engineers newsletter

volume 37–1 • providing insights for today's hvac system designer

ASHRAE Standard 15 applied to

Packaged, Split and VRF Systems

From the editor...
In a previous newsletter, we discussed the application of ANSI/ASHRAE Standard 15, "Safety Standard for Refrigeration Systems," to large chillers and the machinery rooms that house them. It's important to remember that Standard 15 applies to more than large chillers. In this Newsletter, we examine the requirements of Standard 15 as they apply to smaller refrigeration systems—specifically, packaged units, split systems, and the newer variable refrigerant flow (VRF) systems.

Introduction. ANSI/ASHRAE Standard 15 is widely recognized as the preeminent guide for the safe use of refrigeration equipment, as evidenced by its inclusion in model codes and state and local codes. Inclusion in these codes provides enforcement by the authority having jurisdiction (AHJ). However, progression from ANSI/ASHRAE standard to state and local code can take several years and often changes portions of the original standard (see "The Tortuous Path from ASHRAE Standard to State Code," *Engineers Newsletter*, volume 28-2). This process can result in slight variations in the enforced code from state to state, and sometimes even from city to city. For this reason, it's best to review both the local code and any standards that are referenced by the code when designing refrigeration systems.

This newsletter reviews the application of the ASHRAE requirements for packaged, split, and VRF systems in various applications using the current version (Standard 15-2007) for reference. Very little has changed over the last few revision cycles of Standard 15 as applied to these systems; however, Standard 15 relies on ANSI/ASHRAE Standard 34 for refrigerant safety data, and recent changes to Standard 34 will impact the application of these systems.

Start at the Beginning. The first two sections of Standard 15 define the purpose and scope respectively as:

> "This standard specifies safe design, construction, installation, and operation of refrigeration systems." (ANSI/ASHRAE Standard 15-2007, Section 1)

> "This standard establishes safeguards for life, limb, health, and property and prescribes safety requirements." (ANSI/ASHRAE Standard 15-2007, Section 2.1)

The scope of Standard 15 goes on to state that it covers all types of mechanical and absorption refrigeration equipment in the areas of design, construction, test, installation, operation, and inspection. With application to such a wide variety of equipment, ASHRAE Standard 15 has a broad range of requirements, although not all requirements apply to all types of equipment. Determining which requirements apply to a given system is accomplished using three basic sorting classifications: **occupancy** (Section 4), **system** (Section 5), and **refrigerant** (Section 6).

Occupancy classification divides buildings according to the ability of people to respond to a refrigerant-related emergency, and Section 4 defines six unique occupancy classifications. The same general requirements apply to all occupancies with the exception of industrial and institutional occupancies. An **institutional** occupancy is defined as a:

> "...premise or that portion of a premise from which, because they are disabled, debilitated, or confined, occupants can not readily leave without the assistance of others. Institutional occupancies include, among others, hospitals, nursing homes, asylums, and spaces containing locked cells." (ANSI/ASHRAE Standard 15-2007, Section 4.1.1)

System classification divides refrigeration system types according to the potential of the refrigeration equipment to expose the occupants to refrigerant. A **low probability** system is one:

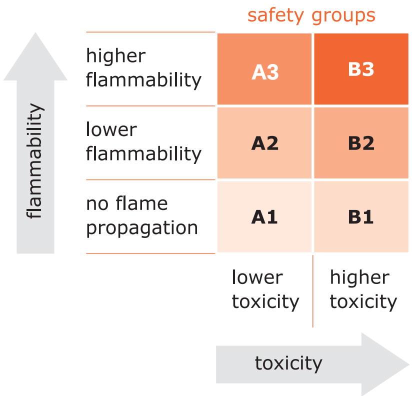
> "... in which the basic design, or location of the components, is such that leakage of refrigerant from a failed connection, seal, or component can not enter the occupied space." (ANSI/ASHRAE Standard 15-2007, Section 5.2.2)

Conversely a **high probability** system is one:

> "... in which the basic design, or the location of components, is such that a leakage of refrigerant from a failed connection, seal, or component will enter the occupied space." (ANSI/ASHRAE Standard 15-2007, Section 5.2.1)

By this definition, any refrigeration system with a refrigerant containing component in the occupied space, or the airstream serving an occupied space, is considered a high probability system.

