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Building Terrorism Mitigation – Building Design

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This course was adapted from the Federal Emergency Management Agency (FEMA), Chapter 3 "Building Design Guidance", Publication FEMA 426 "Mitigating Potential Terrorist Attacks Against Buildings", which is in the public domain.

This chapter addresses explosive blast and CBR concerns from terrorist attacks, highlighting mitigation measures that may be applied to building elements, including architectural, structural, and building envelope systems. After the site design considerations to enhance protection presented in Chapter 2 have been taken into account (recognizing that many may not be applicable to buildings in urban settings), additional building design measures, such as hardening, must be considered to protect building occupants. That is, when the desired level of protection cannot be achieved through site design, building envelope design measures must be considered. Catastrophic collapse of the building is a primary concern. Historically, the majority of fatalities that occur in terrorist attacks directed against buildings are due to building collapse. This was true for the Oklahoma City bombing in 1995 when 87 percent of the building occupants who were killed were in the collapsed portion of the Murrah Federal Building; however, other threats such as CBR agents should also be considered.

When considering mitigation measures for explosive blast threats, the primary strategy is to keep explosive devices as far away from the building as possible (maximize stand-off distance). This is usually the easiest and least costly way to achieve a desired level of protection. In cases where sufficient stand-off distance is not available to protect the building, hardening of the building's structural systems may be required, as well as design to prevent progressive collapse. In addition, designers should try to minimize hazardous flying debris during an explosive event because a high number of injuries can result from flying glass fragments and debris from walls, ceilings, and non-structural features. The hardening of the building envelope should be balanced so that the columns, walls, and windows have approximately equal response for damage and injury/casualty for the design basis threat weapon at the available stand-off distance. Window design is the element that is usually the most diverse in conventional construction. Good blast engineering is a multi-disciplinary effort that requires the concerted

efforts of the architect, structural engineer, mechanical engineer, and the other design team members in order to achieve a balanced building envelope.

When considering mitigation measures for CBR hazards, the HVAC systems are of particular concern. A building can provide protection against CBR agents released outdoors if the flow of fresh air is filtered or interrupted; however, HVAC systems can also become an entry point and distribution system for hazardous contaminants. If installed, HVAC air filtration and air-cleaning systems can reduce the effects of a CBR agent by removing the contaminants from the air within a building. There are a variety of ways to protect building occupants from airborne hazards. These protective measures can be as simple as defining a protective action plan or as complex as strict design measures practical only for new construction.

Building design should be optimized to facilitate emergency evacuation, rescue, and recovery efforts through effective placement, structural design, and redundancy of emergency exits and critical mechanical/electrical systems. Through effective structural design, the overall damage levels may be reduced to make it easier for people to get out safely and allow emergency responders to enter safely. The designer must also balance measures to protect people with the requirements of the ADAAG, UFAS, NFPC, and all applicable local building codes.

The primary focus of this chapter is the protection of buildings where the occupants are the primary asset. In this case, the objective of the designer is to save lives by mitigating building damages and reducing the chances of catastrophic collapse of the building, at least until the building is fully evacuated. The measures described in this chapter are designed to minimize the loss of life through deterrence and detection, as well as strengthening of the building against a variety of terrorist tactics. The design team must determine which measures are appropriate and cost-effective for incorporation into the building design. The measures presented here are not all-inclusive, and additional technical information for implementation can be found in the referenced documents.

3.1 ARCHITECTURAL

A lot can be done architecturally to mitigate the effects of a terrorist bombing on a facility. These measures often cost nothing or very little if implemented early in the design process. Architectural considerations include building configuration, space design, and building detailing. It is recommended that architects be brought into the design process as early as site selection, to optimize the protection provided. FEMA 430 contains an expanded discussion of incorporating security components in architectural design.

3.1.1 Building Configuration

The vertical or horizontal profile of a building has implications for its protection. As with the discussion of clustered versus dispersed buildings, designers should balance a number of relevant considerations to the extent that site, economic, and other factors allow. Some of the relevant considerations include the following:

Low, Large-footprint Buildings:

- Distribute people, assets, and operations across a wider area, to limit damage
- Use vegetation, terrain, and other screening elements to protect from hostile surveillance
- Maximize the benefits of green roof technologies, which can help reduce a building's heat signature and lower its visual profile

Leadership in Energy and Environmental Design (LEED)

As with CPTED, some of the Leadership in Energy and Environmental Design (LEED) concepts complement security concerns and others conflict with physical security principles. The LEED Green Building Rating System represents the U.S. Green Building Council's (USGBC's) effort to provide a national standard for what constitutes a "green building." Through its use as a design guideline and third-party certification tool, it aims to improve occupant well-being, environmental performance, and economic returns of buildings using established and innovative practices, standards, and technologies.¹ LEED is a voluntary building assessment tool that is most applicable to commercial, institutional, and high-rise residential construction. Owners, architects, and engineers must work together to strike a balance between building design objectives.

LEED looks at six basic categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation and Design Process. Within each category, points are awarded for achieving specific goals. A total of 69 points is possible. A score of 26-32 points achieves basic certification; 33-38 achieves Silver; 39-51 achieves Gold; and 52-69 points achieve Platinum certification. The LEED rating is awarded after the project has been documented by the USGBC.

Another goal in the LEED effort is to encourage more sustainable construction practices. LEED encourages manufacturers to provide materials that:

- contain high recycled content and sustainable use raw materials
- are manufactured close to the construction site
- have low volatile organic compound emissions
- are designed to minimize energy consumption and packaging

¹ U.S. Green Building Council, *LEED Green Building Rating System for New Construction & Major Renovations Version 2.1*, November 2002. <http://www.usgbc.org>

- Require the use of additional measures (at additional cost) to prevent introduction of CBR agents due to easier access to HVAC intakes by intruders

Tall, Small-footprint Buildings:

- Suffer damage to a greater percentage of their façades, structures, and interiors at best, and catastrophic damage or collapse at worst, should a large blast occur near the building if not constructed with progressive collapse prevention in mind
- Elevate occupied areas above vegetation, terrain, and other screening elements, making it potentially more difficult to protect interior spaces from outside surveillance
- Minimize the amount of impervious surface, contributing to a reduction in stormwater runoff, which reduces the need for culverts, drainage pipes, manholes, and other covert site access and weapon concealment opportunities
- Provide greater opportunity to elevate HVAC intakes to prevent the introduction of CBR agents

The shape of the building may also contribute to the overall damage to the structure. For example, “U” or “L” shaped buildings tend to trap shock waves, which may exacerbate the effect of explosive blasts. For this reason, it is recommended that re-entrant corners be avoided. In general, convex rather than concave shapes are preferred for the exterior of the building. For example, circular buildings act to reduce the air-blast pressures because the angle of incidence of the shock wave increases more rapidly than in a rectangular building. The following design considerations are recommended:

- Reduce a building’s vulnerability to attack by using earth-sheltered design
- Orient buildings horizontally rather than vertically to reduce the building’s profile and exposure
- Place the ground floor elevation of a building at 4 feet above grade to prevent vehicle ramming

- Avoid eaves and overhangs, because they can be points of high local pressure and suction during blasts; when these elements are used, they should be designed to withstand blast effects
- Orient glazing perpendicular to the primary facade to reduce exposure to blast and projectiles (see Figure 3-1)

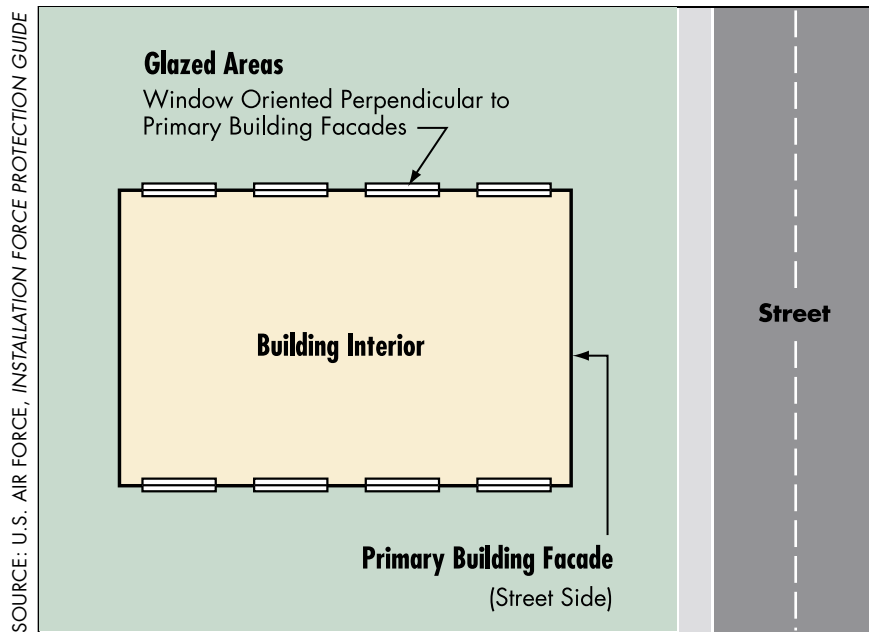


Figure 3-1 Glazed areas perpendicularly oriented away from streets

- Avoid exposed structural elements (e.g., columns) on the exterior of the facility
- Provide pitched roofs to allow deflection of launched explosives
- Avoid re-entrant corners on the building exterior where blast pressures may build up (see Figure 3-2)

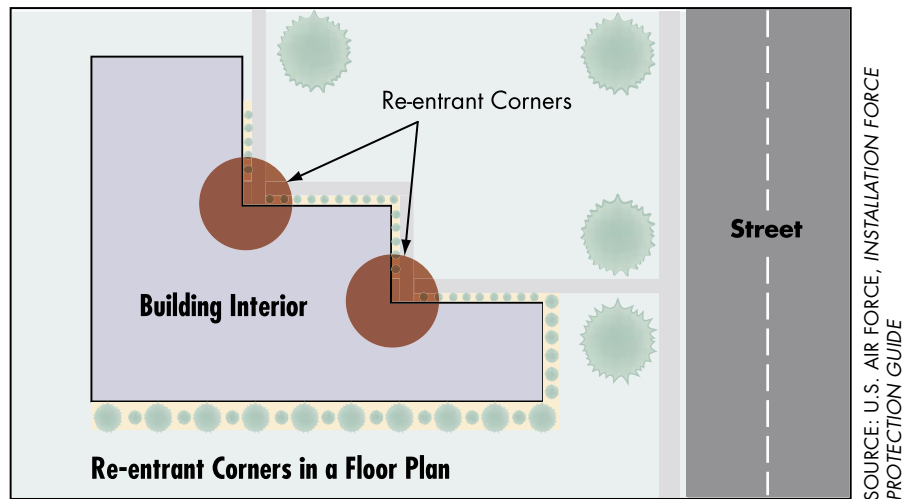


Figure 3-2 Re-entrant corners in a floor plan

3.1.2 Space Design

Unsecured areas should be physically separated from the main building to the extent possible. For example, a separate lobby pavilion or loading dock outside the main footprint provides enhanced protection against damages and potential building collapse in the event of an explosion. Similarly, placing parking areas outside the main footprint of the building can be highly effective in reducing the vulnerability to catastrophic collapse.

