 ft x 10 ft x 9.5 ft
	=	**760 ft^3**

Airflow required for 6 ACH	=	room volume x 6 ACH
	=	760 ft^3 x 6 ACH
	=	4,560 ft^3/h ÷ 60 min/h
	=	**76 CFM**

The actual CADR may be less than advertised. To compensate, Catherine adds a 50% safety factor to get a required airflow of 114 CFM.

76 CFM x 1.5 = 114 CFM

Most units have an adjustable speed setting. They become noisier at the higher speeds. Catherine plans on running the unit at low speeds during interviews, so she decides to select a RAC with a low-speed CADR of at least 114 CFM (if the CADR was evaluated at the low airflow rate).

ASK:

Should Catherine aim to achieve 6 ACH or a higher rate? Why?

Aim for >6 ACH if possible because CADR will decrease as the filter loads (gets dirty).

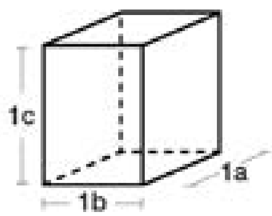
VENTILATION **APPENDIX A:**

Room Clearance Time Calculation Worksheet

Note: For information on how to use a manometer (Vaneometer™) see Chapter 4, *Airborne Infection Isolation Rooms*, section *Monitoring AIIR environmental controls*

Room or Booth # ______________________________

Step 1: Calculate Room Volume



1a. = Room Length (l)

1b. = Room Width (w)

1c. = Room Height (h)

1d. = 1a x 1b x 1c = volume

1a. ________________ ft (m)

1b. ________________ ft (m)

1c. ________________ ft (m)

1d. ________________ ft^3 (m^3)

Step 2: Calculate Air Changes Per Hour (ACH)

2a. Measure the height (h) and width (w) of the exhaust grille

2a. h = ____________ in (cm)

w = ____________ in (cm)

2b. Calculate the area (**2b**) by multiplying the height by the width
2b = **h** x **w**

2b. ______________ in^2 (cm^2)

2c. Convert in^2 to ft^2 by dividing **2b** by 144 in^2/ft^2
Convert cm^2 to m^2 by dividing **2b** by 1,000 cm^2/m^2

2c. ________________ft^2 (m^2)

2d. Measure the average air velocity, at several points (directly at front of exhaust grille), using a Vaneometer™ or electronic velocity meter.

2d. ____________ ft/min (m/s)

2e. Calculate the exhaust airflow rate by multiplying the exhaust grille area (**2c**) by the average velocity (**2d**)
2e = **2c** x **2d**

2e. _____________CFM (m^3/s)

2f. Convert CFM (ft^3/min) to ft^3/hr by multiplying **2e** by 60 min/hr
Convert m^3/s to m^3/hr by multiplying **2e** by 3,600 sec/hr

2f. ____________ ft^3/hr (m^3/h)

2g. Calculate the Air Changes per Hour (ACH) by dividing the exhaust airflow rate (**2f**) by room volume (**1d**)
2g = **2f** ÷ **1d**

2g. ________________ ACH

Step 3: Calculate Room Clearance Time (99% or 99.9%)

3a. Find the Uncorrected Clearance Time

Using Table A-1 (Table 1 of the CDC 2005 Guidelines) on next page, follow the first column down until the ACH value on line **2g** is found.

- A removal efficiency of >99% is preferred; ideally the value in the third column (99.9% removal efficiency) should be used.
- Record this value (number of minutes). This is the amount of time that should elapse before staff or other patients enter a sputum induction area (booth, hood, or room) after sputum has been induced on a person with suspected or known infectious TB and the patient has left, assuming the room has perfect air mixing.

3a. __________________ min

3b. Choose Appropriate Mixing Factor (MF) for the Room/Booth Since perfect room mixing rarely occurs, the value on line 3a must be multiplied by a mixing factor ranging from "1" for perfect mixing to "10" for poor mixing (a "1" represents perfect mixing, use 2 for good mixing and 3 for fair mixing; most healthcare settings have MF of 1 to 2). Smoke visualization and/or observations regarding supply and exhaust vent placement can help you in estimating your mixing factor.	**3b. MF =** ______________
3c. Find the CORRECTED Room Clearance Time: 3a × 3b This is the amount of time, accounting for imperfect mixing, which should elapse before staff or other patients enter a sputum induction area (booth, hood, or room) after sputum has been induced on a person with suspected or known infectious TB and the person has left.	**3c.** ________________ min

TABLE A-1.

