Calculating Refrigerant Concentration Limit in the UMC

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Refrigerants can convert easily between liquid and gas states, absorbing and releasing heat in the process. Such thermodynamic properties make refrigerants ideal for use in vapor-compression refrigeration systems. Refrigerants can be found in variety of places, such as office buildings, cold storage areas, recreational facilities, etc. Some refrigerants, such as ammonia (R-717), are very toxic while other refrigerants, such as R-410A, are low in toxicity. Although R-410A refrigerants are low in toxicity, they can displace oxygen, possibly making a refrigerant leak fatal through asphyxiation. Exposure to refrigerants can cause a variety of health problems, including nausea and headaches. To prevent fatalities or health problems, the amount of refrigerant in a system should be capable of being diluted if it were to leak into a space. To protect the public, the Uniform Mechanical Code (UMC®) takes the necessary steps to ensure that it addresses provisions intended to protect the public from high levels of refrigerant exposure.

Let’s consider a typical Variable Refrigerant Flow (VRF) system and a package rooftop refrigeration system. The dilution volumes for these systems will be analyzed to determine if
there is sufficient volume in a given space to dilute the refrigerant in case of a leak. The key point to consider is how the leak will be dispersed. Is the leaked refrigerant going to be dispersed such that it is concentrated into a single space or is it going to be dispersed throughout multiple spaces?

A VRF system consists of individual indoor unit fan coils serving their own respective enclosed space. For spaces that have any part of the refrigerant piping circuit, such space should be considered in case of a refrigerant leak. Section 1104.2.2 of the 2015 UMC states:

Where a refrigerating system or 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. Where different stories and floor levels connect through an open atrium or mezzanine arrangement, the volume to be used in calculating the refrigerant quantity limit shall be determined by multiplying the floor area of the lowest space by 8.2 feet (2498 mm).

Since the indoor unit fan coils are connected to the condensing unit and each other, a leak in a coil can cause the entire refrigerant charge to be discharged to the space it is serving. Therefore, Section 1104.2.2 of the UMC tells us that the volume of the smallest occupied space(s) should be used to determine the allowable system refrigerant charge in each refrigerant circuit (only one circuit is assumed to have a leak). This is because the volume of the smallest occupied space needs to be large enough to dilute the refrigerant concentration to a safe level.

To determine the allowable system refrigerant charge, the following Equation (1) can be used:

\[
\text{Allowable System Refrigerant Charge (lbs) \leq Dilution Volume (ft}^3\times RCL
\]

[Equation (1)]

For example, consider a VRF system with a refrigerant charge of 60 lbs of R-410A in its largest circuit and volume of the smallest occupied space(s) that has any part of the refrigerant circuit installed is 2,000 ft\(^3\). The volume of the smallest occupied space(s) is the dilution volume. The refrigerant concentration level (RCL) for R-410A is 26 lbs for every 1000 ft\(^3\) of space, which can be obtained from Table 1102.2 of the UMC. For institutional occupancies, the refrigerant concentration limit found in Table 1102.2 of the UMC must be reduced by 50 percent. For industrial occupancies, the provisions from Section 1104.2.2 are not applicable as long as they meet some specific requirements which are stated in Section 1104.4 of the UMC. Using Equation 1, the allowable system refrigerant charge will be as follows:

\[
\text{Allowable System Refrigerant Charge}\leq2,000\text{ft}^3\times 26\text{lbs}=52\text{lbs}
\]

Since the VRF system has a refrigerant charge of 60 lbs and the calculated allowable system refrigeration charge is 52 lbs, the dilution volume is not sufficient to dilute 60 lbs of refrigerant. When the smallest space is not large enough to dilute the refrigerant, it is permitted to combine spaces via ducts or through permanent openings such as transfer grilles to increase the dilution volume. The UMC does not address how to calculate a permanent opening; the engineer of record should determine this with review by the Authority Having Jurisdiction (AHJ). The AHJ should be contacted to determine if a door undercut is considered a permanent opening. Another option would be to use a different system with a system refrigeration charge that is less than 52 lbs, e.g. by dividing the system into smaller, multiple refrigerant circuits or reducing the length of refrigerant piping.

