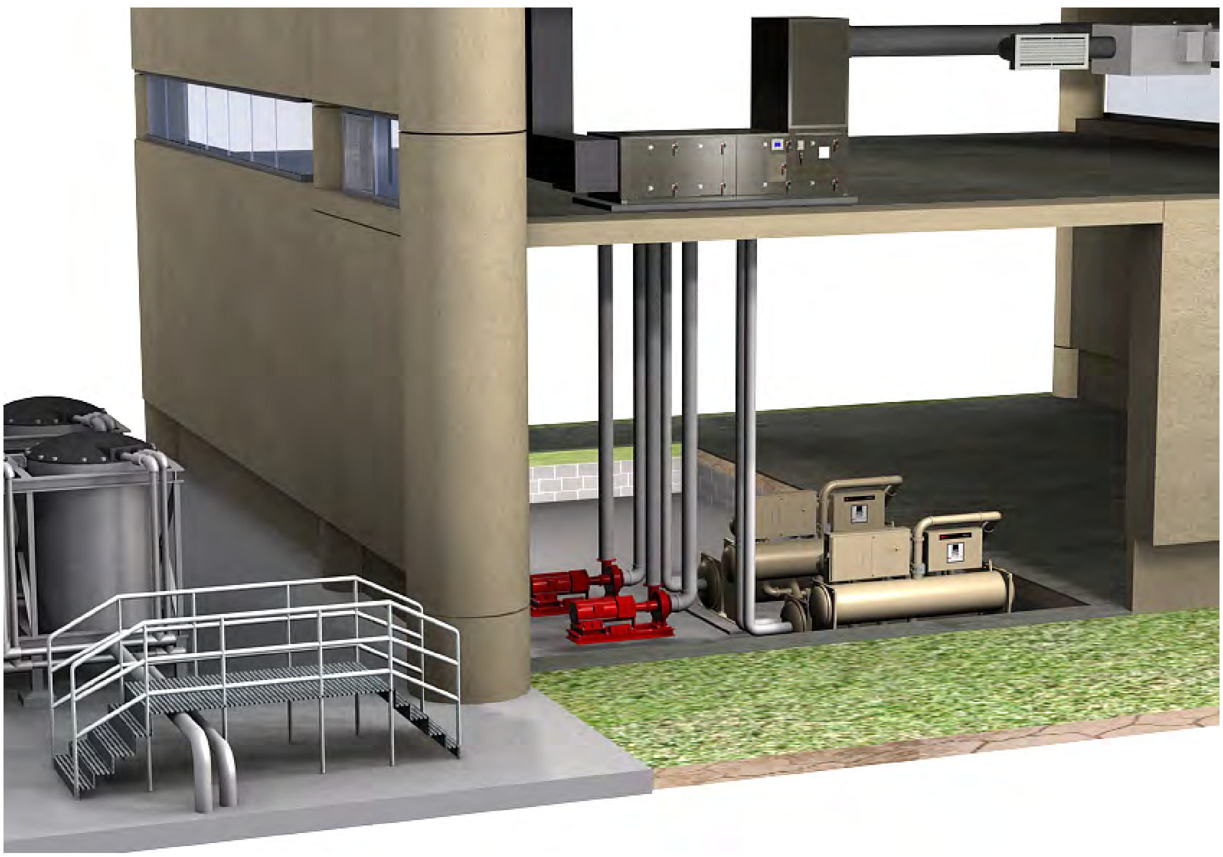
Applications Engineering Manual

Refrigeration Systems and Machinery Rooms

Application Considerations for Compliance with ASHRAE® Standard 15-2022



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Introduction

Building code requirements often originate from published standards (see inset below). Although the original wording and intent may be modified during the code-writing process, familiarity with the underlying standard can be useful in achieving compliance. With that in mind, this manual has been written to help readers understand the refrigerant use restrictions outlined in ANSI/ASHRAE Standard 15–2022, *Safety Standard for Refrigeration Systems*. It is not intended to discuss every requirement in the standard; rather, it attempts to focus on those aspects of the standard that are most pertinent to the HVAC system design engineer.

Enforceability: Industry standard versus building code

Industry standards, such as those authored by ASHRAE® for the HVAC industry, serve as an important reference for code-writing agencies ... but standards are *not* enforceable.

Model code agencies, such as the International Code Council (ICC), look to industry standards and other materials for "best practices." They then develop model (example) codes that states and other governing bodies can legislate into enforceable minimum requirements, which are in turn used as criteria for approval by building inspectors.

The process that transforms an industry standard into enforceable requirements can take several years. Changes in wording, and sometimes intent, may occur along the way to arrive at language that is legally defensible (if not always readily understood).

At minimum, engineering professionals are responsible for specifying designs that satisfy code requirements; but they also may be held accountable for adhering to the relevant ASHRAE standards in their designs. For this reason, we encourage practicing engineers to remain conversant with relevant industry standards and guidelines, as well as the building code.

- **Ammonia.** Standard 15 no longer applies to refrigeration systems that use ammonia (R-717), so this manual does not address ammonia-based systems.
- **Residential applications.** Standard 15 does not apply to residential refrigeration systems that serve only a single dwelling or sleeping unit. These are addressed by ANSI/ASHRAE Standard 15.2, *Safety Standard for Refrigeration Systems in Residential Applications,* and not discussed in this manual.
- **Refrigeration systems used for applications other than human comfort.** While Standard 15 includes requirements related to commercial refrigeration systems, this manual does not address them. Rather, it focuses only on HVAC systems used for human comfort.
- **Section 9.** Most of the requirements in Section 9 of Standard 15 are in the purview of the equipment manufacturer, not the HVAC system design engineer. Therefore, this manual does not discuss Section 9, except for requirements related to the installation of field-installed refrigerant piping used to connect separate components of a refrigeration system (p. 70) and requirements related to sizing and routing of discharge piping from pressure-relief devices (p. 73).

VERSIONS ADDRESSED IN THIS MANUAL

Because ASHRAE Standards 15 and 34 are under continuous maintenance, they can change frequently. This manual is based on the 2022 published version of both standards (consult earlier versions of this manual for content based on older versions of these standards).

Refer to the ASHRAE web site for the most current version of these standards, including any published addenda and errata.

How ASHRAE Classifies Refrigerants

As its title implies, ANSI/ASHRAE Standard 34, *Designation and Safety Classification of Refrigerants*, provides a system for naming and classifying refrigerants.

1. **Purpose.** *This standard is intended to establish a simple means of referring to common refrigerants instead of using the chemical name, formula, or trade name. It establishes a uniform system for assigning reference numbers, safety classifications, and refrigerant concentration limits to refrigerants.*
2. **Scope**. *This standard provides an unambiguous system for numbering refrigerants and assigning composition-designating prefixes for refrigerants. Safety classifications based on toxicity and flammability data are included along with refrigerant concentration limits for the refrigerants.*

Familiarity with refrigerant safety classifications and naming conventions is fundamental to the discussion of design practices for refrigeration systems and machinery rooms. For that reason, a brief review of Standard 34 follows.

NAMING CONVENTIONS

Standard 34 establishes a shorthand method of refrigerant numbering that provides a simple, unambiguous alternative to trade names and chemical formulas. Table 1 (p. 7) shows the proper prefix and identifying numbers for several common refrigerants and refrigerant blends. The R prefix followed by the refrigerant number should be used in technical publications (for international uniformity and to preserve archival consistency), on equipment nameplates, and in project specifications.

In addition to the R prefix, the refrigerant's identifying number is sometimes preceded by a more descriptive, composition-designating identifier that indicates whether the refrigerant contains hydrogen (H), bromine (B), chlorine (Cl), fluorine (F), or carbon (C). For example, R-11—which contains chlorine, fluorine, and carbon—is sometimes designated as CFC-11, while R-22—which contains hydrogen, chlorine, fluorine, and carbon—becomes HCFC-22. In nontechnical, public, and regulatory communications, where distinction between the presence or absence of particular elements is pertinent (e.g., when addressing compounds having environmental impact, such as ozone depletion or global warming potential), the composition designation may be appropriate.

To avoid confusion or misunderstanding when referring to refrigerants, choose one of the permitted naming conventions (either R-22 or HCFC-22, for example) and use it consistently throughout the documentation for a project.

Table 1. Characteristics, safety classification, and allowable amounts for several common refrigerants[a]

Refrigerant Number	Safety Group	OEL	RCL			LFL			Relative Molar Mass, M[b]	"Highly Toxic" or "Toxic" per code[c]
		(ppm)	(ppm)	(g/m^3)	(lb/1000 ft^3)	(ppm)	(g/m^3)	(lb/1000 ft^3)		
R-11	A1	1,000	1,100	6.1	0.39				137.4	Neither
R-12	A1	1,000	18,000	90	5.6				120.9	Neither
R-22	A1	1,000	59,000	210	13				86.5	Neither
R-32	A2L	1,000	36,000	77	4.8	144,000	306	19.1	52.0	Neither
R-113	A1	1,000	2,600	20	1.2				187.4	Neither
R-123	B1	50	9,100	57	3.5				153.0	Neither
R-134a	A1	1,000	50,000	210	13				102.0	Neither
R-152a	A2	1,000	12,000	32	2.0	48,000	130	8.1	66.0	Neither
R-404A[d]	A1	1,000	130,000	500	31				97.6	Neither
R-407C[e]	A1	1,000	81,000	290	18				86.2	Neither
R-410A[d]	A1	1,000	140,000	420	26				72.6	Neither
R-454B[f]	A2L	850	29,000	74	4.6	115,000	296.8	18.5	62.6	Neither
R-513A	A1	650	72,000	320	20				108.4	Neither
R-514A	B1	320	2,400	14	0.86				139.6	Neither
R-515B	A1	810	61,000	290	18				117.9	Neither
R-1233zd(E)	A1	800	16,000	85	5.3				130.5	Neither
R-1234ze(E)	A2L	800	16,000	76	4.7	65,000	303	18.8	114.0	Neither

[a] Refer to Tables 4-1 and 4-2 of ANSI/ASHRAE Standard 34 (including published addenda to the 2022 version) for a complete list of data sources.
[b] Refer to Appendix D of ANSI/ASHRAE Standard 34 (including published addenda to the 2022 version) for a complete list of data sources.
[c] Per ANSI/ASHRAE Standard 34-2022: "*Highly toxic*, *toxic*, or *neither*, where *highly toxic* and *toxic* are as defined in the *International Fire Code, Uniform Fire Code*, and OSHA regulations, and *neither* identifies those refrigerants having lesser toxicity than either of those groups."
[d] Per ANSI/ASHRAE Standard 34-2022: "At locations with altitudes higher than 3300 ft (1000 m) but below or equal to 4920 ft (1500 m), the ODL and RCL shall be 112,000 ppm, and at altitudes higher than 4920 ft (1500 m), the ODL and RCL shall be 69,100 ppm."
[e] Per ANSI/ASHRAE Standard 34-2022: "At locations with altitudes higher than 4920 ft (1500 m), the ODL and RCL shall be 69,100 ppm."
[f] Updated data per addendum a to ANSI/ASHRAE Standard 34-2022 (see sidebar on p. 10).

For more detailed information about the health hazards or recommended handling practices for a particular refrigerant, request a copy of the Material Safety Data Sheet (MSDS) from the refrigerant manufacturer.

Why is GWP not in Standard 34?

The purpose of Standard 34 is to establish a uniform system for assigning reference numbers, safety classifications, and refrigerant concentration limits to refrigerants. It is not intended to be an environmental protection standard.

Global Warming Potential (GWP), defined by the Kyoto Protocol, is a metric that compares all gasses to the baseline of carbon dioxide (CO_2), which has a GWP of 1. Due to the thermodynamic properties of refrigerants, and their stability in the atmosphere, they can often have higher GWP numbers. For example, R-134a has a GWP of 1430, meaning one pound of R-134a is equivalent to 1430 pounds of CO_2. This is significant when understanding the large quantities of refrigerant used by some systems.

In response to global warming concerns, the HVAC industry has responded with HFO refrigerants. These refrigerants have excellent thermodynamic properties, yet are atmospherically unstable. This instability leads to much lower GWPs. For example, R-514A, which is available for use in some centrifugal water chillers, has a GWP of 2.0.

SAFETY GROUP CLASSIFICATIONS

In addition to establishing uniform naming conventions, Standard 34 classifies each refrigerant according to its *toxicity* (Class A or B) and its *flammability* (Class 1, 2L, 2, or 3).

Toxicity

Section 6.1.2 of Standard 34 defines two toxicity categories based on allowable exposure:

- Class A refrigerants are of a lower degree of toxicity, as indicated by an OEL >= 400 ppm.
- Class B refrigerants are of a higher degree of toxicity, as indicated by an OEL < 400 ppm.

Standard 34 defines OEL as the following:

> **occupational exposure limit (OEL):** *The time-weighted average (TWA) concentration for a normal 8-hour workday and a 40-hour workweek to which nearly all workers can be repeatedly exposed without adverse effect.*

A number of similar exposure designations are used in the industry, as shown in this definition from Standard 34:

> **permissible exposure level (PEL):** *The TWA concentration (set by the U.S. Occupational Safety and Health Administration [OSHA]) for a normal 8-hour workday and a 40-hour workweek to which nearly all workers can be repeatedly exposed without adverse effect. Chemical manufacturers publish similar recommendations (e.g., acceptable exposure level [AEL], industrial exposure limit [IEL], or occupational exposure limit [OEL], depending on the company), generally for substances for which PEL has not been established.*

Note that the toxicity classification system used by Standard 34 is different than the classification system used by some building codes. To avoid confusion between the two systems, Tables 4-1 and 4-2 in Standard 34 include a column titled “Highly Toxic or Toxic Under Code Classification.” Code requirements for toxic or highly toxic chemicals should not be applied to chemicals that are classified as “Neither” under the code classification system (see Table 1).

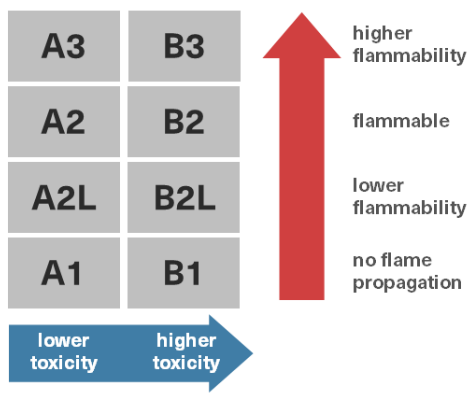
Flammability

The letter designation for toxicity is followed by a number that indicates how readily the refrigerant may ignite. Section 6.1.3 of Standard 34 defines the flammability classifications:

- A Class 3 refrigerant has a very low lower flammability limit (LFL), indicating that it ignites easily and the flame propagates easily.
- A Class 2 refrigerant has lesser flammability characteristics than a Class 3 refrigerant. It has a higher LFL, but is still easy to ignite and propagates flames well.
- A Class 2L refrigerant has an even higher LFL and is more difficult to ignite. (Note: While a Class 2L refrigerant is more difficult to ignite, it is a flammable refrigerant and an ignition event can occur in uncontrolled situations.)
- A Class 1 refrigerant does not exhibit flame propagation, and is commonly referred to as "non-flammable."

Together, the toxicity and flammability classifications define eight safety groups—A1, A2L, A2, A3, B1, B2L, B2, and B3—which are represented by the matrix in Figure 1. Standard 15 refers to these safety group designations in its requirements for refrigeration systems located in or near a building.

Figure 1. Refrigerant safety groups from ASHRAE Standard 34



Refrigerant Concentration Limit (RCL)

Standard 34 also defines the refrigerant concentration limit for each refrigerant. The RCL is the lowest of the quantities calculated in accordance with the standard for these effects; oxygen deprivation limit (ODL), flammable concentration limit (FCL), and acute toxicity exposure limit (ATEL). By considering this wide array of health and safety effects, the RCL is intended to reduce the risks of acute toxicity, asphyxiation, and flammability hazards in normally-occupied, enclosed spaces.

RCL replaced the "Quantity of Refrigerant Per Occupied Space" values used in earlier versions of Standards 15 and 34. The RCL for a flammable refrigerant is typically defined as the lower flammability limit (LFL) divided by four.

Lower Flammability Limit (LFL)

Standard 34 defines the LFL for all Class 2L, Class 2, and Class 3 refrigerants as:

> **lower flammability limit (LFL):** *The minimum concentration of a substance, a refrigerant in this standard, that is capable of propagating a flame through a homogeneous mixture of the substance and air under specified test conditions.*

The LFL is also used by Standard 15 to define restrictions and requirements related to the use of flammable refrigerants, as explained in the rest of this manual.

When complying with the requirements of Standard 15, it is important to use the latest data related to refrigerant safety.

The foreword to Standard 15 explains that *"Although changes to Standard 15 are closely coordinated with those to Standard 34, users of Standard 15 should also review the most recent version of Standard 34 and its associated addenda for the latest information related to refrigerant designations and safety classifications."*

Appendix A of the standard further explains that *"the user should refer to addenda to the most recent published edition of ASHRAE Standard 34 for the most current values of LFL."*

USING THE TABLES IN STANDARD 34

Table 1 (p. 7) in this manual includes a partial list of the refrigerants and refrigerant blends that are classified in Standard 34.

As an example, R-134a is classified as a Group A1 refrigerant: Class A because it's OEL is >= 400 ppm, and Class 1 because it will not propagate a flame. The RCL for R-134a is 13 lbs/1000 ft^3 (210 g/m^3).

As an another example, R-32 is classified as a Group A2L refrigerant: Class A because it's OEL is >= 400 ppm, but Class 2L because it is flammable. In addition to the RCL, the table in Standard 34 also defines the LFL for this refrigerant as 19.1 lbs/1000 ft^3 (306 g/m^3).

Restrictions on Refrigerant Use

The stated purpose of ANSI/ASHRAE Standard 15, *Safety Standard for Refrigeration Systems,* is to help in specifying:

> *... safe design, construction, installation, and operation of refrigeration systems.*

And Section 2 outlines its scope:

> *This standard applies to:*
>
> *(a) the design, construction, test, installation, operation, and inspection of mechanical and absorption refrigeration systems, including heat-pump systems used in stationary applications;*
>
> *(b) modifications, including replacement of parts or components if they are not identical in function and capacity; and*
>
> *(c) substitutions of refrigerants having a different designation.*

Standard 15 details the design and installation requirements for a broad range of refrigeration systems, from a small window air conditioner to a large water chiller. It applies not only to newly-installed systems, but also to replacements or alterations that change the function of the system, as well as conversions to a different type of refrigerant. Some of the requirements of the standard are general and apply to all system types. Other requirements are specific to the type and use of the refrigeration system.

ANSI/ASHRAE Standard 15 is subject to continuous maintenance to help ensure that its content remains relevant. This review process allows portions of the standard to be revised without republishing the entire document. Upon approval, each revision is issued as an electronic addendum. Addenda to standards can be downloaded at no cost from the ASHRAE web site (www.ashrae.org).

The design practices presented in this application manual are based on the **2022 edition** of Standard 15 (without addenda, but with errata as of 7/17/2023). Visit the ASHRAE web site regularly to check for updated errata, addenda or newer published versions.

REFRIGERANT, OCCUPANCY, AND SYSTEM CLASSIFICATIONS

To help identify which safety requirements must be met to achieve compliance with Standard 15:

1. Identify the *safety group classification* of the refrigerant.
2. Determine the *occupancy classification* of the room being served by the refrigeration system.
3. Determine the relevant *system probability* classification.

Step 1: Identify the safety group classification of the refrigerant

As discussed in the previous chapter, refrigerants are classified into one of eight groups according to their *flammability* and *toxicity*. These safety classification criteria are listed and defined in Standard 34. Table 1 (p. 7) lists the safety group classifications for several commonly-used single-compound refrigerants and refrigerant blends.

Step 2: Determine the occupancy classification

Section 4 in Standard 15 defines six occupancy classifications to reflect the various uses of a building and the ability of the people inside to respond in case of emergency (Table 2).

Key to proper use of these classifications is an understanding of what is meant by the terms *occupied space* and *machinery room*. Standard 15 offers these definitions:

occupied space: That portion of the premises accessible to or occupied by people, excluding machinery rooms.

machinery room: A designated space meeting the requirements of Sections 8.9, 8.10, and 8.11 that contains one or more refrigeration systems or portions thereof, such as compressors and pressure vessels.

In other words, a room that contains refrigeration equipment is *initially* considered an occupied space. Based on the “restrictions on refrigerant use” defined in Section 7 of the standard, that room may need to meet the specific requirements in Sections 8.9, 8.10, and 8.11, which in turn qualify it as a *machinery room*.

For residential applications that are limited to only a single dwelling unit or sleeping unit, refer to ANSI/ASHRAE Standard 15.2, *Safety Standard for Refrigeration Systems in Residential Applications*.

Table 2. Occupancy classifications from ASHRAE Standard 15

Occupancy Classification[a]	Characteristics	Examples
Institutional	Occupants cannot readily leave without the assistance of others	Hospitals, nursing homes, prisons
Public assembly	Occupants cannot quickly vacate due to large numbers of people	Auditoriums, ballrooms, classrooms, restaurants, theaters, depots
Residential	Occupants are provided with complete, independent living facilities	Hotels, dormitories, apartments
Commercial	Occupants transact business, receive personal services, or purchase food and other goods	Office and professional buildings, markets (excluding large mercantile)
Large mercantile	More than 100 occupants congregate either above or below street level to purchase merchandise	Shopping malls
Industrial	Occupancy by the general public is prohibited; access by authorized personnel is controlled	Manufacturing plants, processing plants, storage facilities

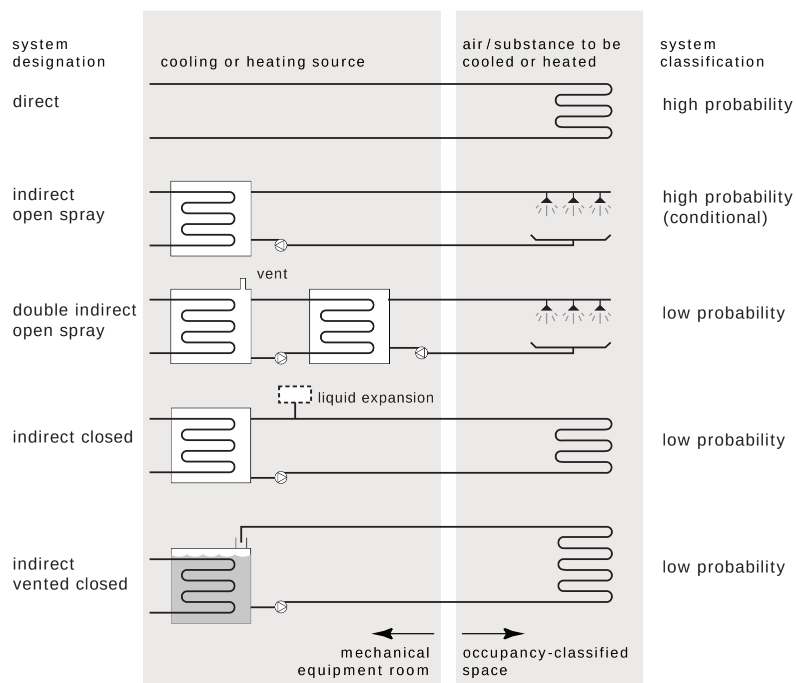
[a] Per Section 4.1.7 of the standard, when each occupancy is isolated from the rest of the building by tight walls, floors, and ceilings, and by self-closing doors, the requirements for each occupancy apply to that portion of the building. (For example, a cold-storage space in a hotel might be classified as an industrial occupancy, while the rest of the building is considered residential.) When the occupancy areas are not isolated in this manner, the occupancy with the most stringent requirements governs the entire area.

Step 3: Determine system probability classification

Section 5 of Standard 15 divides refrigeration systems into two categories based on the likelihood (probability) of refrigerant leaking from a refrigeration system into an occupancy-classified area (i.e., an occupied space). As described below and depicted in Figure 2, p. 13, refrigeration systems are classified as either *high probability* or *low probability:*

- **High-probability systems** are those in which the basic design or location of components is such that leaked refrigerant from a failed connection, seal, or component has a high probability of entering the occupied space. Some common examples include a direct-expansion (DX) split-system, a packaged DX rooftop unit, a water-source heat pump, a variable refrigerant flow (VRF) system, or a PTAC.
- **Low-probability systems** are those in which the basic design or location of components is such that leaked refrigerant from a failed connection, seal, or component has a low probability of entering the occupied space. A typical example is a water chiller, located either outdoors or in a machinery room, that delivers chilled water to one or more remote air-handling units or terminal units.

Figure 2. Refrigeration system classifications from ASHRAE Standard 15



IDENTIFY SAFETY REQUIREMENTS BASED ON THE SYSTEM REFRIGERANT CHARGE

After the safety group, occupancy, and system-probability classifications have been identified, Section 7 of Standard 15 is then used to determine which of the standard's "restrictions on refrigerant use" apply. And then Standard 15 includes general requirements (Section 10), which apply to any type of refrigeration system, as well as restrictions on refrigerant use (Section 7) and installation restrictions (Section 8), which apply to specific types of refrigeration systems.

Group A3 and B3 refrigerants are restricted to only certain applications

Section 7.5.3 of the standard prohibits the use of Group A3 and B3 refrigerants, with only a few exceptions:

- Refrigeration systems located in machinery rooms or outdoors are exempt.
- Industrial occupancies are exempt.
- Laboratories with more than 100 ft^2 (9.3 m^2) of floor space per person are exempt.
- Listed, self-contained systems containing no more than 0.331 lb (150 g) of a Group A3 refrigerant are exempt.
- Equipment listed to UL 60335-2-89/CSA C22.2 No. 60335-2-89, and containing no more than 0.459 x LFL lb (13 x LFL kg) of a Group A3 refrigerant, is exempt.
- Equipment listed to UL 60335-2-40/CSA C22.2 No. 60335-2-40, and containing no more than 0.106 x LFL lb (3 x LFL kg) of a Group A3 refrigerant, is exempt.

