

ASHRAE Guide for HVAC in Hazardous Spaces

Michael K. Baucom



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Peachtree Corners

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Dedication

This guide is dedicated to the fond memory of Mr. Wayne Lawton, a fellow ASHRAE committee member, friend, and trusted mentor. May he rest in peace, assured that his adamant insights regarding the purpose and intention of this guide have been faithfully instilled.

This guide is also dedicated to the individuals who work at oil refineries and chemical manufacturing facilities and put their lives on the line every day to provide us all with the products and services we depend upon daily, in the hope that it can provide meaningful information and make their facilities safer places to work.

About the Author

Michael K. Baucom is currently the Executive Director of Bebco Environmental Controls Corporation in La Marque, Texas. He has been deeply involved in the design, manufacturing, and installation of control panels, modular industrial facility buildings, purging and pressurization systems for enclosures, and building HVAC and pressurization equipment for hazardous electrically classified areas for more than 40 years, beginning with an extended career at his father's company, Bebco Industries, Incorporated, in 1977.

Before joining ASHRAE in 2004, he was a member of the National Fire Protection Association (NFPA) Electrical Equipment in Chemical Atmospheres Committee for more than 15 years, and as a member of a special subcommittee he made significant contributions to the development of a more comprehensive version of NFPA 496 that was published in 1986.

Between 1985 and 1989, he toured the USA extensively from coast to coast, conducting on-site safety assessments, lectures, and educational training seminars regarding enclosure purging and building pressurization technologies.

Since joining ASHRAE, he has served extended terms as the webmaster and chair of Technical Committee (TC) 5.8, Industrial Ventilation, and TC 9.2, Industrial Air Conditioning. These TCs were recently merged, and he has continued as the webmaster for this new merged TC 9.2.

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Preface

This book is presented as an educational tool to guide designers, engineers, and technicians in regard to the proper design, engineering, installation, operation, and maintenance of safe and effective heating, ventilation, pressurization, dilution, filtration, and air-conditioning systems for hazardous spaces. As herein defined, such spaces are surrounded by or may contain various concentrations and mixtures of airborne contaminants and hazardous substances. This guide places particular emphasis on toxic chemicals, asphyxiants, flammable gases, and combustible dusts.

The guide presents various techniques and methods, as developed and refined over the current and past centuries by countless experts within specific fields of interest. It is written in a manner to ensure that the reader gains intuitive insight into the best possible means to ensure that a space is effectively ventilated and conditioned for various levels of occupancy while preserving all aspects of the safety and health of the occupants and protection of the surrounding facilities.

To this end, many well-suited standards and design guides developed by notable and highly qualified organizations and individuals are cited throughout this guide. These standards and guides provide the best possible resources of information to accomplish the essential goal of maintain-

ing safety as the highest priority in potentially hazardous working environments.

Protecting the health and safety of countless individuals depends on making proper and thoughtful decisions. Each decision regarding what types of equipment to design and install, how the equipment will operate, and how it is maintained incurs potential life-safety risks. Readers are therefore encouraged to take great care, carefully deliberate decisions, and consult with experts as necessary to minimize any potential life-safety risks when designing and installing HVAC systems in hazardous spaces.

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1

Introduction

This guide provides technical references, insights, and recommendations for professionals who design, engineer, install, operate, and maintain equipment necessary to ventilate and condition hazardous spaces while prioritizing the preservation of occupant health and safety and protecting the surrounding facilities.

The book recommends safe practices and equipment selection parameters associated with the design, installation, and operation of heating, ventilation, pressurization, dilution, filtration, and air-conditioning systems and related hardware serving hazardous spaces, which are spaces considered to contain known sources of airborne contaminants and toxic, flammable, or combustible substances. The emphasis in this guide is on spaces containing toxic chemicals, asphyxiants, flammable gases, and combustible dusts. The guidance in this book does not touch on radioactive or pathogenic substances.

This chapter includes definitions of the terms used throughout this book as well as a list of additional resources for designing, installing, operating, and maintaining HVAC systems in hazardous spaces.

DEFINITIONS

adequate ventilation: as defined by API RP-505, “Ventilation (natural or artificial) that is sufficient to prevent the accumulation of significant

quantities of vapor-air or gas-air mixtures in concentrations above 25 percent of their lower flammable (explosive) limit, LFL (LEL)” (2018, p. 8).

asphyxiant: substance that by the nature of its chemical composition can displace breathable air and/or oxygen within a space to a level of being fatal to occupants.

atmospheric pressure: the force exerted by the weight of the atmosphere on a given area; measured in units of inches of water column (in. WC), pascals (Pa), or millimeters of mercury (mmHg or torr). Normal atmospheric pressure is 14.7 psi, 101 (kPa), or 760 mmHg (or torr).

authority having jurisdiction (AHJ): as defined by the *National Electrical Code (NEC)*, “an organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure” (NFPA 2014, p. 27).

blast damper: device that protects occupants and equipment of a structure against overpressures that can occur as a result of an external explosion; typically installed in air inlets and exhaust penetrations of an otherwise hardened structure.

combustible dust: as defined by the *NEC*, “dust particles that are 500 microns or smaller (material passing a U.S. No. 35 Standard Sieve as defined in ASTM E 11-09, *Standard Specification for Wire Cloth and Sieves for Testing Purposes*) and present a fire or explosion hazard when dispersed and ignited in air” (NFPA 2014, p. 382).

contaminant: substance or material in the form of particulate matter that is suspended in an atmosphere and may pose or create risks of equipment damage or injury, including but not limited to combustion, corrosion, ignition, and eye, skin, or throat irritation; may be in the form of gases, vapors, dusts, suspended particles, fumes, or mists.

contaminant-free air: ventilation, pressurization, purging, or HVAC unit makeup air that is essentially free of any trace amounts of combustible dust, flammable gas, or toxic substance.

density: weight of a unit volume of a substance; for example:

$$\text{air} = 0.075 \text{ lb/ft}^3 \text{ (1.2 kg/m}^3\text{)}$$

$$\text{water} = 62.3 \text{ lb/ft}^3 \text{ (1 kg/L)}$$

dilution: for the purposes of this guide, a process that may occur during natural or induced ventilation, as fresh or clean air is introduced into a

space that contains contaminants or hazardous substances, at a sufficient rate to diminish or reduce the concentration level of the contaminants or hazardous substances.

duct: thin-walled, low-pressure pipe used to conduct ventilation air.

emergency ventilation: process of supplying a protected space with sufficient volumes of contaminant-free air to remove accumulated concentrations of hazardous substances.

fan: mechanical device that causes air movement.

flammable gas: gas or vapor that at ambient temperature and pressure forms a flammable mixture with air at a concentration of 12% (or less) by volume.

flammable liquid: liquid having a closed-cup flash point below 100°F (37.8°C) at a vapor pressure less than 60 psi (4.138 bar).

fumes: solid airborne particles which may be created by condensation, evaporation, fire, high temperatures, or a chemical reaction.

gas: substance in a gaseous state at room temperature and pressure.

hazardous area: as defined by Articles 500–517 of the *NEC* (NFPA 2020), hazardous areas or hazardous (classified) locations are areas where ignitable concentrations of flammable gases, flammable liquid-produced vapors, or combustible liquid-produced vapors, combustible dust, or easily ignitable fibers or flyings may be present during normal or abnormal operating conditions. Additional definitions are available in API RP 500 and API RP 505 (1991, 2018).

hazardous space: for the purposes of this guide, a room, building, or occupiable space, such as a walk-in enclosure, where toxic, combustible, or flammable substances are introduced, stored, or processed in a manner that may create a hazardous situation, under either abnormal or normal operating conditions, and pose a life-safety or serious injury risk.

hazardous substance: any substance that is irritating, toxic, asphyxiating, flammable, or combustible in nature.

high-efficiency particulate air (HEPA): filter designed to remove 99.97% of a specific type of particulate material (0.3 μm in diameter) from air.

hood: for the purposes of this guide, a device that contains or captures airborne particles and directs them to an exhaust.

LEL: lower explosive limit of a gas or vapor in an atmosphere that is capable of producing a flash or fire when exposed to any form of ignition source.

LFL: lower flammable limit of a gas or vapor in an atmosphere that is capable of producing a flash or fire when exposed to any form of ignition source; has come into use in place of LEL by various organizations.

makeup air: air supplied to a space to replace air exhausted from that space; sometimes called *replacement air*.

mist: aerosol consisting of liquid particles generated by condensation of a substance from a gaseous to a liquid state.

odor threshold: lowest concentration level of an airborne substance that can be detected by the sense of human smell.

oxygen deficiency: concentration of oxygen at less than 19.15% by volume in the atmosphere of a particular space.

particulate matter: fine solid or liquid particles suspended in air, such as dust, fog, fume, mist, smoke or sprays; commonly known as *aerosol*.

permissible exposure limit (PEL): enforceable legal limit imposed by the Occupational Safety and Health Administration (OSHA) which dictates the maximum permissible exposure of an employee to a chemical substance or excessive noise levels.

pressurization: process of supplying contaminant-free air in accordance with NFPA 496 (2021b) for the purpose of creating a safe environment with the specific intent of creating a differential pressure in relation to surrounding atmosphere.

protected space: room or building protected by dilution, ventilation, pressurization, or purging for the purpose of expelling or preventing the entrance of hazardous substances.

protection system: for the purposes of this guide, all control components, hardware, equipment, ducting, and other elements of a protected space's ventilation, pressurization, air-conditioning, or heating system used for the purposes of providing or working in conjunction with a method of protection as defined in Chapter 4 of this guide.

purging: process of supplying contaminant-free air in accordance with NFPA 496 (2021b) at a sufficient velocity and for a sufficient period of time for the purpose of removing any trace amounts of combustible dust,

flammable gas or toxic substance from a specific area or space, as a precursor to pressurization.

smoke: aerosols, gases, and vapors resulting from incomplete combustion of a substance.

specific gravity: ratio of the mass of a unit volume of a substance to the mass of the same volume of a standard substance.

toxic substance: man-made (synthetic) substance that creates a risk of death, disease, injury, or birth defects in exposed individuals through absorption, ingestion, or inhalation.

UEL: upper explosive limit of a gas or vapor in an atmosphere that is capable of producing a flash or fire when exposed to any form of ignition source.

UFL: upper flammable limit of a gas or vapor in an atmosphere that is capable of producing a flash or fire when exposed to any form of ignition source; has come into use in place of UEL by various organizations.

vapor: gaseous state of a substance that under ambient conditions is a solid or a liquid.

ventilation: process of supplying contaminant-free air for the purpose of creating a safe environment with or without creating a differential pressure in relation to surrounding atmosphere.

ADDITIONAL SOURCES OF INFORMATION

The publications listed in this section are additional reading materials that are essential to the proper design, engineering, installation, operation, and maintenance of safe and effective heating, ventilation, pressurization, dilution, filtration, and air-conditioning systems for use in hazardous spaces. To the best possible extent, all of these publications and their specific content are referenced throughout this guide, as applicable, to prevent duplication or possible conflict.

Note that the following list does not include the date or revision number of each referenced publication. It is the reader's responsibility to use the most recent edition of any referenced publication to ensure that they have the most current and applicable information available. In limited instances, a section or chapter of a particular publication may be referenced to best guide the reader to a specific area of interest; however, no section or chapter numbers are provided, as they may change in subse-

quent editions of the publications. When these sources are cited in other chapters of this guide, the edition that is current as of the publication of this guide is cited, but that should not imply that this is the edition readers should use.

The following sources are listed by publisher for ease of organization; the order of the sources listed here does not reflect their importance.