For a rooftop air conditioning system, the dilution volume is not always the smallest volume that is used since a refrigerant leak in the coil will allow refrigerant to disperse throughout multiple spaces. Section 1104.2.3 of the 2015 UMC requires that:

Where a refrigerating system or a part thereof is located within an air handler, in 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. The worst case or the smallest volume in which the leaked refrigerant disperses shall be used to determine the refrigerant quantity limit, subject to the criteria in accordance with Section 1104.2.3.1 through Section 1104.2.3.3.

Section 1104.2.3.1 indicates that closures in
the system need to be considered unless one or more spaces of several arranged in parallel are capable of being closed off from the source of the refrigerant leak. Section 1104.2.3.1 also includes an exception that indicates when dampers, such as variable-air-volume (VAV), provide limited closure, where the airflow is not reduced below 10 percent of its maximum with the fan running, then such closure devices shall not be considered. In other words, if the airflow were to be 1,000 cubic feet per minute (cfm), the closure device must reduce the design airflow to more than 100 cfm with the fan running in order for that volume to not be considered. The plenum space above a suspended ceiling can be considered a part of the room only if the plenum is part of the air supply or return system. It is also permitted to include the air volume of the supply and return ducts connected to the fan coil, but only if the airflow cannot be shut off, ignoring smoke and fire dampers that close only in an emergency not associated with a refrigerant leak.

Therefore, to obtain the dilution volume the volumes of all the spaces should be added. However, when the airflow to a space is reduced below 10 percent of its maximum, the volume of that space is not added to obtain the dilution volume. The dilution volume obtained will be used to determine the allowable system refrigerant charge.

For example, consider a rooftop dual circuit unit with a refrigerant charge of 26.4 lbs and 16 lbs of R-410A. The unit supplies conditioned air to a total of three occupied spaces (1,000 ft³ each) and the VAV boxes have a setting of 15 percent of the design airflow except for one space, which has a minimum VAV flow setting of 5 percent. Using Equation 1, the allowable system refrigerant charge will be as follows:

$$\text{Allowable System Refrigerant Charge} \leq 2,000 \, \text{ft}^3 \times 26 \, \text{lbs/}1,000 \, \text{ft}^3 = 52 \, \text{lbs}$$

The calculation tells us that the allowable refrigerant charge must be less than 52 lbs. The largest circuit of the rooftop unit has a refrigerant charge of 26.4 lbs; therefore, the dilution volume is in compliance with Section 1104.2.3 of the UMC. It is worth noting that the circuit with the largest refrigerant charge (26.4 lbs) was used in the calculation as it is the most critical and the volume for the VAV setting of 5 percent was not included as part of the dilution volume as it was reduced below 10 percent of its maximum.

The total charge for a VRF or split AC system can be determined by adding the component (condensing unit and air handler) refrigerant charges to the amount of refrigerant in the lines. The amount of refrigerant in the lines can be determined based on the volume of the lines and the density of the refrigerant. The RCL can be obtained from Table 1102.2 of the UMC. The manufacturer typically provides the component (condensing units and air handlers) refrigerant charge. For VRF systems, it is common for the manufacturer to provide piping diagrams and refrigerant quantities.

In conclusion, all direct expansion cooling systems have the potential to leak refrigerant into occupied spaces. The 2015 UMC requires that the amount of refrigerant that can leak into occupied spaces never exceed the RCL assuming the refrigerant expands to uniformly fill the space. For most standard air conditioning units, such as packaged single zone units and through-the-wall AC units, the refrigerant charge is small enough and/or room volume is large enough that the RCL limit will never be reached. Systems in application that can be problematic are those with large refrigerant charges, such as VRF systems, that serve small spaces. It is possible that the entire refrigerant charge could leak into a small space such that the RCL will be exceeded. Solutions include dividing the VRF into multiple systems with smaller charges, moving fan-coils and piping out of small rooms, and opening small rooms to other spaces with permanent openings.