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Airborne Infection Isolation Rooms

What is an airborne infection isolation room (AIIR)?

AIIRs use dilution ventilation principles to reduce the concentration of airborne infectious particles within the rooms. AIIRs also use mechanical containment methods to keep contaminated air in the rooms from potentially moving into shared corridors or other adjacent indoor spaces.

To achieve airborne infection isolation conditions , a negative pressure differential is created relative to adjacent spaces by exhausting more air from the room than the amount supplied. These are sometimes referred to as **"negative pressure" rooms.**

Basic information and mechanical ventilation principles are described in Chapter 2, *Environmental Controls: Part 1 – Ventilation.* These include:

- Description and definitions for mechanical airflow rate, clean air delivery rate (CADR), air changes per hour (ACH), and room clearance (includes worksheet); see Chapter 2, *Environmental Controls: Part 1 – Ventilation* and Appendix A, *Room clearance time calculation (and ACH) worksheet.*
- Description of airflow and pressure differentials; see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *Using negative or positive pressure to reduce TB transmission.*
- Description, configuration, and components (e.g., air supply and recirculation, placement of supply diffusers and exhaust grilles) for heating, ventilation, and air-conditioning (HVAC) systems; see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, section, *HVAC systems.*
- General summary of how negative pressure is used to contain and prevent spread of infectious particles and basic description of AIIRs (to be expanded upon in this chapter); see Chapter 2, *Environmental Controls: Part 1 – Ventilation*, sections, *Mechanical ventilation* and *Negative pressure: Airborne infection isolation rooms.*

Tuberculosis (TB) infection prevention and control (IPC) policies and interventions are commonly organized in a hierarchy: Administrative (or work practice) controls are the most important, followed by environmental controls, and then respiratory protection. All three components should be in place for an effective TB IPC program and are covered in detail in designated chapters within this guide. **Aspects specific to planning for and managing AIIRs are covered in this chapter.**

Administrative controls for AIIRs

Administrative controls for TB IPC are interventions through institutional policies, protocols, education, and oversight to reduce or prevent both exposure to and transmission of TB within a facility. Facilities with AIIRs should have a clear and comprehensive IPC plan that includes the following TB IPC components:

- TB IPC facility risk assessment and IPC plan addressing specific standard operating procedures for use and management of AIIRs. The IPC plan for AIIR use should include criteria and procedures for initiation and discontinuation of isolation, including a discussion of the legal and ethical considerations.[1]
- Monitoring and evaluation plan for conducting AIIR checks (e.g., confirm negative pressure is functioning appropriately).
- IPC training and education programs for healthcare personnel (HCP) that includes proper use and basic IPC principles of AIIRs.
- AIIR signage, e.g., when AIIR is in use, post an *"Airborne infection isolation"* sign on the door to the corridor, and warnings to *"Keep door(s) closed to maintain negative pressure"* on room and anteroom doors. A *"Cover your cough"* sign can be used inside the room for the patient.
- Personal respiratory protection policy for use of N95 or more protective respirators (e.g., powered air-purifying respirator) by all HCP entering an AIIR occupied by a person with presumptive or known TB disease. Once unoccupied, persons entering the room should continue to wear a respirator until the time required for 99% of the airborne contaminants to be removed from the room has elapsed. See Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Room clearance*, Table 2, for ACH and clearance times.

For more general information on administrative controls, see Chapter 1, *Administrative Controls.*

Environmental controls for AIIRs

An improperly designed and/or improperly operating AIIR can place HCP, other patients, and other people in the vicinity of an AIIR at risk for TB infection and disease. In this situation, infectious particles may not be contained in the room, and/or their concentration inside the room may not be adequately reduced. Staff members who rely on such an AIIR may have a false sense of security.

This section provides basic information about how to assess and improve the design and operation of an AIIR. It also includes options to convert an existing patient room into an AIIR, advice on monitoring of AIIRs, and information on guidelines and regulations covering AIIR environmental controls.

See *Resources* for additional guidance on mechanical ventilation principles for AIIRs.

Architectural considerations

Architecturally, an AIIR should meet all the detailed requirements for a single-patient room, including a dedicated adjacent bathroom. An anteroom is not required but may be part of the design concept.

Architectural design elements should also meet IPC building standards (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] 170-2021, Facility Guidelines Institute [FGI] 2022a, FGI 2022b, FGI 2022c)[2,3,4,5] and local code requirements. For example:

- Minimum clearance around the bed
- Minimum room area
- Personal protective equipment storage and disposal areas at the entry to the room

Location of AIIR: The location of the proposed AIIR should also be considered. Avoid, if possible, areas prone to strong drafts, such as those near elevators or doors to the outside.

Doors: AIIR doors should be equipped with self-closing devices.

Dedicated bathroom: Ideally, an AIIR should have a dedicated bathroom that is part of the AIIR suite and only for use by the isolated patient. This is not always the case with AIIRs found in clinics that are not designed for long-term occupancy by patients. The advantage of a dedicated bathroom is that the patient will not have to leave the suite, minimizing the times the suite door is opened and closed. When the bathroom is part of an AIIR suite, exhaust ventilation (volumetric airflow rate) of the dedicated bathroom must be considered when calculating the ACH requirements.

Sealing an AIIR: To increase the effectiveness of negative pressure, the architectural elements should ensure that the AIIR suite is well sealed, except for a nominal air gap under the door. Further discussion on sealing AIIRs can be found in the section, *Upgrading or converting an existing room into an AIIR* and Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Negative pressure: AIIRs.*

The mechanical design elements of a new hospital AIIR should, at a minimum, meet all local code requirements, as well as Centers for Disease Control and Prevention (CDC) recommendations, ASHRAE standards, and other applicable codes, standards, and regulations.

Determining the correct airflow rate and negative pressure

CDC 2005[6] recommendations specify that AIIRs should:

- Have a **minimum of 12 air changes per hour (ACH)** (including 2 ACH supplied from outdoor air) for dilution of TB or other airborne infectious microorganisms.
- Have a **minimum pressure differential, relative to surrounding areas, of at least 0.01 inches of water gauge ("w.g.) (2.5 Pa)** such that air flows into the AIIR for containment of airborne TB or other microorganisms.

  Note: AIIRs are **generally set for a minimum of 0.05 "w.g. (12.5 Pa)** to maintain containment during small fluctuations in HVAC system airflow rates.
- Maintain a negative pressure (pressure differential) relative to surrounding spaces. The minimum airflow differential (exhaust vs. supply) should be at least 10% or 100 CFM (>170 m^3/h), whichever is greater, for maintaining a negative pressure relative to surrounding spaces.

Variable air volume (VAV) systems should not be used for AIIRs. VAVs are installed systems whose primary purpose is to vary the airflow rate based on room temperature and may not reliably meet the requirements for contaminant control.

ACH: One air change occurs in a room when a volume of air equal to the volume of the room is supplied and/or exhausted. The air exchange rate in ACH is the volume of air circulating every hour divided by the room volume. By calculating the ACH, the room airflow rate can be compared to published standards, codes, and recommendations. It can also be used to estimate the length of time required to remove infectious particles.

- See Chapter 2, *Environmental Controls: Part 1 – Ventilation*, Appendix A, *Room Clearance Time Calculation Worksheet* for step-by-step instructions for calculating ACH and room clearance time.
- For AIIRs, **the total exhaust airflow rate should be used to calculate the ACH,** rather than the supply airflow. The total exhaust airflow rate is the exhaust airflow rate directly from the AIIR plus the exhaust airflow rate of the dedicated bathroom (assuming no separate supply airflow directly to the dedicated bathroom). The ACH of the dedicated bathroom or anteroom, when present, should also be calculated separately from that of the AIIR itself. See section, *Upgrading or converting an existing room into an AIIR – Case Study: AIIR with dedicated bathroom.*

Maintaining negative pressure: Negative pressure is achieved when exhaust airflow rate exceeds supply airflow rate and the room is well sealed (except for a gap under the door).

