Applying VRF?

Don't Overlook Standard 15

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Variable refrigerant flow (VRF) systems have been used in Japan for at least two decades, and are now receiving attention in North America as a potential HVAC system choice in commercial, retail, institutional, hospitality, and multifamily residential applications. Indeed, the recently renovated ASHRAE headquarters in Atlanta includes such a system in a portion of the building. HVAC system designers who once applied water-source heat pump loops, hydronic fan-coil networks, packaged terminal units, rooftop direct-expansion units and other all-air systems, are now applying VRF.

Why VRF? In many cases, VRF can be shown to offer good seasonal energy efficiency at a reasonable first cost. VRF is mentioned in the Advanced Energy Design Guide Series,[1] so there is certainly a sustainability component behind the interest in VRF. But the pros and cons of VRF systems are beyond the scope of this article; the intent of which is simply to remind design professionals of the relevant refrigerant safety requirements found in Standard 15-2010. For peer-reviewed literature on VRF, see the April 2007 *ASHRAE Journal*,[2] the June 2008 *ASHRAE Journal*,[3] and the *2012 ASHRAE Handbook—HVAC Systems and Equipment*.[4] The *2012 ASHRAE Handbook—HVAC Systems and Equipment* has a full new chapter on VRF systems.

This article explores the following objectives:

- Why Standard 15 should not be overlooked when applying VRF;
- How to find and look up the Refrigerant Concentration Limit (RCL);
- How to calculate refrigerant application limits;
- Understand what situations may cause a VRF installation to violate Standard 15;
- Understand and use favorable design techniques to apply VRF within Standard 15; and
- Address ambiguities in Standard 15.

About the Author

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(This article is based on a published conference paper by the author,[5] and the reader is referred to that paper for additional technical detail.)

Standard 15 and VRF

In part, Standard 15, *Safety Standard for Refrigeration Systems*,[6] strives to ensure a safe system by limiting the maximum quantity of refrigerant below that which is a danger to human occupants if a leak occurs. Anecdotally, there is sometimes a misconception that Standard 15 applies only to large chiller plants. In fact, Standard 15 applies to any mechanical refrigeration system used in stationary applications (Standard 15-2010 §2.2.a).

The nature of a VRF system is such that multiple evaporators are served by one common condensing unit and one common network of interconnecting refrigerant piping (*Figure 1*). Manufacturers of VRF system components advertise that 40 or more evaporators can be included on one piping network, with more than 3,000 ft (914 m) of refrigerant pipe, all connected to a single condensing unit. The evaporator units may be ductless; they may be installed above a ceiling with some distribution ductwork; or they may be ducted to serve two or more rooms.

A traditional DX split system applied room-by-room has one condensing unit for each evaporator, with no interconnection to other split systems, and a refrigerant leak, therefore, would discharge only that refrigerant contained in one individual split system. A water-source heat pump system uses a modest amount of refrigerant in each individual heat pump unit, but the interconnecting piping between rooms carries water, not refrigerant. Because of the interconnecting refrigerant piping, a VRF system has the theoretical potential to discharge a much larger quantity of refrigerant to indoor spaces in a catastrophic leak occurrence.

At first glance, one might suppose that a large direct expansion (DX) rooftop unit would have the potential to leak and disperse a large charge of refrigerant into an occupied space, similar to a VRF system. Of course, this is a concern which should be addressed via a careful application of Standard 15. On close examination, one will see that a large DX rooftop unit serves many rooms through a network of ducts. Should the evaporator in a rooftop unit open a catastrophic leak of refrigerant, the leaked refrigerant would be dispersed to multiple rooms via the ductwork, in some rough proportion to the overall room-by-room volume based on the connected air-distribution system. A VRF system has a magnified concern because it could potentially discharge all of a comparable refrigerant charge to one individual room.

Applying Standard 15

Moving further into the application of Standard 15, Section 4 requires the design professional to select an Occupancy Classification from among seven choices. In Section 5, a Refrigerating System Classification must be selected. A VRF system is classified as a Direct System (§5.1.1) for which the evaporator coils are in direct contact with the air being cooled. This is in contrast to an Indirect System; for example, a chilled water fan-coil system in which only the water coil is in direct contact with the air being cooled. Under Standard 15, a VRF system is a High-Probability System (§5.2.1) because the location of components (e.g., the evaporator) is such that a leakage of refrigerant from a failed connection, seal, or component can enter the occupied space. A Direct System is also a High-Probability System as defined by Standard 15.

