AHRTI Project No. 9015

Assessment of Refrigerant Leakage Mitigation Effectiveness for Air-Conditioning and Refrigeration Equipment

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Executive Summary

There has been an industry trend to utilize new refrigerants. As the HVAC/R industries look towards refrigerants which have chemical properties which limit the global warming potential in the event that the refrigerant is released into the atmosphere, the hazards associated with lower GWP refrigerants will need to be mitigated. One such hazard is the flammability as defined by ASHRAE 34 (ASHRAE, 2019) Class 2, 2L and 3 refrigerants.

This report investigates the effectivity of mitigation effects as presented in current and proposed North American and International standards. When an appliance is installed in a single room the codes and standards limit the mass of refrigerant in the equipment. The mass limit can be selected for the specific appliance and room size to ensure that when the refrigerant is mixed in the space it will not propagate fire in the presence of an ignition source. However, as all safety group A2L refrigerants are heavier than air the release height and discharge velocity have a significant impact on localized refrigerant concentrations. The installation and operation of the HVAC/R appliance will also contribute to potential leak locations.

HVAC Equipment:
All tests for the HVAC portion of the project were simulated in a test room that was 18 m^2 (193 ft^2) with a 2.4 m (8 ft) ceiling height. Installation of equipment was varied to simulate a typical arrangement for products in North America: underfloor horizontal installation with ducts discharging up through the floor, a closet mounted vertical arrangement with ductwork discharging horizontally into the room, and a ductless wall mounted minisplit cassette. Mitigation effects investigated include the release location, quality of refrigerant leak, unit airflow and overall response time to minimum airflow. With the exception of transient conditions resulting from specific installation conditions which contained the released refrigerant inside the unit cabinet prior to fan activation, airflow introduced into the room space by the integral blower resulted in lower refrigerant concentrations at the points specified.

The positioning of the unit and the location of the ductwork had an impact on the refrigerant introduced into the test space. With the vertical unit test arrangement, there is evidence of refrigerant entering the room space via the return grill. Initially the refrigerant remains closer to the ground and has higher concentrations. However when the fan is energized the refrigerant mixes with a large portion of the room space and the local concentrations are reduced. With the unit in a horizontal configuration there is not a significant amount of refrigerant entering the space without mitigation. For an underfloor system the volume of the ductwork was sufficient to contain the volume of the refrigerant. Due to the installation the ductwork and unit were considered to be outside of the defined test room and added an additional 1.1 m^3 (38 ft^3) to the test space. In the horizontal configuration there was evidence of refrigerant leaking from the unit and ductwork to the space where the unit was installed. In both of these orientations when the mitigation (indoor blower motor) was activated higher concentrations of refrigerant entered the test space from the ductwork. This higher concentration was as the fan pushes the volume of higher concentration refrigerant which had previously been retained in the ductwork out into the room.
Response time for the mitigation can limit the amount of refrigerant above the Lower Flammability Limit (LFL) from entering the test space. For the vertical arrangement, a faster mitigation response resulted in the total time that sensors registered above the LFL to be reduced and also reduced the

average maximum reading for all sensors. For the horizontal arrangement depending on the construction of the unit and leak location, detection and mitigation of a leak could prevent a concentration above the LFL from being present in the space.

Mitigation response time had less effect with the ductless units tested, because of the installation heights and the effects of refrigerant mixing that occurred when the leak was introduced. During some of the tests there were short durations of volumes above the LFL. Other constructions of minisplit appliance or installation heights could result in the need for mitigation.

