3.1 OVERVIEW

This chapter describes how to add CBR protection capability to a shelter or safe room.

A CBR safe room protects its occupants from contaminated air outside it by providing clean, breathable air in two ways: (1) by trapping air inside the room and minimizing the air exchange (an unventilated safe room) and (2) by passing contaminated air through a filter to purify it as it is supplied to the room (a ventilated safe room).

Unventilated safe rooms that are tightly sealed cannot be occupied for long periods without the risk of high carbon dioxide levels. This constraint does not apply to ventilated safe rooms, which can be designed to provide filtered and conditioned fresh air at any desired rate. Ventilated safe rooms can therefore be used on a routine basis, although most are designed as standby systems, not for continuous, routine use.

Obtaining protection from an unventilated safe room can be as simple as selecting a relatively tight room, entering it, and closing the door. This procedure is commonly referred to as expedient sheltering-in-place. In this simple form, a safe room protects its occupants by retaining a volume of clean air and minimizing the infiltration of contaminated outdoor air. In practice, however, a safe room is not perfectly tight. The natural forces of wind and buoyancy act on small, distributed leakage paths to exchange air between the inside and outside.

As contaminated air infiltrates a safe room, the level of protection to the occupants diminishes with time. With infiltration in a sustained exposure, the concentration of toxic vapor, gas, or aerosol in the safe room may actually exceed the concentration outdoors because the sealed safe room tends to retain the airborne contaminants when they infiltrate. Once contaminants have entered, they are released slowly after the outdoor hazard has passed. To minimize the hazard of this retention, an unventilated safe room requires two actions to achieve protection:

- The first is to tighten the safe room, to reduce the indoor-outdoor air exchange rate, before the hazardous plume arrives. This is done by closing doors and windows and turning off fans, air conditioners, and combustion heaters.

- The second is to aerate, to increase the indoor-outdoor air exchange rate as soon as the plume has passed. This is done by opening doors and windows and turning on all fans and/or exiting the building into clean outdoor air.

The protection a safe room provides can be increased substantially by adding high-efficiency air filtration. Filtration is employed in two different ways to remove contaminants from the air as it enters the safe room or to remove contaminants as air is circulated within the room. The two ways of incorporating filtration, or not incorporating it at all, yield three general configurations or classes of safe rooms, designated Classes 1, 2, and 3. Table 3-1 shows these three classes and summarizes their advantages and limitations. A common element of all three is a tight enclosure. The three classes differ in whether/how air filtration is applied, resulting in differences in cost, level of protection, and duration of protection.

> When planning to use sheltering as a protective action from a CBR release, it is important to consider when the sheltering process should end. Sheltering provides protection by reducing the airflow from the outside that could contain potentially contaminated air. However, some leakage into the shelter may occur and air inside the shelter may reach unacceptable levels of contamination. It is important to leave the shelter when the threat outside has passed.

- **Class 1**. In a Class 1 Safe Room, air is drawn from outside the room, filtered, and discharged inside the room at a rate sufficient to produce an internal pressure. The safe room is thus ventilated with filtered air, eliminating the constraints related to carbon dioxide accumulation. The internal pressure produced with filtered air prevents infiltration of outside air through leakage paths.

- **Class 2**. This class also includes air filtration, but with little or no internal pressure. Without positive pressure, the safe room does not prevent the infiltration of contaminated air. A Class 2 Safe Room may be ventilated or unventilated. In an unventilated Class 2 Safe Room, air is drawn from inside the safe room, filtered, and discharged inside it. In a ventilated Class 2 Safe Room, air is drawn from outside but at a flow rate too small to create a measurable differential pressure.

- **Class 3**. This class has no air-filtering capability and is unventilated. It is a basic safe room that derives protection only by retained clean air within its tight enclosure. Use of the Class 3 Safe Room is commonly referred to as sheltering-in-place.

Table 3-1: Comparison of the Three General Classes of Toxic-agent Safe Rooms

Class	Protection	Cost	Advantages and Limitations
1. Ventilated and pressurized with filtered air	high	high	Protection has no time limits, but it provides no protection against some toxic chemicals of high vapor pressure.
2. Filtration with little or no pressurization	medium	medium	Unventilated Class 2 is protective against all gases, but protection diminishes with duration of exposure (and against non-filterable gases).
3. Unventilated, no filtration	low	low	Protective against all agents, but protection diminishes with time of exposure. Carbon dioxide buildup may limit time in the shelter.

The Class 1 Safe Room provides the highest level of protection for most chemicals, but the lowest level of protection for those chemicals that are not filterable. It is also the most expensive option. Its disadvantage is that it does not protect against a limited number of toxic gases that cannot be filtered by conventional gas filters/adsorbers.

Although the Class 2 Safe Room employs air filters, it does not prevent the infiltration of outdoor air driven by natural forces of wind and buoyancy. It therefore provides a lower level of protection than a Class 1. If exposed to an unfilterable gas, the unventilated Class 2 Safe Room retains a level of protection provided by the sealed enclosure. The unventilated Class 2 Safe Room would thus not have a complete loss of protection as could occur with the gas penetrating the filter of a Class 1 or Class 2 ventilated Safe Room.

The Class 3 Safe Room, with no air filtration, is the simplest and lowest in cost. It can be prepared with permanent sealing measures or with the quick application of expedient sealing techniques such as applying duct tape over the gap at the bottom of the door or over the bathroom exhaust fan grille. The disadvantage is that there is no intentional ventilation; therefore, this class of safe room cannot conform to ventilation requirements of other types of emergency shelters.

Most safe rooms are designed as standby systems; that is, certain actions must be taken to make them protective when a hazardous condition occurs or is expected. They do not provide protection on a continuous basis. Merely tightening a room or weatherizing a building does not increase the protection to the occupants. Making the safe room protective requires turning off fans, air conditioners, and combustion heaters as well as closing doors and windows. It may also involve closing off supply, return, or exhaust ducts or temporarily sealing them with duct tape. In a residence, taking these actions is relatively simple and can be done quickly. In an office building, doing so usually requires more time and planning, as there may be several switches for air-handling units and exhaust fans, which may be at diverse locations around the building.

Unventilated safe rooms have been widely used in sheltering-in-place to protect against accidental releases of industrial chemicals. Local authorities make the decision on whether to shelter-in-place or evacuate based on conditions, the likely duration of the hazard, and the time needed to evacuate. Although sheltering-in-place (i.e., use of an unventilated safe room) is applicable for relatively short durations, experience shows that it may be necessary for people to occupy safe rooms for longer periods as a precautionary measure.

The potential for safe room stays of longer duration make it important to consider human factors in designing and planning safe rooms. Human factors considerations include ventilation, environmental control, drinking water, toilets, lighting, and communications.

3.2 HOW AIR FILTRATION AFFECTS PROTECTION

The addition of air filtering improves the protection a safe room provides, although there are limitations as to what gases can be filtered. Ventilation with filtered air also removes the time constraints associated with unventilated shelters.

To protect against the many gases, vapors, and aerosols that could be released in an accident or terrorist act requires three different filtering processes. Mechanical filtration is most commonly used for aerosols; physical adsorption, for chemical agents of low vapor pressure; and chemisorption, for chemical agents of high vapor pressure. These three processes can be provided by a combination of two types of filters: the HEPA filter to remove aerosols and a high-efficiency gas adsorber with impregnated carbon to remove vapors and gases. A filter system for a safe room must contain at least one HEPA and one gas adsorber in series, with the HEPA normally placed first in the flow stream.

HEPA adequately removes all toxic aerosols, including sub-micron size biological agents. A gas adsorber works for most, but not all gases/vapors. Several of the common industrial gases, such as ammonia, are not removed by the best broad-spectrum impregnated carbon available.