The protection of the building interior can be divided into two categories: functional layout and structural layout. In terms of functional layout, public areas such as the lobby, loading dock, mail room, garage, and retail areas need to be separated from the more secured areas of the facility. This can be done by creating internal “hard lines” or buffer zones, using secondary stairwells, elevator shafts, corridors, and storage areas between public and secured areas.

In lobby areas, the architect would be wise to consider the queuing requirements in front of the inspection stations so that visitors are not forced to stand outside during bad weather conditions or in a congested line inside a small lobby while waiting to enter the secured areas.

Emergency functions (e.g., sprinkler systems and generators, which are critical for mitigating the effects of an explosion) and elevator shafts should be placed away from internal parking areas and loading docks. In the 1993 World Trade Center bombing incident, elevator shafts became chimneys, transmitting smoke and heat from the explosion in the basement to all levels of the building. This hindered evacuation and caused smoke inhalation injuries. When it is not possible to separate mechanical areas and parking, the walls need to be designed to resist explosive forces. The following design measures should be considered:

- Do not collocate high-risk facilities with lower risk tenants. For example, a post office or supply center/room should not be located in the same building as a childcare facility.
- Locate key assets as far into the interior of a building as possible.
- Place areas of high visitor activity away from key assets.
- Locate critical assets in spaces that are occupied 24 hours per day.
- Locate assets in areas where they are visible to more than one person.
- Eliminate hiding places within the building.
- Use interior barriers to differentiate levels of security within a building.
- Stagger doors located across from one another in interior hallways to limit the effects of a blast through a structure (see Figure 3-3).
- Provide foyers with reinforced concrete walls, and offset interior and exterior doors.
- Consider methods to facilitate the venting of explosive forces and gases from the interior spaces to the

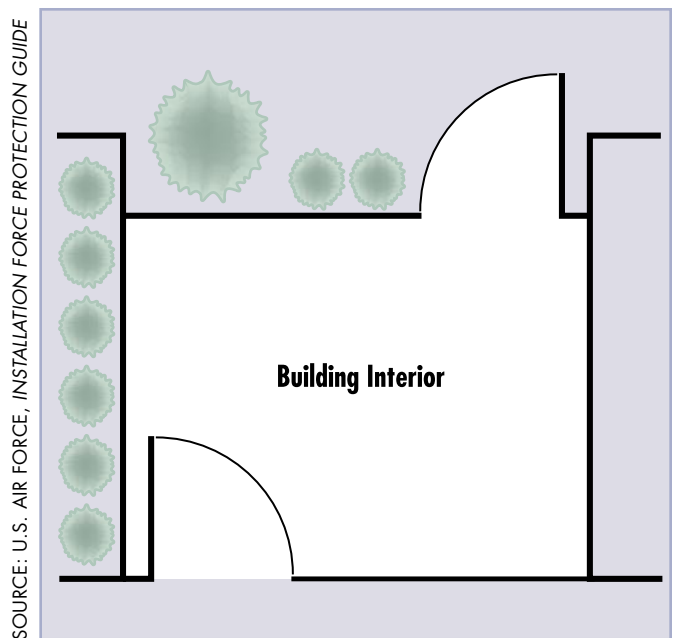


Figure 3-3 Offset doors through foyer

outside of the structure. Examples of such methods include the use of blow-out panels and window system designs that provide protection from blast pressure applied to the outside, but that readily fail and vent if exposed to blast pressure on the inside.

- Physically isolate lobbies, mailrooms (includes various mail processing areas), loading docks, and other entry and storage areas from the rest of the building. These are areas where bulk quantities of CBR agents are likely to enter a building. Building doors, including vestibule and loading dock doors, should remain closed when not in use.
- Design buildings so that lobbies, mailrooms, and loading docks do not share a return-air system or return pathway (e.g., ceiling plenum) with other areas of the building. Some of these measures are more feasible for new construction or buildings undergoing major renovation.

3.1.3 Other Design Considerations

When designing high-risk buildings, engineers and architects should consider the following:

- **Safe havens.** The innermost layer of protection within a physical security system is the safe haven. Safe havens are not intended to withstand a disciplined, paramilitary attack featuring explosives and heavy weapons. The safe haven should be designed such that the time attackers need to penetrate the protected area is greater than the time that first responders need to reach the protected area. For additional information on safe havens, see FEMA 428, *Primer to Design Safe School Projects in Case of Terrorist Attacks*.
- **Office locations.** Offices considered to be high risk (more likely to be targeted by terrorists) should be placed or glazed so that the occupants cannot be seen from an uncontrolled public area such as a street. Whenever possible, these spaces should face courtyards, internal sites, or controlled areas. If this is not possible, suitable obscuring glazing or window treatment should be provided, including ballistic-resistant glass, blast curtains, or other interior protection systems.

- **Mixed occupancies.** High-risk tenants should not be housed with low-risk tenants. Terrorists may identify some targets based on their symbology, visibility, ideology, political views, potential for publicity, or simply the consequences of their loss.
- **Public toilets and service areas.** Public toilets, service spaces, or access to vertical circulation systems should not be located in any non-secure areas, including the queuing area before visitor screening at the public entrance.
- **Retail uses in the lobby.** Retail and other mixed uses, which have been encouraged in public buildings by the Public Buildings Cooperative Use Act of 1976, create spaces that are open and inviting. Although important to the public nature of the buildings, the presence of retail and other mixed uses may present a risk to buildings and their occupants and should be carefully considered on a project-specific basis during project design. In areas exposed to potential terrorist attacks, retail and mixed uses may be accommodated through such means as separating entryways, controlling access, and hardening shared partitions, as well as with special security operational countermeasures.
- **Stairwells.** Stairwells required for emergency egress should be located as remotely as possible from areas where blast events might occur and, wherever possible, should not discharge into lobbies, parking, or loading areas.
- **Mailroom.** The mailroom should be located away from facility main entrances areas containing critical services, utilities, distribution systems, and important assets. In addition, the mailroom should be located at the perimeter of the building with an outside wall or window designed for pressure relief. It should have adequate space for explosive disposal containers. An area near the loading dock is a preferred mailroom location. Where these rooms are located in occupied areas or adjacent to critical utilities, walls, ceilings, and floors, they should be blast- and fragment-resistant. Significant structural damage to the walls, ceilings, and floors of the mailroom is acceptable; however, the areas adjacent to the mailroom should not experience severe damage or collapse.

- **Non-structural elements.** False ceilings, light fixtures, venetian blinds, ductwork, air conditioners, and other equipment may become flying debris in the event of an explosion. Wherever possible, it is recommended that the design be simplified to limit these hazards. Placing heavy equipment such as air conditioners near the floor rather than the ceiling is one idea; using curtains rather than venetian blinds, and using exposed ductwork as an architectural device are others.

3.2 BUILDING STRUCTURAL AND NON-STRUCTURAL SYSTEMS

3.2.1 Building Design to Achieve a Desired Protection Level

The assessment process described in Chapter 1 determines the level of protection sought for the building structure and defines the threat/hazard specific to the facility. Explosive blast threats usually govern building structural design for high-risk buildings. A structural engineer should determine the building design features needed to achieve the desired level of protection against the design blast threat, considering collapse of the building, as well as incipient injuries and fatalities. In addition, Chapter 4 discusses other structural systems related to explosive blast.

3.2.2 Progressive Collapse

Progressive collapse is a situation where local failure of a primary structural component leads to the collapse of adjoining members, which, in turn, leads to additional collapse. Hence, the total damage is disproportionate to the original cause. Progressive collapse is a chain reaction of structural failures that follows from damage to a relatively small portion of a structure. Information on progressive collapse can also be found in FEMA 427, *Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks*.

All buildings should be designed with the intent of reducing the potential for progressive collapse as a result of an abnormal loading event, regardless of the required level of protection. The following

structural characteristics (from *GSA Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects*, November 2000) should be considered in the initial phases of structural design. Incorporation of these features will provide a more robust structure and decrease the potential for progressive collapse. Designers should consider the following:

- **Redundancy.** The use of redundant lateral and vertical force resisting systems is highly encouraged when considering progressive collapse. Redundancy tends to promote a more robust structure and helps to ensure that alternate load paths are available in the case of a structural element(s) failure. Additionally, redundancy provides multiple locations for yielding to occur, which increases the probability that damage will be constrained.
- **The use of ductile structural elements and detailing.** It is critical that both the primary and secondary structural elements be capable of deforming well beyond the elastic limit, without experiencing structural collapse. The use of ductile construction materials (i.e., steel, cast-in-place reinforced concrete, etc.) for both the structural elements and connection detailing is encouraged. The capability of achieving a ductile response is imperative when considering an extreme redistribution of loading such as that encountered in structural element(s) failure.
- **Capacity for resisting load reversals.** Both the primary and secondary structural elements should be designed to resist load reversals in case of a structural element(s) failure.
- **Capacity for resisting shear failure.** Primary structural elements maintain sufficient strength and ductility under an abnormal loading event to preclude a shear failure. If the shear capacity is reached before flexural capacity, the sudden, non-ductile failure of the element could potentially lead to a progressive collapse of the structure.

Both the GSA and DoD take a threat-independent approach to progressive collapse. The goal of a threat-independent approach

is not to prevent collapse from a specific design threat, but to control and stop the continuing spread of damage after localized damage or localized collapse has occurred.

The GSA and DoD require that the structural response of a building be analyzed in a test that removes a key structural element (e.g., vertical load carrying column, section of bearing wall, beam, etc.) to simulate local damage from an explosion. If effective alternative load paths are available for redistributing the loads, originally supported by the removed structural element, the building has a low potential for progressive collapse. The details of the GSA and DoD guidelines and criteria can be found in *GSA Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects* (November 2000) and *DoD Unified Facilities Criteria (UFC) 4-010-01* (31 July 2002). Although these criteria provide specific guidance on which structural elements must be analyzed for removal from the structural design configuration, they do not provide specific guidance for choosing an engineering structural response model for verifying the effectiveness of alternate load paths.

Several other design codes and guidelines in use throughout the world (notably in the United Kingdom and Sweden) require some form of analysis or measures to reduce the potential for progressive collapse. However, there is no specific engineering design method prescribed for the structural design process to prevent progressive collapse. Unless a building is being designed to meet the GSA or DoD criteria, it is up to the owner and the design team to decide how much progressive collapse analysis and mitigation to incorporate into their design.

To address blast resistance (Chapter 4 contains a detailed discussion of explosive blast theory) and to minimize the possibility of progressive collapse, the priority of upgrades should be based on the relative importance of a structural or non-structural element, in the order below:

- **Primary structural elements.** These are the essential parts of the building's resistance to catastrophic blast loads and

progressive collapse (e.g., columns, girders, roof beams, and the main lateral resistance system).

- **Secondary structural elements.** These include all other load bearing members (e.g., floor beams, slabs, etc.).
- **Primary non-structural elements.** These are the elements (including their attachments) that are essential for life safety systems or elements that can cause substantial injury if failure occurs (e.g., ceilings or heavy suspended mechanical units).
- **Secondary non-structural elements.** These include elements not covered in primary non-structural elements (e.g., partitions, furniture, and light fixtures).

