Technical Report

Sensor Response in HVAC Systems

Full-scale refrigerant release testing results

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UL Solutions

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Introduction

Current North American and international safety standards contain requirements that permit the use of safety class A2L, A2 and A3 refrigerants in air-conditioning and heat pump products. Hazards associated with the potential flammability of these refrigerants are mitigated by requirements in the HVAC appliance safety standards as well as local installation codes. The IEC/UL 60335-2-40, Household And Similar Electrical Appliances – Safety – Part 2-40: Particular Requirements for Electrical Heat Pumps, Air-Conditioners and Dehumidifiers, Series of Standards for the international (IEC, 2018) and North American (UL, 2019) markets permit limited refrigerant charges to be used without any additional mitigation. For larger charge systems, the Standards require that any potential refrigerant release be passively or actively mixed with the air within the space or spaces. Annex GG of UL/CSA and IEC 60335-2-40 detail these systems' charge limits and mitigation requirements. Several previous research projects have shown the ability of airflow to prevent the buildup of flammable mixtures.

UL/CSA and IEC versions of 60335-2-40 permit the use of continuous airflow to circulate any released refrigerant in the room space. There also exist requirements utilizing a refrigerant detection system to activate a fan to circulate air in the room space. Similar requirements exist in ASHRAE 15 (ASHRAE, 2019). The main difference between these standards is the allowable response time of the sensors.

HVAC/R products in North America need to be installed following local building codes, derived from ASHRAE 15 for most of the U.S. and CSA B52 (CSA, 2018) for Canada. ASHRAE 15 currently requires that sensors shall be integral to a Listed product and trigger mitigation measure(s) within 15 seconds when the refrigerant concentration reaches 25% of the lower flammability limit (LFL). The LFL is the lowest concentration of flammable gas in air that will propagate flame when ignited.

Several sections of the IEC/UL 60335-2-40 series address the total response of the sensor. This can be broken down into three distinct times for mitigation:

- Transport time from a refrigerant leak location to a sensor location
- Sensor response and output signal activation time
- Mitigation response time

Transport time for refrigerant dispersion

The testing of Annex MM for both IEC and UL/CSA versions of 60335-2-40 confirms the adequacy of the sensor location inside the unit. This test intends to determine if the sensors are located in such a position that a simulated refrigerant leak will be detected within a defined time window. Current requirements specify that the refrigerant concentration at the location of at least one sensor, with a relatively small leak, must exceed the set point of the detection system within 90 seconds.

Current published editions of the 60335-2-40 standards establish the simulated leak rate based on the free internal volume of the unit under test, however, the next editions prescribe a minimum leak rate e.g., 1.22 grams per second for R-32, which may be increased based on either the airflow rate of the unit (IEC only) or the size of the unit (UL/CSA only; up to the equivalent of a one-hour leak of the entire charge).

Sensor response time

The current edition of UL/CSA 60335-2-40 requires the refrigerant detection system to respond within 10 seconds or less when the sensor is placed in a concentration of 100% of LFL (or lower), per the requirements of Annex LL. It is understood that manufacturers may elect to choose a refrigerant detection system and set point that will respond to lower refrigerant concentrations. The current edition of IEC 60335-2-40 and proposed language for the subsequent edition of the UL/CSA version require the refrigerant detection system to indicate a leak within 30 seconds or less upon exposure to a refrigerant concentration of 25% of LFL. The current edition of ASHRAE 15 has the most stringent response time requirement of 15 seconds or less when exposed to 25% of LFL (Zheng, Zang, Yu, & Elbel, 2021).

Mitigation system response time

Annex GG in IEC/UL 60335-2-40 details charge limits and mitigation methods for refrigeration systems utilizing class A2L, A2 or A3 refrigerants. For A2L refrigerant, airflow can be used to dilute and mitigate the hazard of refrigerant accumulating in any space by mixing the released refrigerant with air, reducing refrigerant concentration below its lower flammability limit. The minimum volumetric airflow requirements are identified in the standards. The UL/CSA version of 60335-2-40 states that the unit must meet or exceed the required airflow within 15 seconds of receiving the output signal from the refrigerant detection system while the IEC version does not establish a time limit.