To protect against highly toxic chemicals, a Class 1 system requires ultra high-efficiency filtration, at least 99.999 percent removal in a single pass. HEPA filters, which are defined as having at least 99.97 percent efficiency against the most penetrating particle size (about 0.3 micron), have efficiencies greater than 99.999 percent against aerosols of 1- to 10-micron size, the most likely size range for biological-agent aerosols.

With a filtration system drawing outside air, the level of protection the safe room provides is a function of the filter efficiency. With an unventilated Class 2 system, the level of protection is not affected as greatly by changes in filter efficiency. For example, increasing filter efficiency from 99 percent to 99.999 percent in an unventilated Class 2 system improves the protection factor by about 1 percent. The same change in a Class 1 system yields a protection factor 1,000 times higher.

All filters have limited service life. In operation, a gas adsorber loads as molecules fill the micropores of the carbon, and a HEPA filter loads with dust and other particles to increase the resistance to flow. The adsorber loses capacity for gases over time when exposed to the atmosphere, even if air is not flowing through it. The shelf life of an adsorber ranges from 5 to 10 years when the filters are hermetically sealed in a container. The service life of the adsorber varies with the operating environment and is generally less than 5 years. For this reason, filters intended for use in safe rooms in the home or office are typically designed to remain sealed in a metal canister until they are needed in an emergency. This hermetic sealing can ensure the filters retain full filtering capacity for 10 years or more, although most manufacturers do not warranty them for more than 10 years.

Commercial filter units that are designed for indoor air quality can be used in an unventilated Class 2 Safe Room. There are many different models available from several manufacturers; however, the filtering performance varies over a wide range. These filter units can be ceiling-mounted, duct-mounted, or free-standing floor or table units having both HEPA filters and adsorbers (usually an activated carbon and zeolite mix). The HEPA filter element provides protection against a biological agent and other solid aerosols such as tear gas, while the adsorber protects against gases and vapors.

3.3 SAFE ROOM CRITERIA

This section presents criteria for selecting or designing a safe room for protection against airborne toxic materials. Although the protective envelope can be defined as the whole building, a room within the building (i.e., a safe room) can provide a higher level of protection if it is tighter than the building as a whole and/or the location of the room is less subject to wind or buoyancy forces that induce infiltration.

Any type of room can be used as a safe room if it meets the criteria listed below. In office buildings, safe rooms have been established in conference rooms, offices, stairwells, and other large common areas. In dwellings, safe rooms have been established in bedrooms, basements, and bathrooms. The criteria are as follows:

- **Accessibility**. The safe room must be rapidly accessible to all people who are to be sheltered. It should be located so that it can be reached in minimum time with minimum outdoor travel. There are no specific requirements for the time to reach a safe room; however, moving to the safe room from the most distant point in the building should take less than 2 minutes. For maximum accessibility, the ideal safe room is one in which one spends a substantial portion of time during a normal day. The safe room should be accessible to persons with mobility, cognitive, or other disabilities. Appropriate use of stirs or ramps when shelters are located above or below grade must account for such occupants.

- **Size**. The size criterion for the toxic-agent safe room is the same as tornado shelters. Per FEMA 361, the room should provide 5 square feet per standing adult, 6 square feet per seated adult, and 10 square feet per wheelchair user for occupancy of up to 2 hours.

- Tightness. There is no specific criterion for air tightness. With doors closed, the safe room must have a low rate of air exchange between it and the outdoors or the adjacent indoor spaces. Rooms with few or no windows are preferable if the windows are of a type and condition that do not seal tightly (e.g., older sliders). The room must not have lay-in ceilings (suspended tile ceilings) unless there is a hard ceiling above. The room should have a minimum number of doors, and the doors should not have louvers unless they can be sealed quickly. The door undercut must be small enough to allow sealing with a door-sweep weather strip or expediently with duct tape.

- **HVAC system**. The safe room must be isolated or capable of being isolated quickly from the HVAC system of the building. If the selected room is served by supply and return ducts, modifications or preparations must include a means of temporarily closing the ducts to the safe room. In the simplest form, this involves placing duct tape or contact paper over the supply, return, and exhaust grilles and turning off fans and air-handling units. If there is a window-type or through-the-wall air conditioner in the selected room, plastic sheeting and tape must be available to place over the inside of the window and/or air conditioner, which must be turned off when sheltering in the safe room.

- **Ventilation**. For Class 1 Safe Rooms, 15 cfm per person is the desired ventilation rate; however, the minimum ventilation rate is 5 cfm per person if that rate is adequate for pressurization. Class 3 and unventilated Class 2 Safe Rooms are suitable only for short-duration use, not only because the low ventilation rate when occupied can cause carbon dioxide levels to rise, but also because protection diminishes as the time of exposure to the hazard increases.

- **Location**. For unventilated shelters (Class 3 and some Class 2), there are three considerations for location within a building. First, relative to the prevailing wind, the safe room should be on the leeward side of a building. Second, if there is a toxic-materials storage or processing plant in the community, the safe room should be on the side opposite the plant. Third, an interior room is preferable to a room with exterior walls, if it meets criteria for size, tightness, and accessibility. For a low-rise building, there is no substantial advantage in a room on the higher floors, and a location should not be selected based on height above ground level if it increases the time required to reach the shelter in an emergency.

- **Water and toilets**. Drinking water and a toilet(s) should be available to occupants of a safe room. This may involve the use of canned/bottled water and portable toilets. Toilet fixture allowance is presented in FEMA 361.

- **Communications**. For sheltering situations initiated by local authorities, the safe room must contain a radio with which to receive emergency instructions for the termination of sheltering. A telephone or cell phone can be used to receive emergency instructions and to communicate with emergency management agencies. Electrical power and lighting are also required.

3.4 DESIGN AND INSTALLATION OF A TOXIC-AGENT SAFE ROOM

After the room or location for the safe room has been decided based on the criteria listed above, the first design decision is to determine the class of safe room. Design details for the three classes of safe rooms are presented below. A Class 3 Safe Room is the simplest in that it requires only a tight enclosure. It is presented first because the requirements of the tight enclosure are common to all three classes. The unventilated Class 2 Safe Room, which involves the simplest application of a filter unit, is presented next, and the Class 1 Safe Room, which involves a more complex application of a filter unit, is presented last.

3.4.1 Class 3 Safe Room

Features of the Class 3 Safe Room can be either permanent or expedient. Guidance for preparing the safe room is presented in four parts:

- How to tighten the room before an emergency – to permanently seal unintentional openings

- How to prepare for sealing the room in an emergency – to temporarily close intentional openings such as ducts, doors, and windows in an emergency

- How to prepare for rapid deactivation of fans

- How to accommodate the safe use of air conditioning or heating in protective mode

3.4.1.1 Tightening the Room

- **Ceiling-to-wall juncture.** Typically, most leakage occurs through the wall-to-ceiling and wall-to-floor junctures, particularly if suspended lay-in ceilings are used without a hard ceiling or a well-sealed roof-wall juncture above the lay-in ceiling. If the selected room has only a lay-in ceiling between the living space and attic space, the ceiling should be replaced with one of gypsum wallboard or other monolithic ceiling configuration.

- **Floor-to-wall juncture.** A baseboard often obscures leakage paths at the floor-to-wall juncture, and to seal these leakage paths may require sealing behind the baseboards. One approach is to temporarily remove the baseboards and apply foam sealant in the gap at the floor-to-wall juncture. The alternate approach is to use clear or paintable caulk to seal the top and bottom of baseboards and quarter rounds. If there are electric baseboard heaters, the heaters should be temporarily removed to seal the wiring penetrations and the gap at the floor-to-wall juncture.

- **Penetrations.** Measures for reducing air leakage through penetrations are as follows:

  - Seal penetrations for pipes, conduits, ducts, and cables using caulk, foam sealants, or duct seal.

