

Airborne Infection Isolation Rooms



AIRBORNE INFECTION ISOLATION ROOMS (AIIRS)

A properly designed and operating AIIR can be an effective infection control measure. Infectious airborne particles are contained within the room, and the concentration of these particles inside the room is reduced.

However, a badly designed and/or incorrectly operating AIIR can place HCWs and other patients 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 effectively reduced. Staff members who rely on such an AIIR may have a false sense of security.

The mechanical elements that make an AIIR effective will deteriorate over time, which may make the controls ineffective. For example, fans can break and ducts can become clogged with dust and lint. People who have not been trained in environmental controls may inadvertently adjust or alter the controls. An AIIR that was successfully tested after construction may not be operating correctly a month later. Hence, periodic and ongoing assessment of AIIRs is important.

This manual provides basic information about assessing and improving the design and operation of an AIIR. It also includes options to convert an existing patient room into an AIIR and information on guidelines and regulations covering AIIR environmental controls.

TB control in high-risk settings is commonly organized in a hierarchy: administrative (or work practice) controls are the most important, followed by environmental controls, and then respiratory protection. Although this section only addresses environmental controls, all three components should be in place for an effective TB control program.

Whenever an AIIR is used, written policies and procedures should be developed and implemented to address the administrative aspects of the AIIR. They should include:

- criteria for initiating and discontinuing isolation
- who has authority for initiating and discontinuing isolation
- isolation practices
- how often and by whom the policy and procedure is evaluated
- developing and implementing a written respiratory protection program is also required.

Designing a New State-of-the-Art AIIR

This section describes the requirements and guidelines to be considered when designing a new AIIR, either during new construction or during renovation.

Planning Stage

During the planning stages of a new construction or a remodel project, users often meet with architects to discuss various design elements. This enables the users to provide input to the design team. These discussions usually concentrate on the physical layout of the space. The mechanical elements are often left to the mechanical engineer's discretion.

Infection control coordinators and other appropriate managers should be included in this process. The infection control aspects of the mechanical system should be addressed so that the people relying on the controls understand this system.

Architects and mechanical engineers may not be aware of some infection control requirements. While engineers must comply with building codes to get approval for construction and occupancy, they may not be aware of CDC recommendations, or of federal or local OSHA requirements. However, architects and engineers should be familiar and comply with the most current AIA Guidelines for Design and Construction of Hospital and Health Care Facilities and ANSI/ASHRAE Standard for Ventilation for Acceptable Indoor Air Quality.

The mechanical design elements of a new hospital AIIR should, at a minimum, meet all local code requirements, as well as OSHA requirements, CDC recommendations, AIA Guidelines, and ANSI/ASHRAE Standards.

Architectural Considerations

Architecturally, an AIIR should meet all the detailed requirements for a single-patient room, including a dedicated adjacent bathroom.

Architectural design elements should also meet local code requirements. For example, California requirements include:

- Code minimum clearance around the bed
- Code minimum room area
- Windows operable only by use of tools or keys

To increase the effectiveness of negative pressure, the architectural elements should ensure that the AIIR suite is sealed, except for a half-inch high air gap under the door. Towards this end, the ceiling should be plaster/sheet rock rather than removable ceiling tiles, and lights should be surface-mounted. Gasketing should be provided at the sides and top of the door, and at ceiling and wall penetrations such as those around medical and electrical outlets.

The location of the proposed AIIR should also be considered: areas prone to strong drafts, such as those near elevator banks or doorways, should be avoided if possible.

AIIR doors should be equipped with self-closing devices.

The mechanical design elements of a new hospital AIIR should, at a minimum, meet all local code requirements, as well as OSHA requirements, CDC recommendations, AIA Guidelines, and ANSI/ASHRAE Standards.

Determining the Correct Ventilation Rate

When designing the heating, ventilating, and air-conditioning (HVAC) elements of a building, the amount of air supplied to each room is usually selected on the basis of comfort concerns. Unless there are governing code requirements, the engineer will provide ventilation air as required to keep the space comfortable. This air quantity is usually less than the amount required for effective dilution and removal of infectious particles.

For many spaces in healthcare facilities, such as AIIRs, infection control concerns may be more important than comfort concerns. Engineers should increase the airflow rate accordingly. A straightforward way to increase the effectiveness of ventilation is to increase the amount of air moving through a space—in other words, to increase the ventilation rate.

A room's ventilation rate can be calculated if it has mechanical ventilation. The ventilation rate is usually expressed in air changes per hour (ACH). By calculating the ACH, the room ventilation 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.

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 change rate in ACH is the volume of air circulating every hour divided by the room volume. Appendix K (page 156) describes air change rates in more detail and demonstrates how to calculate the air change rate of a room that has mechanical ventilation and/or a HEPA filter unit.

It is recommended that AIIRs have an exhaust air ventilation rate of at least 12 ACH. This recommendation is consistent with the CDC Guidelines and meets all local requirements known to CNTC.

The ACH is the airflow per hour divided by room volume (see Appendix K). For AIIRs, the exhaust airflow should be calculated, rather than supply airflow. The ACH of the dedicated bathroom or anteroom, when present, should be calculated separately from that of the AIIR itself. In other words, only include exhaust air that is exhausted in the AIIR.

Variable Air Volume (VAV) Systems

Many mechanical systems do not provide a constant airflow rate. These are called variable air volume (VAV) systems. They are designed to continually vary the amount of cooling or heating air delivered to a room in response to the amount of cooling or heating required. Supply air varies between a fixed minimum and a fixed maximum using a VAV box installed in the ductwork. VAV systems are generally not found in hospitals, but are common in buildings that may include clinics.

The volume of air supplied to an AIIR should not vary. Therefore, if an AIIR is to be included in a building served by a VAV system, the box supplying air to the AIIR should be set to deliver constant airflow. The mechanical engineer will need to address comfort control of this room separately.

Locating Supply and Exhaust Ductwork and Outlets

The supply and exhaust location should be chosen to maximize air mixing and to optimize directional airflow from the staff member towards the patient. Exhaust should be removed near the possible contamination source.

The best arrangement is to supply air at the ceiling above the foot of the bed, and to exhaust air on the wall near the floor at the head of the bed (where the patient's head is likely to be).

The supply diffuser should be the louvered blade type, rather than the perforated face type. The diffuser neck size and blow pattern should be selected so that air is directed to all parts of the room. Locate the diffuser where the airflow is not obstructed by items such as surface-mounted light fixtures or a suspended television set.