Changing the volumetric airflow had an effect in two ways: it produced a higher velocity which resulted in additional mixing in the space and it often required that the fan turn on at an earlier time. The requirements in the standard identify that the appliance will need to reach the defined volumetric flow for the test at a specific time. As one of the variables identified during this project was the flow rate this resulted in the fan need to be commanded on at differing times. For the horizontal setup: increasing the volumetric flow above what is currently identified in UL 60335-2-40 had the effect of lowering the average maximum refrigeration concentration at each of the sensor locations in the space. Increasing the volumetric flow also decreased the time that the sensors were in the flammable range. For the vertical setup, increasing the volumetric flow above what is currently identified in UL 60335-2-40 had the effect of lowering the average maximum refrigeration concentration at each of the sensor locations in the space in all but one test. Due to the fact that we had to select individual fan speeds for the ductless there are several tests with varying release charges for which the fan speed was the same. One such case in Ductless 3, Ductless 24 and Ductless 22. In this case we have approximately the same mitigation time, 35 s for Ductless 3 and 30 s for the other two. In effect what we are varying is the released charge: 25% LFL average room concentration (3.42 kg), 50% LFL average room concentration (6.84 kg) and IEC charge for installation (7.41 kg). The similarities between all of these tests show that with this airflow we are mixing well inside the room space.

The majority of the testing on the ductless system was conducted with the indoor cassette installed 1.8 m above the floor. A set of tests was conducted with the unit reinstalled installed at 1.2 m off the floor (67% of the original height). These tests indicate that without airflow in the room there is stratification of the refrigerant in the space. With this unit arrangement there was evidence that the lower installation height does have an effect on the refrigerant concentrations lower in the space, but once the refrigerant release is complete the induced air movement does continue to mix the entire room space. The testing without mitigation shows that there is a was a concentration difference when the unit was installed at a lower height in the room space. For the sensors located below the unit the 1.2 m install resulted in a 38% higher refrigerant value at the start of the test, 21%, for the sensor 50 mm (2 in) off the floor. After the refrigerant flow had been completed and the room concentrations were stable (~400 s after start) the refrigerant concentrations below the unit were 48% higher for the 1.2 m unit than for the unit installed at 1.8 m. This was confirmed when reviewing the sensors in the middle of the room, which were 47%, 39% and 15% higher for the 1.2 m installation, for sensors located 50 mm (2 in), 300 mm (12 in) and 900 mm (36 in) off the floor (see Figure 29). With both of these tests, the sensor located near the ceiling did not indicate a significant rise, indicating that for even a unit installed at 1.8 m the refrigerant is not mixing within the entire room space.

The results show it is possible to limit the mass of refrigerant entering the space by use of a safety shutoff valve (SSV). If the SSV are permitted to close quickly the potential mass of refrigerant is limited based on the size of the coil and the length of the line set located on the room side of the shutoff valves. This will vary between manufacturer and installed system construction. When the SSV are closed at the same time there was a direct correlation between the delay time and the mass of refrigerant that was released. Closing one SSV before another can have a limited effect on the mass of refrigerant remaining in the coil, depending on the operating mode. When the system was operated in the cooling mode it was possible to reduce the mass of refrigerant in the indoor coil by using a delay and allowing the compressor to draw refrigerant from the coil.

Commercial Refrigeration Equipment:
The testing for the refrigeration portion of the project were conducted in three room sizes: 7.2 m^2, 14.4 m^2, 24 m^2 (78 ft^2, 155 ft^2 and 258 ft^2). The testing was conducted to verify if the method in Annex CC of IEC 60335-2-89. The largest room size corresponds to the largest permitted room size for the Annex CC testing. Testing was conducted with two units: a single door reach in unit and a three door reach in unit, both units had hinged doors. Release locations were selected to be representative of potential leak locations. The internal leak location was near a return bend for the evaporator. Both the three door and single door reach in units had evaporators located at the top of the cabinet. For tests where an external leak was simulated a leak at the condenser was simulated. The effects investigated were room size, case loading, unit airflow and refrigerant release rate.

The refrigerant release was scaled proportionally with the room size. With the fan off the tests in the larger room sizes resulted in higher localized concentrations. There was evidence of higher refrigerant concentrations near the unit before and after the door was opened with the larger release mass. The larger refrigerant mass in the cabinet was released into the test space past the door seals. The concentration buildup before the door openings were similar across the sensors in front of the unit. This effect was directly related to the charge size. However, in no case did the refrigerant concentration reach 50% of the LFL prior to the door being opened. When the door opens the higher concentration refrigerant that was inside the cabinet was introduced into the test space. This resulted in a peak of high concentration of refrigerant which then mixed with the lower part of the room space. This effect was similar across all of the room sizes. The refrigerant is not mixing completely with the room space as the larger charge sizes for the medium and large room result in a higher refrigerant concentrations.