Priority should be given to the critical elements that are essential to mitigating the extent of collapse. Designs for secondary structural elements should minimize injury and damage. Consideration should be given to reducing damage and injury from primary as well as secondary non-structural elements. For example, if an explosive event causes the local failure of one column, which results in major collapse within a structural bay, a design that mitigated progressive collapse would preclude the additional loss of primary structural members beyond this localized damage zone (i.e., the loss of additional columns, main girders, etc.). This would not necessarily preclude the additional loss of secondary structural or non-structural elements outside the initial zone of localized damage, provided the loss of such members is acceptable for that performance level and the loss does not precipitate the onset of progressive collapse.

3.2.3 Loads and Stresses

Structures should be designed to resist blast loads. The DoD designates the level of blast protection a building must meet based on how many occupants it contains and its function. The demands on the structure will be equal to the combined effects of dead, live, and blast loads. Blast loads or dynamic rebound may occur in directions opposed to typical gravity loads.

For purposes of designing against progressive collapse, loads should be defined as dead load plus a realistic estimate of actual live load. The value of the live load may be as low as 25 percent of the code-prescribed live load. The design should use ultimate strengths with dynamic enhancements based on strain rates. Allowable responses are generally post elastic.

3.2.4 Good Engineering Practice Guidelines

The following guidelines are commonly used to mitigate the effects of blast on structures and to mitigate the potential for progressive collapse. Details and more complete guidance are available in the references below. These guidelines are not meant to be complete, but are provided to assist the designer in the initial evaluation and selection of design approaches. For higher levels of protection from blast, cast-in-place reinforced concrete is normally the construction type of choice. Other types of construction such as properly designed and detailed steel structures are also allowed. Several material and construction types, although not disallowed by these criteria, may be undesirable and uneconomical for protection from blast.

The following additional references are recommended:

- **Biggs, John M.** *Introduction to Structural Dynamics*. McGraw-Hill. (1964).
- **The Institute of Structural Engineers.** *The Structural Engineer's Response to Explosive Damage*. SETO, Ltd., 11 Upper Belgrave Street, London SW1X8BH. (1995).
- **Mays, G.S. and Smith, P.D.** *Blast Effects on Buildings: Design of Buildings to Optimize Resistance to Blast Loading*. Thomas Telford Publications, 1 Heron Quay, London E14 4JD. (1995).
- **National Research Council.** *Protecting Buildings from Bomb Damage*. National Academy Press. (1995).
- Consider incorporating internal damping into the structural system to absorb the blast impact.
- The use of symmetric reinforcement can increase the ultimate load capacity of the structure.
- Consider wire mesh in plaster to reduce the incidence of flying fragments.
- Avoid the use of masonry when blast is a threat. Masonry walls break up readily and become secondary fragments during blasts.

- The use of multiple barrier materials and construction techniques can sometimes accomplish the same goal with less expense than a single material or technique.
- The designer should recognize that components might act in directions for which they were not designed. This is due to the engulfment of structural members by blast, the negative phase, the upward loading of elements, and dynamic rebound of members. Making steel reinforcement (positive and negative faces) symmetric in all floor slabs, roof slabs, walls, beams, and girders will address this issue. Symmetric reinforcement also increases the ultimate load capacity of the members.
- Lap splices should fully develop the capacity of the reinforcement.
- Lap splices and other discontinuities should be staggered.
- Deflections around certain members, such as windows, should be controlled to prevent premature failure. Additional reinforcement is generally required.
- In general, column spacing should be minimized so that reasonably sized members can be designed to resist the design loads and increase the redundancy of the system. A practical upper level for column spacing is 30 feet for the levels of blast loads described herein.
- In general, floor to floor heights should be minimized. Unless there is an overriding architectural requirement, a practical limit is generally less than or equal to 16 feet.
- It is recommended that the designer use fully grouted and reinforced concrete masonry unit (CMU) construction when CMU is selected.
- It is essential that the designer actively coordinate structural requirements for blast with other disciplines, including architectural and mechanical.

- The use of one-way wall elements spanning from floor-to-floor is generally a preferred method to minimize blast loads imparted to columns.
- In many cases, the ductile detailing requirements for seismic design and the alternate load paths provided by progressive collapse design assist in the protection from blast. The designer must bear in mind, however, that the design approaches are, at times, in conflict. These conflicts must be worked out on a case by case basis.
- It is recommended that architectural or structural features be used that deny contact with exposed primary vertical load members. A minimum stand-off of at least 6 inches from these members is required.

3.2.5 Building Materials

All building materials and types acceptable under model building codes are allowed; however, special consideration should be given to materials that have inherent flexibility and that are better able to respond to load reversals (i.e., cast in place reinforced concrete and steel construction). Careful detailing is required for material such as pre-stressed concrete, pre-cast concrete, and masonry (brick and concrete masonry unit) to adequately respond to the design loads. The construction type selected must meet all performance criteria of the specified level of protection.

3.2.6 Methods and References

All building components requiring blast resistance should be designed using established methods and approaches for determining dynamic loads, structural detailing, and dynamic structural response. Design and analysis approaches should be consistent with those in the technical manuals or the GSA *Security Design Criteria* and the American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE 7. Alternative analysis and mitigation methods are permitted, provided that the performance level is attained. A peer group should evaluate new and untested methods.

3.3 BUILDING ENVELOPE

3.3.1 Building Exterior

At the building exterior, the focus shifts from deterring and delaying the attack, to mitigating the effects of an explosion. The exterior envelope of the building is the most vulnerable to an exterior explosive threat because it is the part of the building closest to the weapon.

It also is a critical line of defense for protecting the occupants of the building from CBR threats. Significant quantities of air can enter a building by means of infiltration through unintentional leakage paths in the building envelope. Such leakage is of more concern during an exterior CBR release, such as a large-scale attack, than for a directed terrorist act. The reduction of air leakage is a matter of tight building construction in combination with building pressurization. Although building pressurization may be a valuable CBR-protection strategy in any building, it is much more likely to be effective in a tight building. However, to be effective, filtration of building supply air must be appropriate for the CBR agent introduced. Although increasing the air tightness of an existing building can be more challenging than during new construction, it should still be seriously considered.

The design philosophy to be used here is that simpler is better. Generally, simple geometries, with minimal ornamentation (which may become flying debris during an explosion) are recommended. If ornamentation is used, it is recommended that it consist of lightweight material such as timber or plastic, which is less likely to become a projectile in the event of an explosion than, for example, brick, stone, or metal.

Soil can be highly effective in reducing the impact of a major explosive attack. Bermed walls and buried rooftops have been found to be highly effective for military applications and can be effectively extended to conventional construction. This type of solution can also be effective in improving the energy efficiency of the

building. Note that, if this approach is taken, no parking should be permitted on top of the building.

3.3.2 Exterior Wall Design

The exterior walls provide the first line of defense to prevent air-blast pressures and hazardous debris from entering the building. They would be subject to direct reflected pressures from an explosive threat located directly across from the wall along the secured perimeter line. If the building is more than four stories high, it may be advantageous to consider the reduction in pressure with height due to the increased distance and angle of incidence. At a minimum, the objective of design is to ensure that these members fail in a flexible mode rather than a brittle mode such as shear. The walls also need to be able to resist the loads transmitted by the windows and doors. It is not uncommon for bullet-resistant windows to have a higher ultimate capacity than the walls to which they are attached. Beyond ensuring a flexible failure mode, the exterior wall may be designed to resist the actual or reduced pressure levels of the defined threat. Special reinforcing and anchors should be provided around blast-resistant window and door frames.

Poured-in-place reinforced concrete will provide the highest level of protection, but solutions like pre-cast concrete, reinforced CMU block, and metal studs may also be used to achieve lower levels of protection.

For pre-cast panels, consider a minimum thickness of 5 inches with two-way reinforcing bars spaced not greater than the thickness of the panel. Connections into the structure should provide a straight line of load transmittal, using as few connecting pieces as possible.

For CMU block walls, use 8-inch block walls, fully grouted with vertical centered reinforcing bars placed in each cell and horizontal reinforcement at each layer. Connections into the structure should be able to resist the ultimate lateral capacity of the wall. A preferred system is to have a continuous exterior CMU wall that laterally bears against the floor system. For increased protection, consider using 12-inch blocks with two layers of reinforcement.

For metal stud systems, use metal studs back to back and mechanically attached, to minimize lateral torsion effects. To catch exterior cladding fragments, attach a wire mesh to the exterior side of the metal stud system. The supports of the wall are to be designed to resist the ultimate lateral capacity load of the system.

Exterior Walls. For the design of exterior walls, consider the following:

- Exterior walls should resist the actual pressures and impulses acting on the exterior wall surfaces from the threats defined for the facility.
- Exterior walls should be capable of withstanding the dynamic reactions from the windows.
- Shear walls that are essential to the lateral and vertical load bearing system, and that also function as exterior walls, should be considered primary structures. Design exterior shear walls to resist the actual blast loads predicted from the threats specified.
- Special consideration should be given to construction types that reduce the potential for collapse where exterior walls are not designed for the full design loads.
- By U.S. military standards (per Army Technical Manual 5-853), a medium protection level for walls would be the equivalent of 4-inch concrete with #5 reinforcing steel at 6-inch intervals each way or 8-inch CMU with #4 reinforcing steel at 8-inch intervals. TM 5-853 provides other alternatives for low, medium, and high protection.

Cladding and Finishes. Designers should consider the following:

- Substitute strengthened building elements and systems when stand-off distances cannot be accommodated.
- Use ductile materials capable of very large plastic deformations without complete failure.
- Provide blast-resistant walls when a high threat is present.

- Consider use of sacrificial exterior wall panels to absorb blast.
- Use earthtone-colored materials and finishes on exterior surfaces to diminish the prominence of a building.
- Consider reinforced concrete wall systems in lieu of masonry or curtain walls to minimize flying debris in a blast.
- Reinforced wall panels can protect columns and assist in preventing progressive collapse, because the wall will assist in carrying the load of a damaged column.

Exterior Column Design. Exterior columns should be designed to resist the peak reflected pressure of an explosive event, including the load transmitted by supported walls. Because these elements are slender, the air-blast tends to “wash around” them if they are free standing, reducing the duration of the loading. This is referred to as a “clearing time” effect. Although it is conservative to neglect these effects, it may be advantageous to take them into account in some situations, like close-in explosions. The design must provide for both the axial and flexible loads and stability. For concrete columns, spiral reinforcing or closed stirrups should be placed at a spacing of not less than half the minimum thickness of the member to ensure that adequate confinement and ductility are provided. For steel columns, the connections are the most vulnerable part of the design. If possible, place the base plate below ground level and protect with concrete and use multi-story segments for the lower floors.