The bottom of the exhaust grille should be located approximately 6 inches above the floor. Because the grille does not direct air, its face pattern is not as important as that of the diffuser. The vertical exhaust duct should be installed in the AIIR wall. An enlarged wall cavity will be required and should be coordinated with the architect. To reduce noise, dampers should be located at a point in the duct far from the outlet. The area in front of the exhaust grille should be kept clear of obstructions, such as furniture and supply carts.

The individual air ducts providing supply and exhaust air for the AIIR suite should have control dampers to adjust the airflow quantity. These dampers are usually manually operated, but may be automatic. To ensure access, the handles for the dampers should not be above the AIIR ceiling. They should be either accessible from above the corridor ceiling, or remote, tamper-proof handles should be provided in the ceiling or wall of the AIIR.

Maintaining Negative Pressure

As described previously (on page 26), negative pressure is achieved when exhaust air exceeds supply air and the room is well sealed except for a gap under the door.

The CDC Guidelines recommend a negative pressure differential of at least 0.01 inches of water gauge (" W.G.).

In practice, an offset this small can 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 smoke may migrate into a room during a fire, building code officials are concerned with the amount of air drawn into a room under the door from a corridor. The amount of exhaust air offset from the corridor will need to comply with local codes, which may limit the maximum allowable offset. If the AIIR is equipped with an anteroom, this issue will not be as important.

CNTC recommends that the negative pressure differential across the AIIR door be approximately 0.03" W.G. In practice, this may require that the airflow offset be adjusted to more than 100 CFM after the room is built, but before it is occupied. Engineers should allow for this possibility in their designs.

AIRR with Dedicated Bathroom

Some AIIRs have a dedicated bathroom that is part of the AIIR suite and only for use by the isolated patient. Such AIIRs are more likely to be found in hospitals than in clinics. The advantage of the bathroom is that the patient will not have to open and close the door as often to leave the suite.

To contain odors, the AIIR bathroom should be at negative pressure with respect to the AIIR, where applicable. The bathroom ventilation should comply with local requirements. For example the California Mechanical Code (CMC) 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 is sufficient between the bathroom and the AIIR.

Both the AIIR and the combined AIIR and bathroom should be at negative pressure. 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 the “Case Study: Dedicated Bathroom” on page 107.

Handling AIIR Exhaust

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

While not included as a minimum recommendation by the CDC 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.

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

Labeling

Maintenance personnel and contractors often re-route ducts to accommodate new services. To help protect these workers from potentially contaminated AIIR exhaust, the exhaust ductwork should be permanently labeled. The label should read, “Caution—AIIR Exhaust,” or similar words to that effect. The labels should be attached, at most, 20 feet apart, and at all floor and wall penetrations.

Maintenance workers may also shut down the exhaust fan without realizing this will cause a loss of negative pressure. To avoid this possibility, a permanent warning sign should be posted on the fan at the electrical disconnect and at appropriate electrical panel breakers. The sign should read, “AIIR Exhaust Fan—Contact Infection Control Coordinator Before Turning Off Fan,” or have similar wording. The sign should also include the telephone number of the infection control coordinator and the room number(s) of the AIIR(s) exhausted by the fan.

Exhaust 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 (i.e., walkways) or openings into the building (i.e., windows or outside air intakes).

To promote dilution, the fan discharge should be directed vertically upward at a speed of at least 2,000 FPM. The discharge location should be at least 25 feet away from public areas or openings into a building.

If a suitable discharge location is unavailable, then the exhaust can be disinfected using a HEPA filter (see page 42). In this case, a HEPA filter must be installed in the discharge duct upstream of the exhaust fan. This is not a desirable option, however, because it will be considerably more expensive to install, maintain, and operate than a simple exhaust fan assembly.

Installing a Permanent Room Pressure Monitor

After a new AIIR is constructed and before it is occupied, the mechanical contractor will adjust the airflow quantities as directed by the engineer to ensure that it operates as designed. However, mechanical systems do drift out of balance over time. It is important to regularly check that an AIIR is still operating under negative pressure; planning for this should be included in the initial mechanical design of the room. Room pressure monitors should be used as a supplement to daily visual checks when the room is in use.

The most reliable way to monitor negative pressure is to install a permanent electronic room pressure monitor as part of the construction project.

When properly selected and installed, a room pressure monitor can provide continuous qualitative and quantitative confirmation of negative pressure across a room boundary. This is in contrast to routine periodic smoke testing, which merely provides an indication of directional airflow at the moment of testing.

Continuous monitoring can provide instant notification if the pressurization fails or fluctuates during the day.

Most monitors consist of two main components: a wall-mounted panel and a sensor. The panel is usually mounted on the corridor wall just outside the AIIR suite and displays the pressure difference in units of " water gauge.

There are two common types of permanent pressure monitors: those that measure and display the actual air pressure difference between the AIIR and the reference space (direct type); and those that measure the velocity of air moving between the two spaces through a fixed opening and convert this to a pressure value (indirect). Both types require an electrical power connection at the wall panel. Either type is suitable for an AIIR, but indirect monitors generally provide a more accurate pressure reading.

Pressure differentials across room boundaries can be very small, often in the range of thousandths of an inch. For example, the CDC Guidelines recommend that negative pressure be at least ≥ 0.01 " of water gauge. 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 difference this small.

Direct Room Pressure Monitor

To record a pressure differential directly, two readings are required: the air pressure in the room and the reference pressure in the corridor. A remote sensor to measure the room pressure is installed in the negative pressure room wall or ceiling. Another sensor measures the air pressure in the corridor. The difference in these two pressure values is the relative room pressurization, which is displayed on the panel.

If there is an anteroom between the AIIR and the corridor, the pressure differential to be measured is the one between the AIIR and the anteroom. In this case, both measurement points are remote from the corridor panel. If there is no anteroom, the reference pressure can be measured right at the panel, and only one remote reading is required.

The location of the remote sensors will affect the accuracy of the measurement. They should be installed as close as possible to the AIIR door, but away from drafts.

Tubing will need to be run from the panel to the sensor(s). For new construction, this tubing will typically be run out of sight inside wall cavities and above the ceiling. Air tubing is usually rigid plastic, but can be made of copper.

Indirect Room Pressure Monitor

The sensing component of a velocity-reading room pressure monitor consists of an air tube with an interior velocity-sensing element. The tube is installed in the wall between the AIIR and the anteroom or corridor. An electrical device measures the air velocity and direction. This signal is run back to the wall panel, where it is converted to a pressure readout.

Again, care should be taken when installing the sensor. It should be located above or next to the door, but away from the influence of drafts. To help shield the sensors, louvered cover plates are usually provided on both sides of the wall.