- CDC and ASHRAE guidelines recommend a negative pressure differential of at least 0.01 "w.g. However, in practice, a differential pressure this low may be inadequate. Negative pressure may not be consistently maintained if there are other external factors, such as fluctuating air currents caused by elevators, doors, or windows to the outside. Because of these fluctuations, a differential pressure of a **minimum of 0.05 "w.g. (12.5 Pa)** is often used.
- On occasion, higher pressure differentials up to 0.10 "w.g. (25 Pa) are used; however, this differential is difficult to maintain and requires more powerful ventilation equipment, stronger ductwork, and a tightly sealed room.

Electronic pressure monitor: An AIIR may include the installation of an electronic pressure monitor.

- When properly selected and installed, a room pressure monitor can provide continuous qualitative and/or quantitative confirmation of negative pressure across a room boundary and connect to a local alarm or an alarm through the HVAC system.
- Several room pressure monitors are available with added options, e.g., a "warning" light that illuminates when negative pressure is lost; an adjustment for use in positive pressure rooms; and a remote control for a fan or damper to maintain and control negative pressure.
- Pressure differentials across room boundaries can be very low, often in the range of thousandths of an inch. For example, CDC[6] and ASHRAE[2] recommend that negative pressure be at least 0.01"w.g. Some devices that measure differential pressure are not accurate to this level. Before specifying or purchasing a room pressure monitor, make sure that the device is capable of accurately and reliably measuring a pressure differential this low.
- Room pressure monitors may be used as a supplement to, but not a replacement for, daily visual checks when the room is in use. See section, *How to do a daily visual check for negative pressure: Smoke/fog, tissue, or simple swing-vane velometer.*

Airflow patterns and air mixing

Design of the HVAC system for an AIIR must also include consideration of the airflow patterns and air mixing within the room.

- **Directional airflow:** Ideally, the clean supply air will be introduced near areas used by the HCP, while exhaust air will be removed near the patient.
- **Placement of supply air diffuser and exhaust grilles:** Positioning of the supply air diffuser should be at a distance far enough from the exhaust grille (optimally, locate the exhaust grille in the vicinity of the patient or head of the bed) to **avoid "short-circuiting"** of clean air (supply air is exhausted before mixing with room air to support dilution of infectious particles).
- **Air mixing:** To avoid areas of air stagnation, choose the placement of supply air diffusers and exhaust grilles (as well as the design of the diffuser) that will ensure adequate air-mixing within the room. Caution: Room occupants may find drafts with airflow velocities of >50 feet per minute (FPM) (>0.25 m/s) uncomfortable.

For further discussion, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* sections, *Using directional airflow to reduce TB transmission; Air supply and exhaust;* and *Components: Diffusers and grilles.*

Exhaust ductwork and discharge

Exhaust air removed from AIIRs is likely to contain infectious aerosols. Consequently, this air should be discharged directly outside the building where the particles can be diluted by outdoor air.

Exhaust ductwork

Dedicated exhaust system:

- While not included as a minimum recommendation by the CDC 2005 guidelines, **the optimum type of exhaust system should serve only AIIR suites, (i.e., a dedicated exhaust system).** Where applicable, this exhaust system should also serve the dedicated AIIR bathroom and anteroom.
- In some jurisdictions this is mandated by the building code for new or renovated rooms. Because most building codes are not retroactive, it is usually acceptable for an existing AIIR to combine the exhaust air with other exhaust systems, such as those serving bathrooms. ASHRAE Standard 170-2021 allows for mixing of AIIR exhaust air with other exhaust streams only after the AIIR exhaust has passed through a HEPA filter.[2]

The engineering department staff at the facility should trace the path taken by the exhaust air duct after it leaves the AIIR. If applicable, they should also check the exhaust duct serving the bathroom and anteroom, if present.

- For the record, a set of "as built" drawings should be generated (or an existing design set marked) to show the location and design specifications of the ductwork, filters, and fan.
- Also check the exhaust ductwork and fan for optimum performance. Conditions that should be corrected include excess air leakage at duct joints, damaged ductwork, incorrectly adjusted dampers, and fans in need of servicing.

Over time, dust and lint can collect at exhaust grilles and in exhaust ducts. Also, seals at duct joints break down and leak. These two effects result in diminished exhaust airflow from the AIIR and loss of required negative pressure.

- To compensate, AIIR exhaust ducts and fan systems should be sized for the required airflow rate plus an extra 50%.

Recirculating air systems

- If air from an AIIR is returned to a recirculating HVAC system that does not include filtration, this room should no longer be used for isolation. Staff and patients in rooms served by this system may be exposed to airborne *M. tuberculosis* from patients in isolation.
- **The risk of exposure from a recirculating mechanical system is affected by dilution of the return air with outside air and by the efficiency of the filter in the mechanical system.** The risk is reduced as the percentage of outside air is increased and the efficiency of the filter is increased. Filtration in hospital HVAC systems is usually better than in clinics because hospitals are typically covered by stricter building codes and have larger facility and maintenance budgets.

Exhaust air discharge

- The exhaust fan discharge should be located and designed to minimize the possibility that this air is inhaled by people who are outdoors or inside the building. Exhaust air should be directed away from occupied areas (e.g., walkways) or openings into the building (windows or outside air intakes).
- To promote dilution, the exhaust discharge should be directed vertically upward and at least 10 ft (3 m) above the adjoining roof level. The discharge location should be at least 25 ft (7.6 m) away from public areas or openings into a building.
- If a suitable discharge location is unavailable, then the exhaust air stream can be cleaned using a HEPA filter. In this case, a HEPA filter must be installed in the discharge duct upstream of the exhaust fan. However, this is not a desirable option because it will be considerably more expensive to install, maintain, and operate than a simple exhaust to the outdoors.

Duct and fan 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.

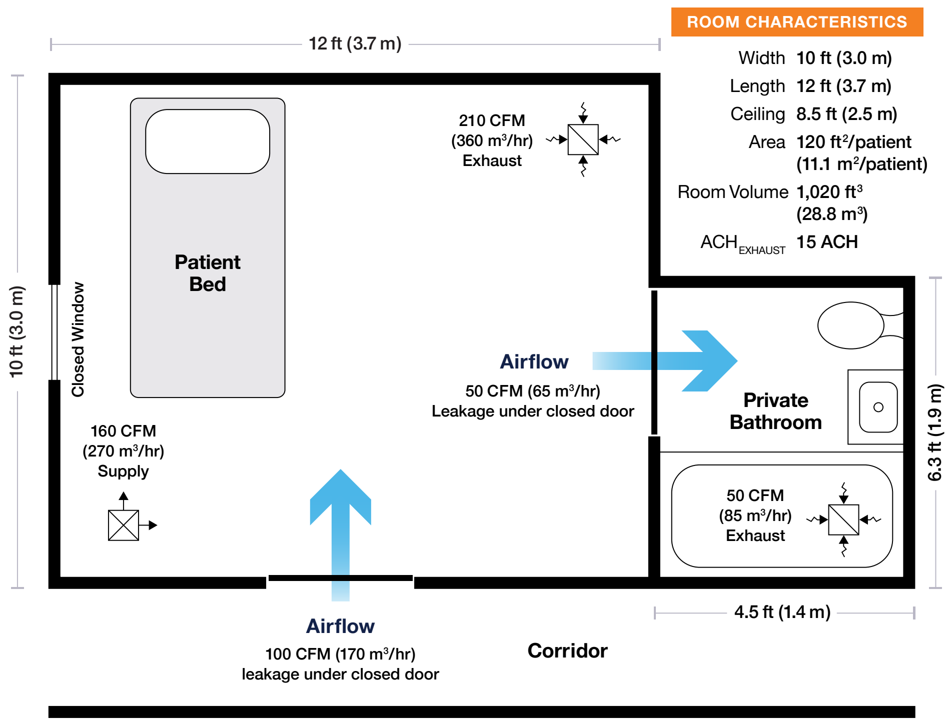
- To help protect these workers, **exhaust ducts, fans, and filter housings should be permanently labeled clearly** with the words, *"Caution — TB contaminated air"* or *"TB-contaminated air — Contact infection prevention and control coordinator before turning off fan or performing maintenance,"* or 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 fan and filter housings should include the telephone number of the IPC coordinator and the room number(s) of the AIIR(s) exhausted by the fan or through the filter.[6]