UL 60335-2-89/CSA C22.2 No. 60335-2-89 is a product safety standard for commercial refrigeration equipment.

UL 60335-2-40/CSA C22.2 No. 60335-2-40 is a product safety standard for heat pump, air conditioning, and dehumidification equipment (see p. 26 for further discussion).

As technology has advanced, higher-flammability refrigerants are being used more frequently in equipment like vending machines, refrigerators, and water coolers. As long as these "listed" systems have a refrigerant charge that does not exceed the stated threshold, they are allowed by Standard 15. However, use and location of this equipment may be subject to other codes.

Group A2, A3, B1, B2L, B2, and B3 refrigerants cannot be used in high-probability systems for human comfort, with few exceptions

Standard 15 uses the terms **unit system** or **self-contained system** interchangeably, defined as *"a complete, factory-assembled and factory-tested system that is shipped in one or more sections and has no refrigerant containing parts that are joined in the field by other than companion valves or block valves."*

Section 7.5.2.1 of the standard prohibits the use of these refrigerants in high-probability systems that provide human comfort. That leaves only Group A1 or A2L refrigerants that may be used in this application. However, due to the flammability characteristics of A2L refrigerants, the standard prescribes special requirements for their use in this application (see "Requirements for Group A2L Refrigerants Used in High-Probability Systems for Human Comfort," p. 26).

There are a few exceptions to Section 7.5.2.1:

- Industrial occupancies are exempt.
- Unit systems that have a refrigerant charge less than 6.6 lb (3 kg) in a residential occupancy, or less than 22 lb (10 kg) in a commercial occupancy, are exempt.

Refrigerant system charge limits

If all or part of a refrigeration system is housed indoors, then Section 7.3 defines the maximum refrigerant charge permitted, using compliance path depicted in a flowchart (Figures 7-1 and 7-2 in the standard). Portions of this flowchart have been recreated for explanation in this manual.

In addition to this compliance path, the standard includes the following overriding limitations:

According to Standard 15, **listed equipment** is *"included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose."*

These organizations are called nationally recognized testing laboratories (NRTL). Common examples include Underwriters Laboratory (UL), Intertek (ETL), and CSA Group.

- The total refrigerant charge of all systems containing Group A2, A3, B2, and B3 refrigerants cannot exceed 1100 lb (500 kg), unless approved by the authority having jurisdiction (Section 7.5.1.1).
- For an institutional occupancy, the total refrigerant charge of all systems containing Group A2, A3, B2, and B3 refrigerants cannot exceed 550 lb (250 kg), even if some or all of the equipment is installed in a machinery room (Section 7.3.2).

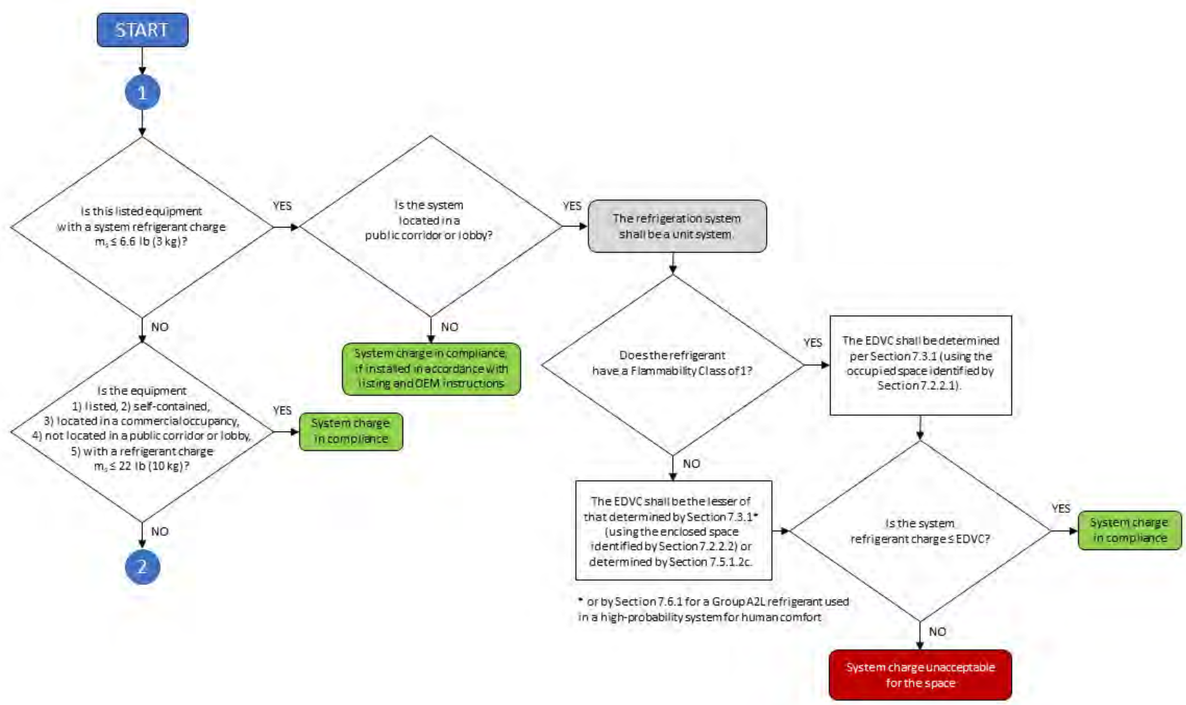
Listed equipment in a residential occupancy

If the refrigeration equipment is a) "listed," b) "self-contained," and c) is located in a residential occupancy (but not in a public corridor or lobby), then the system charge will be in compliance if it contains <= 6.6 lb (3 kg) of any refrigerant, provided the equipment is installed in accordance with the listing and with the manufacturer's installation instructions (Figure 3).

Listed equipment in a commercial occupancy

If the refrigeration equipment is a) "listed," b) "self-contained," and c) is located in a commercial occupancy (but not in a public corridor or lobby), then the system charge will be in compliance if it contains <= 22 lb (10 kg) of refrigerant (Figure 3).

Figure 3. Refrigerant system charge limit compliance path (flowchart segment 1)



System in a public corridor and lobby

If the refrigeration system is located in a public corridor or lobby (Figure 3 or see Section 7.5.1.2), then it must be a "unit system" with a refrigerant charge no greater than the effective dispersal volume charge, or EDVC (see "Effective dispersal volume charge," p. 20).

If the refrigerant has a **Flammability Class of 1**, the EDVC is determined using the equation in Section 7.3.1 with the effective dispersal volume (V_{eff}) based on the occupied space served by the refrigeration system.

If the refrigerant has a **Flammability Class of 2L, 2, or 3**, the system must be "listed" with the EDVC being the lesser of the values determined using a) the equation in Section 7.3.1* with the effective dispersal volume (V_{eff}) based on the occupied space or non-occupied space served by the refrigeration system, or b) the following equation from Section 7.5.1.2c:

* or by Section 7.6.1 for a Group A2L refrigerant used in a high-probability system for human comfort.

$m_S = 0.106 \times LFL$
($m_S = 3 \times LFL$)

where,

m_S = maximum refrigerant charge for each unit system, lb (kg)

LFL = lower flammability limit of the refrigerant, lb/1000 ft^3 (kg/m^3)*

* Note that the values tabulated in ASHRAE Standard 34 are in units of g/m^3, so be sure to convert to the correct units when using this formula.

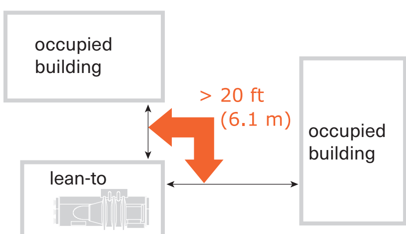
System located in a machinery room or outdoors

If all the refrigerant-containing components of a "low-probability" system are located in a machinery room or outdoors, the system charge is in compliance (Figure 5 or see Section 7.4).

The term "machinery room" has a special meaning in Standard 15; it is defined as a designated space that complies with the requirements listed in Sections 8.9, 8.10, and 8.11. Which of these requirements apply depends on the safety group classification of the refrigerant(s) in use (see "Machinery Rooms," p. 45).

Refrigeration systems that are located outdoors must comply with the requirements listed in Section 8.12. If the refrigerant-containing equipment is enclosed by a penthouse, lean-to, or other open structure, then either natural or mechanical ventilation must be provided.

Figure 4. Remote naturally-ventilated structure



location is a naturally vented, remote structure more than 20 ft (6.1 m) from openings in adjacent occupied buildings

To use natural ventilation, the structure must be more than 20 ft (6.1 m) from building openings (see Figure 4), and the size of the natural ventilation openings must be determined by the following equation:

$F = G^{0.5}$
$(F = 0.138 \times G^{0.5})$

where,

F = minimum required free open area, ft^2 (m^2)

G = mass of refrigerant in largest system, any part of which is located in the machinery room, lb (kg)

The location of these natural ventilation openings must then be based on the relative density of the refrigerant to air.

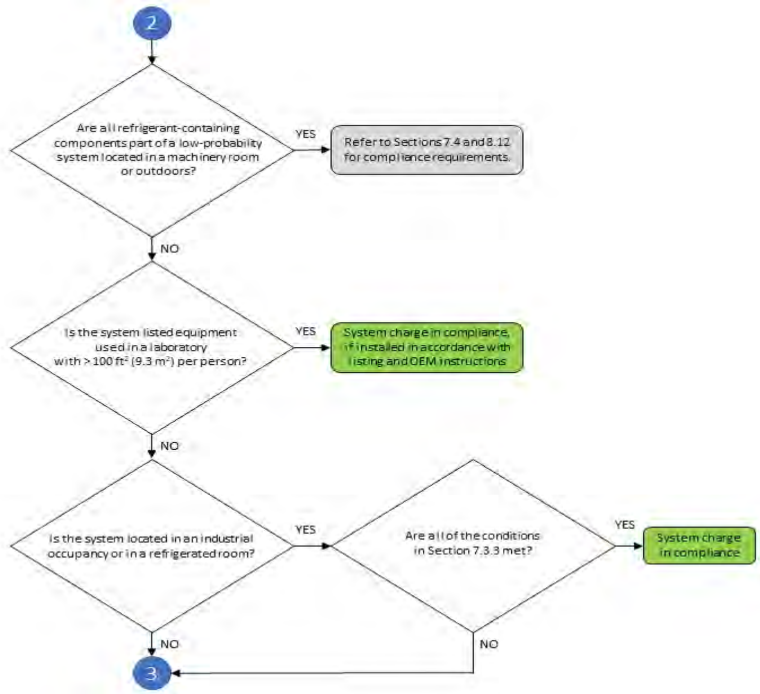
Listed equipment in a laboratory

If the refrigeration system is "listed" and used in a laboratory with > 100 ft^2 (9.3 m^2) of floor area per person, then the system charge is in compliance, provided the equipment is installed in accordance with the listing and with the manufacturer's installation instructions (Figure 5).

System in an industrial occupancy or in a refrigerated room

If the refrigeration system is located in an industrial occupancy or in a refrigerated room, and it meets all of the requirements listed in Section 7.3.3, then the system charge is in compliance (Figure 5).

Figure 5. Refrigerant system charge limit compliance path (continued, flowchart segment 2)



For all other systems, the releasable refrigerant charge (m_{rel}) must be no greater than the effective dispersal volume charge (EDVC)

If none of the previous conditions apply, the releasable refrigerant charge (m_{rel}) of the system must be no greater than the EDVC (Figure 6). The EDVC (see "Effective dispersal volume charge," p. 20) depends on the safety group classification of the refrigerant:

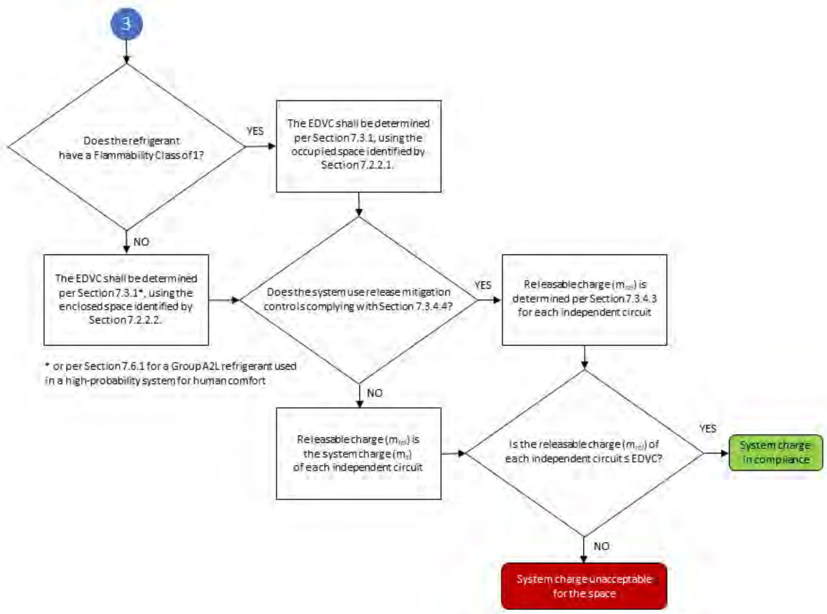
- If the refrigerant has a **Flammability Class of 1**, the EDVC is determined using the equation in Section 7.3.1 with the effective dispersal volume (V_{eff}) based on the occupied space served by a refrigeration system (see Section 7.2.2.1).
- If the refrigerant has a **Flammability Class of 2L, 2, or 3**, the EDVC is determined using the equation in Section 7.3.1 with the effective dispersal volume (V_{eff}) based on the occupied space or non-occupied space served by a refrigeration system (see Section 7.2.2.2). However, when a Group A2L refrigerant in used in a high-probability system for human comfort, the EDVC is determined per Section 7.6.1 instead (see “Requirements for Group A2L Refrigerants Used in High-Probability Systems for Human Comfort,” p. 26).

Determination of the releasable refrigerant charge (m_{rel}) depends on whether the refrigeration system uses "release mitigation controls" (Figure 6):

- If release mitigation controls are not used, or for any system located in an institutional occupancy, m_{rel} is the total mass of refrigerant in each independent circuit of the refrigeration system, including both factory and field refrigerant charges.

- If release mitigation controls complying with Section 7.3.4.4 are used, and the occupancy classification is anything other than institutional, m_{rel} is determined using the equations in Section 7.3.4.3 (see "Releasable refrigerant charge," p. 23).

Figure 6. Refrigerant system charge limit compliance path (continued, flowchart segment 3)



If the releasable refrigerant charge exceeds the EDVC, can a refrigerant detector be installed to allow compliance with Standard 15?

The standard does not currently exempt a “high-probability” system that exceeds the EDVC by installing just a refrigerant detector. Where detectors are required by the standard—such as in a machinery room or to permit the use of a Group A2L refrigerant—they are one component of a multiple-component compliance package. Refrigerant detectors are never allowed as a standalone mitigation.

If the releasable refrigerant charge (m_{rel}) is greater than the effective dispersal volume charge (EDVC), consider one (or a combination) of the following modifications, which are each described in the following sections:

- The effective dispersal volume (V_{eff}) could be increased by connecting the non-compliant space to other spaces via permanent natural ventilation openings. This would result in a higher EDVC.
- The configuration of the refrigeration system could be changed to make use of a ducted air distribution system, thereby increasing the effective dispersal volume (V_{eff}) by connecting the non-compliant space to other spaces via the air distribution system. This would result in a higher EDVC.
- A mechanical ventilation system could be used to remove excess leaked refrigerant from the non-compliant space. The portion of the system refrigerant charge that is removed by the mechanical ventilation system (m_S – EDVC) is not included when determining compliance with the EDVC.
- The refrigeration system could be equipped with release mitigation controls that limit the release of refrigerant by automatically isolating the leaking piping or equipment. This would result in a smaller releasable refrigerant charge (m_{rel}).
- The system could be changed to use more independent refrigerationcircuits, which would result in a smaller releasable refrigerant charge (m_{rel}).

Effective dispersal volume charge

Section 7.3.1 describes how to calculate the effective dispersal volume charge (EDVC), which is the maximum charge permitted for an effective dispersal volume (see "Effective dispersal volume," p. 20). The concept is based on a maximum allowable concentration of refrigerant (RCL) that could result from a complete discharge into the volume of a space. If the resulting concentration of refrigerant in that space does not exceed the RCL, the building occupants should not be exposed to a harmful level of refrigerant, provided that the refrigerant disperses equally throughout the space.

To calculate the EDVC, the refrigerant concentration limit (RCL) is multiplied by the effective dispersal volume (V_{eff}) and an adjustment factor for the occupancy classification (F_{occ}):

$$EDVC = RCL \times V_{eff} \times F_{occ}$$
$$(EDVC = RCL \times V_{eff} \times F_{occ} / 1000)$$

where,

EDVC = effective dispersal volume charge, lb (kg)

RCL = refrigerant concentration limit of the refrigerant, lb/ft^3 (g/m^3)*

V_{eff} = effective dispersal volume per Sections 7.2.1 through 7.2.3, ft^3 (m^3)

F_{occ} = occupancy adjustment factor (0.5 for institutional; 1.0 for all others)

* Note that the values tabulated in ASHRAE Standard 34 are in units of lb/1000 ft^3, so be sure to convert to the correct units when using this formula.

See the "EDVC Examples" chapter (p. 33) for examples of this calculation for various types of refrigeration systems.

If a **Group A2L refrigerant** is used in a high-probability system for human comfort, the EDVC is calculated per Section 7.6.1 instead (see "Requirements for Group A2L Refrigerants Used in High-Probability Systems for Human Comfort," p. 26).

Effective dispersal volume

The effective dispersal volume (V_{eff}) is the volume of a space (or connected spaces) into which refrigerant is expected to disperse in the event of a refrigerant leak.

Section 7.2 describes how to calculate this dispersal volume, and whether to use just the volume of an individual room or to include the volume of connected spaces.

The volume of an individual room is defined in Section 7.2.3.1:

> *7.2.3.1 Room Volume. The effective dispersal volume shall be established by the following physical enclosure elements: walls, floors, ceilings, windows or doors which can be closed, and partitions connecting to and extending from the finished floor to more than 5.5 ft (1.7 m) above the floor. Where different stories and floor levels connect through an open atrium or mezzanine, the effective dispersal volume shall be determined by multiplying the floor area of the lowest floor level by 8.2 ft (2.5 m) ceiling height.*

- If the refrigerant has a **Flammability Class of 1**, V_{eff} is based on the occupied space served by a refrigeration system (per Section 7.2.2.1).
- If the refrigerant has a **Flammability Class of 2L, 2, or 3**, V_{eff} is based on the occupied space or non-occupied space served by a refrigeration system (per Section 7.2.2.2).

As defined in Standard 15, an **occupied space** is *"that portion of the premises accessible to or occupied by people, excluding machinery rooms."*

Areas of the building that contain only continuous sections of refrigerant piping, or that contain only joints and connections that have been tested in accordance with Section 9.13 (see "Inspection and leak testing," p. 71), are exempt per Section 7.2.3.1.1. This means that they do not need to be considered in the V_{eff} calculations, unless these areas are part of connected spaces (see below).

When calculating V_{eff} it is helpful to think of room volumes in terms of non-connected spaces and connected spaces.

A **non-connected space** is an enclosed space that contains part of a refrigeration system, but is not connected to other spaces by permanent natural ventilation openings, a ducted air distribution system, or a mechanical ventilation system. Refrigerant released into a non-connected space essentially stays in that space and does not disperse into other parts of the building.

Some examples might include a hotel guest room that includes a packaged terminal air conditioner (PTAC) along the exterior wall or an office with a high sidewall terminal unit that is part of a VRF system.

In this case, the room volume of this individual, non-connected space is used to calculate V_{eff}.

Connected spaces are two or more spaces that are connected by permanent natural ventilation openings, a ducted air distribution system, or a mechanical ventilation system. Refrigerant released into a connected space, or into the air distribution system, can disperse into all the connected spaces, as well as into the air distribution system itself.

Spaces connected by permanent natural ventilation openings

When two or more spaces are connected by permanent natural ventilation openings, refrigerant released into one of the connected spaces can disperse into all the other connected spaces.

In previous versions of Standard 15, it was left up to the design engineer to determine what constituted a suitable "permanent opening" for the spaces to be deemed connected. In the 2022 version of the standard, however, Section 7.2.3.2 now includes prescriptive requirements for these openings:

- Spaces connected by natural ventilation openings must be on the same floor of a building.
- Equations are provided in the standard to determine the required minimum size (net free area) of the permanent natural ventilation opening(s). These equations differ depending on the Flammability Class of the refrigerant being used.
- The lower edge of any natural ventilation opening(s) between the connected spaces must be no higher than 12 in. (305 mm) above the finished floor.
- Any area of the opening(s) that is higher than 12 in. (305 mm) above the floor cannot be considered for meeting the minimum size requirement.

For a non-ducted system—such as a VRF system, mini-split, or PTAC—V_{eff} is the room volume plus the volume of any adjacent space(s) connected via permanent natural ventilation openings.

For example, if a PTAC is located in a hotel guest room, the volume of the bathroom is likely excluded because the bathroom door can isolate it from the portion of the guest room that contains the refrigeration system.

See the "EDVC Examples" chapter (p. 33) for examples of calculating the required minimum size (A_{vent}) of permanent natural ventilation openings.

Spaces connected by a ducted air distribution system

When all or part of the refrigeration system is located within an air distribution system, or in a space that is served by a ducted air distribution system, refrigerant released can disperse into all the connected spaces, as well as into the air distribution system itself.

A common example is a packaged DX rooftop unit where an evaporator coil is located in the airstream that supplies conditioned air to several spaces in the building. Another example might be a water-source heat pump or VRF terminal installed in the ceiling plenum and connected to one or more spaces by ductwork.

Per Section 7.2.3.3, when calculating V_{eff} for spaces connected by a ducted air distribution system, include:

- The volumes of all spaces that are served by common supply and return ductwork, unless a space can be totally closed off from the source of the refrigerant leak by something other than a smoke or fire damper. The standard specifically addresses VAV terminal units: as long as the VAV damper does not reduce airflow below 10 percent of its design airflow (whenever the central supply fan is operating), the volume of the space it serves may be included in the calculation of V_{eff}.
- The volume of the supply and return ductwork itself.
- The volume of a ceiling or floor plenum, if it is part of the supply- or return-air path.

...but exclude:

- The volumes of any spaces that can be closed off (isolated) from the source of the refrigerant leak by a door, shutter, or other device.

See the "EDVC Examples" chapter (p. 33) for examples of calculating V_{eff} and EDVC for various types of ducted air distribution systems.

Spaces connected by a mechanical ventilation system

In the context of Standard 15, **mechanical ventilation** refers to removing air (and leaked refrigerant) from a space, and either exhausting it outdoors or transferring it to another space. This is different than introducing outdoor air to a space for the purpose of achieving acceptable indoor air quality.

Per Section 7.2.3.4, when two or more spaces are connected by a mechanical ventilation system (used to comply with the requirements in Section 7.6.4), refrigerant released can disperse into all the connected spaces, as well as any transfer ductwork that is part of the ventilation system.

As clarified in the footnote under Table 7-4 of the standard, the portion of the system refrigerant charge (m_s – EDVC) that is removed by the mechanical ventilation system is not considered when determining compliance with the EDVC (see "Mechanical ventilation requirements," p. 31).

Releasable refrigerant charge

Section 7.3.4 describes how to determine the releasable refrigerant charge (m_{rel}). Note that m_{rel} is not the sum of the refrigerant charges in all of the refrigeration systems; rather it is the mass of refrigerant that would completely discharge from an independent refrigeration circuit. If a space is affected by components of more than one refrigeration system, or a system with more than one circuit, it is necessary to review each circuit separately to ensure that it’s releasable refrigerant charge does not exceed the EDVC threshold.

Determination of m_{rel} depends on whether the refrigeration system uses "release mitigation controls":

- If release mitigation controls are not used, or for any system located in an institutional occupancy, m_{rel} is the total mass of refrigerant in each independent circuit of the refrigeration system, including both factory and field refrigerant charges.
- If release mitigation controls complying with Section 7.3.4.4 are used to limit a release by automatically isolating the leaking piping or equipment, and the occupancy classification is anything other than institutional, m_{rel} can be determined using the following equations from Section 7.3.4.3. This accounts for the quantity of refrigerant that will release prior to operation of the release mitigation controls plus the quantity of refrigerant that is downstream of any release mitigation controls.

$m_{rel} = (t_{r1} \times 0.0062\ lb/s) + m_{r2} + m_{r3}$
$(m_{rel} = [t_{r1} \times 0.0028\ kg/s) + m_{r2} + m_{r3})$

$m_{r2} = t_{close} \times 0.0062\ lb/s$
$(m_{r2} = t_{close} \times 0.0028\ kg/s)$

$m_{r3} = \Sigma V_{pipe} \times \rho_{ref}$

where,

m_{rel} = releasable refrigerant charge, lb (kg)

t_{r1} = time before the leak is detected (per Section 7.6.2.4), sec

m_{r2} = leakage that occurs between detection of the leak and closing of the safety shutoff valve, lb (kg)

m_{r3} = leakage that occurs from piping downstream of safety shutoff valve after the valve is closed, lb (kg)

t_{close} = time from when a leak is detected until safety shutoff valve closes, sec

ΣV_{pipe} = total internal volume of all piping, and the heat exchanger coil, downstream of safety shutoff valve, ft^3 (m^3)

ρ_{ref} = density of refrigerant in piping downstream of safety shutoff valve, lb/ft^3 (kg/m^3)

See the "EDVC Examples" chapter (p. 33) for examples of calculating m_{rel} when release mitigation controls are used.