The signal between the sensor and the wall panel is a low voltage electrical signal instead of the air tubing used in direct pressure monitors.

Alarm(s) and Controls

In addition to providing a continuous readout of the pressure difference, the wall panel should include an audible and visual alarm to warn staff when pressurization is lost.

The alarm will sound when the measured room pressurization drifts to less than the monitor's reference pressure value. Reference pressure values are programmed into the unit by an engineer or trained staff member. It will be a value between the steady state pressure differential maintained by the room and zero (neutral pressure).

For example, in a room with a steady state pressure differential of minus 0.03" W.G., the alarm could be programmed to activate when the pressure differential falls to minus 0.001" W.G.. Minus 0.001" W.G. is the reference pressure value.

The wall panel should also allow staff to program a built-in time delay between loss of pressurization and alarm activation. The time delay will allow staff a sufficient interval to routinely enter and leave the room without setting off the alarm. A typical time delay is 45 seconds.

The audible alarm is usually a beeping sound, which will stop when negative pressure is restored or when a "mute" button on the panel is pressed.

The visual alarm usually consists of a red warning light. Most wall panels also have a green "normal" or "safe" light, which indicates that the monitor is operating and negative pres-

sure is within programmed parameters. Unlike the audible alarm, the visual alarm will not reset when the “mute” button is pressed. After negative pressure is restored, the lights will either automatically reset or the “reset” button must be pressed, depending on the brand of the monitor. In case no one was present, the latter option will indicate that negative pressure was temporarily lost.

Remote Alarm

In addition to the alarm included on the wall panel, most room pressure monitors include an extra identical signal that allows a “safe” or “alarm” signal to be sent from the wall panel to a remote location. Common locations for this remote alarm are the nurses’ station, the engineering department, and the central switchboard.

It is usually possible to connect the alarm signals from a number of AIR monitors to a remote alarm panel. In California, for example, the hospital building codes require that AIRs be equipped with an alarm that annunciates at the room *and* at a nurses’ station or other suitable location.

Other Optional Features

There are a number of room pressure monitors available with additional options. Examples of such options include: an amber “warning” light that illuminates during the time delay when negative pressure is lost; adjustment for use in positive pressure rooms; and remote control of a fan or damper to maintain and control negative pressure.

Commissioning and Staff Training

The monitor installer’s responsibilities should include verifying the operation of the sensor. A detailed checklist is included as Appendix C on page 145. The following should be completed before the room is used to isolate suspected or confirmed infectious TB patients:

- 1. Verify that the alarm works.** Hold the room door open. After the time delay, the audible and visual alarm should annunciate. The alarm should reset after the “mute” or “reset” button is pressed and/or the door is closed again.
- 2. Verify that the monitor is correctly reading the pressure.** While the door is held open, the pressure reading should be at or near 0” water gauge.
- 3. Instruct staff on monitor usage.** The floor staff that depend on the monitor for their safety should feel comfortable using it. They should receive detailed instructions on how the monitor works and how it is used.

The checklist should be completed for each AIR monitor in the facility. A copy of the completed steps in the checklist should be kept in the Policies and Procedures binder for that department.

Ongoing Monitor Checks

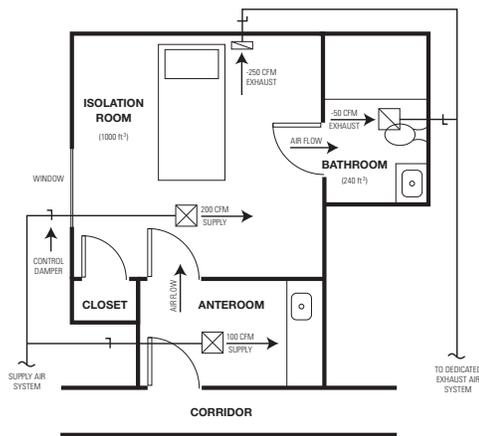
To validate the continuous pressure monitor, negative pressure should be verified monthly with smoke tube or similar testing (see page 81). Daily verification is required when the room is in use or if there are no alarms on the pressure monitor. The results should be recorded. Space for this is included in the checklist.

Most manufacturers recommend that each monitor be recalibrated annually. The recalibration procedure will depend on the monitor type and should be available from the manufacturer. CNTC recommends that the step in the new monitor checklist be completed at the same time.

To validate the continuous pressure monitor, negative pressure should be verified monthly with smoke tube or similar testing.

FIGURE 10.

AIIR with Anteroom



Providing an Anteroom

An anteroom should be provided between the AIIR and the corridor. This will help prevent infectious particles in the AIIR from escaping into the corridor.

When an AIIR door is open, negative pressure 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 lock” between the AIIR and the rest of the facility.

An anteroom should be at positive pressure with respect to the AIIR, and at either neutral or negative pressure with respect 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 to the corridor, rather than negative. However, in practice this is very difficult to accomplish. 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.

Local codes should be consulted regarding other design elements of anterooms for AIIRs. For example, California requirements include:

- Provision of a sink, cabinets, and work counter
- Provision of a view window in the door to the AIIR
- Alignment of door to corridor with door to AIIR, or provision of a second locked and gasketed entry for gurney
- Maximum of two AIIRs per anteroom.

Assessing an Existing AIIR

This section covers the steps that should be taken to evaluate the effectiveness of an existing AIIR.

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

Items that should be checked include the exhaust and supply airflow rate, negative pressure, and exhaust duct termination location.

Ventilation

To determine the ACH of a space, you will need to measure the airflow and calculate the room volume. See Appendix K on page 156.

The airflow measurements and calculations should be performed by a certified testing and balancing agency or by in-house engineering staff.

Airflow Measurement

The airflow of a room is usually measured at the individual registers and diffusers using a balometer. This is a device that consists of a hood, a velocity sensor, and a microprocessor.

The hood is placed over a register or diffuser and should completely cover the air outlet. The top of the hood should have a foam gasket that establishes a good seal between the hood and the ceiling or wall around the outlet.

The hood directs all air entering or leaving the outlet past a velocity-sensing grid. The area of the grid is fixed. Therefore, the microprocessor can calculate and display the quantity of air being exhausted or supplied by the air outlet. Balometers usually provide an airflow reading in cubic feet of air per minute (CFM).

The standard size of a balometer hood outlet is 24" X 24", although adapters are provided to adjust the hood size. This size hood can be used to measure the airflow of any outlet equal to or smaller than this (e.g., 12" X 24" or 18" X 18" diffuser). For other size outlets, such as a 36" X 6" slot diffuser, the hood size on the balometer may need to be changed.