3.3.3 Window Design

Window systems on the exterior façade of a building should be designed to mitigate the hazardous effects of flying glass during an explosion event. Designs should integrate the features of the glass, connection of the glass to the frame (bite), and anchoring of the frame to the building structure to achieve a “balanced design.” This means all the components should have compatible capacities and theoretically would all fail at the same pressure-pulse levels. In this way, the damage sequence and extent of damage are controlled. Table 3-1 presents six GSA glazing protection levels based

on how far glass fragments would enter a space and potentially injure its occupants. Figure 3-4 depicts how far glass fragments could enter a structure for each GSA performance condition.

The divide between performance conditions 3a and 3b can be equated to the “threshold of injury.” The divide between performance conditions 4 and 5 can be equated to the “threshold of lethality.” The GSA glazing performance conditions shown below correlate with the DoD levels of protection presented in Table 3-2.

Glass Design. Four types of glass are commonly used in window glazing systems: annealed glass, heat strengthened glass, fully thermally tempered glass, and polycarbonate. Other types of glass materials exist, but are not commonly used in typical commercial window systems. Of the four common types, annealed glass and fully thermally tempered glass are the type of windows for most of-fice buildings.

Table 3-1: Glazing Protection Levels Based on Fragment Impact Locations¹

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2*	Very High	None	Glazing cracks, but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a*	High	Very Low	Glazing cracks. Fragments enter space and land on floor no more than 3.3 feet from the window.
3b*	High	Low	Glazing cracks. Fragments enter space and land on floor no more than 10 feet from the window.
4*	Medium	Medium	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 feet from the window at a height no greater than 2 feet above the floor.
5*	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter space, impacting a vertical witness panel at a distance of no more than 10 feet from the window at a height greater than 2 feet above the floor.

* In conditions 2, 3a, 3b, 4 and 5, glazing fragments may be thrown to the outside of the protected space toward the detonation location.

¹ From GSA PBS-PQ100.1, *Facilities Standards for the Public Building Service*, June 14, 1996

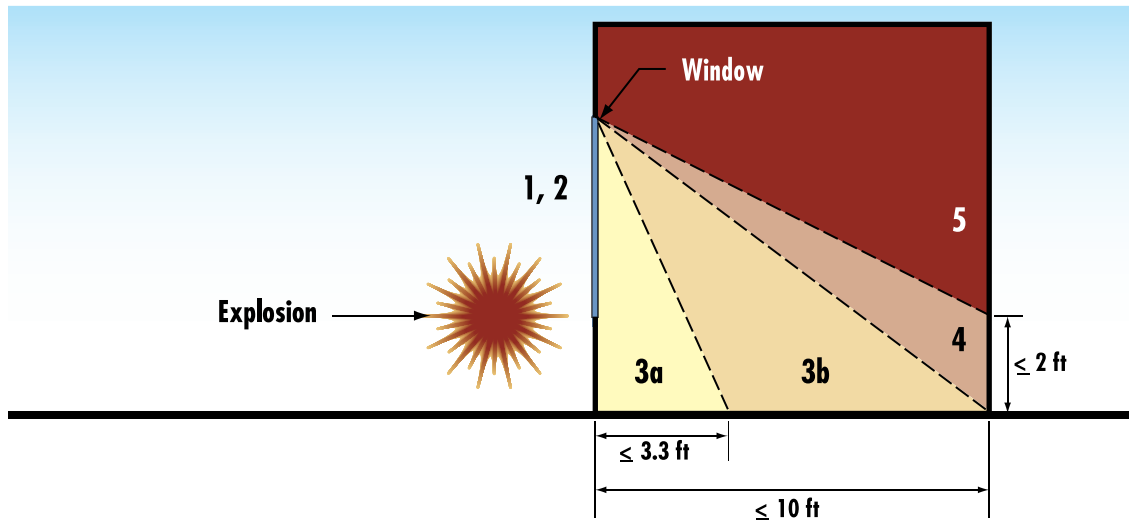


Figure 3-4 Side view of a test structure illustrating performance conditions of Table 3-2

Table 3-2:
Correlation of GSA Glazing Performance Conditions and DoD Levels of Protection for New Buildings

GSA Glazing Performance Condition	Corresponding DoD Level of Protection for New Buildings
1	High
2	Medium
3a	Low
3b/4	Very Low
5	Below antiterrorism (AT) Standards

Annealed glass, also known as float, plate, or sheet glass, is the most common glass type used in commercial construction. Annealed glass is of relatively low strength and upon failure, fractures into razor sharp, dagger-shaped fragments (see Figure 3-5).

Fully thermally tempered glass (TTG) is typically four to five times stronger than annealed glass with a design stress of 16,000 psi (112,000 kPa). The fracture characteristics of tempered glass are superior to those of annealed glass. Upon failure, it will eventu-

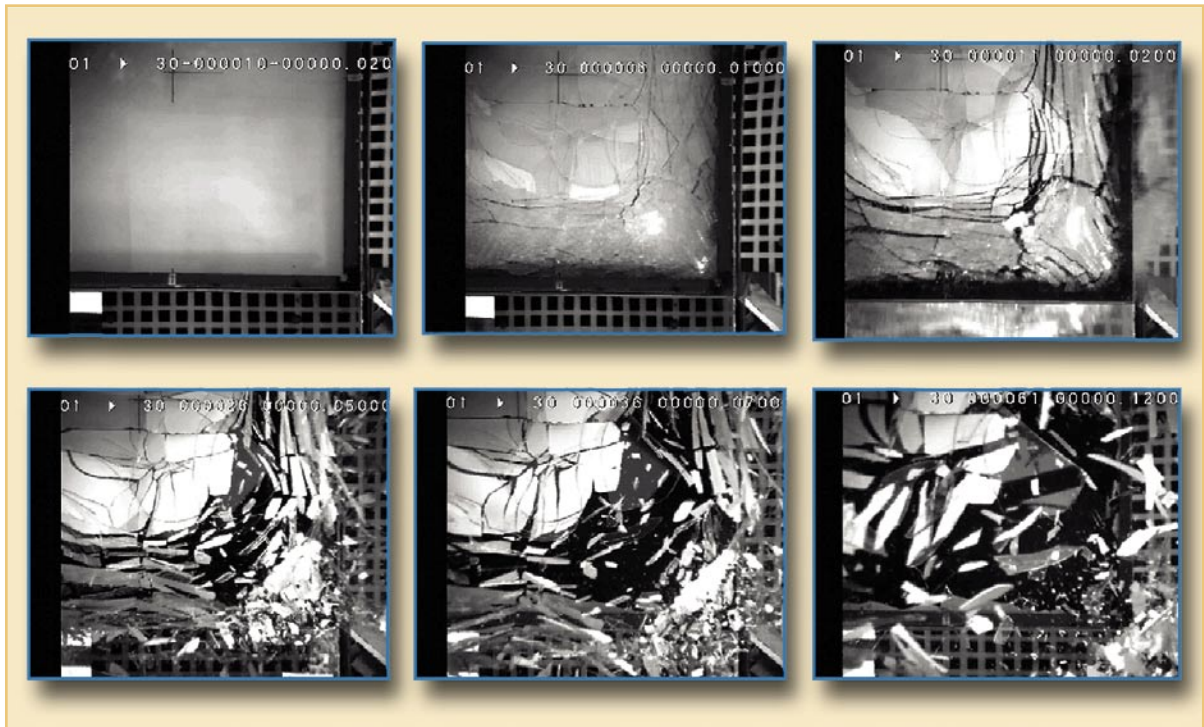


Figure 3-5 An unprotected window subject to a large explosion

ally fracture into small cube-shaped fragments. Breakage patterns of side and rear windows in American automobiles are a good example of the failure mode of thermally tempered glass. Current building codes generally require thermally tempered glass anywhere the public can physically touch the glass such as entrance doors and sidelights. Although thermally tempered glass exhibits a relatively safe failure mode for conventional usage, failure under blast loading still presents a significant health hazard. Results from blast tests reveal that, upon fracture, TTG fragments may be propelled into cohesive clumps that only fragment upon impact into smaller rock salt-type fragments. Even if the tempered glass breaks up initially into small fragments, the blast overpressure can propel the fragments at a high enough velocity to constitute a severe hazard.

Wire-reinforced glass is a common glazing material. It consists of annealed glass with an embedded layer of wire mesh. Its primary use is as a fire-resistant and forced entry barrier. Wire-reinforced glass has the fracture and low strength characteristics of annealed

glass and, although the wire binds some fragments, it still ejects a considerable amount of sharp glass and metal fragments. Wire-reinforced glass is not recommended for blast-resistant windows.

Laminated glass is a pane with multiple glass layers and a pliable interlayer material (usually made from polyvinyl butyral (PVB)) between the glass layers. Combining interlayer bonding materials with layers of glass produces cross-sections that perform well against blast, ballistic, and forced entry attacks. The interlayer acts as the glue that bonds the multiple layers of glass into a single pane of a given thickness and provides a membrane response after the glass layers crack under loading. Laminated glass offers significant advantages over monolithic glass. It is stronger and, if failure occurs, the interlayer material may retain most of the glass fragments. Also, if a projectile passes through the glass, most spalling glass fragments will be retained. Increased safety for fragment retention can be obtained in the event of catastrophic failure from an explosive blast by placing a decorative crossbar or grillwork on the interior of the glazing. Note, crossbars must be mounted across the center of mass of each window pane to be effective.

Another treatment used for mitigating the effects of an explosive attack is security window film. The polyester film used in commercial products is commonly referred to as fragment retention film (FRF), safety film, security film, protective film, or shatter-resistant film. These films are adhered to the interior surface of the window to provide fragment retention and reduce the overall velocity of the glass fragments at failure. Fragment retention film combines a strong pressure sensitive adhesive with a tough polyester layer. Four methods are used to attach security film to windows: a daylight attachment (applied only to the vision opening); edge-to-edge attachment (applied out to the edge of the glass); wet-glazed attachment (daylight or edge-to-edge film with a silicone bead along edge of the frame); and a mechanical attachment. Because fragment retention film applies directly to the glass surface of a window pane, it is beneficial for retrofitting existing windows as well as on new windows.

Fragment retention film behaves similarly to relatively thin laminated and polycarbonate glazing in terms of fragmentation. It is available in common thicknesses of 2, 4, 7, and 10 mils. Fragment retention film improves the performance of the glass under blast loading to varying degrees, depending on the thickness, quality, and type of film installation. The best performance is achieved when the film is installed into the bite of the glazing or is connected to the frame. Fragment retention film can also provide solar control benefits. As with laminates, increased safety can be obtained with window films by placing a decorative crossbar or grillwork on the interior of the glazing.

Thermoplastic polycarbonates are very strong and suitable for blast- and forced entry-resistant window design. Monolithic polycarbonate is available in thicknesses up to ½ inch, but can be fused together to obtain any thickness needed. However, polycarbonate is expensive and subject to environmental degradation (especially from exposure to aromatic hydrocarbons) and abrasion. Local building codes should be consulted when considering polycarbonates. There are several fire safety issues associated with its use (thermoplastic polycarbonate is rated as a class CC-1 material and will often test with a smoke density rating over 500). Additionally, because of its strength, local fire codes may require a percentage of polycarbonate glazing to pop out for emergency egress.