For all tests where a fan was not operated the refrigerant concentrations were above 50% LFL at five minutes into the test. It was possible to use the condenser fan to mix the refrigerant in the space and have refrigerant concentrations below 50% LFL after five minutes. The tests conducted in the small room utilized the condenser fans which were provided with the unit. These blowers provided enough airflow to ensure that the refrigerant concentrations were below 50% of the LFL before the five minute time. For the medium and large room airflow was checked at the expected nominal value and then adjusted to determine if there was a minimum airflow which could be identified. In all cases the airflow provided by the condenser fan is able to mix the refrigerant being leaked into the space prior to the door opening. When the door opens, the amount of refrigerant entering the space is similar between all tests. In the majority of the tests the amount of airflow required for unit operation can mix the refrigerant in the space. Different geometries will have an impact on the airflow in the unit. Based on the results observed it is possible to construct a unit which would comply with the requirements in the current edition of IEC 60335-2-89.

Annex CC of -2-89 specifies two release rates: one simulates when the motor-compressor is non-operating (Condition A), and the other simulates when the motor-compressor is operating (Condition B). The release rate comparison was limited in scope and for the bottom mounted condenser there was no significant difference. With the fan off all of the sensors were above the LFL. With the condenser fan operating the refrigerant concentrations remained below 50% of the LFL. There could exist a situation where a more construction with internal geometries which would restrict the release of refrigerant into the space or the condensing unit mounted in a different orientation could result in differences in these tests. However that was outside the scope of this study.

Contents

1 Introduction

In the 1980s it was identified that refrigerants being released were having an impact on the ozone layer. The Montreal protocol limited the use of CFC and HCFCs. The industry then made a change to HFCs, which have zero ozone depletion potential, but remain in the atmosphere and have a high global warming potential (GWP). As a result of the restriction of higher Global Warming Potential (GWP) refrigerants, the hazards associated with lower GWP refrigerants will need to be mitigated. One such hazard is the flammability as defined by ASHRAE 34 (ASHRAE, 2019) Class 2, 2L and 3 refrigerants. The current approach to limit the hazard associated with safety group A2, A2L and A3 refrigerants in codes and standards is done with two main principles: limit the refrigerant charge or detect the refrigerant leak and then circulate the air in the space. The limits for the first approach were identified during full scale refrigerant release tests. These full scale release tests identified that the ability of the system to mitigate an event is critical. There are several approaches which are currently used in various codes/standards.

In the US the installation code for refrigerant containing appliances is ASHRAE 15. This standard limits the use of refrigerants on the spaces. Current standard identifies the use of a particular material based on the refrigeration charge limits (RCL) as identified in ASHRAE 34. This calculation limits the use of the refrigerant based on flammability, toxicity as well as the oxygen deprivation limit. The use of this number would limit the total amount of charge that could be present in a space in the event of a leak of the charge into that space.

Some international standards, such as ISO 5149 have traditionally used a risk analysis, but now has been updated to include mitigation strategies that are currently in some of the applicable IEC 60335 series for appliances.

For HVAC systems the largest challenge with the use of safety group A2L and A3 refrigerants are the current differences between US and International versions of the 60335-2-40 standard. The US has a limitation of 3xLFL as the m1 value for all cord connected and portable products (the m1 value for fixed products is 6xLFL for A2L refrigerants). Above the m1 value there is a need to take action to prevent the buildup of refrigerant in the event of a leak. This could be mitigation or it could rely on sizing the charge for the room that the unit is installed. The IEC standard allows 4xLFL for m1, but in some cases allows up to 1 kg with mitigation. There are also differences in the safety factors used for sizing the equipment in the room space or the required airflow for mitigation. The IEC standards permits a refrigerant detection system to be installed in the room space, while the current UL/CSA -2-40 approach would limit the installation to a sensor located inside the unit.

