Related Commercial Resources

# CHAPTER 61. HVAC RESILIENCE AND SECURITY

THIS chapter is intended to be an overview of HVAC resilience and security considerations relative to natural events, accidents, terrorism, and national threats, as well as addressing chemical, biological, radiological, and explosive (CBRE) incidents that do not cause major structural damage to a building or its infrastructure. This added focus on CBRE incidents, either accidental (e.g., an industrial spill) or premeditated, is intended to be a general overview and not used as design guidelines.

HVAC resilience and security of a building should be designed for compliance with federal, state and local codes as they pertain to HVAC but building programs that require more (e.g., a closed-circuit television [CCTV]) should be provided by a qualified consultant and/or installing contractor. The same design process should occur for how a building is brought back to normal operation during and/or after a crisis (e.g., flood, power outage, health pandemic, extreme weather occurrence). How a facility functions under or after these conditions will require an internal building operation and maintenance team to draft the needed procedure, implement these procedures, and routinely practice the recovery process.

Because of the nature of security, the documentation available pertaining to designing, constructing, renovating, operating, commissioning, or recommissioning and maintaining HVAC equipment and systems from a security and environmental health and safety (EHS) standpoint will change over time. Organizations such as the U.S. Department of Defense have guidelines that are considered highly confidential and are only shared with others on an as-needed basis. In other situations, special security organizations follow behind the design and/or construction teams with security measures that are not shared with these design/construction organizations. As a result, the owner’s project requirement (OPR) document should include a resilience and security statement, and the HVAC design engineer must include information in the Basis of Design (BOD) document to raise awareness of the approach and level of resilience and security for the specific project.

In general, HVAC resilience and security apply to all building applications based on a broad range of reasons, needs, and requests. They play a particularly important role for businesses such as pharmaceutical companies, property managers of high-profile commercial buildings where workers and visitors come and go on a regular basis throughout the day and night, and convention centers and sport stadiums entertainment venues where thousands of people are present for a few hours. Recently, security considerations have expanded to include all building programs, whether a K-12 school, movie theater, or simply a tenant fit-out of a small business space.

This chapter is not intended to be used for design or development of life safety systems or procedures, or for protection of personnel during an incident; rather, it offers an approach to HVAC resilience and security that includes a segment in the design team BOD document that can address HVAC resilience and security, EHS, commissioning, and recommissioning of systems; details the need to provide proactive maintenance of these components and systems; and provides descriptions of some CBRE incidents and their associated effects on buildings, building equipment, and occupants, along with general guidelines for how to address their effects on building infrastructure.

Since September 11, 2001, more published information has been available about procedures for preventing, mitigating, and remediating terrorist or other CBRE incidents. ASHRAE’s (2003a) *Report of Presidential Ad Hoc Committee for Building Health and Safety under Extraordinary Incidents* discusses many aspects of buildings, building infrastructure, and measures that can both reduce the threat and/or damage from such incidents. Several departments of the U.S. federal government, including the Federal Emergency Management Agency (FEMA), Department of Homeland Security (DHS), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control (CDC), and Department of Defense (DOD), have produced reports and guidelines for dealing with terrorist threats to buildings (see the Bibliography). Emphasis is generally on actions to reduce the potential harm to building occupants and minimizing the potential for an accident, both reducing the threat of harm, by instituting procedures that reduce the hazard during an incident.

HVAC resilience and security begin in the building program phase of a renovation or new construction project. The design team should address the level of security via a risk evaluation and document the level of resilience and security to be invested in the building program. For most buildings, the risk evaluation will fall into the category of low to medium, but do not overlook the potential for high risk based on the building’s application.

In almost any case of a terrorist event affecting a building, its infrastructure, or its occupants, the affected building and its immediate surroundings are likely to be in police or military control for several days (or longer) after the event. During this period, the role of the building(s) owner or facilities management and physical plant staff is to assist in controlling or remediating the affected areas through their knowledge of the building and its infrastructure systems. Assessment of damage or remaining danger to the building or personnel is difficult, particularly with chemical, biological, and radiological events, in which the contaminating agent often is invisible and is only revealed through adverse health effects. As such, there are no specific guidelines for how or when a building can be brought back online and readied for occupancy; each event is unique. Any preparation or response protocol for CBRE incidents internal or external to the facility should be designed to consider the specifics of the building and its occupants. It is impossible to provide general guidelines for incidents that are so unpredictable and potentially so devastating. This chapter attempts to shed light on design intent, construction administration, commissioning, and recommissioning, and on some of the possible effects on buildings, their systems, and their occupants, which may aid in the development of a more specific protocol in line with a particular facility's needs.

# 1. OWNER'S PROJECT REQUIREMENTS

The initial process of any building program is establishing the owner's project requirement (OPR) document, which is an abbreviated overview of the owner's project goals. Both the OPR and the BOD must be drafted in the conceptual phase of a renovation or new construction project. The OPR covers a wide range of categories to document the owner's intent in investing in this new construction, renovation, or infrastructure project. The OPR identifies the drivers that will shape the design, how it will be constructed, the energy budget, and how it will be operated and maintained over the building's life. It also sets a construction budget and project timeline. Safety and security requirements may remain confidential, with limited documentation between the owner's security professionals and the designer. A separate design team focused on this safety and security BOD could also be brought into the project as the design progresses towards completion and before the owner begins occupancy, to fulfill the more confidential BOD items.

When drafting an OPR, the building owner, owner representative, and the design team should consider the following:

- Who are the main occupants?
- What critical assets are housed in the building?
- What is the intended use of the building?
- What is the total planned population of the building, including visitors and service staff?
- What types of operations will the facility and/or occupants conduct?
- What threats and incidents should the design take into account?
- What is the planned response to an incident? Will occupants evacuate, shelter in place, and/or carry on normal activities uninterrupted?
- Which spaces and systems require continuous uninterrupted operation?
- How will the building staff become aware of a threat, and what is the likely notification time?
- What level of protection is required against threats?
- Will some occupants have planned responses that differ significantly from the general building plan?
- How will the building return to normal operation after a safety or security incident?
- What level of access will the general public be allowed in the building?
- Does the owner have a dedicated security team and/or consultant?
- What life safety measures are planned for the building?
- Will occupants be required to remain in the building after an incident (e.g., in a high-security prison)?
- Are there any unique environmental health concerns (e.g., infectious disease, explosive atmosphere, laboratory)?

In addition to the preceding, the design engineer should also consider lessons learned from past HVAC resilience and security process failures associated with the type of building (e.g., for a hospital project: emergency generators and primary HVAC equipment located below flood water levels that took out the emergency power and special HVAC central air systems serving in-patient space). An Internet search of related issues and concerns is also recommended.

The OPR should be complete, thorough and exhaustive, and should adequately cover the owner's overall goals for the building's HVAC resilience and security. Many HVAC resilience and security measures are relatively low in cost and effort during new construction or renovation planning, but may require significant cost and effort if implemented after construction is completed. Therefore, it is critical to capture these requirements early in any design process.

All projects should include some minimal level of HVAC resilience and security design and planning. These measures are typically included in the life safety requirements, specific designs, or best practices typically applied to building construction. These **baseline measures** include equipment or design features that can be applied to all buildings at a minimal cost and effort to provide basic protection against internal and external threats and incidents. Baseline measures support the safe sheltering in place and/or evacuation of occupants during an incident. Many baseline measures can be implemented in an existing facility with little or no additional engineering design or cost, and with minor alteration to the facility operations. **Enhanced measures** include equipment or design features beyond the baseline level, and are intended for facilities with identified risks or critical operations. Costs for design, construction, and sustainment can be significant, depending on the measures selected; however, the protection afforded by these systems typically allows longer-term sheltering in place or continuous uninterrupted operations for the duration of the incident. Specific design features and equipment to provide these measures of protection are discussed later in this chapter. A building's particular HVAC resilience and security design uses its own unique collection of HVAC resilience and security measures, depending on risk and requirements.

## 2. RISK EVALUATION

In parallel with development of the OPR, a risk evaluation should be conducted for the building and its planned design. FEMA and other industry organizations have developed various guidance documents and software to assess the risk and appropriate response from both external and internal events. Significant detail regarding risk management for catastrophic events is included in ASHRAE *Guideline* 29-2017.

Risk is a function of the **probability** of an event occurring and the **consequence** of this event. For HVAC resilience and security planning, the probability of a catastrophic event occurring is typically nearly zero. This probability is shaped by multiple factors, including the facility's occupants, its location, and nearby objects that may pose a threat. The consequence of an event, however, is usually considered extremely high. Factors to be considered include potential loss of life, failure of critical infrastructure, and remediation time and effort.