- American Conference of Governmental Industrial Hygienists (ACGIH)
 - *Handbook of Ventilation for Contaminant Control*
 - *Industrial Ventilation: Recommended Practice for Design*
 - *Industrial Ventilation: Recommended Practice for Operation and Maintenance*
- American Petroleum Institute (API)
 - API RP 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities*
 - API RP 505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2*
- ASHRAE
 - ANSI/ASHRAE/IES Standard 202, *Commissioning Process for Buildings and Systems*
- International Society of Automation (ISA)
 - ANSI/ISA-71.04, *Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants*
- National Fire Protection Association (NFPA)
 - NFPA 204, *Standard for Smoke and Heat Venting*
 - NFPA 68, *Standard on Explosion Protection by Deflagration Venting*
 - NFPA 70, *National Electrical Code*
 - NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*
 - NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*
 - NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*

- National Institute for Occupational Safety and Health (NIOSH)
 - *NIOSH Pocket Guide to Chemical Hazards*
- Occupational Safety and Health Administration (OSHA)
 - OSHA 1910.1000—*Air Contaminants*
- Sheet Metal & Air Conditioning Contractors' National Association (SMACNA)
 - *Round Industrial Duct Construction Standards*
 - *Rectangular Industrial Duct Construction Standards*
 - *Guide for Free Standing Steel Stack Construction*
 - *Guyed Steel Stacks*
- UL
 - UL 823, *Electric Heaters For Use in Hazardous (Classified) Locations*



2 Applicable Hazardous Substances

The first and most important step in designing proper protection systems for hazardous spaces is identifying the hazards to be overcome. For the purposes of this guide, the hazards are toxic, asphyxiating, flammable, combustible, or corrosive substances.

TOXIC SUBSTANCES

Toxic substances, or *toxins*, are a primary concern when ventilating or conditioning the air within a hazardous space. When airborne in the forms of gases, vapors, or dust particles, such substances are poisonous, can cause chronic health effects or life-safety risks, and should be carefully mitigated.

Toxic gases are numerous and include arsenic, boron, bromine, carbon monoxide, chlorine, cyanogen, fluorine, formaldehyde, nitrogen dioxide, phosgene, selenium, sulfur, and tetraethyl, among many others. Because the list is so broad, and because many gases may not reach or exceed an odor threshold before reaching a toxic threshold, it is essential to understand and analyze the presence of potentially toxic gases prior to the design of protection systems in any industrial space to ensure the system does not introduce or trap such toxins within the space.

Toxic dusts are also numerous and are generally defined as particles ranging in size from below 1 μm up to 100 μm . The most common industrial-area dusts include asbestos; mineral dust, including silica; metallic dusts such as lead and cadmium; and chemical dusts, which can range from arsenic used in pesticides and timber preservation to zinc, which is used in the manufacturing of paints, rubber, cosmetics, textiles, and electrical equipment. In addition, other more common forms of dust such as wood, flour, cotton, and tea can also be toxic or may be hazardous to health when present in high concentrations. Any form of airborne particulate should be considered both hazardous and very likely toxic until proven otherwise.

Unless containment and reasonable ventilation are maintained, many liquids and solids emit toxic vapors under normal room conditions. Like toxic gases, toxic vapors also may not exceed odor thresholds at toxic levels, and the list of toxic vapors is likewise lengthy.

Among the life-safety risks of exposure to toxic substances, acute effects include asphyxiation, itching, headaches, and mild to severe nausea and fatigue. Chronic effects can include jaundice, loss of appetite, extreme fatigue and vomiting and, in the most severe cases, convulsions, coma, or death.

Toxic gases present an essential detection and mitigation challenge and pose life-safety risks. It is essential to secure Material Safety Data Sheets (MSDSs) or Globally Harmonized System (GHS) compliant Safety Data Sheets (SDSs) for all substances located within the surrounding atmosphere or that may be released within a protected space in any quantity. For more information on toxic substances, carefully review *NIOSH Pocket Guide to Chemical Hazards* (2007) and OSHA 1910.1000—*Air Contaminants* (n.d.). Qualified process or facility safety engineers should also ensure exposure to asphyxiants and other hazardous substances is within or below the time-weighted average (TWA) of chemical exposure requirements as published by OSHA (n.d.; see Annotated Tables Z-1, Z-2, and Z-3).

ASPHYXIATING SUBSTANCES

Asphyxiants are also an essential concern when ventilating or conditioning the air within a hazardous space. As commonly defined, asphyxia is a condition arising when the body is deprived of oxygen, causing unconsciousness or death by suffocation.

The most common asphyxiant substances include argon, carbon dioxide, helium, nitrogen, and ozone, which compose over 79% of the Earth's atmosphere and are generally nontoxic or minimally toxic but reduce or displace the normal oxygen concentration in breathing air. Other asphyxiant substances include acetylene, butane, methane, and propane. A significant number of other substances are also considered asphyxiants, so it is imperative to consider all substances that surround or may be introduced into a space to be asphyxiants until proven otherwise.

Many asphyxiants are odorless, making them extremely dangerous. For example, nitrogen is a very common substance that is both produced and used in various refining and chemical manufacturing processes but has no detectable odor. Propane and natural gas also have no significant odor until an odorant such as thiol is added at the end of their refining processes. In the case of propane and natural gas, an odorant is mandated to protect the general population since these two particular substances are commonly used around homes and commercial properties; if these substances were released into the atmosphere in sufficient quantities before an odorant were added, they could easily remain undetected by smell and cause significant harm or death.

As a special consideration, the chemicals used in many fire suppression systems should be considered asphyxiant gases, and special provisions should be made to post warnings to operators in regard to the necessity to immediately evacuate any spaces when such systems are activated. In certain situations, fire-suppressing chemicals are allowed to remain for calculated retention times within spaces to properly extinguish fires, which may require isolation dampers to seal the spaces and retain the fire-suppression chemicals.

The effect of incomplete carbon fuel combustion is carbon monoxide, a very deadly and odorless asphyxiant gas. This gas is present in varying concentrations near any fuel-driven engine and should be considered during the design of ventilation systems for rooms or buildings that contain any form of fuel-driven engine, regardless of its size. In addition, because accumulation of carbon monoxide is possible, the use of pressurization as a protection method should be avoided, unless the pressurization system features or is supplemented by an emergency ventilation system.

Any form of asphyxiant dust or, more specifically, fine airborne particles in sufficient quantities over a sufficient period of time can lead to mild or severe asphyxiation and can pose life-safety risks.

Mild symptoms of gas- or vapor-related asphyxia include headaches, dizziness, nausea, and vomiting. More severe symptoms range from labored breathing, altered senses, and abnormal heartbeats to severe blood flow disruption, loss of consciousness, seizures, and death. Though the condition is difficult to clinically diagnose in many circumstances, the symptoms are easily recognizable and are best treated by removing the victim from the affected area and providing them with oxygen. Asphyxiation by dust is rarer, unless a victim is trapped within an enclosed space. However, the obvious effects of intermittent or prolonged exposure to significant quantities of hazardous substances such as asbestos or coal dust are well known to cause symptoms ranging from extreme irritation, fatigue, and difficulty in breathing to chronic lung diseases, cancers, and death.

The proper design of protection systems for hazardous spaces should include a careful assessment and analysis to determine the presence or potential presence of asphyxiants, whether as present in the surrounding atmosphere or as introduced by any means into an enclosed space. Such spaces include laboratories, analyzer rooms, chemical blending rooms, and any other space where hazardous substances are stored, blended, processed, measured, dispensed, or packaged. The introduction of sufficient makeup air is typically a reasonable solution but may not be adequate in worst-case scenarios. Under these circumstances, the installation of gas detection and alarm devices, along with emergency ventilation systems, should be considered and may be essential to proper protection system design.

FLAMMABLE AND COMBUSTIBLE SUBSTANCES

Flammable and combustible substances include many of the aforementioned substances, along with a long list of other gases and dusts that are very common in high concentrations within industrial refining and commercial manufacturing facilities.

A flammable gas is commonly defined as a substance that forms a flammable mixture with air at a concentration of 12% or less by volume at ambient temperatures and normal atmospheric pressures. However, depending on the particular substance, the specific levels of atmospheric

concentrations of lower explosive limit (LEL) or lower flammable limit (LFL) and upper explosive limit (UEL) or upper flammable limit (UFL) may vary greatly. Such substances are defined by NFPA 497 (2021c), which indicates the actual concentrations at which a particular gas by volume in relation to atmosphere becomes flammable and then ceases to be flammable. However, in relation to the design of protection systems for rooms or buildings in hazardous areas, the presence of flammable gases in any concentration should be mitigated.

Combustible dusts are defined in much the same manner as flammable gases, and their explosive limits are also defined over a range of concentrations in the atmosphere, although the terms LEL, LFL, UEL, and UFL are not applicable to dusts. Many combustible dusts are defined by NFPA 499 (2021d), but as with all standards and publications, a dust substance should not be considered noncombustible just because it is not included in that publication.

Flammable vapors are also emitted by many solids and liquids and can best be mitigated by proper containment and adequate area ventilation. Again, the list of such substances is extensive, and careful assessment and analysis of the conditioned space and surrounding atmosphere are essential to the design of proper protection systems for hazardous spaces.

The effects of exposure to flammable gases or vapors and combustible dusts include all of the aforementioned effects of exposure to toxic or asphyxiant substances but can also include chemical burns; severe skin, eye, nose, throat, and lung irritation; and various forms of benign and terminal cancers.

One of the most comprehensive lists of flammable and combustible substances is included in NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* (2021c). Additional data are available in NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* (2021d). Other sources of information are also available, but if the flammable or combustible nature of any substance is unknown, it should never be assumed to be inert. Rather, it is imperative to research all substances carefully to properly recognize or rule out life-safety risks.

CORROSIVE SUBSTANCES

Hazardous substances that are considered toxic, asphyxiating, flammable, or combustible may also be corrosive or caustic in nature. Among such substances, hydrogen sulfide (H_2S), sulfur dioxide (SO_2), and chlorine (Cl_2) are considered corrosive, while potash, potassium, phosphate, sodium chloride, sodium hydroxide, and sodium nitrate are considered caustic.

Because they overlap all other forms of hazardous substances, corrosive substances may have the same acute and chronic hazards and health effects of all aforementioned substances. They can pose life-safety risks and also cause significant damage to electrical and electronic equipment as well as other devices, instruments, and fixtures used in industrial environments. Corrosive substances in the form of airborne contaminants can also adversely affect the performance of measurement and control systems. The limitation, removal, and chemical filtration of corrosive substances should be considered when designing proper protection systems for hazardous spaces.

For more information on corrosive substances and their effects on equipment and health, refer to ANSI/ISA-71.04 (ISA 2013).

CONCLUSION

The identification of all hazardous substances, along with a carefully calculated determination of their potential concentrations, both within a protected space and the surrounding atmosphere is essential. Identification of hazardous substances under both normal and abnormal operating conditions should be established prior to the initiation of designing proper protection systems for hazardous spaces.



3

Sources of Hazards in Relationship to Protected Spaces

When designing proper heating, ventilation, pressurization, dilution, filtration, and air-conditioning systems, it is essential to determine where hazardous substances are located in relation to the space to be protected. This establishes whether the protection system should prevent the entry of hazardous substances or mitigate concentrations that are introduced into or emanate from within the space, or in some cases whether both capabilities or emergency ventilation should be provided.

EXTERNAL SOURCES

External sources of hazardous substances surround control rooms, switchgear or motor control centers, electrical board rooms, analyzer rooms, laboratories, security centers, and other occupied and unoccupied structures. They are typically created by chemical manufacturing or oil refining operations, but regardless of origin they are usually known to exist under either normal or abnormal operating conditions.

External sources are typically identified by qualified process or facility safety engineers, which results in the development of hazardous (classified) location maps or zones in accordance with NFPA 497 (2021c). However, NFPA 497 only addresses flammable or ignitable concentrations of gases and vapors or combustible dusts. Careful review of facility

gas dispersion models should be considered, if available. In addition, consulting with facility safety engineers regarding the potential existence of external sources of other hazardous substances, such as asphyxiants or corrosive substances, is advised.