  - Place weather-stripping (including a door sweep) on the door(s) of the safe room. If the selected room is a bathroom, and there is a supply duct but no exhaust duct, the door sweep may be omitted because it would reduce the supply flow rate in normal use. In this case, duct tape can be used to seal the gap beneath the door temporarily in an emergency. If there is carpeting in the safe room, a door sweep may be more effective than tape. There may be louvers in the door for return airflow, but they should not be modified to ensure proper ventilation can be maintained in normal conditions. Door louvers should be expediently sealed as described in Section 3.4.1.2.

  - Windows that are old and/or in poor condition can allow substantial leakage; however, newer, non-operable windows are not likely to require any sealing. Window leakage can be measured using a blower door to determine whether window replacement or sealing measures are necessary. In some cases, the leakage of windows, such as poorly maintained sliders, can be reduced only by replacing them or by using expedient sealing measures such as taping plastic sheeting over them.

  - Expanding foam can be used to seal electrical outlets and switches. Also, ready-made outlet sealers can be used to seal gaps behind switches and outlets.

3.4.1.2 Preparing for Rapidly Sealing the Room. The selected safe room may have one or all of the following intentional openings, which are necessary for normal operation. The openings must be sealed so that the safe room can be used in a toxic-materials emergency unless the HVAC system for the safe room is designed to safely operate in the protective mode (as described below).

- Supply and return ducts
- Exhaust fan
- Door louvers
- Window-type air conditioner or unit ventilator
- Door undercut

It is neither practical or advisable to seal these openings beforehand if the room is one that has normal day-to-day use, in which case plans and preparations should be made for sealing them temporarily during rapid transition to the protective mode. The sealing capability can be either permanent or expedient.

- **Permanent capabilities for rapid sealing.** There are two general approaches to closing the intentional openings in transition to the protective mode. The first is to use hinged covers mounted within the safe room. The second is to use automatic dampers, particularly in ducts for supply, return, and exhaust. Hinged covers can be custom-made of sheet metal or wood, as shown in Figure 3-1, to be attached above or beside the opening for all applications except the door periphery. A hinged cover provides the capability to seal vents rapidly. In a safe room having several openings to be sealed, use of hinged covers allows the sealing to be completed more quickly than use of tape and adhesive backed plastic material.

Figure 3-1
Hinged covers facilitate the rapid sealing of supply, return, or exhaust ducts in a safe room.
SOURCE: BATTELLE

- **Temporary measures for rapid sealing.** For expedient sealing, a small kit of materials should be provided in the safe room, along with a written checklist of the sealing measures required specifically for the safe room. The following is an example of a checklist that applies to a bathroom. The sealing supplies are contact paper, precut to size, and 2-inch wide painter's tape. Alternately, duct tape and plastic sheeting can be used.
    - Cover the door louvers with adhesive backed film (contact paper) 18 inches by 12 inches in size.
    - Cover the gap beneath the door with a strip of 2-inch-wide tape.
    - Cover the exhaust fan grille with adhesive-backed film (18 inches by 18 inches).
    - Cover the supply grille with adhesive backed film (12 inches by 12 inches).
    - Pour water into the floor drain and drains of the shower and sink to ensure the traps are filled.

In a bathroom, drain traps for the sink, tub, shower, or floor are usually filled with water, but should be checked to ensure water is present to prevent air leakage through the drain pipes.

A window-type or through-the-wall air conditioner can be sealed by turning it off, and placing either contact paper or plastic sheeting with duct tape over the air conditioner.

3.4.1.3 Preparing for Deactivation of Fans. Some safe room systems have been designed with the capability to automatically deactivate all fans in the building with a single switch. This single-switch control can also be designed to close dampers in outside-air ducts serving the safe room. The low-cost alternative to automatic fan shutoff is to record on a checklist the location of switches for all fans in the building, not just those that serve the safe room. This includes air-handling units, exhaust fans, supply fans, window air conditioners, and combustion heaters.

This checklist must also include the procedures for the purging step of sheltering-in-place (e.g., opening windows and doors, and turning on fans and air handlers that were turned off to shelter-in-place after the hazardous condition has passed).

3.4.1.4 Accommodating Air Conditioning and Heating. Conventional air conditioning and heating systems must not be operated in the protective mode because the fans directly or indirectly introduce outside air. This includes the air-handling units and fans serving spaces outside the safe room. An exception is combustion heaters of hydronic systems that are located in separately ventilated mechanical rooms.

In extreme weather conditions, however, confining people in a sealed room without air conditioning or heating can result in intolerable conditions, causing people to exit the safe room before it is safe to do so.

The mechanical ventilation system often has a higher potential for indoor-outdoor air exchange than the leakage paths of the enclosure subjected to wind and buoyancy pressures. Window-type air conditioners and unit ventilators cannot be used in the protective mode, because they introduce outdoor air, even when set to the recirculating mode. The dampers for outside air in such units seal poorly even when well maintained.

The following are options for air conditioning and heating systems that can be safely operated in the protective mode:

- **Ductless mini split-type air-conditioner.** This type of room air conditioner, an alternative to the standard unitary window air conditioner, circulates air across the indoor coils without ducts and does not introduce outdoor air in either the normal or protective mode. The only required penetration through the safe room boundary wall is for a conduit for refrigerant tubing, suction tubing, condensate drain, and power cable.

- **Electric heater or steam radiator.** Similar to the ductless split-type air conditioner, the electric or steam heater does not introduce outdoor air and does not require ducts.

- **Fully enclosed air-handling unit.** An air-handling unit can be operated in a safe room in the protective mode only if the unit and its ducts are fully within the safe room (i.e., the unit is in an interior mechanical closet and the return ducts are not above the ceiling, beneath the floor, or outside the walls). If the air-handling unit draws outdoor air through a duct, it must also have a damper system for reliably cutting off outside air in the protective mode. This may require a set of three dampers: two dampers in the outside air duct with a relief damper between them that opens (to protected space) when the other two close. The air-handling unit must serve the safe room exclusively.

- **Makeup air unit.** This is a once-through type unit for introducing fresh air; it is not applicable to an unventilated safe room. The makeup-air unit does not recirculate air through ducts; it supplies filtered air through duct coils for cooling and heating.

3.4.1.5 Safety Equipment. Unventilated safe rooms, whether Class 2 or Class 3, must have a carbon dioxide detector or monitor in the safe room.

3.4.2 Class 2 Safe Room

The design details of the enclosure presented above apply also to the Class 2 Safe Room, ventilated and unventilated. The ventilated Class 2 Safe Room is one that supplies filtered air from outside the safe room, but has inadequate air flow to pressurize the room. For the unventilated Class 2 Safe Room, the improvement in protection over the Class 3 Safe Room is determined by the flow rate and the efficiency of the particulate filter for aerosols and the efficiency of the adsorber for gases and vapors. These filter units, commonly referred to as indoor air purifiers, indoor air cleaners, or indoor air quality units, recirculate air within the safe room. There are four configurations:

- Free-standing table top unit
- Free-standing floor unit
- Ceiling-mounted unit
- Duct-mounted unit (with ducts completely inside the safe room)

3.4.2.1 Filter Unit Requirements for the Unventilated Class 2 Safe Room. The protection provided by an unventilated Class 2 Safe Room is determined by the clean-air delivery rate of the filter unit and the tightness of the enclosure. The clean-air delivery rate is a product of the filter removal efficiency (expressed as a decimal fraction) and the actual flow rate of the filter unit. If a high-efficiency filter unit is used, the clean-air delivery rate approaches the actual flow rate of the unit. If the filter has a single-pass efficiency of 50 percent, for example, the clean-air delivery rate is half the actual flow rate. For a given unit, the clean-air delivery rate is likely to be higher for aerosols than for gases and vapors because efficiencies of adsorbers are typically lower than the efficiencies of particulate filters in these units.