There may not be sufficient space in front of some outlets to place the balometer. In this case, the airflow should be measured by a pitot traverse in the duct that serves the outlet.

A pitot traverse is a specialized measurement that requires access above the ceiling. Air velocity is measured at a number of sample locations inside the duct. Airflow is calculated based on these velocity readings and the area of the duct cross-section. However, pitot traverses are not as accurate as balometers.

If a dedicated exhaust fan serves the AIIR suite, it may be possible to estimate the airflow at the room by measuring the airflow at this fan. Because of duct leakage, this measurement will not be as accurate as one taken at or near the outlet. Inadequately sealed duct joints can result in extra air being sucked into the duct between the AIIR exhaust grille and the fan, which would result in an overestimate of airflow in the room. To compensate for this, an allowance of at least 10% should be made. This allowance should be increased in the case of a long duct run.

If room airflow is found to be inadequate, i.e., less than 12 ACH, it should be increased. For information on modifying existing room airflow, see "Upgrading or Converting an Existing Room" on page 101.

Air Mixing and Directional Airflow

After establishing the airflow, the next step is to evaluate how effectively this air is used in the AIIR. This assessment is not as straightforward as calculating the airflow rate because there is no clearly defined numerical standard to meet.

Smoke testing can be used to visualize the direction of room air and to estimate how well air is mixing. Consequently, ventilation problems can be identified, such as undesirable directional airflow patterns and poor mixing.

Ideally, the clean supply air will be introduced near a HCW, while exhaust air will be removed near the patient. Good air mixing is confirmed by rapid dissipation of the test smoke in all parts of the room, which demonstrates that particles generated in the room are being diluted and removed.

If air mixing is not optimal due to short-circuiting or stagnation, the diffuser and/or register should be relocated or replaced. Either of these options will require the services of a consultant mechanical engineer. In the interim, a supplemental propeller-type fan can be placed in the AIIR to encourage air mixing. Such a fan is not recommended as a long-term solution because it may create uncomfortable drafts and be turned off by the patient.

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

Exhaust Ductwork and Discharge

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. For the record, a set of drawings should be generated (or an existing design set marked) to show the ductwork and fan.

The exhaust ductwork and fan should also be checked 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.

Recirculating Air Systems

If air from an AIIR is returned to a recirculating ventilation system that does not include HEPA filtration, this room should no longer be used for isolation. Staff and patients in rooms served by this system may be exposed to *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 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 ventilation systems is usually better than in clinics because hospitals are typically covered by stricter building codes and have larger facilities and maintenance budgets.

Dedicated or Shared Exhaust System

The CDC Guidelines do not address the issue of dedicated exhaust air systems serving AIIRs. However, 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.

Duct and Fan Labeling

If the existing exhaust system is dedicated, make sure that the ductwork is labeled as recommended for a new AIIR (“Caution—AIIR Exhaust”). For a shared system, only the ductwork between the AIIR and the main exhaust trunk needs to be labeled.

The exhaust fan, whether dedicated or shared, should have a warning label as recommended for a new system (“AIIR Exhaust Fan—Contact Infection Control Coordinator Before Turning Off Fan”).

See “Handling AIIR Exhaust” on page 92, for additional information on labeling of exhaust ductwork and fans.

Verifying Negative Pressure

Negative pressure is the easiest characteristic of an AIIR to check. Several methods are available to qualitatively assess negative air pressure, including smoke tube testing and tissue testing.

If the AIIR is operating as intended, there will be an air current moving into the room under the door. The existence and direction of this current should be verified.

Smoke Tube Test

Smoke tube testing helps visualize the current near a room door. In this simple procedure, smoke is released near the air gap under an AIIR door. See “Smoke Tube Testing Method for AIIRs” on page 106 for more detailed instructions.

Commercially available smoke-generating kits produce a visible cloud, which usually consists of water and acid. The quantity of smoke typically issued from the tube is minimal and is undetectable at short distances from the tube. Because inhalation of this smoke in concentrated form can cause irritation, care should be taken not to expose workers or patients until the smoke has been diluted. The amount of smoke used should not be excessive.

There are many different types of easy-to-use smoke-generating kits available from safety supply companies. A typical design is the disposable self-contained puff bottle. Another common design is the disposable smoke tube, which attaches to a rubber bulb that acts like a bellows.

If commercial smoke-generating devices are not available, incense sticks can be used. CNTC recommends that two sticks be used side-by-side. However, incense smoke does have a strong odor, and is not as visible or controllable as commercial smoke.

Tissue Test

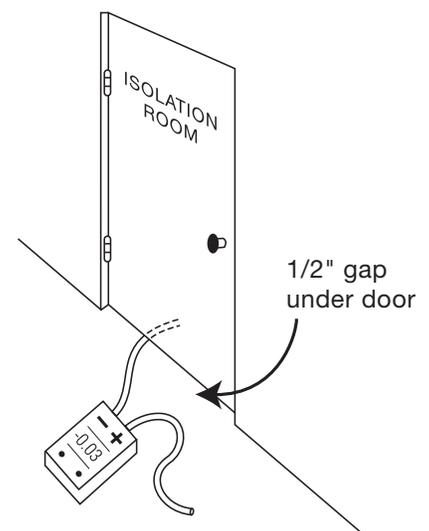
If smoke-generating devices are not available, or if the room is occupied by a patient who may be vulnerable to the irritant properties of smoke, a thin strip of tissue can be used to determine whether a room is at negative, neutral, or positive pressure. A thin strip of tissue should be held parallel to the gap between the floor and bottom of the door. The direction of the tissue's movement will indicate the direction of air movement.

Manometer

Relative room pressurization can also be verified using a handheld pressure gauge or manometer, which is similar to a direct room pressure monitor, except it is portable. A length of rubber tubing is attached to each of the two ports on the manometer. The manometer displays " W.G., the pressure difference between the two spaces at the termination of the tubes. If one of the tubes is threaded under the door into the AIIR and the other is in the hallway, the manometer will indicate the pressure difference between the two spaces. A negative symbol verifies that the room is at negative pressure.

FIGURE 11.

Manometer



Velometer

Air speed is measured by a velometer, usually in units of feet per minute (FPM). These devices can be placed near the gap under the AIIR door to measure the speed of the airstream. Velometers are available in a number of different configurations. Many only indicate air speed regardless of air direction. For instance, some velometers indicate how fast the air is moving, but not whether the air is entering or leaving the room. However, there are models available that can also be used to determine airflow direction.

Repeat Test

All of these tests to verify negative pressure should be conducted at least three times until the results are consistent.