AIIR anteroom and bathroom considerations

Anterooms are not required with AIIRs. An example of an AIIR without an anteroom is shown in Figure 1 (for a detailed description of the airflows and pressure differentials for this AIIR example, see Chapter 2, *Environmental Control: Part 1 – Ventilation*, section, *Negative pressure: Airborne infection isolation rooms).* When planning an AIIR, an anteroom (Figure 2) may be provided between the AIIR and the corridor, based on risk assessment. An anteroom will further help prevent infectious particles in the AIIR from escaping into the corridor and provide HCP with a space to change clothes as well as don and doff PPE. The ventilation requirements of the AIIR with or without an anteroom remain the same:[6]

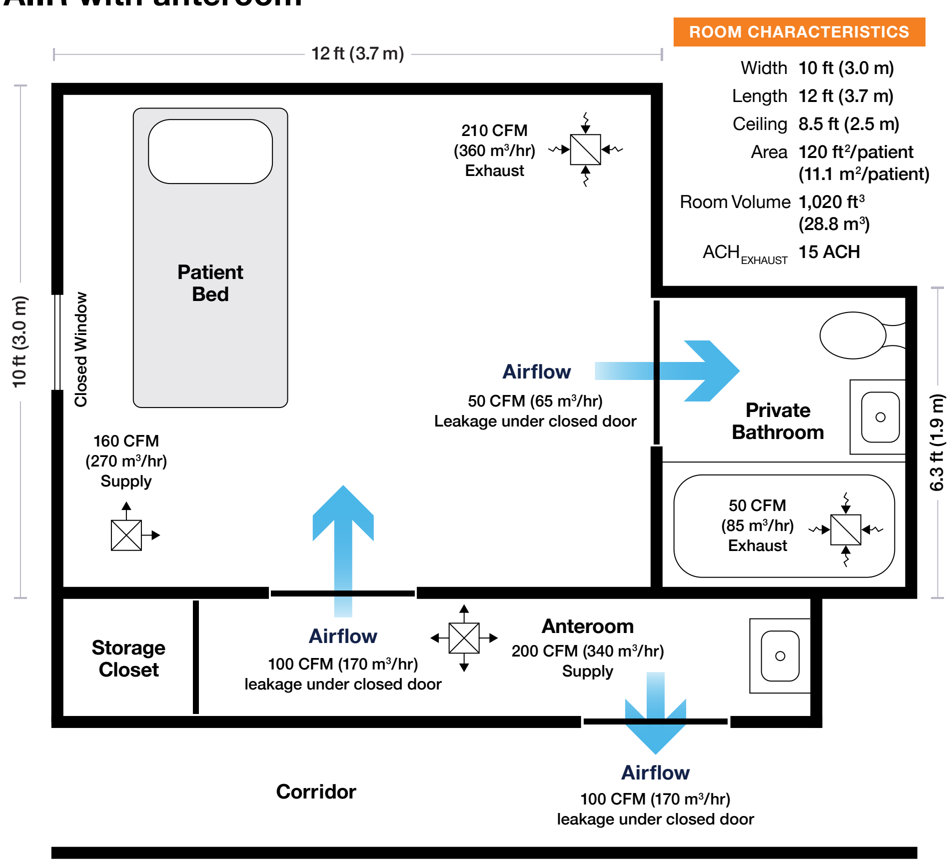
- Minimum of 12 ACH (including 2 ACH supplied from outdoor air)
- Minimum pressure differential, relative to surrounding areas (e.g., corridor, anteroom), of at least 0.01 "w.g. (2.5 Pa) such that air flows into the AIIR
- Minimum airflow differential (exhaust vs. supply) should be at least 10% or 100 cubic feet per minute (CFM) (170 m^3/h), whichever is greater

FIGURE 1. **AIIR without anteroom**



Source: Adapted from CDC *Core Curriculum on Tuberculosis*, Chapter 6, 2021

FIGURE 2. **AIIR with anteroom**



Source: Adapted from CDC *Core Curriculum on Tuberculosis*, Chapter 6, 2021

When an AIIR door is open, pressure differential is immediately lost. If there is an anteroom that is negative to the corridor, then the overall integrity of the suite is maintained. The anteroom provides an “air buffer” between the AIIR and the rest of the facility.

An anteroom should be at positive pressure with respect to the AIIR, and at neutral, positive, or negative pressure with respect to the corridor. See *Case Study: AIIR with dedicated bathroom*, Figure 11, for an example of an AIIR with a positive-pressure anteroom (positive to both the AIIR and to the corridor). Because smoke may migrate from the corridor if there is a fire, some codes and regulations mandate that the anteroom be neutral or positive to the corridor, rather than negative. It is not easy to balance airflow to a space so that it will be positive at one door and neutral at the other. Furthermore, air pressure in the corridor will vary due to external factors such as elevators and corridor doors to the outside.

Consult local codes regarding other design elements of anterooms for AIIRs. For example, requirements under the FGI guidelines include:

- Adequate space for staff to don/doff PPE
- Provision for storage of unused PPE
- Disposal container for used PPE
- Handwashing station

A dedicated bathroom should be negative pressure relative to the AIIR, and the AIIR should be negative pressure relative to the anteroom (or corridor if no anteroom). In other words, not only must the total exhaust for the AIIR plus bathroom exceed the total supply for AIIR plus bathroom, but the AIIR exhaust should also exceed the AIIR supply. This is illustrated in *Case Study: AIIR with dedicated bathroom.*

- The bathroom exhaust ventilation should comply with local requirements. For example, ASHRAE Standard 170-2021[2] mandates an air change rate of 10 ACH, negative pressure, and direct exhaust to the outdoors for bathrooms. In general, an offset of 50 CFM (85 m^3/hr) is sufficient between the bathroom and the AIIR. The negative pressure of the bathroom in relationship to the AIIR room also serves to control odors.

Monitoring AIIR environmental controls

Failed environmental controls in AIIRs have been identified as factors in documented hospital TB outbreaks. Regularly scheduled assessments of environmental controls will identify and may help prevent failures.[7]

Regularly scheduled assessments of environmental controls will identify and may help prevent failures.

AIIR monitoring includes:

- **Measuring airflow rate and calculating ACH**
- **Evaluating airflow patterns (air mixing)**
- **Verifying negative pressure**

Conduct and document comprehensive evaluations of the AIIR (verifying airflow patterns and quantifying airflow rate, ACH, and negative pressure) and the electronic pressure monitor on an annual basis or as needed if any irregularities arise during use.

Table 1 summarizes three ways to quantify negative pressure and airflow differential with the corresponding units of measurement and the measuring device for each method.

TABLE 1. **How to quantify negative pressure and airflow differential**

PARAMETER	UNITS OF MEASUREMENT	MEASURING DEVICE
Pressure differential	• inches of water gauge ("w.g.) • Pascals (Pa)	Manometer
Speed of air under the door	• feet per minute (FPM) • meters per second (m/s)	Velometer
Exhaust airflow differential	• cubic feet per minute (CFM) • cubic meters per hour (m^3/hr)	Air capture hood

Verification of negative pressure also includes simple daily checks and documentation by staff to confirm negative pressure is working, ensuring containment when an AIIR is in use as an isolation room for someone with potential or known infectious TB.

AIIR monitoring details should be clearly outlined within the IPC Plan. The next sections in this chapter will describe some of these monitoring methods in more detail.

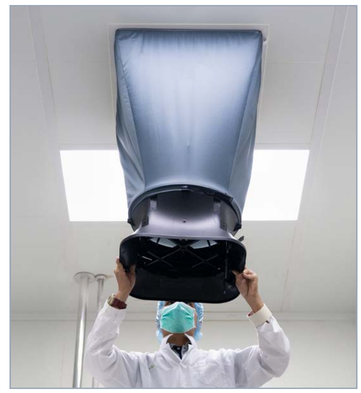
Measuring AIIR airflow rate and calculating ACH

Annual airflow and ACH testing:
Measure airflow rates and calculate ACH at least once a year to ensure that the rates have not deviated more than 10% from the initial values.