Frame and Anchorage Design. Window frames need to retain the glass so that the entire pane does not fall out and also should be designed to resist the breaking stress of the window glass. To retain the glass in the frame, a minimum of a ¼-inch bead of structural sealant (i.e., silicone or polyvinyl butyral) should be used around the inner perimeter of the window. The allowable tensile strength should be at least 20 psi. Also, the window bite (i.e., the depth of window captured by the frame) needs to be at least ½ inch. In some applications (e.g., the lobby area where large panes of glass are used), a larger bite with more structural sealant may be needed. Frame and anchorage design is performed by applying the breaking strength of the window to the frame and the fasteners. In most conventionally designed

buildings, the frames will be aluminum; however, in some applications, steel frames are used.

Mullion and Wall Design. The frame members connecting adjoining windows are referred to as mullions. These members may be designed using a static approach when the breaking strength of the window glass is applied to the mullion, or a dynamic load may be applied using the peak pressure and impulse values. Although the static approach may seem easier, it often yields a design that is not practical, because the mullion can become very deep and heavy, driving up the weight and cost of the window system. In addition, it may not be consistent with the overall architectural objectives of the project. A dynamic approach is likely to provide a section that meets the design constraints of the project. To accomplish this, a single-degree-of-freedom solution is often used. The governing equation of motion may be solved using numerical methods. There are also charts available for linearly decaying loads that circumvent the need to solve differential equations. These charts only require that the fundamental period of the mullion (including the tributary area of the window glass), the ultimate resistance force of the mullion, the peak pressure, and the equivalent linear decay time are known.

Peak lateral response of the mullion is to be limited to a 2-degree support rotation. Also, the displacement ductility is to be limited to a 4-degree support rotation. As with frames, it is good engineering practice to limit the number of interlocking parts used for the mullion.

A similar approach may be used for checking the response of the supporting wall response. It makes no sense to have blast mitigating windows if they are stronger than the wall that they are anchored into. The maximum strength of any window and anchorage system should be equal to the wall strength. This becomes particularly important in the design of ballistic-resistant and forced entry mitigating windows, which consist of one or more inches of glass and polycarbonate. These windows can easily become stronger than the supporting wall. In some applications, even the use of tempered glass can become problematic.

Design up to Specified Load. Window systems design (glazing, frames, anchorage to supporting walls, etc.) on the exterior facade should be balanced to mitigate the hazardous effects of flying debris in an explosive event. The walls, anchorage, and window framing should fully develop the capacity of the glazing material selected. The designer may use a combination of methods such as government produced and sponsored computer programs (e.g., Window Lite Analysis Code (WINLAC), Safety Viewport Analysis Code (SAFEVU), Blast-Resistant Window Program (BLASTOP), and Window Glazing Analysis Response and Design (WINGARD)) coupled with test data and recognized dynamic structural analysis techniques to show that the glazing either survives the specified threats or the post damage performance of the glazing protects the occupants in accordance with the conditions specified in Table 3-2. In general, laminated glass is the preferred glazing material for new construction. Tests have shown that laminated glass performs well under blast loads if mounted in properly designed window frames and it can be engineered to offer the highest levels of protection from glass fragments.

Limitation of Glass Hazard Mitigation. Keep in mind that the pressures exerted on a building in a large explosion (e.g., a truck bomb) are often significantly greater than the pressures for which protected windows are designed. For these large events, the upgraded solutions may not be effective, except for windows on the sides of the building not facing the explosion or adjacent buildings. This is particularly true if structural damage occurs. Flying debris generated by structural damage typically causes more severe injuries than window damage alone; however, blast mitigating window designs are expected to be effective for a large number of threats where the pressures are low. Two such scenarios include a package bomb near the building and a truck bomb that goes off a block away.

Although these solutions do provide protection at modest pressure levels, they are not a “magic shield.” The threat of attack still exists and injuries may still occur if an attack occurs. These measures will be most effective if considered a “last resort” measure

used in conjunction with a full range of physical and operational security measures at the facility.

General Guidelines for Windows and Glazing. General guidelines for windows and glazing include the following:

- Do not place windows adjacent to doors because, if the windows are broken, the doors can be unlocked.
- Minimize the number and size of windows in a facade. If possible, limit the amount of glazed area in building facades to 15 percent. The amount of blast entering a space is directly proportional to the amount of openings on the facade.
- Consider using burglary- and ballistic-resistant glazing in high-risk buildings.
- Consider using laminated glass in place of conventional glass.
- Consider window safety laminate (such as mylar) or another fragment retention film over glazing (properly installed) to reduce fragmentation.
- Consider placing guards, such as grills, screens, or meshwork, across window openings to protect against covert entry. Affix protective window guards firmly to the structure.
- Consider installing blast curtains, blast shades, or spall shields to prevent glass fragments from flying into the occupied space.
- Consider curtains, blinds, and shades to limit entry of incendiary devices.
- Consider narrow recessed windows with sloped sills because they are less vulnerable than conventional windows (see Figure 3-6).
- Consider windows with key-operated locks because they provide a greater level of protection than windows with simple latches. Stationary, non-operating windows are preferred for security.
- Position the operable section of a sliding window on the inside of the fixed section and secure it with a broomstick, metal rod, or similar device placed at the bottom of the track.



Figure 3-6 Narrow and recessed windows with sloped sills

SOURCE: U.S. AIR FORCE, *INSTALLATION FORCE PROTECTION GUIDE*

- Provide horizontal windows 6 feet above the finished floor to limit entry.
- Harden the windows by using steel window frames securely fastened or cement grouted to the surrounding structure.

Additional Glazing Requirements. Additional glazing requirements include the following:

- Ballistic windows, if required, should meet the requirements of Underwriters Laboratory (UL) 752 Bullet-Resistant Glazing for a level appropriate for the project. Glassclad polycarbonate or laminated polycarbonate are two types of acceptable glazing material.
- Security glazing, if required, should meet the requirements of the American Society for Testing and Materials (ASTM) F1233 or UL 972, Burglary-Resistant Glazing Material.
- Glazing should meet the minimum performance specified in Table 3-2; however, special consideration should be given to frames and anchorages for ballistic-resistant windows and security glazing because their inherent resistance to blast may impart large reaction.

- Resistance of window assemblies to forced entry (excluding glazing) should meet the requirements of ASTM F 588 for a grade appropriate for the project.
- Interior glazing should be minimized where a threat exists. The designer should avoid locating critical functions next to high-risk areas with glazing, such as lobbies, loading docks, etc.

Multi-hazard Considerations. Under normal operating conditions, windows function in a variety of ways, including:

- Allowing light into a building
- Conserving energy by reducing thermal transmission
- Reducing noise through acoustic transmission

Explosions are one of a number of abnormal loading conditions that the building may be designed to mitigate. Some of the others are fire, earthquake, hurricane, gunfire, and forced entry.

In developing a protection strategy for windows to mitigate the effects of a particular explosion threat scenario, it is important to consider how this protection may interfere with some of these other functions or other explosion threat scenarios. Some questions that may be worthwhile to consider are:

- If an internal explosion occurs, will the upgraded windows increase smoke inhalation injuries by preventing the smoke from venting through windows that would normally break in an explosion event?
- If a fire occurs, will it be more difficult to break protected windows in order to vent the building and gain access to the injured?
- Will a window upgrade that is intended to protect the occupants worsen the hazards to passersby?

3.3.4 Doors

A door system includes the door, frame, and anchorage to the building. As part of a balanced design approach, exterior doors in high-risk buildings should be designed to withstand the maximum dynamic pressure and duration of the load from the design threat explosive blast. Other general door considerations are as follows:

- Provide hollow steel doors or steel-clad doors with steel frames.
- Provide blast-resistant doors for high threats and high levels of protection.
- Limit normal entry/egress through one door, if possible.
- Keep exterior doors to a minimum while accommodating emergency egress. Doors are less attack-resistant than adjacent walls because of functional requirements, construction, and method of attachment.
- Ensure that exterior doors open outward from inhabited areas. In addition to facilitating egress, the doors can be seated into the door frames so that they will not enter the buildings as hazardous debris in an explosion.
- Replace externally mounted locks and hasps with internally locking devices because the weakest part of a door system is the latching component.
- Install doors, where practical, so that they present a blank, flush surface to the outside to reduce their vulnerability to attack.
- Locate hinges on the interior or provide concealed hinges to reduce their vulnerability to tampering.
- Install emergency exit doors so that they facilitate only exiting movement.
- Equip any outward-opening double door with protective hinges and key-operated mortise-type locks.
- Provide solid doors or walls as a backup for glass doors in foyers.
- Strengthen and harden the upright surfaces of door jambs.

3.3.5 Roof System Design

For an explosive threat, the primary loading on the roof is downward over-pressure. Secondary loads include upward pressure due to the blast penetrating through openings and upward suction during the negative loading phase. The upward pressures may have an increased duration due to multiple reflections of the air-blast internally. It is conservative to consider the downward and upward loads separately.

The preferred system is to use poured-in-place reinforced concrete with beams in two directions. If this system is used, beams should have stirrups along the entire span spaced not greater than one half the beam depths. A second system uses steel frames with a concrete and metal deck slab to achieve higher levels of protection. For this system to work well, a two-way system of reinforcing bars spaced not more than the total thickness of the slab should be provided. Also, puddle welds or other robust systems are needed along the perimeter to resist the shear forces on the slab as it deflects downward.

Less desirable systems include metal plate systems without concrete, and precast and pre/post tensioned systems. The metal plate system is prone to fail due to its light weight and direct pressure, or by the negative phase pressure that creates a suction effect on the roof. Precast panels are problematic because of the tendency to fail at the connections. Pre/post tensioned systems tend to fail in a brittle manner if stressed beyond their elastic limit and they also are not able to accept upward loads without additional reinforcement. If pre/post tensioned systems are used, continuous mild steel needs to be added to the top and the bottom faces to provide the flexibility needed to resist explosion loads.

Flat slab/plate systems are also less desirable because of limited two-way action and the potential of shear failure at the columns.

Miscellaneous Roof System. Designers should consider the following:

- Designing buildings with a sacrificial sloping roof that is above a protected ceiling (see Figure 3-7).

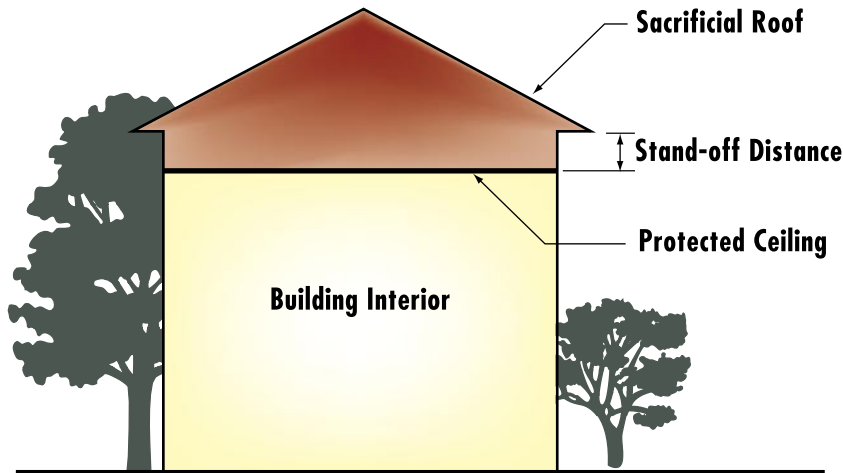


Figure 3-7 Sacrificial roof

- Controlling access to roofs to minimize the possibility of aggressors placing explosives or chemical, biological, or radiological agents there or otherwise threatening building occupants or critical infrastructure. For new buildings, eliminate all external roof access by providing access from internal stairways or ladders, such as in mechanical rooms. For existing buildings, eliminate external access where possible or make roof access ladders removable, retractable, or lockable.
- Protecting roof openings to a facility from covert entry by installing screens or grates or attaching Intrusion Detection System sensors.