Air changes per hour (ACH) and time required for removal efficiencies of 99% and 99.9% of airborne contaminants*

ACH	99%	99.9%
	Minutes Required for Removal Efficiency†	
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

* This table can be used to estimate the time necessary to clear the air of airborne *Mycobacterium tuberculosis* after the source patient leaves the area or when aerosol-producing procedures are complete.

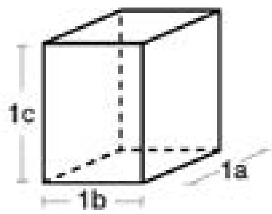
† Time in minutes to reduce the airborne concentration by 99% or 99.9%.

VENTILATION **APPENDIX A:**

Room Clearance Time Calculation Worksheet: Example

Room or Booth # ______________________________

Step 1: Calculate Room Volume



1a. = Room Length (l)

1b. = Room Width (w)

1c. = Room Height (h)

1d. = 1a x 1b x 1c = volume

1a. 12 ft (m)

1b. 15 ft (m)

1c. 9 ft (m)

1d. 1,620 ft^3 (m^3)

Step 2: Calculate Air Changes Per Hour (ACH)

2a. Measure the height (h) and width (w) of the exhaust grille

2b. Calculate the area (**2b**) by multiplying the height by the width
2b = **h** x **w** = **20 in x 20 in** = **400** in^2

2c. Convert in^2 to ft^2 by dividing **2b** by 144 in^2/ft^2
2c = **400** in^2 ÷ **144** in^2 **/** ft^2 = **2.78** ft^2

2d. Measure the average air velocity, at several points, using a Vaneometer™ or electronic velocity meter. Average velocity = **2d**

2e. Calculate the exhaust airflow rate by multiplying the exhaust grille area (**2c**) by the average velocity (**2d**)
2e = **2c** x **2d** = **2.78** ft^2 x **36 ft/min** = **100 CFM**

2f. Convert CFM (ft^3/min) to ft^3/hr by multiplying **2e** by 60 min/hr
2f = **2e** x **60 min/hr** = **100 CFM** x **60 min/hr** = **6,000** ft^3**/hr**

2g. Calculate the Air Changes per Hour (ACH) by dividing the exhaust airflow rate (**2f**) by room volume (**1d**)
2g = **2f** ÷ **1d** = **6,000** ft^3**/hr** ÷ **1,620** ft^3 = **3.7 ACH**

2a. h = 20 in (cm)
w = 20 in (cm)

2b. 400 in^2 (cm^2)

2c. 2.78 ft^2 (m^2)

2d. 36 ft/min (m/s)

2e. 100 CFM (m^3/s)

2f. 6,000 ft^3/hr (m^3/h)

2g. 3.7 ACH

Step 3: Calculate Room Clearance Time (99.9%)

3a. Find the Uncorrected Clearance Time

Rounded up 3.7 ACH to 4 ACH. Using Table A-1, followed the third column (99.9%) down until the ACH value on line **2c** is found.

3a. ~104 min

3b. Choose a Mixing Factor (MF) of 2, good air mixing, for the room

3b. MF = 2

3c. Find the CORRECTED Room Clearance Time: 3a × 3b

This is the amount of time, accounting for imperfect mixing, which should elapse before staff or other patients enter a sputum induction area (booth, hood, or room) after sputum has been induced on a person with suspected or known infectious TB and the person has left.

3c. 208 min

VENTILATION **APPENDIX B:**

Airborne Infection Isolation Room (AIIR) Pressure Monitor Checklist

ROOM NAME and NUMBER ____

MONITOR MANUFACTURER and MODEL NUMBER ______________________________

This form should be completed annually and updated monthly for each room pressure monitor.
Negative pressure should be verified **monthly*** to validate the monitor.
A copy of the completed form should be kept in the Policies and Procedures binder for the department.