- The airflow rate in a room is usually measured at the individual exhaust air grilles and supply air diffusers using an air capture hood. This is a device that consists of a hood (sometimes called a tent), a velocity sensor, and a microprocessor (Figure 3). The hood is placed over, and should completely cover, the air diffuser or grille. The hood directs all air entering or leaving the outlet past a velocity-sensing grid. The microprocessor then calculates and displays the quantity of air being exhausted or supplied. Air capture hoods usually provide an airflow rate reading in CFM or cubic meters of air per second (m^3/s).
- The standard size of an air capture hood is 24" × 24" (61 cm x 61 cm), although an assortment of different hood sizes can be adapted to the instrument frame for measuring outlets with other shapes and sizes. If there is insufficient space around some outlets to easily use an air capture hood, air velocity should be measured in the duct that serves the outlet.
- If the room airflow rate is found to be inadequate (i.e., resulting in <12 ACH), the airflow rates should be rebalanced. For information on modifying existing room airflow rates, see section, *Upgrading or converting an existing room into an AIIR.*
- The airflow measurements and calculations should be performed by a certified testing and balancing agency or by in-house engineering staff with appropriate HVAC instrumentation and training.[8]

FIGURE 3.

Air capture hood



Source: Shutterstock

Evaluating AIIR airflow patterns (air mixing)

Annual checking of airflow patterns within the AIIR:
Airflow patterns should be verified using smoke/fog devices so that the movement of air within the AIIR remains as specified in the IPC plan.

- Air, as demonstrated by the movement of smoke/fog, should move from the bottom of the door and into the AIIR.
- Air should also flow from cleaner areas to less-clean areas (e.g., corridor › HCP › patient › exhaust grille and/or bathroom exhaust), with no observed areas of air stagnation.

Verifying AIIR negative pressure

After a new AIIR is constructed or renovated and before it is occupied, the mechanical contractor will adjust the airflow rates as directed by the engineer to ensure that it operates as designed. However, mechanical systems do drift out of balance over time.

Routine monitoring of AIIR room pressurization should include:

- **Annual recalibration of electronic pressure monitors** (or per manufacturer specifications; repeat as needed during the year if malfunction concerns arise): Recalibration should be performed by the original equipment manufacturer, a certified testing and balancing agency, or by in-house engineering staff with appropriate HVAC instrumentation and training.
- **Intermittent checks of electronic pressure monitors:** Calibration should be done by trained personnel using a micromanometer to verify the readings and/or alarms functions (e.g., monthly, quarterly, or if a discrepancy between electronic pressure monitor and visual check is noted). Note that both an electronic pressure monitor and a micromanometer may give an incorrect readout if the tubing is not connected properly.
- **Daily negative pressure verification while the room is occupied;** documentation should include both readings from the permanent room pressure monitor and additional visual checks (smoke/fog or tissue testing) to confirm that the negative pressure is functioning.

> CDC 2005 guidelines state: "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 presumptive or confirmed TB disease."[6]
>
> This policy statement was originally developed because of the poor performance of physical and electronic pressure monitors.

If the AIIR's HVAC system is operating as intended, there will be an air current moving into the room from under the door. Use smoke/fog tests, tissue tests, or a simple hand-held swinging-vane velometer (e.g., Vaneometer™) at the gap under the entrance door to the AIIR as a qualitative daily check to confirm negative pressure is working. Note that most electronic velometers will measure velocity of air but will not indicate direction of airflow.

For more details on how to use these tests for monitoring daily negative pressure status, see section, *How to do a daily visual check for negative pressure: Smoke/ fog, tissue, or simple velometer.*

Documentation of AIIR monitoring

Keep records of all AIIR environmental control tests and measurements. Local regulatory agencies may require that these records be kept for a number of years. For example, Cal/OSHA requires that records be kept for a minimum of five years.

See Chapter 2, *Environmental controls: Part 1 – Ventilation*, Appendix B, *Airborne Infection Isolation Room Pressure Monitor Checklist* for a template to record results.

How to do a daily visual check for negative pressure: Smoke/fog, tissue, or simple swing-vane velometer

Smoke tube/fog test

- Smoke tube/fog testing must be performed outside the room with the door closed. Explain the testing to the room occupant so as not to cause worry when smoke is seen entering the AIIR (Figure 4).
- If commercial smoke/fog-generating devices are not available, incense sticks may be used (consider use of two sticks held side-by-side, Figure 5). However, incense smoke has a strong odor, and is not as visible or as controllable as smoke produced from commercial smoke tube kits.

To check the negative pressure in a room, hold the smoke tube or fogging device near the bottom of the door in a horizontal orientation, approximately 2 in (5 cm) in front of the door. Generate a small amount of smoke by gently squeezing the bulb (or fog per device instructions).

- Hold the device parallel to the door and release the smoke/fog slowly to ensure that the velocity of the release of the smoke/fog does not overpower the air velocity. The smoke/fog will travel in the direction of airflow.
- If the room is at negative pressure, the smoke/fog will travel under the door and into the room (from higher to lower pressure, Figure 4). If the room is not at negative pressure, the smoke/fog will be blown outward (Figure 5) or will remain relatively stationary.
- If there is an anteroom, release smoke/fog at the inner door undercut (bottom of the door), with both the anteroom-corridor and anteroom-AIIR doors shut.
- In addition to a pedestrian entry, some AIIRs or areas are accessed through a wider wheeled-bed stretcher door. Check smoke/fog at all door entrances to AIIRs.
- To check the exhaust ventilation in the room, hold the smoke tube or fogging device near the face of the exhaust grille (Figure 6). This will only confirm if you have some exhaust airflow but does not confirm there is adequate exhaust airflow or desired airflow rate.
- If room air cleaners (RACs),with HEPA or other high-efficiency filter, are being used in the room, they should be running during the test.

FIGURE 4.

Smoke tube at door

Source: P. Jensen

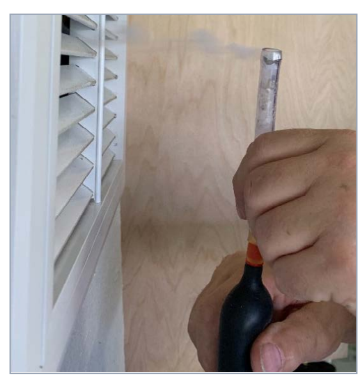
FIGURE 5.

Incense sticks at door

Source: CITC

FIGURE 6.

Smoke tube at grille



Source: P. Jensen

As a general rule, an air velocity of 100 ft/min (0.5 m/s) under the door would be desirable to assure adequate negative pressure. Because 100 ft/min is approximately the same as 1.5 ft/s, a puff of smoke/fog moving (somewhat) horizontally through the air at this velocity would move 3 feet over 2 seconds. To visually estimate air velocity, activate the smoke/fog and note the distance the smoke/fog travels while counting "one, one-thousand, two, one-thousand." If the smoke/fog moves at least 3 feet over this time, the air velocity is probably sufficient.

- While this type of visual approximation can offer a rough sense of adequate versus stagnant/minimal air movement, simple devices like a swinging-vane velometer (e.g., Vaneometer™) can give a quantitative velocity measurement as well as an indication of direction of airflow. See section, *Velometer (swinging-vane model) measurement*.

Because some smoke/fog may be irritating if inhaled, take care to prevent direct inhalation. The quantity of smoke/fog emitted from the devices is minimal and should not be detectable at short distances from the point of release.

Tissue test

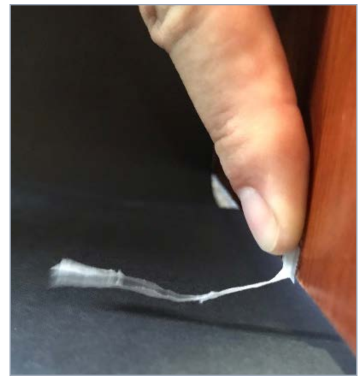
If smoke-generating devices are not available, or if the room is occupied by a patient who may be vulnerable to the potential irritant properties of smoke, a thin strip of tissue can be used to determine whether a room is at negative, neutral, or positive pressure relative to the surrounding area. Hold a thin strip of tissue parallel to the gap between the floor and bottom of the door (Figure 7). The tissue movement will indicate the direction of air movement. The horizontal flutter of the tissue may also give a rough guide of the airflow rate (strong versus weak).