Many models of these indoor air purifiers are available commercially, but not all of them have performance suitable for use in protecting against toxic aerosols, gases, and vapors. The following are criteria for selection of recirculating filter units for use in safe rooms:

- The filter unit must have both an adsorber containing activated carbon and a particulate filter.
- The adsorber must have at least 1 pound of activated carbon for each 20 cfm of flow rate. For example, a 200-cfm unit requires at least 10 pounds of carbon adsorbent.
- The particulate filter must have an efficiency of at least 99 percent against 1-micron particles.
- The unit(s) must provide a total clean-air delivery rate of at least 1 cfm per square foot of floor area.
- The adsorber must have the capability for chemisorption (i.e., for removal of gases that are not removed by physical adsorption).

There are also ventilated Class 2 Safe Rooms and essentially these are ones for which the filter unit has inadequate capacity to produce a measurable overpressure with the size of the selected safe room. In essence, the filter units are over-rated by the filter unit manufacturer. Generally, if a filter unit capacity in cfm is less than one-fourth the area (in square feet) of the selected safe room, depending on the type of construction, it will not produce a measurable overpressure. Matching the filter unit capacity to safe room size for Class 1 (pressurized) Safe Rooms is addressed in Section 3.4.3.2.

3.4.2.2 Installation and Operation. For the unventilated safe room, floor/table model filter units and ceiling-mounted models should be placed in the center of the room to maximize air mixing. There should be no obstruction to the airflow into and out of the filter units.

Duct-mounted models must conform to the requirements stated above for air-handling units. Ducts cannot be outside the envelope formed by the walls, ceiling, and floor.

The adsorbers of these commercial units are generally lacking in capability for filtering a broad range of high-vapor-pressure agents. Several of the common industrial chemicals (e.g., ammonia) are not removed.

The filter unit can be used routinely for indoor air quality; a spare set of filters should be kept on hand for use in a toxic-materials emergency, along with instructions for changing the filters so that the change can be made rapidly.

3.4.3 Class 1 Safe Room

Designing and installing a ventilated safe room is much more complex than an unventilated safe room, particularly with regard to the filter unit. Pressurization requires introducing air from outside the protective enclosure; therefore, the removal efficiency of the filters is more critical in determining the protection provided. The system must employ ultra-high efficiency filters, and it must allow no air to bypass the filter as it is forced into the safe room.

Except for military standards, there are no performance standards specifically for ultra-high efficiency adsorbers intended for protection of people from highly toxic chemicals. Performance of HEPA filters for aerosols is defined by ASME AG-1, *Code on Nuclear Air and Gas Treatment,* and N509, *Nuclear Power Plant Air-Cleaning Units and Components*. The specifications for filter units available commercially may present information that only partially defines the performance of an adsorber.

3.4.3.1 Selecting a Filter Unit for a Class 1 Safe Room. Generally, filter units available commercially are not designed to standards that ensure protection against highly toxic chemical, biological, and radiological materials. Some may provide very little protection, particularly if the manufacturer is not experienced in designing and building ultra-high efficiency filter units. Minimum requirements for the Class 1 applications are listed below. In purchasing a filter unit, certifications relative to the following requirements should be provided by the vendor:

- The filter unit must have both a HEPA filter and an ultra-high-efficiency gas adsorber in series.

- The adsorber must contain carbon impregnated ASZM-TEDA or the equivalent. Carbon mesh size should be 12x30 or 8x16.

- The adsorber must have efficiency of at least 99.999 percent for physically adsorbed chemical agents and 99.9 percent for chemisorbed agents.

- The adsorber must have a total capacity of 300,000 milligram (mg)-minutes per cubic meter for physically adsorbed chemical agents.

- Bypass at the seals between the adsorber and its housing must not exceed 0.1 percent.

- For installation of the filter unit outside the safe room, the fan must be upstream of the filters (blow-through configuration). For installation inside with a duct from the wall to the filter unit, the fan must be downstream of the filters (draw-through configuration).

- If a flexible duct is used outside the shelter to convey air from the filter unit to the safe room, it must be made of a material resistant to the penetration of toxic chemicals.

- If chemical manufacturing and storage facilities in the community present a special risk for release of toxic materials, special sorbents or sorbent layers may be required. In some cases, the chemicals produced/stored may not be filterable with a broad-spectrum impregnated carbon. For example, a nearby ammonia plant requires a special adsorber for protection against ammonia.

3.4.3.2 Sizing the Filter Unit for Pressurization. If a filter unit is undersized (i.e., it provides inadequate flow for pressurization), the result is substantially lower protection factors and the system becomes a ventilated Class 2 Safe Room. Filter unit(s) must be sized to provide makeup air at a flow rate sufficient to produce a pressure of at least 0.1 inch water gauge (iwg) in the shelter for protected zones of one or two stories. Taller buildings require an internal pressure higher than 0.1 iwg to overcome the buoyancy pressures that result in extreme weather conditions (i.e., large temperature differences between the inside and outside of the safe room).

The airflow rate needed to achieve this pressure in a safe room varies with the size and construction of the safe room. Generally, commercial filter units designed for home or office safe rooms are under-rated with regard to the quantity of air needed for pressurization. For safe rooms of frame construction and standard ceiling height, most can be pressurized to 0.1 iwg with airflow in the range of 0.5 to 1 cfm per square foot. Table 3-2 provides additional guidance in estimating the size of a filter unit for a safe room based on square footage.

The recommended procedure for ensuring that pressurization can be achieved is to perform a blower door test after all permanent sealing measures have been completed. The test should be conducted per ASTM E779-03, *Standard Test Method for Determining Air Leakage by Fan Pressurization* with temporary sealing measures in place.

Table 3-2: Leakage per Square Foot for 0.1 Iwg (estimated makeup airflow rate per square foot (floor area) to achieve an overpressure of 0.1 inch water gauge)

Construction Type	cfm per square foot of floor area
Very tight: 26-inch thick concrete walls and roof with no windows	0.04
Tight: 12-inch thick concrete or block walls and roof with tight windows and multiple, sealed penetrations	0.20
Typical: 12-inch thick concrete or block walls with gypsum wall board ceilings or composition roof and multiple, sealed penetrations	0.50
Loose: Wood-frame construction without special sealing measures	1.00

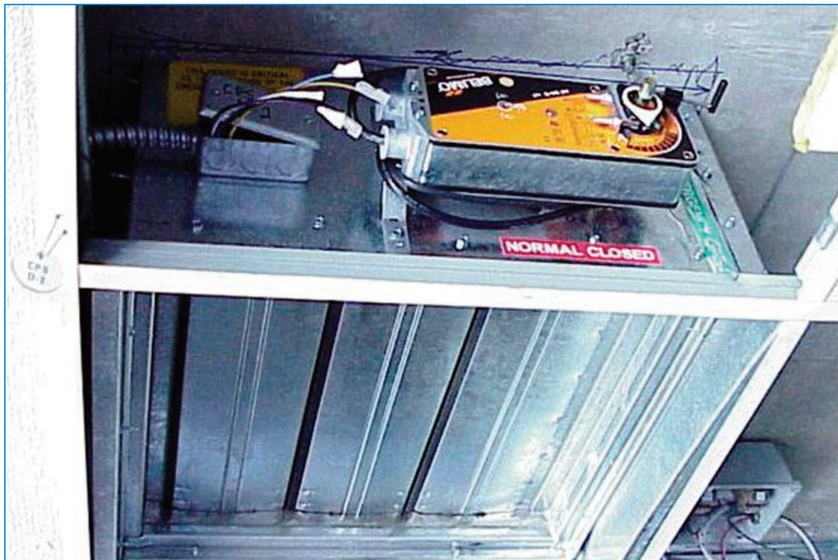
3.4.3.3 Other Considerations for Design of a Class 1 Safe Room

- **Heating and cooling the safe room**. A safe room does not require heating and cooling; however, in extreme weather, the conditions in the safe room may become uncomfortable due to the lack of ventilation or the introduction of outdoor air that is not tempered. In hot weather, this can be worsened by the temperature rise that occurs as air passes through the filter unit. Because of the relatively high pressure drop across the high efficiency filters, the temperature of the air typically increases by 5 to 10 degrees Fahrenheit as it passes through the filter unit. The use of inefficient fans, such as brush-type high-speed fans, should be avoided for this reason, because a temperature rise of 15 degrees can result.