MONITOR SETTINGS

Normal pressure reading (monitor reading with door closed) ______________"wg or Pa

Alarm will sound if pressure differential drops to ______________"wg or Pa

Time delay ______________ seconds

Remote alarm location(s) ______________________________

ANNUAL MONITOR CHECKS

Task	Date Completed	Signed Off By
Monitor calibrated in accordance with manufacturer's requirements		
Confirmed negative pressure using smoke tube testing (this test should be repeated **monthly*** and signed below to confirm)		
Verified alarm operation (by holding door open or blocking off exhaust grille)		
Alarm sounded after ___________ seconds		
Pressure reading at alarm ___________"wg or Pa		
Monitor use and functions demonstrated to all floor staff		

MONTHLY* NEGATIVE PRESSURE CHECK

Initials ________ Month/Year ___________	Initials ________ Month/Year ___________	Initials ________ Month/Year ___________
Initials ________ Month/Year ___________	Initials ________ Month/Year ___________	Initials ________ Month/Year ___________
Initials ________ Month/Year ___________	Initials ________ Month/Year ___________	Initials ________ Month/Year ___________
Initials ________ Month/Year ___________	Initials ________ Month/Year ___________	Initials ________ Month/Year ___________

*When in use for suspected or known pulmonary or laryngeal TB patients, airborne infection isolation rooms should also be checked for negative pressure by using smoke tubes or other visual checks before **occupancy, then daily while occupied.**

VENTILATION **APPENDIX C:**

Minimum Efficiency Rating Value (MERV) Parameters

Adapted from Table 12-1, ASHRAE 52.2-2017[25]

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm*		
	Minimum mechanical ACH	**Air recirculated**	**Minimum filter efficiency**
1	N/A	N/A	E3 < 20
2	N/A	N/A	E3 < 20
3	N/A	N/A	E3 < 20
4	N/A	N/A	E3 < 20
5	N/A	N/A	20 ≤ E3
6	N/A	N/A	35 ≤ E3
7	N/A	N/A	50 ≤ E3
8	N/A	20 ≤ E2	70 ≤ E3
9	N/A	35 ≤ E2	75 ≤ E3
10	N/A	50 ≤ E2	80 ≤ E3
11	20 ≤ E1	65 ≤ E2	85 ≤ E3
12	35 ≤ E1	80 ≤ E2	90 ≤ E3
13	50 ≤ E1	85 ≤ E2	90 ≤ E3
14	75 ≤ E1	90 ≤ E2	95 ≤ E3
15	85 ≤ E1	90 ≤ E2	95 ≤ E3
16	95 ≤ E1	90 ≤ E2	95 ≤ E3

* E1 = 0.3-1.0 µm, E2 = 1.0-3.0 µm, and E3 = 3.0-10.0 µm

Summary of HVAC Systems Worksheet: Example

The following form should be completed to create a handy summary of information on the HVAC systems in a building. A sample of a blank template form is also included.

<table>
<tr><th colspan="4">SUMMARY OF HVAC UNITS</th></tr>
<tr><th>Unit Location</th><th>Rooms Served by HVAC System</th><th>Thermostat Location</th><th>Filter(s) (#, size, MERV-#)</th></tr>
<tr><td>Attic above men’s dorm</td><td>Women’s and men’s dorm</td><td>Large men’s dorm</td><td>(1) 20″ x 25″ x 1″, MERV-5</td></tr>
<tr><td colspan="4">Filter is behind return grille in large men’s dorm.
Spare filters are stored in janitor’s closet.
Access to unit is through ceiling hatch in men’s dorm.</td></tr>
<tr><td>Janitor’s closet in kitchen</td><td>Kitchen, meeting room, dining room, women’s bathroom</td><td>Dining room</td><td>(1) 19″ x 20″ x 1″, MERV-7</td></tr>
<tr><td colspan="4">Filter is at unit; undo four screws to change.
Spare filters are stored in janitor’s closet.</td></tr>
<tr><td>Roof above director’s office</td><td>Offices, women’s dorm, small men’s dorm, men’s bathroom</td><td>Women’s room</td><td>(1) 22″ x 22″ x 1″, MERV-9</td></tr>
<tr><td colspan="4">Filter is near HVAC system on roof; ladder to get to roof is in shed. Spare filters are stored in janitor’s closet.</td></tr>
</table>

VENTILATION **APPENDIX D:**

Summary of HVAC Systems Worksheet: Template

SUMMARY OF HVAC UNITS			
Unit Location	**Rooms Served by HVAC System**	**Thermostat Location**	**Filter(s) (#, size, MERV-#)**