In accordance with the safety requirements of many industrial facilities and standards such as NFPA 496 (2021b), API RP 500 (1991), and API RP 505 (2018), the installation of gas detection and audible and/or visual alarm devices along with pressurization or ventilation systems that operate continuously or under emergency conditions should be considered.

In addition, installation of gas isolation dampers may be warranted and essential to proper design if external sources of hazardous substances are in close proximity to the space to be protected or if external sources are continuously present under normal operation conditions.

INTERNAL SOURCES

Internal sources of hazardous substances are common in laboratories, analyzer rooms, battery storage and charging rooms, hydrocarbon processing areas, and chemical blending or storage areas and where coatings or finishes are stored, dispensed, mixed, or applied. Such spaces include areas where spraying, pouring, filling, and other processes are performed and where toxic or corrosive substances, combustible dusts, flammable gases, or flammable liquids are handled or stored in any manner, regardless of whether they are normally contained or isolated from the protected space environment.

In accordance with the safety requirements of many industrial facilities and standards such as NFPA 496 (2021b), API RP 500 (1991), and API RP 505 (2018), the installation of gas detection and audible and/or visual alarm devices to activate emergency ventilation and mitigate detected releases from internal sources of hazardous substances should be considered.

Contained Sources

Objects such as sealed canisters and drums or instruments such as analyzers or sample conditioning systems and flow metering or measuring equipment may normally contain hazardous substances but should be considered potential life-safety risks if they are located within a protected space.

Uncontained Sources

Open containers, blending drums or mixing vats, laboratory analyzers, sample preparation workstations, machining equipment, and coating equipment should be considered potential life-safety risks. This consideration is important even if such items are protected by exhaust ventilation equipment such as hoods or fume extraction systems and regardless of whether the emitted hazardous substance is a gas, vapor, or dust, because failure of associated exhaust systems poses a life-safety risk.

Fugitive Emission Sources

Fugitive emission sources are considered to be any pressurized or unpressurized vessels, cylinders, containers, tubing, or pipes that may release gases or vapors due to any form of mechanical failure and other unintended or irregular releases of gases or vapors.

Horizontal Surface Sources

Protected space architectural features and fixtures such as beams, window sills, shelves, racks, and tables should be kept clean to prevent excessive accumulation of combustible dusts. This concern is emphasized because during an ignition of airborne particles, excessive accumulation of the hazardous substances on horizontal surfaces is disturbed and may subsequently ignite, creating a much more cataclysmic secondary explosion. See the Interior Construction Assessment section of Chapter 5 for more information about the potentially severe hazards associated with the accumulation of combustible dusts on horizontal surfaces.

Limited and Unlimited Releases

As a further means of defining internal sources of hazardous substances, the term *limited release* is used by NFPA 496 (2021b) to define an ignitable source of flammable gases or vapors that can be limited to a concentration of less than 25% of its lower flammable limit (LFL). The term *unlimited release* is used by NFPA 496 to define an ignitable source of flammable gases or vapors that cannot be limited to a concentration of less than 25% of its LFL. If such conditions exist within a protected space it is imperative to collaborate with the designers and installers of equipment that may be capable of producing limited or unlimited releases. Through collaboration, it should be possible to determine the maximum

potential volume of hazardous substances that can be released into a protected space and how to mitigate it. If mitigation is not practical due to the potential volume of a release or other underlying conditions or limitations, it may be better to relocate the source to an outdoor or more adequately ventilated area or space. This collaboration should be intended to prevent unnecessary risk of ignition and workforce exposure while also ensuring the selection of a proper protection method. Among essential topics to discuss and resolve, the following should be considered:

- **Source Limitation.** Verify or recommend the use of externally located restriction orifices in addition to externally located regulating devices to positively limit the amount of hazardous substances that are introduced into the protected space.
- **Source Elimination.** Verify or recommend the external location of sample preparation systems and external storage of calibration, purging, and span gases to greatly limit the potential release of these hazardous substances within the protected space.

Flow Modeling of Sources

Computational fluid dynamics (CFD) flow model simulations should be considered to provide detailed results for ventilation system effectiveness. These types of models expand the ventilation performance analysis from simple air changes or flow rates to highly detailed measurable metrics and visual representations for design. These results provide the authority having jurisdiction (AHJ) with valuable data in approving the design.

CFD models can verify a clean supply of air to the system by simulating the impacts of the ambient environment on the ventilation system. The use of modeling can vary the locations for supply and return openings or ducts in a space, room or building in relation to the local contaminant sources and microclimates to provide a design that has thoroughly considered the ambient environment, wind impacts, local obstructions, and local contamination sources.

Such models also provide detailed flow analysis throughout the treatment space, showing areas where dilution is excessive or inadequate. In contrast to this, air changes and flow rates only provide a bulk average view of the LFL. A CFD simulation can be used to evaluate design changes to balance the LFL throughout the space and minimize LFL in

high-risk zones. This level of design within a hazardous space can only be accomplished with the aid of computational modeling.

Capture velocity should be considered a critical parameter in spaces where significant concentrations of hazardous substances such as dusts or aerosols are present. The velocity profiles should provide the designer with sufficient knowledge to see where containment entrainment or drop-out will occur. CFD simulation should then provide a complete velocity profile throughout the model space to identify areas where capture velocity should be maintained. The ventilation system design should also leverage modeling of the dusts or aerosols to document the transport of the materials.

COMBINED SOURCES

In worst-case scenarios, a protected space may be surrounded by or adjacent to external sources of hazardous substances and may also contain internal sources, in the form of either limited or unlimited releases. A pressurization system with an ability to provide emergency ventilation may be required to address all potential life-safety risks.

In accordance with the safety requirements of many industrial facilities and standards such as NFPA 496 (2021b) and API RP 500 (1991), these situations may require installation of gas detection and alarm devices to activate emergency ventilation and mitigate detected releases from limited or unlimited sources of hazardous substances.

SYNOPSIS

To enable full understanding of sources in relation to protected spaces, the most comprehensive guides to establishing the hazardous area classifications of hazardous substances and determining the applicable ratings of areas surrounding their potential release are provided in the following documents:

- NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*
- NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*

- API RP 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities*
- API RP 505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2*

The American Conference of Governmental Industrial Hygienists (ACGIH) publications listed in the Additional Sources of Information section of Chapter 1 also provide useful information regarding identifying and mitigating sources of hazards in relation to protected spaces.

In addition, CFD simulation should be considered the most pragmatic modeling approach for hazardous space ventilation applications, as referenced in the Indoor Environmental Modeling chapter of *ASHRAE Handbook—Fundamentals* (2021) and the Indoor Airflow Modeling chapter of *ASHRAE Handbook—HVAC Applications* (2019).

4

Protection Methods



To advance the design of a proper heating, ventilation, pressurization, dilution, filtration, or air-conditioning system for a hazardous space, this chapter enables development of a comprehensive understanding of protection methods as currently defined by American Petroleum Institute (API) and National Fire Protection Association (NFPA). The potential control of hazardous substance introduction to protected spaces, the design characteristics of the building or room to be protected, and the potential needs to filter makeup and recirculated air should be comprehended and considered.

VENTILATION

Ventilation is the most common protection method for spaces such as buildings or rooms in hazardous areas. As described in API RP 500 and API RP 505 (1991, 2018), this protection method makes use of fans or blowers that either provide contaminant-free air to a protected space or extract contaminated air from a protected space.

In addition to API RP 500 and API RP 505, which serve as consensus standards for most professionals within the petrochemical industry, the Industrial Local Exhaust chapter of *ASHRAE Handbook—HVAC Applications* (2019) is an excellent resource of information for proper ventilation

of work spaces in all industrial and commercial facilities. The relevant publications from American Conference of Governmental Industrial Hygienists (ACGIH), American Industrial Hygiene Association (AIHA), NFPA, and Occupational Safety and Health Administration (OSHA) listed in the Additional Sources of Information section of Chapter 1 also contain essential recommendations and requirements that should be considered by qualified process or facility safety engineers depending on the type, size, location, and conditions of any space to be protected.

It is important to note that ventilation as an API-recommended protection method does not require the development of any specific static or atmospheric pressure within the protected space. In addition, this protection method may be designed to operate either continuously or only during adverse conditions, depending on the specific conditions of each application. Such methods are commonly referred to as *positive ventilation* or *negative ventilation* and are herein defined.

Positive Ventilation

As a method of protection, positive ventilation should be designed to provide a sufficient source of contaminant-free air to prevent hazardous substances present in the surrounding atmosphere or adjacent areas from entering into or accumulating within a protected space. This typically requires one or more inlets equipped with fans or blowers, along with one or more pressure-relief exhaust dampers or exhaust fan outlets that are located in an area opposite from or as far as possible from the inlet's supply fans or blowers. This arrangement is recommended to best promote cross-ventilation and prevent the creation of trapped or restricted air pockets within the protected space.

Negative Ventilation

As a method of protection, negative ventilation should be designed to provide a sufficient flow of air to remove hazardous substances that are emitted by sources within a protected space and to prevent migration of contaminant to adjacent areas. One or more outlets featuring exhaust fans or blowers should be installed as near as possible to the sources of hazardous substances. In addition, one or more inlet vents located in an area opposite from or as far as possible from the source of hazardous substances should also be installed. In no instance should the exhaust fan out-

lets be located in a manner which draws hazardous substances further into or across a protected space.

Potential Adverse Effects

Both positive and negative ventilation can have adverse effects if the makeup air introduced into the space is not preconditioned to limit humidity and be introduced at acceptable temperatures. These effects can be particularly adverse for any positive or negative ventilation system that operates continuously, as opposed to operating only during adverse conditions. In extremely hot or cold climates, it is advised to pass makeup air through an air-conditioning system or an in-line chilling or heating unit to prevent issues such as the accumulation of condensation and moisture on structural surfaces and equipment within a protected space or adverse temperature fluctuations within a protected space.

Ventilation Inlet and Outlet Locations

When applying positive ventilation, the specific gravity of all hazardous substances should be considered for proper location of exhaust vents, so that they are located in a manner to promote easy removal, as assisted by gravity. In the same manner, the specific gravity of internally released hazardous substances should be considered so that exhaust vents are either located just above or below such sources, so gravity can assist with removal of the substances.

However, in addition to these considerations and the initial points of exhaust for positive or negative ventilation systems, care should be exercised to ensure that adjacent occupied spaces or areas are not contaminated by the exhaust air. If this issue cannot be mitigated, the use of external exhaust ducting may be required.

All above concerns should be addressed by qualified process or facility safety engineers, who should provide the ventilation system designer with placement guidelines for inlet and outlet locations and the need for any required external exhaust ducting.

Air Changes per Hour or Flow Rate

The number of air changes per hour (ACH) to provide an adequate ventilation airflow rate should be established to properly size a positive or negative ventilation system. The protection system required by the author-

ity having jurisdiction (AHJ) to meet or exceed the ACH will vary depending on the recommended practices chosen for implementation.

For example, API RP 500 (1991) recommends that adequate ventilation be defined as a flow rate sufficient to prevent the accumulation of vapor-air or gas-air mixtures in concentrations exceeding 25% of their lower flammable limit (LFL). However, and in sharp contrast, it further states that enclosed spaces with at least 6 ach by natural or mechanical means can be considered adequately ventilated.

It should be noted that these API-recommended ACH and flow rates should be considered only minimum requirements. It is imperative that a ventilation system designer rely on the consensus or directives of the AHJ and/or qualified process or facility safety engineers. In turn, they should specify the required ACH to provide an adequate ventilation airflow rate.