While it is possible to install release mitigation controls at the job site, it is not enough for the components to simply be listed for the purpose. They must be specifically listed for the purpose and with the specific system. This requirement is meant to prohibit the installation of field-engineered release mitigation controls that may not be safe.

While there is a limitation on the maximum capacity of the "indoor unit," there is no limitation on the number of indoor units on the system. Further, it is not required to install release mitigation controls on every indoor unit.

These controls can be used with either an A2L or A1 refrigerant. For a Group A1 refrigerant, the refrigerant detector setpoint is the RCL.

Requirements for release mitigation controls

In order to take credit for the presence of release mitigation controls when calculating the releasable refrigerant charge (m_{rel}), these controls must comply with all the requirements in Section 7.3.4.4.

7.3.4.4 Release Mitigation Controls. Release mitigation controls used to limit the releasable refrigerant charge (m_{rel}) shall comply with the following:

a. Release mitigation systems shall be components of a refrigeration system that is listed per UL 60335-2-40/CSA C22.2 No. 60335-2-40 or UL 60335-2-89/CSA C22.2 No. 60335-2-89 and evaluated by the nationally recognized testing laboratory as part of the listing.

b. Release mitigation controls shall only be permitted for reducing the releasable refrigerant charge (m_{rel}) on a refrigeration system where each indoor unit has a cooling capacity of 5 tons (17.5 kW) or less.

c. Release mitigation controls shall be activated by a refrigerant detection system. A refrigerant detector shall be located either in all refrigeration equipment serving the spaces or in all spaces served by the release-mitigation-controlled circuit. The refrigerant detector shall activate the release mitigation controls and isolate all possible paths of refrigerant that can leak into the space(s).

d. In the event of a failure of the release mitigation controls or a refrigerant detector, the release mitigation controls shall isolate all possible paths of refrigerant that can leak into the space(s).

e. Refrigerant detectors shall comply with Section 7.6.2.4 and shall activate the mitigation controls per Section 7.6.2.5. For Group A1 refrigerants, 100% of RCL shall be substituted in place of 25% of LFL.

f. The location of refrigerant mitigation controls shall be marked in accordance with the requirements of ASME A13.1.

g. Release mitigation controls shall be tested in accordance with Section 9.13.

Requirements for Group A2L Refrigerants Used in High-Probability Systems for Human Comfort

Per Section 7.5.2.1, a Group A2L refrigerant is allowed to be used in a "high-probability" system that provides human comfort. However, Section 7.6 prescribes additional requirements for this application, due to the flammable nature of the refrigerant.

"LISTED" EQUIPMENT MUST BE USED

High-probability systems used for human comfort, which contain a Group A2L refrigerant, must be "listed" in accordance with one of the following standards (Section 7.6.2):

- UL 60335-2-40/CSA C22.2 No. 60335-2-40, *Standard for Household and Similar Electrical Appliances–Safety–Part 2-40: Particular Requirements for Electrical Heat Pumps, Air-Conditioners and Dehumidifiers*
- UL 484, *Standard for Room Air Conditioners*

According to Standard 15, **listed equipment** is *"included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose."*

These organizations are called nationally recognized testing laboratories (NRTL). Common examples include Underwriters Laboratory (UL), Intertek (ETL), and CSA Group.

UL 60335-2-40/CSA C22.2 No. 60335-2-40

Prepared by Underwriters Laboratories Inc. (UL) and CSA Group, UL 60335-2-40/CSA C22.2 No. 60335-2-40 is a product safety standard for HVAC equipment in the United States and Canada.

While the ASHRAE committee attempted to harmonize the requirements in Standard 15 with those in UL 60335-2-40/CSA C22.2 No. 60335-2-40, there are some instances where the standards differ.

Manufacturers of HVAC equipment are likely to follow the requirements of UL 60335-2-40/CSA C22.2 No. 60335-2-40 strictly, in order to ensure that their products are "listed"—as noted previously, this listing is a requirement of Section 7.6.2 in Standard 15. Depending on the application, it is possible that a specific requirement of Standard 15 could be more stringent than what is required by UL 60335-2-40/CSA C22.2 No. 60335-2-40. Following are some examples of these differences, not an exhaustive comparison of the standards:

- Both standards prescribe a maximum refrigerant charge. Based on this charge, UL 60335-2-40/CSA C22.2 No. 60335-2-40 requires the manufacturer to calculate the minimum floor area of the room served by the equipment using a determined minimum installation height, and then indicate both of these values on the product nameplate. As explained below, Section 7.6.1 of Standard 15 bases its EDVC calculation on an effective dispersal volume (V_{eff}).

- UL 60335-2-40/CSA C22.2 No. 60335-2-40 does not include an occupant adjustment factor (F_{OCC}) when determining the maximum refrigerant charge. Therefore, for an occupancy classified as "institutional," the Standard 15 calculation of EDVC will likely be more stringent.
- There are some applications where Standard 15 might require a refrigerant detection system, while UL 60335-2-40/CSA C22.2 No. 60335-2-40 does not (see "Refrigerant Detection System," p. 29).
- UL 60335-2-40/CSA C22.2 No. 60335-2-40 prescribes several methods for the manufacturer to measure or calculate the releasable refrigerant charge (m_{rel}). This may result in a value higher or lower than is calculated per Section 7.3.4 in Standard 15.

REFRIGERANT QUANTITY LIMITS

As explained in the previous chapter of this manual, Standard 15 allows the use of certain strategies, such as release mitigation controls and/or connected spaces, to comply with the effective dispersal volume charge (EDVC) limit.

When a Group A2L refrigerant is used in a high-probability system for human comfort, the EDVC is calculated per Section 7.6.1. This limit depends on whether or not the system has "air circulation" (either continuous or that is initiated by a refrigerant detector).

Standard 15 defines **air circulation** as *"mechanically inducing airflow within a space or spaces connected by air ducts."* The explanatory material in Appendix A further clarifies that:

> *"Continuous air circulation will be performed by the listed equipment. The airflow will be detected continuously or monitored continuously. As specified by the product safety standard, within ten seconds of the event that the airflow is reduced below a certain quantity, the user is warned and compressor operation may be disabled. Continuous air circulation by means other than the listed equipment is not acceptable. The minimum continuous air circulation airflow rate is established in the product safety standard and does not require the fan to operate at full speed."*

In the context of Standard 15, air circulation is used to help disperse leaked refrigerant throughout the effective dispersal volume. It does not require supplying outdoor air to the space or exhausting air from the space.

Air circulation is different than **mechanical ventilation**. In the context of Standard 15, mechanical ventilation refers to removing air (along with leaked refrigerant) from a space, and either exhausting it the outdoors or transferring it to another space. This requires replacing this removed air with makeup air, either brought in from outdoors or from another indoor space.

Systems with air circulation

If the system has either continuous air circulation (except during short periods for maintenance or service) or air circulation that is initiated by a refrigerant detector that complies with Section 7.6.2.4, the EDVC is calculated as follows (Section 7.6.1.1):

$$EDVC = LFL \times V_{eff} \times CF \times F_{occ}$$

where,

EDVC = effective dispersal volume charge, lb (kg)

LFL = lower flammability limit of the refrigerant, lb/ft^3 (kg/m^3)*

V_{eff} = effective dispersal volume per Sections 7.2.1 through 7.2.3, ft^3 (m^3)

CF = concentration factor = 0.5

F_{occ} = occupancy adjustment factor (0.5 for institutional; 1.0 for all others)

* Note that the values tabulated in ASHRAE Standard 34 are in units of lb/1000 ft^3 and g/m^3, so be sure to convert to the correct units when using this formula.

See the "EDVC Examples" chapter (p. 33) for examples of calculating EDVC when a Group A2L refrigerant is used in a high-probability system for human comfort.

Other systems

If the system does not have either continuous air circulation, or air circulation that is initiated by a refrigerant detector, the EDVC is calculated as follows (Section 7.6.1.2):

$$EDVC = M_{def} \times F_{LFL} \times F_{occ}$$

where,

EDVC = effective dispersal volume charge, lb (kg)

M_{def} = refrigerant charge from Table 7-1, lb (or from Table 7-2, kg)

F_{LFL} = LFL conversion factor from Table 7-3, dimensionless

F_{occ} = occupancy adjustment factor (0.5 for institutional; 1.0 for all others)

While Table 7-1 (or Table 7-2) in the standard includes values for heights between 2.0 ft (0.6 m) and 9.0 ft (2.75 m), this does not mean that a lower or higher release height is prohibited. The standard clarifies that:

"Heights below 2.0 ft (0.6 m) shall use the first height column. Heights greater than 9.0 ft (2.75 m) shall use the last height

When using this method, M_{def} is read from Table 7-1 (or Table 7-2) in the standard, and is based on the floor area and height of the refrigerant release into the space:

- The floor area is for the effective dispersal volume, established in accordance with Section 7.2.

- The height is the lowest point of any opening in the supply air duct, the return air duct, or in the equipment itself. This is the lowest height from which leaked refrigerant can enter the space.

With regard to the “opening” from which leaked refrigerant can enter the space, the explanatory material in Appendix A clarifies that:

> *Opening: Cumulative openings smaller than 0.8 in.^{2} (5 cm^2) and openings with a single dimension of not more than 0.004 in. (0.1 mm) are not considered as openings from where leaking refrigerant can escape.*

Note that in Table 7-1 (or Table 7-2), for a larger floor area the allowable refrigerant charge (M_{def}) will be higher. And for a higher release height, M_{def} will be higher, since the refrigerant is expected to disperse wider as it drops toward the floor.

REFRIGERANT DETECTION SYSTEM

If a high-probability system for human comfort uses a Group A2L refrigerant, Section 7.6.2.3 requires that it must have an integral refrigerant detection system in any of the following cases:

- A ducted HVAC system that has a releasable refrigerant charge (m_{rel}) greater than 4.0 lb (1.8 kg) and has any duct openings lower than 5.9 ft (1.8 m) above the finished floor.
- A ducted HVAC system in which "connected spaces" served by the same supply air duct are used to calculate the effective dispersal volume (V_{eff}) per Section 7.2.
- A refrigeration system installed where the occupancy classification is institutional.

Even if not required by the standard, many systems will likely be equipped with a refrigerant detector to enable the use of the EDVC calculation for systems with air circulation (see "Systems with air circulation," p. 28). Additionally, this does provide an added level of safety. Finally, having the refrigerant detector installed in the factory by the manufacturer reduces the risk of improper installation in the field.

When required, this integral refrigerant detection system must meet the following requirements from Section 7.6.2.4:

- Must be capable of detecting the presence of the specific refrigerant contained in the refrigeration system.
- If exposed to a refrigerant concentration that exceeds a setpoint (determined by the manufacturer, but not to exceed 0.25 × LFL), it must generate an output signal (within 30 seconds or less) to initiate the mitigation actions required by Section 7.6.2.5.

- This setpoint must not be adjustable in the field and field recalibration of the refrigerant detection system is not permitted.
- The detection system must include self-diagnostics to determine the operational status of the sensing element, and must energize the air circulation fan(s) of the equipment upon failure of a self-diagnostic check.
- The equipment must allow access for replacement of refrigerant detection system components.

The explanatory material in Appendix A clarifies that these requirements:

> *"are intended to harmonize Standard 15 with the requirements of ... UL 60335-2-40/CSA C22.2 No. 60335-2-40. A refrigerant detection system* [that is part] *of equipment listed to UL 60335-2-40/CSA C22.2 No. 60335-2-40 meets the requirements of this section.*

REQUIRED MITIGATION ACTIONS

Once the refrigerant detection system generates the output signal (see above), Section 7.6.2.5 requires the following mitigation actions to be completed within 15 seconds or less, and must continue for at least 5 minutes after the detector has sensed a drop in refrigerant concentration below the setpoint value:

- Energize the air circulation fan(s) of the equipment.
- Open any zone dampers installed in the ductwork connected to the refrigeration system (or set zone dampers to their maximum airflow setpoint).
- De-energize any electric resistance heaters installed in the ductwork connected to the refrigeration system, and de-energize any other potential ignition sources (see further discussion below).
- Activate any safety shutoff valves that are used to reduce the releasable refrigerant charge.
- Activate mechanical ventilation, if it's required by Section 7.6.4 (see further discussion below).

The explanatory material in Appendix A clarifies that:

> *"safety shutoff valves located on the low side of the refrigeration system may remain open during pump-down to reduce releasable refrigerant charge. The pump-down cycle should not reduce the low-side pressure below atmospheric pressure, and the safety shutoff valves must close at the end of the pump-down cycle to be considered to meet this requirement."*

IGNITION SOURCES CANNOT BE INSTALLED IN DUCTWORK

If a ducted system experiences a refrigerant leak, it is critical to prevent ignition in the ductwork. Therefore, open-flame-producing devices and unclassified electrical devices cannot be installed in ductwork that serves the space (Section 7.6.3).

Hot surfaces exceeding 1290°F (700°C) are permitted in the ductwork if an average air velocity >= 200 ft/min (1.0 m/s) can be maintained across the heating device, and a proof-of-airflow device ensures airflow before the heating device is energized (Section 7.6.3.3).

The explanatory material in Appendix A clarifies that **mechanical ventilation** required by Standard 15 is *"not intended to control indoor air quality. Rather, ventilation in Standard 15 serves as a safety mitigation method for reducing the refrigerant concentration within a space."*

In the context of Standard 15, mechanical ventilation refers to removing air (along with leaked refrigerant) from a space, and either exhausting it the outdoors or transferring it to another space.

MECHANICAL VENTILATION REQUIREMENTS

According to Section 7.6.4, if the largest refrigerant charge from an independent circuit (m_S) exceeds the EDVC , then a mechanical ventilation system is required to remove this excess leaked refrigerant (m_S – EDVC) from the space. This requires the use of a separate fan to exhaust air from the space, or to transfer air to a separate indoor space.

As clarified in the footnote under Table 7-4 of the standard, (m_S – EDVC) is the portion of the system refrigerant charge that is removed by mechanical ventilation, so it is therefore not included when determining compliance with the EDVC.

Required ventilation rate

The required minimum mechanical ventilation rate can be determined using Tables 7-4 and 7-5 in the standard, or by using the following equation:

$$Q_{req} = SF_{vent} \times (m_S - EDVC) / (4 \text{ minutes} \times LFL)$$
$$(Q_{req} = SF_{vent} \times 60 \text{ minutes/hour} \times [m_S - EDVC] / [4 \text{ minutes} \times LFL])$$

where,

Q_{req} = required mechanical ventilation airflow rate, ft^3/min (m^3/h)

m_S = largest system refrigerant charge from an independent circuit, lb (kg)

EDVC = effective dispersal volume charge calculated per Section 7.6.1, lb (kg)

LFL = lower flammability limit of the refrigerant, lb/ft^3 (kg/m^3)*

SF_{vent} = safety factor = 2

* Note that the values tabulated in ASHRAE Standard 34 are in units of lb/1000 ft^3 and g/m^3, so be sure to convert to the correct units when using this formula.

See the "EDVC Examples" chapter (p. 33) for an example of calculating Q_{req} when mechanical ventilation is required.

The mechanical ventilation system can either operate continuously (except during short periods for maintenance or service) or be activated by a refrigerant detector (in accordance with Section 7.6.2.4) and continue to operate for at least 5 minutes after the detector has sensed a drop in refrigerant concentration below the setpoint value.

Makeup- and discharge-air openings

When the mechanical ventilation system is operating, makeup air must be provided at a volumetric flow rate that does not exceed Q_{req}. Openings for makeup air should be positioned to allow the makeup air to mix with leaked refrigerant.

Intakes for the exhaust air (or intakes used to transfer air to another indoor space), must be located such that the bottom of the intake is no higher than 12 in. (30 cm) above the lowest elevation in the space where leaked refrigerant would be expected to accumulate.

Discharge from this ventilation system must be located to prevent recirculation of exhaust air back into the space.

Fans in mechanical ventilation system

The fan(s) used in this mechanical ventilation system must be listed in accordance with either UL 507, *Standard for Electric Fans*, or UL 705, *Power Ventilators*.

Rotating elements must be non-ferrous or non-sparking, or the casing must consist of (or be lined with) such material.

Electric fan motors larger than 1 hp (0.7 kW) located in the airstream on the discharge side of the ventilation system must be totally enclosed or hermetically sealed.

Verification of ventilation function

The function of the ventilation system must be verified by a monthly self-test (or continuously, if the mechanical ventilation operates continuously) to confirm operation.

If the test fails, compressor operation must be stopped and a notification sent to an operator workstation (or by a local audible alarm).

No ignition sources in the space where equipment is located

There can be no open-flame-producing devices that do not contain a flame arrestor, or hot surfaces exceeding 1290°F (700°C), installed in the space where the refrigerant-containing equipment is located.

EDVC Examples

As explained in the previous chapters, in order for most applications to comply with Standard 15, the releasable refrigerant charge (m_{rel}) must not exceed the effective dispersal volume charge (EDVC). This chapter includes several examples for calculating m_{rel} and EDVC.

EXAMPLE 1: PACKAGED (DX) ROOFTOP UNIT SERVING A CLASSROOM

A single 5-ton (18-kW), packaged, direct-expansion (DX) rooftop unit serves a 1000-ft^2 (93-m^2) classroom in a K-12 school building, with a 10-ft (3-m) ceiling height. The occupancy classification is "public assembly," so the occupancy adjustment factor (F_{occ}) is 1.0.

The rooftop unit consists of a single refrigeration circuit. Supply air is ducted to four diffusers located throughout the classroom, while return air passes through a ceiling-mounted grille into a 1.5-ft (0.46-m) tall open ceiling plenum before traveling through a short section of return ductwork into the rooftop unit.

This system is categorized as a "high-probability" system because a portion of the refrigeration system (the evaporator) is located in the airstream, and a refrigerant leak from this evaporator would result in refrigerant being dispersed to the occupied space by the supply air.

This is an example of "connected spaces" via a ducted air distribution system. As explained in a previous chapter, when calculating the effective dispersal volume (V_{eff}) of the connected spaces in this example, include the following:

- The volume of the classroom, which is 10,000 ft^3 (280 m^3).
- The volume of the supply and return ductwork. (However, this will be ignored in this example since the supply ductwork is routed through a ceiling plenum that is used as part of the return-air path.)
- The volume of the open ceiling plenum—since it is part of the return-air path in this example—, which is 1500 ft^3 (43 m^3).

...but exclude the following:

- The volume of the restroom that is attached to this classroom, since it is not served by the rooftop unit or the return-air plenum, and can be closed (isolated) from the source of the refrigerant leak by a door.

For this example, the effective dispersal volume (V_{eff}) of the connected spaces is 11,500 ft^3 (323 m^3).

If this system uses a Group A1 refrigerant:

The rooftop unit consists of a single 5-ton (18-kW) refrigeration circuit containing 6 lb (2.7 kg) of R-410A refrigerant. Per Section 7.3.4.1, the releasable refrigerant charge (m_{rel}) is the entire charge of 6 lb (2.7 kg).

Standard 34 lists R-410A as Group A1 refrigerant with an RCL equal to 26 lb/1000 ft^3 or 0.026 lb/ft^3 (420 g/m^3). Therefore, the EDVC is calculated to be 299 lb (136 kg):

$$\text{EDVC} = 0.026 \text{ lb/ft}^3 \times 11{,}500 \text{ ft}^3 \times 1.0 = 299 \text{ lb}$$
$$(\text{EDVC} = 420 \text{ g/m}^3 \times 323 \text{ m}^3 \times 1.0 / 1000 = 136 \text{ kg})$$

The releasable refrigerant charge—m_{rel} = 6 lb (2.7 kg)—is much lower than the EDVC, so this system complies with the limit prescribed by Section 7.3.

In these examples, note that using R-454B requires a smaller refrigerant charge than R-410A, when providing the same cooling capacity.

If this system uses a Group A2L refrigerant:

The rooftop unit consists of a single 5-ton (18-kW) refrigeration circuit containing 5.1 lb (2.3 kg) of R-454B refrigerant. Per Per Section 7.3.4.1, the releasable refrigerant charge (m_{rel}) is the entire charge of 5.1 lb (2.3 kg).

Standard 34 lists R-454B as Group A2L refrigerant with an LFL equal to 18.5 lb/1000 ft^3 or 0.0185 lb/ft^3 (296.8 g/m^3 or 0.2968 kg/m^3).

In this example, if the roofop unit did not include a refrigerant detector to initiate air circulation when a leak is detected, the EDVC must be calculated per Section 7.6.1.2 (see "Other systems," p. 28).

Since this is a high-probability system used for human comfort, the use of a Group A2L refrigerant means that the requirements of Section 7.6 apply. The rooftop unit in this example includes a refrigerant detector—that complies with Section 7.6.2.4—to initiate air circulation in the event that a leak is detected. Therefore, per Section 7.6.1.1, the EDVC is calculated to be 106 lb (47.9 kg):

$$EDVC = 0.0185\ lb/ft^3 \times 11{,}500\ ft^3 \times 0.5 \times 1.0 = 106\ lb$$
$$(EDVC = 0.2968\ kg/m^3 \times 323\ m^3 \times 0.5 \times 1.0 = 47.9\ kg)$$

For a refrigeration system listed by UL 60335-2-40, the maximum charge is limited by that product listing standard. If a product is listed, this ensures compliance with the maximum charge rules.

For this example, the releasable refrigerant charge—m_{rel} = 5.1 lb (2.3 kg)—is much lower than the EDVC, so this system complies with the limit prescribed by Section 7.6.1.

EXAMPLE 2: VRF SYSTEM SERVING A "COMMERCIAL" OCCUPANCY

A variable-refrigerant-flow (VRF) system serves several private offices and conference rooms in a small commercial office building. This VRF system consists of a 12-ton (42-kW) air-source outdoor unit with a single refrigeration circuit, and a ceiling cassette serving each zone.

The room being analyzed is a 100-ft^2 (9.3-m^2) private office with a 10-ft (3-m) ceiling height, so the effective dispersal volume (V_{eff}) of this room is 1000 ft^3 (28 m^3). For a "commercial" occupancy classification, the occupancy adjustment factor (F_{occ}) is 1.0.

If this system uses a Group A1 refrigerant:

Including the interconnecting refrigerant piping, the total charge of this example VRF system is 32 lb (14.5 kg) of R-410A refrigerant. Per Section 7.3.4.1, if the system is not equipped with release mitigation controls, the releasable refrigerant charge (m_{rel}) is equal to the entire charge of 32 lb (14.5 kg).

Standard 34 lists R-410A as Group A1 refrigerant with an RCL equal to 26 lb/1000 ft^3 or 0.026 lb/ft^3 (420 g/m^3). Therefore, the EDVC for this private office is calculated to be 26.0 lb (11.8 kg):

$$EDVC = 0.026\ lb/ft^3 \times 1000\ ft^3 \times 1.0 = 26.0\ lb$$
$$(EDVC = 420\ g/m^3 \times 28\ m^3 \times 1.0\ /\ 1000 = 11.8\ kg)$$

Since the releasable refrigerant charge—m_{rel} = 32 lb (14.5 kg)—is greater than the EDVC for this private office, the system does NOT comply with the limit prescribed by Section 7.3 in the standard.

As described in the "Restrictions on Refrigerant Use" chapter (p. 11), this VRF system could be equipped with release mitigation controls, which would result in a smaller releasable refrigerant charge (m_{rel}). Or the effective dispersal volume (V_{eff}) could be increased by connecting this non-compliant private office to other spaces either by permanent natural ventilation openings or by an air distribution system. Each of these modifications will be explored below. The design engineer might choose to implement only one or a combination of these modifications.

Adding release mitigation controls

The indoor VRF cassette serving this private office is equipped with a safety shutoff valve—that complies with the requirements of Section 7.3.4.4—to limit the release of refrigerant by automatically isolating leaking piping or equipment.

The time (t_{close}) from when a leak is detected until the safety shutoff valve closes is 10 seconds. Therefore, the leakage (m_{r2}) that occurs between detection of the leak and closing of the safety shutoff valve is calculated to be 0.062 lb (0.028 kg):

m_{r2} = 10 sec × 0.0062 lb/s = 0.062 lb
(m_{r2} = 10 sec × 0.0028 kg/s = 0.028 kg)

Standard 15 does not provide any guidance as the what value(s) to use for refrigerant density in this calculation. For this example, calculation of m_{r3} assumes the piping and heat exchanger are completely flooded with liquid refrigerant. While this may not be a normal operating condition, it is a worst case scenario that might occur if the refrigerant migrates when the system is off and equalizes with the surrounding air temperature.

The UL/CSA standard (see p. 26) prescribes several methods for the manufacturer to measure or calculate this releasable refrigerant charge (m_{rel}). This value provided by the manufacturer may be higher or lower than is calculated per Standard 15.

Downstream of the safety shutoff valve, there is 50.0 ft (15.2 m) of ACR copper piping to route refrigerant to and from the VRF ceiling cassette. One run of piping is 1/2-in. diameter—inside diameter, ID = 0.430 in. or 0.0358 ft (10.9 mm or 0.0109 m)—and the other run is 5/8-in. diameter—inside diameter, ID = 0.545 in. or 0.0454 ft (13.8 mm or 0.0138 m). The heat exchanger inside the indoor VRF cassette serving this private office has an internal volume of 0.0156 ft^3 (0.000442 m^3), so the total internal volume (ΣV_{pipe}) of the piping downstream of the safety shutoff valve, plus the heat exchanger, is calculated to be 0.147 ft^3 (0.00413 m^3):

$$\Sigma V_{pipe} = [\pi \times (0.0358\ ft/2)^2] \times 50.0\ ft + [\pi \times (0.0454\ ft/2)^2] \times 50.0\ ft + 0.0156\ ft^3 = 0.147\ ft^3$$

$$(\Sigma V_{pipe} = [\pi \times (0.0109\ m/2)^2] \times 15.2\ m + [\pi \times (0.0138\ m/2)^2] \times 15.2\ m + 0.000442\ m^3 = 0.00413\ m^3)$$

At a room temperature of 70°F (21°C), the saturated liquid density of R-410A is 66.1 lb/ft^3 (1060 kg/m^3). Therefore, the leakage (m_{r3}) that occurs from piping downstream of the safety shutoff valve, after the valve is closed, is calculated to be 9.72 lb (4.38 kg):

m_{r3} = 0.147 ft^3 × 66.1 lb/ft^3 = 9.72 lb
(m_{r3} = 0.00413 m^3 × 1060 kg/m^3 = 4.38 kg)

The time (t_{r1}) before the leak is detected is 10 seconds. Therefore, the releasable refrigerant charge (m_{rel}) for this occupied space is calculated to be 9.84 lb (4.44 kg):

m_{rel} = (10 sec × 0.0062 lb/s) + 0.062 lb + 9.72 lb = 9.84 lb
(m_{rel} = [10 sec × 0.0028 kg/s] + 0.028 kg + 4.38 kg = 4.44 kg)

With the release mitigation controls, the reduced releasable refrigerant charge—m_{rel} = 9.84 lb (4.44 kg)—is now lower than the calculated EDVC of 26.0 lb (11.8 kg), so the system charge is now in compliance for this private office.