- **Control system**. An interlocking system should be considered for closing automatic dampers (as shown in Figure 3-2), turning off air-handling units, exhaust fans, and ventilation fans serving the building's unprotected spaces while the safe room is in the protective mode. This increases the level of protection the safe room provides against an outdoor release of agent.

Figure 3-2
Automatic dampers are used to isolate the safe room from the ducts or vents used in normal HVAC system operation.

SOURCE: CHEMICAL STOCKPILE EMERGENCY PREPAREDNESS PROGRAM



- **Heating system safety**. If a fuel-fired indirect heater (i.e., heat exchanger) is used to heat the safe room, a carbon monoxide detector with a visual display and an audible alarm should be installed in the safe room. Electric coil and hot-water coil systems do not require a carbon monoxide detector.

- **Pressure gauge**. For Class 1 Safe Rooms, the pressure gauge is the indicator that the system is operating properly. This gauge displays the pressure in the safe room relative to outdoors or outside the safe room indoors. If the reference pressure is measured indoors, the readings can be subject to variations caused by fan pressures unless other building heating, ventilation, and air conditioning (HVAC) fans are turned off when the safe room is in use. Reading the reference pressure outdoors can be subject to positive and negative variations caused by air flows over and around the building. If the pressure sensor is outdoors, it should be shielded from the wind. Indoors is the best location if the building HVAC fans are turned off when the safe room is in use.

3.5 OPERATIONS AND MAINTENANCE

For a shelter to be successful, it is critical to have an understanding and dedication to operations and maintenance. Depending on the shelter type, specific operations instructions and maintenance are needed.

- **Instructions and checklists**. As a minimum for operating procedures, the condensed operating and maintenance instructions should be posted in each safe room. The operating instructions should explain the steps of placing the safe room into operation and may be as simple as a one-page typed checklist; instructions that should be included are safe room operating procedures, a list of doors to be secured, a list of switches for fans to be turned off, stations/channels for emergency instructions, emergency phone numbers, and dates by which filters should be changed, if applicable.

- **Status indicators**. For safe rooms that require multiple automatic dampers to isolate the safe room from the HVAC ducts in the protective mode, status lights and/or visual indicators should be used to show the position of each damper. Indicators can also be used to show door position, if there are multiple boundary doors in the safe room. Each status light should be marked with a reference number corresponding to a diagram so an operator can easily determine the location of any damper/door and conduct troubleshooting if problems occur. The indicator lights should have push-to-test capability for the light bulbs of the status lights.

- **Public-address system**. For safe rooms in large buildings, a public address system is the most efficient means of instructing building occupants to proceed to a safe room in an emergency. Telephone or audible alarm systems can also be used, but they are less efficient than a broadcast voice system. Communications systems (telephone, alarm, and mass notification systems) should be tied to emergency phone systems. Non-verbal warning systems are generally less effective because they require training on the meaning of different types of alarm sounds.

- **Auxiliary or Battery Power**. Class 3 Safe Rooms do not require electrical power to protect their occupants. Class 1 and Class 2 Safe Rooms require power for the air-filtration units to protect at a higher level than Class 3. If power is lost in a Class 1 or Class 2 Safe Room, it will continue to protect at the level of a Class 3 Safe Room as long as the room remains sealed. Power failure, therefore, does not lead to protective failure, but rather a reduced level of protection and reduced level of comfort in some conditions. For this reason, auxiliary power is not essential for a CBR safe room. Auxiliary power is provided on some CBR safe rooms so that the highest level of protection and comfortable conditions can be maintained if a power loss is caused by or coincides with the event causing the release of toxic agent.

3.5.1 Operating a Safe Room in a Home

The essence of operating a Class 3 Safe Room is to close the safe room and ensure that building fans, combustion heaters, and air conditioners are turned off so that they do not cause an exchange of air between the safe room and its surroundings. General procedures for the home safe room are as follows:

- Close all windows and doors (both interior doors and exterior doors of the home).

- Turn off the central fan, exhaust fans, window air conditioners, or combustion heaters in the home.

- Enter the safe room. If there is no telephone in the safe room, take a cell phone or portable phone into the safe room for emergency communications.

- Close the safe room door and apply tape to the periphery of the door, unless there are weather seals on the door.

- Turn on a radio or TV in the safe room and listen for emergency information.

- If the safe room has a carbon dioxide detector, monitor it, particularly if the time in the sealed safe room exceeds 1 hour.

- When the "all clear" determination is made, open the windows and doors, turn on ventilation systems, and go outside until the house has been fully aerated.

The following is a list of supplies for the safe room:

- Rolls of duct tape for sealing doors and securing plastic over vents and windows
- Pre-cut plastic sheeting to fit over supply and return vents (also for windows if they are judged to be less than airtight)
- Battery operated radio with spare batteries
- Flashlight with spare batteries
- Drinking water
- First aid kit
- Telephone (cell phone) for emergency instructions

3.5.2 Operating a Safe Room in an Office Building

For the office-building safe room, the supplies are generally the same as the home safe room listed above.

Procedures differ in that there are likely to be more exterior doors to be closed and multiple locations for the switches that control building fans. To ensure that all doors are closed and fans are turned off, an emergency plan and checklist should be developed, assigning employees to these tasks at various locations in the building. The general procedures for the office building safe room are as follows:

- A building-wide announcement is made for all building occupants to proceed to the designated safe room(s).

- Assigned monitors secure all exterior doors and windows.

- Assigned building engineering staff turn off all air handling units, ventilation fans, and window air conditioners as applicable (or security turns them off if a single switch capability has been installed).

- Safe room doors are secured as soon as possible once all who are assigned to the safe room have entered.

- Employees and visitors are accounted for by use of a roster and visitor's sign-in sheets.

- Emergency information is obtained by radio, TV, telephone, or cell phone in the safe room.

- If the safe room has a carbon dioxide detector, monitor it if the time in the safe room exceeds 1 hour.

- When the "all clear" determination is made, open the windows and doors, turn on ventilation systems, and go outside until the building has been fully aerated.

3.5.3 Operating Procedures for a Class 1 Safe Room

Operating procedures for Class 1 (pressurized) Safe Rooms are similar to those of Classes 2 and 3.

The system is turned on immediately upon receipt of a warning.

Control panels for Class 1 systems typically include pressure gauges and status lights for automatic dampers, which provide assurance that the system is operating properly and a means of troubleshooting if the system does not pressurize.

Tape, plastic, and carbon dioxide detectors are not necessary in the Class 1 Safe Room.

3.6 MAINTAINING THE CBR SHELTER

Depending on the shelter type, the shelter may require more maintenance. Shelters that have increasing levels of protection from filters will require more frequent checks and will require more funding to keep them operational.