Method

UL Solutions was contracted to conduct a project consisting of full-scale refrigerant release testing. This testing was conducted at UL Solutions laboratories in Northbrook, Illinois.

As part of this study, rooms were constructed to simulate a 66.9 m^2 (720 ft^2) apartment in one of UL Solutions test chambers. All refrigerant releases detailed in this report were conducted using a single component refrigerant, R-32. The indoor unit is a typical air handler, Goodman model AVTPC25B14AA rated at two tons of refrigeration cooling capacity with dimensions of 1,143 millimeters (45 inches) high, by 444 millimeters (17.5 inches) wide, by 533 millimeters (21 inches) deep. This unit was installed to simulate the indoor section of a split system air conditioner with a single return at floor level and several discharge registers located at, or near, ceiling level. The refrigerant was released via a discharge tube located near the A-coil of an air-handler unit vertically installed in a closet at location "A", as shown in Figure 1. The release took place inside the indoor unit at a critical leak point at three different rates:

- 50 grams per second simulating leak rate of AHRTI 9007-1 residential split A/C scenarios (Gandhi, Hunter, Haseman, & Rodgers, 2017)
- 16 grams per second simulating four-minute leak rate of 60335-2-40
- 3 grams per second simulating the Enhanced Tightness Refrigerant System (ETRS) leak rate of 60335-2-40

The released refrigerant flows down and spread on the floor through the return grill below the unit without mitigation. With an operating fan, the refrigerant is carried up by the airflow through the duct, and the refrigerant mixture is discharged into the room or space via the supply grills. Sensors that were calibrated to determine the volume fraction of refrigerant were placed at various points in the room. For the purpose of this paper, we will detail results at four locations: location above the A-coil, centered below the A-coil, in the duct above the air handler and at a location 60 centimeters in front of the grill. Data presented has been deconvoluted to account for sensor response time. The released refrigerant flows down and spreads on the floor through the return grill below the unit without mitigation. With an operating fan, the refrigerant is carried up by the airflow through the duct, and the refrigerant mixture is discharged into the room or space via the supply grills. Sensors that were calibrated to determine the volume fraction of refrigerant were placed at various points in the room. For the purpose of this paper, we will detail results at four locations: location above the A-coil, centered below the A-coil, in the duct above the air handler and at a location 60 centimeters in front of the grill. Data presented has been deconvoluted to account for sensor response time.

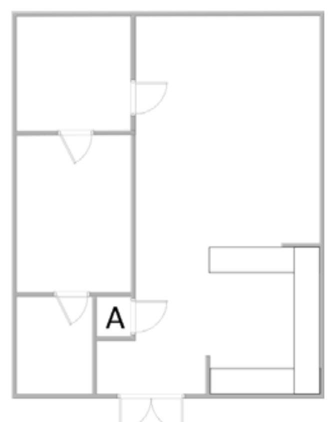

Figure 1 - Overall Structure Layout

Results

50 grams per second rate

Testing was conducted at the 50 grams per second release rate, using two different fan activation times of 30 seconds and 10 seconds after the start of the release. This simulated a slow-responding system and a fast-responding system. Refrigerant concentrations for the 30-second and 10-second activation times are detailed in Figure 2 and Figure 3, respectively.

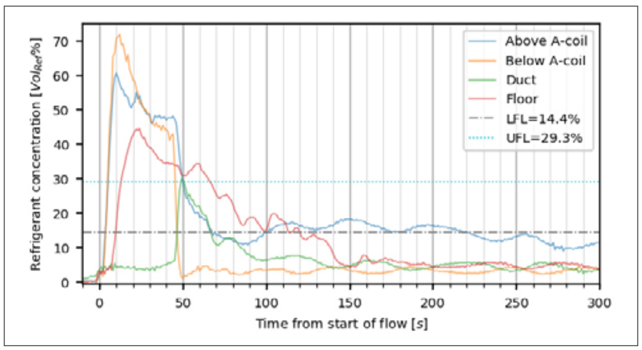

Figure 2 - 50 grams per second release; fan activation at 30 seconds

The cabinets' refrigeration concentration unit (above and below A-coil) for both releases was well above the LFL within a few seconds. This data also shows that the concentration for this leak rate will result in a concentration that's higher than the set point required by the safety standards. Once the fan had been activated and was running at the required airflow, the concentration below the A-coil dropped significantly. Furthermore, the refrigerant concentrations above the A-coil started decreasing after the fan was at speed, despite the refrigerant still being released into the unit. The sensor located in the ductwork did not see a significant refrigerant concentration rise until the fan was running, however, as with the sensor above the A-coil, the concentration dropped as the fan circulated air and diluted the refrigerant by mixing.