Figure 1 presents a generalized framework for managing building security risks. The key considerations for a risk analysis include the following:

- Vulnerabilities: what elements of the building design, construction, location, or operations present opportunities for catastrophic events?
- Acceptable vulnerabilities: what identified vulnerabilities cannot or should not be addressed, and thus must be accepted as operational risks?
- Impact: what are the consequences of an adverse event, including remediation, reconstruction, and lost business, and how does this compare to the cost of implementing HVAC resilience and security measures?
- Constraints: what limitations exist that would shape the HVAC resilience and security design of a building?

Successful risk evaluation should include a review of all facets of the planned building design and operations to determine the risk. This evaluation may include the following areas of assessment:

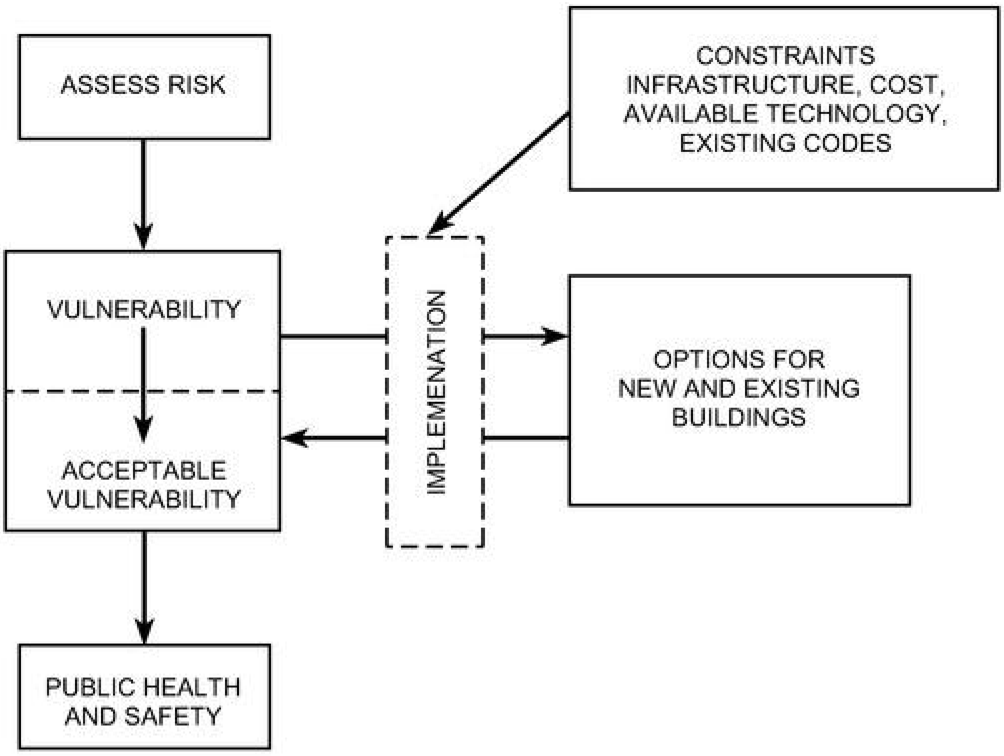


**Figure 1. Risk Management Framework (Adapted from ASHRAE *Guideline* 29-2017)**

## BUILDING AND OCCUPANTS

- Identification of potential high-value targets
- Identification of specific vulnerabilities
- Classification of occupants and operations
- Assessment of benefits of containment versus evacuation

## POTENTIAL THREATS AND VULNERABILITIES

- Identification of potential aggressors
- Identification of potential delivery systems

## LIKELY SUPPORT MECHANISMS

- Identification of likely first-responder units
- Identification of infrastructural support

## POST-EVENT REMEDIATION

- Consideration for potential consequences if building is unoccupied or unusable for extended periods
- Estimation of relative magnitude of remediation measures

Examples of considerations that may increase the overall risk assessment of the facility include the following:

- Potential effect of building remaining unoccupied for extended periods
- Military-critical missions
- Government emergency operations or command centers
- Significant landmarks
- Critical infrastructure elements
- Single-failure point operations or equipment
- Corporate headquarters or critical operations centers
- Transportation hubs
- Communications nodes
- Popular tourist destinations
- Approach and takeoff areas for major airports
- Sites open to the public
- Sites frequently targeted by protests and demonstrations
- Locations near significant potential hazards such as nuclear power plants or chemical manufacturing facilities
- Locations adjacent to major shipping and transportation routes where external events may affect building occupants (e.g., truck fire, ruptured tanker car on train)
- Sites frequently subjected to severe natural or weather events, such as tornadoes, floods, hurricanes, or earthquakes

- Potential for spread of infectious disease

Obviously, this list is not all-inclusive, and many buildings may have unique circumstances or characteristics that warrant specialized HVAC resilience and security measures. Generally, it is difficult or impossible to completely mitigate against all risks; thus, the overall goal of a risk evaluation and implementation of security measures is to move subsequent evaluated risks to lower levels. That is, if a building's overall risk is assessed as high, measures should be implemented such that subsequent risk assessments for the same building would be medium or low.

## 3. HVAC SYSTEM DESIGN FOR RESILIENCE AND SECURITY

Building design and operations during a CBRE event should leverage strongly from the OPR and risk evaluation documents. This section presents generalized recommendations and practices for HVAC system security design, and detailed information on specific threats is provided in subsequent sections. The BOD document should include an HVAC resilience and security segment that highlights the mechanical system design intent as it pertains to the OPR and risk evaluation.

Figure 2 presents a generalized BOD HVAC resilience and security section, which can be enhanced on a project-by-project basis.

AREAS OF INCIDENT:

Consultant(s)
- None
- In-house security management
- Outside security consultant
- Government security (at time of design; confidential)
- Government security (at time of construction; highly confidential)

Risk Evaluation Status (see risk evaluation document for more detail)
- Baseline: No specialized operations, tenants may be relocated, long-term nonoccupancy presents minimal challenge
- Enhanced: Specialized or unique operations, larger facilities with high populations, long-term nonoccupancy undesirable
- Critical: Highly specialized or unique operations, high importance or visibility, long-term nonoccupancy unacceptable

Design Features: HVAC Resilience and Security
- List Features

Design Features: Environmental Health and Safety
- List systems with enhanced air filtration and MERV rating
- List systems with enhanced safeties and alarms and types of devices used
- List zoning application
- List air intake minimum height above grade requirements
- List equipment to be located above exterior historical flood level data
- List systems to be on emergency power

Commissioning, Operation, Maintenance, and Recommissioning
- Commission beginning in design phase through construction phase
- Continuous commissioning in warranty phase
- Operation training and documentation beginning in design phase
- Preventive maintenance work order ready to implement in construction/commissioning phase
- Predictive maintenance features
- Mode of operation: evacuation, shelter-in-place, uninterrupted operation (list systems by one of these three categories)
- Building recovery plan, training, and routine drill to return the facility back to normal operation after a critical event
- Recommissioning every (X) years by ___________

**Figure 2. HVAC Resilience and Security BOD Segment**

**From Outside the Building**: Safety and security from outside should address those potential events that could eventually infiltrate into the building through the HVAC system, such as a chemical spill or smoke from a fire in the vicinity of the building's outdoor air intake louvers. Other consideration regarding outside building potential compromises is:

- Windows, intake louvers, exterior doors, below grade areaways, and skylights where toxic fumes, flooding, and non-terrorist incidents, accidents, and natural events can compromise the building security and safety.
- Outdoor equipment serving the building including HVAC equipment, both on the ground and on the roof, as well as roof-hatches, relief vents, and open-ended pipes and ductwork.

**From Within The Building:** Safety and security from within should address those potential events that could eventually spread from the point of incident e.g., a chemical spill to adjacent rooms or zones both on the floor and the floor(s) below and above. These events may occur by accident or be intentionally executed. Also, infectious disease potential with occupants entering and leaving the facility should be considered.

# 3.1 MODES OF OPERATION

**Building Response:** Three main building situations should be considered in HVAC resilience and security design with each mode presenting unique challenges, costs, and benefits, and each should be reviewed and compared to the risk assessment and OPR to determine which best meets the building owner's needs:

1. Evacuation
2. Sheltering-in-Place
3. Uninterrupted Operation
4. Operating under constraints
5. Recovery after incident

Each mode presents unique challenges, costs, and benefits, and each should be reviewed and compared to the risk assessment and OPR to determine which best meets the building owner's needs.

## Evacuation

Evacuation is the immediate, rapid, and controlled egress of occupants from a facility in the event of an emergency. This mode is commonly used in fire protection engineering. Planning and design for evacuation includes measures to prevent catastrophic failure of the facility for a short duration, and egress direction support, including emergency lighting, signage, and doors.

This mode is effective in many cases and generally is the easiest to implement. However, this mode may not be effective against external threats where personnel may evacuate directly into the path of a threat, and can present difficulty for triage and containment. Typically, minimal cost and design efforts are required to implement an evacuation during an event, because most buildings are required to include similar measures and equipment for fire protection and smoke removal. Also, typically limited or no additional training is required for building occupants, most of whom are familiar with normal evacuation procedures.