Regardless of the above recommendations, continuous ventilation at a sufficient rate to overcome the specific conditions of each application is essential. Alternatively, to minimize the potentially adverse effects noted above, the use of a combustible gas detection system to activate an equally sufficient ventilation system only during adverse conditions is another pragmatic method to ensure adequate ventilation of flammable gases and vapors. There is no equivalent method for the detection of ignitable concentrations of dusts.

The determination of an adequate ventilation airflow rate is the most challenging and controversial aspect of designing a positive or negative ventilation system. As of the publication date of this guide, there is no consensus standard for ignitable concentrations of dusts. Much depends on the parameters, conditions, and related circumstances of each particular application.

Monitoring, Alarm, and Performance

An adequate ventilation airflow rate may be determined by various means to ensure the protection system will maintain safe conditions. In addition, the use of flow monitoring devices at the point of discharge through dedicated exhaust vents may be preferred. The use of gas detection and alarm devices should also be considered for protected spaces containing internal sources of flammable gases or combustible dusts.

Section 6 of API RP 500 (1991) requires gas detection devices to automatically modify ventilation methods in any space where air is recirculated. Section 6.5 of this recommended practice contains recommenda-

tions regarding combustible gas detection devices. Additional information is also provided in Section 6 of API RP 505 (2018).

Natural Ventilation

In addition to the API-recommended practices of positive and negative ventilation, natural ventilation may also be used extensively in some industrial facilities. In most instances, this process is intended for spaces that are not fully enclosed or that are purposely ventilated using large openings or vents. If natural ventilation is considered sufficient by an AHJ, fans, blowers, and other mechanical devices used to promote ventilation as described above may not be essential or may only be essential under emergency conditions.

However, the installation of gas detection devices is recommended to monitor such spaces and activate alarm devices. It may also be essential to install other safety devices, including emergency ventilation fans or blowers that are activated manually or automatically upon detection of any significant concentrations of hazardous substances.

As implied by its name, the process of natural ventilation should occur organically and in the potential absence of any wind velocity. This process should only be used if all of the following conditions are true:

- The potential release of any hazardous substance, although well contained within a protected space, is unlikely.
- The hazardous substance is not toxic or corrosive in nature.
- The hazardous substance normally rises and disperses into the surrounding atmosphere freely, instead of settling at ground level to form gaseous pools.
- The roof of the space being protected by natural ventilation is well ventilated in such a manner as to prevent the accumulation of any significant concentrations of hazardous substances within the space.
- The natural dispersant of hazardous substances will not adversely affect adjacent areas or spaces or potentially make them more hazardous.
- Prior authorization of the AHJ and qualified process or facility safety engineers has been received.

Emergency Ventilation

Emergency ventilation may be preferred or required under a number of circumstances and is usually engaged manually by emergency push buttons or automatically by devices such as gas detection devices. It may be provided as a separately installed system to enhance ventilation, pressurization, or dilution systems, or it may be incorporated within these protection systems as a special full-speed mode.

This protection method is intended to supply a protected space with sufficient volumes of contaminant-free air to remove accumulated concentrations of hazardous substances. The use of barometric or mechanically operated dampers or louvers in appropriate locations should be considered to allow the rapid removal of hazardous substances and should be designed to operate when the emergency ventilation system is activated.

The locations of these dampers or louvers should be based upon the locations of the emergency ventilation system's fans or blowers. Their locations should also be based on the specific gravity or density of the hazardous substances that may accumulate within the protected space to ensure total and effective removal with the assistance of gravity.

As of the publication date of this guide, there is no known industrial standard or code that specifically covers emergency ventilation as a protection method. However, such systems are becoming more common in industrial facilities, serving spaces such as analyzer rooms or whole buildings and laboratories.

An emergency ventilation system designer should rely upon the AHJ or qualified process safety engineers to provide complete specifications for such systems. In addition to any automatic activation method, these systems should also activate alarm devices and include clearly marked manual activation devices, such as large emergency push buttons near the exit points of the protected space.

PRESSURIZATION

The protection method of pressurization, as defined by NFPA 496 (2021b), is appropriate only for protected spaces that contain no sources of limited or unlimited hazardous substance releases. This protection method is intended to prevent the ingress of flammable gases or vapors and is suitable for spaces such as control rooms, switchgear or motor con-

trol centers, security centers, and other occupied structures other than laboratories or analyzer rooms or chemical processing, blending, mixing, machining, packaging, filling, and application spaces.

As with positive or negative ventilation, for effective pressurization the speed and direction (velocity) of prevailing winds should be considered along with the location of a contaminant-free air source that contains no more than trace amounts of any hazardous substance. To offset the adverse effects of prevailing winds and to sustain pressurization during ingress and egress, the use of separately pressurized or unpressurized vestibules should be considered. Such vestibules may also feature opposable interlocking doors to serve as an effective means of satisfying the requirements of all affected operators and all facility management and safety officials.

NFPA 496 (2021b) provides minimum requirements for electrical equipment enclosure and building pressurization and purging system performance. In addition, the applicable ACGIH, NFPA, and OSHA publications listed in the Additional Sources of Information section of Chapter 1 contain essential recommendations and requirements that should be considered by qualified process or facility safety engineers depending on the type, size, location, and conditions of any space to be protected.

Principles of Operation

NFPA 496 (2021b) is the consensus standard for pressurization of buildings spaces located within Class I Hazardous (Classified) Locations as defined under Article 500 of the *National Electrical Code (NEC; NFPA 2020)*. Chapter 7 of NFPA 496 covers the pressurization of control rooms (any protected spaces containing no internal sources of flammable gases, vapors, or liquids) and Chapter 9 covers analyzer rooms (any protected spaces containing flammable gases, vapors, or liquids). The standard requires protected spaces to be pressurized above the surrounding atmosphere to a pressure of at least 0.10 in. WC (25 Pa), along with other protection criteria.

Achieving pressurization as prescribed under Chapter 7 of NFPA 496 (2021b) presumes that hazardous substances can be prevented from entering the protected space in any quantities sufficient to pose a life-safety risk or to damage equipment within the protected space. The standard requires that a minimum safe pressure of at least 0.10 in. WC (25 Pa) be maintained when all openings are closed. It also requires an air velocity of

60 fpm (0.305 m/s) simultaneously through all openings capable of being opened (regardless of whether minimum pressure is maintained) to further limit or prevent the entry of hazardous substances.

The required air velocity is typically achieved by secondary or variable-speed fans or blowers that engage or speed up automatically during a loss of pressure.

The flow rate required to compensate for the area of all openings capable of being opened is reduced by an exception to exclude certain openings. These openings are defined as equipment doors that remain sealed during normal operation and are labeled in such a manner as to warn against their use for routine or frequent ingress and egress.

AHJs or safety managers may allow a slight delay of increased air velocity to enable easy ingress and egress, but NFPA 496 (2021b) does not currently recognize this practice.

In addition, to ease door closure after air velocity is increased upon pressure loss during egress or to prevent overpressurization and allow emergency ventilation as prescribed in the Gas Detection System Design and Installation section of Chapter 7 of this book, the addition of sufficiently sized barometric exhaust vents should be considered.

Achieving pressurization as prescribed under Chapter 9 of NFPA 496 (2021b) requires that all the requirements of Chapter 7 apply except as modified by Chapter 9. There are a number of distinct differences, so designers should carefully review both chapters if designing HVAC, pressurization, dilution, or filtration equipment for use in spaces containing either abnormally occurring or continuously present sources of flammable gases, vapors, or liquids.

Monitoring, Alarm, and Performance Requirements

Chapter 7 of NFPA 496 requires that failure of a positive-pressure air system be detected at “the discharge end of the fan” (2017, p. 12). The NFPA 496 appendix recommends that loss of air pressure can be detected by devices including velocity or static-pressure switches, differential pressure sensors, or plenum chambers fitted with orifices. When these forms of detection are not practical, pressure should be sensed within the protected space, and under no circumstances should the detection of fan or blower motor operation be considered acceptable verification of pressurization (NFPA 496).

NFPA 496 does not require a specific device to monitor or measure the 60 fpm (0.305 m/s) velocity through all openings capable of being opened. Designers should make precise opening area calculations and ensure the pressurization system can supply ample airflow to meet this requirement.

The use of combustible gas detection devices is not required by NFPA 496. However, gas detection devices should be considered a monitoring method. These devices may also activate emergency ventilation systems automatically in protected spaces that contain a source of combustible gases or vapors.

Chapter 7 of NFPA 496 (2021b) requires type Y and Z pressurization systems (which reduce area classification within a protected space from Class I, Division 1, to Division 2 or Class I, Division 2, to Unclassified) to activate an alarm device at a constantly attended location upon loss of room pressure. It also requires that type X systems (which reduce area classification within a protected space from Class I, Division 1, to Unclassified) de-energize power automatically from all circuits within a protected space not approved for use in Class I, Division 1, areas. As an exception, NFPA 496 requirements allow power to remain energized for a “short period” if the immediate loss of power would constitute a greater hazard (NFPA 2017, p. 12, Section 7.4.5).

Chapter 9 of NFPA 496 has similar requirements for an alarm device and power removal for type X, Y, and Z pressurization systems, with exceptions for power removal based on the type of system and the anticipated release within the space as being either “none” or “limited” (2017, p. 15, Section 9.3.8).

When power is removed automatically or manually, and regardless of whether the space is protected by a type X, Y, or Z pressurization system or by a ventilation system or by a dilution system (covered in the following section), procedures to ensure that the protected space is free of any flammable or combustible levels of hazardous substances should be performed before restoring power to any unrated devices within the protected space.

In regard to Class II Areas, the NFPA chapter covering pressurization of control rooms does not distinguish a Class I or II area classification, but the NFPA chapter covering analyzer rooms is clearly intended only for Class I areas. It is reasonable to assume that pressurization is an adequate

form of protection against Class II dusts, but additional provisions for housekeeping as noted throughout this guide are essential.

DILUTION

The protection method of dilution is appropriate for protected spaces that contain a source of limited or unlimited hazardous substance releases, as defined by NFPA 496 (2021b). This protection method is intended for spaces such as laboratories; analyzer rooms; chemical or hydrocarbon processing, blending, mixing, machining, packaging, or container-filling spaces; and other enclosed spaces with known concentrations of hazardous substances.

While dilution as a principle is well recognized, there is no specific consensus standard for this method of protection. However, NFPA 496 (2021b) has specific information about dilution in Annex A, and *ASHRAE Handbook—HVAC Applications* (2019) references dilution numerous times, specifically in the Ventilation of the Industrial Environment chapter as well as in many other chapters applicable to specific applications. In addition, the applicable ACGIH, AIHA, NFPA and OSHA publications listed in the Additional Sources of Information section of Chapter 1 contain essential recommendations and requirements that should be considered by qualified process or facility safety engineers depending on the type, size, location and conditions of any space to be protected.

The most important aspect of designing an effective dilution system is determining the amount of ventilation required to offset any normal or abnormal release of contaminants or hazardous substances within a protected space.

If a protected space is surrounded by significant levels of contaminants or hazardous substances, the direction of prevailing winds should be considered. In addition, the location of a contaminant-free air source that contains no more than trace amounts of any contaminant or hazardous substance should be considered.

It may also be essential to offset the adverse effects of prevailing winds and to sustain pressurization during ingress and egress by the use of separately pressurized or unpressurized vestibules. Such vestibules may also feature opposable interlocking doors to serve as an effective means of satisfying the requirements of all affected operators and all facility management and safety officials.

To fully emphasize the value of dilution as a protection method, it should be noted that dilution should be considered along with either positive or negative ventilation as the best means of protecting any space that contains any limited or unlimited release of any gaseous hazardous substances. This consideration may be very important if the substances are flammable, toxic, corrosive, or asphyxiating.