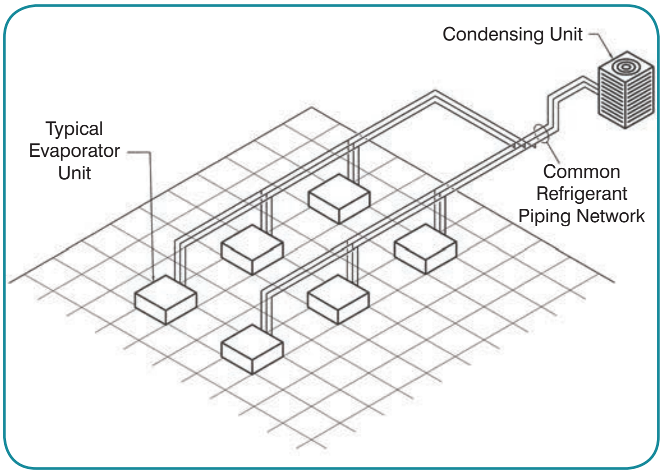

Figure 1: Simplified variable refrigerant flow system.

Refrigerant Concentration Limit (RCL)

At this point, one must refer to ANSI/ASHRAE Standard 34-2010[7] to determine the maximum allowable refrigerant concentration, or RCL (refrigerant concentration limit) and other pertinent safety classifications. (RCL was once found in Standard 15 but has been moved to Standard 34 beginning with the 2010 edition.)

A common refrigerant for commercial VRF systems is R-410A, and that refrigerant will be followed throughout this article. Per Standard 34, Table 2, the safety classification of R-410A is Group A1 (meaning non-flammable and non-toxic). Even though R-410A is Group A1, its ability to displace oxygen is a serious danger to occupants if released in large quantities into smaller-volume spaces. Therefore, Standard 34, Table 2 (through Addendum *l**) has established an RCL for R-410A at 26 lbs of refrigerant per 1,000 ft^3 of room volume (420 g/m^3).

Now the Occupancy Classification becomes important. For Institutional Occupancies such as patient care areas of hospitals, the RCL is cut in half (§7.2.1), effectively changing the RCL for R-410A to 13 lb/1,000 ft^3 (210 g/m^3) in that classification.

The volume of the smallest individual space(s) served by an individual evaporator unit, or the smallest individual room

*ASHRAE Standard 34-2010 Addendum *l* recently increased this value from 25 to 26 lb/1,000 ft^3 (420 g/m^3). State or local codes[10] that reference 34-2010 may not include the addenda for code purposes, in which case the new value would not take effect until Standard 34-2013 edition (not yet published) is adopted by those bodies.

through which refrigerant piping is installed, is used to determine the maximum potential refrigerant concentration in the event of a leak (§7.3). If that room has permanent opening(s) to adjacent room(s), the combined room volumes may be used (§7.3.1). The space above a suspended ceiling is not considered as part of the room volume unless it is used as part of the air supply or return path (§7.3.2.2). Any proposed VRF system will need to respect the RCL of 26 lb/1,000 ft^3 (420 g/m^3), or 13 lb/1,000 ft^3 (210 g/m^3) if institutional, for the smallest space(s) served by an individual evaporator unit or crossed by refrigerant piping.

The Machinery Room paragraphs (Standard 15-2010 §8.11 and 8.12) are not discussed here. While Machinery Room provisions such as refrigerant leak detection, alarms and increased ventilation will be familiar to experienced designers of large chiller systems, Machinery Rooms are not an applicable compliance path for VRF systems. Machinery Rooms are not to be occupied by anybody other than authorized personnel (§8.11.8), effectively voiding any attempt to use a Machinery Room compliance path in a VRF system serving occupied space.