## Shelter-in-Place

This is short-duration occupancy of a facility or section thereof to avoid immediate threats. This mode requires occupants to remain in the building during the event and seal the building against intake or further dissemination of threats until the immediate danger has passed. Although some facilities provide full-building shelter-in-place coverage, many designate discrete rooms or areas for occupants to remain in. The normal expected duration is on the order of several hours or less.

Sheltering in place is an effective protective measure when implemented properly and quickly after identification of a threat. Many government and military facilities implement some level of sheltering in place. Effective application requires immediate identification of a threat and subsequent shutdown of HVAC systems to prevent the spread of contamination in the building. Additionally, designated shelter-in-place locations may include some food and water supply for occupant consumption during an event, as well as means of communication with emergency responder personnel. Generally during a shelter-in-place event, occupants do not continue normal work because of the anxiety of the event and the potential requirement for occupants to move into a common area (e.g., conference room, break room) without normal work equipment. Because durations are typically expected to be several hours or less, no bedding is required, and the relative population density can be high. Implementation of a shelter-in-place strategy requires early coordination and training of building occupants to avoid confusion during an event.

### Uninterrupted Operation

Uninterrupted operation is the continuous occupancy and use of a building, or some portions therein, during an event without contamination of personnel and equipment. This mode allows for occupants to continue their normal activities without evacuating or sheltering in place. Although some buildings may address this mode by providing personal protective equipment to occupants, many have installed collective protection systems in the building HVAC systems, including advanced filtration, airflow balancing, controls, and architectural modifications. Collective protection is achieved by filtering all incoming air to a building and providing this air at an overpressure to spaces, thus creating a protective zone where occupants can continue to operate during an event.

This mode can be extremely effective against both internal and external threats, depending upon configuration and design. Typically, buildings can operate in these modes for hours or days, depending upon the threat; however, with this extended duration, bedding, food, and water, along with lower population densities, should be considered. The relative cost (both capital and sustainment) for this mode can be extremely high, so it is generally used only for critical facilities such as command centers and vital infrastructure elements.

### Operating Under Constraints

Operation under constraints is the continuous occupancy and use of a building, or some portions therein, during an event without contamination of personnel and equipment. This mode allows for occupants to continue their normal activities but under specific health, safety and security guidelines. Building HVAC systems may include resilience measures such as increased air changes, enhanced minimum efficiency reporting values (MERV) rating filtration, and airflow balancing and controls modifications within an existing building or included in a new building project.

### Recovery After Incident

While this building mode of operation may not be included in the initial HVAC design intent document, operation and maintenance after the HVAC system(s) have been installed and commissioned should be addressed in advance of building occupancy and this owner requirement should be implemented by the facility's operation and maintenance management and acted upon depending on the building application.

### Modes of Operation

**Building HVAC Response:** The HVAC systems, serving the building must be coordinated with the BOD as it pertains to the "Building Response" based on one of the five methods chosen. The associated HVAC system sequences of operation will need to be engineered to automatically switch to a safety and security mode of operation both for the building response and areas of incident outside or inside. This may result in some or all of the systems shutting down and/or certain systems continuing to operate but under the engineered incident response.

## 3.2 RESILIENCE AND SECURITY DESIGN MEASURES

Multiple measures can be implemented to provide HVAC resilience and security and protections, some of which are discussed in this section. It is important to consider that these measures are typically combined with other design elements to enhance building protection, and that not all measures may be applicable to all buildings or locations. The BOD is the documentation of design criteria, set points, parameters, and narrative that outlines the HVAC system security. Again, because of the nature of the security OPR, BOD documentation may not be published. BOD considerations may include some or all of the following measures.

### Emergency Power

HVAC systems that are designed to respond to a CBRE incident by continuing to operate should be powered from an emergency electrical power distribution system. Some considerations may include redundant external feed from two sources, generator sets, and/or uninterruptible power supplies (UPS). Any of these options may require significant first cost as well as maintenance and sustainment costs. In designing emergency power for the HVAC system, carefully consider the location of emergency generator(s) and associated switchgear and motor control center so that they are well above flood water levels. Other considerations are to ensure electrical power is provided to the building automation system (BAS) so that the HVAC safety and security system functions with the building automation computer under emergency power.

### Redundant Design

Similar to power loss, failure of a critical component can place overall building HVAC safety and security in jeopardy. Building designers should consider including redundant equipment in systems, such as air-handling units, blowers, or motors. Robust systems should include automatic control of these components, thus allowing for switchover from a failed component to the back-up immediately and automatically. If redundant systems cannot be installed, the owner should consider stocking critical or hard-to-find components in the facility so failed components can be replaced quickly in case of a failure.

## System Shutdown and/or Isolation

Rapid shutdown and/or isolation of air-handling units, including outdoor air intakes, can prevent or limit intake of contaminants into the air distribution system and thus decrease the potential spread of these agents. Many facilities use digital controls networks that readily allow the addition of a shutoff actuator button. For manual initiation, these buttons should be located in one or more areas regularly accessible by building occupants or normally staffed locations (e.g., security guard stations, central lobbies, reception desks) and treated in a manner similar to fire alarm activation stations. Automatic initiation methods using external detectors may be used, but the rate of false positives and negatives, capabilities of existing detection technology, and overall reaction time should be considered. On activation, the system should initiate rapid closure of air distribution dampers and rampdown of equipment to prevent movement of air through areas of the building. In these cases, consider using a spring-shut damper, although precautions such as bypass or relief duct systems should be taken in case of potential system damage by these closures.

## Protective Equipment

Many facilities have begun to distribute **personal protective equipment (PPE)** to facility occupants. This equipment, including escape hoods and respirators, may be issued to building staff as well as being placed in centrally available locations for occupant and visitor use. Equipment is generally intended for single-time use to allow occupants to safely evacuate the building during an event. Several manufacturers can provide this equipment, with varying levels of protection, shelf life, and recertification requirements. The designer should consider the overall burden to the building when providing PPE to occupants, including capital costs, training, shelf life, and life-cycle costs for the equipment.

## 100% Outdoor Air Operation

Normal air-handling systems using returns present an issue for internal release scenarios, because these returns can carry contaminants from the release point in its zone and redistribute throughout the HVAC systems, possibly contaminating the entire building. Designing air-handling systems that use 100% outdoor air is a good alternative to prevent this type of distribution, and limits the spread of contaminants in a space. Although 100% outdoor air systems can present a significant cost and energy burden, this may be offset by the added capability for occupant protection. Typically, this approach is suitable for small buildings or sections of a building. Alternatively, the designer may consider using local terminal units with integrated fans to provide local recirculation and meet space heating or cooling demands, thus reducing the outdoor air required to each unit.

## HVAC Zoning

Using multiple HVAC zones in a building allows localized control of the air movement equipment, and can limit the transport mechanisms for contaminant spread. Each zone, especially when enclosed with walls or partitions, can contain airborne contaminants without widespread movement to adjacent spaces. HVAC zoning can provide occupants with enhanced control over the systems in their spaces and can also help limit the spread of airborne diseases such as influenza.

## Increased Standoff Distances

Close proximity to publicly accessible areas increases the risk of an external event having catastrophic consequences for a facility. The presence of a buffer with controlled or limited access can significantly lessen the effect of an airborne contaminant release or blast. This standoff area must have limited access to the general public and should limit vehicular traffic to emergency access, deliveries, and facility maintenance. Increased standoff distances also provide additional area for emergency first responders during or after an event. Although these buffer areas present an additional cost associated with capital investment, they also provide occupants with aesthetic benefits, including additional green space.

## Occupant Notification Systems

The moments immediately before, during, and after an event can be confusing for building staff and occupants, especially if some occupants panic and do not fully understand what actions should be taken. Most buildings include some type of notification system that can be used to communicate to occupants in critical situations. Systems include loudspeakers, alarm horns and strobes, automated telephone alerts, or computer notification systems; at minimum, many buildings can implement mass e-mail notification or designation of certain personnel to serve as runners with little or no cost. Building managers may consider providing emergency action information cards for all occupants to keep in their work spaces, to refer to during an emergency.

## Air Intake Protection

For new buildings and HVAC systems, fresh-air intakes should be elevated to help prevent malicious acts (e.g., inserting a hazardous material directly into the intake) and minimize the concentration of hazardous materials during a ground-level release. Intakes should be placed at the highest practical level on the building, at least 3 m above grade. Most ground-level releases near the building will remain close to ground level, and the concentration of hazardous material in the air decreases with increasing height. Existing fresh-air intakes close to ground level can be modified to prevent physical tampering by placing fencing or barriers or building a plenum around the intake to limit potential intake of contaminants. Physical access to system intakes should be limited, and security cameras focused on intake areas may be considered. To prevent direct tampering of intakes, a sloped screen should be installed at the top of the intake to prevent direct insertion of any hazardous substance or container.