NFPA 496 (2021b) uses the same concepts of type X, Y, and Z protection for dilution as it does for pressurization. It requires type Y and Z pressurization systems to activate an alarm device at a constantly attended location upon loss of room pressure and requires type X systems to de-energize power automatically from all circuits within a protected space not approved for use in Class I, Division 1, areas. NFPA 496 also has exceptions for power removal based on the type of system and the anticipated release within the space as being either “none” or “limited” (NFPA 2017, p. 15).

In regard to analyzer rooms containing a source of flammable gas, vapor, or liquid, NFPA 496 (2021b) provides essential requirements for flow-limiting devices as well as other piping system and equipment design requirements to prevent the unlimited release of flammable gases and vapors within a protected space.

Principles of Operation

Dilution is defined in this guide as a process that may occur during natural or induced ventilation, as fresh or clean air is introduced into a space that contains contaminants or hazardous substances, at a sufficient rate to diminish or reduce the concentration level of the contaminants or hazardous substances. Before choosing dilution as a protection method, it should be determined whether reducing concentrations of flammable gases or vapors within a protected space only to a level below their lower explosive limit (LEL) will be sufficient to offset the potential life-safety risks of these substances.

As required by Chapters 7 and 9 of NFPA 496 (2021b), when a protected space is surrounded by an atmosphere containing a significant level of contaminants or hazardous substances, the protected space requires pressurization in addition to ventilation. A dilution system should act as a ventilation system that may also be required to maintain pressure within the protected space, in accordance with the principles of operation for both protection methods as described previously.

Monitoring, Alarm, and Performance Requirements

In the absence of any consensus standard for the dilution of protected spaces, monitoring of ventilation airflow should be accomplished by measuring the differential pressure between the inlet and dedicated exhaust vents. Insufficient airflow or pressure should activate an alarm device located in a constantly attended location.

Furthermore, monitoring of protected space room pressure should be considered if the space is located in an area rated as a hazardous (classified) location. The monitors can then alert operators and safety officials to the potential introduction of additional hazardous substances from the surrounding atmosphere into the protected space.

In addition, contaminant and hazardous substance monitoring may also be essential. Considerations should be based on whether contaminants or hazardous substances are normally present in the surrounding atmosphere and whether contaminants or hazardous substances within the protected space are normally contained or frequently released within the protected space. However, availability of such monitoring equipment may be limited, depending on the substance to be detected.

In regard to performance requirements, monitoring and alarm devices should provide sufficient safeguards. Redundant ventilation or pressurization systems may also be considered if the potential danger of space contamination due to accidental or inadvertent release of hazardous substances is possible.

FILTRATION

The protection method of filtration is essential if a contaminant-free source of makeup air for ventilation or pressurization cannot be attained without either potentially unacceptable or sustained levels of contaminants or hazardous substances. This method should also be considered when processes within a protected space can cause the release of contaminants or hazardous substances within the protected space. ANSI/ISA-71.04 (ISA 2013) provides guidance on air filtration levels for liquids, solids, and gases.

When the level of anticipated contamination of air within a protected space is considered unacceptable, various methods of air filtration for introduced makeup air and recirculated air are readily available. Commonly used forms of air filtration include pleated filters, dust collectors,

deep-bed scrubbers, electrostatic precipitators, gas-phase filtration units, and cyclonic filter systems. Each method of filtration may also incorporate multiple-stage prefilters, postfilters, and high-efficiency particulate air (HEPA) filters. The selection of a filtration method should depend on the contaminant's origin, its concentration, and the risk it poses to the occupants or equipment within a protected space. Selection should also depend on the characteristics of all contaminants and hazardous substances to be mitigated.

Particulate Collection Air Filters

Filtration via particulate collection air filters mitigates moderate to substantial volumes of suspended particulate matter, including dust, fog, fume, mist, smoke, and spray (commonly referred to as *aerosol*). This matter may either infiltrate a protected space from external sources or be emitted by a process performed within a protected space. Dust collection filters may include primary particulate filter cartridges, may feature wet or dry primary particle collection systems, and may also include postfilters and HEPA filters. This method of filtration is passive in nature and is suitable to remediate or limit the concentration of contaminants and hazardous substances, including those with flammable or combustible characteristics, such as hydrocarbon vapors and gases or metallic dusts. However, filter size and design characteristics may not be ideally suited for direct integration with an air-conditioning system. If this is the case, filters may be installed as stand-alone devices that can either separately filter recirculated air, collect particles by hood extraction near a point of internal release, or filter contaminant-free makeup air prior to entering an air-conditioning unit.

Deep-Bed or Gas-Phase Chemical Scrubbers

Filtration via deep-bed or gas-phase chemical scrubbers features a specific blend of sorbent media or activated cartridges and can be placed in line with ventilation systems to filter makeup air and/or recirculated air within a protected space. They are ideal for applications where corrosive gases or vapors such as hydrogen sulfide (H_2S), sulfur dioxide (SO_2), or chlorine (Cl_2) are present, and they can also feature prefilters, postfilters, and HEPA filters. The sorbent material, prefilters, and postfilters should be replaced periodically at a rate dependent upon the airflow rate and the level of contaminants filtered. As another passive filtration method, this

method is ideal for any toxic, corrosive, flammable, or combustible substance. Because they are passive in nature, scrubbers are often integrated directly into air-conditioning units to filter both recirculated and contaminant-free makeup air.

Electrostatic Precipitation Air Filters

Filtration via electrostatic precipitation air filters removes fine dust and smoke particles with minimal impediment to the flow of ducted air by inducing an electrostatic charge to collection media or plates. By the nature of their design, these filters are typically easy to clean and maintain. This filtration method is ideal for contaminants and nonflammable and noncombustible hazardous substances. However, because these units use an electric charge to attract particles, they are not suitable for the filtration of flammable or combustible substances. When practical, this filtration method can filter recirculated air as a separate unit or be integrated with an air-conditioning unit.

Cyclonic Air Filters

Filtration via cyclonic air filters is considered uniquely suited to first remove larger particles by cyclonic action and then finer particles by post-filtration. While noise levels are significantly higher for this method than all aforementioned filtration methods, cyclonic filters may be ideal for protected spaces that contain high concentrations of noncombustible contaminants or toxic, corrosive, or combustible dust particles. However, they are not considered suitable for the filtration of toxic, corrosive, or flammable gases and vapors. Furthermore, due to their size and design characteristics, these filters are primarily intended to independently filter recirculated air. They may also be used to filter makeup air or collect particles by hood extraction near a point of internal release, but they cannot be integrated directly with an air-conditioning unit.

CONTAINMENT, ISOLATION, AND REMOVAL OF AIRBORNE DUSTS AND PARTICLES

If significant accumulations of airborne dust and particle contaminants or hazardous substances are anticipated within a protected space, their containment, isolation, and removal should be carefully considered by the AHJ. These efforts should be completed prior to any efforts to

design a heating, ventilation, pressurization, dilution, filtration, or air-conditioning system for the space.

Allowing the accumulation of dust, particle contaminants, or hazardous substances in any volume sufficient to constitute what the AHJ deems a hazard should be avoided, overcome, or mitigated. To affect a solution, the development of routine preventive measures may be required by the AHJ as a prerequisite, prior to authorizing the design of a system to protect a space from external or internal sources of contaminants or hazardous substances.

Developing an effective solution to prevent the accumulation of dust is wholly dependent on a carefully planned preventive maintenance procedure, as opposed to system design and installation. It is recommended that the preventive maintenance procedure be presented to the AHJ along with key maintenance personnel and qualified process or facility safety engineers for their consideration.

Foremost, key maintenance personnel and qualified process or facility safety engineers should determine how excessive accumulations of airborne dust and particles can be fully contained or isolated from a protected space. It is of utmost importance that measures to minimize, contain, or isolate such contaminants and hazardous substances be fully implemented before any electrical devices within a space become operational.

It is also extremely important to emphasize that the most efficient protection system for spaces where combustible dust is allowed to accumulate on horizontal surfaces is incapable of ensuring critically essential worker and facility safety unless that system is supplemented with rigorously enforced preventive maintenance procedures to remove dust accumulations frequently.

Implementation of rigorous preventive maintenance procedures to remove dust frequently should therefore be considered one of the most essential facility safety practices to prevent a catastrophic explosion.



5 Protected Space Integrity

After an adequate protection method has been selected and any required procedures to contain, isolate, or remove contaminants and hazardous substances have been implemented or planned, another factor to assess is the structural or architectural integrity of the protected space. This assessment is not covered to any significant extent by the publications listed in the Additional Sources of Information section of Chapter 1, but it is essential, especially if pressurization is the selected protection method. Without such an assessment, it is very possible to design and install a ventilation, dilution, or pressurization system only to discover that serious flaws in the construction of the protected space render the system incapable of performing as anticipated.

GENERAL CONSTRUCTION ASSESSMENT

The general construction assessment should commence with a detailed examination of the exterior walls, windows, doors, bulkheads, roof, and base or foundation of the space. This examination should determine whether any holes, gaps, cracks, or other anomalies will allow the entrance of hazardous substances or will require excessive amounts of contaminant-free airflow to overcome their entrance. If it is determined that such anomalies exist, they should be eliminated or mitigated, depend-

ing on the selected protection method. Among areas to examine carefully, special emphasis should be given to bulkhead seals, window weather stripping, mechanical penetrations, door seals, and door thresholds.

ELECTRICAL CONDUIT ENTRY ASSESSMENT

As the next essential process, all electrical conduit entries should be carefully examined to ensure they are sealed. In some cases, the transition from a surrounding atmosphere to a protected space environment that is modified by any protection method to reduce its area classification should be sealed to comply with Article 500 of the *National Electrical Code* (NFPA 2020). The loss of integrity due to unsealed conduit entries adds up and can quickly equate to what constitutes a significant opening in the structure.

PIPING, DUCTING, AND PLUMBING SYSTEM DRAIN AND VENT ASSESSMENTS

Examination of all piping, ducting, and plumbing systems is essential regardless of the protection method selected, but in particular in regard to spaces protected by negative or natural ventilation. All pipe and duct penetrations through the floor, walls, or roof of a protected space should be sealed in a manner that prevents the ingress of external contaminants or hazardous substances. For the same purpose, plumbing drains in floors, sinks, showers, and wash basins should be equipped with ball float or trap devices, and all vent standpipes should be fitted with automatic air admittance devices that prevent uncontrolled airflow.

INTERIOR CONSTRUCTION ASSESSMENT

As another aspect of protected space assessment, the presence of false or drop-in panel ceilings and raised or computer flooring should be determined, along with any partitions or interior walls, closets, cabinets, or rooms within a protected space. Such anomalies are restricted by standards such as NFPA 496 (2021b) for analyzer rooms and create confined or trapped spaces that can pocket or retain dangerous concentrations of hazardous substances. These anomalies present particularly difficult challenges to the effectiveness of any protection method. Overcoming these challenges may require eliminating such anomalies or adding venting grilles, more ventilation equipment, and/or special ducting.

Vapor Barriers

It may also be essential, necessary, or preferred to install vapor barriers behind interior wall liners and above interior ceiling systems if the building contains a source of limited or unlimited hazardous substance releases. Otherwise, a very dangerous condition of trapped gases can be created even while a protection system performs exactly as designed.

Isolated Area Assessment

Gas detection devices may be used to alert operators to unacceptable concentrations of hazardous substances trapped in an isolated area within a protected space, such as a false ceiling, so that operators, maintenance personnel, or safety engineers can take mitigating actions. The modification of a protected space may be the more pragmatic approach, unless confined or isolated spaces are essential and considered well beyond the possibility of being exposed to hazardous substances. However, as noted previously, compliance with NFPA 496 (2021b) analyzer room requirements negates the use of false or drop-in panel ceilings and raised or computer flooring in spaces with a known source of internal release.