Figure 1. ASHRAE Standard 34-2007 Safety Classifications



Refrigerant classification is based on the safety of the refrigerant used. Standard 15 draws refrigerant safety classification from ANSI/ASHRAE Standard 34, which classifies refrigerants by toxicity and flammability into one of six categories (see Figure 1). All of the refrigerants shown in Figure 2 are Class A (lower toxicity) and Class 1 (no flame propagation).

Figure 2. Refrigerant safety data from Table 1 of ASHRAE Standard 34-2007

Refrigerant number	Safety group	RCL lb/Mcf*	Highly toxic or toxic under code classification
R-22	A1	5.5	neither
R-134a	A1	13	neither
R-407C	A1	15	neither
R-410A	A1	10	neither

*These values are included in the 2006 International Mechanical Code

Standard 34 is also the source of the refrigerant quantity limits shown in Standard 15 and in Figure 2. See accompanying sidebar for more information on how recent changes in Standard 34 have changed both the rating system and the refrigerant quantity limits for each refrigerant.

Where do we go from here? Once our application has been classified by occupancy, system, and refrigerant safety, we can reference Section 7, "Restrictions on Refrigerant Use," to determine which of the ANSI/ASHRAE Standard 15 requirements must be followed to assure a safe installation:

> "The quantity of refrigerant in each independent circuit of high probability systems shall not exceed the amounts shown in Table 1, except as provided in 7.2.1 and 7.2.2, based on volumes determined in accordance with 7.3." (ANSI/ASHRAE Standard 15, Section 7.2)

Section 7.2.1 reduces the refrigerant quantity by 50 percent for institutional occupancies. This additional restriction is required because the occupants can not leave the building quickly in the event of a refrigerant release. Section 7.2.2 exempts industrial occupancies and refrigerated rooms from these limits, provided certain conditions are met.

The purpose of the limits imposed by Section 7.2 is to prevent the occupants of a building from being exposed to an unsafe concentration of refrigerant if a leak occurs. If a leak does occur, the resulting refrigerant concentration in the occupied space is dependent on the quantity of refrigerant in the equipment and the volume of space available for dilution. The concentration limits are listed both in terms of parts per million and pounds per 1000 cubic feet (lb/Mcf).

Refrigerant concentration limits can not be exceeded in any occupied space. If the calculated concentration for the refrigerant being used exceeds the levels shown in ASHRAE Standard 15, Table 1 (or, for institutional occupancies, 50 percent of those concentrations), the system is not permitted. ASHRAE Standard 15 defines an occupied space as "… that portion of the premises accessible to or occupied by people, excluding machinery rooms."[1]

Misinterpretations have been made regarding the ASHRAE toxicity-rating system. ASHRAE designates refrigerants as lower toxicity (Class A) or higher toxicity (Class B). Refrigerants designated as Class A are *not* non-toxic—there are hazards associated with all refrigerants.

In the past, the cardiac sensitization effect of a refrigerant was used to set the allowable quantity for occupied spaces for Class A refrigerants. Threshold Limit Value-Time Weighted Average (TLV-TWA) was used to set the allowable limit for Class B refrigerants. Although this system has worked fairly well it did not consider many of the personnel escape-impairing effects of refrigerants.

With the 2007 edition of Standard 34, ASHRAE changed to using **refrigerant concentration limit** (RCL) to determine the allowable pounds of refrigerant per 1000 cubic feet (lb/Mcf) of occupied space. RCL takes into consideration a variety of acute exposure criteria including cardiac sensitization, oxygen deprivation, flammability, and other escape-impairing effects.

Essentially, the change to Standard 34 is a change to Standard 15. Note (a), on the column labeled "Quantity of Refrigerant per Occupied Space", in Table 1 of Standard 15 states:

> "The refrigerant safety groups in Table 1 are not part of ASHRAE Standard 15. The classifications shown are from ASHRAE Standard 34, which governs in the event of a difference."

The next revision of Standard 15 will include RCL values in Table 1; model and local codes are also making the change.

Secondly, there has been some confusion about the correlation between ASHRAE Classes A and B (lower and higher toxicity) and the toxicity classifications used in the *International Fire Code*, the *Uniform Fire Code*, and by OSHA. These codes use a toxicity rating system that differs substantially from the ASHRAE rating system.