A second simple tissue test can visually indicate that the negative pressure is working. This method entails releasing a small piece of tissue at the gap between the floor and bottom of the closed AIIR door from the corridor (or anteroom if present). If air is moving from the corridor/anteroom into the AIIR room as desired, the small piece of tissue should be quickly drawn under the door with the airflow into the AIIR (Figure 8).

FIGURE 7.

Tissue strip test

Thin strip of tissue held at base of door inside AIIR confirms inward air movement.



Source: CITC

FIGURE 8.

Tissue test from corridor/anteroom

Small piece of tissue placed outside AIIR will be whisked under door into AIIR if negative pressure present.

Source: CITC

Velometer (swinging-vane model) measurement

Simple velometer devices can demonstrate airflow direction and measure air velocity.

- With the AIIR door closed, place the velometer on the floor at base of door inside of the AIIR (Figure 9). The swing-vane within the device will indicate both the airflow direction and the air velocity as measured on the device.

Note: All methods to verify negative pressure should be repeated at least three times until the results are consistent.

Non-AIIR use of velometer when calculating airflow rate and ACH

Velometers may also be used to measure air velocity to calculate airflow rate and ACH for settings such as non-AIIR clinic exam or waiting rooms (see Chapter 2, *Environmental Controls: Part 1 – Ventilation* and Appendix A, *Room Clearance Time Calculation Worksheet* for more details and considerations for performing these measurements).

- Identify and confirm all sites of **air exhaust** from the room under normal use conditions (i.e., open or closed windows/doors, use of fans or RAC, or HVAC system settings); noting that actual airflow and ACH will be based on these same conditions being used.
- Measure the dimensions (to calculate area) for all sites of air exhaust for the ACH calculations in the worksheet. If multiple sites of exhaust are identified, they should all be included in the calculations. Calculate the area of each exhaust grille (Figure 10A).
- Hold the velometer horizontally, level to the exhaust grille (Figure 10B), check in several places, divide the face of the grille into a grid, and average the readings over multiple points to confirm that the measured air velocity is consistent.
    - If air is exhausting through an open window or door, the device may be held steady against vertical or horizontal window or door frames.
    - Note: These simple swing-vane velometers only measure velocities in the horizontal direction and only measure velocities up to 400 fpm (2 m/s). If sites of air exhaust are in ceilings, alternate measuring methods will be required (e.g., electronic velometers or air capture hood).
- Ideally, these measurements should be done by trained facilities engineers or other HVAC professionals.
- Calculate the airflow rate and the ACH as described in Chapter 2, *Environmental Controls: Part 1 – Ventilation* and Appendix A, *Room Clearance Time Calculation Worksheet.*

FIGURE 9.

Velometer

Vaneometer™ swing-vane velometer demonstrating airflow moving from under door into room (R to L) at a velocity of 0.85 m/s (170 FPM).

Source: CITC

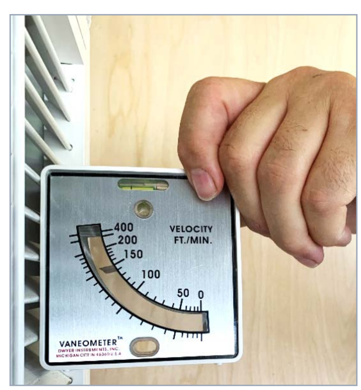
FIGURE 10A.

Measuring exhaust grille dimensions

Source: P. Jensen

FIGURE 10B.

Measuring air velocity at exhaust grille strip test



Source: P. Jensen

Upgrading or converting an existing room into an AIIR

This section covers methods of improving the ventilation characteristics of an existing room to make it more effective for use as an AIIR. Methods to support the conversion include:

- **Disconnect recirculating air system.** A first step is to ensure that contaminated air from the room is not directly recirculated to other areas. The air removed from the room must either be exhausted directly outdoors to a safe location or filtered (HEPA or other high-efficiency filter). If the room exhaust is currently connected to a recirculating air system that does not include a HEPA or other high-efficiency filter, it should be disconnected from this system.
- **Install HEPA or other high-efficiency filter in existing return air system.** Theoretically, correcting a recirculating system by replacing the existing filter with a HEPA or other high-efficiency filter could be an option within an existing HVAC system. However, it is often not feasible to use HEPA or other high-efficiency filters in HVAC systems not specifically designed to accommodate them. HEPA or other high-efficiency filters are physically larger than most filters and require more powerful fans to overcome the increased resistance to airflow. For more information on types of filters, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Filters*.

There are two basic approaches to upgrading or creating an AIIR.

- The **preferred option is to adjust the building HVAC system to create a permanent AIIR.**
- A **temporary solution is to add a recirculating RAC with HEPA or other high-efficiency filter** to supplement, or even replace, the building HVAC system.

Sealing the room: When upgrading an existing AIIR or converting an existing room to operate at negative pressure, it is important to make the best use of the excess exhaust by sealing the room as tightly as possible to reduce unwanted air from leaking into the room. For a given exhaust airflow differential, the better the room is sealed, the greater the amount of air that will flow into the room under the door and the greater the negative pressure.

Steps that can improve a room's airtightness include:

- Apply gasketing at the sides and top of the room door.
- Caulk around windowpanes and window frames.
- Apply gasketing at the connection of all ceiling and wall penetrations such as those around medical equipment, lighting, plumbing, and electrical outlets.
- Replace acoustic ceiling tiles with non-porous tiles (e.g., vinyl or drywall) and apply gasketing and clips at the tile connection to the ceiling grid. Ideally, ceilings should be plaster/sheetrock rather than removable ceiling tiles.
- Replace traditional recessed light fixtures with surface-mounted fixtures.

For additional discussion on AIIR leakage and sealing, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *Negative pressure: AIIRs.*

Adjusting the HVAC system

If the room is not currently connected to an exhaust system, it should either be connected to an existing exhaust system or a new system should be installed. Consult with the building facilities department staff, who may hire a mechanical engineering consultant to design this work and oversee the construction.

Connect to an existing exhaust system or add a new one: If there is an accessible exhaust air duct nearby, it may be possible to make a new exhaust connection to the existing exhaust grille. Otherwise, a new exhaust air fan and ductwork system should be installed.

- New exhaust ducts, and new or existing exhaust fans serving AIIRs, should have the same warning labels used for new AIIRs.

Rebalance existing HVAC system: To increase room exhaust airflow rate and/or create, or increase, negative pressure, the existing HVAC system needs to be adjusted to exhaust more air. The supply air quantity may also need to be increased. Airflow is varied using dampers or other controls.

Adjust dampers: Dampers are devices that control the flow of air in ducts, similar to the way valves control the flow of fluids in pipes. Dampers are usually located above the ceiling and should only be adjusted by a facility engineer or certified air-balance contractor. To increase exhaust airflow rate, the dampers in the ducts serving the room should be opened wider. It usually takes an air balancer multiple adjustments to obtain the desired airflow rates, airflow differentials, and level of negative pressure.

- The exhaust airflow rate should result in at least 12 ACH.
- The supply should be approximately 100 CFM (170 m^3/hr) less than exhaust. However, the most important aspects of the supply air are that the room is supplied with at least 2 ACH of fresh, outdoor air and that occupant comfort (temperature and humidity) can be maintained. So, more or less supply air may be required. Similarly, depending on how well the room is sealed, more air may need to be exhausted to achieve the required pressure differential (0.01 "w.g. or 2.5 Pa).

Most AIIRs do not have a dedicated HVAC system. They are connected to a ventilation system that serves other rooms in the building. Before and after adjusting the AIIR airflow rates, the air balancer should measure the airflow in some of these other spaces to make sure that the AIIR adjustments do not have an adverse effect on ventilation elsewhere.

Ensure appropriate air mixing and airflow patterns: Adequate levels of air mixing and optimized airflow patterns within the room should be considered as upgrades or renovations are planned. Evaluate how effectively air is being distributed within the room. Smoke testing can be used to visualize the AIIR airflow patterns during initial assessments to identify potential problems, and again after remediation to assess improvements.