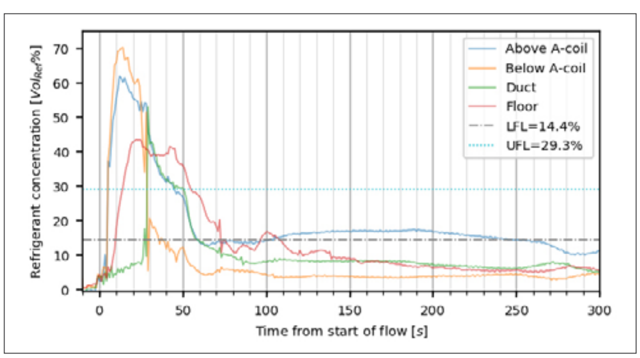

Figure 3 - 50 grams per second reelease; fan activation at 10 seconds

16 grams per second rate

Testing was conducted at the 16 grams per second release rate for a fan-off condition. Testing was also conducted using two different fan activation times of eight seconds and 11 seconds after the start of the release. The 20-second activation simulated a slow responding system. The fan activation at eight seconds was based on a commercially available refrigerant detector located inside the unit indicating the presence of refrigerant. Refrigerant concentration is detailed in Figure 4, Figure 5 and Figure 6.

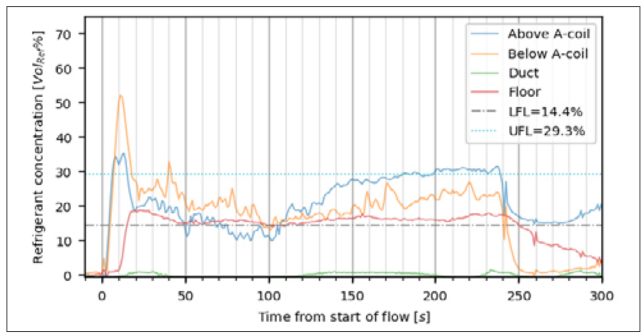

Figure 4 - our-minute leak; no fan

Similar profiles exist for refrigerant release with the call for fan at eight and 11 seconds after the start of the release. In both cases, once the fan has circulated refrigerant in the room or space, the refrigerant concentrations are below the LFL.