3.6.1 Maintenance for a Class 3 Safe Room

The Class 3 Safe Room has no air filtration equipment and, therefore, requires little or no routine maintenance. It has no mechanical equipment unless there are dampers for isolating the air conditioner (configured for fail-safe operation). Maintenance requirements are limited to periodically checking supplies for deterioration or loss: duct tape, plastic sheeting, radio spare batteries, flashlight spare batteries, drinking water, and first aid kit.

3.6.2 Maintenance for a Class 2 Safe Room

The filter unit used in a Class 2 safe room is an indoor air quality filter unit (see Figure 3-3) and, as such, it can be used routinely to improve the air quality in the spaces in or around the designated safe room. If this is done, a spare filter set, both adsorber and HEPA filter, should be stored in a sealed bag in the safe room along with instructions and any tools needed for changing the filter quickly in an emergency. Other supplies to be checked on a regular basis are the same as listed for the Class 3 Safe Room above.

Figure 3-3
A tabletop recirculation filter unit with a substantial adsorber is a simple means of providing higher levels of CBR protection to unventilated safe rooms.

SOURCE: BATTELLE

3.6.3 Maintenance for a Class 1 Safe Room

Maintenance of the Class 1 Safe Room consists primarily of serviceability checks and replacing filters. Serviceability checks should be performed about every 2 months by turning the system on and checking for the following while it is operating:

- **System pressure**. The system pressure is indicated by a gauge typically mounted on the control panel, with the correct operating range marked on the gauge. If the pressure is outside this range while the system operates, troubleshooting should be initiated.

- **Isolation dampers**. Correct damper positioning is indicated by damper status lights on the control panel. Troubleshooting should be initiated if the status lights indicate a damper is not properly positioned.

- **Relief damper**. If the system contains a pressure-relief damper, it should be visually inspected while the system is operating. A properly functioning relief damper should be open when the safe room is pressurized, and it should close immediately when a door is opened into the safe room, releasing pressure.

- **HEPA filter resistance**. The differential pressure across the HEPA filter is measured by a gauge mounted on the filter unit with taps on either side of the HEPA filter. If the pressure across the filter is greater than specified (approximately 3 iwg or higher), it is an indication that the HEPA filter has become loaded with dust and its higher resistance is reducing the flow rate of the filter unit. If such is the case, the HEPA filter should be changed.

- **Cooling system**. If the safe room supply air is cooled and heated, the temperature of the air flowing from the supply register should be checked with a thermometer during serviceability checks. In warm weather, this should be approximately 55 degrees if the cooling system is operating properly.

- **Door latches**. All doors into the safe room should be adjusted to latch automatically with the force of the door closer. For safe rooms with multiple doors, leakage past unlatched doors can cause internal pressure to fall below the specified operating range.

- **Weather stripping**. The weather stripping on each door on the boundary of the safe room should be visually inspected to ensure it has not been removed or damaged through wear and tear. For wipe seals at the bottom of the door, the alignment and height of the seal above the floor should be inspected and adjusted as necessary.

- **Filters**. Routine maintenance includes replacing filters. If a canister-type filter is used, it is replaced as a unit at its expiration date. For other types of filter units, three types of filters are replaced: the pre-filter, HEPA filter, and carbon adsorber. Ideally, with only intermittent operation, all three types of filters should be replaced at the same time, every 3 to 4 years. This period is defined mainly by the service life of the adsorber.

  Each time the CBR filters are replaced, in-place leakage testing should be performed, except in the case of canister filters (see Figure 3-4), to ensure the critical seals between the filters and/or between the mounting frame and the filters are established properly (i.e., there is no leakage past the filters' peripheral seals). To test the seals of the HEPA filter, the unit is challenged with an aerosol; poly-alpha olefin (PAO) is the industry standard. To test the seals of the adsorbers requires a chemical that is loosely adsorbed in the filter bed. Halide gases are typically used for this purpose. For the adsorber, the criterion is that the leak must be less than 0.1 percent of the upstream concentration. For the HEPA filter, the criterion is 0.03 percent. Procedures for both tests are described in American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME) N510, *Testing of Nuclear Air Treatment Systems.*

Figure 3-4
A canister-type filter unit is often used for Class 1 Safe Rooms to maximize storage life of the filters.
SOURCE: BATTELLE

3.7 COMMISSIONING A CLASS 1 CBR SAFE ROOM

Commissioning applies to the Class 1 Safe Room. It involves testing, checking the configuration, and performing functional checks to ensure the safe room has been installed properly, protects as intended, and can be operated and maintained by its owner. Commissioning addresses not only the safe room and its components, but also the operations and maintenance instructions.

For a Class 1 Safe Room, the principal performance indicator is the pressure developed in the safe room by the flow of filtered air. Commissioning requires measuring the internal pressure, the supply air flow rate, and leakage at the seals of the filters. If an air conditioning and/or heating system and dampers are part of the system, it also requires verifying their proper function. The following should be addressed in commissioning a Class 1 Safe Room:

3.7.1 Measurements

- Measure the flow rate of filtered air and compare with design flow rate. Airflow rate measurements are usually made by certified test-and-balance contractors. A filter unit with integral motor-blower and fixed supply-duct length may not require airflow measurements after installation.
- Conduct in-place leakage testing to determine if filters are sealed properly to their mounting frames to prevent air bypassing the filters. This is necessary if the filter unit has replaceable filters. If a canister type filter unit is employed, these critical seals are factory tested, and in-place testing for bypass is not necessary.
- Measure the pressure in the safe room with a calibrated gauge independent of the installed pressure gauge.
- Measure the temperature of the supply air and compare it with design values for both heating and cooling modes.

3.7.2 Configuration

- Visually inspect the seals applied to wall penetrations (pipes, cables, conduit) and to doors (weather-stripping and wipe seals).
- For filter units with replaceable filters, determine that the filter unit has been installed with adequate clearance for changing the filters.
- Verify that the pressure-sensing tubes for the pressure gauge have been installed properly, reference pressure sensors

have been appropriately placed to provide accurate ambient pressure readings without the effects of dynamic pressure, and that they are shielded to prevent blockage by moisture, insects, etc.

- ❍ If there is air conditioning or heating, inspect to determine that outside air will not be drawn in through closed dampers or other leakage points.
- ❍ Verify that gauge and status lights of the control panel gauges are marked with operating ranges.
- ❍ Verify that markings, signs, and condensed operating instructions are adequate for the user to operate the system properly.

3.7.3 Functionality

- ❍ Visually inspect all dampers to ensure they move freely and assume the correct position for both normal and protective modes.
- ❍ For a mechanical pressure gauge, determine that the gauge has been zeroed properly.
- ❍ If there is a low-pressure alarm or status indicator, verify it has been adjusted to the correct pressure threshold.
- ❍ Verify that status lights accurately indicate position/operation of dampers and fans.
- ❍ Verify the push-to-test capability for status lights.
- ❍ Verify that instructions for operating and maintaining the system are available at the safe room and provide clear and accurate guidance for an untrained operator to activate the protective system.
- ❍ Verify the operation of communications equipment for safe room occupants.
- ❍ Verify the proper function of the change-HEPA gauge or indicator.

3.8 UPGRADING A CBR SAFE ROOM

The simplest and least costly upgrade in protective capability for a safe room is to upgrade from Class 3 to unventilated Class 2. This involves adding a recirculation filter unit, the simplest of which is a free-standing unit. This type of filter unit is available in many models, flow rates, filter types, and cost levels; however, not all have the same capability. Requirements for the grade of adsorbers and particulate filters, as well as flow rate per square foot of safe room, are listed in Section 3.4.2.1.

Upgrading from Class 2 or 3 to Class 1 involves the greatest expense. It can be as simple as purchasing a high-efficiency filter unit and installing it to supply filtered air through a special duct. Rules of thumb on flow rates required to pressurize the safe room are presented in Section 3.4.3.2. An interlocking system should be considered for turning off air-handling units, exhaust fans, and ventilation fans of the building's unprotected zones while the safe room is in the protective mode.