Refrigeration systems have also had charge limit differences between the US and International versions of the standards. Most UL commercial refrigeration standards limited the charge for each circuit of a safety group A2L, A2 or A3 refrigerant to 150 g (UL 471 – Commercial Refrigerators and Freezers, UL 60335-2-89 – Commercial Refrigerating Appliances). With this approach there was an evaluation of construction and component with a test that evaluated the hazard due to ignition of the flammable refrigerant associated with the appliance. The current IEC standard increases this limit for to 13x LFL with a maximum of 1.2 kg, per circuit. This upper limit was proposed to be higher, but the final value was confirmed during the committee draft voting for the Third Edition of

IEC -2-89. This standard also includes a new test (identified in Annex CC of the standard) to identify the hazard of the refrigerant due to an ignition exterior to the appliance.

One question that this report does not address is what an expected leak rate or hole size would be. As refrigerant expands at the leak point there will be localized subcooling of the refrigerant remaining in the system. This will act to condense refrigerant and will then slow the refrigerant release into the room. Because of this it is expected that not all of the refrigerant would leak into the room space. For the tests in this project the values released were the total refrigerant charge quantity that was leaked into the room space, regardless of how much would have remained in the equipment. It could be useful in the future to understand what type of leaks are expected and how quickly the refrigerant is expected to be released.

This report is divided into two parts: Part I investigates the application of safety group A2L refrigerants for HVAC applications. Part II investigates the application safety group A2L and A3 refrigerants for commercial refrigeration applications. The methods applied for the tests as well as the results for each of these are located in these parts.

Part I – HVAC

2 Method

When an appliance is installed in a single room the codes and standards limit the mass of refrigerant in the equipment. The mass limit can be selected for the specific appliance and room size to ensure that when the refrigerant is mixed in the space it would not propagate fire in the presence of an ignition source. However, as most A2L refrigerants are heavier than air the release height and discharge velocity have a significant impact on localized refrigerant concentrations.

Previous research has shown that mitigation airflow can prevent localized concentration of refrigerants (P. Gandhi, 2017) (Hunter, 2019) (Davis, 2017). This report will investigate the impact of refrigerant mass safety factor (equipment charge level), response rate of the overall mitigation system, mitigation flow rate, and the refrigerant release quality.

For each of these conditions a test was conducted with the refrigerant release as a baseline, there were no mitigation steps taken, except to limit the refrigerant charge in the test room.

All test for the HVAC (A/C) portion of the report were simulated in a test room that was 17.9 m^2 (193 ft^2) with a 2.44 m (8 ft) ceiling height. Installation of equipment was varied to simulate a typical arrangement for products in North America: underfloor horizontal installation with ducts discharging up through the floor, a closet mounted vertical arrangement with ductwork discharging horizontally into the room, and a ductless wall mounted minisplit cassette. Tests were also conducted to determine the expected refrigerant release of a multi-split system which incorporated refrigerant shut-off valves to limit the refrigerant mass released into a single room.

The maximum refrigerant charge in the room is defined by for ducted system both the end product standard and in the installation code ASHRAE 15. The standard and code have similar requirements, the baseline refrigerant release was chosen to be 3.42 kg of R-32, as this was equal to 25% of the LFL for the whole room volume. For the tests which looked at the refrigerant mass safety factor a release mass of 6.84 kg of R-32 was selected due to the 0.50 safety factor of IEC -2-40 GG.22. These refrigerant release values were also used during the ductless portion. A constant release rate was selected over a 4 minute leak as defined in IEC and UL/CSA 60335-2-40. For the larger refrigerant release the rate was the same, resulting in an 8 minute long leak.