## Increased Prefiltration Efficiency

A relatively simple and cost-effective protective measure that can be undertaken in most every facility is upgrading existing prefilters to a higher-efficiency model. An increase in prefiltration efficiency can prevent the intake of a significant fraction of external airborne material, including biological and radiological particles; a related benefit includes the reduction of airborne allergens entering a building, thus resulting in a potential decrease in worker health issues and absenteeism. Typically, increased efficiency prefilters present a relatively minimal cost increase as compared to standard prefilters, and require no system modifications or additional maintenance.

## Additional Filtration

As with increased prefiltration, adding additional filtration can reduce or eliminate airborne threats entering a building. Multiple options and levels of efficiency are available, ranging from cost-efficient low-efficiency models to military-grade filtration. Full-time filtration provides occupants with protection without the requirement for advance notification; however, part-time or standby systems can be effective if advance warning or detection is available. The current standard used in government, military, and private-sector buildings includes high-efficiency air filtration (HEPA) filters for biological and radiological threats, and activated and impregnated carbon filters for chemical threats. These filtration measures present significant capital and sustainment costs, which may make these systems unaffordable for lower-cost, noncritical buildings.

## Location of Mechanical Equipment

When designers develop plans for building mechanical systems, one of the main considerations is system accessibility for regular maintenance and replacement. However, in some cases, the placement of mechanical systems may present security risks. Mechanical and electrical rooms should be placed in secure areas of the building that are not accessible to the general building population, and should be located away from any potential hazards such as flood areas, hazardous materials storage, loading docks, central lobbies, and areas that may be vulnerable to vehicle impact. Where possible, mechanical spaces should be accessible by maintenance personnel from within the facility to allow repair during an event.

## Physical Security Measures

Many physical security measures can be applied to HVAC systems and overall building protection that may prevent the release of a hazardous material or contaminants. Security screening at entry points can help detect containers that may contain hazardous materials. This screening may include x-ray scanning, metal detectors, or manual searching of personal belongings such as briefcases and handbags. Rooftop access should be restricted to authorized personnel, because mechanical equipment, exhaust stacks, and ducting may allow introduction of contaminants. Rooftop entries and exits should be monitored and controlled by the building security system.

## Air Supply Quantities and Pressure Gradients

Many contaminant releases depend on air movement to move contaminants throughout the building. Small differential pressures between spaces, often less than 25 Pa, can influence this transport. These gradients may be effectively used to limit the spread of airborne contaminants between offices, corridors, and common areas. HVAC designers may consider providing a small excess of air to selected areas to effectively overpressurize these spaces with respect to adjacent spaces. This is of particular importance in systems where the HVAC system includes filtration equipment, allowing the protected space to be maintained at an overpressure with clean filtered air.

### Sensors

Detection and early warning of a threat are extremely important to building protection. With rapid notification, building staff can implement measures to protect against the threat, including initiating sheltering in place or evacuation. However, implementing a robust detection system can pose many challenges. Technology is being developed in both the government/military and commercial sectors, but these new devices still have limitations. Currently, although many products exist for point and standoff detection, some of these methods still place a significant burden on the building staff, such as laboratory-scale analysis for confirmation and specially trained personnel. In all cases, designers should consider the sustainment cost and relative frequency of false positives/negatives when specifying detection equipment.

### Mailroom and Lobby Measures

The mailroom and central lobbies of buildings are highly vulnerable areas: they act as building interfaces with the general public. In most buildings, these are areas where uncleared personnel or packages come in proximate contact with the facility and where threats can cause the greatest harm. These areas should be given special consideration and additional protective measures to ensure all threats are minimized.

In entry areas, many buildings have mandatory security access procedures for regular building occupants as well as visitors. Security measures such as magnetometers, x-ray scanners, and personnel screening may be used to limit potential hazards from entering the building. Designers should consider using segregated HVAC systems in lobby areas with dedicated air-handling units (AHUs) for the lobby area, and maintaining the lobby spaces at a negative differential pressure with respect to interior spaces. Lobby windows and doors should include blast-resistant glazing and construction, and walls between the lobby and general building interior may include enhanced blast resistance ratings. Security or reception personnel should have controls in their work areas to allow rapid lockdown of all building entries and exits.

The anthrax mailings of 2001 highlighted the vulnerability of buildings to attack by mailborne threats. The U.S. Postal Service and package delivery companies have since implemented enhanced security, but building owners may consider additional measures. Mailrooms and package-receiving areas should include the measures described for lobbies, especially segregated HVAC systems that maintain these areas at a negative pressure compared to the rest of the building. Some facilities have enhanced mail- and package-screening procedures, including separate mail-handling facilities, x-ray or metal detection scans, individual parcel opening and screening, and laboratory analysis of packages. At minimum, mailroom staff should review incoming mail and immediately notify law enforcement of any suspicious letters and packages, such as those with exposed wires, irregular shapes or weights, misaddressed labels, or unexpected senders or locations.

## 3.3 COMMISSIONING AND RECOMMISSIONING

To ensure equipment and system performance per the BOD, HVAC resilience and security measures should be commissioned following ASHRAE *Guideline* 29’s recommendations. Recommissioning after a set number of years, or designing the BAS to provide continuous commissioning, is also recommended. The following ASHRAE commissioning guidelines should be considered when incorporating HVAC safety and security into the project’s BOD and OPR:

- ASHRAE Guideline 0-2019 -- *The Commissioning Process*
- *Standard* 202-2018, Commissioning Process for Buildings and Systems
- *Guideline* 0.2-2015, Commissioning Process for Existing Systems and Assemblies

## 3.4 MAINTENANCE MANAGEMENT AND BUILDING AUTOMATION

Because of the nature of HVAC resilience and security, operation is a critical requirement as it pertains to reliability and repeatability. Similar to how emergency generators are operated once a week, once a month, and fully loaded annually, HVAC resilience and security systems need to be operated on a scheduled basis to ensure the equipment will respond in an emergency situation. Operation of the building automation system is an integral part of this routine exercising of the HVAC systems.

Proactive maintenance management also contributes to system performance and reliability. Modern facilities most likely have computerized maintenance management software (CMMS) system to manage the maintenance process and documentation of this process. It is important to emphasize the value of documentation management; the design engineer should account for this in the design phase, specifying in the operation and maintenance requirements that the CMMS system will be populated and the work orders formatted and ready to be used before project closeout. These requirements should complement the CMMS database criteria so that project closeout documents are electronic and compatible with the CMMS system. Predictive maintenance should also be incorporated into the engineered systems in sync with the continuous commissioning design, operation, and reporting.

Building automation plays an important role in maintenance management, as well as day-to-day HVAC operation. Take care to limit access to these building systems so the sequences of operation are not compromised in an emergency or incident. Building systems may be disrupted by action from within the building or from an outside actor (e.g., via the Internet).

# 4. CHEMICAL INCIDENTS

A chemical incident is defined as the accidental or intentional release of a gaseous or vaporous compound into breathable air. Releases of toxic liquids, solids, or powders are not addressed in this chapter. A release may occur inside or outside a building, and may be of short duration (e.g., from a broken container, an accidental valve opening, or a terrorist incident) or sustained (e.g., from a leaking storage tank or broken supply line). Descriptions of classes of and individual air contaminants, including chemicals, are found in Chapter 11 of the 2021 *ASHRAE Handbook—Fundamentals*, and removal techniques are covered in Chapter 30 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* and Chapter 47 of this volume. Discussions in this chapter are limited to chemicals that are considered acutely toxic or corrosive, and present immediate danger to building occupants or systems.

Industrial buildings, where harmful chemicals may be used routinely, are likely at higher risk for internal chemical incidents than a typical commercial building, but, because of training, established procedures, and experienced personnel, they are also likely to be more prepared to handle an incident. Most commercial buildings, except for some government and high-profile buildings, do not have procedures in place for handling a chemical incident. A terrorist chemical event in a typical commercial building adds new difficulties, because details of the release are not known until long after the incident, and affected buildings and occupants are generally caught off guard, with little or no procedure in place for handling the event.

Chemical substances that can cause physical distress when introduced into breathable air are numerous; this chapter addresses only gaseous or vaporous compounds, and of those, addresses only two groups (1) those specifically known as chemical agents (in terms of warfare/terrorist activities) that might be intentionally introduced into a building's environment, and (2) a few common industrial gaseous substances that might accidentally be introduced into a building HVAC system through external or internal release, thus requiring HVAC or facility remediation of some kind. The purpose of this section is to address buildings that have no expectation of an accidental chemical release, based on the activities performed within the facility, as opposed to those of surrounding, related facilities (e.g., industrial facilities that have their own response plans). For control of airborne gases and vapors that are used as part of the building's normal operation, such as in laboratories or industrial processes, see Chapter 30 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment* and any of the application-specific chapters in this volume.