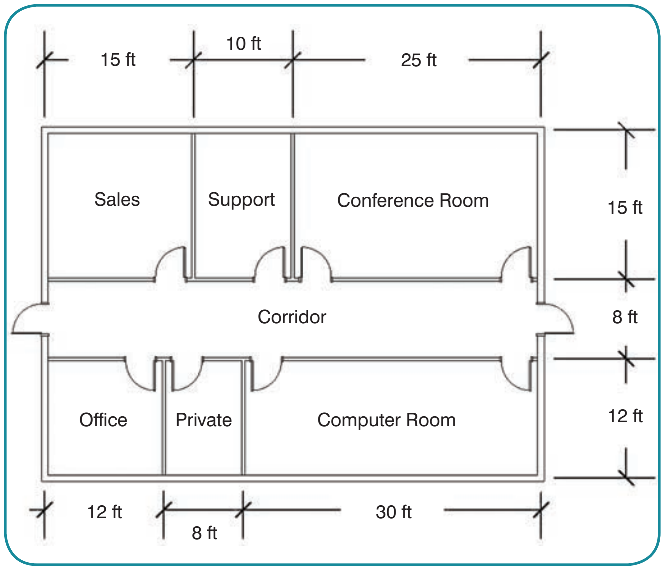

Figure 2: Commercial office layout. Seven evaporator units, one installed within each room plus the corridor, are networked on one common refrigerant circuit with one condensing unit.

Example Calculations

Published catalog data from manufacturers show a typical factory refrigerant charge of 2 to 3 lb per nominal ton of capacity (0.3 to 0.4 kg/kW), with an additional 1 to 3 lb per nominal ton (0.1 to 0.4 kg/kW) contained in the field piping (subject to routing and layout), for a practical range of 3 to 6 lb per ton (0.4 to 0.8 kg/kW). Operating pressures for R-410A systems are on the order of 450 psig (3.1 MPa).[9] These operating parameters of commercial VRF systems are followed by three examples.

Example 1: Commercial Office Building

One actual installed-and-operating VRF system the author viewed in preparation for this article served a commercial office. The VRF system's condensing unit nameplate was stamped 478 psig (3.3 MPa) high side and 320 psig (2.2 MPa) low side; 550 psig (3.8 MPa) test pressure; 96 MBh (28 kW) capacity; 23.4 lbs (10.6 kg) factory charge of R-410A. The network features three parallel field pipes (liquid, suction, and hot gas) because the system is designed as a heat pump network, allowing some zones to be in heat mode while other zones are in cooling mode. The total charge was 40 to 41 lb (18 to 19 kg) when field piping was included.

A simplified sketch of the office layout is found in *Figure 2*. A total of seven ductless in-room console evaporator units, one installed in each room plus the corridor, are networked with one condensing unit. In this example, the smallest individual room with its own evaporator is 12 ft by 8 ft (3.7 m by 2.4 m), with a 9 ft (2.7 m) ceiling, for a volume of 864 ft^3 (24.5 m^3). Therefore, the maximum allowable refrigerant charge of R-410A is 22.4 lb (10.2 kg). Since the actual system charge is 40 to 41 lb (18 to 19 kg), it initially appears this installation does not comply with Standard 15.

One common approach to compliance is the connecting space clause. If the room includes permanent openings to adjacent rooms, those rooms may be combined in the volume calculation (§7.3.1). The room's door probably does not qualify as a permanent opening, because the door will be closed at least some of the time, making the opening non-permanent. If one imagines this room is a human resource director's office, for example, it should be assumed that room doors will be occasionally closed for private conversations, and other permanent openings between rooms (such as air transfer grilles) might not be permitted for reasons of crosstalk. More on this topic is found in the "Ambiguities" section.

Finally, we must discuss the corridor itself. Refrigerant piping shall not be installed in an enclosed public stairway, stair landing, or means of egress (§8.10.2). If the corridor shown in *Figure 2* is a means of egress, one should route the piping so it does not pass through the corridor, and the evaporator unit serving the corridor should be located outside the corridor.

Tips Toward Compliance

In Example 1, we found a potential safety issue with a higher-than-allowable system charge serving a small office. Several options are available to the design professional to avoid this situation.