Validate Existing Monitor

If the existing room is equipped with a permanent room pressure monitor, one of the above tests should be performed to confirm negative pressure and to validate the monitor. Also, the AIIR Pressure Monitor Checklist (Appendix C on page 145) should be completed for the monitor.

Measuring Negative Pressure

After negative pressure has been verified, it should be measured. Table 10 summarizes three ways to quantify negative pressure. The corresponding units of measurement and the measuring device for each method are also shown.

TABLE 10.

How to Quantify Negative Pressure

PARAMETER	UNITS OF MEASUREMENT	MEASURING DEVICE
pressure difference	inches of water gauge (" W.G.)	manometer
speed of air under the door	feet per minute (FPM)	velometer
exhaust air offset	cubic feet per minute (CFM)	balometer

Upgrading or Converting an Existing Room

This section covers methods of improving the ventilation characteristics of an existing room to make it more effective for AIIR.

Previous sections have outlined recommendations for a new state-of-the-art AIIR and have shown how to assess an existing room to see how it compares with these recommendations. This section describes how to correct deficiencies found during the assessment.

The methods outlined below could also be used to convert an existing patient room into an AIIR.

- **Disconnect Recirculating Air System**

The first step is to ensure that air from the room is not inadequately filtered and recirculated to other areas. The air removed from the room must either be exhausted outdoors to a safe location or HEPA-filtered. If room exhaust is currently connected to a recirculating air system that does not include a HEPA filter, it should be disconnected from this system.

- **Install HEPA Filter in Existing Return Air System**

Theoretically, another safe option for correcting a recirculating system is to replace the existing filter with a HEPA filter. However, CNTC does not recommend this. A HEPA filter is a specialized piece of equipment that should only be used in a ventilation system specifically designed to accommodate it. HEPA filters are physically larger than most filters and require larger fans to overcome increased resistance to airflow.

- **Two Upgrade/Conversion Options**

There are two basic approaches to upgrading or creating an AIIR. The preferred option is to adjust the building ventilation system to create a permanent AIIR. A temporary solution is to add a recirculating HEPA filter unit to supplement, or even replace, the building ventilation system.

Regardless of the upgrade option selected, steps must be taken to reduce unwanted air leakage from the room, i.e., the room must be sealed.

- **Negative Pressure**

As explained previously, the negative pressure value will depend on two factors: how much more air is exhausted than supplied (i.e., the offset); and how well the room is sealed. In general, when converting or upgrading a room, the negative pressure value will not be as high as that attainable for new construction because there is less control over the architectural elements.

CNTC recommends that the negative pressure value should be at least minus 0.006" W.G. for upgraded or converted AIIRs.

This is more stringent than the CDC Guidelines, which recommend ≥ 0.01 " of water gauge as a minimum negative pressure value.

Sealing the Room

A room in which exhaust exceeds supply will not necessarily be at negative pressure with respect to the corridor; it is not unusual to have such a room at positive pressure.

For example, a room could have exhaust air from the central system exceeding supply by 100 CFM. Assume this room has leaky windows and some holes in the ceiling tiles. If it is windy outdoors, 75 CFM could enter through the leaks around the windows, and another 75 CFM could enter through the ceiling. Now the air being introduced to the room exceeds exhaust by 50 CFM. Smoke testing at the door would probably indicate positive pressurization.

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. For a given exhaust air offset, 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.

The following are some examples of steps that can be taken to improve a room's airtightness:

- Apply gasketing at sides and top of room door
- Caulk around windowpanes and around window frames
- Apply gasketing at the connection of the ceiling and the walls
- Apply gasketing around electrical boxes
- Replace acoustic ceiling tiles with non-porous vinyl tiles and apply gasketing at tile connection to ceiling grid
- Replace recessed light fixtures with surface-mounted fixtures

Adjusting the Ventilation System

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

Connect to Existing Exhaust System or Add New One

If there is an accessible exhaust air system nearby, such as a toilet exhaust system, with sufficient capacity, it may be possible to make a new exhaust connection to the existing return register. 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 Mechanical System

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

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, usually located above the ceiling, should only be adjusted by a facility engineer or certified air balance contractor. To increase airflow, the dampers in the ducts serving the room should be opened wider. It usually takes an air balancer two or three adjustments to obtain the desired airflow.

The exhaust airflow rate should be at least 12 ACH. For existing rooms, this recommendation is more restrictive than the CDC Guidelines, which accept an air change rate of 6 ACH. However, 6 ACH will not satisfy some local regulatory agencies, including Cal/OSHA and the Office of Statewide Health Planning and Development (OSHPD) in California. Twelve (12) ACH, which meets all local requirements known to CNTC, is readily achievable using HEPA filter units.

The supply should be approximately 100 CFM less than exhaust. Depending on how well the room is sealed, more air may need to be exhausted in order to achieve a larger pressure differential.

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

Adding a Recirculating HEPA Filter Unit

It may not be possible or practical to connect to an existing exhaust air system, or to install a new one. It is possible to create a temporary and less expensive AIRR. This can be done using a recirculating HEPA filter unit. There are two basic ways to use these units in AIRRs. They can be used to increase only the ventilation rate of a room without affecting room pressurization. Or they can be used to simultaneously:

- Increase the ventilation rate,
- Create or increase negative pressure, and
- Replace the need for additional exhaust.

HEPA Filter Units

HEPA filter units are readily available electrical devices that consist primarily of a fan, a HEPA filter, and a prefilter. They also include controls, such as a three-speed switch, and possibly an indicator light to indicate when the filter needs to be changed.

HEPA filter units are available in a number of different physical configurations, including wall- and ceiling-mounted types. The most popular configuration is the floor-standing, portable type.

Wall- or ceiling-mounted units are less obtrusive and do not take up floor space. They are also less likely to be tampered with by staff and patients. However, floor-mounted units are more portable and are easier to service. Regulatory bodies, such as OSHPD in California, may require that a structural engineer oversee the design and construction of the support system for a wall-mounted or ceiling-mounted HEPA filter unit.

Increase Ventilation Rate

If negative pressure in the AIR is satisfactory, but the ventilation rate is low, a HEPA filter can be used to supplement the room airflow rate. The effective ventilation rate of the room is the sum of the central system airflow and the HEPA filter unit airflow.

Sizing HEPA Filter Units

The size of the unit selected should be based on the additional airflow (in CFM) required to achieve the desired ACH in your room. To determine the additional airflow:

- Measure the actual CFM exhausted from the room, and
- Calculate the CFM required to achieve the desired ACH. The HEPA filter unit should be sized to make up the difference.