To help clarify the difference in the two rating methods, the 2007 edition of ASHRAE Standard 34 has added a column to Table 1 titled "Highly Toxic or Toxic[c] under Code Classification". **Note c** states: "'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." All refrigerants listed in Figure 2 of this newsletter are identified as "neither."

[1]Standard 15 defines a machinery room as "… a space, meeting the requirements of Sections 8.11 and 8.12, that is designed to house compressors and pressure vessels."

Follow the refrigerant. To provide for the safety of all occupants, it is necessary to determine the occupied area with the potential to have the highest concentration in the event of a leak. Finding this area requires knowing both the quantity of refrigerant in the system and how the refrigerant will distribute if it leaks.

For packaged systems, the total charge is provided as part of the unit data. Total charge for split systems and VRF systems is determined by adding the component charges provided by the manufacturer to the calculated amount of refrigerant in the lines connecting the various components. Line charge can be calculated based on the volume of the lines and the density of the refrigerant or by using a lookup table.

After the total charge is determined, the next step is to determine the dilution volume. The following guidance is provided for determining the dilution volume:

> "Where a refrigerating system or a part thereof is located within an air handler, an air distribution duct system, or in an occupied space served by a mechanical ventilation system, the entire air distribution system shall be analyzed to determine the worst case distribution of leaked refrigerant." (ANSI/ASHRAE Standard 15, Section 7.3.2)

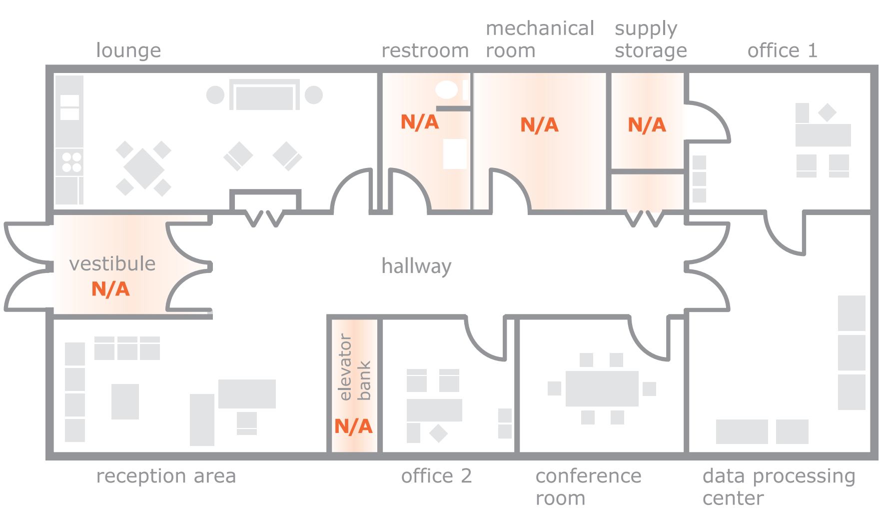
A common example of the **ventilated spaces** system described in Section 7.3.2 is a packaged rooftop unit which is connected to several rooms via ductwork. When calculating the dilution volume for this system, it is permissible to include the volume of the supply and return ducts or the plenum space if an un-ducted return is used. The volume of rooms supplied by the unit can also be included, provided that the airflow can not be shut off to those rooms. The shut-off stipulation excludes fire and smoke dampers, and variable-air-volume (VAV) boxes, if the boxes can not shut below 10 percent of design airflow.

Section 7.3.1 covers **non-connecting spaces** or those spaces:

> "Where a refrigerating system or a part thereof is located in one or more enclosed occupied spaces that do not connect through permanent openings or HVAC ducts, the volume of the smallest occupied space shall be used to determine the refrigerant quantity limit in the system."

A common example of the non-connecting spaces described in 7.3.1 is a hotel room served by a packaged-terminal air-conditioning (PTAC) unit. For non-connected spaces, refrigerant concentration in the event of a leak is determined by assuming that the entire charge is dispersed into the room where the unit is located. Unit charge (in pounds) divided by the room volume (in cubic feet) determines the concentration in the occupied area due to the leak.