1. One option is to remove the smallest office from the VRF system and condition it with a separate unit, perhaps a packaged terminal air conditioner (PTAC), and route the VRF refrigerant pipe so that it does not pass through the smallest office. In Example 1, the next-smallest office becomes the critical room, at 12 ft by 12 ft (3.7 m by 3.7 m), with a 9 ft (2.7 m) ceiling, for a volume of 1,296 ft^3 (36.7 m^3) and maximum allowable R-410A charge of 33.7 lbs (15.3 kg). With the reduced capacity found by eliminating one evaporator unit,

along with a re-optimized piping layout, perhaps the total system charge will now be in compliance.

2. Another allowable "fix" would be to use one common ducted evaporator to condition the two smallest rooms together, allowing both rooms to be summed for purpose of compliance.

3. In lieu of an in-room console unit, another option is to use an above-ceiling evaporator unit ducted to one or more of the smaller rooms, while drawing unducted return air through the ceiling cavity. Therefore, the ceiling void space could now be counted as part of the room volume (§7.3.2.2).

4. Finally, one could use two completely separate VRF systems: one for each side of the corridor, and avoid the corridor altogether, particularly if the corridor is a means of egress.

Example	"Critical" Room Size (ft^3)	Maximum RCL Factor for R-410A from Std 15 (lb/1,000 ft^3)	Net System Refrigerant Concentration Limit (lb)
1a–Commercial Office Building	864	26	22.4
1b*	1,296	26	33.7
2–Hotel	2,516	26	65.4
3–Hospital	1,700	13	22.1

*Similar to Example 1a with the smallest room removed from the variable refrigerant flow system.

Table 1: Summary of three example calculations.

Example 2: Hotel Guest Rooms

Next, imagine a guest room floor of a hotel featuring a series of identical units of 350 ft^2 (32.5 m^2) with an 8.5 ft (2.6 m) ceiling, for a volume of 2,975 ft^3 (84.2 m^3). A VRF system using R-410A is proposed, with a 1 ton (3.5 kW) evaporator per guest unit. What is the maximum refrigerant capacity permitted in one VRF network? The RCL is 26 lb/1,000 ft^3 (420 g/m^3) for R-410A in a Residential occupancy. Therefore, the maximum permissible total refrigerant charge is 77.3 lb (35.1 kg) including the condensing unit, all evaporator units, and the field refrigerant piping.

However, system designers should consider the ramifications of the bathroom in a typical hotel guest room. Some hotel guests close the door of their bathroom before sleeping. With the bathroom door closed, the volume of space to which the refrigerant may disperse now would exclude the bathroom. Formal Interpretation IC 15-2007-2[8] implies that the bathroom of a typical hotel guest room should not be counted in the room volume calculation. If, for example, the bathroom is 54 ft^2 (5.0 m^2), the effective volume of the guest room proper is reduced to 2,516 ft^3 (71.2 m^3). In this case, the maximum permissible total system refrigerant charge is 65.4 lb (29.7 kg).

How many of these guest rooms can be networked on one VRF system? For illustrative purposes only, let us assume an R-410A refrigerant charge of 4.5 lb per ton (0.6 kg/kW). In the example above, a 65.4 lb (29.7 kg) refrigerant charge limit would allow a 14 ton (49 kW) system, or a maximum of 14 rooms with a 1 ton (3.5 kW) capacity requirement per guest room. So a VRF system in this hypothetical hotel would meet the RCL limit, as long as guest rooms are grouped into separate VRF systems of not more than 14 rooms/each. The actual capacity, room size, load calculation, refrigerant type and refrigerant charge of each system must be evaluated on a case-by-case basis and may differ from this example, but these figures lend some order-of-magnitude to the discussion.

Since VRF evaporator units are often 100% recirculating types, a separate system for delivering outdoor air, such as a dedicated outdoor air system (DOAS) is often provided. An example is a hotel room continuously ventilated with outdoor air delivered to the sleeping area and exhaust air in the bathroom. Can the parallel ventilation system be relied upon for dilution of a hypothetical refrigerant leak? Formal Interpretation IC 15-2007-3[8] stated that increasing the allowable refrigerant limits for R-410A due to dilution by supply and/or exhaust air ventilation should not be considered.