VENTILATION **APPENDIX E:**

Ventilation Recommendations for Selected Areas in Healthcare Settings

ASHRAE Standard 170-2021[1]

Healthcare setting	Minimum mechanical ACH	Minimum outdoor ACH	Air movement relative to adjacent areas	Air exhausted directly outdoors	Air recirculated	Minimum filter efficiency
Anteroom for AIIR	10	**NR**	In/Out	Yes	No	MERV-8
AIIR	12	2	In	Yes	No	MERV-14
Autopsy suite	12	2	In	Yes	No	MERV-8
Bronchoscopy room	12	2	In	Yes	No	MERV-14
Emergency department and radiology waiting rooms	12	2	In	Yes	**NR**	MERV-8
Operating room or surgical room	20	4	Out	**NR**	No	MERV-16

NR = No requirement

Resources

General Infection Prevention and Control

Centers for Disease Control and Prevention (CDC)

- *Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings* (2005)
  https://www.cdc.gov/mmwr/pdf/rr/rr5417.pdf
- *Infection Control in Health-Care Settings Fact Sheet* (2016)
  https://www.cdc.gov/tb/publications/factsheets/prevention/ichcs.htm
- Chapter 6: *Tuberculosis Infection Control. In Core Curriculum on Tuberculosis: What the Clinician Should Know, 7th edition* (2021)
  https://www.cdc.gov/tb/education/corecurr/core-curr-tb.htm

World Health Organization (WHO)

- *WHO Consolidated Guidelines on Tuberculosis: Module 1: Prevention – Infection Prevention and Control* (2022)
  https://www.who.int/publications/i/item/9789240055889
- *WHO Operational Handbook on Tuberculosis. Module 1: Prevention – Tuberculosis Infection Prevention and Control* (2023)
  https://www.who.int/publications/i/item/9789240078154

Occupational Safety and Health Administration (OSHA)

- Readers of this guide are encouraged to refer to their state and local regulations and contact their local OSHA office
  https://www.osha.gov/contactus/bystate

American National Standards Institute / American Society of Heating, Refrigerating and Air-Conditioning Engineers / Illuminating Engineering Society (ANSI/ASHRAE/IES)

- *Commissioning Process for Buildings and Systems. ANSI/ASHRAE/IES Addendum a to ANSI/ASHRAE/IES Standard 202-2018.* (2020)
  https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/202_2018_a_20200630.pdf

References

Overview

1. ASHRAE. ANSI/ASHRAE/IES Standard 202-2018, Commissioning Process for Buildings and Systems. ASHRAE; 2020. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/202_2018_a_20200630.pdf