Figure 3. Example office building floor plan



Consider this example.
A 20-ton, packaged, cooling-only rooftop air conditioner with VAV control serves the small office building shown in Figure 3. Each of the occupied spaces served by the unit has a 9-ft ceiling. The building includes an 18-in ceiling plenum that is interrupted over the restroom, mechanical room, supply storage room, elevator bank, and vestibule, where the walls extend from the floor slab to the roof. The rooftop unit contains two refrigeration circuits; one contains 26.4 lb and the other 16 lb of R-410A. VAV boxes with a minimum flow setting of 15 percent deliver supply air to all rooms except the conference room, which is served by a VAV box with a minimum flow setting of 5 percent. An open plenum provides the return-air path to the unit.

Based on this information, we can deduce that:

- the relevant safety group classification of the refrigerant is *A1*,
- the occupancy is *commercial*, and
- the refrigerating system classification is *high probability*.

According to Section 7.2 of Standard 15, the allowable refrigerant quantity for this scenario is limited to 10 lb/1000 ft³ of occupied space (Figure 2).

With this system the occupied areas are considered ventilated spaces so dilution volume includes both the occupied spaces and the open return plenum. The restroom, mechanical room, supply storage, vestibule, and elevator bank volumes are not included because these spaces are not served by the rooftop. We will also exclude the conference room because its minimum airflow setting is less than 10 percent of design. With these exceptions, the total occupied-room volume is 23652 ft³. The plenum area above these rooms that is used to return air to the unit has an additional volume of 3942 ft³. Total dilution volume for this system is 27594 ft³.

Having determined the dilution volume available for this system, we can now calculate refrigerant concentration in the occupied areas in the event of a leak. The unit charge used for this calculation is the refrigerant quantity in the largest single circuit (26.4 lb). The resulting value [26.4 lb/ (27594/1000) = 1.0 lb/Mcf] is well below the 10 lb/ 1,000 ft³ limit set by Standard 15.

The calculations are similar for a split system with an indoor air-handling unit, with the exception of the additional charge required for the refrigerant lines. Suppose the packaged unit was replaced with a single circuit, R-22, 20-ton condensing unit serving an air-handler, with 80 ft of interconnecting refrigerant line. Per the manufacturer, 39 lb of refrigerant are required for condensing unit and air-handler. The 80 ft of liquid and suction refrigerant lines connecting these components contain an additional 11 lb, for a total system charge of 50 lb.

Dilution volume is the same as it was for the packaged unit (27594 ft³). As with the packaged unit system, the diluted refrigerant concentration [50 lb/ (27594/1000) = 1.8 lb/Mcf] is well below the maximum permissible level of 5.5 lb/Mcf for R-22, so the system is permitted.

Switching to a VRF system generally changes both the refrigerant charge and the volume available for dilution. In a typical VRF system, each room is served by a terminal unit located in the room. All of the terminal units are connected to the condensing unit and each other using either a loop of refrigerant lines or a header system. The refrigerant contained in all the lines must be included when determining the total system refrigerant charge.

Dilution volume generally decreases because the standard assumes that if a terminal unit located in a room leaks, the entire refrigerant charge will leak into that room. In this case, the smallest occupied space served by the system and the entire refrigerant charge are used to calculate the diluted refrigerant concentration. For VRF systems, it might be easier to determine system acceptability by viewing required dilution volume differently.