Adding permanent natural ventilation openings

The VRF system in this example contains R-410A, which is a Group A1 refrigerant, so the equation from Section 7.2.3.2.1 is used for determining the required minimum size (A_{vent}) of a permanent natural ventilation opening:

$$A_{vent} = \frac{m_{rel} - m_{room}}{RCL \times 0.833} \times \sqrt{\frac{A}{g \times m_{room}} \times \frac{M}{M - 29}}$$

$$\left(A_{vent} = \frac{m_{rel} - m_{room}}{RCL \times 208} \times \sqrt{\frac{A}{g \times m_{room}} \times \frac{M}{M - 29}}\right)$$

If the system in this example is NOT equipped with release mitigation controls, the releasable refrigerant charge (m_{rel}) is equal to the entire charge of 32 lb (14.5 kg). The allowable refrigerant charge (m_{room} or EDVC) was previously calculated to be 26.0 lb (11.8 kg).

Per Appendix D in Standard 34, the relative molar mass (M) of R-410A is 72.6 (dimensionless). Therefore, the required minimum net free area of the permanent natural ventilation opening (A_{vent}) is calculated to be 0.123 ft^2 or 17.7 in^2 (0.0113 m^2 or 113 cm^2):

$$A_{vent} = \frac{32\text{ lb} - 26\text{ lb}}{26\text{ lb}/1000\text{ ft}^3 \times 0.833} \times \sqrt{\frac{100\text{ ft}^2}{32.2\frac{\text{ft}}{\text{s}^2} \times 26\text{ lb}} \times \frac{72.6}{72.6 - 29}} = 0.123\text{ ft}^2$$

$$A_{vent} = \frac{14.5\text{ kg} - 11.8\text{ kg}}{0.42\text{ kg/m}^3 \times 208} \times \sqrt{\frac{9.3\text{ m}^2}{9.81\frac{\text{m}}{\text{s}^2} \times 11.8\text{ kg}} \times \frac{72.6}{72.6 - 29}} = 0.0113\text{ m}^2$$

Therefore, this private office could be constructed with permanent natural ventilation openings to one or more adjacent rooms. If the net free area of these openings is at least 0.123 ft^2 or 17.7 in^2 (0.0113 m^2 or 113 cm^2), and they comply with the requirements of Section 7.2.3.2, then the private office and those adjacent rooms can be considered "connected spaces." This would allow the volumes of those adjacent rooms to be added to the volume of this private office to increase the effective dispersal volume (V_{eff}), which would subsequently increase the EDVC.

Reconfiguring the system to use a ducted air distribution system

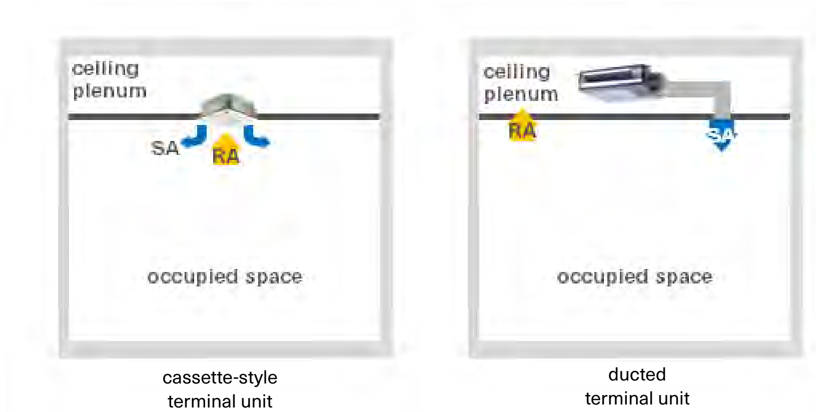
The VRF ceiling cassette serving the private office in this example could be replaced by a ducted VRF terminal installed in the open ceiling plenum, which is then used as part of the return-air path (Figure 7). According to Section 7.2.3.3.2, the volume of this ceiling plenum could then be included in the effective dispersal volume (V_{eff}), since it is part of the return-air system.

The combined volume of this private office plus the entire open ceiling plenum of this office building is now 7300 ft^3 (207 m^3), which increases the EDVC to 190 lb (86.9 kg):

EDVC = 0.026 lb/ft^3 × 7300 ft^3 × 1.0 = 190 lb
(EDVC = 420 g/m^3 × 207 m^3 × 1.0 / 1000 = 86.9 kg)

Even without release mitigation controls, the releasable refrigerant charge—m_{rel} = 32 lb (14.5 kg)—is lower than this newly-calculated EDVC, so the system charge is now in compliance for this private office.

Figure 7. Example space served by a VRF indoor terminal unit



In these examples, note that using R-454B requires a smaller refrigerant charge than R-410A, when providing the same cooling capacity.

If this system uses a Group A2L refrigerant:

Including the interconnecting refrigerant piping, the total charge of this example VRF system is 27 lb (12.2 kg) of R-454B refrigerant. Per Section 7.3.4.1, if the example system is not equipped with release mitigation controls, the releasable refrigerant charge (m_{rel}) is equal to the entire charge of 27 lb (12.2 kg).

In this example, if the VRF terminal unit did not include a refrigerant detector to initiate air circulation when a leak is detected, the EDVC must be calculated per Section 7.6.1.2 (see “Other systems,” p. 28).

Standard 34 lists R-454B as Group A2L refrigerant with an LFL equal to 18.5 lb/1000 ft^3 or 0.0185 lb/ft^3 (296.8 g/m^3 or 0.2968 kg/m^3).

Since this is a high-probability system used for human comfort, the use of a Group A2L refrigerant means that the requirements of Section 7.6 apply. The VRF terminal unit serving the private office in this example includes a refrigerant detector—that complies with the requirements of Section

7.6.2.4—to initiate air circulation in the event that a leak is detected. Therefore, per Section 7.6.1.1, the EDVC is calculated to be 9.25 lb (4.16 kg):

$$EDVC = 0.0185\ lb/ft^3 \times 1000\ ft^3 \times 0.5 \times 1.0 = 9.25\ lb$$
$$(EDVC = 0.2968\ kg/m^3 \times 28\ m^3 \times 0.5 \times 1.0 = 4.16\ kg)$$

For this example, the releasable refrigerant charge—m_{rel} = 27 lb (12.2 kg)—is greater than the EDVC for this private office, so the system does NOT comply with the limit prescribed by Section 7.6.1.

As described in the "Restrictions on Refrigerant Use" chapter (p. 11), this VRF system could be equipped with release mitigation controls, which would result in a smaller releasable refrigerant charge (m_{rel}). Or the effective dispersal volume (V_{eff}) could be increased by connecting this non-compliant private office to other spaces either by permanent natural ventilation openings or by an air distribution system. Or a mechanical ventilation system could be used to remove excess leaked refrigerant from the non-compliant space; the charge that is removed by the mechanical ventilation system is not included when determining compliance with the EDVC. Each of these modifications will be explored below. The design engineer might choose to implement only one or a combination of these modifications.

Adding release mitigation controls

The indoor VRF cassette serving this private office is equipped with a safety shutoff valve—that complies with the requirements of Section 7.3.4.4—to limit the release of refrigerant by automatically isolating leaking piping or equipment.

The time (t_{close}) from when a leak is detected until the safety shutoff valve closes is 10 seconds. Therefore, the leakage (m_{r2}) that occurs between detection of the leak and closing of the safety shutoff valve is calculated to be 0.062 lb (0.028 kg):

$$m_{r2} = 10\ sec \times 0.0062\ lb/s = 0.062\ lb$$
$$(m_{r2} = 10\ sec \times 0.0028\ kg/s = 0.028\ kg)$$

Downstream of the safety shutoff valve, there is 50.0 ft (15.2 m) of ACR copper piping to route refrigerant to and from the VRF ceiling cassette. One run of piping is 1/2-in. diameter—inside diameter, ID = 0.430 in. or 0.0358 ft (10.9 mm or 0.0109 m)—and the other run is 5/8-in. diameter—inside diameter, ID = 0.545 in. or 0.0454 ft (13.8 mm or 0.0138 m). The heat exchanger inside the indoor VRF cassette serving this private office has an internal volume of 0.0156 ft^3 (0.000442 m^3), so the total internal volume (ΣV_{pipe}) of the piping downstream of the safety shutoff valve, plus the heat exchanger, is calculated to be 0.147 ft^3 (0.00413 m^3):

$$\Sigma V_{pipe} = [\pi \times (0.0358\ ft/2)^2] \times 50.0\ ft + [\pi \times (0.0454\ ft/2)^2] \times 50.0\ ft + 0.0156\ ft^3 = 0.147\ ft^3$$

$$(\Sigma V_{pipe} = [\pi \times (0.0109\ m/2)^2] \times 15.2\ m + [\pi \times (0.0138\ m/2)^2] \times 15.2\ m + 0.000442\ m^3 = 0.00413\ m^3)$$

Standard 15 does not provide any guidance as the what value(s) to use for refrigerant density in this calculation. For this example, calculation of m_{r3} assumes the piping and heat exchanger are completely flooded with liquid refrigerant. While this may not be a normal operating condition, it is a worst case scenario that might occur if the refrigerant migrates when the system is off and equalizes with the surrounding air temperature.

The UL/CSA standard (see p. 26) prescribes several methods for the manufacturer to measure or calculate this releasable refrigerant charge (m_{rel}). This value provided by the manufacturer may be higher or lower than is calculated per Standard 15.

At a room temperature of 70°F (21°C), the saturated liquid density of R-454B is 62.6 lb/ft^3 (1000 kg/m^3). Therefore, the leakage (m_{r3}) that occurs from piping downstream of the safety shutoff valve, after the valve is closed, is calculated to be 9.20 lb (4.13 kg):

m_{r3} = 0.147 ft^3 × 62.6 lb/ft^3 = 9.20 lb
(m_{r3} = 0.00413 m^3 × 1000 kg/m^3 = 4.13 kg)

The time (t_{r1}) before the leak is detected is 10 seconds. Therefore, the releasable refrigerant charge (m_{rel}) for this occupied space is calculated to be 9.32 lb (4.19 kg):

m_{rel} = (10 sec × 0.0062 lb/s) + 0.062 lb + 9.20 lb = 9.32 lb
(m_{rel} = [10 sec × 0.0028 kg/s] + 0.028 kg + 4.13 kg = 4.19 kg)

With the release mitigation controls, the reduced releasable refrigerant charge—m_{rel} = 9.32 lb (4.19 kg)—is still slightly higher than the calculated EDVC of 9.25 lb (4.16 kg), so the system charge is still NOT in compliance for this private office. Most of the releasable charge is due to term m_{r3} in the calculation, which is leakage that occurs from piping downstream of the safety shutoff valve after the valve is closed. One option could be to move the safety shutoff valve closer to the VRF ceiling cassette, which would reduce the value of m_{r3}.

Adding permanent natural ventilation openings

The VRF system in this example contains R-454B, which is a Group A2L refrigerant, so the equation from Section 7.2.3.2.2 is used for determining the required minimum size (A_{vent}) of a permanent natural ventilation opening:

$$A_{vent} = \frac{m_{rel} - m_{room}}{LFL \times 0.417} \times \sqrt{\frac{A}{g \times m_{room}} \times \frac{M}{M - 29}}$$

$$\left(A_{vent} = \frac{m_{rel} - m_{room}}{LFL \times 104} \times \sqrt{\frac{A}{g \times m_{room}} \times \frac{M}{M - 29}}\right)$$

Assuming the system is equipped with release mitigation controls per the example above, the releasable refrigerant charge (m_{rel}) is 9.32 lb (4.19 kg). The allowable refrigerant charge (m_{room} or EDVC) was previously calculated to be 9.25 lb (4.16 kg).

Per Appendix D in Standard 34, the relative molar mass (M) of R-454B is 62.6 (dimensionless). Therefore, the required minimum net free area of the permanent natural ventilation opening (A_{vent}) is calculated to be 0.00717 ft^2 or 1.03 in^2 (0.000632 m^2 or 6.32 cm^2):

$$A_{vent} = \frac{9.32\ \text{lb} - 9.25\ \text{lb}}{18.5\ \text{lb}/1000\ \text{ft}^3 \times 0.417} \times \sqrt{\frac{100\ \text{ft}^2}{32.2\frac{\text{ft}}{\text{s}^2} \times 9.25\ \text{lb}} \times \frac{62.6}{62.6 - 29}} = 0.00717\ \text{ft}^2$$

$$A_{vent} = \frac{4.19\ \text{kg} - 4.16\ \text{kg}}{0.2968\ \text{kg}/\text{m}^3 \times 104} \times \sqrt{\frac{9.3\ \text{m}^2}{9.81\frac{\text{m}}{\text{s}^2} \times 4.16\ \text{kg}} \times \frac{62.6}{62.6 - 29}} = 0.000632\ \text{m}^2$$

Therefore, this private office could be constructed with permanent natural ventilation openings to one or more adjacent rooms. If the net free area of these openings is at least 0.00717 ft^2 or 1.03 in^2 (0.000632 m^2 or 6.32 cm^2), and they comply with the requirements of Section 7.2.3.2, then the private office and those adjacent rooms can be considered "connected spaces." This would allow the volumes of those adjacent rooms to be added to the volume of this private office to increase the effective dispersal volume (V_{eff}), which would subsequently increase the EDVC.

Reconfiguring the system to use a ducted air distribution system

The VRF ceiling cassette serving the private office could be replaced by a ducted VRF terminal installed in the open ceiling plenum, which is then used as the return-air path (Figure 7). According to Section 7.2.3.3.2, the volume of this ceiling plenum could then be included in the effective dispersal volume (V_{eff}), since it is part of the return-air system.

The combined volume of this private office plus the entire open ceiling plenum in this office building is now 7300 ft^3 (207 m^3), which increases the EDVC to 67.5 lb (30.7 kg):

$EDVC = 0.0185\ lb/ft^3 \times 7300\ ft^3 \times 0.5 \times 1.0 = 67.5\ lb$
$(EDVC = 0.2968\ kg/m^3 \times 207\ m^3 \times 0.5 \times 1.0 = 30.7\ kg)$

Even without release mitigation controls, the releasable refrigerant charge—m_{rel} = 27 lb (12.2 kg)—is lower than this newly-calculated EDVC, so the system charge is now in compliance for this private office.

Adding a mechanical ventilation system

Since the refrigerant charge in this example system—m_s = 27 lb (12.2 kg), without release mitigation controls—is greater than the calculated EDVC for this private office—9.25 lb (4.16 kg)—a mechanical ventilation system can be used to remove this excess leaked refrigerant (m_s – EDVC) from the space (see "Mechanical ventilation requirements," p. 31).

For this example private office, the excess charge that must be removed by a mechanical ventilation system is 17.75 lb (8.04 kg):

m_s – EDVC = 27.0 lb – 9.25 lb = 17.75 lb
(m_s – EDVC = 12.2 kg – 4.16 kg = 8.04 kg)

Using the equation in Section 7.6.4, the mechanical ventilation airflow rate (Q_{req}) required to remove this excess refrigerant is 480 cfm (813 m^3/h):

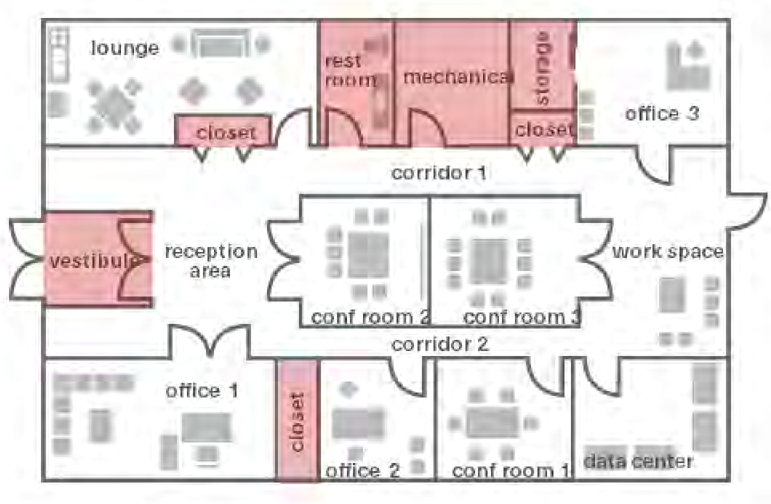
Q_{req} = 2 × 17.75 lb / (4 minutes × 0.0185 lb/ft^3) = 480 ft^3/min
(Q_{req} = 2 × 60 min/hr × 8.04 kg / [4 minutes × 0.2968 kg/m^3] = 813 m^3/h)

This mechanical ventilation system then must comply with the requirements of Section 7.6.4

EXAMPLE 3: PACKAGED (DX) ROOFTOP VAV SYSTEM SERVING A "COMMERCIAL" OCCUPANCY

A 20-ton (70-kW), packaged, direct-expansion (DX) rooftop unit with variable-airflow control serves a small office building (Figure 8). The rooftop unit consists of two 10-ton (35-kW) independent refrigeration circuits. Each occupied space is served by a VAV terminal unit, with minimum airflow setpoints higher than 10 percent of design supply airflow. An open ceiling plenum provides the return-air path to the rooftop unit.

Figure 8. Example office building served by a packaged DX rooftop VAV system



The occupancy classification is "commercial" (F_{OCC} = 1.0), and this system is categorized as a "high-probability" system because a portion of the refrigeration system (the evaporator) is located in the airstream, and a refrigerant leak from this evaporator would result in refrigerant being dispersed to the occupied spaces by the supply air.

This is an example of "connected spaces" via a ducted air distribution system. As explained in a previous chapter, when calculating the effective dispersal volume (V_{eff}) of the connected spaces in this example, include the following:

- The volumes of all spaces served by the common supply and return ductwork, since the VAV dampers in this example do not close below 10 percent of design supply airflow when the supply fan is operating.
- The volume of the supply and return ductwork. (However, this will be ignored in this example since the supply ductwork is routed through a ceiling plenum that is used as part of the return-air path.)
- The volume of the open ceiling plenum, since it is part of the return-air path in this example.

...but exclude the following:

- The volumes of the mechanical room, storage room, and closets, since these spaces are not served by the rooftop unit or the return-air plenum, and can be closed (isolated) from the source of the refrigerant leak by a door.
- The volumes of the vestibule and restroom, since they are conditioned by transfer air only.

For this example (Table 3), the effective dispersal volume (V_{eff}) of the connected spaces is calculated to be 61,072 ft^3 (1730 m^3).

Table 3. Example office building served by a rooftop VAV system

occupied space	volume of space, ft^3 (m^3)	V_{eff}, ft^3 (m^3)
office 2	2695 (76.3)	61,072 (1730)
conf room 1	3144 (89.0)	
conf room 2	3327 (94.2)	
data center	3593 (102)	
conf room 3	3826 (108)	
office 3	3992 (113)	
office 1	5389 (153)	
lounge	7319 (207)	
reception	8383 (237)	
corridor 1	2146 (60.8)	
corridor 2	2146 (60.8)	
work space	6387 (181)	
ceiling plenum	8725 (247)	

If this system uses a Group A1 refrigerant:

The rooftop unit consists of two 10-ton (35-kW) independent refrigeration circuits, each of which contains 12 lb (5.4 kg) of R-410A refrigerant. Per Section 7.3.4.2, the releasable refrigerant charge (m_{rel}) is the largest refrigerant charge in an independent circuit—which is 12 lb (5.4 kg) in this case.

Standard 34 lists R-410A as Group A1 refrigerant with an RCL equal to 26 lb/1000 ft^3 or 0.026 lb/ft^3 (420 g/m^3). Therefore, the EDVC is calculated to be 1588 lb (727 kg):

EDVC = 0.026 lb/ft^3 × 61,072 ft^3 × 1.0 = 1588 lb
(EDVC = 420 g/m^3 × 1730 m^3 × 1.0 / 1000 = 727 kg)

The releasable refrigerant charge—m_{rel} = 12 lb (5.4 kg)—is much less than the EDVC, so this system complies with the limit prescribed by Section 7.3.

If this system uses a Group A2L refrigerant:

In these examples, note that using R-454B requires a smaller refrigerant charge than R-410A, when providing the same cooling capacity.

The rooftop unit consists of two 10-ton (35-kW) independent refrigeration circuits, each of which contains 10.2 lb (4.6 kg) of R-454B refrigerant. Per Section 7.3.4.2, the releasable refrigerant charge (m_{rel}) is the largest refrigerant charge in an independent circuit—which is 10.2 lb (4.6 kg) in this case.

Standard 34 lists R-454B as Group A2L refrigerant with an LFL equal to 18.5 lb/1000 ft^3 or 0.0185 lb/ft^3 (296.8 g/m^3 or 0.2968 kg/m^3).

Since this is a high-probability system used for human comfort, the use of a Group A2L refrigerant means that the requirements of Section 7.6 apply. The rooftop unit in the example includes a refrigerant detector—that complies with the requirements of Section 7.6.2.4—to initiate air circulation in the event that a leak is detected. Therefore, per Section 7.6.1.1, the EDVC is calculated to be 565 lb (257 kg):

EDVC = 0.0185 lb/ft^3 × 61,072 ft^3 × 0.5 × 1.0 = 565 lb
(EDVC = 0.2968 kg/m^3 × 1730 m^3 × 0.5 × 1.0 = 257 kg)

For this example, the releasable refrigerant charge—m_{rel} = 10.2 lb (4.6 kg)—is much lower than the EDVC, so this system complies with the limit prescribed by Section 7.6.1.

EXAMPLE 4: WATER CHILLER INSTALLED INDOORS

A 600-ton (2100-kW) water chiller is located in a separate room with a volume of 32,400 ft^3 (917 m^3). Since the entire refrigeration system—the packaged water chiller—is housed indoors, a refrigerant leak from a failed connection, seal, or component of the water chiller would enter this enclosed room. The building has a "commercial" occupancy classification, so the occupancy adjustment factor (F_{occ}) is 1.0.

This chiller is comprised of a single refrigeration circuit containing 1800 lb (816 kg) of R-134a refrigerant. Per Section 7.3.4.1, the releasable refrigerant charge (m_{rel}) is the entire charge of 1800 lb (816 kg).

Standard 34 lists R-134A as Group A1 refrigerant with an RCL equal to 13 lb/1000 ft^3 or 0.013 lb/ft^3 (210 g/m^3). Therefore, per Section 7.3.1, the EDVC is calculated to be 421 lb (193 kg):

$$EDVC = 0.013\ lb/ft^3 \times 32{,}400\ ft^3 \times 1.0 = 421\ lb$$
$$(EDVC = 210\ g/m^3 \times 917\ m^3 \times 1.0\ /\ 1000\ g/kg = 193\ kg)$$

The releasable refrigerant charge—m_{rel} = 1800 lb (816 kg)—exceeds the EDVC limit defined by Section 7.3.

Therefore, according to Section 7.4 of the standard, the room where this water chiller is located must meet all the requirements of a “machinery room” (see “Machinery Rooms,” p. 45).

Machinery Rooms

For a large refrigeration system, such as a water chiller, Section 7.4 often requires that all components containing refrigerant shall be located in a "machinery room," or outdoors, if the quantity of refrigerant exceeds the EDVC calculated per Section 7.3 (see example on p. 44):

7.4 Location in a Machinery Room or Outdoors. *All components containing refrigerant shall be located either in a machinery room or outdoors, where the quantity of refrigerant needed exceeds the limits defined by Sections 7.2 and 7.3. Refrigeration systems located outdoors shall comply with Section 8.12.*

7.4.1 *Direct-fired absorption equipment shall be located in a machinery room or outdoors.*

7.4.2 Class 1 Refrigerants. *Machinery rooms required by Section 7.4 and containing only Group A1 or B1 refrigerants shall be constructed and maintained in accordance with Section 8.9.*

7.4.3 Class 2L, Class 2, and Class 3 Refrigerants. *Machinery rooms required by Section 7.4 and containing any Group A2, A3, B2, or B3 flammable refrigerants shall be constructed and maintained in accordance with Sections 8.9 and 8.10. Machinery rooms required by Section 7.4, containing any Group A2L or B2L flammable refrigerants and containing no Group A2, A3, B2, or B3 flammable refrigerants, shall be constructed and maintained in accordance with Sections 8.9.1 through 8.9.4 and Section 8.11.*

Refrigeration systems in large spaces

Occasionally, a water chiller or other large refrigeration equipment is located in a very large space, such as a manufacturing facility. These cases require special attention. Why? Even if the large room volume results in a refrigerant charge that does not exceed the EDVC, if a leak occurs that results in a rapid release of the refrigerant, it could create a high, localized concentration of refrigerant. As a precaution, it may be appropriate to provide a refrigerant detector and ventilation.

The term "machinery room" has a very specific meaning in Standard 15, and is defined as a space that meets specific requirements laid out in Section 8 of the standard (see a summary of these requirements in Table 4).