Ventilation

1. ASHRAE. *ANSI/ASHRAE/ASHE Standard 170-2017, Ventilation of Health Care Facilities.* ASHRAE; 2021. https://www.ashrae.org/technical-resources/standards-and-guidelines/standards-addenda/ansi-ashrae-ashe-standard-170-2017-ventilation-of-health-care-facilities
2. ASHRAE. *ANSI/ASHRAE 62.2-2022, Ventilation and Acceptable Indoor Air Quality in Residential Buildings.* ASHRAE; 2022. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/62_2_2022_k_20230727.pdf
3. Association of Home Appliance Manufacturers. *ANSI/AHAM AC-1-2006, Method for Measuring Performance of Portable Household Electric Room Air Cleaners.* Association of Home Appliance Manufacturers; 2006. https://webstore.ansi.org/preview-pages/AHAM/preview_ANSI+AHAM+AC-1-2006.pdf
4. Association of Home Appliance Manufacturers. *ANSI/AHAM AC-5-2022, Method for Assessing the Reduction Rate of Key Bioaerosols by Portable Air Cleaners Using an Aerobiology Test Chamber.* Association of Home Appliance Manufacturers; 2022. https://webstore.ansi.org/standards/aham/ansiahamac2022
5. Jensen PA, Lambert LA, Iademarco MF, Ridzon R; CDC. Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings, 2005. *MMWR Recomm Rep.* 2005;54(RR-17):1-141. https://www.cdc.gov/mmwr/pdf/rr/rr5417.pdf
6. ASHRAE. Chapter 17. Ultraviolet Lamp Systems. In: *2020 ASHRAE Handbook—HVAC Systems and Equipment.* ASHRAE; 2020. https://www.ashrae.org/technical-resources/ashrae-handbook/description-2020-ashrae-handbook-hvac-systems-and-equipment
7. ASHRAE. Chapter 62. Ultraviolet Air and Surface Treatment. In: *2023 ASHRAE Handbook—HVAC Applications.* ASHRAE; 2023. https://www.ashrae.org/technical-resources/ashrae-handbook/description-2023-ashrae-handbook-hvac-applications
8. Mutchler JE. Chapter 39: Principles of Ventilation. In: *The Industrial Environment, Its Evaluation & Control.* National Institute for Occupational Safety and Health, Center for Disease Control; 1973. https://www.cdc.gov/niosh/docs/74-117/
9. Centers for Disease Control and Prevention. Chapter 6: Tuberculosis Infection Control. In: *Core Curriculum on Tuberculosis: What the Clinician Should Know.* 7th ed. Centers for Disease Control and Prevention; 2021. https://www.cdc.gov/tb/education/corecurr/
10. *Engineering Guide Displacement Ventilation.* Price Industries; 2016. https://www.priceindustries.com/content/uploads/assets/literature/engineering-guides/displacement-ventilation-engineering-guide.pdf
11. GPC 37. *Guidelines for the Application of Upper-Air (Upper Room) Ultraviolet Germicidal (UV-C) Devices to Control the Transmission of Airborne Pathogens.* ASHRAE; 2023. https://www.ashrae.org/technical-resources/standards-and-guidelines/project-committee-interim-meetings
12. Jensen PA, Hayden II CS, Burroughs GE, Hughes RT. Assessment of the health hazard associated with the use of smoke tubes in healthcare facilities. *Appl Occup Environ Hyg*. 1998;13(3):172-176. https://www.tandfonline.com/doi/abs/10.1080/1047322X.1998.10390058
13. Sehulster LM, Chinn RYW, Arduino MJ, et al; Centers for Disease Control and Prevention. *Guidelines for Environmental Infection Control in Health-Care Facilities. Recommendations from CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC).* American Society for Healthcare Engineering/American Hospital Association; 2019. https://www.cdc.gov/infectioncontrol/pdf/guidelines/environmental-guidelines-P.pdf
14. Facility Guidelines Institute. *Guidelines for Design and Construction of Hospitals.* Facility Guidelines Institute; 2022. https://shop.fgiguidelines.org/products/15
15. Facility Guidelines Institute. *Guidelines for Design and Construction of Outpatient Facilities.* Facility Guidelines Institute; 2022. https://shop.fgiguidelines.org/products/17
16. Facility Guidelines Institute. *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities.* Facility Guidelines Institute; 2022. https://shop.fgiguidelines.org/products/19
17. Hayden II CS, Johnston OE, Hughes RT, Jensen PA. Air volume migration from negative pressure isolation rooms during entry/exit. *Appl Occup Environ Hyg*. 1998;13(7):518-527. https://www.tandfonline.com/doi/abs/10.1080/1047322X.1998.10390100

18. Angra P, Ridderhof J, Timperi R, Fernandes P. *Ventilated Workstation Manual for AFB Smear Microscopy.* Centers for Disease Control and Prevention; 2011. https://www.aphl.org/programs/global_health/Documents/GH_2011July_VentilatedWorkstationGuidance.pdf

19. Menzies D, Fanning A, Yuan L, FitzGerald JM. Hospital ventilation and risk for tuberculous infection in Canadian health care workers. Canadian Collaborative Group in Nosocomial Transmission of TB. *Ann Intern Med.* 2000;133(10):779-789. doi:10.7326/0003-4819-133-10-200011210-00010

20. Pearson ML, Jereb JA, Frieden TR, et al. Nosocomial transmission of multidrug-resistant Mycobacterium tuberculosis. A risk to patients and health care workers. *Ann Intern Med.* 1992;117(3):191-196. doi:10.7326/0003-4819-117-3-191

21. Price Industries. Chapter 1. Fundamentals of HVAC. In: *Engineer's HVAC Handbook: A Comprehensive Guide to HVAC Fundamentals.* Price Industries; 2011. https://info.priceindustries.com/hubfs/Engineers%20Handbook%20Chapters/Chapters%20with%20Quizzes/Handbook_Chapter1_BasicsofHVAC.pdf