Most HEPA filter units allow staff to adjust the amount of air delivered by means of a switch. Common examples of switches include those with three fixed settings and those that allow any setting between the maximum and minimum. Manufacturers' catalogs generally list a CFM delivered by the unit at each of the three speeds, or at the high and low setting.

In practice, people usually turn down the HEPA filter unit switch and operate the units at or near the low setting. This is because the units can be very noisy and/or drafty when the fan is at, or near, full speed.

CNTC recommends that HEPA filter units be selected based on the airflow at or near the low speed.

These units may deliver less than the manufacturers' listed airflow, and output of the units may decrease as the filters load up. To compensate for this, it is recommended that the unit selected have a listed capacity that is 25% more than required. The marginal cost of selecting a unit with more capacity is usually not significant, compared to the initial cost of the unit.

To summarize, it is recommended that a unit is selected that can deliver 25% more CFM than required at or near the low speed fan setting.

For example, if 150 CFM is measured, and 220 CFM is required to achieve 12 ACH, then the required additional airflow is 70 CFM. If a HEPA filter unit is used to increase airflow, then 25% should be added to 70 CFM for a total of approximately 90 CFM. Therefore, a unit with a listed capacity of at least 90 CFM at or near the low fan speed setting should be selected.

Increase Ventilation Rate and Create or Increase Negative Pressure

If a sufficient portion of the discharge from a HEPA filter unit is ducted somewhere outside of the room, then the HEPA filter unit can create negative pressure and replace the need for any extra exhaust.

A HEPA filter unit supplements ventilation as follows:

- The effective exhaust air quantity is increased by an amount equal to the airflow of the HEPA filter unit (because this air is now being removed and droplet nuclei are removed by the filter)
- The effective supply is increased by an amount equal to the returned air quantity (HEPA unit airflow minus the amount discharged outside the room)
- The effective negative pressure offset is increased by an amount equal to the HEPA unit airflow discharged outside the room.

Theoretically, the technique described above could also be used to create negative pressure in a room that had no ventilation system. However, this is not recommended because the room would then have no outside air at all, only recirculated, HEPA-filtered air. Building codes mandate that fresh outdoor air be supplied to all occupied spaces that do not have an operable window.

Monitoring the Environmental Controls

Once the AIIR upgrade has been completed, procedures to monitor the environmental controls must be implemented. This is essential to ensure that staff will be alerted if the controls fail.

The two items that need to be monitored are the airflow rates and the room pressurization.

Airflow Rate Monitoring

The airflow rates are monitored by measuring with a balometer to ensure that the rates have not deviated more than about 5% from the initial values.

Airflow rates should be measured and air change rates calculated at least once a year.

Room Pressurization Monitoring

Room pressurization should be continuously monitored to ensure that the room remains under negative pressure.

The CDC Guidelines recommend that room pressurization be confirmed daily while the room is occupied by a suspected or known infectious TB patient, and at least once a month at other times.

These tests can be done with smoke or a telltale device, such as a tissue. However, it is recommended that each AIIR be equipped with a permanent room pressure monitor.

Documentation

Records should be kept 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.

Smoke Trail (or Smoke Tube) Testing Method for Negative Pressure AIIRs

Smoke from a smoke tube can be used to observe airflow between areas or airflow patterns within an area. Smoke tube testing must be performed outside the room with the door closed.

To check the negative pressure in a room, hold the smoke tube near the bottom of the door and approximately 2 inches in front of the door, or at the face of a grille or other door opening. Generate a small amount of smoke by gently squeezing the bulb.

The smoke tube should be held parallel to the door, and the smoke should be issued slowly from the tube to ensure that the velocity of the smoke does not overpower the air velocity. The smoke will travel in the direction of airflow.

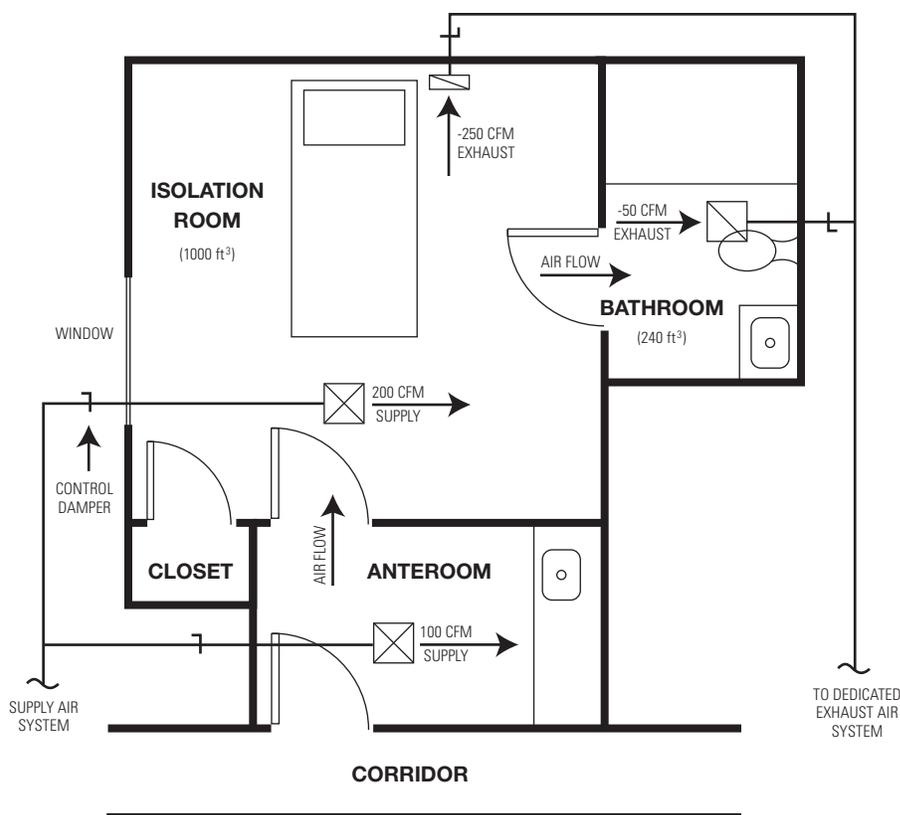
If the room is at negative pressure, the smoke will travel under the door and into the room (e.g., from higher to lower pressure). If the room is not at negative pressure, the smoke will be blown outward or will remain stationary.

If there is an anteroom, release smoke at the inner door undercut, with both anteroom doors shut.

In addition to a pedestrian entry, some AIIRs or areas are accessed through a wider wheeled-bed stretcher door. Release smoke at all door entrances to AIIRs or areas.