The current requirements in IEC 60335-2-40, edition 6.0, indicates the refrigeration detection system shall activate the mitigation device and the fan shall be switched on within 30 s:

> *LL.3 Refrigerant detection system range, accuracy and response time*
> *Refrigerant detection system shall make output according to the applicable clauses of Annex GG of this standard within 30 s when the sensor is put into refrigerant concentration of 25 % of LFL or lower.*

The requirements in UL/CSA 60335-2-40, edition 3, has a national deviation which divides the mitigation time into two: the refrigerant detection response and the fan response. This deviation was added to the North American version of the standard to address the response and ramp time for fans that are driven by modern variable speed motors (e.g. electronically commutated). These two requirements ensure that the fan is at Q_{min} within 25 s (or less) of the refrigerant detection system being exposed to a sufficient percentage of refrigerant in air.

LL.3DV Refrigerant detection system range, accuracy and response time
Including the worst case combined effects of declared manufacturing tolerances and drift, the pre-set level shall be selected such that the REFRIGERANT DETECTION SYSTEM shall provide an output according to applicable clauses of Annex GG of this standard within 10 s or less when the sensor is put into refrigerant concentration of 100 % LFL or lower...

GG.2.2.3DV.1 D2 Modification of the 1st bullet of Clause GG.2.2.3 of the part 2 by replacing
with the following.
• Energize the fan (s) of the appliance to deliver indoor airflow at or above the minimum airflow Q_{min}. The minimum airflow Q_{min} shall be attained within 15 s following the input signal to turn on the fan.

The purpose of this project was to look at the effectiveness of the mitigation itself, and therefore was indifferent to how quickly the refrigerant detector responded vs how quickly the fan speed responded. The fan control was initiated at a given time such that the fan was at minimum volumetric flow value at the required time for the test. Two times were chosen for to compare UL airflow rates: 25 s and 35 s after the start of the release. An evaluation was also made comparing IEC flow rates when compared to table GG.2, these times were at 10s and 30 s after the start of the release.

The minimum required airflow Q_{min} for a ducted system is defined by equation GG.19 in IEC and UL/CSA 60335-2-40. The minimum airflow is defined in clause ASHRAE 15 as the following equation:

Q_{min} = 60,000 × M/LFL (SI)
where
Q_{min} = minimum airflow rate, ft3/min (m3/h)
M = refrigerant charge of the largest independent
refrigerating circuit of the system, lb (kg)
LFL = lower flammability limit, lb per 1000 ft3 (g/m3)

There is limited data to show the size, quality of the refrigerant, and expected locations of refrigerant leaks when installed in the field. In order to understand if there was any difference between a liquid and vapor release a release at both of these states was conducted. The quality of the release was changed by drawing refrigerant from the top or bottom of refrigerant tank. The refrigerant released was R-32, a single compound refrigerant, so there was no potential issue with fractionation.

Table 1 provides a summary of the charge limit and airflow calculations for the ducted system per ASHRAE 15-2019, UL/CSA 60335-2-40 3rd Ed (2019) and IEC 60335-2-40 6th Ed (2018).

		ASHRAE 15-2019		UL 60335-2-40 ed3		IEC 60335-2-40 ed6	
Charge Limit	Charge Limit Source	§7.2 (from §7.6)		GG.9 Eq. (GG.22)		GG.9 Eq. (GG.22)	
	mass	M = RCL_a × volume (=SF × LFL_a × H × TA)		m_max =SF×LFL×H×TA		m_max =SF×LFL×H×TA	
	SF	0.25		0.25		0.50	
	R32 LFL [kg/m^3]	0.306		0.306		0.307	
	LFL_a [kg/m^3]	ASHRAE 34 §7.4.2	0.301 (h=200 m)		N/A		N/A
	H	8.00 ft	2.44 m	7.22 ft	2.20 m	7.22 ft	2.20 m
	TA	193 ft^2	17.9 m^2	193 ft^2	17.9 m^2	193 ft^2	17.9 m^2
	m_c	7.23 lb	3.35 kg	6.63 lb	3.01 kg	13.30 lb	6.04 kg
Recirculation Airflow Rate	Qmin Source	§7.6.4.2		GG.9 Eq. (GG.21)		GG.9 Eq. (GG.21)	
	Qmin	=1000×M/LFL	=60×M/LFL	=60 × m_c / LFL		=60 × m_c / LFL	
	Qmin	386 ft^3/min	655 m^3/h	348 ft^3/min	591 m^3/h	695 ft^3/min	1181 m^3/h

Table 1 - Charge and Airflow Calculations – Ducted

Table 2 provides a summary of the charge limit and airflow calculations for the ductless system per UL/CSA 60335-2-40 3rd Ed and IEC 60335-2-40 6th Ed.