Adding a room air cleaner (RAC)

It may not be economically feasible or time-efficient to modify the existing HVAC system. RACs are readily available equipment that can be used in many spaces to **provide "clean" air.** RACs allow improvement of air quality in any room. Limited 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.** There are two basic ways to use RACs in AIIRs:

- RACs can be used to increase the ACH of a room (by providing additional clean air) without affecting room pressurization.
- Many large RACs may be configured to create or increase negative pressure in a room if adapted to exhaust a portion of the room air outdoors. See *Case Study – AIIR: Part 2.*

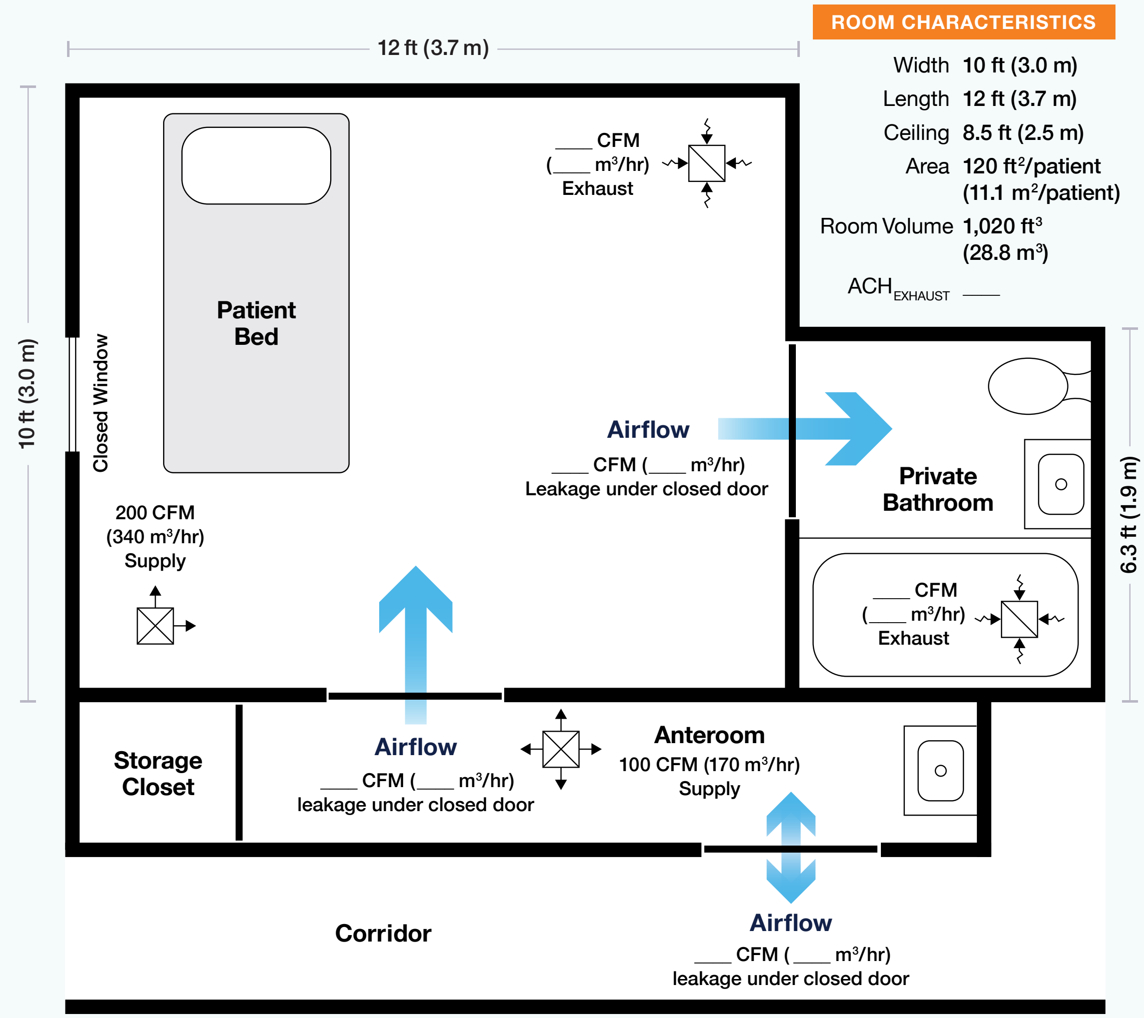
Select a RAC to meet your CADR ventilation strategy. CADR is the rate at which an air cleaning device or equipment, including RACs, delivers clean or disinfected air to a room or space. The CADR is measured in CFM or m^3/h.[9,10]

For more information on RACs, CADR, and selecting a RAC based on room size, see Chapter 2, *Environmental Controls: Part 1 – Ventilation,* section, *RACs*.

CASE STUDY

AIIR with dedicated bathroom

FIGURE 11. **AIIR with anteroom and dedicated bathroom**



Background

The setting is an AIIR with a dedicated bathroom. You are installing a new exhaust fan in the AIIR.

Description

- The supply airflow rate to the AIIR is 200 CFM (340 m^3/hr) from a supply air diffuser in the AIIR ceiling.
- The supply airflow rate to the anteroom is 100 CFM (170 m^3/hr) from a supply air diffuser in the anteroom ceiling.
- The AIIR (without bathroom) volume is 1,020 ft^3 (10 ft x 12 ft x 8.5 ft) or 28.9 m^3 (3.0 m x 3.7 m x 2.6 m).
- The bathroom volume is 240 ft^3 (4.5 ft x 6.3 ft x 8,5 ft) or 6.8 m^3 (1.4 m x 1.9 m x 2.5m); bathroom supply air comes from the AIIR
- Assuming no other air entering the AIIR, the ACH_{SUPPLY} is 12 ([300 CFM x 60 min/hr] / 1,020 ft^3).
- There is currently no air exhausted from the dedicated bathroom because the exhaust fan is not functional.

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CASE STUDY

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New exhaust fan

The new exhaust fan with a capacity of 300 CFM (510 m³/hr) will serve the AIIR suite (AIIR with dedicated bathroom).

- Local codes mandate a minimum of 10 ACH in bathrooms; a minimum of 40 CFM (67 m³/hr) exhaust is required.
- The anteroom door to the corridor has airtight seals installed on all four sides; no air from the anteroom will escape to the corridor.

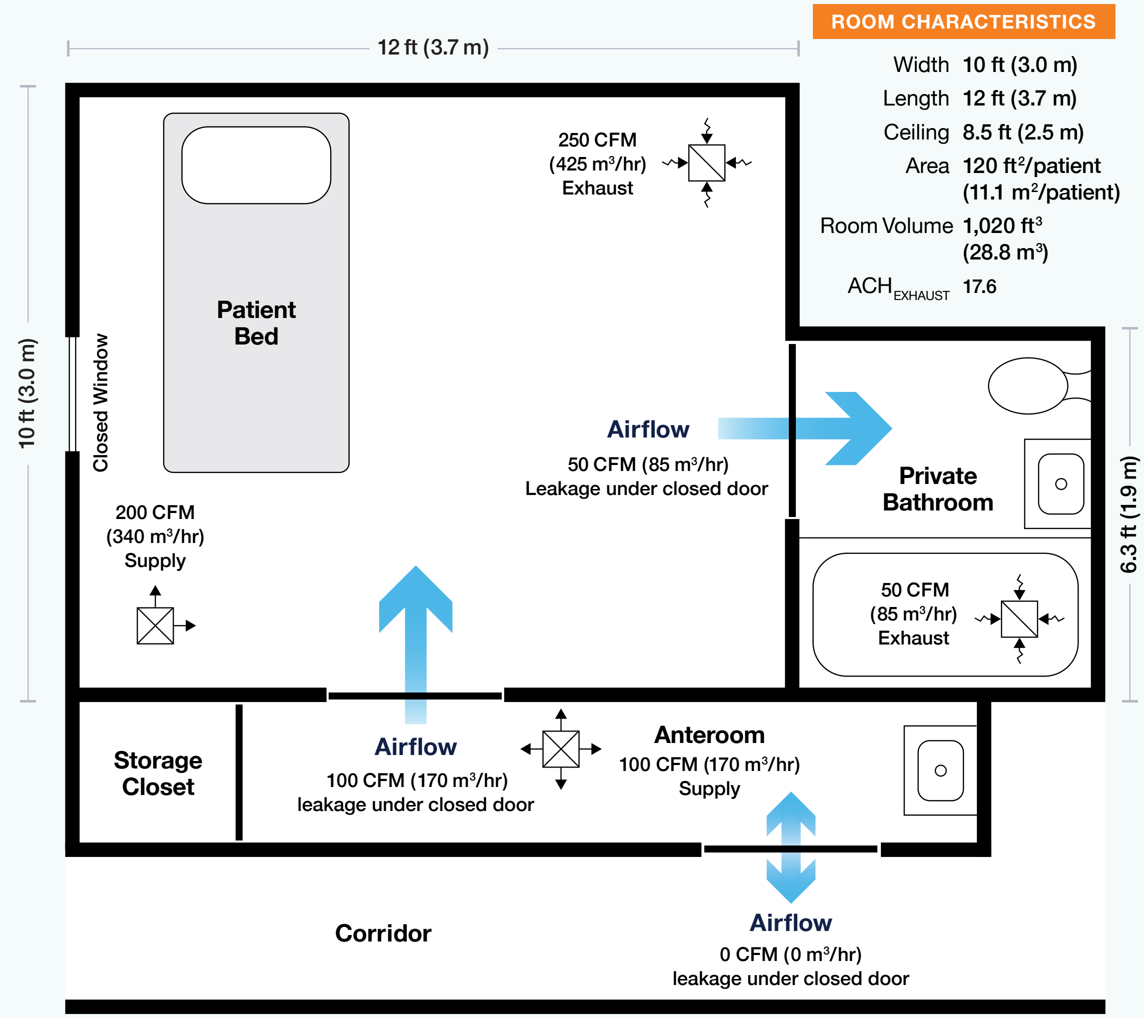
ASK: How should the 300 CFM (510 m³/hr) of exhaust air be split up between the AIIR and bathroom?