3.4 MECHANICAL SYSTEMS

Mechanical system design standards address limiting damage to critical infrastructure and protecting building occupants against CBR threats. The primary goal of a mechanical system after a terrorist attack should be to continue to operate key life safety systems. This can be accomplished by locating components in less vulnerable areas, limiting access to mechanical systems, and providing a reasonable amount of redundancy. Other aspects of mechanical systems are discussed in Section 2.10.

During an interior bombing event, smoke removal and control are of paramount importance. The designer should consider the fact that, if window glazing is hardened, a blast may not blow out windows, and smoke may be trapped in the building. In the event of a blast, the available smoke removal system may be essential to smoke removal, particularly in large, open spaces. This equipment should be located away from high-risk areas (e.g., garages and loading docks). The system controls and power wiring to the equipment should be protected, and the system should be connected to emergency power to provide smoke removal. Smoke removal equipment should be provided with standalone local control panels that can continue to individually function in the event the control wiring is severed from the main control system.

Designers should consider the following:

- Do not mount plumbing, electrical fixtures, or utility lines on the inside of exterior walls, but, when this is unavoidable, mount fixtures on a separate wall at least 6 inches from the exterior wall face.
- Avoid placing plumbing on the roof slab.
- Avoid suspending plumbing fixtures and piping from the ceiling.
- Reduce the number of utility openings, manholes, tunnels, air conditioning ducts, filters, and access panels into the structure.
- Locate utility systems away from likely areas of potential attack, such as loading docks, lobbies, and parking areas.
- Protect building operational control areas and utility feeds to lessen the negative effects of a blast.
- Design operational redundancies to survive all kinds of attack.
- Use lockable systems for utility openings and manholes where appropriate. Infrequently used utility covers/manholes can be tack-welded as an inexpensive alternative to locking tamper-resistant covers.

Key HVAC System Considerations. The following HVAC design measures (from Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, *Guidance for Protecting Building Environments from Airborne Chemical, Biological, or Radiological Attacks*, May 2002) should be considered to mitigate the risk of CBR threats for high security buildings. HVAC protective actions are discussed in Chapter 5.

- Elevating the fresh-air intakes to reduce the potential for hazardous materials entering a building from a ground-level outdoor release is most easily applied in new construction (see Figures 3-8 and 3-9). This has two main benefits. The first benefit is that it provides passive security against malicious acts, which makes it more difficult for a container of hazardous material to be inserted directly into the building's HVAC system and to be conveyed to various parts of the building. The second benefit is that it makes it less likely that high concentrations of hazardous material will occur at the intakes if there is a ground-level release near the building.
- Locating ground-level intakes near streets or parking areas can cause exhaust fumes to be drawn indoors under certain conditions of wind and stability (see Figure 3-10). In elevating the intakes, the dilution increases with the distance from the source. In stable conditions, contaminants released near the ground will likely remain close to the ground unless the airflow over the building lifts it upward. Contaminants that are heavier than air will also tend to remain close to the ground under calm conditions.
- Placing intakes at the highest practical level on the building is beneficial. For protection against malicious acts, the intakes should also be covered by screens so that objects cannot be tossed into the intakes or into air wells from the ground (see Figure 3-10). Such screens should be sloped to allow thrown objects to roll or slide off the screen, away from the intake. Many existing buildings have air intakes that are located at or below ground level. For those that have wall-mounted or below-grade intakes close to the building, the intakes can be elevated

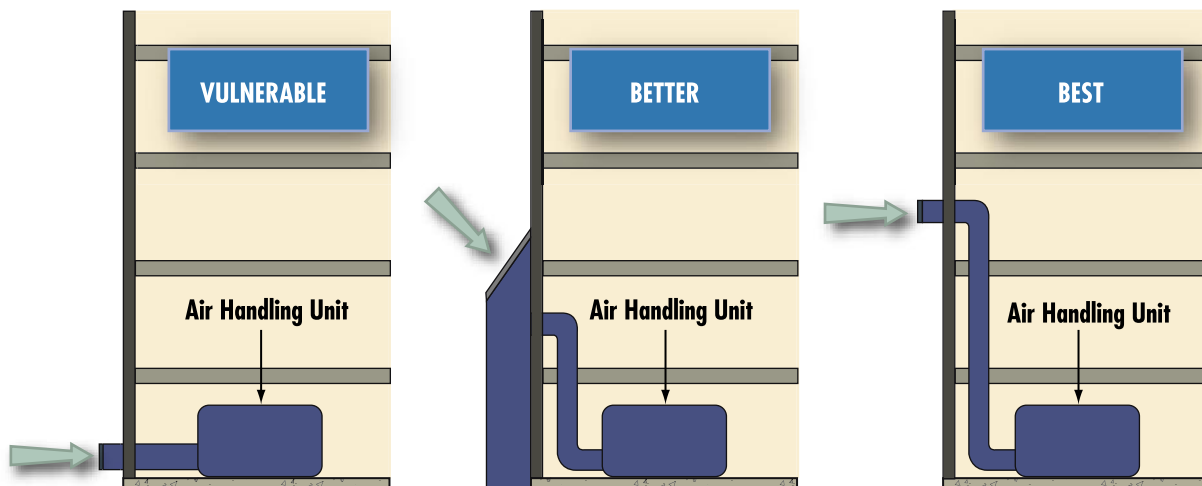
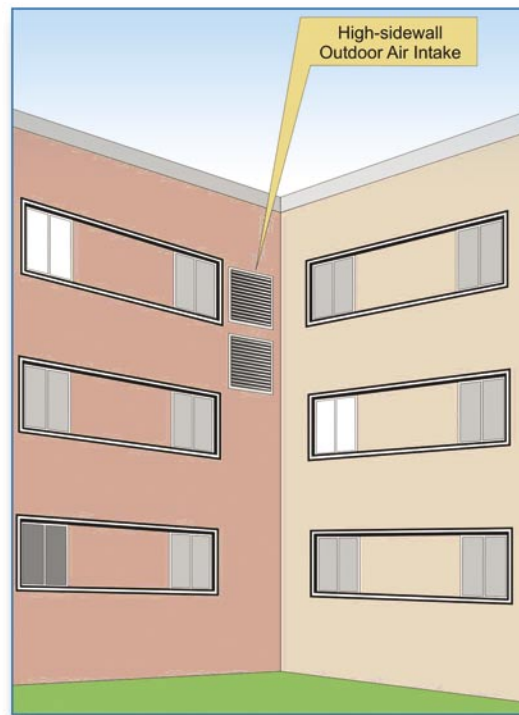


Figure 3-8 Example of protecting outdoor air intakes

SOURCE: CDC/NIOSH, PUBLICATION NO. 2002-139, *GUIDANCE FOR PROTECTING BUILDING ENVIRONMENTS FROM AIRBORNE CHEMICAL, BIOLOGICAL, OR RADIOLOGICAL ATTACKS*, MAY 2002

Figure 3-9
Example of elevated air
intake



SOURCE: CDC/NIOSH, PUBLICATION NO. 2002-139, *GUIDANCE FOR PROTECTING BUILDING ENVIRONMENTS FROM AIRBORNE CHEMICAL, BIOLOGICAL, OR RADIOLOGICAL ATTACKS*, MAY 2002