		UL 60335-2-40 ed3				IEC 60335-2-40 ed6			
Charge Limit	Charge Limit Source	GG.2.1DV Eq. (GG.10)				GG.2.2.1 Eq. (GG.10)			
	mass	mmax = SF × LFL × h0 × A				mmax = SF × LFL × h0 × A			
	SF	0.25				0.75			
	R32 LFL [kg/m^3]	0.306				0.307			
	H	5.9 ft	1.8 m	3.9 ft	1.2 m	5.9 ft	1.8 m	3.9 ft	1.2 m
	TA	193 ft^2	17.9 m^2	193 ft^2	17.9 m^2	193 ft^2	17.9 m^2	193 ft^2	17.9 m^2
	m_c	5.42 lb	2.46 kg	3.61 lb	1.63 kg	16.32 lb	7.42 kg	10.88 lb	4.95 kg
Recirculation Airflow Rate	Qmin Source	GG.2.2.1DV				GG.2.2.1 Table GG.2			
	Qmin	=60 × m_c / LFL				=30 × m_c / LFL			
	Qmin	284 ft^3/min	482 m^3/h	188 ft^3/min	320 m^3/h	427 ft^3/min	725 m^3/h	285 ft^3/min	483 m^3/h

Table 2 - Charge and Airflow Calculations - Ductless

2.1 Horizontal

The test room was installed above a simulated crawlspace. The unit under test was suspended horizontally from the floor joists such that the top of the unit was 25 cm (10 in) below the floor of the test room. Drain lines were plugged at the drain pan. Ductwork was connected to the outlet of the unit under test and run through the crawlspace which discharged vertically through the floor. Ductwork consisted of a transition to a 36 cm x 36 cm (14 in x 14 in) main trunk and a 25 cm x 25 cm (10 in x 10 in) secondary trunk. Four registers, two in each section of trunk) permitted the airflow into the test room. Return air to the unit under test was provided via a single 41 cm x 51 cm (16 in x 20 in) return grill, which also held a spun fiberglass air filter. All ductwork was manufactured onsite using standard duct materials and connection methods. Duct joints were sealed using a mastic painted on with a brush. Electrical power was provided to the unit under test to power the indoor blower. The blower was commanded using direct PWM control of the electronically commutated motor.

Tests conducted to evaluate the UL airflow rates were calculated using Equation GG.21 in Clause GG.9.1 of UL/CSA 60335-2-40. A mitigation delay time of 25 s and 35 s was evaluated using this airflow.

Test conducted for the IEC airflow were determined using Table GG.2 in Clause GG.2.2.1 of IEC 60335-2-40. A mitigation delay time of 10 s and 30 s was evaluated using this airflow. This table incorporates not only a minimum volumetric flow but also a minimum velocity. The duct arrangement was modified for these tests to restrict the discharge to the first two registers, this was done to ensure that the velocity from the ducts was fast enough to allow for the lower total volumetric flowrate.

A summary of the tests conducted with this setup is located in Table 3, below.