3.9 TRAINING ON THE USE OF A SAFE ROOM

As is the case with fire safety, all people who are to be protected in a safe room, whether in a home or commercial building, must be familiar with the procedures of using the safe room. Getting into it quickly and closing the safe room door(s) is important for all types of shelters. Whether sheltering from toxic agents, blast, or storms, the protection a safe room provides is compromised when it is not fully closed.

Training the people who work or reside in the building on safe room procedures has four main objectives:

- To familiarize them with the locations of the safe rooms and the procedures for using them.
- To inform them about who the emergency manager/coordinator of the building is, what his/her responsibilities are, and how he/she can be contacted.

- To develop an understanding of the range of protective responses, including evacuation, and what to do for each of the possible protective actions.

- To develop an employee awareness of the threats and hazards. Trained building occupants can serve to detect threats and reduce the time to respond by being aware of indications of suspicious activities, symptoms of toxic agent exposure, or odors from chemical releases.

Plans should be made to conduct a safe room drill, similar to a fire drill, semi-annually.

3.10 CASE STUDY: CLASS 1 SAFE ROOM

This case study describes a Class 1 Safe Room, one that is ventilated and pressurized with an ultra-high efficiency filter unit in a multi-story office building.

The concept of operation for this safe room is that, in response to a release of toxic chemicals outside the building, security personnel activate the safe room filtration unit and turn off all other HVAC fans in the building to place the building in the shelter-in-place mode. Employees are instructed via the public-address system to proceed immediately to the safe room. They remain in the safe room until building security officers, consulting with the local emergency management agency, determine that there is no longer a hazard.

A ventilated, pressurized safe room was selected so that a large number of people could be protected during a sheltering period of 1 to 2 hours without the potential for carbon dioxide buildup.

Task 1. Select the Safe Room Space

Applying the criteria of adequate space, accessibility, and capability to be rapidly secured, the fire-rated stairwell is the best choice in a multi-story office building for a safe room.

The safe room must accommodate all occupants and visitors in this portion of the building. The stairwell is 11 stories high (140 feet) with cross-section dimensions of 35 feet by 12 feet. At 5 square feet per person, it can accommodate 600 people.

The stairwell meets the criterion of accessibility because it spans all floors of the building and is accessible to all building occupants in an estimated 1 minute or less. It also provides access for people with impaired mobility.

As a fire-rated stairwell, it is unventilated. It can therefore be rapidly secured and isolated from the mechanical ventilation system and the other spaces of the building. With no mechanical ventilation, it can be secured by simply closing its doors, which are normally held closed by door closers for fire-safety purposes.

Task 2. Determine How Well the Selected Space Can Be Sealed

Airtightness is indicated by the construction of the stairwell, which is of cast-in-place concrete with few wall penetrations, none of which has apparent sealing requirements beyond caulk or foam sealant. Penetrations include sprinkler standpipes and conduit/cables for wall-mounted lights at each landing, an emergency telephone, and intercom. The doors into the stairwell are fire-rated and have an undercut of ½ to 1 inch. Collectively, the undercut of the doors into the stairwell is the largest leakage path to be sealed.

To confirm the airtightness and estimate the airflow capacity of the filter unit, a blower-door test, as illustrated in Figure 3-5, was performed per ASTM E779-03. Use of the blower door in the depressurization mode can also facilitate finding leaks that may not be readily apparent.

Figure 3-5
A blower door test on the selected safe room aids in estimating the size of air-filtration unit required and in identifying air leakage paths.

SOURCE: BATTELLE

Task 3. Determine the Level of Safe Room Positive Pressure Required

For a safe room of this height, buoyancy pressure is significant, and both wind pressure and buoyancy pressure must be considered in determining the safe room operating pressure. As a corner stairwell, it has two exterior walls. The pressure requirement is defined as the velocity pressure of a 20-mph wind plus the buoyancy pressure that occurs against ground-level doors and other points of leakage at winter design conditions. With a height of 140 feet, the maximum buoyancy pressure at the lowest level of the stairwell is calculated at 0.11 iwg for a 60-degree Fahrenheit indoor-outdoor temperature differential. Adding the maximum wind pressure of 0.2 iwg for a 20-mph wind yields a design pressure of 0.3 iwg. At an internal pressure of 0.3 iwg, the force required to open the doors into the stairwell is slightly less than 30 pounds at the door handle for the (inward opening) doors, the maximum door opening force allowed by fire code.

Ideally, a blower door-test is performed after the permanent sealing measures, including door seals, have been added. In performing the blower door test before these permanent sealing measures are applied, the doors are taped temporarily at the periphery to simulate their being permanently sealed. Results of the blower door test, graphed in Figure 3-6, show that, with doors sealed with tape, the stairwell could be pressurized to 0.3 iwg with about 3,000 cubic feet per minute (cfm).