The best option:

FIGURE 12. **AIIR with anteroom and dedicated bathroom — best option**

ROOM CHARACTERISTICS

Width	10 ft (3.0 m)
Length	12 ft (3.7 m)
Ceiling	8.5 ft (2.5 m)
Area	120 ft²/patient (11.1 m²/patient)
Room Volume	1,020 ft³ (28.8 m³)
$ACH_{EXHAUST}$	17.6



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CASE STUDY

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- **Note: the minimum airflow differential between total supply and exhaust in the AIIR should be at least 10% of the total supply airflow rate** (i.e.,10% of 300 CFM is 30 CFM) or at least 100 CFM (170 m^3/h).
- The total airflow differential in the AIIR is 100 CFM
  - 200 CFM supply air in the AIIR
  - 250 CFM exhaust air directly from the AIIR
  - 50 CFM exhaust from the bathroom
  - (250 CFM + 50 CFM) – 200 CFM = 100 CFM airflow differential
  - The 100 CFM airflow differential is drawn from the anteroom into the AIIR

The reason

This arrangement results in both a total of 100 CFM (170 m^3/hr) off-set across the AIIR door and an equal volume of air moving through the AIIR.

- This option provides more exhaust than supply in the AIIR itself, resulting in negative pressure, and increases airflow toward the head of the bed.
- Some local codes may require that direct exhaust from the AIIR itself (excluding the bathroom exhaust) exceed direct supply air.

The calculations

ACH_{AIIR} equals the sum of the total airflow rate into the AIIR as well as equal to the sum of the total airflow rate out of the AIIR.

ACH_{AIIR} = (100 CFM from anteroom + 200 CFM from HVAC supply) * 60 min/hr / 1,020 ft^3

= 17.6 $ACH_{AIIR\text{-}Supply}$

= (250 CFM from AIIR HVAC exhaust + 50 CFM to bathroom) * 60 min/hr / 1,020 ft^3

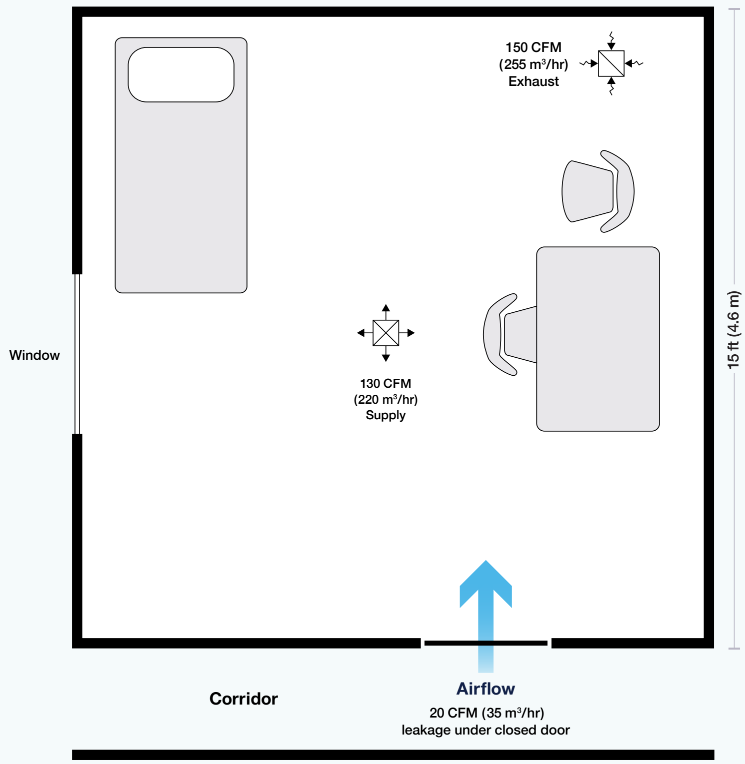
= 17.6 $ACH_{AIIR\text{-}Exhaust}$

Note: This AIIR meets the minimum requirement of 12 ACH for AIIRs[6]

CASE STUDY

AIIR: Part 1

FIGURE 13. **Treatment and exam room for potential and confirmed TB patients – original HVAC design**



Background

An employee at a TB clinic was diagnosed with latent TB infection using a TB blood test (interferon-gamma release assay [IGRA]). He is a clerk in the billing department and has no patient contact and had a baseline negative IGRA upon hire one year ago. He has a history of diabetes but no known TB exposure or travel to TB endemic areas. The TB clinic is in a small, single-story county building. Concerned because of his new TB test conversion, the employee suspected his only possible exposure was at work and informed the clinic manager, Janet.

Assessment

Janet was concerned because the billing department shares a corridor with the room used to isolate TB patients. After confirming that the employee's clinician did not find other possible reasons for his verified IGRA-positive conversion, Janet wondered whether *M. tuberculosis* transmission may have occurred due to failed environmental controls in the AIIR.

Janet tested pressurization of the AIIR with a piece of tissue. The room clearly had positive pressure with respect to the corridor. She felt airflow from the supply diffuser. Even after wiping off the considerable amount of dust on the exhaust grille, air was moving into the corridor from the AIIR. A tissue held against the exhaust grille was not pulled toward the grille as would be expected.

The county facilities department sent out a maintenance engineer, Cynthia, to investigate further. The original HVAC design is shown in Figure 13.

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CASE STUDY

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Cynthia remembered converting this room into an AIIR for TB patients about 2 years ago. She had sealed the room and installed a small, dedicated rooftop exhaust fan. But now she found the fan making squealing noises and the fan motor was very hot to the touch. She replaced the fan and motor. Exhaust was now measured and found to be the design airflow rate of 150 CFM (250 m^3/hr).

Room airflow supply (fresh air) was measured to be 130 CFM (220 m^3/hr), which was 20 CFM (35 m^3/hr) less than the exhaust airflow rate. However, a series of smoke tests showed that the room was now at neutral pressure rather than negative pressure. Room air leakage exceeded the 15% airflow differential. Cynthia then noticed the window was not closed completely. Upon closing the window completely, air from the corridor moved into the AIIR.