# 4.1 TYPES OF CHEMICAL AGENTS

Intentional contamination of facilities and their HVAC systems (and thus very ready dispersion to occupants) with gaseous or vaporous chemical substances has become a real concern. Chemical agents are classified by the U.S. Army (2005) as either toxic or incapacitating. Toxic chemical agents include nerve, blister, lung-damaging, and blood agents. Any of these agents may be introduced in sufficient quantity so as to injure building occupants and, in the process, compromise the building's HVAC system. Irritating agents (e.g., tear gas), which cause temporary trauma through reflexive action but are not generally lethal, are not considered by the U.S. military to be chemical agents.

### Incapacitating Agents

Incapacitating agents are defined by the U.S. DOD as chemical agents that produce temporary physiological or mental effects, or both, that make individuals unable to make a concerted effort to perform their assigned duties. In occupational medicine, *incapacitation* generally means *disability*, and denotes the inability to perform a task because of a quantifiable physical or mental impairment. Thus, by definition, any of the chemical warfare agents may incapacitate a victim; however, by the military definition, incapacitation refers to impairments that are temporary and nonlethal, and does not include low-dose "lethal" agents. Incapacitating agents may cause symptoms that persist for hours to days, but are temporary and recoverable even without treatment. Incapacitating agents can be classified as either central nervous system (CNS) depressants or stimulants.

**CNS depressants** are compounds that depress or block activity of the CNS by inhibiting the transfer of information across synapses. Common CNS depressants include

- 3-quinuclidinyl benzilate (BZ)
- Cannabinols
- Phenothiazines

- Fentanyls
- Hypnotics

**CNS stimulants** cause excessive nervous activity by facilitating transmission of impulses across certain synapses that may otherwise be insufficient pathways. The brain becomes flooded with information, making concentration and decision making difficult. The most common CNS stimulant is d-lysergic acid diethyl amide (LSD).

Symptoms of poisoning by these agents include confusion, disorientation, restlessness, dizziness, staggering, or vomiting. Some may cause dryness of mouth, elevated temperature, pupil dilation, slurred/nonsensical speech, inappropriate behavior, and hallucinations. If several personnel exhibit any such behavior, it is prudent to move outside the building, because these agents are usually delivered by smoke-producing munitions or aerosols and are introduced through the respiratory system.

## Irritants

Irritants can be classified as either tear-producing or vomiting-producing agents. The sole purpose of irritants, which include tear gas, riot control agents, and lachrimators, is to produce immediate discomfort and eye closure, thus rendering the victim incapable of fighting or resisting. Irritants cause eye discomfort, and some may cause vomiting; all are usually introduced to an environment as a gas. Police forces use irritants for crowd control. Irritants were used before World War I, and, during the war, they were the first chemical agents used, well before better-known agents such as chlorine, phosgene, and mustard gas.

Tear gas (CS) and chloroacetophenone (CN; sold in diluted form as a protective spray) are by far the most important pulmonary irritants. Capsaicin (methyl vanillyl nonenamide) is the active ingredient in pepper spray, also called OC (oleoresin capsicum). Pepper spray has, to some extent, replaced CN as a personal protective agent, with less dangerous effects. As its common name implies, the active ingredient is the burning agent in pepper plant fruits.

Although CS and CN are the most important agents in this class, several others require mention. Chloropicrin (PS) and bromobenzenecyanide (CA) were developed before World War I. Both largely have been replaced, because they were too lethal for their intended effects but not lethal enough to compete with the more effective blistering and nerve agents. PS still is used occasionally as a soil sterilant or grain disinfectant.

## Toxic Chemical Agents

**Nerve Agents.** Nerve agents are organophosphate ester derivatives of phosphoric acid, and are among the deadliest of rapid-onset chemical agents. Nerve agents can be divided into G and V agents. **G agents** are fluorine- or cyanide-containing organophosphates. These agents are colorless and have an odor that ranges from weakly “fruity” to odorless. In an unmodified state, G agents are highly volatile, resulting in low persistency. However, they can be combined with various thickening substances, increasing persistency and penetration of intact skin. The primary hazard of G agents is vapor contact because of their high volatilities.

**V agents** are sulfur-containing organophosphates. These agents are low-volatile oily liquids, resulting in increased persistency. The increased persistency makes V agents primarily a contact hazard.

Common nerve agents include

- VX
- Tabun (GA)
- Sarin (GB)
- Soman (GD)
- Cyclosarin (GF)

Both G and V agents are potent inhibitors of the enzyme acetlycholinesterase (AChE) and present the same symptoms after exposure. Inhibiting AChE allows acetylcholine to accumulate, which mimics a massive release of acetylcholine in the nervous system. Nerve agents may be absorbed through any body surface (skin, eyes, respiratory) or ingested. Symptoms of nerve agent poisoning include

- Sweating and/or muscular twitching
- Pupil contraction, eye pain, or blurred vision
- Headache, pain
- Weakness

- Nausea, vomiting (particularly in ingestion)
- Mucous secretions in respiratory pathways, nose, or throat
- Wheezing, coughing
- Severe exposure: convulsions; vomiting; red, pinpoint eyes; unconsciousness; or respiratory failure

Mild exposure to nerve agents may cause anxiety, restlessness, and giddiness. Further exposure results in the listed symptoms and/or memory impairment, slowed reactions, or difficulty in concentration. Moderate exposure, if diagnosed and monitored, shows abnormalities in electroencephalograms (EEGs) as well as the symptoms listed. Reactions to nerve agents are immediate (i.e., within minutes of exposure). Recovery from nerve agent exposure is slow, usually days, and susceptibility to the agent is increased for months afterward.

Nerve agents are liquid at room temperature, but their volatilities can vary. Highly volatile agents (G agents) can be easily introduced as vapors into HVAC systems, whereas low-volatility agents (V and thickened G agents) can be introduced as droplets or vapors by mechanical means. Highly volatile agents are less persistent and require less intense cleanup than naturally persistent, highly volatile agents, which require intense cleanup if introduced into a building. For the most part, these agents are moderately soluble in water and highly soluble in lipids. They are rapidly inactivated by strong alkalis and chlorinating compounds, which are used in the decontamination/neutralization of these agents.

If nerve agents are suspected, evacuate the facility immediately. Because many nerve agents are (or can be made) persistent and dose is accumulative, evacuation is necessary. A facility must be decontaminated if exposed to nerve agents.

**Blister Agents.** Blister agents (vesicants) can be classified as mustards, arsenicals, and urticants. These agents are generally used as warfare agents meant to degrade fighting efficiency rather than to kill. They are usually thickened to make them persistent and contaminate surfaces, but may be introduced as a gas or vapor. Vesicants result in burns and blisters to the skin, eyes, and/or respiratory tract.

**Mustard agents** contain either sulfur or nitrogen and are persistent in cold and temperate conditions. They can be combined with other substances to thicken the agent, increasing their persistency. Warmer temperatures decrease persistency, but concentrations in air can be high because of the greater evaporation rate. Common mustard agents include

- Sulfur mustard (H and HD)
- Nitrogen mustards (HN)

**Arsenical agents** contain a central arsenic atom. These agents hydrolyze rapidly with water and lose most of their vesicant properties. Arsenicals are more volatile than mustards and are less toxic than other blister agents. Common arsenical agents include

- Lewisite (L)
- Mustard-lewisite (HL)
- Phenyldichloroarsine (PD)

**Urticants** are halogenated oximes and have a disagreeable, penetrating odor. The most recognized urticant is phosgene oxime (CX), which is one of the most irritating substances known.

The most likely routes of exposure are inhalation, dermal contact, and ocular contact. Depending on the particular vesicant, clinical effects may occur immediately (as with phosgene oxime or lewisite) or may be delayed for 2 to 24 h (as with mustards). Blister agents must be cleaned from the skin and membranes immediately to lessen their effects. Persons exposed to blister agents must be handled so as not contaminate those helping them. Evacuation is necessary, and contaminated people should be kept outdoors to prevent accumulation of the vesicant in a confined space. Effects of exposure include

- Mild to severe conjunctivitis, possibly progressing to ulceration
- Lesions on skin; burns
- Itching
- Pain (immediate with exposure to lewisite)
- Respiratory damage (in small doses may take time to appear as bronchitis, etc.)

Vesicants are, for the most part, soluble in nonaqueous solvents, not in water. They are more dangerous as liquids, because the degree to which they cause health problems is related to their concentration on body surfaces. In general, they have high vapor pressures and thus are easily vaporized in a confined space. Decontamination of exposed surfaces is needed.