DESIGN CONSIDERATIONS FOR DUST HAZARDS

When a protected space is subjected to external sources of combustible dust particles or internal sources of limited or unlimited combustible dust particle releases, horizontal surfaces such as beams, racks, shelves, windowsills, and tables should be minimized. All essential horizontal surfaces should be sloped if possible, and all wall, ceiling, and fixture surfaces should feature a smooth finish to limit dust accumulation.

Although they are not a structural design consideration, housekeeping procedures to remove significant accumulations of combustible dusts should also be carefully established and rigorously enforced at all times. This recommendation is provided because when disturbed by the concussive force of an airborne dust partial ignition, such accumulations have been shown to cause much more cataclysmic secondary explosions.

DESIGN CONSIDERATIONS FOR BLAST-RATED SPACES

When a protected space is designed or rated to perform as a blast-resistant structure, the use of blast dampers or attenuators should be considered by qualified process or facility safety engineers. Typically, in

order to protect occupants of a protected space from the concussive forces of an explosion within the surrounding atmosphere, all ventilation inlet and exhaust ducts and all HVAC unit supply and return air penetrations should be assessed.

Blast dampers or attenuators may not be required for any particular ventilation duct or HVAC supply and return air penetration if 1) their size is limited, 2) they are oriented in a manner that does not expose them to the potential blast force, or 3) the anticipated blast force is not determined to be harmful to occupants. However, if warranted, blast dampers or attenuators should be designed and/or rated to match the blast resistance rating of the protected space and should close instantaneously and automatically upon an external explosion.

DESIGN CONSIDERATIONS FOR BLAST-VENTED SPACES

When a protected space is equipped with pressure relief or blowout panels or vents to relieve the pressure created by an internal explosion, the panels or vents should be positioned carefully. Considerations should include placement in a location and manner that will not endanger workers or occupants located in adjacent areas or spaces and in a location and manner that will not damage surrounding equipment or structures.

To ensure the proper ventilation of a protected space, qualified process or facility safety engineers should consider the use of NFPA 68, *Standard on Explosion Protection by Deflagration Venting* (2018), as a guide. This standard addresses the design, location, installation, maintenance, and use of devices and systems that vent contaminants, hazardous substances, and excessive pressures resulting from a deflagration within protected spaces. Adherence to the provisions of this standard should ensure that structural and mechanical damages are minimized.

To ensure the sustained integrity of a protected space, qualified process or facility safety engineers should consider the use of ANSI/ASHRAE/IES Standard 202, *Commissioning Process for Buildings and Systems* (ASHRAE 2018), as a guide. This standard describes the commissioning process and the roles of all participants and provides a guide for developing design documents, specifications, procedures, and reports. It also carefully describes training program requirements to ensure continued system and assembly performance. Appendices provide useful information including but not limited to sample checklists, system manuals, reports, and training plans.

SYNOPSIS

Virtually any room or building can accommodate any protection method if properly provisioned; however, disregarding the protected space's integrity may result in the installation of a system that does not perform properly. The result is a system that may not satisfy essential operating parameters or that may not properly ventilate, pressurize, or filter the air within all areas of a protected space.



6

Equipment Selection Criteria

Upon determination of applicable hazardous substances, their sources in relation to the protected space, the protection methods to be used, and the integrity of the protected space, the selection of equipment is the next step in designing proper protection systems and air-conditioning systems.

Though installation site conditions should be a primary consideration, only a basic parameter is provided in Chapter 7 of NFPA 496, which requires that “the location of the control room relative to the direction of the prevailing wind and to the location of process units” be considered “in designing a control room suitable for safe operation in a a hazardous (classified) location” (2017, p. 12, Section 7.3.1, Note (3)). Additional considerations may be essential for harsh conditions, such as those encountered in desert or arctic regions.

For desert region conditions, there is no known authoritative source of information, but the ability of equipment to function properly will be dependent on its ability to withstand extreme high and low temperatures and may be dependent on its ability to withstand sandstorms. For arctic conditions, one source of information is *Cold-Climate Buildings Design Guide* (ASHRAE 2015), which provides exceptional information regarding climate control systems for extremely cold conditions.

HOUSINGS AND COMPONENT MATERIALS

Selection of a protection system's structural materials and components is essential. For example, NFPA 496 requires that ducts for pressurization be constructed from noncombustible materials and that what they define as "fan suction lines" are to be constructed in a manner that will not leak (2017, p. 12). In addition, NFPA 496 requires that these lines be protected against mechanical damage and corrosion to prevent any hazardous substances normally or abnormally present within the surrounding atmosphere from being drawn into the protected space environment.

Noncorrosive Conditions

When corrosive substances are not present in the surrounding atmosphere or protected space environment, standard materials of construction, including painted steel equipment housings, electrical equipment enclosures, motors, and compressor cases, are acceptable. In addition, reasonably resilient and fully sealed ducting and fan or blower housings and galvanized or zinc-coated conduit, conduit fittings, and fasteners are also acceptable. Finally, under these conditions, uncoated aluminum-finned and copper tube heating and cooling coils and copper refrigerant tubing for air-conditioning units are acceptable.

Corrosive Conditions

When corrosive substances are present in the surrounding atmosphere or protected space environment, the use of corrosion-resistant equipment housings, ducting, and fan or blower housings and fastener materials is mandated by NFPA 496 (2021b). In addition, specially coated motor, compressor, and electrical equipment enclosures, along with polyvinyl chloride (PVC) coated or nonmetallic conduit and conduit fittings, are recommended to ensure that all devices listed above have the ability to withstand corrosive conditions. Finally, the use of coated heating and cooling coils and refrigerant tubing is recommended. Disregarding this important element of design may lead to excessive maintenance concerns or premature component failure and potential failure of the protection system.

Fan Blade and Blower Wheel Materials

When flammable gases and/or combustible dusts are present in the surrounding atmosphere or protected space environment, NFPA 496 (2021b) mandates that all fan and blower wheels in the protection system be constructed from nonferrous metal, such as cast aluminum or aluminum sheet metal, or from a resilient plastic or polymer material. This requirement is intended to ensure that these moving parts of a protection system cannot generate a spark if they come in contact with any foreign metal object or their respective housings.

For additional information regarding the selection of suitable fan blade and blower wheel materials, refer to ANSI/AMCA 99-0401 (AMCA 1986), published by the Air Movement and Control Association International.

PROTECTION SYSTEM EQUIPMENT ELECTRICAL RATINGS

Equipment electrical ratings are dependent on surrounding atmosphere and protected space environment ratings as established by the authority having jurisdiction (AHJ) or qualified facility safety engineers. Typically, this determination is established using NFPA 497 or NFPA 499 (2021c, 2021d) to determine the hazardous (classified) location rating of a particular area as a preemptive procedure before protected spaces are designed or constructed. The established hazardous (classified) location ratings may be used to establish protection system equipment ratings in accordance with Article 500 of the *National Electrical Code (NEC; NFPA 2020)*. However, it is important to note that, as mandated by NFPA 496 (2021b), all protection system equipment must be rated for use in the absence of any protection method.

Surrounding Atmosphere Classification

Determining classification of hazardous areas establishes class, division, and group ratings. A proper rating establishes a temperature code (T-Code) that designates an autoignition threshold. To ensure the integrity of a protection system and meet *NEC* Article 500 requirements (NFPA 2020), all electrical devices and equipment exposed to the surrounding atmosphere must be rated for the area and perform properly without exceeding the T-Code. This requirement should be considered regardless of whether the equipment in question is electrically energized. For exam-

ple, a direct expansion (DX) air-conditioner condenser coil's maximum operating temperature is just as essential as that of the condenser fan motor that cools it.

Protected Space Classification

The classification of a protected space should also establish class, division, and group ratings along with a temperature code (T-Code) in the absence of any protection method. However, to ensure that the intent of a protection system is clearly established, qualified process or facility safety engineers should also establish a secondary rating to indicate the rating and T-Code of the protected space when the protection system is functioning. This secondary rating establishes the rating of protection system equipment within the protected space and establishes how it should perform, as noted in Chapter 4, particularly as detailed in the alarm devices and power control discussion in the Monitoring, Alarm, and Performance Requirements subsection of the Pressurization section.

Equipment Rating Establishment

To satisfy NFPA 496 (2021b) requirements, the rating of a protection system's electrical equipment must be based on the most onerous condition. As a matter of strict interpretation, this requirement applies whether the more onerous condition exists within the surrounding atmosphere or within the protected space in the absence of any protection.

Some recommendations of API RP 500 and API RP 505 (1991, 2018) and requirements of NFPA 496 (2021b) lead readers to presume the atmosphere surrounding a protected space is always hazardous and more onerous than the protected space environment. These recommendations and requirements do not address circumstances where the environment within a protected space may be more onerous.

In these circumstances, it might seem acceptable for protection system, heating, or air-conditioning equipment located outside the protected space to be rated for the less onerous surrounding atmosphere. However, such equipment outside of the protected space should actually be rated for the more onerous protected space's hazardous rating if it is exposed to any airflow that exhausts from or is recirculated within the protected space. In other words, such equipment should be rated as if it were within the protected space in the absence of any protection.

As an example, consider an atmosphere surrounding an analyzer building that may be rated as nonhazardous or unclassified while the protected space environment is rated as Class I, Division 1 or 2. In this instance, consideration of practical exceptions to existing consensus standards should be applied to properly address the recommendation stated at the beginning of this subsection.

AIR-CONDITIONING SYSTEM EQUIPMENT ELECTRICAL RATINGS

This section primarily focuses on provisions for direct expansion (DX) air conditioners. However, all following provisions also apply to heat pumps, electric or hydronic heating systems, chilled-water systems, evaporative coolers, and other forms of climate control or enhancement systems that may operate in tandem, be integrated with, or be controlled by a protection system.

This section is presented separately from protection systems for several reasons. First, the requirements for air-conditioning system equipment are different from those of protection systems, because this equipment may be interlocked and not allowed to operate until the protection system achieves the required level of protection. Second, more often than not, air-conditioning system equipment is designed to operate independently from a protection system. Finally, due to these parameters, the method of determining the rating of air-conditioning system equipment is significantly different than the method used to rate protection system equipment.

As the first phase of determining air-conditioning equipment ratings, the designer should establish whether there is a total separation between the compartments of the air-conditioning system that are exposed to the surrounding atmosphere and the compartments that are exposed to the protected space environment.

The purpose of separation is twofold. First, under most circumstances it should be preferred that the surrounding atmosphere be prohibited from entering the protected space. Second, equipment isolation may allow derating of interior equipment under certain conditions. However, if air is allowed to pass freely between exterior and interior compartments, all equipment within both compartments should be rated for the most onerous condition in accordance with NFPA 496 (2021b), whether that rating is for the surrounding atmosphere or the protected space environment.

For example, within a protected space a DX air-conditioning system is typically designed to recirculate air throughout that space. The exterior compartment contains the condenser coil, the condenser fan, and the compressor and is well separated from the interior compartment containing the electrical controls, evaporator coil, and evaporator recirculation fan or blower and heating coils.

If separation can be achieved as described previously, a designer can establish that the exterior compartment will be exposed only to the surrounding atmosphere and that the interior compartment will be exposed only to the recirculated air within the protected space. However, careful examination and modification may be required to establish a suitable degree of mechanical and physical separation, particularly where refrigerant lines, wiring, or mechanical items such as linkage or motor shafts cross between the two compartments.

Additionally, the locations of ancillary electrical equipment such as capacitors, relays, sensors, contactors, refrigerant flow-reversing solenoids (as used for heat pumps), and all other associated electrical equipment and electronics should be assessed to determine their suitability for the atmosphere or environment they will be exposed to during operation.

Regardless of whether separation can be achieved, all air-conditioning system electrical equipment exposed only to the protected space environment should be rated to meet the applicable protected space area classification and temperature code (T-Code) rating per *NEC* Article 500 (NFPA 2020) in the absence of protection to satisfy NFPA 496 (2021b) requirements.