If room air cleaners are being used in the room, they should be running during the test.

Because the smoke is irritating if inhaled, care should be taken to prevent direct inhalation from the smoke tube. However, the quantity of smoke issued from the tube is minimal and is not detectable at short distances from the tube.



Dedicated Bathroom

Background

The setting is an AIIR with a dedicated bathroom. Supply air to the AIIR is 200 CFM.

The Options

The AIIR volume is approximately 1,000 cubic feet, so the supply air change rate is 12 ACH.

You are installing a new exhaust fan with a capacity of 300 CFM that will serve only the AIIR suite. Local codes mandate a minimum of 10 ACH in bathrooms. The bathroom volume is approximately 240 cubic feet, so a minimum of 40 CFM exhaust is required.

How should the 300 CFM of exhaust air be split up between the bathroom and the AIIR?

Should 250 CFM be exhausted in the AIIR and 50 CFM in the bathroom?

Or should 200 CFM be exhausted in the AIIR and the remaining 100 CFM in the bathroom?

The Best Option

The preferred arrangement is to exhaust 250 CFM at the AIIR and 50 CFM at the bathroom (as shown in the above diagram), rather than 200 CFM at the AIIR and 100 CFM at the bathroom.

The Reason

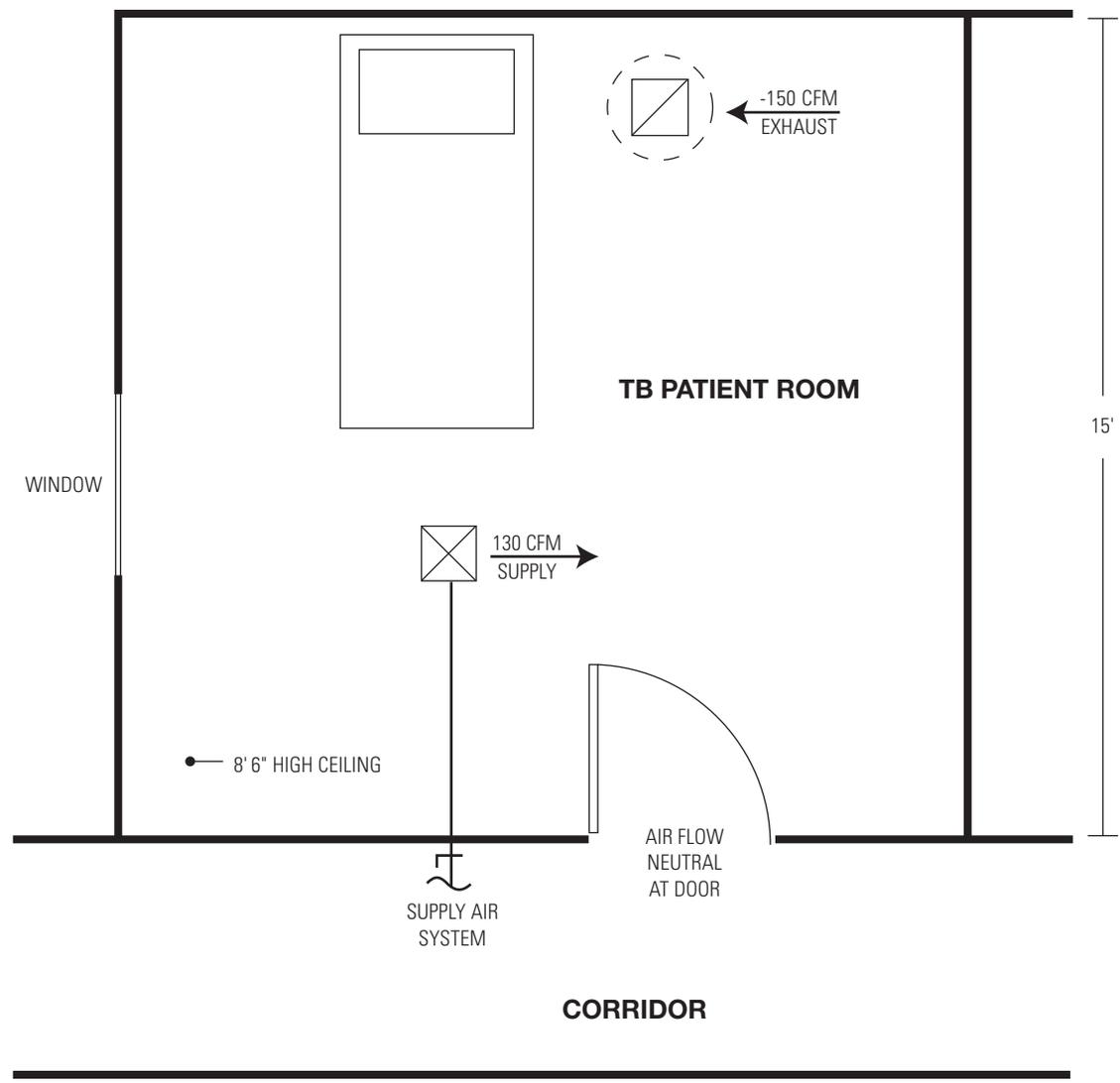
Each arrangement will result in both a 100 CFM offset across the AIIR door and an equal volume of air moving through the AIIR. But only the preferred option provides more exhaust than supply in the AIIR itself, resulting in negative pressure, and increases airflow towards the head of the bed.

Also, code officials may require that direct exhaust from the AIIR exceed direct supply air. The latter option would result in a room with supply equal to exhaust.

CASE STUDY



TB CLINIC HOURS	
Monday	1:00 - 4:30
Tuesday	9:00 - 6:30
Wednesday	Closed
Thursday	9:00 - 6:30
Friday	8:00 - 10:30
CLOSED WEEKENDS	



AIRR: Part One

Background

Routine annual tuberculin skin testing revealed that two employees in a small, single-story county clinic converted their TSTs over the last year. Both employees were clerks in the billing department; neither had patient contact.

Assessment

The clinic manager, Janet, was concerned because the billing department shares a corridor with the room used to isolate TB patients. *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 grille. Even after wiping off the considerable amount of dust on the exhaust grille, there was no air movement. A tissue held against the grille was not pulled toward the grille as would be expected.

The county facilities department sent out a maintenance engineer, Cynthia, to investigate further.

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 that dust and lint had accumulated on the fan motor, causing the motor to overheat and burn out. She cleaned the fan and ductwork and replaced the motor. Exhaust was now measured and found to be 150 CFM.