**Lung-Damaging Agents.** Lung-damaging (choking) agents are those that primarily attack lung tissue, causing pulmonary edema. Examples include

- Phosgene (CG)
- Diphosgene (DP)
- Chlorine
- Chloropicrin (PS)

As choking agents, most of these agents (except for diphosgene) exist as gases at room temperature and pressure, and are thus easily spread through ventilation systems. Exposure symptoms include

- Choking sensations, coughing
- Tightness in chest
- Nausea, vomiting
- Headache

Because these agents are gaseous, they will disperse. They all have specific odors; for example, CG smells like fresh-mown hay. Thorough ventilation of contaminated areas is necessary. Choking agent gases typically are heavier than air, and thus tend to accumulate in low-lying areas.

**Blood Agents.** Blood agents, also known as cyanogens, interfere with the absorption and use of oxygen at the cellular level, and thus are usually introduced through the respiratory system. Examples include hydrogen cyanide (AC) and cyanogen chloride (CK). These agents are highly volatile and gaseous at temperatures over 21°C and are nonpersistent even at low temperatures. They therefore dissipate quickly in air, especially hydrogen cyanide, which is light; cyanogen chloride is heavier than air and tends to collect in low places. These two blood agents have different symptoms. Symptoms of exposure to AC include

- Faint odor of almonds
- Internal hemorrhaging
- Pink skin color
- Highly toxic, high concentrations can cause immediate death

CK symptoms include

- Intense irritation to the lungs and eyes
- Coughing
- Tightness in chest
- Dizziness
- Unconsciousness
- Respiratory failure

Because these agents are not persistent, thorough ventilation should dissipate the gases.

**Other HVAC-Compromising Gases and Vapors**

**Table 1 Corrosive Gases and Vapors**

| Corrosive Gases | Corrosive Acidic Vapors | Corrosive Basic Vapors |
|---|---|---|
| Hydrogen cyanide | Hydrochloric acid | Sodium hydroxide |
| Ammonia | Sulfuric acid | Ammonium hydroxide |
| Sulfur dioxide | Nitric acid | Caustic soda |

| | | |
|---|---|---|
| Chlorine | Hydrofluoric acid | Potassium hydroxide |
| Hydrogen bromide | Acetic acid | Other hydroxides |
| Boron trichloride | Other acids | |
| Monomethylamine | | |
| Phosphorus pentafluoride | | |

Accidental contamination of facility HVAC systems by gaseous or vaporous chemical substances has been a real concern for years, mainly because of the extensive production, use, and transport of large quantities of hazardous materials for manufacturing purposes. Intentional contamination of a facility could be accomplished with chemicals other than the specific chemical agents discussed previously. Contamination inside a building should result in immediate evacuation. However, external contamination might entail evacuation to a more distant location or shelter in place (i.e., not evacuating). Contamination from an incident in the immediate vicinity of (but external to) a facility might require shutdown of the facility's HVAC system for a short period of time. For instance, a large corrosive spill nearby might necessitate staying in a building for protection while transportation is arranged (if not available immediately). This might occur at a school where children would be more susceptible to injury upon exiting the building, having no way to evacuate a safe distance. Because the situations and possibilities are so varied, this discussion is limited to more typical scenarios.

**Toxic Gases.** The most common toxic gas that might threaten a facility and its personnel is carbon monoxide (CO), which is colorless, odorless, and tasteless. Carbon monoxide is produced by incomplete combustion of fossil fuels (gas, oil, coal, wood) used in boilers, engines, oil burners, gas fires, water heaters, solid-fuel appliances, and open fires. Dangerous amounts of CO can accumulate when, as a result of poor installation, poor maintenance, or failure, an appliance's fuel is not burned properly, or when rooms are poorly ventilated and the carbon monoxide is unable to escape. Because CO has no smell, taste, or color, it is important to have good ventilation, maintain all appliances regularly, and have reliable detector alarms installed to give both a visual and audible warning in case of a dangerous build-up of CO. Scenarios involving toxic gases usually entail evacuation to a safe distance. HVAC systems normally require cleaning using clean purge air the through the ventilation distribution system.

**Corrosive Substances.** Corrosive gases and vapors encompass a large class of materials. A few are purely gaseous in nature at room conditions, but some vapors result from the vapor pressure created by a liquid (or solid) presence. Some examples of corrosive gases and vapors are given in Table 1.

Corrosive gases and vapors are hazardous to all parts of the body, although some organs (e.g., eyes, respiratory tract) are particularly sensitive. The magnitude of the effect is related to the solubility of the material in body fluids. Highly soluble gases (e.g., ammonia, hydrogen chloride) cause severe nose and throat irritation, whereas lower-solubility substances (e.g., nitrogen dioxide, phosgene, sulfur dioxide) can penetrate deep into the lungs. Exposed skin may also be at risk for irritation or burns at higher concentrations or longer-term exposures. For some substances, warnings such as odor or eye, nose, or respiratory tract irritation may be inadequate. Accidents involving corrosive substances inside or outside a building require cleanup and decontamination of the facility's HVAC system and other equipment, because of the substances' persistence. In some cases, physical damage to a building's infrastructure may result from exposure to corrosives (e.g., etching of metal surfaces, which can lead to holes in ducting and compromised wiring). Building codes outline methods of design and installation for mechanical and electrical systems in corrosive environments (NFPA *Standard* 70), but in buildings that are not classified as such, and thus are not constructed accordingly, systems may be damaged when exposed to corrosive chemicals. In such a case, the building and its systems should be thoroughly inspected and tested before reoccupation.

# 5. BIOLOGICAL INCIDENTS

Biological incidents involve the intentional or accidental release of unwanted bioaerosols and/or biocontaminants in or around a building, such that the building's integrity or usefulness is compromised. Bioaerosols are airborne particulates derived from living organisms and include living microorganisms, viruses, spores, and toxins derived from remnants or fragments of living tissue. Bioaerosols are in the air, both indoors and outdoors, and their presence mostly goes unnoticed except for seasonal allergies or an occasional cold. There is an evolved balance between the types and levels of bioaerosols in the ambient air and the animals breathing that air. That balance can be disturbed locally by the purposeful or accidental release of a bioaerosol in or around a building. Unfortunately, bioaerosols are difficult to detect and identify in real time, because identification generally involves DNA analysis or other skilled analytical techniques. As a consequence, bioaerosols may be fully distributed in a building hours or days before anything is detected, much less identified, and the first sign of an incident may be symptoms of personnel.

There are hundreds of known bioaerosols that are pathogenic to humans to varying degrees. These include the spore-forming bacteria *Bacillus anthracis* (commonly known as anthrax), *Variola* spp. (the virus that causes smallpox), the bacteria *Yersinia pestis* (cause of bubonic plague), and many others. Human susceptibility varies by microorganism, and is gaged by several dose measures:

- **$ID_{50}$, mean infectious dose**, is the number of microorganisms or bioaerosol particles that causes 50% of an exposed population to be infected.

- **$LD_{50}$, mean lethal dose**, is the number of microorganisms or bioaerosol particles that causes death in 50% of an exposed population.

One of the greatest threats in a biological incident or attack is toxins, which are poisonous chemicals produced by living organisms and that may have effects resembling those of chemical agents. Toxicity and lethality of toxins vary, but highly toxic, stable toxins pose a risk for weaponization. Two classifications of potentially threatening toxins are neuro- and cytotoxins. **Neurotoxins** interfere with nerve impulse transmission and have significant effects on the nervous system. However, they can work in different manners, inhibiting or stimulating various enzymes and blocking various receptors. Effects are similar to those of chemical nerve agents, and include convulsions or paralysis, blurred vision, seizures, and muscle fatigue. **Cytotoxins** disrupt or destroy cells and cellular processes such as protein synthesis and other biochemical process. Symptoms may be similar to those of chemical blister, choking, and vomiting agents, as well as nausea, diarrhea, rashes, inflammation, and necrosis. Toxins can be produced by a variety of organisms such as bacteria, fungi, mold, algae, plants, and animals.

A summary of potential bioaerosol weapon agents is given in Table 2 along with $ID_{50}$ and $LD_{50}$ values. A more comprehensive list can be found in Kowalski (2003). More detailed descriptions of bioaerosols, their health effects, and methods of measurement can be found in most epidemiology texts. *Bioaerosols: Assessment and Control*, from the American Conference of Governmental Industrial Hygienists (ACGIH 1999), is a recommended starting point for quantitative determination of bioaerosol levels. General information on bioaerosols, their health effects, and their removal from building airstreams is found in Chapters 10 and 11 of the 2021 *ASHRAE Handbook—Fundamentals*, as well as Chapter 29 of the 2020 *ASHRAE Handbook—HVAC Systems and Equipment*.