As an important exception, the electrical equipment exposed only to the protected space environment need not be rated as noted above if it is electrically interlocked to prevent it from being engaged until the protection system becomes fully active and achieves the required level of protection.

If separation can be achieved, all the electrical equipment of an air-conditioning system that is exposed to the surrounding atmosphere should be rated to meet the applicable exterior area classification and T-Code rating, to meet *NEC* Article 500 requirements (NFPA 2020), because this equipment will always operate in the absence of the declassifying effect provided by the protection system.

If separation can be achieved, wiring between the exterior and interior compartments should be sealed in accordance with *NEC* Article 500

(NFPA 2020), because in most circumstances the exterior and interior compartments reside in what can be considered separate but adjacent area classifications.

Additionally, if the protected space contains any source of flammable gases, flammable vapors, or combustible dusts, fail-safe interlocks may be required by provisions in NFPA 496 (2021b), depending on the rating of the protected space. NFPA 496 requirements are based on the rating of the protected space while protected and whether a potential release is limited or unlimited. NFPA 496 requires these interlocks to automatically deactivate all unrated electrical components within the protected space, which includes all electrical components of the air-conditioning system, upon failure of the protection system.

Such fail-safe interlocks should deactivate all nonrated air-conditioning system electrical devices upon the failure of any ventilation hoods or fume extraction systems that may be located within the protected space. The interlocks should also activate the protection system upon the detection of any flammable gases, flammable vapors, or combustible dusts within the protected space and isolate makeup air ducting to the protected space.

This method of isolating air-conditioner compartments and rating air-conditioning system electrical devices is common among manufacturers who produce various types of hazardous location air-conditioning products. This method can be replicated by designers who elect to use other methods of climate control for a protected space, such as those listed within this section.

If total separation of exterior and interior compartments cannot be achieved, all electrical equipment and devices of the air-conditioner system should be rated for the most onerous condition to satisfy NFPA 496 (2021b) requirements, whether that is the rating of the surrounding atmosphere or of the protected space environment.

ELECTRIC HEATING EQUIPMENT ELECTRICAL RATINGS

This section primarily focuses on independent electric heating equipment used in hazardous spaces that is designed to operate independently from any air-conditioning system equipment and the protection system.

As the first phase of determining electric heating equipment ratings, a designer should identify the hazardous (classified) location ratings for the protected space in the absence of a protection system and for the sur-

rounding atmosphere, because they may be different. These ratings should be identified by consulting with facility safety engineers, as recommended in Chapter 3.

The selection of electric heating equipment should then be limited to equipment that is certified by a federally approved Nationally Recognized Testing Laboratory (NRTL), such as UL, FM Approvals (FM), or Canadian Standards Association (CSA), to ensure that the equipment meets the requirements outlined in UL 823, *Electric Heaters For Use in Hazardous (Classified) Locations* (2006).

As the second phase of determining ratings of the electric heating equipment, a designer should identify the temperature code (T-Code) rating of the hazardous (classified) location within the protected space and surrounding atmosphere that would exist in the absence of protection system operation. As noted previously, this rating should be identified by consulting facility safety engineers. The selection of electric heating equipment should then be limited to equipment that is certified as suitable for the identified T-Code rating.

Additionally, if the protected space contains any source of flammable gases, flammable vapors, or combustible dusts, fail-safe interlocks may be required by provisions in NFPA 496 (2021b), depending on the rating of the protected space. NFPA 496 requirements are based on the rating of the protected space while protected and whether a potential release is limited or unlimited. NFPA 496 requires these interlocks to automatically deactivate all unrated electrical devices within the protected space, including all nonrated electrical components of the electric heating system, upon failure of the protection system.

Such fail-safe interlocks should deactivate all nonrated electric heating system equipment upon the failure of any ventilation hoods or fume extraction systems that may be located within the protected space. The interlocks should also activate the protection system upon the detection of any flammable gases, flammable vapors, or combustible dusts within the protected space and isolate makeup air ducting to the protected space.

EQUIPMENT SIZING, REDUNDANCY, AND SAFETY FACTORS

Air-conditioning systems for protected spaces should be sized to overcome the anticipated ambient temperatures of the surrounding atmosphere and the maximum anticipated heat load of all equipment within the protected space using the Nonresidential Cooling and Heating Load Cal-

culations chapter of *ASHRAE Handbook—Fundamentals* (2021). They should also be capable of delivering the required amount of contaminant-free makeup air that is introduced to the protected space.

These systems should also sustain a reasonable level of comfort heating and cooling for occupants and a sustained temperature within the operational levels of all equipment in the protected space. Finally, they should also be sized to overcome any loss of recirculated air within the protected space. Such losses are typically created by frequent egress or as extracted from the space by ventilation hoods or fume extraction systems.

Equipment for protected spaces should be designed with adequate safety factors to ensure faults will be detected and brought to the attention of operators and safety and maintenance personnel. Such safety factors should also include automated activation of emergency ventilation systems as needed to prevent accumulation of hazardous substances and potential ignition, asphyxiation, and other life-safety risks.

Applications such as security centers and living quarters typically have more stable and less demanding heat load compensation requirements. Failure of air conditioners for these spaces may not constitute imminent danger or loss of significant productivity. Such protected spaces may be managed by single-stage air-conditioning systems and conventional heating coils.

In circumstances where frequent egress significantly compromises the efficiency or capacity of an air-conditioning system, entry vestibules may be considered a best practice to maintain pressurization, reduce or eliminate infiltration of unconditioned air, and circumvent the need for equipment oversizing.

Applications such as switchgear buildings, motor control centers, and spaces containing large variable-frequency drives may have less stable and more demanding heat load compensation requirements and also control vital processes within a facility. As a result, failure of air conditioners for these spaces may constitute imminent danger or loss of significant productivity. Such protected spaces may require multistage or redundant air-conditioning systems and heating coils.

Protection systems may require equivalent forms of redundancy or be designed to provide a much wider and more responsive range of capacity.

Additionally, when designing air-conditioning systems for protected spaces that contain sources of substantial heat loads, multiple-stage or variable-capacity air-conditioning systems, potentially apart from the

concept and purpose of redundancy, should be considered to manage potential fluctuating heat loads. This provision is essential if the maximum heat load is not constant or sustained. Otherwise, a single air conditioner designed for the maximum heat load with no means of providing variable cooling capacity will cause excessive condensation in the protected space.

Applications such as analyzer rooms; chemical processing, mixing, and blending spaces; laboratories; and other spaces may contain sources of limited or unlimited releases as defined in the Limited and Unlimited Releases section of Chapter 3. They may also have less stable and more demanding heat load compensation requirements and also either control vital processes or disrupt essential processes within a facility. As a result, failure of air conditioners for these spaces may constitute imminent danger or loss of significant productivity. Such protected spaces may require multistage or redundant air-conditioning systems and heating coils.

Additionally, because these spaces, unlike spaces such as security centers, living quarters, switchgear buildings, and motor control centers, will likely contain a source of contaminants or hazardous substances, additional considerations regarding how the air-conditioning system will interface with or be controlled by the protection system should also be considered.

7

Associated Equipment Design and Installation Requirements



As the final aspect of effective protection systems, proper design and installation are essential for all associated elements of the protection system.

Because protection system equipment impacts life safety, it is imperative that all such equipment is installed in a manner that enables easy service, replacement, and calibration access by maintenance personnel and easy control and monitoring access by operators. In addition, to ensure proper recognition of its purpose, all protection system equipment should be properly identified as safety equipment.

INTAKE DUCT AND STACK PIPE DESIGN AND INSTALLATION

Positive ventilation, pressurization, and dilution protection intake ducts and stack pipes must be sealed to prevent the entrance of contaminants or hazardous substances to satisfy NFPA 496 (2021b) requirements. To further satisfy these requirements, the duct or stack pipe must be constructed from materials that are resistant to prevailing corrosive elements of the surrounding atmosphere so they are protected against mechanical damage. The protection should include provisions to fully secure the duct and pipe so they withstand damage due to inclement weather.

Detailed materials specifications, construction methods, and engineering calculations may be required to ensure the sufficient integrity of the intake duct or stack and to ensure adequate support to withstand maximum wind loads and weights loads.

The intake point for such intake ducts or stacks must draw contaminant-free air to meet NFPA 496 requirements. To achieve this requirement, prevailing wind conditions and normative site conditions should be determined; in the case of offshore installations, the best source of contaminant-free air may be under a deck or platform, not above it.

The same requirements must be applied to duct or stack pipe for negative ventilation and for the exhaust of contaminants or hazardous substances from a protected space.

Additionally, it is essential to ensure that the point of exhaust be directed to an area that is not normally occupied and/or that any particulates be captured in such a manner to ensure they do not contaminate or accumulate within the surrounding environment. Specifically, accumulations should be limited to below enforceable legal permissible exposure limits (PELs) imposed by the Occupational Safety and Health Administration (OSHA; n.d.; see Annotated Tables Z-1, Z-2, and Z-3) and should be limited in a manner that does not render an adjacent space more hazardous or jeopardize the health and safety of people in surrounding environments, spaces, or adjacent areas.

The Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) publishes several useful publications regarding best practices for duct and stack pipe design and construction, including *Round Industrial Duct Construction Standards* (2013), *Rectangular Industrial Duct Construction Standards* (2011c), *Guide for Free Standing Steel Stack Construction* (2011a), and *Guyed Steel Stacks* (2011b).

CONTAMINANT-FREE AIR INLET AND EXHAUST VENT DESIGN AND INSTALLATION

For proper inlet and exhaust vent installation for ventilation, pressurization, and dilution systems, the particle density or specific gravity of all the contaminants and hazardous substances in the surrounding atmosphere or that are emitted by sources within the protected space should be determined. This determination should establish whether the majority of such substances remain suspended, rise, or fall within the protected space environment.

In circumstances where a majority of contaminants or hazardous substances remain suspended or rise, contaminant-free positive ventilation or dilution air inlets should be placed low in the protected space, as far as possible from any potential source within the protected space. Exhaust vents should be placed level to or above and as close as possible to any internal source. These recommendations should apply regardless of the position or location of any associated ductwork that may feed or supply contaminant-free air to the inlets or carry potentially contaminated air to the exhaust vents.

In circumstances where a majority of contaminants or hazardous substances do not remain suspended or fall, contaminant-free positive ventilation or dilution air inlets should be placed high in the protected space, as far as possible from any potential source within the protected space. Where possible, exhaust vents should also be placed level to or below and as close as possible to any internal source.

For negative ventilation, the Ventilation of the Industrial Environment chapter of *ASHRAE Handbook—HVAC Applications* (2019) is the consensus guidance for ensuring the proper removal of contaminants or hazardous substances from a protected space.

When it is essential to prevent the entrance of contaminants or hazardous substances from the surrounding atmosphere, contaminant-free air intake and exhaust vents should be equipped with automatic gas dampers that close upon failure of the protection system.

ROOM PRESSURE AND AIRFLOW SENSOR AND SWITCH DESIGN AND INSTALLATION

All room pressure and airflow sensors or switches should be rated for the most onerous conditions of the surrounding atmosphere or the protected space environment and be wired in accordance with applicable *National Electrical Code* (NEC; NFPA 2020) requirements.

To provide a minimal margin of increased safety, switches and sensors should be calibrated to activate at set points slightly above minimum pressure and airflow requirements.

To satisfy NFPA 496 (2021b) requirements, room pressure sensors and switches should detect differential pressure between the surrounding atmosphere and the protected space environment. They should not be located upstream of any air filter, intake fan, or blower. Satisfying these requirements will prevent any form of false pressure indication.

Airflow sensors for ventilation and pressurization systems should be located as close as possible to dedicated exhaust vents. To prevent any form of false indication, they should not be located upstream of any air filter or at any intake location.

The location of sensors within a protected space for the purpose of detecting potential contaminants or hazardous substances should be planned by qualified process or facility safety engineers.