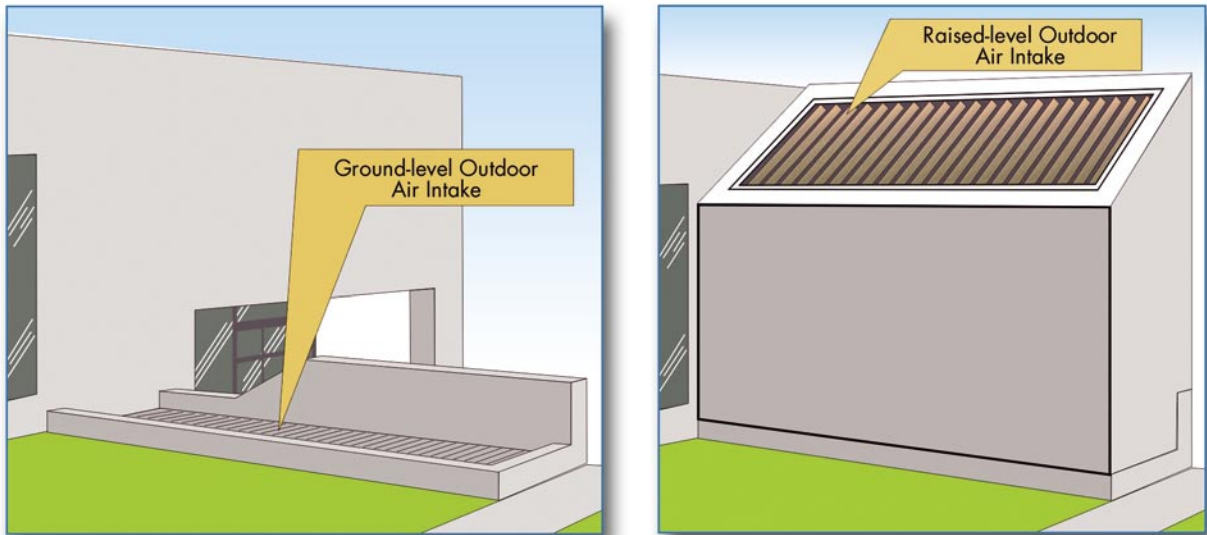


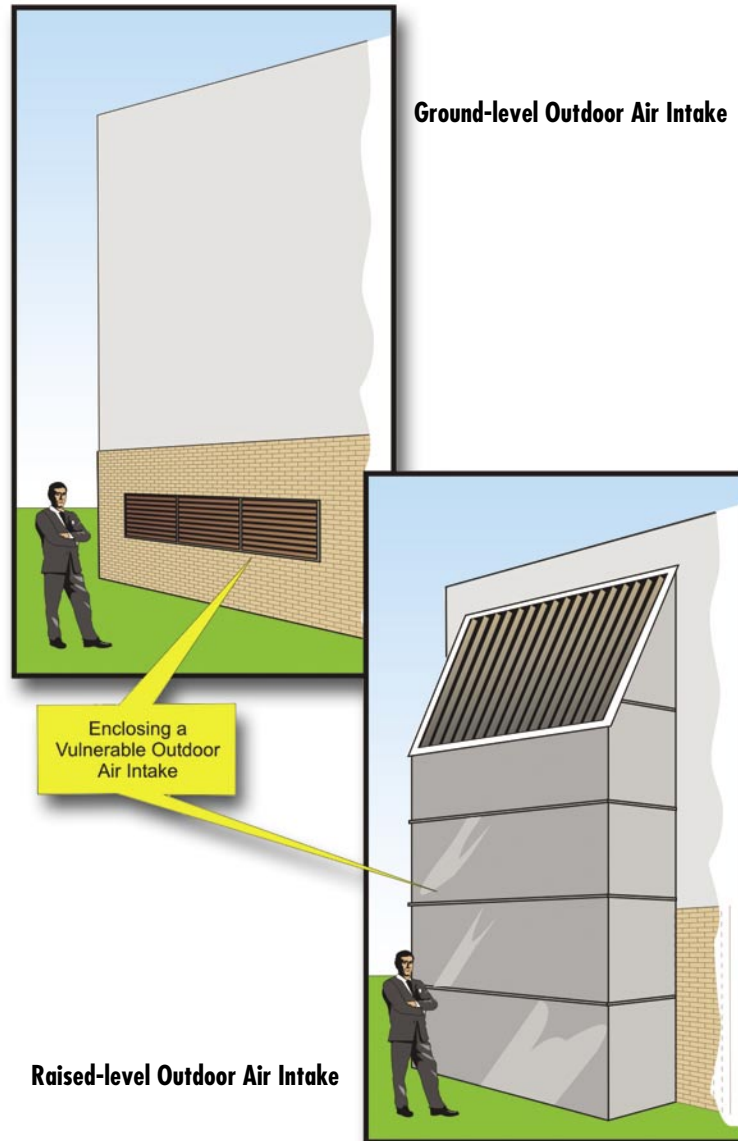
Figure 3-10 Another example of protecting outdoor air intakes

SOURCE: CDC/NIOSH, PUBLICATION NO. 2002-139, *GUIDANCE FOR PROTECTING BUILDING ENVIRONMENTS FROM AIRBORNE CHEMICAL, BIOLOGICAL, OR RADIOLOGICAL ATTACKS*, MAY 2002

by constructing a plenum or external shaft over the intake (see Figure 3-11). An extension height of 12 feet will place the intake out of reach of individuals without some assistance.

- Effectively elevating intakes has practical limits. A plume or cloud of hazardous materials can reach the intakes, particularly if the source is large and distant. For low-rise buildings (i.e., those having a width more than twice the height), a plume originating at ground level near the building will travel over the building rather than around it; thus, the wind will convey contaminants to the top of the building, with some dilution occurring.
- For existing buildings with air intakes below grade, at ground level, or wall-mounted outside secure areas, some protection can be gained with physical security measures (e.g., placing fencing, surveillance cameras, and motion detectors around the intakes to facilitate monitoring by security personnel). These measures can help prevent malicious acts, but are less effective than elevating the intakes, because ground level releases under certain conditions can enter the intakes from points outside the area fenced or under surveillance.

Figure 3-11
Example of enclosing an
existing vulnerable air
intake



SOURCE: CDC/NIOSH, PUBLICATION NO. 2002-139, *GUIDANCE FOR PROTECTING BUILDING ENVIRONMENTS FROM AIRBORNE CHEMICAL, BIOLOGICAL, OR RADIOLOGICAL ATTACKS*, MAY 2002

- Physical security for mechanical rooms to prevent the direct introduction of hazardous materials into the system of ducts that distributes air to the building should be maintained. This includes locking and controlling the access to all mechanical rooms containing HVAC equipment.

- Public access to building roofs should be prevented. Access to the roof may allow entry to the building and access to air intakes and HVAC equipment (e.g., self-contained HVAC units, laboratory or bathroom exhausts) located on the roof. From a physical security perspective, roofs are like other entrances to the building and should be secured appropriately. Roofs with HVAC equipment should be treated like mechanical areas. Fencing or other barriers should restrict access from adjacent roofs.
- Access to building operation systems by outsiders should be restricted. A building staff member should escort maintenance workers throughout their service visit and should visually inspect their work before final acceptance of the service. Alternatively, building managers can ensure the reliability of pre-screened service personnel from a trusted contractor.
- Access to information on building operations (including mechanical, electrical, vertical transport, fire and life safety, security system plans and schematics, and emergency operations procedures) should be strictly controlled. Such information should be released to authorized personnel through the development of an access list and controlled copy numbering.
- To prevent widespread dispersion of a contaminant released within lobbies, mailrooms, and loading docks, their HVAC systems should be isolated and the areas maintained at a negative pressure relative to the rest of the building, but at positive pressure relative to the outdoors. Physical isolation of these areas (well-sealed floor to roof-deck walls, sealed wall penetrations) is critical to maintaining the pressure differential. It requires special attention to ensure airtight boundaries between these areas and adjacent spaces. In some building designs (those having lobbies with elevator access, for example), establishing a negative pressure differential presents a challenge. A qualified mechanical engineer can assist in determining if the recommended isolation is feasible for a given building.

- Large buildings usually have multiple HVAC zones, with each zone served by its own air handling unit and duct system. In practice, these zones are not completely separated if they are on the same floor. Air flows between zones through hallways, atria, and doorways that are normally left open. Isolating the separate HVAC zones minimizes the potential spread of an airborne hazard within a building, and reduces the number of people potentially exposed if an internal release occurs. Zone separation provides a limited benefit against an external release. It increases internal resistance to air movement that is produced by wind forces and chimney effect, therefore reducing the rate of infiltration. In essence, isolating zones divide the building into separate environments, limiting the effects of single release to an isolated portion of the building. Isolation of zones requires full-height walls between each zone and its adjacent zone and hallway.
- Consider “shelter-in-place” rooms or areas where people can congregate in the event of an outdoor release. The goal is to create areas where outdoor air infiltration is very low. Usually such rooms will be in the inner part of the building in an area with no exterior windows. The rooms should have doors that are effective at preventing airflow and should contain staging supplies such as duct tape and plastic to help further seal the areas from the hallways. Typically, restrooms are a bad choice, because they have exhaust ducts that lead directly to the outside. Opening and closing a conventional hinged door can pump large amounts of air into the room. If practical, replace the door with a code compliant sliding door to reduce this effect. Shelter-in-place is discussed in detail in Section 5.2.
- Many central HVAC systems have energy management and control systems that can regulate airflow and pressures within a building on an emergency response basis. Some fire alarm systems provide useful capabilities during CBR events. In some cases, the best response option (given sufficient warning) might be to shut off the building’s HVAC and exhaust system(s), thus avoiding the introduction of a CBR agent

from outside. In other cases, interior pressure and airflow control may prevent the spread of a CBR agent released in the building and/or ensure the safety of egress pathways. The decision to install emergency HVAC control options should be made in consultation with a qualified mechanical engineer who understands the ramifications of various HVAC operating modes on building operation and safety systems.

- HVAC control may not be appropriate in all emergency situations. Protection from CBR attacks depends upon the design and operation of the HVAC system and the nature of the CBR agent release. Lobbies, loading docks, and mailrooms might be provided with manually operated exhaust systems, activated by trained personnel to remove contaminants in the event of a known release, exhausting air to an appropriate area. Manipulation of the HVAC system could minimize the spread of an agent. If an HVAC control plan is pursued, building personnel should be trained to recognize a terrorist attack and know when to initiate the control measures. For example, emergency egress stairwells should remain pressurized (unless they are known to contain the CBR source). Other areas, such as laboratories, clean rooms, or pressure isolation rooms in hospitals, may need to remain ventilated. All procedures and training associated with the control of the HVAC system should be addressed in the building's Emergency Response Plan (ERP).
- Ducted returns offer limited access points to introduce a CBR agent. The return vents can be placed in conspicuous locations, reducing the risk of an agent being secretly introduced into the return system. Non-ducted return air systems commonly use hallways or spaces above suspended ceilings as a return-air path or plenum. CBR agents introduced at any location above the suspended ceiling in a ceiling plenum return system will probably migrate back to the HVAC unit and, without highly efficient filtration for the particular agent, redistribute it to occupied areas. Buildings should be designed to minimize interaction between air-

handling zones. This can be partially accomplished by limiting shared returns. Where ducted returns are not feasible or warranted, hold-down clips may be used for the accessible areas of suspended ceilings that serve as the return plenum. This issue is closely related to the isolation of lobbies and mailrooms, because shared returns are a common way for contaminants from these areas to disperse into the rest of the building. These modifications may be more feasible for new building construction or those undergoing major renovation.

- A rapid response, such as shutting down an HVAC system, may involve closing various dampers, especially those controlling the flow of outdoor air (in the event of an exterior CBR release). When the HVAC system is turned off, the building pressure compared to outdoors may still be negative, drawing outdoor air into the building via many leakage pathways, including the HVAC system. Consideration should be given to installing low leakage dampers to minimize this flow pathway. Damper leakage ratings are available as part of the manufacturer's specifications and range from ultra-low to normal categories. Assuming that there is some warning prior to a direct CBR release, the speed with which these dampers respond to a "close" instruction can also be important. From a protective standpoint, dampers that respond quickly are preferred over dampers that might take 30 seconds or more to respond.

Emergency Plans, Training, and Procedures for HVAC Systems.

All buildings should have current emergency plans to address fire, weather, and other types of emergencies. In light of past U.S. experiences with anthrax and similar threats, these plans should be updated to consider CBR attack scenarios and the associated procedures. Emergency plans should have procedures for communicating instructions to building occupants, identifying suitable shelter-in-place areas (if they exist), identifying appropriate use and selection of personal protective equipment (i.e., clothing, gloves, respirators), and directing emergency evacuations. Individuals developing emergency plans and procedures should recognize that there are fundamental differences

between chemical, biological, and radiological agents. In general, chemical agents will show a rapid onset of symptoms, while the response to biological and radiological agents will be delayed. Issues such as designated areas and procedures for chemical storage, HVAC control or shutdown, and communications with building occupants and emergency responders, should all be addressed. The plans should be as comprehensive as possible, but, as described earlier, protected by limited and controlled access. When appropriately developed, these plans, policies, and procedures can have a major impact upon occupant survivability in the event of a CBR release. Staff training, particularly for those with specific responsibilities during an event, is essential and should cover both internal and external events. Holding regularly scheduled practice drills, similar to the common fire drill, allows for plan testing, as well as occupant and key staff rehearsal of the plan, and increases the likelihood for success in an actual event. For protection systems in which HVAC control is done via the energy management and control system, emergency procedures should be exercised periodically to ascertain that the various control options work (and continue to work) as planned.

Periodic training of HVAC maintenance staff in system operations and maintenance should be conducted. This training should include the procedures to be followed in the event of a suspected CBR agent release. Training should also cover health and safety aspects for maintenance personnel, as well as the potential health consequences to occupants of poorly performing systems. Development of current, accurate HVAC diagrams and HVAC system labeling protocols should be addressed. These documents can be of great value in the event of a CBR release.