**Table 2 Limited List of Human Pathogenic Microorganisms**

| Bioaerosol | Incubation Period, Days | $ID_{50}$, Organisms | $LD_{50}$, Organisms |
|---|---|---|---|
| *Bacillus anthracis* (anthrax) | 2 to 3 | 10 000 | 28 000 |
| *Ebolavirus* spp. (Ebola) | 14 to 21 | 10 | Low |
| *Francisella tularensis* (tularemia) | 1 to 14 | 10 | Low |
| *Hantavirus* (Hanta) | 14 to 30 | N/A | N/A |
| *Variola* spp. (smallpox) | 12 | N/A | N/A |
| *Yersinia pestis* (bubonic plague) | 2 to 6 | N/A | N/A |

The primary threat to buildings from airborne biological incidents is adverse health effects to building occupants. Once an event happens, there is an immediate danger to building occupants from the initial dose, but there is also the risk of prolonged exposure from contaminated surfaces and reaerosolization of the agent. Depending on the agent, the prolonged exposure risk may dissipate quickly if the pathogenic organism has a short life outside a host, or it may remain indefinitely until the contaminating agent is fully removed. Anthrax, which is a spore-forming bacterium, falls into this latter category because it can lie dormant in many environments for long periods of time, only to come out of dormancy when exposed to a proper host. Excluding incidents of extreme mold growth (which is not covered in this chapter; see, e.g., ASHRAE [2003b] for information), biological incidents present no real threat to the integrity of building equipment; however, building equipment may play an important role in both distribution and possible removal of air contaminants. Remediation after an incident is likely to involve comprehensive cleaning of building equipment (particularly air-handling equipment), and may require removal and replacement of contaminated systems. Techniques for remediating contaminated equipment include surface cleaning with bleach or alcohol solutions, treatment with ultraviolet (UV) light, and volume gaseous treatments with ozone, hydrogen peroxide, or gas plasma. New technologies and procedures are under development, particularly since the anthrax events of 2001 in the United States. See the Bibliography and Online Resources for sources of information on the latest developments in remediation technology.

It is important to determine as much as possible about a release, whether purposeful or accidental, as rapidly as possible. It may be more difficult to completely assess the nature of a purposeful release, because it may contain more than one pathogenic agent, with different incubation periods, and the release may have taken place in several locations. Accidental releases are more likely to be a single pathogen at a single location, and the release is more likely to have been known to occur.

Biological pathogens have been weaponized to enable delivery in a variety of forms. Effective delivery of bioagents to a large population is difficult because of the need to get relatively large doses to large numbers of people. Dilution of contaminants in ambient air is rapid, and very large numbers of organisms are required to produce lethal concentrations. The confines of a building and controlled air exchanges rates can help maintain concentrations of agents for longer periods of time than would occur in outdoor air. However, filtration and real-time killing mechanisms in building air-handling systems can remove or render ineffective airborne bioaerosols. Engineering requirements for design of filtration or other techniques for treating indoor air are addressed more fully in other publications (e.g., NIOSH [2003]). Information is rapidly evolving; for the latest, consult the most recent versions of publications on building protection.

# 6. RADIOLOGICAL INCIDENTS

The occurrence of a significant accidental or intentional radiological release to the environment is of low probability because there are limited locations where considerable amounts of radiological material reside. These sources include spent fuel or low-level radioactive waste (radwaste) storage facilities, nuclear generating stations, and weapons fabrication and storage facilities. These facilities are usually analyzed beforehand, as part of the construction licensing process, for postulated accidental releases of radiological material and the consequences to both on- and off-site personnel.

An intentional release of radiological material is most likely to be in the form of the deployment of a nuclear weapon or a **radiological dispersal device (RDD)**, sometimes called a **dirty bomb**. It is normally assumed that a terrorist group is highly unlikely to possess and use conventional, sophisticated nuclear weapons because of the difficulties of obtaining or independently developing the necessary materials and technology. Development and deployment of an RDD, however, is considered viable because of its simplicity of design. RDDs combine conventional explosives and radioactive material, and are designed to scatter dangerous amounts of radioactive material over a general area. Terrorist use of RDDs also seems more likely because radiological materials used in medicine, agriculture, industry, and research are comparatively more obtainable than weapons-grade uranium or plutonium. A significant amount of the damage from an RDD would be from the initial blast. See the section on Explosive Incidents for design of HVAC system protection against blast effects.

## 6.1 RADIOACTIVE MATERIALS' EFFECTS AND SOURCES

Decay of radioactive materials produces energetic emissions (ionizing radiation) that can effect changes in human tissue cells. These energetic emissions are divided into **alpha** particles, **beta** particles, and **gamma/x-rays**. Alpha and beta radiation can only travel very short distances (about a metre, maximum) and do not have enough energy to penetrate the outer layers of human skin; they are, however, a hazard if directly inhaled or ingested. Gamma and x-rays can travel long distances in air and can pass through the body, potentially exposing internal organs to significant damage, depending on the amount absorbed. The radiation effect on humans is usually measured in sievert (Sv), the product of the absorbed dose and the biological efficiency of the radiation.

In developing an RDD, a significant quantity of radioactive material must first be collected. Some common radioactive materials currently used in industry include

- Colbalt-60 (Co-60), cesium-137 (Cs-137), and iridium-192 (Ir-192) are used in cancer therapy, industrial radiography and gages, food irradiation, oil well production, and medical implants. These are all considered gamma emitters.
- Strontium-90 (Sr-90) is used in the production of radioisotope thermoelectric generators (RTGs), which produce electricity for remote devices such as spacecraft. This is considered a beta emitter.
- Plutonium-238 (Pu-238) and americium-241 (Am-241) are used in oil well production, RTGs, and industrial gages. These are considered alpha emitters.

## 6.2 RADIOLOGICAL DISPERSION

Dispersion may be by conventional explosives, using aircraft to disperse the material in the form of an aerosol or particulate, or simply placing a container of radioactive material within a confined area or facility. In most cases, a dirty bomb or other RDD would have localized effects (based on the strength of material used) ranging from less than a city block to several square kilometres. The area affected by the dispersion of the material is a function of various factors, including

- Meteorological conditions, including atmospheric stability and wind speed
- Local topography, location of buildings, and other landscape characteristics
- Amount and type of radioactive material dispersed
- Dispersal mechanism (e.g., particulate, aerosol)
- Physical and chemical form of the radioactive material (e.g., dispersal as fine particles versus heavier droplets or particulate)

Radioactive material released as either an aerosol or fine particulate in a plume spreads roughly at the speed and direction of the prevailing wind velocity. The conditions of atmospheric stability (sometimes referred to in terms of the Pasquill stability classification) also determine the fallout's overall spread and concentration. Atmospheric dispersion computer models are sometimes used to predict the spread, location, and concentration of a postulated radioactive plume. These analytical tools can be useful in providing early warning to residences and facilities projected to be in the affected fallout path.

# 6.3 RADIATION MONITORING

Radioactivity cannot be seen, smelled, or tasted by humans. However, in the United States, there are many radiation-monitoring programs available at the federal, state, and local level that can measure radiation levels and/or track the released radiation plume. There may be a local facility (e.g., a nuclear power plant) that can track radiological fallout in the affected area. State-level officials have access to various monitoring programs for their areas. These programs use current weather patterns and wind velocities to track radiological plumes and provide public warning. Depending on the severity of the release, the radioactive plume may travel hundreds of kilometres or, more typically, be localized.

# 6.4 FACILITY RESPONSE

Physical safety of personnel should be of primary concern in responding to a radiological event. Time, distance, and shielding are the three most important aspects to minimizing the effects of human exposure to ionizing radiation. Shielding with stone, concrete, or other dense materials is usually not considered in the initial design of most commercial buildings. However, most facilities use these materials for structural strength (foundations and basements) or for fire protection in protective corridors and stairways. Consider developing procedures to instruct building occupants to immediately move to identified safe locations in the facility in the event of a known or suspected release. Limiting the time of exposure to a radiation field also helps reduce the total amount of exposure and subsequent health effects. Distance from the radiation source is the greatest factor in reducing the amount of direct (deep-dose) exposure, especially if the hazard is present for a considerable time period. The distance required to minimize this dose is usually small (little more than a metre).

Perhaps the greatest potential hazard from the release of low-level radiological debris from an RDD is inhalation or ingestion. Health effects from ingested contamination particles that enter the body from breathing, cuts/abrasions, eating, or drinking can be more severe than external exposure, depending on the amount of material consumed. Individuals should be instructed to move to more isolated rooms, or areas in the facility that may be isolated or filtered from significant inleakage of contaminated air. Distribution of personal protection equipment (PPE) should also be considered, depending on the risk assessment of a potential threat. If the release is determined to be internal, an organized evacuation should occur (consider developing evacuation procedures). Because evacuees may have become externally contaminated, an egress plan should be considered that includes a radiation detection monitoring procedure implemented either by internal personnel or by local emergency authorities. This procedure may include instruction to dispose of outer clothing and the use of showers to remove radioactive particles from body surfaces.