Room air supply was 130 CFM, which was 20 CFM less than exhaust. However, a series of smoke tests showed that the room was now at neutral pressure rather than negative pressure. Room air leakage exceeded the 20 CFM offset.

Calculate Air Change Rate

The room was square-shaped (15 feet each side), with a ceiling height of 8.5 feet. The exhaust air change rate was calculated as follows:

$$\text{Room Volume} = 15 \times 15 \times 8.5 = \mathbf{1913 \text{ cubic feet}}$$

$$\frac{150 \text{ CFM} \times 60 \text{ minutes}}{1913 \text{ cubic feet}} = \text{approx. } \mathbf{5 \text{ ACH}}$$

Therefore, even with the exhaust fan fixed, the room was unsuitable for isolation because it was at neutral pressure with a low air change rate.

Clearly, something had to be done. See "AIIR: Part 2" for conclusion.

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

AIIR: Part Two

Calculate 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 accomplish this.

Cynthia, the engineer, suggested a portable HEPA filter unit as an affordable upgrade option. A HEPA filter unit would provide additional airflow. If a portion of the discharge were ducted outside, it would also create negative pressure.

The first step was to calculate the additional airflow required:

$$\text{Airflow required for 12 ACH} = \frac{1913 \text{ cubic feet} \times 12 \text{ ACH}}{60 \text{ minutes}} = \text{approx. } \mathbf{400 \text{ CFM}}$$

$$\text{Additional airflow required} = 400 \text{ CFM} - 150 \text{ CFM} = \mathbf{250 \text{ CFM}}$$

Sizing and Installing a Portable HEPA Filter Unit

A HEPA filter unit that produced at least 250 CFM airflow was required. Cynthia contacted a mechanical equipment supplier. Two units were available: a small unit rated for 150 to 300 CFM; and a large unit rated for 250 to 750 CFM. Each unit had a variable speed switch and an optional connection that could be used to duct some of the discharge air outdoors.

Janet suggested buying the small unit to save money. If run at high speed, it would provide more than enough airflow. However, Cynthia explained that most people turn down the fan speed switch because the units can be noisy. The units may also produce less airflow than the catalog claims. She suggested adding a 25% safety factor, then buying a unit listed for this airflow at low or medium speed.

$$\text{Additional airflow} + \text{safety factor} = 250 \text{ CFM} + 25\% = \text{approx. } \mathbf{310 \text{ CFM}}$$

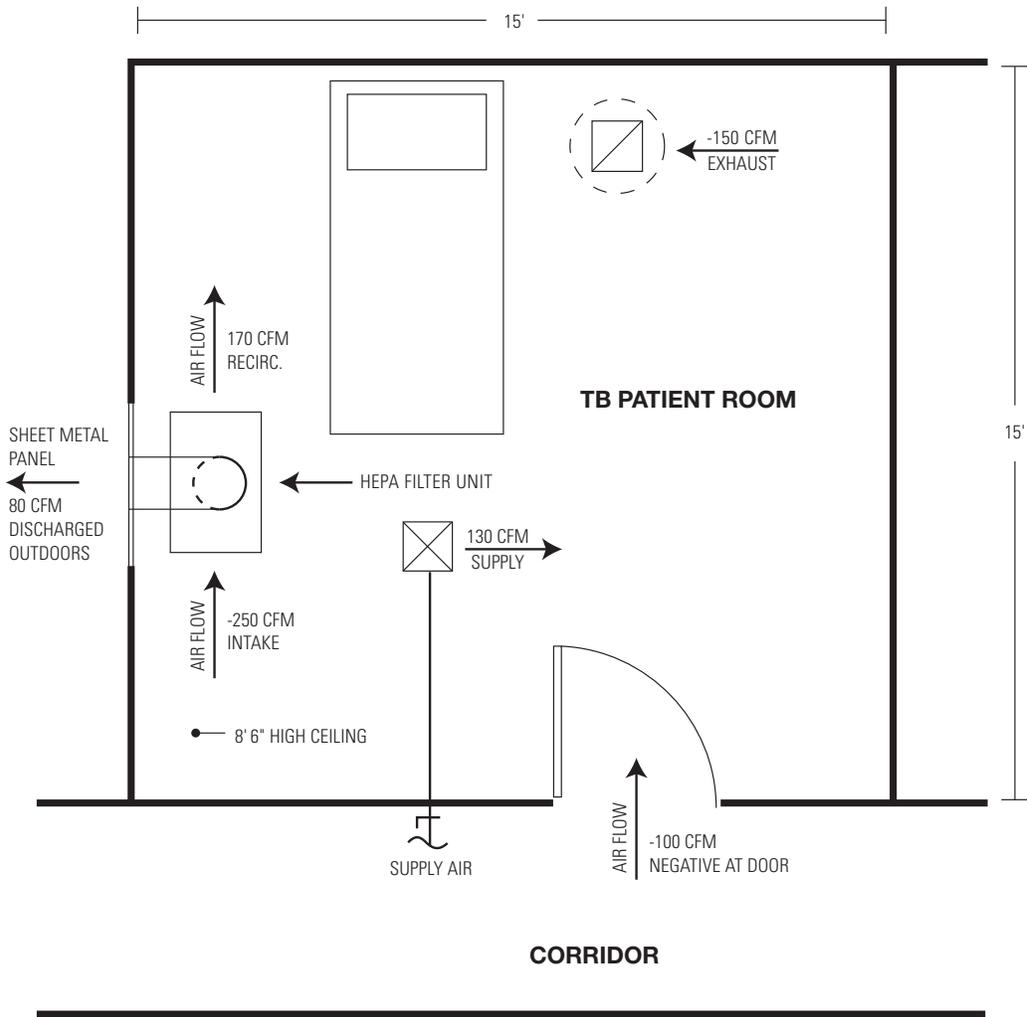
Based on this, the larger unit was selected and placed in the room. Cynthia replaced a windowpane with a sheet metal panel. She connected a flexible duct from the HEPA unit discharge to a hole in the sheet metal panel, set the unit to about 300 CFM, and diverted about a third of the discharge air to the outdoors.

The Happy Ending

The room was now clearly at negative pressure, the airflow was improved, and the noise from the HEPA filter unit was acceptable.

Cynthia's final measurements showed that the HEPA filter was returning approximately 250 CFM, with 80 CFM of this discharged outside and the remaining 170 CFM recirculating in the room.

Effective supply = 130 CFM + 170 CFM = **300 CFM**
 Effective exhaust = 150 CFM + 250 CFM = **400 CFM**
 Effective supply = 400 CFM - 300 CFM = **100 CFM**



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