Calculate air exchange rate

The room was square-shaped (15 ft [4.6 m] each side) with a ceiling height of 8.5 ft (2.6 m). The exhaust ACH was calculated as follows:

$$\textbf{Room volume} = 15\text{ ft} \times 15\text{ ft} \times 8.5\text{ ft} = \mathbf{1{,}910\ ft^3}$$

$$\mathbf{ACH_{AIIR}} \quad \frac{150\text{ CFM} \times 60\text{ min/hr}}{1910\text{ ft}^3} = \mathbf{4.7}$$

Janet's staff tested the AIIR daily and noticed the speed of the air going under the door slowly decreased and the room went neutral relative to the corridor after two weeks. Therefore, even with the exhaust fan replaced, the AIIR was unsuitable for isolation because it was at neutral pressure relative to the corridor.

Clearly, something had to be done.

ASK: What steps should be taken to achieve negative pressure in the AIIR?

See *Case Study – AIIR: Part 2* for conclusion.

CASE STUDY

AIIR: Part 2

Calculate required additional airflow

Although Janet, the clinic manager, wanted to bring the AIIR into compliance with CDC environmental control recommendations, she thought her budget was too limited to install a new HVAC system.

Cynthia, the engineer, suggested a portable RAC with a HEPA filter as an affordable upgrade option. The RAC would provide additional airflow of clean air. If a portion of the air from the RAC were ducted outside, it would also create negative pressure.

The first step was to calculate the additional airflow required:

$$\textbf{Airflow required for 12 ACH} \quad \frac{1910\ \text{ft}^3 \times 12\ \text{ACH}}{60\ \text{min/hr}} = \textbf{380 CFM}$$

Additional airflow rate required = 380 CFM - 150 CFM

= **230 CFM**

Sizing and installing a portable RAC with a HEPA filter

A RAC with HEPA filter that produced at least 230 CFM (390 m^3/hr) airflow rate was required. Cynthia contacted a mechanical equipment supplier. Two units were available: a smaller unit rated at 150 to 300 CFM (250-500 m^3/hr); and a larger unit rated at 250 to 750 CFM (420-1,270 m^3/hr). Each unit had a multi-speed switch and an optional connection that could be used to exhaust some or all the air outdoors.

Janet suggested buying the smaller RAC to save money. If run at high speed, it would provide more than enough additional airflow. However, Cynthia explained that most people turn down the fan speed switch because the units can be noisy at their high-speed setting. The RACs may also produce less airflow than the manufacturer's catalog claims. Cynthia suggested adding a 50% safety factor, then buying a RAC listed for this airflow at low or medium speed. The larger RAC had three airflow rate settings: 250, 500, and 750 CFM (420, 850, and 1,270 m^3/hr) with a clean HEPA filter.

Required airflow rate of RAC = Additional airflow rate required + safety factor

230 CFM + 50% = **345 CFM**

Based on this calculation, the larger RAC was selected and placed in the room. Cynthia replaced a windowpane with a sheet metal panel. She connected a flexible duct from the RAC discharge to a hole in the sheet metal panel, set the RAC to about 500 CFM (850 m^3/hr), and diverted almost half of the discharge air, 150 CFM (250 m^3/hr), to the outdoors. The RAC was located where the clean air from the RAC mixes well with the air in the room. See Figure 14.

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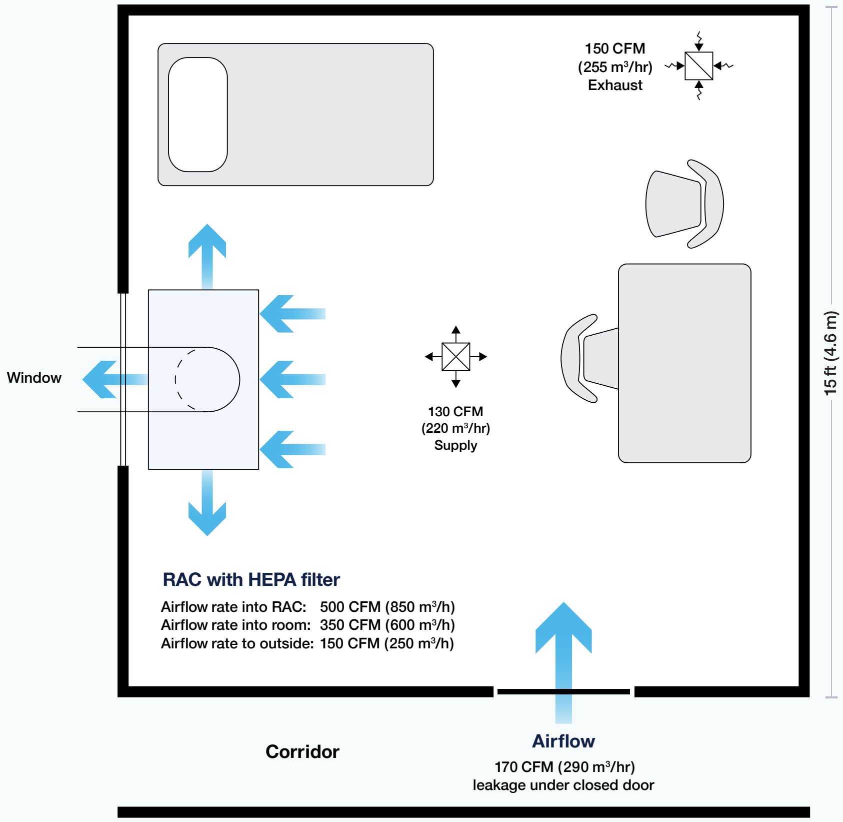
FIGURE 14. **Treatment and exam room for potential and confirmed TB patients: Addition of RAC with HEPA filter**



Assuming a clean HEPA filter, the ACH_{AIIR} is 20 ([150 CFM of room exhaust + 500 CFM CADR of RAC] x 60 min/hr / 1910 ft^3 = 20). Because the pre-existing exhaust ventilation system was weak and the RAC airflow rate will decrease as the HEPA gets loaded with airborne contaminants, higher initial airflow rate/ACH is a good practice to ensure the ACH_{AIIR} remains at or above 12. The additional air (170 CFM [290 m^3/hr]) will come from the corridor and under the door. Luckily, there was a 2 in (50 mm) gap under the door; otherwise, the air might “whistle” as it went under the door.

The happy ending

The room was now clearly at negative pressure relative to the corridor, the overall ACH was improved significantly, and the noise from the RAC was acceptable.

Janet will include RAC maintenance into the clinic budget (including coarse and HEPA filter replacement per manufacturer recommendation) and update the IPC plan to include regular RAC performance verification.

Cynthia‘s final measurements showed that the RAC was pulling approximately 500 CFM (850 m^3/hr) from the room, with 150 CFM (250 m^3/hr) of this airflow discharged outside and the remaining 350 CFM (600 m^3/hr) recirculating back into the room.

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CASE STUDY

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ASK:

How often should the negative pressure be verified for this AIIR?

When occupied, daily using smoke/fog. When unoccupied, monthly.

How often should airflow rates be verified?

At least annually, but preferably every six months.

How often should the HEPA filter be changed?

Per manufacturer's recommendation, when the airflow rate decreases below an acceptable level (e.g., room at low negative pressure), or if the filter is damaged.

Is upper-room UVC an alternative to the RAC?

Yes and no.

Yes, upper-room UVC will inactivate airborne *M. tuberculosis* at efficiencies equal to or greater than a RAC.

No, upper-room UVC does not provide or enhance negative pressure.

Resources

Centers for Disease Control and Prevention (CDC)

- General guidance, including use of negative pressure for TB IPC
  Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Health-Care Settings, 2005
  https://www.cdc.gov/mmwr/pdf/rr/rr5417.pdf
- AIIRs
  Guidelines for Environmental Infection Control in Health-Care Facilities, Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC) – 2019 update
  https://www.cdc.gov/infectioncontrol/pdf/guidelines/environmental-guidelines-P.pdf

Facilities Guidelines Institute (FGI)

- *Guidelines for Design and Construction of Hospitals* (2022)
  https://shop.fgiguidelines.org/products/digital-2022-user-hospital
- *Guidelines for Design and Construction of Outpatient Facilities* (2022)
  https://shop.fgiguidelines.org/products/digital-2022-user-outpatient
- *Guidelines for Design and Construction of Residential Health, Care, and Support Facilities* (2022)
  https://shop.fgiguidelines.org/products/digital-2022-user-residential

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