# 7. EXPLOSIVE INCIDENTS

Detonation of high explosives near a building generates pressures that act on all exposed surfaces. The magnitude of pressure depends on the size and shape of the charge, distance from the charge, and any intervening barriers. In addition to increased pressures, blasts may generate projectiles from either loose materials or fragments from damaged components. This section considers only loads that do not generate significant structural damage; it is assumed that, if the structure is severely damaged, continued operation of the HVAC systems is not crucial. Also, it is important to remember that life safety is the primary goal of all protective systems. This section deals strictly with HVAC equipment and systems, but any solutions must not compromise the safety of building occupants.

# 7.1 LOADING DESCRIPTION

Detonation of high explosives generates a pressure wave (blast wave) that propagates out from the explosion with decreasing velocity. The free-field blast wave, far from any surfaces, is characterized by a rapid, almost instantaneous increase in pressure, followed by a gradual decay in pressure and a negative-pressure phase. A typical free-field blast overpressure $P_{so}$, reaching the target at time $t_A$, is shown in Figure 3. When the blast wave impinges on a rigid surface, the pressure is reflected ($P_r$) and magnified over the free-field values. Peak pressure varies inversely with the cube of the distance from the explosion. Intervening barriers may reduce the blast load, but quantifying the effect is difficult, and great care must be taken when determining the resulting loads.

Internal explosions can generate extremely large loads on HVAC equipment. In addition to short-duration reflected pressures generated by the explosion, a quasi-static pressure may develop, greatly increasing the impulse to which the equipment is exposed. The magnitude and duration of quasi-static loading is a function of room volume and vented area.

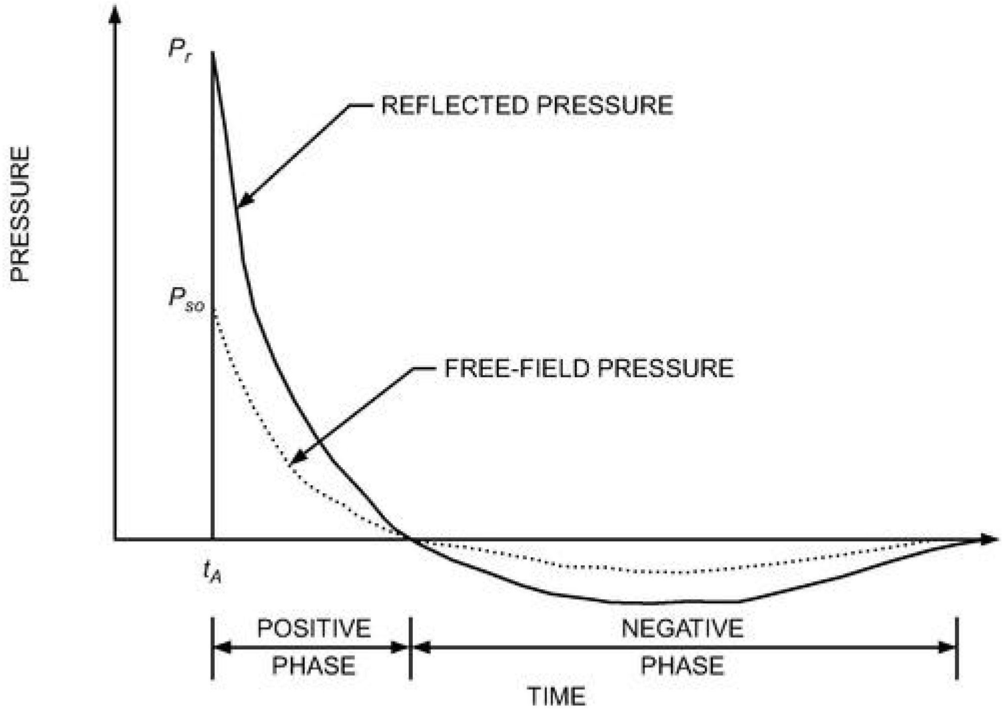


**Figure 3. Free-Field and Reflected Pressure Wave Pulses**

In addition to direct air blast, HVAC equipment in buildings subjected to explosions can experience large accelerations and relative displacements caused by the resulting structure motion. The structure responds to loads imposed both through the foundation (ground shock) and from the air blast (air shock). In general, accurately predicting the time history of motion in the building is extremely difficult. However, because structural design of equipment is based on peak loads, there is usually no need to determine the full time history. Methods are available for predicting the peak motion caused by a given event, including the frequency dependence of the response.

Blast loads can also enter the interior space of buildings through utility openings, even if the building shell is undamaged. The blast can damage the passageway itself, and can also build up pressure in the building and subsequently damage other equipment. Pressure build-up depends upon the opening area and volume of interior space, as well as the pressure differential.

Explosions can produce primary and secondary fragments that may damage equipment and piping. Primary fragments are generated from the explosive casing, whereas secondary fragments result from damage to the structure and nonstructural components (e.g., concrete spalling, glass breakage). Predictions of fragment size and velocity can be used to estimate damage to equipment, ducts, and piping.

## 7.2 DESIGN CONSIDERATIONS

The best protection from any explosive effects is to locate equipment in a nonvulnerable area. Assuming the exterior building shell is adequately designed, any interior room may be considered protected. Barrier walls can protect equipment that must be externally located, or equipment can be positioned far enough away from any possible blast location that pressures are reduced below damaging levels. In general, correctly locating equipment is the least expensive option for handling blast loads. Hardening equipment, anchorage, and connection should be considered only after relocation has been eliminated as a possibility.

In addition to the direct air blast, equipment in a building subject to a blast experiences a support shock loading. Guidelines for the maximum shock that can be withstood by various equipment types are given in Chapter 56. Although general information can be obtained from these tables, it is important to realize that the data are several decades old and may not apply to modern HVAC equipment. If the shock is greater than the equipment’s capacity, it may be possible to provide a shock isolation system to lower the demand. The isolation system works by decoupling horizontal motion of the support structure from that of the equipment. Note that this is different from typical equipment isolation applications, which are generally concerned with vertical vibrations of the equipment itself.

Although it has been stated that proper seismic design also protects against blast loads, this is not generally true. The effect of blast loading on equipment has some similarities to that of seismic loads, but there are some key differences. Both loads generate horizontal and vertical forces that act on equipment. However, in both magnitude and distribution, seismic forces are proportional to equipment mass, whereas blast loads are proportional to the equipment surface area. The effect is essentially the same for some types of equipment, such as pumps, where the mass and surface area distributions are approximately identical. However, equipment covered by a sheet metal shell is loaded very differently. Seismic loads are applied directly to the heavy components in the shell, whereas blast loads are applied to the shell itself, with little or no load acting directly on the interior components. Thus, even equipment that has been seismically rated or certified needs additional investigation for blast resistance.

In contrast, anchorage design is identical for blast and seismic loads. Properly designed seismic anchorage for most equipment in moderate to high seismic zones is adequate for reasonable levels of blast loading. In either case, loads applied to equipment are used to determine shear and uplift loads on the anchorage that are checked against the allowable load for the specific attachment hardware. Although in reality the dynamic reactions from the resulting equipment motion are the actual anchorage force, for nonisolated equipment it is usually conservative to assume a static distribution of the maximum applied loads. This is not always the case for isolated equipment, because resonance of the load, equipment, and isolation system may produce dynamic forces well above those predicted from a static analysis.

When designing HVAC systems for blast load, it is important to remember that there are two types of failure. The first is a temporary loss of service, such as might be caused by tripping a breaker. The second, more serious case involves actual damage to the equipment or system. It is important to determine which scenario is important for the system, and design accordingly. Preventing temporary outages is, in general, much more expensive than preventing a catastrophic failure.

Exposed piping and ductwork are also subject to both pressure and fragment loading. Pressure loading can be carried through proper selection and spacing of supports. The flexure and shear capacities of the pipe or duct, and the capacity of the support, determine the spacing. Fragment effects are more difficult to analyze, because the exact size and velocity of any fragments are impossible to predict. The only way to fully protect against fragments is to locate the pipe or duct where fragment impact is not possible.

Openings in the building for HVAC or other purposes must also be designed for blast effects. HVAC systems can be damaged by pressure propagated through the opening or blockage of the opening. Grilles or louvers can be analytically designed to resist the blast load, preventing blockage and allowing continued operation. Additionally, the pressure increase in ducts, and subsequently in interior rooms, can be calculated. Properly designed silencers may reduce pressure in ducts. Design of openings for blast resistance must also be closely coordinated with protection from chemical and biological agents.

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# ONLINE RESOURCES

U.S. Centers for Disease Control and Prevention: Emergency Preparedness and Response
See www.bt.cdc.gov.

U.S. Department of Homeland Security, Ready.Gov website
See www.ready.gov.

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