22. Dieckmann J, Erbe D, Fisher J, et al; ASHRAE TC 5.5. *Practical Guidance for Epidemic Operation of Energy Recovery Ventilation Systems.* ASHRAE; 2020. https://www.ashrae.org/file%20library/technical%20resources/covid-19/practical-guidance-for-epidemic-operation-of-ervs.pdf

23. ASHRAE. Chapter 26. Air-to-Air Energy Recovery Equipment. In: *2020 ASHRAE Handbook—HVAC Systems and Equipment.* ASHRAE; 2020. https://www.ashrae.org/technical-resources/ashrae-handbook/table-of-contents-2020-ashrae-handbook-hvac-systems-and-equipment

24. Price Industries. Chapter 9. Introduction to Mixing Ventilation. In: *Engineer's HVAC Handbook: A Comprehensive Guide to HVAC Fundamentals.* Price Industries; 2011. https://info.priceindustries.com/hubfs/Engineers%20Handbook%20Chapters/Chapters%20with%20Quizzes/Handbook_Chapter9_MixingVentilation.pdf

25. ASHRAE. ANSI/ASHRAE Standard 52.2-2017, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.* ASHRAE; 2017. https://www.ashrae.org/File%20Library/Technical%20Resources/COVID-19/52_2_2017_COVID-19_20200401.pdf

26. Price Industries. Chapter 20. Introduction to Healthcare HVAC. In: *Engineer's HVAC Handbook: A Comprehensive Guide to HVAC Fundamentals.* Price Industries; 2011. https://info.priceindustries.com/hubfs/Engineers%20Handbook%20Chapters/Chapters%20with%20Quizzes/Handbook_Chapter20_Healthcare.pdf

27. Price Industries. Chapter 21. Applications of Healthcare HVAC. In: *Engineer's HVAC Handbook: A Comprehensive Guide to HVAC Fundamentals.* Price Industries; 2011. https://info.priceindustries.com/hubfs/Engineers%20Handbook%20Chapters/Chapters%20with%20Quizzes/Handbook_Chapter21_AppsHealthcare.pdf

28. ASHRAE. Chapter 29. Air Cleaners for Particulate Contaminants. In: *2020 ASHRAE Handbook—HVAC Systems and Equipment.* ASHRAE; 2020. https://www.ashrae.org/technical-resources/ashrae-handbook/table-of-contents-2020-ashrae-handbook-hvac-systems-and-equipment

29. Institute of Environmental Sciences and Technology. *IEST RP-CC001.7 Contamination Control Division Recommended Practice 001.7: HEPA and ULPA Filters.* Institute of Environmental Sciences and Technology; 2002. https://www.techstreet.com/standards/iest-rp-cc001-7?product_id=2504630

30. National Air Filtration Association. *Recommended Practices for Filtration for Airborne Infectious Containment Rooms in Health Care Facilities.* National Air Filtration Association; 2016. https://growthzonesitesprod.azureedge.net/wp-content/uploads/sites/3916/2023/04/Airborne-Infections-Containment-Rooms-in-Health-Care-Facilities-Secured.pdf

31. Int-Hout D. Basics of Well-Mixed Room Air Distribution. *ASHRAE Journal.* Published online July 2015:12-19. https://www.krueger-hvac.com/files/white%20papers/article_basics_of_ad.pdf

32. ASHRAE. ANSI/ASHRAE 61.2-2022, *Ventilation and Acceptable Indoor Air Quality.* ASHRAE; 2022. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/62_1_2022_x_20221108.pdf

33. Atkinson J, Chartier Y, Pessoa-Silva CL, et al, eds. *Natural Ventilation for Infection Control in Health-Care Settings.* World Health Organization; 2009. https://apps.who.int/iris/bitstream/handle/10665/44167/9789241547857_eng.pdf;jsessionid=517C7DBB61DCE6

34. *Guide to Air Cleaners in the Home: Portable Air Cleaners, Furnace and HVAC Filters.* 2nd ed. U.S. Environmental Protection Agency; 2018. https://www.epa.gov/sites/default/files/2018-07/documents/guide_to_air_cleaners_in_the_home_2nd_edition.pdf