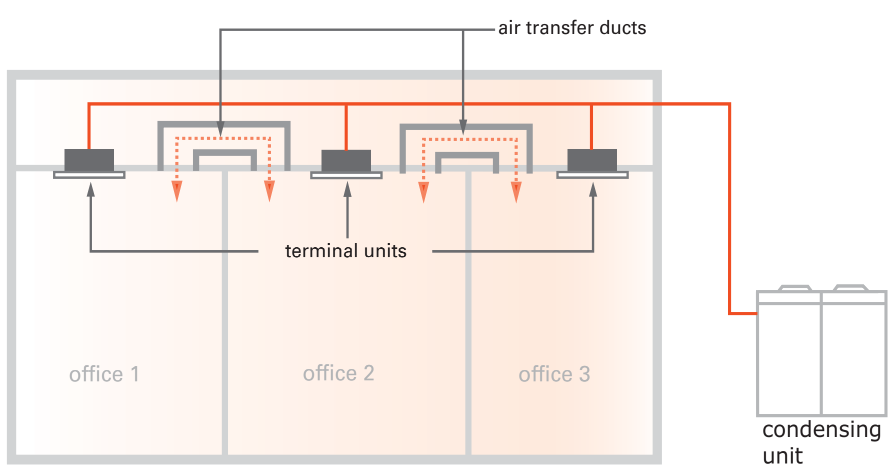
The refrigerant limits in Table 1 can also be used to determine the minimum volume of occupied space required to sufficiently dilute a given refrigerant charge. For example, inverting the 10 lb/Mcf limit for R-410A and dividing out the 1000 yields 100 ft³/lb. This indicates that each pound of R-410A in the system will require 100 ft³ of occupied space to provide sufficient dilution. In the case of a VRF system, the result can then be used to determine whether the smallest room served by the system has sufficient volume to dilute the refrigerant charge.

In our example building, the smallest space served by a terminal unit is office 2 with a volume of 2916 ft³. The maximum R-410A refrigerant charge that could be leaked into this space without exceeding the allowed concentration limit is 29.2 lb. For "non-connecting" space types, the standard assumes the entire charge (unit plus lines) will discharge into the room.

Apply Engineering Judgment. As with most standards, ASHRAE Standard 15 is not a design manual and some engineering judgment is required in its application. This is evident in making a distinction about when a room is considered non-connecting (meaning that only the volume of the room is used), and when it has sufficient open area to another space that the volume of both rooms can be used.

Per Section 7.3.1, non-connecting spaces do not include those that, "… connect through permanent openings or HVAC ducts …" to other occupied spaces. In our example, should the hallway volume be added to the office 2 volume if the door has an undercut? What if the door has a ventilation grille or there is a permanent open service window between office 2 and the hallway? Should the volume of all connected rooms be used if there are short air-transfer ducts from room to room (as shown in Figure 4). What is the dilution volume if the rooms are served by a 100 percent outdoor-air system? The answers to these questions are not clearly defined by the standard. Determining what is permitted is a combination of engineering judgment and interpretation of the code by the AHJ.

Figure 4. Air transfer ducts connecting adjacent rooms



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Unless the rooms are sealed, leaked refrigerant will **eventually** exit the building even without an exhaust system to force it out; because this is a safety standard, the time it takes for this process to occur is the concern. If we assume that the hallway volume can be included in the dilution volume because we put an air transfer grille in the door, an analysis could be conducted to see how long it would take for the refrigerant concentration in office 2 to drop below the values specified in ASHRAE Standard 34 (Table 1).

If a component of the refrigeration system ruptures because it is under pressure, the refrigerant will leak rapidly into the office. The room volume and unit charge determine the initial refrigerant concentration in the room. Refrigerant concentration will then begin to drop as the refrigerant moves to the hallway through the transfer grille, partly by diffusion and partly due to the density difference between refrigerant gas and air. A curve showing refrigerant concentration versus time could be drawn to show how long it will take for the refrigerant concentration in the room to drop to the RCL.

Unfortunately, the standard doesn't provide any direct guidance regarding acceptable timeframes for reducing refrigerant concentrations. Some evidence of the importance of time is indirectly provided by the 50-percent reduction in Table 1 (Standard 34) values for institutional occupancy because the occupants, "… can not readily leave without the assistance of others." Careful application of engineering judgment is always important, but especially so under such circumstances.

Closing Thoughts. Standard 15 applies to all types of refrigeration equipment in all applications using a classification system to identify appropriate safeguards. Particularly with VRF being a relatively new system type, there may be variations in how code inspectors interpret compliance requirements from one jurisdiction to the next. Regardless, ASHRAE Standard 15 is of particular importance because of its focus on safety. Enforcement of this standard through building codes has resulted in minimal refrigerant exposure incidents from refrigeration equipment.

Applying the requirements of Standard 15 to a specific situation demands detailed assessment and proper engineering judgment. Guidance for that engineering judgment is summarized by the purpose and scope of Standard 15: the safe application of refrigeration equipment. For packaged, split, and VRF systems this translates to designing systems with sufficient dilution volume for the refrigerant charge.

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ADM-APN027-EN (March 2008)