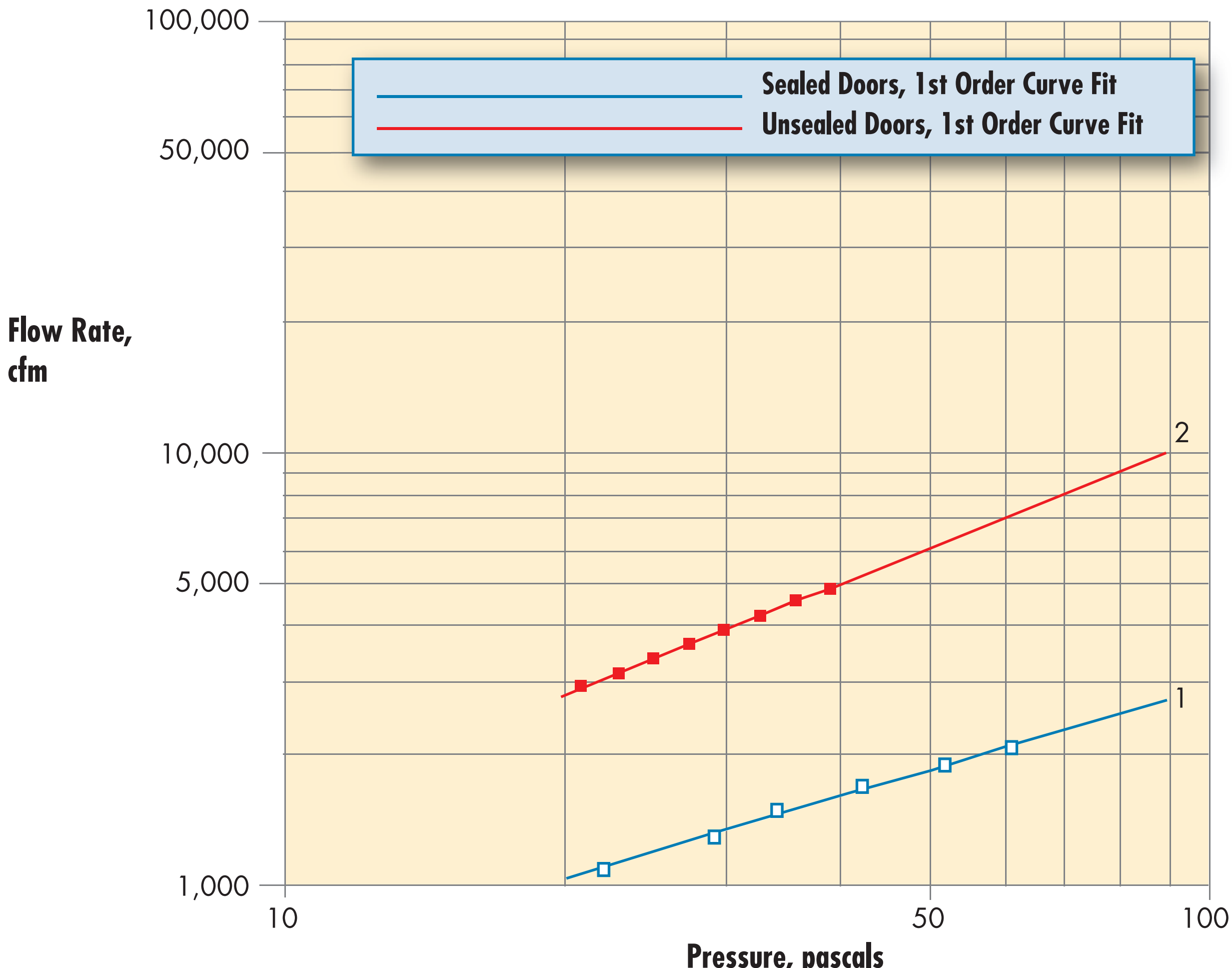


Figure 3-6
Blower-door test results on the stairwell selected for a safe room

SOURCE: BATTELLE

Task 4. Determine How Much Filtered Air Flow is Required

The total filtered, ventilation air flow required is the larger of: (1) the flow rate required for pressurization and (2) the flow rate required to supply greater than 5 cfm of outside air per person in the safe room. At a maximum safe room occupancy of 600 people, the 5 cfm/person ventilation requirement is met with a flow rate of 3,000 cfm. Using a filter unit of 4,000 cfm capacity yields a ventilation rate greater than 5 cfm per person. This ventilation flow rate is not adequate; however, to deliver the cooling required for the heat load of the fully occupied stairwell, two fan-coil units are added to the lower levels for additional cooling.

Task 5. Design and Install the System

Design and installation requires a licensed mechanical contractor with experience in the installation of high-efficiency filtration systems.

The safe room requires the following components installed in the stairwell and a penthouse mechanical room adjacent to the stairwell:

- Air-filtration unit and supply fan of 4,000-cfm capacity
- Pre-heat coil cabinet containing pre-filters, heating coils, and isolation damper
- Cooling-coil cabinet containing coils and an isolation damper
- Spiral ductwork
- Control panel with pressure gauge and system status lights
- Remote on/off switch connected via the building automation system
- Pressure relief damper at the lowest level of the stairwell
- Supply register at the top level of the stairwell
- Pressure sensor and thermostats installed in the stairwell
- Weather stripping and wipe seals on doors into the stairwell

Air-filtration Unit Type. A filter unit employing an adsorber containing ASZM-TEDA carbon of 12x30 mesh size was selected to provide ultra-high efficiency filtration of a broad spectrum of toxic chemicals. A military radial-flow filter set, carbon adsorber, and HEPA filter, shown in Figure 3-7, were selected. Manufactured to a government purchase description, the 4,000-cfm filter unit employs 20 replaceable sets of radial-flow filters. The filter sets were purchased from Hunter Manufacturing Company, Solon, OH, part number HF-200S.

Figure 3-7
A military radial-flow CBR filter set was selected for safe room filtration.

PHOTO COURTESY OF HUNTER MANUFACTURING COMPANY

Air-filtration Unit Location. A penthouse mechanical room adjacent to the stairwell is selected as the mounting location for the filter unit to provide an elevated and secure location for the equipment and its air intake. This is selected to achieve physical security of the intake and to make it most-distant from ground level releases. The filter unit, with its access panel removed, is shown in Figure 3-8.

Isolation Dampers. Two sets of automatic dampers are installed in the system, one upstream and one downstream of the filter unit to isolate the filters when not in use.

Figure 3-8
A 4,000-cfm filter unit using radial flow filters was selected for the stairwell safe room.

SOURCE: BATTELLE

Pre-heat Coil Module. This module contains pre-filters, pre-heat coil, and an outside air damper. Pre-filters selected for the system are ASHRAE 25-35 percent pleated. The building in which this system is installed has chilled water and hot water service from a central plant.

Cooling-coil Module. Cooling coils and an isolation damper are contained in a module mounted on the wall between the mechanical room and stairwell. Temperature control of the pressurization air is maintained with an electronic thermostat located in the stairwell.

Control Panel. The control panel as shown in Figure 3-9 has the following controls and indicators:

- Start/stop switch
- Status lights for the system, supply fan, and two isolation dampers
- Pressure gauge indicating the pressure differential between the stairwell and the adjoining hallway

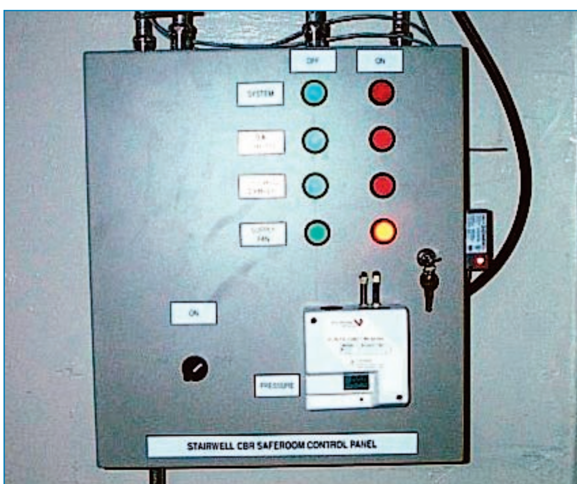


Figure 3-9
The Class 1 Safe Room control panel has a system start/stop switch, status indicators for dampers, and a pressure gauge.
SOURCE: BATTELLE

Relief Damper. In supplying filtered air from the top of the stairwell, the carbon dioxide concentration in the occupied stairwell increases with the vertical distance from the source of fresh air, because leakage paths are evenly distributed along the vertical axis. To ensure carbon dioxide levels remain within safe limits at the lowest levels of the stairwell and to facilitate removal of heat and humidity generated by the occupants, a relief damper was installed at the lowest level to maximize the flow-path length for clean air. The relief damper was adjusted to prevent the internal pressure from exceeding 0.30 iwg, a pressure above which the doors that open into the stairwell could require more than 30 pounds of force at the door handle to open (depending upon door closer force).

Door Seals. Weather-type seals were installed on doors into the stairwell to minimize air leakage around the closed doors. According to blower door test results, leakage around the stairwell doors before the addition of weather-stripping and wipe seals was substantial (approximately 3,000 cfm at 0.3 iwg).

Warning System. A public address system was installed in the building so that voice messages could be broadcast throughout the building to notify people at any location of an emergency.

Accessibility. The stairwell offers a point of entry accessible to wheelchairs, and each landing provides an area adequate for two wheelchairs without blocking access to the door.

Drinking Water. The stairwell has no accommodation for drinking water. There were plans to make water available by storing bottled water in a compartment on each landing of the stairwell.

Communications. Each level of the stairwell has an emergency telephone and an intercom to provide contact with the security operations center.

Cost. Total cost of the installed system was $190,000, or about $300 per person sheltered. This does not include the cost of the public address system or the single-switch fan shutdown for the building. Cost of the filter unit and initial set of filters was about one-fourth the total cost of the system. Costs included:

- Purchase of filter unit and supply fan, $28,000
- Purchase of CBR filters, 20 sets, $22,000
- Detailed design and purchase and installation of other components, $140,000:
    - Chilled-water coils, hot water coils, piping, insulation, supports
    - Double-wall and single-wall spiral ductwork
    - Two isolation dampers and one relief damper
    - Control panel and remote activation capability
    - Concrete equipment pads
    - Door sweeps and jamb seals on stairwell doors
    - Sealing penetrations through stairwell walls
    - Motor control center and electrical service
    - Test, adjust, and balance
    - In-place leak testing of filter unit
    - Signage for condensed operating instructions