Table 4. Machinery room requirements for differing refrigerant safety classifications

Machinery Room Requirement	Refrigerant Safety Classification (see excerpt from Section 7.4 on p. 45)		
	A1 or B1	A2, B2, A3, or B3	A2L or B2L
Equipment clearances with clear head room	Required (Section 8.9.1)	Required (Section 8.9.1)	Required (Section 8.9.1)
Tight-fitting, self-closing doors	Required (Section 8.9.2)	Required (Sections 8.9.2 and 8.10.b)	Required (Sections 8.9.2 and 8.11.2)
Exterior doors not under fire escape or stairway	Not required	Required (Section 8.10.d)	Required (Section 8.11.4)
No openings to building, tightly-sealed penetrations	Required (Section 8.9.2)	Required (Sections 8.9.2 and 8.10.e)	Required (Section 8.9.2 and 8.11.5)
No airflow to or from occupied spaces, gasketed doors and panels in ductwork and AHUs	Required (Section 8.9.3)	Required (Section 8.9.3)	Required (Section 8.9.3)
Restricted access, door signage	Required (Sections 8.9.4 and 10.1.3)	Required (Sections 8.9.4 and 10.1.3)	Required (Sections 8.9.4 and 10.1.3)
Refrigerant detector	Required (Section 8.9.5)	Required (Section 8.9.5)	Required (Sections 8.11.8 – 8.11.10)
Mechanical ventilation to the outdoors	Required (Sections 8.9.6 – 8.9.8)	Required (Sections 8.9.6 – 8.9.8)	Required (Section 8.11.11)
No open flames or hot surfaces	Exceptions allowed (Section 8.9.9)	No exceptions (Section 8.10.a)	Exceptions allowed (Section 8.11.1)
Noncombustible construction of walls, floor, and ceiling	Not required	Required (Section 8.10.c)	Required (Section 8.11.3)
Conform to Class 1, Division 2, of NEC	Not required	Required (Section 8.10.f)	Required only if ventilation and shutdown do not comply with Section 8.11.6
Remote control for shutting down equipment	Not required	Required (Section 8.10.g)	Required (Section 8.11.7)

EQUIPMENT CLEARANCES

Equipment manufacturers typically include minimum clearance requirements in their submittals. This information is useful for ensuring that the size and layout of the machinery room provides sufficient space to operate, maintain, and service equipment housed there. With respect to equipment clearance, Standard 15 specifically requires no less than 7.25 ft (2.2 m) of clear headroom below equipment situated over a passageway (Section 8.9.1).

The standard also mandates “safe access” to the components of the refrigeration system:

> **8.3 Safe Access.** *A clear and unobstructed approach and space shall be provided for inspection, service, and emergency shutdown of condensing units, compressor units, condensers, stop valves, and other serviceable components of refrigerating machinery. Permanent ladders, platforms, or portable access equipment shall be provided in accordance with the requirements of the authority having jurisdiction.*

Standard 15 provides for minimum protection to help prevent injury from accidents in machinery rooms. The presiding code authority may impose additional requirements related to equipment access.

For machinery rooms that contain an A2L, A2, B2L, B2, A3, or B3 refrigerant, doors opening to the building must be “fire doors” acceptable to the authority having jurisdiction (Section 8.10.b or Section 8.11.2) and exterior doors cannot be located underneath a fire escape or an open stairway (Section 8.10.d or Section 8.11.4).

DOORS, OPENINGS, AND PENETRATIONS

Standard 15 requires that:

> **8.9.2.** *Each refrigerating machinery room shall have a tight-fitting door or doors opening outward, self-closing if they open into the building and adequate in number to ensure freedom for persons to escape in an emergency. With the exception of access doors and panels in air ducts and air-handling units conforming to Section 8.9.3, there shall be no openings that will permit passage of escaping refrigerant to other parts of the building.*

In other words:

- There must be enough doors to permit rapid evacuation in case of an emergency (Section 8.9.2).
- Machinery doors must fit tightly, open outward, and be self-closing if they open into a building (Sections 8.9.2, 8.10b, and 8.11.2).
- Any openings, such as pipe tunnels and conduit raceways, must be tightly sealed to prevent leaked refrigerant from escaping to other parts of the building (Sections 8.9.2, 8.10e, and 8.11.5).
- Air handlers and ductwork that serve other parts of the building can be installed in the machinery room; however, access panels and doors must be gasketed and tight fitting (Section 8.9.3).

This portion of the standard focuses on keeping escaped refrigerant within the machinery room, which would seemingly preclude the use of louvered doors. However, an exception may be granted for exterior louvered doors as long as they do not open onto a walkway and if they are used only as inlets for ventilation air and to provide service clearance. Be sure to consult the local code authority to verify compliance.

RESTRICTED ACCESS AND SIGNAGE

Sections 8.9.4 and 10.1.3 of Standard 15 limit machinery-room access to authorized personnel:

> **8.9.4.** *Access to the refrigerating machinery room shall be restricted to authorized personnel. Doors shall be clearly marked, or permanent signs shall be posted at each entrance to indicate this restriction.*

> **10.1.3.** *Each entrance to a refrigerating machinery room shall be provided with a legible permanent sign, securely attached and easily accessible, reading “Machinery Room—Authorized Personnel Only.” The sign shall further communicate that entry is forbidden except by those personnel trained in the emergency procedures required by Section 10.6 when the refrigerant alarm, required by Section 8.9.5, has been activated.*

As explained in “Reentering a machinery room” (p. 68), Standard 15 no longer prescribes that a self-contained breathing apparatus (SCBAs) be located outside the machinery-room entrance. However, Section 10.6 forbids entry without appropriate respiratory protective equipment used by *trained* personnel. For further discussion of this requirement, see “Handling Machinery-Room Emergencies” (p. 66).

REFRIGERANT DETECTION

According to Standard 15, every machinery room that houses refrigeration equipment (regardless of the refrigerant’s safety classification) must be equipped with a refrigerant detection system—one that will activate an alarm and start the ventilation system if a refrigerant release occurs.

However, the standard's requirements related to refrigerant detection in a machinery room differ depending on the refrigerant's safety classification.

A1, B1, A2, B2, A3, or B3 refrigerant

If either an A1, B1, A2, B2, A3, or B3 refrigerant is used, Section 8.9.5 defines the requirements for refrigerant detection:

> **8.9.5.** *Each refrigerating machinery room shall contain a detector, located in an area where refrigerant from a leak will concentrate, that actuates an alarm and mechanical ventilation in accordance with Section 8.9.7 at a set point not greater than the OEL value as published in ASHRAE Standard 34...*
>
> *The alarm shall annunciate visual and audible alarms inside the refrigerating machinery room and outside each entrance to the refrigerating machinery room. The alarms required in this section shall be of the manual reset type with the reset located inside the refrigerating machinery room.*
>
> *Alarms set at other levels (such as IDLH)and automatic reset alarms are permitted in addition to those required by this section. The meaning of each alarm shall be clearly marked by signage near the annunciators.*

To comply with this section of Standard 15:

- Choose a detector that is capable of detecting the specific refrigerant(s) used in the machinery room and actuates at or below the Occupational Exposure Limit (OEL) of the refrigerant in use. Other alarm levels are permitted as long as the actions required at the OEL (alarming and ventilation) are provided.
- Install the sensor in a location where leaked refrigerant is likely to concentrate.
- Ensure that the detector not only signals both audible and visual alarms when it actuates, but also starts alarm-rate ventilation (defined in Section 8.9.8).
- Situate the alarms inside the machinery room *and* outside each entrance, with the manual reset of the alarm located inside the machinery room.

A2L or B2L refrigerant

If either an A2L or B2L refrigerant is used, Sections 8.11.8 thru 8.11.10 define the requirements for refrigerant detection:

8.11.8. *Each refrigerating machinery room in accordance with Section 8.11 shall contain one or more refrigerant detectors in accordance with Section 8.11.9, with sensing element located in areas where refrigerant from a leak will concentrate, with one or more set points that activate responses in accordance with Section 8.11.10 for alarms and Section 8.11.11 for mechanical ventilation. Multiport-type devices shall be prohibited.*

8.11.9. *Refrigerant detectors required by Section 8.11.8 shall meet all of the following conditions:*

a. A refrigerant detector shall be capable of detecting each of the specific refrigerant designations in the machinery room.

b. The refrigerant detector shall activate responses within a time not to exceed a limit specified in Sections 8.11.10 and 8.11.11 after exposure to refrigerant concentration exceeding a limit value specified in Sections 8.11.10 and 8.11.11.

c. The refrigerant detector shall have a set point not greater than the applicable OEL value as published in ASHRAE Standard 34. The applicable OEL value shall be the lowest OEL value for any refrigerant designation in the machinery room...

d. The refrigerant detector shall have a set point not greater than the applicable RCL value as published in ASHRAE Standard 34. The applicable RCL value shall be the lowest RCL value for any refrigerant designation in the machinery room...

e. The refrigerant detector shall provide a means for automatic self testing and shall be in accordance with Section 8.11.10.4. The refrigerant detector shall be tested during installation and annually thereafter, or at an interval not exceeding the manufacturer's installation instructions, whichever is less. Testing shall verify compliance with the alarm set points and response times per Sections 8.11.10 and 8.11.11.

8.11.10. *Alarms required by Section 8.11.8 shall comply with the following:*

8.11.10.1 *The alarm shall have visual and audible annunciation inside the refrigerating machinery room and outside each entrance to the refrigerating machinery room.*

8.11.10.2 *The refrigerant detector set points shall activate an alarm in accordance with the type of reset in Table 8-1. Manual reset type alarms shall have the reset located inside the refrigerating machinery room.*

8.11.10.3 *Alarms set at levels other than Table 8-1 (such as IDLH), and automatic reset alarms, are permitted in addition to those required by Section 8.11.10. The meaning of each alarm shall be clearly marked by signage near the annunciators.*

Multiport detectors prohibited

Section 8.11.8 prohibits multiport detectors for machinery rooms with Group A2L or B2L refrigerants. The reason is to prevent dilution of the leak sample when it returns to the sensor, which may result in the detector not responding within the required response time.

8.11.10.4 *In the event of a failure during a refrigerant detector self test in accordance with Section 8.11.9(e), a trouble alarm signal shall be transmitted to an approved monitored location.*

To comply with these sections of Standard 15:

- Choose a detector that is capable of measuring the concentration of the specific refrigerant(s) used in the machinery room, at or below the required set points, and actuating within the required response times (see Table 5). Other alarm levels are permitted, as long as the required actions are provided.
- Install the sensor in a location where leaked refrigerant is likely to concentrate.
- Ensure that the detector not only signals both audible and visual alarms when it actuates, but also starts ventilation at the required rate (see Table 5).
- Situate the alarms inside the machinery room and outside each entrance.

Table 5 lists the alarm requirements included in Table 8-1 of the standard. If the refrigerant concentration in the machinery room exceeds the "trouble alarm" set point—which can be any concentration no higher than the OEL of the refrigerant—the detector must activate both audible and visual alarms and activate "Level 1" ventilation airflow within 300 seconds (5 minutes). If the concentration drops back below this set point, this "trouble alarm" can automatically reset (deactivate alarms and ventilation).

In addition, if the refrigerant concentration exceeds the "emergency alarm" set point—which can be any concentration no higher than the RCL of the refrigerant—the detector must activate both audible and visual alarms and activate "Level 2" ventilation airflow within 15 seconds. This alarm, however, requires a manual reset located inside the machinery room.

Table 5. Refrigerant detector set points, response times, alarm types, and ventilation levels for Class 2L refrigerants

Refrigerant Concentration Set Point	Response Time	Alarm Type	Ventilation Airflow Rate	Alarm/Ventilation Reset
≤ OEL	≤ 300 seconds	Trouble alarm	Level 1	Automatic
≤ RCL	≤ 15 seconds	Emergency alarm	Level 2	Manual

Finally, unless the machinery room conforms to Class 1, Division 2 of the National Electrical Code (see "Non-combustible room construction and conformity to NEC," p. 66), if the only flammable refrigerants used are classified as Group A2L or B2L, the refrigerant detector must de-energize the following equipment in the machinery room if the concentration of refrigerant exceeds 25 percent of the lower flammability limit (LFL):

- Refrigerant compressors
- Refrigerant pumps
- Normally-closed, automatic refrigerant valves
- Other unclassified electrical sources of ignition with apparent power rating greater than 1 kVA

Since the standard requires a manual-type reset located inside the machinery room, remote reset via a building automation system (BAS) is not permitted.

Visual and audible alarms

Standard 15 explicitly requires audible *and* visual alarms, both inside the machinery room and outside each entrance. Furthermore, the standard requires a manual-type alarm reset, and that reset must be located inside the machinery room. To help ensure that these devices remain in good working order, the “general requirements” section of the standard specifies periodic tests:

> **10.5.3 Periodic Tests.** *Detectors, alarms, and mechanical ventilating systems shall be tested in accordance with manufacturers' specifications and the requirements of the authority having jurisdiction (AHJ).*

Continuous monitoring

Implicit in the standard's requirement of a refrigerant detection system is the need for its continuous operation. In other words, the detector must be permanently mounted in the machinery room, which often is unoccupied for extended periods, and it must never shut off. That's because most refrigerants give no warning of their presence; they are odorless, colorless, and tasteless. Continuously monitoring the machinery room for refrigerant—and alarming if a buildup occurs—assures personnel that the room is free from this hazard. Early detection of a refrigerant leak also helps to reduce refrigerant loss.

Notice that Section 8.9.5 (and similar language in Section 8.11.8) stipulates a *detector* that “actuates an alarm and mechanical ventilation ... at a set point not greater than the OEL” rather than a refrigerant vapor monitor. This phrasing deliberately specifies the required function of the detector and not the technology that is used to accomplish it. Note, too, that the requirement to alarm at the OEL means that the detector must be able to discern relatively small amounts of refrigerant.

Where to locate sampling points?

Section 8.9.5 (or 8.11.8) of Standard 15 explicitly states that a machinery room “shall contain a detector, located in an area where refrigerant from a leak will concentrate.” Any machinery room that contains more than one type of refrigerant must satisfy the individual requirements for each system. For example, if the machinery room houses a water chiller containing R-134a and another chiller containing R-123, the room must contain either:

Sampling point refers to the location where the air sample is collected. It coincides with the location of the monitor unless a sampling line is added. A “sampling line” is the length of tubing (usually copper) that connects the monitor to the sampling point.

- One refrigerant detector that can sense both types of refrigerant, or
- Two compound-specific monitors, one for R-134a and one for R-123.

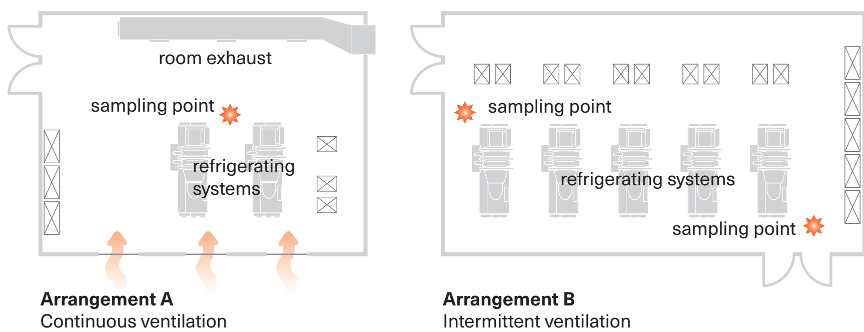
One sampling point likely can provide sufficient detection coverage for a room housing three or fewer chillers, if the chillers are aligned for good airflow (Figure 9, Arrangement A). But a single monitor and sampling point may not adequately ensure occupant safety in all machinery-room configurations.

For example, a system consisting of four to six chillers typically requires two sampling points if housed in a machinery room with either intermittent ventilation or an indeterminate direction of airflow. The sampling points in such cases are likely positioned at opposite corners of the chiller group (Figure 9, Arrangement B). As a general rule, the distance between any refrigeration "system" (chiller) and a refrigerant sampling point should not exceed 50 ft (15 m).

Multiple sampling points also are recommended for large machinery rooms and for machinery rooms with multiple levels.

If a machinery-room layout requires several sampling points for adequate refrigerant monitoring, it may be more cost-effective to install a single monitor that is capable of checking refrigerant concentrations at multiple sampling points rather than installing several "single-channel" monitors. However, for a machinery room with Group A2L or B2L refrigerants, Section 8.11.8 prohibits the use of a multiport detector.

Figure 9. Suggested placement for refrigerant sampling points

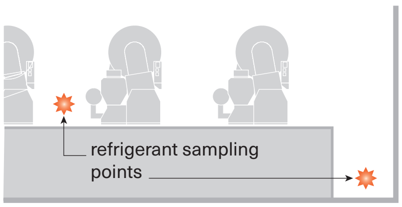


The only instruction that Standard 15 provides for determining where to locate the refrigerant monitor is "... in an area where refrigerant from a leak will concentrate" (Section 8.9.5 or 8.11.8). That guidance is unavoidably vague, given the countless machinery-room layouts. When selecting a mounting location for the monitor or a sampling point, remember that the monitor's purpose is to help ensure occupant safety. The most likely exposure to refrigerant is through inhalation, so proper placement will account for the airflow pattern in the room and the density of the refrigerant vapor.

Elevation

Most commonly used refrigerants are heavier than air, so sampling points typically are positioned near the floor—but not at floor level to avoid causing nuisance alarms. Typical placement is 12 to 18 in. (30 to 46 cm) above the floor. Checking for refrigerant at a height that is well below the normal breathing zone provides occupants with an added margin of safety.

Figure 10. Sample at each level in the machinery room



Low areas that could be occupied—such as stairwells, pits, or trenches (Figure 10)—demand dedicated sampling points because heavier-than-air refrigerants will quickly sink to the floor and spread if released. Pits and other low areas are likely to fill with refrigerant before the released refrigerant is detected at a conventionally mounted sampling point.

Plan location

If the machinery room is continuously ventilated, the pattern of the ventilation airflow will carry refrigerant away from its source. In this case, position the sampling point between the refrigeration equipment and the room's exhaust air inlet (Figure 9–Arrangement A, p. 52).

For machinery rooms with intermittent ventilation or where the direction of airflow is not obvious, position the sampling point so that it is near the refrigeration system or the machinery-room entrance, but no more than 50 ft (15 m) from each piece of refrigeration equipment (Figure 9–Arrangement B, p. 52). As examples, place the sampling point next to the chiller in a single-chiller plant, between the chillers in a two-chiller plant, or at the center chiller in a three-chiller plant.

Types of refrigerant monitors for machinery rooms

Various monitors are available for refrigerant detection applications. Differences in their designs, sensing technologies, and operating characteristics determine which applications best suit each monitor. Table 6 (p. 54) compares three types of refrigerant monitors based on existing technology. Of these, compound-specific monitors are best suited for detecting refrigerant in machinery rooms.

Short-term monitors are used briefly, at regular intervals, to check a refrigeration system for leaks during preventive maintenance or troubleshooting. Consequently, a monitor that serves this purpose must:

- withstand large doses of refrigerant;
- respond and clear rapidly;
- be portable; and
- be sensitive (but not necessarily specific) to the refrigerant in use.

Refrigerant monitors can be divided into two categories based on duration of use: those used periodically for short-term detection of refrigerant leaks, and those that operate continuously. Both kinds of monitors have a use in a machinery room (see sidebar), but compliance with the intent of Standard 15, which is to safeguard occupants, requires installation of a continuous-duty refrigerant monitor.

When selecting a continuous-duty monitor for a machinery room, be sure to consider these important operating characteristics:

- **Refrigerant-specific sensitivity.** Less-discriminating monitors can alarm if non-refrigerant compounds, such as cleaning agents or paints, are detected.
- **Stability over the expected operating range of temperatures, voltages, humidities, and barometric pressures.** Calibration stability is a critical aspect of monitors used for continuous surveillance, and is provided by the electronic component that reads the sensor output. In general, monitor accuracy must be unaffected under all expected conditions.

Table 6. Comparison of refrigerant monitor types

Monitor type	Sensing technology	Accuracy	Advantages	Disadvantages
Nonselective	• Metal-oxide semiconductors • Thermal ionization	20 to 70 ppm (minimum)	• Least expensive • Long used in "pinpointing" leaks	• Unable to differentiate between chemicals • More susceptible to false alarms than other monitor types, which severely limits use as an area monitor • Exposure to a high concentration of some compounds may result in loss of sensitivity or permanent damage
Halogen-specific	• Element-type ionization	10 ppm (maximum)	• Can distinguish refrigerants from other chemicals: responds only to chlorine, fluorine, and bromine • Allows calibration • Typical operating life is 1 year	• Unable to differentiate one refrigerant from another
Compound-specific	• Infrared spectroscopy • Gas chromatography • Photoacoustic spectroscopy	1 ppm (maximum)	• Least susceptible to false alarms • Requires less recalibration than other monitor types • Less susceptible to interference than other monitor types • **Best choice for machinery room applications**	• More expensive than other monitor types

- **Low zero-drift or "auto-zeroing" capability**. To be suitable for continuous duty, the monitor must provide a means of setting the "zero" reference point—that is, either a very small zero-drift (parts per million, ppm, between inspections) or an "auto-zero" feature.
- **Long service life with minimal maintenance.**
- **Alarm limits that correspond to the set points required by Standard 15 (Section 8.9.5 or 8.11.9) for the refrigerant(s) in use.**
- **Alarm output.** To enable compliance with Standard 15 (Section 8.9.5 or 8.11.8), the monitor must provide an output signal that performs two functions: actuates an alarm, which will alert machinery-room occupants that the refrigerant concentration exceeds the allowable threshold (set point) and dilutes the leaked refrigerant by starting mechanical ventilation.

For a machinery room with Group A2L or B2L refrigerant(s), the refrigerant detector must include a means for automatic self testing (Section 8.11.9e). If a self test fails, an alarm signal must be transmitted to a "monitored location" (Section 8.11.10.4).

- **Remote status and refrigerant concentration indicator.** Including a remote display provides a convenient way to check monitor status and current sensed refrigerant concentration in the machinery room, and may even be used to provide the audible and visual alarm signals required. Such a display allows operating personnel to assess the need for respiratory protection equipment or verify that the ventilation system successfully cleared leaked refrigerant from the room.
- **Digital output.** With this capability the refrigerant monitor can be tied to the chiller controller display or Building Automation System.
- **Low level detection.** Using a monitor that can detect refrigerant concentrations well below the allowable threshold (e.g., OEL) allows operators to detect and correct small leaks, thus preventing the loss of valuable refrigerant.

Refrigerant monitor input and output signals

Remote reset input. In response to an elevated refrigerant concentration, the refrigerant monitor triggers an alarm. Some monitors contain a remote reset input, which can be used to cancel the alarm from a distance after the ventilation system has sufficiently dispersed the buildup of refrigerant.

However, for some alarm levels, Standard 15 (Section 8.9.5 or 8.11.10) requires placement of the refrigerant monitor's alarm reset *inside the machinery room*. This requirement also applies to any reset switch that is connected to the remote reset input.

Alarm output(s). Regardless of how many alarm-level outputs the monitor employs or the refrigerant concentration used to trigger the alarm(s), at least one alarm output must activate alarm-rate ventilation *and* signal audible and visual alarms (both inside the machinery room and outside each entrance) at or below the set point required for the refrigerant in use. This particular level of alarm requires manual reset from inside the machinery room.

Follow local regulatory requirements and equipment manufacturers' recommendations when establishing alarm settings and actions.

If either an A2L or B2L refrigerant is used, Sections 8.11.8 through 8.11.10 require a minimum of two stages of alarm (see pages 49-50)

One stage of alarm

The alarm-relay output energizes when the refrigerant concentration exceeds the preset alarm set point. To comply with Standard 15 (Section 8.9.5 or 8.11.9), the alarm set point must be at or below the OEL for the refrigerant in use. It must activate an alarm (both visual and audible, inside the room and outside each entrance) *and* start mechanical ventilation at the alarm rate.

When only one level of alarm is available, consider setting the alarm set point at a concentration lower than the OEL. This meets the alarm requirement and also provides early warning of refrigerant loss.

With only one level of alarm, personnel always must don appropriate protective gear before entering the room to reset the alarm. With multiple alarm levels, it is possible to signal detection of a refrigerant concentration that is low enough to permit safe entry and check for leaks without protective gear.

Two stages of alarm

If either an A1, B1, A2, B2, A3, or B3 refrigerant is used, and the monitor provides two levels of alarm:

- Set the set point of the *first-stage alarm* low enough to provide early leak detection (10 ppm, for example). Use this output to activate alarm-rate ventilation and to notify personnel of the leak by illuminating an indicator light or sending a message via the BAS, for example.

- Set the set point for the *second-stage alarm* equal to the OEL for the refrigerant in use. Use this output to activate alarm-rate ventilation and to activate the alarm (both visual and audible, inside the room and outside each entrance), alerting personnel that the room is not safe to enter without proper personal protective equipment.

If either an A2L or B2L refrigerant is used:

- Set the set point of the *first-stage alarm* no higher than the OEL for the refrigerant in use. Use this output to activate “Level 1" ventilation airflow and to activate the alarm (both visual and audible, inside the room and outside each entrance); can be reset automatically.
- Set the set point for the *second-stage alarm* no higher than the RCL for the refrigerant in use. Use this output to activate “Level 2" ventilation airflow and to activate the alarm (both visual and audible, inside the room and outside each entrance); requires manual reset located inside the machinery room.

Three stages of alarm

Monitors with three levels of alarm provide even greater notification flexibility. This allows for an additional set point at a very low concentration, to provide a means of early leak detection.

For a machinery room with Group A2L or B2L refrigerant(s), the refrigerant detector must include a means for automatic self testing (Section 8.11.9e). If a self test fails, an alarm signal must be transmitted to a “monitored location” (Section 8.11.10.4).