In addition to controlling the operation of a protection system, all room pressure and airflow sensor and switch circuits should be designed to activate a local or remote alarm device upon the detection of room pressure loss or insufficient airflow. Additionally, such sensors should be designed to activate the protection system at the highest velocity and activate all local and remote alarm devices as applicable and installed in accordance with the guidance set forth in the following section.

GAS DETECTION SYSTEM DESIGN AND INSTALLATION

When used to provide a required or an additional level of protection system safety, gas detection systems should be designed and installed by qualified process or facility safety engineers.

The monitor and any associated power supplies of gas detection systems should be rated for the most onerous conditions of the surrounding atmosphere or protected space environment, be separately powered, and be wired in accordance with applicable *NEC* (NFPA 2020) requirements.

Sensors should be selected to detect the most onerous conditions that may be caused by all flammable, corrosive, or asphyxiating hazardous substances in the surrounding atmosphere or protected space environment. They should also be combined at all locations when multiple hazards have the potential to coexist.

Sensors located within intake ducts or stacks for the purpose of detecting potential contaminants or hazardous substances should be located as close to the inlet as possible. Additionally, such sensors should be designed to deactivate the protection system and activate a local or remote alarm as applicable.

Sensors located within a protected space for the purpose of detecting potential contaminants or hazardous substances should be located within the known stream of exhaust air and/or as close as possible to the exhaust vent. Such sensors should also be designed to activate the protection sys-

tem at the highest velocity and activate all local and remote alarm devices as applicable.

Oxygen deficiency sensors within a protected space should be located at the area of greatest potential asphyxiant concentration, such as areas of most limited air circulation and/or at floor or ceiling levels, depending on the asphyxiants' specific gravity. Such sensors should be designed to activate the protection system at the highest velocity and activate all local and remote alarm devices as applicable.

ALARM SYSTEM DESIGN AND INSTALLATION

As required by NFPA 496 (2021b) and recommended by API RP 500 or API RP 505 (1991, 2018), alarm system devices should be rated for the most onerous conditions of the surrounding atmosphere or protected space environment, be separately powered, and be wired in accordance with applicable *NEC* (NFPA 2020) requirements.

Whenever possible, all alarm device circuits of a protection system should be designed to operate in a fail-safe manner, such that any alarm sensor failure, broken sensor wire, or protection system power failure activates the alarm device.

All local audible or visual alarm devices should be of sufficient intensity and located in such a manner as to draw the immediate attention of nearby operators or maintenance personnel and be clearly labeled to identify their purpose.

All remote alarm devices should be located in a constantly attended area, such as a continuously occupied control room, maintenance center, or operator station and be clearly labeled to identify their purpose. In some facilities the label may also need to identify corrective actions that should be taken to mitigate the situation or fault condition that causes the alarm.

EMERGENCY SHUTDOWN AND VENTILATION SWITCH DESIGN AND INSTALLATION

Emergency shutdown and ventilation switches should be intended to prevent the entrance of any contaminants or hazardous substances due to a catastrophic event in the surrounding atmosphere. If they are used with a negative ventilation system, they should be intended to contain a catastrophic release of contaminants of hazardous substances within a protected space.

As they may be required by the authority having jurisdiction (AHJ) or qualified process or facility safety engineers, emergency shutdown and ventilation override switches should be rated for the most onerous conditions of the surrounding atmosphere or protected space environment and be wired in accordance with applicable *NEC* (NFPA 2020) requirements.

Emergency shutdown and ventilation switch circuits should be designed to operate in a fail-safe manner, such that a broken wire or short circuit activates the intended function of the protection system.

Emergency shutdown and ventilation switches should be located in an immediately accessible area at or near the point of the most common protected space egress and be clearly labeled to identify their purpose.

When used with positive ventilation, pressurization, or dilution systems, emergency shutdown switches should be designed to deactivate the protection system, the air-conditioning system, and all unrated equipment within the protected space and fully close all automatic intake or exhaust dampers.

When activated, an emergency ventilation system should also be designed to de-energize the air-conditioning system and all unrated equipment within the protected space and fully open all automatic intake or exhaust dampers.

8

System Maintenance



Considering the nature and intent of the protection systems defined in this guide, maintenance should be considered an essential priority for sustaining the health and safety of the affected workforce. Therefore, protection systems and related heating and air-conditioning systems should be identified as safety devices. This designation should then serve to advise maintenance personnel to give this equipment the highest priority in comparison to the maintenance of all other non-safety-related facility equipment.

ESTABLISHMENT OF PREVENTIVE MAINTENANCE PROCEDURES

As an essential aspect of design, the recommended preventive maintenance procedures of all equipment should be reviewed and retained for the development of a proactive preventive maintenance program for all protection systems and associated equipment.

Preventive maintenance at a minimum should include routine inspections for excessive wear, repair or replacement of faulty devices, and routine cleaning or replacement of all air filters. Maintenance should also include routine lubrication of rotating parts, motor bearings, and other elements of all air-moving, inlet air and exhaust air dampers, blast dampers, and other moving components.

In addition, because protection systems most likely operate in areas with potential concentrations of flammable gases or vapors or combustible dusts, routine examination to determine operating temperatures should be conducted to ensure all devices are operating within acceptable temperature limits to prevent them from becoming potential sources of ignition.

Furthermore, housekeeping is essential for protection systems located in any areas containing any amounts of combustible dusts and should be considered an important element of system maintenance to be conducted on a routine basis to prevent the accumulation of excessive dust particles.

At a minimum, such housekeeping should include careful cleaning of all protection system equipment and air filters within the contaminant-free airflow stream and all associated ducts and stack pipes used for intake air or exhaust.

Finally, routine performance testing and calibration should be conducted on a semiannual or annual basis at a minimum, by properly trained technicians. These processes should ensure the proper performance of the entire protection system and all associated equipment, including gas detectors, alarm devices, and emergency shutdown and ventilation switches.

9

System Operation



Considering the nature and intent of the protection systems defined in this guide, proper operation is an essential priority to sustain the health and safety of the affected workforce.

A commissioning process, start-up assistance, and factory acceptance testing should be required to ensure the integrity and code compliance of all protection systems.

Prior to start-up, complete operating instructions should be attained and studied by all intended operators. When possible, and especially for more sophisticated protection systems, operator training by duly authorized representatives of any manufactured product should be conducted.

Furthermore, due to the nature of the protection systems defined in this guide, strict procedures and rules limiting the operation of protection systems to only properly trained operators should be strictly enforced.

Operator training should include normal start-up and shutdown procedures; pressure, flow, and temperature adjustments as applicable to some protection systems and air-conditioner systems; and comprehensive emergency start-up and shutdown procedures.

Operators should be instructed or trained to understand the normal operating sequence of automated systems, to understand all operator interface devices and the normal readings of all performance indicators, to properly operate all safety devices, to react in a specific preauthorized

manner to all alarm devices, and to detect and report any abnormalities in system performance.

Operators should also be carefully trained and directed to only use authorized operating procedures, to notify maintenance personnel and safety managers of any system performance concerns, and to request immediate attention to any protection system performance issues in accordance with a proactive safety management program.

References

- ACGIH. 2019. *Industrial ventilation: A manual of recommended practice for design*, 30th ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
- ACGIH. 2020. *Industrial ventilation: A manual of recommended practice for operation and maintenance*, 2nd ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
- AMCA. 1986. ANSI/AMCA Standard 99-0401-86, *Classification for spark resistant construction*. Arlington Heights, IL: Air Movement and Control Association International, Inc.
- API. 1991. API RP 500, *Recommended practice for classification of locations for electrical installations at petroleum facilities*. Washington, DC: American Petroleum Institute.
- API. 2018. API RP 505 2nd ed., *Recommended practice for classification of locations for electrical installations at petroleum facilities classified as class I, zone 0, zone 1, and zone 2*. Washington, DC: American Petroleum Institute.
- ASHRAE. 2015. *Cold-climate buildings design guide*. Peachtree Corners, GA: ASHRAE.
- ASHRAE. 2018. ANSI/ASHRAE/IES Standard 202-2018, *Commissioning process for buildings and systems*. Peachtree Corners, GA: ASHRAE.

- ASHRAE. 2019. *ASHRAE handbook—HVAC Applications*. Peachtree Corners, GA: ASHRAE.
- ASHRAE. 2021. *ASHRAE handbook—Fundamentals*. Peachtree Corners, GA: ASHRAE.
- ASTM. 2009. ASTM E 11-09, *Standard specification for wire cloth and sieves for testing purposes*. West Conshohocken, PA: ASTM International.
- ISA. 2013. ANSI/ISA-71.04, *Environmental conditions for process measurement and control systems: Airborne contaminants*. Research Triangle Park, NC: International Society of Automation.
- McDermott, H.J. 2001. *Handbook of ventilation for contaminant control*, 3rd ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
- NFPA. 2014. NFPA 70, *National electrical code*. Quincy, MA: National Fire Protection Association.
- NFPA. 2017. NFPA 496, *Standard for purged and pressurized enclosures for electrical equipment*. Quincy, MA: National Fire Protection Association.
- NFPA. 2018. NFPA 68, *Standard on explosion protection by deflagration venting*. Quincy, MA: National Fire Protection Association.
- NFPA. 2020. NFPA 70, *National electrical code*. Quincy, MA: National Fire Protection Association.
- NFPA. 2021a. NFPA 204, *Standard for smoke and heat venting*. Quincy, MA: National Fire Protection Association.
- NFPA. 2021b. NFPA 496, *Standard for purged and pressurized enclosures for electrical equipment*. Quincy, MA: National Fire Protection Association.
- NFPA. 2021c. NFPA 497, *Recommended practice for the classification of flammable liquids, gases, or vapors and of hazardous (classified) locations for electrical installations in chemical process areas*. Quincy, MA: National Fire Protection Association.
- NFPA. 2021d. NFPA 499, *Recommended practice for the classification of combustible dusts and of hazardous (classified) locations for electrical installations in chemical process areas*. Quincy, MA: National Fire Protection Association.
- NIOSH. 2007. *NIOSH pocket guide to chemical hazards*, 3rd ed. Washington, DC: U.S. Department of Health and Human Services, Centers

- for Disease Control and Prevention, National Institute for Occupational Safety and Health. www.cdc.gov/niosh/npg/default.html.
- OSHA. n.d. OSHA 1910.1000—*Air contaminants*. Washington, DC: United States Department of Labor, Occupational Safety and Health Administration. www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1000.
- SMACNA. 2011a. *Guide for free standing steel stack construction*. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association.
- SMACNA. 2011b. *Guyed steel stacks*. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association.
- SMACNA. 2011c. *Rectangular industrial duct construction standards*. ANSI/SMACNA 002-2011. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association.
- SMACNA. 2013. *Round industrial duct construction standards*. ANSI/SMACNA 005-2013. Chantilly, VA: Sheet Metal and Air Conditioning Contractors' National Association.
- UL. 2006. UL 823, *Electric heaters for use in hazardous (classified) locations*, edition 9. Northbrook, IL: UL LLC.

Ensuring Safety and Health in Hazardous Spaces

This guide is the first and only overview of its kind in the United States. It covers the proper design, engineering, installation, operation, and maintenance of safe and effective heating, ventilation, pressurization, dilution, filtration, and air-conditioning systems for hazardous spaces. The book places particular emphasis on toxic chemicals, asphyxiants, flammable gases, and combustible dusts; it does not touch on radioactive or pathogenic substances.

This guide presents various techniques and methods developed and refined over time by countless experts within specific fields of interest. Readers will gain insight into the best possible means to ensure that a space is effectively ventilated and conditioned for various levels of occupancy while preserving all aspects of the safety and health of the occupants as well as the protection of surrounding facilities. It also serves as a reference to critical standards, recommended practices, and related publications.



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