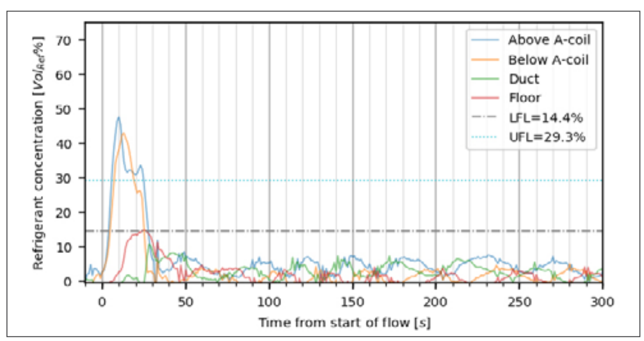

Figure 5 - 4 min Leak, Fan activated at 8 seconds

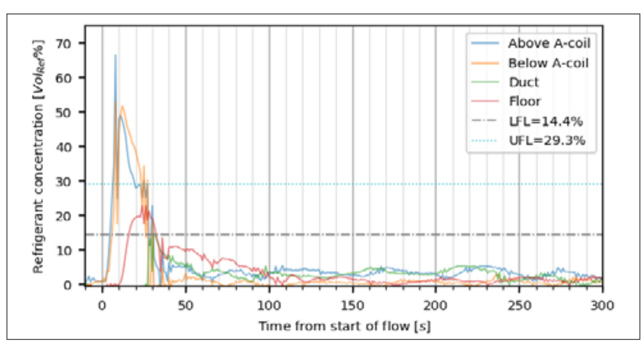

Figure 6 - Four-minute leak; fan activation at 11 seconds

3 grams per second rate

Testing was conducted with a release rate of 3 grams per second which simulates an ETRS (10 kilograms per hour) leak rate. No fan mitigation was utilized during this test. The refrigerant concentrations inside the unit, both above and below the A-coil, reached above the LFL within six seconds. The refrigerant concentration on the test chamber floor in front of the return grill was below 50% of the LFL during the entire release. There was no evidence of refrigerant flowing into the ductwork. This test revealed that even without fan operation, internal concentration decreases after several seconds from the beginning of the leak due to natural convection airflow caused by the higher density of the leaked refrigerant.

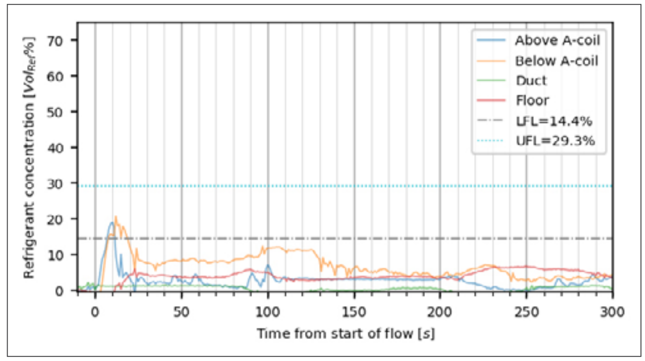

Figure 7 - ETRS release; no fan

Summary

As shown by the data, and other research (Gandhi, Hunter, Haseman, & Rodgers, 2017), it is possible to limit the flammable volume of refrigerant by utilizing airflow to mix with the entire room space. In all of the testing the concentration inside of the unit cabinet quickly reaches above the LFL even with the lower 3 grams per second release rate. With a slow leak and no fan activation, the refrigerant concentration inside the unit cabinet is above the LFL for only about six seconds following the start of the release. Airflow induced by refrigerant density reduces and keeps the concentration below the LFL once such air movement is generated.

This data shows that the release rate is a determining factor on how quickly the system needs to respond to a leak. A leak of 50 grams per second would need to respond quicker than a leak of 3 grams/second. For the 16 grams per second leak, the concentration inside the unit is greater than twice the LFL within 10 seconds. This concentration decreases quickly once the fan activation occurs, not only within the indoor unit but also on the floor in front of the return register. For the 3-grams-per-second leak, even without fan operation, the concentration did not exceed 50% of the LFL near the floor of the room.

These results suggest that the internal concentration of leaked refrigerant in an indoor unit reaches far above 25% of the LFL very quickly and reaches even beyond LFL. The response time of a refrigerant sensor is usually proportional to the inverse of concentration. Current requirements for response time in the standards are 15 or 30 seconds at 25% of the LFL, or 10 seconds at 100% of LFL. The requirement of 15 seconds was proposed considering the ignition with 50-grams-per-second release in AHRTI 9007-1 project. However, a reasonable worst-case scenario of four minutes to release the entire charge is referenced in the safety standards, and concentration within the duct work reaches far beyond the LFL even at a leak rate of 16 grams per second for the system tested.

The above scenarios were created with a vertically installed unit with the return grill located at floor level. A horizontally installed unit might not introduce refrigerant in the same way. Previous research by using a computational fluid dynamic model (Baxter, et al., 2018) has detailed that a refrigerant leak in an underfloor-mounted unit would not introduce significant refrigerant into the living space, because the leaked refrigerant is contained within the duct work when the fan is off. A unit where all return and supply duct openings are located at a high elevation in the space will also have different results. This is due to the fact that as the refrigerant flows into the space it will mix with the room volume, even if there is no forced convection occurring.

To learn more about how requirements impact specific products, visit Flammable Refrigerants Testing for Air Conditioning and Refrigeration on UL.com/Solutions.

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