Failure output. This relay energizes if the refrigerant detector malfunctions due to low airflow, circuit failure, or a saturated (or absent) sensor signal. It also can indicate loss of power if these contacts are normally powered open. Use the failure output to visually or audibly signal the building operator that the monitor must be checked and returned to operation.

As part of monitor checkout, the operator should bring a portable refrigerant detector to the machinery room to determine the refrigerant concentration.

Refrigerant monitor output. Some monitors provide an output signal of the detected concentration of refrigerant. Use this output to provide a remote indication of the refrigerant concentration in the machinery room, for example on a display installed outside the machinery-room entrance. This can help operating personnel assess the need for personal protective equipment or verify that the ventilation system successfully cleared leaked refrigerant from the room.

BAS interface. A Building Automation System (BAS) provides a means for efficient system-level control and documented performance. Using the BAS to monitor the machinery room refrigerant concentration offers several benefits:

- **Automatic logging and documentation of refrigerant monitor readings.** Automatic trend-logging of refrigerant concentrations in the machinery room documents that refrigerant concentrations are maintained below the applicable required threshold(s) and satisfies EPA-imposed regulations requiring verification of the operating procedures used to control refrigerant emissions.

- **Automatic notification upon alarm detection.** The BAS can automatically notify the service contractor when an alarm occurs. In this way, a trained expert—using the proper personal protective equipment—can quickly respond and take corrective action.
- **Purge-rate surveillance for early leak detection.** Leaks are the primary cause of refrigerant loss from refrigeration systems. A refrigerant monitor can detect a leak before a significant amount of refrigerant is lost, but in the case of a low-pressure chiller, a BAS can provide an even earlier indication by monitoring, logging, and plotting operation of the chiller purge unit(s). It also can send a diagnostic message to the operator if the purge rate exceeds a preset limit.

VENTILATION FOR MACHINERY ROOMS

Section 8.9.7 (or Section 8.11.11) of the standard requires the use of "power-driven fans" to exhaust air from the machinery room in the event of a refrigerant leak.

A1, B1, A2, B2, A3, or B3 refrigerant

If either an A1, B1, A2, B2, A3, or B3 refrigerant is used, Section 8.9.8.1 defines the required ventilation airflow:

8.9.8.1. The mechanical ventilation required to exhaust an accumulation of refrigerant due to leaks or a rupture of the refrigeration system shall be capable of removing air from the machinery room in not less than the quantity calculated using:

$Q = 100 \times G^{0.5}$
$(Q = 0.070 \times G^{0.5})$

where,

Q =airflow, ft^3/min or cfm (m^3/s)

G = mass of refrigerant in the largest refrigeration system (independent circuit), any part of which is located in the machinery room, lb (kg)

Denser than air
Many of the commonly used refrigerants in comfort-cooling HVAC applications have vapor densities that are three to five times denser than air. It is important to compensate for this difference when sizing the ventilation system to deliver alarm-rate airflow—especially for refrigerants that boil below the ambient temperature. A liquid spill or a rupture of a vessel containing such a refrigerant will quickly release a large quantity of vapor in the machinery room.

Q represents the minimum airflow that the ventilation system must remove to effectively exhaust "spilled" refrigerant from the room. For chillers with more than one isolated refrigeration circuit, *G* represents the amount of refrigerant in the largest circuit. According to Standard 15, it is not necessary to run the ventilation system at this volume continuously, provided that:

8.9.8.1. *A part of the refrigerating machinery room mechanical ventilation shall be:*

a. Operated, when occupied, to supply at least at 0.5 cfm/ft^2 (0.00254 m^3/s per m^2) of machinery room area or 20 cfm (0.00944 m^3/s) per person, and

b. Operable when occupied at a volume required to not exceed the higher of a temperature rise of 18°F (10°C) above inlet air temperature or a maximum temperature of 122°F (50°C).

For A1, B1, A2, B2, A3, or B3 refrigerants, Standard 15 defines two distinct mechanical ventilation rates for a machinery room:

- **Normal ventilation rate** whenever the equipment room is occupied. In most cases, the prescribed rate of at least 0.5 cfm/ft^2 (0.00254 m^3/s per m^2) or 20 cfm (0.00944 m^3/s) per person, whichever is larger, should be sufficient to meet the secondary requirement that the room temperature not exceed the inlet air temperature by more than 18°F (10°C) nor reach a temperature greater than 122°F (50°C). However, if the machinery room contains a number of heat sources, such as large air-cooled motors, it may be necessary to increase the normal ventilation rate (or provide supplemental cooling) in order to comply with these temperature limitations.

  Although Standard 15 states that the machinery room must be ventilated at the normal rate whenever the room is occupied, it does not specify how. Options include running the fan continuously, starting the fan automatically with a motion detector, or providing a fan switch near the machinery room entrance(s). If you provide a switch, accompany it with a sign or other prompt to indicate the need for ventilation during occupancy.
- **Alarm ventilation rate**, whenever the refrigerant monitor detects a concentration that exceeds the OEL of the refrigerant (per Section 8.9.5). Use the alarm contacts of the monitor to automatically initiate ventilation at the rate calculated based on the mass of refrigerant. As described previously, this alarm ventilation rate must be based on the mass of refrigerant in the largest refrigerating system (any part of which is located in the machinery room). If the system consists of distinct, independent refrigeration circuits, then this calculation is based on the mass of refrigerant in the largest circuit.

  As a further safeguard, consider providing a manually-operated fan switch outside the main entrance to the machinery room.

One way to comply with Standard 15 is to provide a single ventilation system that can operate at both the higher alarm ventilation rate and the lower normal ventilation rate, using multiple fans or fans with multi- or variable-speed drives:

> **8.9.7** *Mechanical ventilation referred to in Section 8.9.6 shall be by one or more power-driven fans capable of exhausting air from the machinery room at least in the amount given in the formula in Section 8.9.8. To obtain a reduced airflow for normal ventilation, multiple fans or multi-speed fans shall be used.*

A2L or B2L refrigerant

If either an A2L or B2L refrigerant is used, Section 8.11.11 defines two levels of required ventilation airflow: Level 1 and Level 2.

> **8.11.11.2 Level 1 Ventilation.** *The refrigerating machinery room mechanical ventilation in Section 8.11.11.1 shall exhaust at an airflow rate not less than shown in Table 8-2.*

8.11.11.3 Level 2 Ventilation. *A part of the refrigerating machinery room mechanical ventilation referred to in Section 8.11.11.1 shall exhaust an accumulation of refrigerant due to leaks or a rupture of a refrigerating system, or portion thereof, in the machinery room. The refrigerant detectors required in accordance with Section 8.11.8 shall activate ventilation at a set point and response time in accordance with Table 8-1, at an airflow rate not less than the value determined in accordance with Section 8.11.11.4.*

When multiple refrigerant designations are in the machinery room, evaluate the required airflow according to each refrigerating system, and the highest airflow quantity shall apply.

Ventilation reset shall be in accordance with the type of reset in Table 8-1. Manual-type ventilation reset shall have the reset located inside the refrigerating machinery room.

8.11.11.4 Safety Group A2L, B2L. *When required by Section 8.11.11.3, the total airflow for Level 2 ventilation shall be not less than the airflow rate determined by either the graphical method of Figure 8-1 (I-P) and Figure 8-2 (SI) or the calculation method using the equations in Table 8-3. The total airflow rate for Level 2 ventilation shall not be less than Level 1 ventilation. The airflow rate (Q) per the calculation method shall be rounded up to the nearest value to two significant figures.*

For A2L or B2L refrigerants, Standard 15 defines two distinct mechanical ventilation rates for a machinery room:

- **Level 1 ventilation rate**, which is activated whenever the equipment room is occupied, or if unoccupied, whenever the measured refrigerant concentration exceeds the "trouble alarm" set point (see Table 5, p. 50). Table 7 lists the Level 1 ventilation rate prescribed in the standard. In most cases, the prescribed rate of at least 0.5 cfm/ft^2 (0.00254 m^3/s per m^2) or 20 cfm (0.00944 m^3/s) per person, whichever is larger, should be sufficient to meet the secondary requirement that the room temperature not exceed the inlet air temperature by more than 18°F (10°C) nor reach a temperature greater than 122°F (50°C). However, if the machinery room contains a number of heat sources, such as large air-cooled motors, it may be necessary to increase the Level 1 ventilation rate (or provide supplemental cooling) in order to comply with these temperature limitations.

Refer to Figure 8-1 or Figure 8-2 in Standard 15 for a graphical method of determining the Level 2 ventilation rate.

- **Level 2 ventilation rate**, which is activated if the measured refrigerant concentration exceeds the "emergency alarm" set point (see Table 5, p. 50). Use the alarm contacts on the refrigerant monitor to automatically initiate Level 2 ventilation at the rate determined based on the design pressure (DP) of the refrigeration system and the mass of refrigerant (G) in the largest refrigeration system (Table 8), any part of which is located in the machinery room. If the system consists of distinct, independent refrigeration circuits, then this is based on the mass of refrigerant in the largest circuit. The Level 2 ventilation rate must not be less than the Level 1 ventilation rate.

Section 8.11.11.1 of the Standard 15 allows for the use of multiple fans, or a fan with a multi-speed or variable-speed drive, to be provide these different ventilation rates.

Table 7. Level 1 ventilation rate for a Class 2L refrigerant

Status	Level 1 Ventilation Rate
Operated whenever machinery room is occupied, and Operated if refrigerant detector indicates refrigerant concentration exceeds the “trouble alarm” setpoint (must be set <= OEL)	Continuously, at the higher of the following airflow rates: • 0.5 cfm/ft^2 (0.00254 m^3/s per m^2) of machinery room floor area or • 20 cfm (0.00944 m^3/s) per person
Whenever machinery room is occupied	Intermittently, at the airflow rate required to: • Prevent the machinery room temperature from exceeding 18°F (10°C) above the inlet air temperature or • Prevent the machinery room temperature from exceeding 122°F (50°C)

Table 8. Level 2 ventilation rate for a Class 2L refrigerant

Refrigerant Charge, G	Level 2 Ventilation Rate, Q
$G < 0.1 \times G'$	$Q >= Q' \times 0.102$ and $Q >= Q_1$
$0.1 \times G' <= G <= G'$	$Q >= Q' \times [1 + 0.39 \times \ln(G/G')]$ and $Q >= Q_1$
$G > G'$	$Q >= Q'$

where,

G = mass of refrigerant in the largest refrigeration system (independent circuit), any part of which is located in the machinery room, lb (kg)

$G' = 21200 \times P^{-0.72}$, lb
($G' = 267 \times P^{-0.72}$, kg)

$P = DP + 14.70$, psia
($P = DP + 0.1013$, MPa)

DP = design gage pressure of the refrigeration system high side, psig (MPa)

Q = Level 2 ventilation rate, ft^3/min (m^3/s), rounded up to the nearest value to two significant figures

$Q' = 646 \times P^{0.62}$, ft^3/min
($Q' = 6.67 \times P^{0.62}$, m^3/s)

Q_1 = Level 1 ventilation rate, ft^3/min (m^3/s)

Example: Machinery room ventilation (alarm, or Level 2, rate)

Two 500-ton (1760-kW) water chillers are located in a machinery room. Each chiller is comprised of a single refrigeration circuit, and the machinery room ventilation rate is based on the mass of refrigerant in the largest independent circuit (G).

If the chillers use either an **A1 or B1 refrigerant**, the alarm ventilation rate (Q) is determined per Section 8.9.8.1:

$Q = 100 \times G^{0.5}$, ft^3/min

($Q = 0.070 \times G^{0.5}$, m^3/s)

- If the chillers use R-123 (Group B1), the refrigerant charge in each chiller (G) is 500 lb (230 kg). The alarm ventilation rate (Q) is calculated to be 2240 cfm (1.06 m^3/s).
- If the chillers use R-134a (Group A1), the refrigerant charge in each chiller (G) is 750 lb (340 kg). The alarm ventilation rate (Q) is calculated to be 2740 cfm (1.29 m^3/s).
- If the chillers use R-514A (Group B1), the refrigerant charge in each chiller (G) is 850 lb (390 kg). The alarm ventilation rate (Q) is calculated to be 2920 cfm (1.38 m^3/s).

If the chillers use an **A2L refrigerant**, the Level 2 ventilation rate is determined per Section 8.11.11.4.

- If the chillers use R-1234ze (Group A2L), the refrigerant charge in each chiller (G) is 1200 lb (540 kg) and the Design Pressure (DP) is 185 psig (1.2756 MPa). The alarm ventilation rate (Q) is calculated to be 18,000 cfm (8.2 m^3/s).

$P = 185 + 14.70 = 199.7$ psia

($P = 1.2756 + 0.1013 = 1.3769$ MPa)

$G' = 21{,}200 \times 199.7^{-0.72} = 467.8$ lb

($G' = 267 \times 1.3769^{-0.72} = 212.1$ kg)

$Q' = 646 \times 199.7^{0.62} = 17{,}240$ cfm

($Q' = 6.67 \times 1.3769^{0.62} = 8.133$ m^3/s)

Since G > G' then Q must be >= Q'

Rounded up to the nearest value to two significant figures, Q = 18,000 cfm (8.2 m^3/s)

Vent locations

Locations for the ventilation system intake and discharge must be properly positioned to provide efficient machinery-room ventilation. Standard 15 addresses this requirement in a general manner, stating:

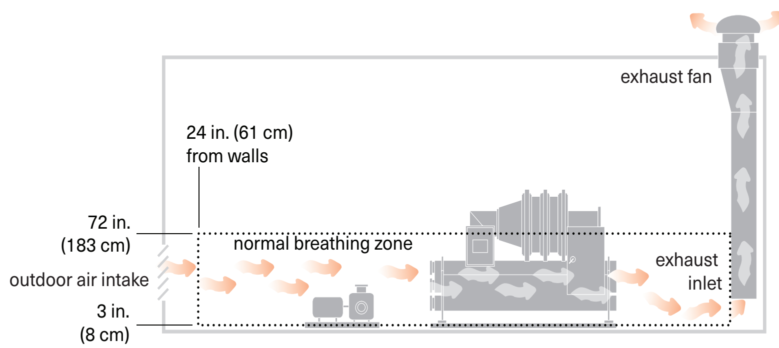
> **8.9.7 (for A1, B1, A2, B2, A3, or B3 refrigerants).** *Provision shall be made for inlet air to replace that being exhausted. Openings for inlet air shall be positioned to avoid recirculation. Air supply and exhaust ducts to the machinery room shall serve no other area. The discharge of the air shall be to the outdoors in such a manner so as not to cause a nuisance or danger. The mechanical exhaust inlets shall be located in an area where refrigerant from a leak is likely to concentrate, in consideration of the location of the replacement air paths, refrigerating machines, and the density of the refrigerant relative to air.*
>
> **8.11.11.1 (for A2L or B2L refrigerants).** *Mechanical ventilation referred to in Section 8.11.11 shall be in accordance with all of the following:*
>
> a. *Include one or more power-driven fans capable of exhausting air from the machinery room; multi-speed fans shall be permitted.*
> b. *Electric motors driving fans shall not be placed inside ducts; fan rotating elements shall be nonferrous or non-sparking, or the casing shall consist of or be lined with such material.*
> c. *Include provision to supply makeup air to replace that being exhausted; ducts for supply to and exhaust from the machinery room shall serve no other area; the makeup air supply locations shall be positioned relative to the exhaust air locations to avoid short circuiting.*
> d. *Inlets to the exhaust ducts shall be located in an area where refrigerant from a leak will concentrate, in consideration of the location of the replacement supply air paths, refrigerating machines, and the density of the refrigerant relative to air.*
> e. *Inlets to exhaust ducts shall be within 1 ft (0.3 m) of the lowest point of the machinery room for refrigerants that are heavier than air and shall be within 1 ft (0.3 m) of the highest point for refrigerants that are lighter than air.*
> f. *The discharge of the exhaust air shall be to the outdoors in such a manner as not to cause a nuisance or danger.*

First, **the machinery-room ventilation system must be separate from the systems that ventilate other parts of the building**. In other words, the fans and ductwork that ventilate the machinery room must not supply or use air from any other part of the building, and the discharge must not interfere with any fresh air intakes. Some fans may not run continuously, so it is important to locate the inlet and discharge for each fan where it will not be inadvertently blocked when the fan is off. Also, outdoor air used to replace the air being exhausted may need to be properly conditioned to avoid potential equipment damage from wide, abrupt temperature swings or freezing temperatures.

Second, **the exhaust fan must remove refrigerant from the machinery room.** To remove heavier-than-air refrigerants, locate the exhaust fan inlets near the equipment (if possible) and close to the floor rather than at ceiling height. (Alternatively, to remove lighter-than-air refrigerant, locate the exhaust fan inlets close to the ceiling rather than at floor level.) As an example, when the refrigerant is heavier than air, maximum protection for machinery-room occupants is provided when the exhaust-fan inlet is situated (see Figure 11):

- Below the normal breathing zone, and must be less than 1 ft (0.3 m) above the floor when either an A2L or B2L refrigerant is used,
- Near the potential source(s) of a refrigerant leak; and,
- Away from the makeup air intake to create a “sweeping” airflow pattern that draws outdoor air across the refrigeration equipment to the exhaust fan.

Figure 11. Position exhaust inlets near the floor when refrigerant is heavier than air



Another important consideration is the airflow pattern that results from interaction of the ventilation system with equipment in the room. Place the chillers between the makeup air intake(s) and exhaust fan inlet(s), and orient them to avoid creating stagnant areas. Figure 12 compares two configurations for a machinery room that houses multiple chillers. Positioning the units as shown in Arrangement A provides good air movement, while Arrangement B may inhibit airflow between the chillers.

Figure 12. Ventilation airflow patterns in machinery rooms that house multiple chillers

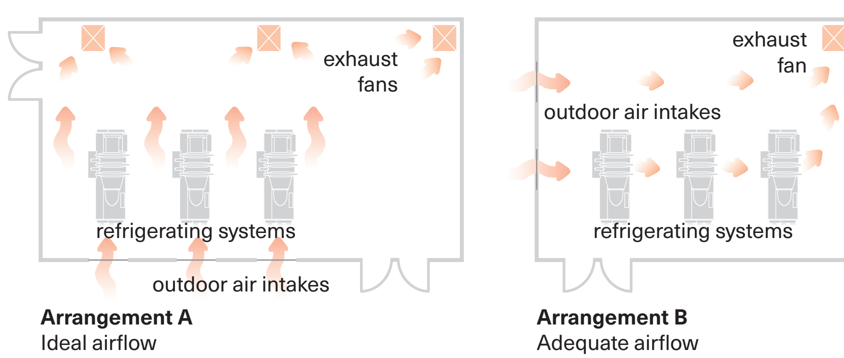
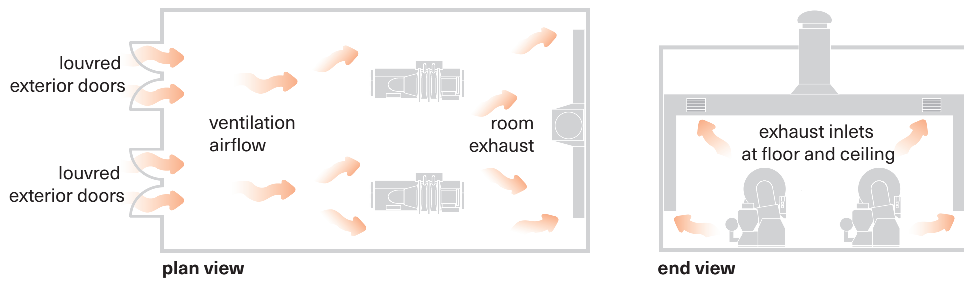


Figure 13. Arrange the ventilation system for adequate airflow throughout the room



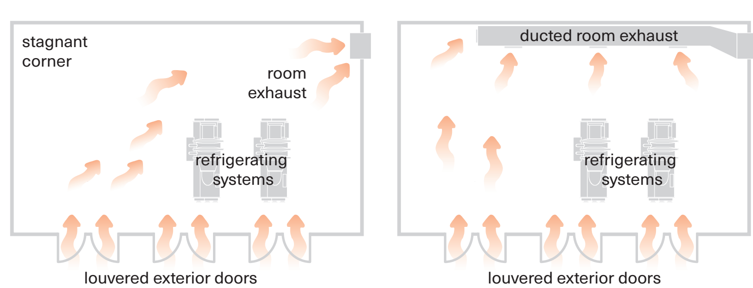
When machinery-room exhaust fans serve a cooling or smoke-removal function, they are usually installed near the ceiling because both heat and smoke rise. However, if the same ventilation system is also used to exhaust "spilled" refrigerant, make provisions for inlets at both floor and ceiling levels if the refrigerant is heavier than air:

- **Dedicated fans**, separate ceiling- and floor-level fans can be operated together to provide the total ventilation volume needed for refrigerant removal. For greatest removal efficiency, make sure that the floor-level fan can deliver the calculated alarm rate of ventilation airflow.
- **Dual-purpose fan**, when using a single fan both for cooling or smoke removal and for removing "spilled" refrigerant, provide ducted inlets at the floor *and* the ceiling (Figure 13). If this arrangement is used, it is important to account for the density of the refrigerant vapor. In some cases, it may be necessary to add properly designed and controlled flow dampers to maximize ventilation effectiveness if an alarm condition occurs.

Case study: Opportunity for improvement

Arrangement A shows the layout of an actual machinery room, which is situated in the corner of a building. Six louvered service doors allow outdoor air to be drawn into the machinery room, while the exhaust fan is mounted near the floor in an adjacent wall.

Although Arrangement A may provide adequate air movement across the chillers, notice that it might create a stagnant area in one corner of the room. Ducting the exhaust fan inlet across the wall that lies opposite of the service doors, as shown in Arrangement B, likely provides better airflow throughout the room.



Arrangement A
Adequate ventilation airflow

Arrangement B
Better ventilation airflow

Do all refrigerants burn?

When heated to a high enough temperature, all refrigerants may break down and produce fluoric acid. However, this process stops when the heat source is removed. In fact, refrigerants were the primary component used in halon fire extinguishers.

However, Class 2L, 2, and 3 refrigerants are unique in that they are capable of self-sustaining combustion, once ignited.

OPEN-FLAME DEVICES

Standard 15 includes requirements related to the use of open-flame devices or hot surfaces in machinery rooms that house refrigeration equipment.

A1 or B1 refrigerant

If either an A1 or B1 refrigerant is used, Section 8.9.9 of the standard states the following:

> **8.9.9.** *No open flames that use combustion air from the machinery room shall be installed where any refrigerant is used. Combustion equipment shall not be installed in the same machinery room with refrigerant-containing equipment except under one of the following conditions:*
>
> a. *Combustion air is ducted from outside the machinery room and sealed in such a manner as to prevent any refrigerant leakage from entering the combustion chamber, or*
>
> b. *A refrigerant detector, conforming to Section 8.9.5, is employed to automatically shut down the combustion process in the event of refrigerant leakage.*
>
> **Exception to 8.9.9.** *Machinery rooms where only carbon dioxide (R-744) or water (R-718) is the refrigerant.*

When combustion equipment, such as a boiler or direct-fired absorption machine, is designed to accept intake ductwork, exception (a)—ducting combustion air from outside the machinery room directly into the open-flame device—offers the best solution for compliance. This strategy separates combustion-air requirements from ventilation needs, and avoids shutting down the combustion equipment if a refrigerant leak or nuisance alarm occurs.

Exception (b) offers a simple, cost-effective method for compliance that is especially useful in retrofit and replacement installations. If properly located, a high-quality, compound-specific refrigerant monitor can avoid nuisance shutdowns that otherwise might be triggered by paints, cleaning agents, and other chemicals.

A2, B2, A3, or B3 refrigerant

If either an A2, B2, A3, or B3 refrigerant is used, Section 8.10.a strictly prohibits the use of either a flame-producing device or a hot surface in the machinery room:

> **8.10.a.** *There shall be no flame-producing device or continuously operating hot surface over 800°F (427°C) permanently installed in the room.*

A2L or B2L refrigerant

If either an A2L or B2L refrigerant is used, Section 8.11.1 prohibits the use of either a flame-producing device or a hot surface in the machinery room, but allows the same exceptions listed in Section 8.9.9 (described above):

> **8.11.1.** *There shall be no flame-producing device or hot surface over 1290°F (700°C) in the room, other than that used for maintenance or repair, unless installed in accordance with Section 8.9.9.*

NONCOMBUSTIBLE ROOM CONSTRUCTION AND CONFORMITY TO NEC

In a machinery room that contains an A2L, A2, B2L, B2, A3, or B3 refrigerant, the walls, floor, and ceiling must be tight, noncombustible construction. And any walls, floor, and ceiling that separates the machinery room from other occupied spaces must be at least one-hour fire-resistive construction (Section 8.10.c or Section 8.11.3).

When an A2, A3, B2, or B3 refrigerant is used, Section 8.10.f requires that the machinery room must conform to Class 1, Division 2, of the National Electrical Code (NEC). This is not required if only A1 and B1 refrigerants are used, and would only be required for A2L or B2L refrigerants if the machinery room does not meet the requirements listed in Section 8.11.6.

REMOTE CONTROL

In a machinery room that contains an A2L, A2, B2L, B2, A3, or B3 refrigerant, remote control of the mechanical equipment must be provided immediately outside the machinery room entrance, for the purpose of shutting down the mechanical equipment inside the room in case of an emergency (Section 8.10.g or Section 8.11.7).

The ventilation fans must be on a separate electrical circuit, to enable them to continue operating.

HANDLING MACHINERY-ROOM EMERGENCIES

Appendix F is an “informative” appendix in Standard 15. That is, its recommendations are not prescriptive requirements; it is included in the standard solely for informational purposes.