Example 3: Hospital Patient Rooms

Finally, consider the application of VRF to the in-patient room wing of a hospital. At first glance, this may seem to be very similar to the previous hotel room example. However, recall that for Institutional occupancies, the RCL is reduced by 50%. A typical hospital patient room (again excluding bathroom as for the hotel) may be 200 ft^2 (18.6 m^2) with an 8.5 ft (2.6 m) ceiling, for a volume of 1,700 ft^3 (48.1 m^3). A VRF system using R-410A is proposed, with one 0.75 ton (2.6 kW) evaporator per guest unit. Now the RCL is 13 lb/1,000 ft^3 (210 g/m^3) and the maximum permissible total system refrigerant charge is 22.1 lb (10.0 kg). Again, assuming a refrigerant charge of 4.5 lb per ton (0.6 kg/kW), the refrigerant charge limit would allow a 4.9 ton (16.6 kW) system, or a maximum of 6 rooms with a 0.75 ton (2.6 kW) capacity requirement per room.

Ambiguities

A key component of the previous example calculations is the determination of the volume of the smallest occupied space not connected to other spaces through permanent openings (§7.3.1). If two or more rooms are connected by permanent openings, the volume of those rooms may be combined to find the RCL. A potential ambiguity exists in the evaluation of what constitutes a permanent opening. Does an undercut door or a transfer opening qualify? If so, how large an undercut or transfer opening would be needed? These questions are not specifically addressed in Standard 15.

Clearly, undercut doors or transfer openings would *eventually* permit a large leak of refrigerant in one small room to disperse to adjacent rooms. However, without detailed study or

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modeling, we do not know that this will occur quickly enough to protect the safety of the room's occupants. The driving force expelling R-410A from a ruptured refrigerant pipe may be on the order of 450 psig (3.1 MPa) for the system high side, but the driving force pushing transfer air under a door or through a transfer opening is five or six orders-of-magnitude less. Ceiling-mounted transfer ducts are also suspect, since most commonly used refrigerants are heavier than air. The Engineer-of-Record must decide whether to rely on undercut doors or transfer openings as a path to compliance.

It is clear that some ASHRAE research would be helpful in better defining how to treat an undercut door or a transfer opening. Concurrent with publication of this article, a research topic acceptance request (RTAR) is being processed through proper ASHRAE channels, proposing ASHRAE research on this topic.

Finally, this author is anecdotally aware of another approach to refrigerant leak management, one that involves the installation of automatic shutoff valves within the field refrigerant piping. In conjunction with refrigerant leak detectors, the intent is to isolate a leak to one piping segment and limit the quantity of refrigerant that can be leaked between valves to a quantity below the RCL. This approach is not addressed by Standard 15. The only place within Standard 15 that refrigerant leak detectors are addressed is within the Machinery Room compliance path, which is not appropriate for occupied space. Furthermore, trapping of liquid refrigerant subject to hydrostatic expansion due to closing of isolation valves must be addressed by pressure relief devices and/or engineering controls (§9.4.3.1).

Conclusions

This article intended simply to remind designers who are applying VRF that careful application of Standard 15 is necessary. Within the bounds of Standard 15, VRF systems can be properly selected, designed, installed, and operated. It may be advantageous to remove small rooms from a VRF system and serve those rooms separately; or use more, smaller, separate VRF system networks in lieu of one larger system, or serve multiple small rooms with one common ducted evaporator. Routing is also a key consideration, to avoid routing refrigerant piping through smaller enclosed rooms with a lower maximum allowable charge. Operating pressures are relatively high, making the integrity of all the field joints critical, so enforce specification language requiring pressure testing of field piping.

Disclaimer

The contents of this article shall not be construed as an official interpretation of Standard 15. While the author of this article is a member of Standing Standards Project Committee (SSPC) 15, the information presented in the article is the view of the author alone and does not necessarily represent the views of SSPC 15. The summary of Standard 15 in this article is specific to VRF systems, and many portions of the standard not specific to these systems were not discussed for reasons of brevity. All numerical examples provided in this article are for illustrative purposes only; every building is unique and must be studied with respect to Standard 15 on a case-by-case basis. Official interpretations may be requested of SSPC 15 through the ASHRAE website.

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