Procedures and preventive maintenance schedules should be implemented for cleaning and maintaining ventilation system components. Replacement filters, parts, etc., should be obtained from known manufacturers and examined prior to installation. It is important that ventilation systems be maintained and cleaned according to the manufacturer's specifications. To do this requires information on HVAC system performance, flow rates, damper

modulation and closure, sensor calibration, filter pressure loss, filter leakage, and filter change-out recommendations. These steps are critical to ensure that protection and mitigation systems, such as particulate filtration, operate as intended.

3.5 ELECTRICAL SYSTEMS

The major security functions of the electrical system are to maintain power to essential building services, especially those required for life safety and evacuation; provide lighting and surveillance to deter criminal activities; and provide emergency communications. Thus, the operability of electrical systems is an important element for deferring terrorist attacks and can become a critical component for life safety systems after an attack. Designers should consider the following recommendations for buildings requiring high security:

- Emergency and normal electric panels, conduits, and switchgear should be installed separately, at different locations, and as far apart as possible. Electric distribution should be run from separate locations.
- Emergency generators should be located away from loading docks, entrances, and parking. More secure locations include the roof, protected grade level, and protected interior areas.
- Fuel tanks should be mounted near the generator, given the same protection as the emergency generator, and sized to store an appropriate amount of fuel. A battery and/or UPS could serve a smaller building or leased facility.
- Conduits and lines should be installed outside to allow a trailer-mounted generator to connect to the building's electrical system. If tertiary power is required, other methods include generators and feeders from alternative substations.
- Site lighting should be coordinated with the CCTV system.
- Emergency lighting should be provided in restrooms.
- Building access points should be illuminated to aid in threat detection.

- Self-contained battery lighting should be provided in stairwells and for exit signs.
- Suspending electrical conduits from the ceiling should be avoided.
- Adequate lighting of perimeters and parking areas should be provided to aid in visual surveillance and to support the use of physical security systems.

3.6 FIRE PROTECTION SYSTEMS

The fire protection system inside the building should maintain life safety protection after an incident and allow for safe evacuation of the building when appropriate. Although fire protection systems are designed to perform well during fires, they are not traditionally designed to survive bomb blasts. To enhance the performance of fire protection systems, especially in the case of an explosive blast, the designer should consider the following:

- The fire protection water system should be protected from single-point failure in case of a blast event. The incoming line should be encased, buried, or located 50 feet away from high-risk areas. The interior mains should be looped and sectionalized.
- To increase the reliability of the fire protection system in strategic locations, a dual pump arrangement should be considered, with one electric pump and one diesel pump. The pumps should be located away from each other.
- All security locking arrangements on doors used for egress must comply with requirements of the National Fire Protection Association (NFPA) 101, Life Safety Code.

3.7 COMMUNICATIONS SYSTEMS

For buildings requiring greater protection, the designer should consider the following:

- **Redundant communications.** The facility could have a second telephone service to maintain communications in

case of an incident. A base radio communication system with antenna should be installed in the stairwell, and portable sets distributed on floors. This is the preferred alternative.

- **Radio telemetry.** Distributed antennas could be located throughout the facility if required for emergency communications through wireless transmission of data.
- **Alarm and information systems.** Alarm and information systems should not be collected and mounted in a single conduit, or even collocated. Circuits to various parts of the building should be installed in at least two directions and/or risers. Low voltage signal and control copper conductors should not share conduits with high voltage power conductors. Fiber-optic conductors are generally preferred over copper.
- **Empty conduits.** Empty conduits and power outlets can be provided for future installation of security control equipment.
- **Mass notification.** All inhabited buildings should have a timely means to notify occupants of threats and give instructions as to responses. Building communications systems should provide real-time notification of occupants and passersby in the immediate vicinity of the building during emergency situations. The information relayed should be specific enough to determine the appropriate response actions.

3.8 ELECTRONIC SECURITY SYSTEMS

Electronic security, including surveillance, intrusion detection, and screening, is a key element of facility protection. Many aspects of electronic security and the posting of security personnel have been adequately dealt with in other criteria and guideline documents. These criteria primarily address access control design, including stair and lobby design, because access control must be considered when design concepts for a building are first conceived. Although fewer options are available for modernization projects, some designs can be altered to consider future access control objectives.

The purpose of electronic security is to improve the reliability and effectiveness of life safety systems, security systems, and building functions. When possible, accommodations should be made for future developments in security systems.

This chapter is not a design guide for Electronic Security Systems (ESS). The following criteria are only intended to stress those concepts and practices that warrant special attention to enhance public safety. Consult design guides pertinent to the specific project for detailed information about electronic security. A description of Electronic Security Systems is provided in Appendix D.

For control centers and building management systems, designers should consider the following:

- The Operational Control Center (OCC), Fire Command Center (FCC), and Security Control Center (SCC) may be collocated. If collocated, the chain of command should be carefully pre-planned to ensure the most qualified leadership is in control for specific types of events. Secure information links should be provided between the OCC, FCC, and SCC.
- A Backup Control Center (BCC) should be provided in a different location, such as a manager's or engineer's office. If feasible, an off-site location should be considered.
- A fully redundant BCC should be installed (this is an alternative to the above).
- Basic intrusion detection devices should be provided: magnetic reed switches for interior doors and openings, glass break sensors for windows up to scalable heights, and balanced magnetic contact switch sets for all exterior doors, including overhead/roll-up doors. Roof intrusion detection should be reviewed.
- Monitoring should be done at an off-site facility.
- An on-site monitoring center should be used during normal business hours and be operational 24 hours.

- A color CCTV surveillance system with recording capability should be provided to view and record activity at the perimeter of the building, particularly at primary entrances and exits. A mix of monochrome cameras should be considered for areas that lack adequate illumination for color cameras.

The following considerations apply when lighting systems are intended to support CCTV assessment or surveillance: field of view of the camera; lighting intensity levels; maximum light-to-dark ratio; scene reflectance; daylight-to-darkness transitions; camera mounting systems relative to lighting; spectral response of the camera; cold-start time; and restrike time.

3.9 ENTRY-CONTROL STATIONS

Entry-control stations should be provided at main perimeter entrances where security personnel are present (see Figure 3-12). In addition, entry-control stations should be located close to the pe-



Figure 3-12 Physical security devices

rimeter entrance to permit people inside the station to maintain constant surveillance over the entrance and its approaches. Additional considerations at entry-control stations include:

- A holding area for unauthorized vehicles or those needing further inspection should be established. A turnaround area should be provided so that traffic is not impeded.
- Control measures such as displaying a decal on the window or having a specially marked vehicle should be established.
- Entry-control stations that are manned 24 hours each day should have interior and exterior lighting, interior heating and cooling (where appropriate), and a sufficient glassed area to afford adequate observation for people inside. Where appropriate, entry-control stations should be designed for optimum personnel ID and movement control. Each station should include a telephone, a radio, and badge racks (if required).
- Signs should be erected to assist in controlling authorized entry, to deter unauthorized entry, and to preclude accidental entry. Signs should be plainly displayed and legible from any approach to the perimeter from a reasonable distance. The size and coloring of a sign, its letters, and the interval of posting must be appropriate to each situation.
- Entry-control stations should be hardened against attacks according to the type of threat. The methods of hardening may include:
 - Reinforced concrete or masonry
 - Steel plating
 - Bullet-resistant glass
 - Commercially fabricated, bullet-resistant building components or assemblies

3.10 PHYSICAL SECURITY SYSTEMS

Physical security concerns the physical measures designed to safeguard people; prevent unauthorized access to equipment, installations, material, and documents; and safeguard against terrorist attacks. As such, all security operations face new and complex physical security challenges across the full spectrum of operations. Challenges relative to physical security include the control of populations, information dominance, multi-national and interagency connectivity, antiterrorism, and the use of physical security assets as a versatile force multiplier.

The rapid evolution of physical security equipment technology leads to physical security challenges, which are exponentially multiplied by the introduction of the information age (see Appendix D). Physical security challenges must be understood, and measures must be taken to minimize them to enhance the protection of people within a facility.

3.11 SUMMARY OF BUILDING ENVELOPE MITIGATION MEASURES

A general spectrum of building envelope mitigation measures ranging from the least protection, cost, and effort going to the greatest protection, cost, and effort is provided below. Detailed discussions of individual measures can be found earlier in the chapter. Please note this is a nominal ranking of mitigation measures. In practice, the effectiveness and cost of individual mitigation measures may deviate from this example based on specific applications.

**Less Protection
Less Cost
Less Effort**

- Ensure that exterior doors into inhabited areas open outward. Ensure emergency exit doors only facilitate exiting.
- Secure roof access hatches from the interior. Prevent public access to building roofs.
- Restrict access to building operation systems.
- Conduct periodic training of HVAC operations and maintenance staff.
- Evaluate HVAC control options.
- Install empty conduits for future security control equipment during initial construction or major renovation.
- Do not mount plumbing, electrical fixtures, or utility lines on the inside of exterior walls.
- Minimize interior glazing near high-risk areas.
- Establish emergency plans, policies, and procedures.
- Establish written plans for evacuation and sheltering in place.
- Illuminate building access points.
- Restrict access to building information.
- Secure HVAC intakes and mechanical rooms.
- Limit the number of doors used for normal entry/egress.
- Lock all utility access openings.
- Provide emergency power for emergency lighting in restrooms, egress routes, and any meeting room without windows.
- Install an internal public address system.
- Stagger interior doors and offset interior and exterior doors.
- Eliminate hiding places.
- Install a second and separate telephone service.
- Install radio telemetry distributed antennas throughout the facility.
- Use a badge identification system for building access.
- Install a CCTV surveillance system.
- Install an electronic security alarm system.
- Install rapid response and isolation features into HVAC systems.
- Use interior barriers to differentiate levels of security.
- Locate utility systems away from likely areas of potential attack.
- Install call buttons at key public contact areas.

**Greater
Protection
Greater Cost
Greater Effort**

Continued on next page

**Less Protection
Less Cost
Less Effort**

- Install emergency and normal electric equipment at different locations.
- Avoid exposed structural elements.
- Reinforce foyer walls.
- Use architectural features to deny contact with exposed primary vertical load members.
- Isolate lobbies, mailrooms, loading docks, and storage areas.
- Locate stairwells remotely. Do not discharge stairs into lobbies, parking, or loading areas.
- Elevate HVAC fresh-air intakes.
- Create "shelter-in-place" rooms or areas.
- Separate HVAC zones. Eliminate leaks and increase building air tightness.
- Install blast-resistant doors or steel doors with steel frames.
- Physically separate unsecured areas from the main building.
- Install HVAC exhausting and purging systems.
- Connect interior non-load bearing walls to structure with non-rigid connections.
- Use structural design techniques to resist progressive collapse.
- Treat exterior shear walls as primary structures.
- Orient glazing perpendicular to the primary façade facing uncontrolled vehicle approaches.
- Use reinforced concrete wall systems in lieu of masonry or curtain walls.
- Ensure active fire system is protected from single-point failure in case of a blast event.
- Install a Backup Control Center (BCC).
- Avoid eaves and overhangs or harden to withstand blast effects.
- Establish ground floor elevation 4 feet above grade.
- Avoid re-entrant corners on the building exterior.

**Greater
Protection
Greater Cost
Greater Effort**