Compliance with the minimum requirements in Standard 15 should help prevent injuries resulting from accidents in a machinery room. But minimal conformance to the standard’s requirements may not allow *expeditious* handling of machinery-room incidents. Appendix F of the standard provides guidance on how to integrate the standard’s minimum requirements for emergency warning and training into a comprehensive health and safety program. The recommendations in this appendix address alarm levels, alternate refrigerant-level measurements, and room reentry during an emergency.

Appendix F also outlines a six-step emergency procedure, which illustrates one of many approaches for handling minor maintenance problems in a machinery room.

Although Appendix F is summarized here, you are urged to obtain and read the standard in its entirety, including the appendixes.

Coordinating with local and national regulations and providing proper training for anyone authorized to enter the machinery room are two key elements of any emergency response plan. It is also important to implement an intuitive warning system that will be explicitly understood by untrained personnel in the area. (As an example, when the alarm sounds/flashes, it should be obvious to bystanders that they must leave the machinery room.)

Alarm levels

As a minimum requirement, Standard 15 prescribes both an alarm signal and the start of alarm-rate ventilation if the refrigerant concentration detected in the room reaches the threshold prescribed for the refrigerant being used. A minimum-response plan would call for evacuation of the machinery room when the alarm sounds, even if the presence of refrigerant results from a routine service operation rather than a genuine emergency. Personnel may not reenter the room to silence the alarm and complete the service operation (or repair any damage, if the incident was an emergency) without the services of emergency responders.

Providing two or more stages of alarm enables a more sophisticated response plan by providing more information about the alarm condition (see "Alarm outputs", p. 55). Based on the level of alarm, machinery-room occupants can determine whether evacuation is necessary. If the concentration is not high enough to warrant evacuation, the "low-level" alarm could alert them to put on appropriate protective gear while warning bystanders not to enter the room.

Alternate refrigerant-level measurements

Standard 15 only requires an alarm that signals when the detected refrigerant concentration exceeds the threshold prescribed for the refrigerant being used, but it may be helpful to provide additional monitoring equipment. For example, a portable monitor could be used to back up the primary detector when it is necessary to open the refrigeration system for service.

Similarly, the primary detector could be augmented by a permanently mounted, secondary detection device that collects and displays more information about the refrigerant concentration in the air—but with two caveats:

- Any secondary detectors or additional alarms must be clearly distinguished from the main alarm to avoid confusing bystanders.
- Automatic-reset devices can be used for secondary alarms, but the main alarm must be manually reset to comply with the standard.

Reentering a machinery room

Beginning with the 2001 edition, Standard 15 no longer includes a prescriptive requirement to provide a self-contained breathing apparatus (SCBA) outside the entrance to a machinery room. This requirement was omitted because of the risk that the SCBA could be used by untrained personnel or vandalized, either of which would result in an unsafe situation. However, the wording in Section 10.6 underscores the ongoing necessity for SCBA:

> **10.6 Responsibility for Operation and Emergency Shutdown.** *When a refrigerating machinery room is used, the emergency procedures shall be posted outside the room, immediately adjacent to each door. The emergency procedures shall forbid entry into the refrigerating machinery room when the refrigerant alarm required by Section 8.9.5 has been activated, except by persons provided with the appropriate respiratory and other protective equipment and trained in accordance with jurisdictional requirements.*

Therefore, Standard 15 still requires the use of SCBA (and other protective gear) to reenter the room when the alarm has been activated, but it permits flexibility in *how* to provide that equipment. For example, a facility could choose to either 1) locate protective gear outside the machinery room entrance, 2) store this gear in an area that is only accessible to trained personnel, or 3) contract with an outside firm to bring this gear when they provide emergency response services.

Example emergency procedures

Ideally, Standard 15's minimum requirements for warning of emergencies and training should be integrated into the facility's occupational health and safety program. The objective is to enable the facility to safely handle minor maintenance problems. There are countless ways to accomplish this objective; Appendix F offers one example (paraphrased here):

- Provide an alarm that triggers at the threshold prescribed for the refrigerant being used, per Section 8.9.5 or 8.11.10.
- Post signage at machinery-room entrances, which warns: "Authorized personnel only. Stay out when refrigerant alarm sounds; call facilities management immediately."
- Provide a digital readout, outside the machinery room, that displays the current concentration being measured by the refrigerant detector in the room. Provide a sign adjacent to the readout, which differentiates it from the alarm indicator required by the standard.
- Provide machinery-room technicians with respiratory protection that is appropriate for use when the refrigerant concentration is less than the IDLH and that complies with all applicable national and local regulations.
- Define an "incidental" (non-emergency) refrigerant release—that is, one that does not produce refrigerant levels above the IDLH in a properly ventilated machinery room.

- Train technicians how to respond to a refrigerant alarm. As an example:
  - Leave the room when the alarm sounds.
  - If the current refrigerant level is below the IDLH, put on appropriate respiratory protection (if necessary) and reenter the room to close valves, fix leaks, shut off alarms, etc.
  - If the refrigerant level exceeds the IDLH or the problem seems uncontrolled in any way, leave the room and call for emergency responders.

As Appendix F notes, implementing additional safety procedures (such as the ones in this example) can "significantly aid the facility's efforts to handle minor maintenance problems safely" without contradicting the requirements of the standard.

STORING REFRIGERANTS

Per Section 10.4, refrigerant can be stored in a machinery room, provided that it is kept in approved storage containers and that the total amount does not exceed 330 lb (150 kg). To store larger quantities of refrigerant in the machinery room, the containers must be provided with relief valves and piping in accordance with Section 9.4.

Standard 15 does not *explicitly* address storage of the refrigerant charge from a chiller during servicing. However, it seems reasonable to infer that it is allowed *provided that the charge is stored in approved and properly filled containers*. The rationale for this inference is that a machinery room is specifically designed to handle the amount (charge) of refrigerant inside the equipment (e.g., water chiller). Temporarily removing this amount of refrigerant from the chiller, and storing it in separate containers during service work, does not change the type or quantity of refrigerant in the room.

MAINTENANCE

Among the safety-focused requirements in Section 10.5 is periodic testing of the detectors, alarms, and mechanical ventilation systems in accordance with the respective equipment manufacturers and the presiding code authority.

Refrigerant Piping

Refrigerant piping is used to convey refrigerant from one part of a refrigeration system to another. Proper installation of refrigerant piping is critical for the safety of the building occupants.

According to Standard 15, refrigerant piping includes *"pipe, flanges, bolting, gaskets, valves, fittings, pipe-supporting fixtures, structural attachments, and the pressure-containing parts of other components, such as expansion joints, strainers, filters, and devices that serve such purposes as mixing, separating, muffling, snubbing, distributing, metering, or controlling flow."*

Sections 9.10 through 9.13 define the requirements related to the installation and testing of refrigerant piping. While this manual does not attempt to address all the requirements, the following section discusses those requirements that are likely most pertinent to the HVAC system design engineer.

PROHIBITED LOCATIONS FOR REFRIGERANT PIPING

Per Section 9.12.1.3, refrigerant piping cannot be installed exposed in either a fire-resistance-rated exit access corridor, an interior exit stairway, an interior exit ramp, or an exit passageway. Similarly, it cannot be installed in an elevator or dumbwaiter shaft, or any other shaft that contains a moving object.

To improve clarity, the term "means of egress" (used in previous versions of the standard) has been replaced by the term "exit passageway," which is defined in the standard as:

"an exit component that is separated from other interior spaces of a building or structure by fire-resistant-rated construction and opening protectives, and provides for a protected path of egress travel in a horizontal direction to an exit or the outside exit door."

In addition, piping installed in open spaces that afford passage must be no less than 7.25 ft (2.2 m) above the finished floor (Section 9.12.1.1). And if installed in concrete floors, refrigerant piping must be encased in pipe duct and properly isolated and supported to prevent damage due to vibration, corrosion, and expansion/contraction stress (Section 9.12.1.4).

In the standard's definition for exit passageway, the word "**in**" was deliberately chosen by the committee to replace the word "over," which had been used in previous versions of the standard.

REFRIGERANT PIPE SHAFTS

Per Section 9.12.1.5, refrigerant piping that penetrates two or more floor/ceiling assemblies must be enclosed in a fire-resistance-rated shaft enclosure, that complies with the building code requirements. Other utilities and piping systems are allowed to be routed inside this same shaft. A shaft enclosure is not required for piping in a high-probability system where the refrigerant concentration does not exceed the RCL for the smallest occupied space through which the piping passes.

The standard's stringent requirements for shafts is due to them being fire rated, and therefore tighter than normal construction.

For systems that use flammable refrigerants, Section 9.12.2.2 requires that any refrigerant pipe shaft must be ventilated. If only Group A2L or B2L refrigerants are used, either natural ventilation or mechanical ventilation can be used. If one or more of the systems use a Group A2, A3, B2, or B3 refrigerant, continuous mechanical ventilation is required.

- When allowed, a naturally-ventilated shaft must have a pipe, duct, or conduit with a diameter of at least 4 in. (102 mm) routed from outdoors to the lowest point in the shaft (installed level or pitched down towards the outdoors). A makeup air opening must then be located at the top of the shaft.
- A mechanically-ventilated shaft must provide a minimum air velocity, which is based on the cross-sectional area of the shaft (see Table 9-12 in the standard), with makeup air provided at the inlet to the shaft. Mechanical ventilation must be continuous if one or more of the systems uses a Group A2, A3, B2, or B3 refrigerant. If only Group A2L or B2L refrigerants are used, continuous ventilation is optional, or mechanical ventilation can be activated by a refrigerant detector (with a setpoint <= the OEL of the refrigerant) located in an area of the shaft where refrigerant from a leak will concentrate.
- The shaft ventilation exhaust outlet must comply with the requirements specified in Section 9.7.8.2.

Double-wall refrigerant pipe, where the interstitial space of the double-wall piping is vented to the outdoors, is exempt and does not require shaft ventilation.

INSPECTION AND LEAK TESTING

Per Section 7.2.3.1.1, areas of the building that contain only continuous sections of refrigerant piping, or that contain only joints and connections that have been tested in accordance with Section 9.13, do not need to be considered in the calculations of effective dispersal volume, unless these areas are part of connected spaces (see "Effective dispersal volume," p. 20).

Refrigerant piping and joints installed on the premises must be exposed for visual inspection and testing prior to being covered or enclosed.

The testing required by Section 9.13 includes a strength test and two leakage tests.

- Components of the refrigeration system that have been strength tested by the manufacturer are not required to be strength tested again on the premises, unless they have been modified or repaired.
- Listed equipment that has not been modified or repaired is not required to be strength tested on the premises.

For the **strength test**, the system is pressured with an inert gas for at least ten minutes. Passing this test requires no rupture or structural failure of any system component or refrigerant piping.

After passing the strength test, the **pressure leak test** involves continuing to monitor the system pressure for a prescribed minimum duration, which is based on the length and diameter of the piping (see Table 9-13 in the standard). For longer or larger-diameter sections of pipe, the duration of this pressure test will be longer. For example, if the length of piping is < 100 ft (30 m) and the pipe diameter is <= 0.75 in. (20 mm), the duration of this pressure test must be at least 15 minutes. However, for this same length of piping, if the pipe diameter is > 0.75 in. (20 mm) but <= 3 in. (75 mm), the duration must be at least 60 minutes. Passing this test requires no loss in pressure over this prescribed duration, although correcting the pressure reading due to a change in ambient temperature is permitted.

Finally, the **vacuum leak test** involves connecting a vacuum pump to lower the pressure of the system below ambient (creating a vacuum), and then disconnecting the pump. Passing this test requires that the pressure not rise above a prescribed threshold over the required duration of the test, which is again based on the length and diameter of the piping (see Table 9-13 of the standard). For example, if the length of piping is < 100 ft (30 m) and the pipe diameter is <= 0.75 in. (20 mm), the duration of this vacuum test must be at least 1 hour. However, for this same length of piping, if the pipe diameter is > 0.75 in. (20 mm) but <= 3 in. (75 mm), the duration must be at least 8 hours.

If a system contains >= 55 lb (25 kg) of refrigerant, the installing contractor or registered engineer must issue a "certificate of test" and provide additional documentation to the authority having jurisdiction:

> *9.13.7 Contractor or Engineer Declaration. The installing contractor or registered design professional of record shall issue a certificate of test, verifying strength test in accordance with Section 9.13.5 and leakage test in accordance with Section 9.13.6, to the AHJ for all systems containing 55 lb (25 kg) or more of refrigerant. The certificate shall give the test date, photograph of the pressure gage at the test pressure, refrigerant designation, test medium, and the field test pressure applied to the high side and the low side of the system. The certificate of test shall be signed by the installing contractor or registered design professional and shall be made part of the public record.*

Pressure-Relief Piping

The “pressure-relief protection” portion of Standard 15 opens with this general requirement:

9.4.1. *Refrigerating systems shall be protected by a pressure-relief device or other approved means to safely relieve pressure due to fire or other abnormal conditions.*

The rest of Section 9.4 specifically describes when pressure-relief devices are needed and how to size them. Manufacturers of packaged refrigeration systems or components for “built-up” systems usually engineer pressure-relief devices into their equipment designs. Despite this convenience, it is still important to use the current edition of Standard 15 to verify that all pressure vessels are adequately protected against rupture.

With respect to refrigeration, ASHRAE Standard 15 defines a **pressure vessel** as:

Any refrigerant-containing receptacle in a refrigerating system. This does not include evaporators where each separate evaporator section does not exceed 0.5 ft^3 (0.014 m^3) of refrigerant-containing volume, regardless of the maximum inside dimension. This also does not include evaporator coils, compressors, condenser coils, controls, headers, pumps, and piping.

Under this definition, the direct-expansion evaporator coil of a split system is not a “pressure vessel” but the flooded evaporator of a water chiller is.

DISCHARGE LOCATION

After the refrigeration equipment is installed, each pressure-relief device must be piped to a safe location, per Section 9.7.8. Section 9.7.8.1 allows pressure relief systems designed for refrigerant vapor to discharge inside the building if ALL of the following conditions are met:

a. *The system contains less than 110 lb (50 kg) of a Group A1 or A2L refrigerant.*
b. *The system contains less than 6.6 lb (3 kg) of a Group A2, B1, B2L, or B2 refrigerant.*
c. *The system does not contain any quantity of a Group A3 or B3 refrigerant.*
d. *The system is not required to be installed in a machinery room as required by Section 7.4.*
e. *The refrigerant charge quantity in Section 7.3 is not exceeded.*

If any of the above conditions are not met, the pressure relief system must discharge to outside of the building, per the requirements of Sections 9.7.8.2, 9.7.8.3, and 9.7.8.4. In summary, these sections require the following of the pressure-relief discharge piping:

- Route the piping so that it discharges outdoors in an area that will not spray refrigerant onto personnel that might be in the vicinity.
- Position the discharge no lower than 15 ft (4.57 m) above the adjoining ground level. Refrigeration systems located outdoors, and containing a Group A1 refrigerant, are exempt from this requirement and allowed to discharge at any elevation, provided that the location is accessible to authorized personnel only.
- Position the discharge at least 20 ft (6.1 m) from any window, building ventilation opening, pedestrian walkway, or building exit. In addition, for refrigerants that are heavier than air, position the discharge at least 20 ft (6.1 m) horizontally from any below-grade walkway, entrance, pit, or ramp, if a release of the entire charge into such a space would result in a concentration that exceeds the RCL.

- Avoid discharge into an enclosed outdoor space (e.g., a courtyard with walls on all sides), if a release of the entire charge into such a space would result in a concentration that exceeds the RCL.
- Provide a piping termination that cannot be blocked by debris and if the piping discharges upwards, a drip leg must be provided (see Figure 17).

Do not underestimate the importance of these requirements—nor the potential consequences of noncompliance. For example, improperly terminating the discharge piping could allow rain to enter the line. Accumulated rainwater can cause the relief device to malfunction; or, in the case of a rupture disc, the rainwater pressure may cause the disc to rupture, allowing water to enter the chiller. Remember, too, that when a pressure-relief device operates, it may discharge a large amount of fluid and/or vapor. An improper termination could allow the discharge to injure bystanders and/or damage property.

DISCHARGE PIPING MATERIALS

All materials in the pressure relief system must be compatible with the refrigerant in use. Commonly used and accepted piping materials include steel and DWV (drain/waste/vent) copper. Consult local codes for restrictions on materials.

The **discharge piping**— also called a vent line or relief line—refers to the length of pipe that carries refrigerant from the relief device (or fusible plug) to the point where it is released to the atmosphere for dispersal. Refrigerant only passes through this discharge pipe if an overpressure condition causes the relief device or fusible plug to operate.

PVC piping is compatible with most refrigerants, but the glue that joins the sections of plastic pipe may not be. When considering the use of plastic piping, such as PVC, make sure that both the pipe material and the adhesive have been tested for refrigerant compatibility. Also, verify that the local code permits PVC for refrigerant discharge piping; even though Standard 15 does not prohibit its use, some local codes might.

Flexible connection devices for vibration isolation must also be compatible with the vented refrigerant. Trane recommends a flexible stainless-steel pump connector (or equivalent).

DISCHARGE PIPE SIZING

Standard 15 provides specific requirements for the discharge piping that allows pressure-relief devices to safely vent refrigerant to the atmosphere if over-pressurization occurs.

Section 9.7.9 in Standard 15 makes these stipulations for compliance:

- The size of the discharge piping must be no smaller than the outlet size of the pressure-relief device (Section 9.7.9.2). A larger pipe size may be necessary to prevent exceeding the allowable back pressure, depending on the length of the piping run (Section 9.7.9.3).
- Two or more relief devices can be connected to a common discharge pipe—but only if the piping is sized large enough to handle all devices that could relieve at the same time (Section 9.7.9.3.3). However, different refrigerants cannot be vented into a common relief piping system (Section 9.7.8).

Section 9.7.9.3 prescribes the maximum length for discharge piping, and provides the equation and data necessary to properly size discharge piping from the outlet of a single pressure-relief valve. The equation accounts for the relationship between pipe diameter, equivalent pipe length, and the pressure difference between the pipe inlet and outlet to help ensure that the pressure relief system provides sufficient flow capacity without exceeding the allowable back pressure.

Manufacturers may use several pressure-relief devices on the same unit, either to vent distinct areas of the machine or to provide more discharge capacity than a single relief device. System designers sometimes use a common header to combine discharge piping from multiple machines.

Appendix E in Standard 15 lists the capacities of various discharge pipe sizes and lengths. However, this data only applies to a single, conventional pressure-relief valve, and NOT to balanced relief valves, rupture members, fusible plugs, or pilot-operated valves. Using Appendix E to size discharge piping for any non-conventional pressure-relief device will result in a maximum equivalent length that is significantly shorter than that calculated using the equation in Section 9.7.9.3 of the standard.

Following are several examples of how to use the equation and data in Standard 15 to properly size refrigerant discharge piping. These examples also demonstrate an analytical method for sizing the common discharge pipe when a single unit has more than one relief device and when multiple units share the same header.

Be sure to consult local codes and product installation information to determine whether other restrictions on refrigerant discharge piping apply. For example, it may not be permissible to manifold the pressure-relief devices of certain types of chillers.

Maximum length of discharge piping

[The following excerpt is from Section 9.7.9 of ANSI/ASHRAE Standard 15–2022.]

9.7.9.2 The size of the discharge pipe from a pressure relief device or fusible plug shall not be less than the outlet size of the pressure relief device or fusible plug.

9.7.9.3 The maximum length of the discharge piping installed on the outlet of pressure relief devices and fusible plugs discharging to the atmosphere shall be determined using the method in this section.

9.7.9.3.1 The design back pressure due to flow in the discharge piping at the outlet of pressure-relief devices and fusible plugs, discharging to atmosphere, shall be limited by the allowable equivalent length of piping determined by the following equations:

$$L = \frac{0.2146 d^5 (P_0^2 - P_2^2)}{f C_r^2} - \frac{d \times \ln(P_0/P_2)}{6f}$$

$$\left(L = \frac{7.4381 \times 10^{-15} d^5 (P_0^2 - P_2^2)}{f C_r^2} - \frac{d \times \ln(P_0/P_2)}{500f} \right)$$

where

L = equivalent length of discharge piping, ft (m)

C_r = rated capacity as stamped on the pressure relief device in lb/min (kg/s), or in SCFM multiplied by 0.0764, or as calculated in Section 9.7.7 for a rupture member or fusible plug, or as adjusted for reduced capacity due to piping as specified by the manufacturer of the device, or as adjusted for reduced capacity due to piping as estimated by an approved method.

f = Moody friction factor in fully turbulent flow *[see typical values in the following table, excerpt from Appendix D in the standard]*

d = inside diameter [ID] of pipe or tube, in. (mm)

ln = natural logarithm

P_2 = absolute pressure at outlet of discharge piping, psia (kPa)

P_0 = allowed back pressure (absolute) at the outlet of pressure-relief device, psia (kPa)

9.7.9.3.2 Unless the maximum allowable back pressure (P_0) is specified by the relief valve's manufacturer, the following maximum allowable back pressure values shall be used for P_0, where P is the set pressure and P_a is atmospheric pressure at the nominal elevation of the installation *(see typical values in the following table, excerpt from Table 9-7 in the standard):*

a. for conventional relief valves, 15 percent of set pressure: $P_0 = (0.15 \times P) + P_a$
b. for balanced relief valves, 25 percent of set pressure: $P_0 = (0.25 \times P) + P_a$
c. for rupture disks alone, fusible plugs, and pilot-operated pressure relief valves, 50 percent of set pressure: $P_0 = (0.50 \times P) + P_a$

For fusible plugs, P shall be the saturated absolute pressure for the stamped temperature melting point of the fusible plug or the critical pressure of the refrigerant used, whichever is smaller.

9.7.9.3.3 When outlets of two or more relief devices or fusible plugs, which are expected to operate simultaneously, connect to a common discharge pipe, the common pipe shall be sized large enough to prevent the back pressure at each pressure relief device from exceeding the maximum allowable back pressure in accordance with Section 9.7.9.3.2.

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Maximum length of discharge piping, continued.

Typical Moody friction factors *(f)* for fully turbulent flow (Appendix D, ASHRAE 15-2022)

Tubing OD (in.)	DN [mm]	ID (in.)	*f*
3/8	8	0.315	0.0136
1/2	10	0.430	0.0128
5/8	13	0.545	0.0122
3/4	16	0.666	0.0117
7/8	20	0.785	0.0114
1 1/8	25	1.025	0.0108
1 3/8	32	1.265	0.0104
1 5/8	40	1.505	0.0101
Piping NPS [in.]	**DN** [mm]	**ID** (in.)	*f*
1/2	15	0.622	0.0259
3/4	20	0.824	0.0240
1	25	1.049	0.0225
1 1/4	32	1.380	0.0209
1 1/2	40	1.610	0.0202
2	50	2.067	0.0190
2 1/2	65	2.469	0.0182
3	80	3.068	0.0173
4	100	4.026	0.0163
5	125	5.047	0.0155
6	150	6.065	0.0149

["DN" represents "Diametre Nominel," which approximates the metric equivalent of NPS (nominal pipe size).]

Informative Table 9-7 Atmospheric Pressure at Nominal Elevation (P_a)

Elevation above sea level (ft)	P_a (psia)	Elevation above sea level (m)	P_a (kPa)
0	14.7	0	101
500	14.4	150	99.5
1000	14.2	300	97.8
1500	13.9	450	96.0
2000	13.7	600	94.3
2500	13.4	750	92.6
3000	13.2	900	91.0
3500	12.9	1050	89.3
4000	12.7	1200	87.7
4500	12.5	1350	86.1
5000	12.2	1500	84.6
6000	11.8	1800	81.5
7000	11.3	2100	78.5
8000	10.9	2400	75.6
9000	10.5	2700	72.8
10000	10.1	3000	70.1

One of the variables in the equation for determining the maximum allowable length is the "allowed back pressure," P_0. The method by which P_0 is calculated varies based on the type of relief device. Refrigeration equipment with helical-rotary or scroll compressors often use conventional relief valves, while rupture members are the norm for equipment with centrifugal compressors. Check with the equipment manufacturer to verify the relief-device type.

The rated discharge capacity, C_r, of a conventional relief device typically is stamped on the exterior of the device. However, for rupture members or fusible plugs, it is common to use either a calculated value for C (calculated in accordance with Section 9.7.7 of Standard 15) or an equipment-specific value provided by the manufacturer.

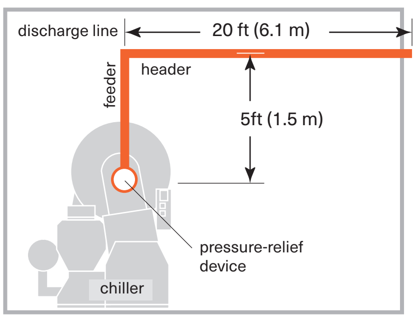
For simplicity, the "equivalent length" calculations in the following examples pertain only to straight piping; they do not account for the pressure drop through fittings.

Non-manifolded relief devices

For a chiller application in which each relief device is piped separately, the equation from Section 9.7.9.3.1of Standard 15 (p. 76) can be used to determine the proper pipe size for the required length of run. The following example demonstrates how.

Example. Consider a low-pressure chiller with a single, rupture-member relief device. The device has an outlet connection of 3 in. NPS (80 mm DN), a calculated discharge rate, C, of 64 lb/minute (0.48 kg/s), and a pressure setting, P, of 15 psig (103 kPa). The discharge piping must run an equivalent length of 25 ft (7.6 m) to exit the building; see Figure 14.

Figure 14. Example of a dedicated pressure-relief discharge pipe (line)



1. Find the inside diameter (ID), d, and Moody friction factor, *f*, that corresponds to the discharge pipe size using the table in Appendix D of Standard 15. To comply with Section 9.7.9.2 of the standard, the discharge pipe size cannot be smaller than the outlet connection of the relief device.

   According to the table in Appendix D of the standard (p. 77), the minimum pipe size of 3 in. NPS (80 mm DN) for our example chiller corresponds to an inside diameter (ID) of d = 3.068 in. (77.93 mm) and *f* = 0.0173.

2. Determine the absolute pressure at the outlet of the discharge piping, P_2. At sea level elevation (p. 77), P_2 = 14.7 psia (101 kPa).

3. Calculate the allowed back pressure (absolute), P_0, based on the type of relief device. For a rupture member, $P_0 = (0.50 \times P) + P_a$. At sea level elevation, P_a = 14.7 psia (101 kPa), so:

   $P_0 = (0.5 \times 15) + 14.7 = 22.2$ psia

   ($P_0 = (0.5 \times 103) + 101 = 153$ kPa)

4. Solve the equation to find the maximum allowable equivalent length (L) for this diameter (d) of discharge piping:

$$L = \frac{0.2146 \times 3.068^5 \times (22.2^2 - 14.7^2)}{0.0173 \times 64^2} - \frac{3.068 \times \ln(22.2/14.7)}{6 \times 0.0173} = 215 \text{ ft}$$

$$\left(L = \frac{(7.4381 \times 10^{-15}) \times (77.93^5) \times (153^2/101^2)}{0.0173 \times 0.48^2} - \frac{77.93 \times \ln(153/101)}{500 \times 0.0173} = 67.1 \text{ m} \right)$$

5. Finally, compare the *allowable* equivalent length, L, to the total equivalent length of the actual discharge piping run (that is, straight piping/tubing *plus* elbows). In this example, L = 215 ft (67.1 m), far exceeding the 25 ft (7.6 m) needed to transport released refrigerant outside the building.

   Although a smaller pipe would satisfy the back pressure requirements, using a pipe size that's smaller than the outlet of the relief device would violate Section 9.7.9.2 of the standard.

The convenience of Appendix E in Standard 15 may tempt its use to size discharge piping for non-conventional relief devices ... but doing so significantly lessens the safety factor. To illustrate, if the discharge pipe in the preceding example was sized according to Appendix E the allowable equivalent length would be only 55 ft (17 m) versus the 215 ft (67.1 m) that was calculated using the equation in Section 9.7.9.3.

Manifolded relief devices with identical capacity ratings

For more information about how to size discharge piping that's shared by multiple relief devices, refer to *User's Manual for ANSI/ASHRAE Standard 15–2001, Safety Standard for Refrigeration Systems*. Visit ASHRAE's online bookstore at www.ashrae.org to order or download a copy.

When a header connects more than one pressure-relief device, the size of the common line must account for the back pressure that would occur if two or more of the devices operate at the same time (Section 9.7.9.3.3). The *User's Manual for ANSI/ASHRAE Standard 15–2001* demonstrates different methods for sizing the common header, depending on the rated capacities of the relief devices and whether the devices can be expected to operate at the same time.

The following equation (Equation 20 from the *User's Manual*) is part of an analytical method for sizing a header that connects identically rated pressure-relief devices that could operate simultaneously.

"resource" used by one discharge pipe feeder or header

$$\frac{LC^2}{d^5} = \frac{0.2146\,(P_0^2 - P_2^2)}{f} - \frac{C^2 \ln(P_0/P_2)}{6fd^4}$$

$$\left(\frac{LC^2}{d^5} = \frac{7.4381 \times 10^{-15}(P_0^2 - P_2^2)}{f} - \frac{C^2 \ln(P_0/P_2)}{500fd^4}\right)$$

"resource" available at the pressure-relief device (K_x)

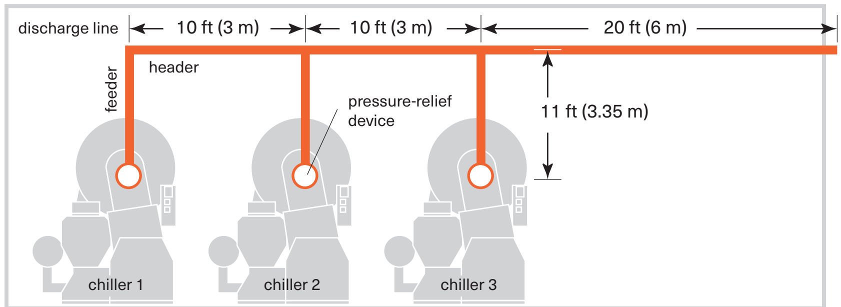
The right-hand side of the equation represents the "resource," K_x, available at the pressure-relief device, while the left-hand side calculates how much of the available "resource" a particular section of header or feeder piping will use.

Example. Consider the three low-pressure chillers shown in Figure 15. The rupture member of each chiller has a 3-in. NPS (80 mm DN) outlet connection, a calculated discharge rate, C, of 64 lb/minute (0.48 kg/s), and a pressure setting of 15 psig (103 kPa). The equivalent length of the feeder pipe from each chiller to the common header is 11 ft (3.35 m), while the equivalent length of the header pipe is 40 ft (12 m).

See previous example for an explanation of how to determine the inside diameter (d) and Moody friction factor (*f*) that corresponds to the discharge pipe size, and how to calculate the absolute pressure at the outlet of the discharge piping (P_2) and the allowed back pressure (P_0).

Per Section 9.7.8 of the standard, *“Different refrigerants shall not be vented into a common relief piping system, unless the refrigerants are included in a blend that is recognized by ASHRAE Standard 34."*

Figure 15. Example of manifolded pressure-relief devices (identical device ratings)



1. Determine the “resource,” K_X, available at the pressure-relief device by solving the right-hand side of the equation. In this case, K_X = 3,249 (5.379 x 10^{-9}):

$$\frac{0.2146 \times (22.2^2 - 14.7^2)}{0.0173} - \frac{(64^2) \times \ln(22.2/14.7)}{6 \times 0.0173 \times 3.068^4} = 3{,}249$$

$$\left(\frac{7.4381 \times 10^{-15} \times (153^2 - 101^2)}{0.0173} - \frac{(0.48^2) \times \ln(153/101)}{500 \times 0.0173 \times 77.93} = 5.379 \times 10^{-9}\right)$$

Per Section 9.7.9.2 of Standard 15, the size of the discharge piping can be no smaller than the outlet connection of the pressure-relief device.

2. Solve the left-hand side of the equation to calculate how much of the available “resource” the feeder pipe will use if it is sized to match the outlet size of the pressure-relief device. In this case, an equivalent length of 11 ft (3.35 m) of 3-in. NPS (80 mm DN) pipe will use 166 (0.269 x 10^{-9}):

$$\frac{11 \times 64^2}{3.068^5} = 166$$

$$\left(\frac{3.35 \times 0.48^2}{77.93^5} = 0.269 \times 10^{-9}\right)$$

3. Compare the “resource” values to verify that each feeder pipe will provide sufficient flow capacity, given the pipe diameter and equivalent length—that is, whether the “resource” used (calculated in step 2) is less than the total available “resource” (calculated in step 1). In this case, a 3-in. NPS (80 mm DN) feeder pipe is large enough because 166 < 3,249 (0.269 x 10^{-9}< 5.379 x 10^{-9}). That leaves an available “resource” remaining of 3,249 – 166 = 3,083 (5.379 x 10^{-9} – 0.269 x 10^{-9} = 5.110 x 10^{-9}) for the common header pipe.

Note: It would be necessary to repeat step 3 using a larger feeder pipe diameter if the “resource” used exceeded the available “resource.”

4. Solve the left-hand side of the equation to determine how much of the remaining available “resource” a 4-in. NPS (100 mm DN) header pipe will use, accounting for the combined discharge rate (C) of the three pressure-relief devices:

$$\frac{40 \times (64 \times 3)^2}{4.026^5} = 1394$$

$$\left(\frac{12 \times (0.48 \times 3)^2}{102.3^5} = 2.221 \times 10^{-9}\right)$$

5. Since the “resource” used by the common header pipe does not exceed the remaining available “resource”—3,083 (5.110×10^{-9}) in this case—then the header pipe diameter provides the required discharge capacity to comply with Standard 15.

Note: It would be necessary to repeat step 4 using a larger header pipe diameter if the “resource” used exceeded the remaining available “resource”.

Manifolded relief devices with unlike capacity ratings

Not all chillers use identically rated pressure-relief devices, so it is not uncommon for a discharge piping system to serve multiple relief devices with *different* rated capacities. The calculation method that was just described for identical relief devices works in this situation, too, but it’s also necessary to:

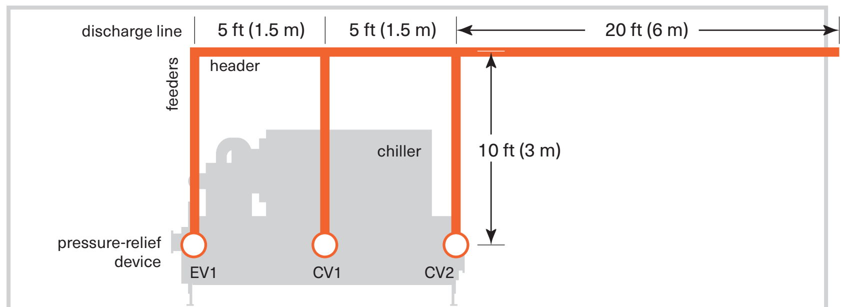
- Calculate the available “resource,” K_x, for *each* of the feeder lines, which connects each pressure-relief device to the common header; and then,
- Choose a header size that’s based on the *smallest remaining* K_x value after accounting for the “resource” required for each feeder.

Example. Consider a single, medium-pressure chiller equipped with three conventional pressure-relief valves, one for the evaporator (EV1) and two for the condenser (CV1, CV2):

Relief-device characteristics	**EV1**	**CV1 and CV2**
Connection size, NPS (DN)	1.25 in. (32 mm)	1.25 in. (32 mm)
Rated discharge capacity, C_r	78 lb/min (0.59 kg/s)	48 lb/min (0.36 kg/s)
Pressure setting, P	200 psig (1379 kPa)	200 psig (1379 kPa)
Absolute pressure at discharge, P_2	14.7 psia (101 kPa)	14.7 psia (101 kPa)
Allowed back pressure, P_0	44.7 psia (308 kPa)	44.7 psia (308 kPa)

The equivalent length of the feeder from each pressure-relief device to the common header is 10 ft (3 m), while the header extends an equivalent length of 30 ft (9 m) to exit the building; see Figure 16. See the first example for an explanation of how to determine the inside diameter (d) and Moody friction factor (*f*) that corresponds to the discharge pipe size, and how to calculate the absolute pressure at the outlet of the discharge piping (P_2).

Figure 16. Example of manifolded pressure-relief devices (unlike device ratings)



1. Calculate the allowed back pressure (absolute), P_0, based on the relief-device type. For conventional relief valves, $P_0 = (0.15 \times P) + P_a$. So:

   $P_0 = (0.15 \times 200) + 14.7 = 44.7$ psia

   ($P_0 = (0.15 \times 1379) + 101 = 308$ kPa)

2. Calculate the available "resource," K_x, for *each* of the pressure-relief valves. To do so, use the values provided on p. 81 to solve the right-hand side of this equation for each C_r value—once for valve EV1 and once for valves CV1 and CV2:

"resource" used by one discharge pipe feeder or header

$$\frac{LC^2}{d^5} = \frac{0.2146\,(P_0^2 - P_2^2)}{f} - \frac{C^2 \ln(P_0/P_2)}{6fd^4}$$

$$\left(\frac{LC^2}{d^5} = \frac{7.4381 \times 10^{-15}(P_0^2 - P_2^2)}{f} - \frac{C^2 \ln(P_0/P_2)}{500fd^4}\right)$$

"resource" available at the pressure-relief device

3. Solve the left-hand side of the equation to calculate how much of the available "resource" each feeder will use if it's sized to match the pressure-relief device.

Per Section 9.7.9.2 of Standard 15, the size of the discharge piping can be no smaller than the outlet connection of the pressure-relief device.

4. Compare each pair of “resource” values for each feeder pipe to verify that the equivalent length and diameter will provide sufficient flow capacity. If the “resource” used exceeds the “available” resource, increase the pipe diameter. In this example, the diameter of the feeder pipe connected to valve EV1 had to be increased to ensure that the “resource” used by that feeder pipe did not exceed the “resource” available. With the three feeder pipes properly sized, the smallest value of “resource” remaining is 4,999 (8.293×10^{-9}).

		“Resource”				
Device	**Feeder pipe diameter**	**Used**		**Available**	**Sufficient flow capacity?**	**“Resource” remaining**
EV1	1.25 in.	12,156	>	3,420	No	–8,736
	1.5 in.	5,624	<	10,623	Yes	4,999
CV1	1.25 in.	4,603	<	12,663	Yes	8,060
CV2	1.25 in.	4,603	<	12,663	Yes	8,060

5. Determine how much of the remaining available “resource” the 3-in. NPS (80 mm DN) header pipe will use by solving the left-hand side of the equation on p. 82. Remember that for this common header, *C* is the sum of the discharge capacities for all of the pressure-relief devices that are connected to it.

$$\frac{30 \times (78 + 48 + 48)^2}{3.068^5} = 3342$$

$$\left(\frac{9 \times (0.59 + 0.36 + 0.36)^2}{77.93^5} = 5.374 \times 10^{-9}\right)$$

6. Verify that the “resource” used by the header pipe is less than the smallest remaining available “resource” for each relief device; see Step 4. In this case, the smallest remaining “resource” from the feeders is 4,999 (8.293×10^{-9}) from EV1, so this combination of discharge pipe diameters and equivalent lengths provides sufficient discharge capacity to comply with Standard 15.

Note: If the header size will use more than the available “resource,” you can either:

- *Increase the size of the header to reduce the amount of “resource” it will use, or*
- *Increase the size of the critical feeder to make more “resource” available for the header. (The critical feeder is the run with the least available “resource” remaining.)*

DRIP LEG

If the discharge piping terminates vertically upward and is subject to moisture entry, Section 9.7.8.2 of the standard requires installation of a “drip leg” (or “drip pocket”) that extends below the first change in direction. The drip leg must be the same diameter as the discharge pipe, no shorter than 24 in. (0.6 m) in length, and be fitted with a valve or drain plug.

Recall that the volume (V) of a length of pipe is calculated as:

$$V = L \times \frac{\pi d^2}{4}$$

Although Standard 15 only requires it in the above-mentioned case, it's prudent to equip each refrigerant discharge pipe with a drip leg that's capable of holding up to 1 gal, or 231 in.^{3} (3800 cm^3), of liquid. Use the following equation to find the required length L, in inches (cm), of pipe for this drip leg...

$$L = 294 / d^2$$

$$(L = 4840 / d^2)$$

... where d is the inside diameter, in inches (cm), of the pipe. Figure 17 illustrates one example of a properly piped pressure-relief system. The standard, capped, 1/4 in. FL × 1/4 in. NPT refrigerant service valve in that arrangement simplifies draining. As part of the regular maintenance program and using appropriate refrigerant-handling procedures, remove any accumulated liquid from the drip leg at least once every six months.

PURGE DISCHARGE

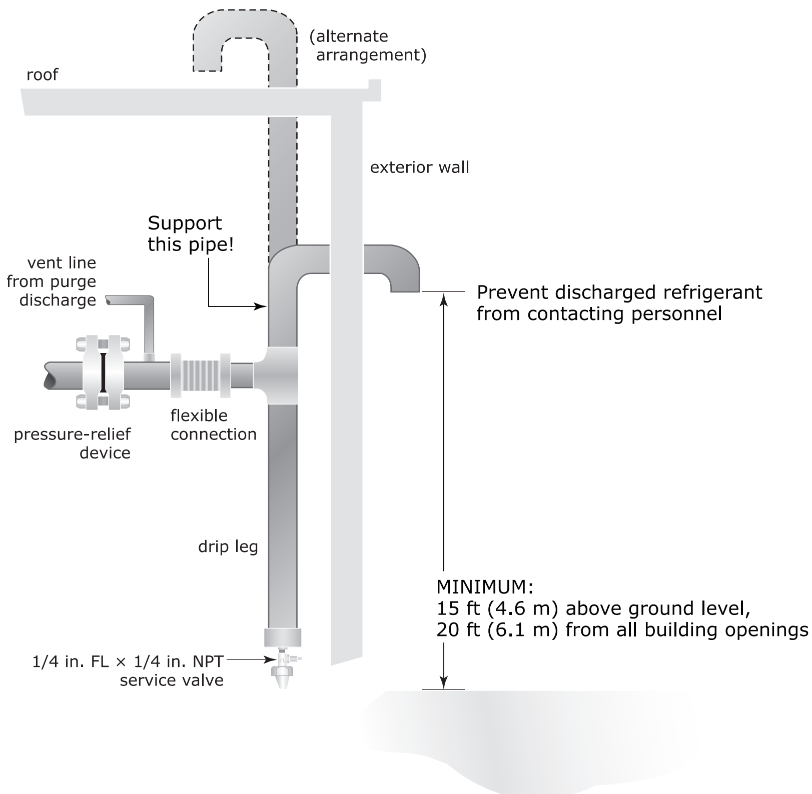
To comply with Standard 15, the discharge piping from purge units that remove non-condensible gas from refrigeration systems must conform to the standard's requirements for pressure relief piping:

> **8.13 Purge Discharge.** *The discharge from purge systems shall be governed by the same rules as pressure-relief devices and fusible plugs (see Section 9.7.8) and shall be piped in conjunction with these devices.*

Generally, the most convenient way to properly vent the purge discharge to the atmosphere is to route it into the discharge piping for the pressure-relief device, upstream of any vibration isolation (Figure 17). Make sure that the purge discharge line does not contain any liquid traps, and that it slopes away from the purge unit to prevent liquid from collecting there. Consult the purge manufacturer for proper discharge-line sizing.

In addition, routinely monitor the refrigeration system for leaks and promptly repair any that are found. Regular logging of purge operation and chiller run-time provides an excellent indicator of system integrity.

Figure 17. Example of a refrigerant discharge piping arrangement (not to scale)



Glossary

ACGIH. American Conference of Governmental Industrial Hygienists.

AEL. Acceptable exposure limit.

AHJ. Authority having jurisdiction.

air circulation. Mechanically inducing airflow within a space or spaces connected by air ducts.

air washer. Device that sprays or atomizes clean water into the supply air path. If heated or chilled, the water can heat, cool, humidify, or dehumidify the passing air, as well as remove some of the entrained liquids or solids. Occasionally used in industrial processes, particularly those associated with textile manufacturing.

ANSI. American National Standards Institute.

azeotropic refrigerant. Blend of two or more component refrigerants (with different volatilities) whose equilibrium vapor-phase and liquid-phase compositions remain the same at a given pressure. *See also* zeotropic refrigerant.

back pressure. Static pressure existing at the outlet of an operating pressure-relief device due to pressure in the discharge (refrigerant vent) line.

balanced relief valve. A pressure relief valve that incorporates means of minimizing the effect of back pressure on the operational characteristics of the valve (opening pressure, closing pressure, and relieving capacity).

building automation system (BAS). Combination of controllers and software that communicates with and controls various mechanical systems, enabling centralized building management.

blends. Refrigerants consisting of mixtures of two or more different chemical compounds, often used individually as refrigerants for other applications.

block valves. *See* companion valves.

brazed joint. A a gas-tight joint obtained by the joining of metal parts with metallic mixtures or alloys that melt at liquidus temperatures above 840°F (450°C) but less than the melting solidus temperatures of the joined parts.

companion valve. Pairs of mating stop valves that allow sections of a system to be joined before opening these valves or separated after closing them.

connected spaces. Two or more spaces connected by natural ventilation, a ducted air distribution system, or mechanical ventilation.

design pressure. The maximum gauge pressure for which a specific part of a refrigeration system is designed.

discharge piping. *See* vent line.

EPA. Environmental Protection Agency.

equipment room. Room that houses mechanical equipment, such as refrigeration systems, but which may not conform to the special requirements for a machinery room, as detailed in ANSI/ASHRAE Standard 15. *See also* machinery room *and* mechanical equipment room.

equivalent length. Flow resistance of fittings or appurtenances in a conduit through which fluid passes, expressed as the length of straight conduit of the same diameter or shape that would have the same resistance; also expressed in length/diameter units.

exhaust air. Air removed from a space and discharged outside of the space by means of mechanical ventilation.

exit passageway. An exit component that is separated from other interior spaces of a building or structure by fire-resistant-rated construction and opening protectives, and provides for a protected path of egress travel in a horizontal direction to an exit or the outside exit door.

fractionation. Change in composition of a blend by preferential evaporation of the more volatile component(s) or condensation of the less volatile component(s). *See also* zeotropic refrigerant.

fusible plug. Plug containing an alloy, which melts at a specified temperature to relieve pressure.

header. Pipe or tube to which other pipes or tubes (from pressure-relief devices, in the context of this manual) are connected.

hydrocarbon. Compound containing only hydrogen and carbon.

HVAC. Heating, ventilation, and air conditioning.

IDLH. "Immediately dangerous to life or health"; that is, the maximum concentration from which unprotected persons are able to escape within 30 minutes without escape-impairing symptoms or irreversible health effects.

informative appendix. Addendum that is not part of the standard but is included for information only. *See also* normative appendix.

labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

lower flammability limit (LFL). Minimum concentration of refrigerant that can propagate a flame through a homogeneous mixture of that refrigerant and air under test conditions; normally expressed as refrigerant percentage by volume.

machinery room. A designated space meeting the requirements of Sections 8.9, 8.10, and 8.11 of ANSI/ASHRAE Standard 15 that contains one or more refrigeration systems or portions thereof, such as compressors and pressure vessels.

makeup air. Air added to a space from outside the building or from other indoor spaces by means of mechanical or natural ventilation.

manifolded relief devices. *See* header.

material safety data sheet (MSDS). Document that provides the following information about a substance: chemical name, hazardous ingredients, physical characteristics, fire and/or explosion data, reactivity, health hazards, usage, handling and/or storage, and special protection and precautions.

MER. Mechanical equipment room; room that houses mechanical equipment, such as refrigeration systems, but which may not conform to the special requirements for a machinery room, as detailed in ANSI/ASHRAE Standard 15. *See also* equipment room *and* machinery room.

normative appendix. Addendum that is integral to the mandatory requirements of the standard but which, for convenience, is placed after all other normative elements. *See also* informative appendix.

occupational exposure limit (OEL). The time-weighted average (TWA) concentration for a normal eight-hour workday and a 40-hour workweek to which nearly all workers can be repeatedly exposed without adverse effect, based on the OSHA PEL, ACGIH TLV-TWA, TERA OARS-WEEL, or consistent value.

occupied space. Portion of the premises that are accessible to or occupied by people, but which excludes machinery rooms.

OSHA. Occupational Safety and Health Administration.

PEL. Permissible exposure limit.

pressure-relief device. Pressure-actuated valve or rupture member that is designed to automatically relieve pressure in excess of the current setting.

pressure vessel. Any refrigerant-containing receptacle in a refrigeration system, excluding: evaporators, provided that the refrigerant-containing volume of each separate evaporator section does not exceed 0.5 ft^3 (0.014 m^3); evaporator coils; compressors; condenser coils; controls; headers; pumps; and piping.

refrigerant. Fluid used for heat transfer in a refrigeration system. Refrigerant absorbs heat and transfers it at a higher temperature and a higher pressure, usually with a phase change.

refrigerant concentration limit (RCL). The refrigerant concentration limit, in air, determined in accordance with this standard and intended to reduce the risks of acute toxicity, asphyxiation, and flammability hazards in normally occupied, enclosed spaces.

refrigerant detection system. A system, or portion of a combination system, that utilizes one or more devices to detect the presence of a specified refrigerant at a specified concentration and initiates one or more mitigation actions required by this standard.

refrigerant detector. Device that can sense the presence of refrigerant vapor.

refrigerating system. A combination of interconnected parts forming a closed circuit in which refrigerant is circulated for the purpose of extracting then rejecting heat.

refrigerating system classification. Refrigerating systems are classified according to the degree of probability, low or high, that leaked refrigerant from a failed connection, seal, or component could enter an occupied area. The distinction is based on the basic design or location of the components.

refrigeration system. *See* refrigerating system.

relief line. *See* vent line.

rupture member. Device that is designed to break open in order to relieve excessive pressure.

safety shutoff valve. An automatically controlled refrigerant valve for the purpose of limiting the amount of refrigerant released into a space when a refrigerant leak is detected.

sampling point. Location where an air sample is collected to determine (in this case) the presence and concentration of refrigerant; the sample "collector" may be at the refrigerant detector or at a remote location that is connected to the detector with tubing.

SCBA. Self-contained breathing apparatus.

self-contained system. A complete, factory-assembled and factory-tested system that is shipped in one or more sections and has no refrigerant-containing parts that are joined in the field by other than companion or block valves.

soldered joint. A gas-tight joint obtained by joining metal parts with alloys that melt at liquidus temperatures not exceeding 840°F (450°C) and above 400°F (205°C).

set pressure. The pressure at which a pressure relief device or pressure control is set to operate.

threshold limit value (TLV). A registered trademark of the American Conference of Governmental Industrial Hygienists. It refers to the airborne concentrations of substances, and represents conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse health effects.

threshold limit value–time-weighted average (TLV–TWA). Time-weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse health effects.

toxicity. Characteristic of a refrigerant to be harmful or lethal due to acute or chronic exposure by contact, inhalation, or ingestion. Effects of concern include (but are not limited to) those of carcinogens, poisons, reproductive toxins, irritants, corrosives, sensitizers, hepatoxins, nephrotoxins, agents that act on the hematopoietic system, and agents that damage the lungs, skin, eyes, or mucous membranes.

unit system. *See* self-contained system.

vent line. Length of pipe that carries refrigerant from the pressure-relief device (or fusible plug) to the point where it is released to the atmosphere for dispersal. Refrigerant only passes through the vent line if an overpressure condition causes the relief device or fusible plug to operate.

zeotropic refrigerant. Blend of two or more component refrigerants (with different volatilities) whose equilibrium vapor-phase and liquid-phase compositions differ at a given temperature. *See also* azeotropic refrigerant.

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