Test Name	Leak Type	Target Release	Mitigation Time	Airflow Rate	Mass Released	Expected Room Concentration
Horizontal 1	4 minute - Liquid	3.42 kg	N/A	N/A	3.15	3.26%
Horizontal 2	4 minute - Liquid	3.42 kg	25 s	Q_{min}	3.52	3.64%
Horizontal 3	4 minute - Liquid	3.42 kg	35 s	Q_{min}	3.76	3.89%
Horizontal 4	4 minute - Liquid	3.42 kg	25 s	$2*Q_{min}$	3.46	3.58%
Horizontal 5	4 minute - Liquid	3.42 kg	35 s	$2*Q_{min}$	3.15	3.26%
Horizontal 6	4 minute - Vapor	3.42 kg	N/A	N/A	2.93	3.03%
Horizontal 7	4 minute - Vapor	3.42 kg	25 s	Q_{min}	3.50	3.62%
Horizontal 8	4 minute - Vapor	3.42 kg	35 s	Q_{min}	3.21	3.32%
Horizontal 9	4 minute - Vapor	3.42 kg	25 s	$2*Q_{min}$	3.56	3.68%
Horizontal 10	4 minute - Vapor	3.42 kg	35 s	$2*Q_{min}$	3.41	3.53%
Horizontal 11	8 minute - Liquid	6.84 kg	N/A	N/A	6.87	7.11%
Horizontal 12	8 minute - Liquid	6.84 kg	25 s	Q_{min}	6.82	7.06%
Horizontal 13	8 minute - Liquid	6.84 kg	35 s	Q_{min}	6.77	7.01%
Horizontal 14	8 minute - Liquid	6.84 kg	25 s	$2*Q_{min}$	6.93	7.17%
Horizontal 15	8 minute - Liquid	6.84 kg	35 s	$2*Q_{min}$	6.79	7.03%
Horizontal 16	8 minute Decay	6.84 kg	N/A	N/A	6.48	6.71%
Horizontal 17	8 minute Decay	6.84 kg	25 s	Q_{min}	6.37	6.59%

Horizontal 18	8 minute Decay	6.84 kg	35 s	Q_{min}	6.37	6.59%
Horizontal 19	8 minute Decay	6.84 kg	25 s	$2*Q_{min}$	6.52	6.75%
Horizontal 20	8 minute Decay	6.84 kg	35 s	$2*Q_{min}$	6.48	6.71%
Horizontal 21	4 minute - Liquid	3.42 kg	10 s	IEC Q_{min}	3.42	3.54%
Horizontal 22	4 minute - Liquid	3.42 kg	30 s	IEC Q_{min}	3.41	3.53%
Horizontal 23	4 minute - Liquid	6.84 kg	10 s	IEC Q_{min}	6.80	7.04%
Horizontal 24	4 minute - Liquid	6.84 kg	30 s	IEC Q_{min}	6.86	7.10%

Table 3 - Summary of Horizontal Tests

2.2 Vertical

The unit under test was installed in a closet installed in the corner of the room. A plywood platform was installed so that the unit under test was supported 54 cm (23 in) above the floor of the test room. Drain lines were plugged at the drain pan. Ductwork was connected to the outlet of the unit under test and run into the test room. The ductwork was installed near the ceiling level and with the airflow discharged horizontally into the room. Ductwork consisted of a transition and 90 ° bend to a 36 cm x 36 cm (14 in x 14 in) main trunk and a 25 cm x 25 cm (10 in x 10 in) secondary trunk. Four registers, two in each section of trunk) permitted the airflow into the test room. Return air to the unit under test was provided via a single 41 cm x 51 cm (16 in x 20 in) return grill, which also held a spun fiberglass air filter. All ductwork was manufactured onsite using standard duct materials and connection methods. Duct joints were sealed using a mastic painted on with a brush. Electrical power was provided to the unit under test to power the indoor blower. The blower was commanded using direct PWM control of the electronically commutated motor.

Tests conducted to evaluate the UL airflow rates were calculated using Equation GG.21 in Clause GG.9.1 of UL/CSA 60335-2-40. A mitigation delay time of 25 s and 35 s was evaluated using this airflow.

Test conducted for the IEC airflow were determined using Table GG.2 in Clause GG.2.2.1 of IEC 60335-2-40. A mitigation delay time of 10 s and 30 s was evaluated using this airflow. This table incorporates not only a minimum volumetric flow but also a minimum velocity. The duct arrangement was modified for these tests to restrict the discharge to the first two registers, this was done to ensure that the velocity from the ducts was fast enough to allow for the lower total volumetric flowrate.

Test Name	Leak Type	Target Release	Mitigation Time	Airflow Rate	Mass Released	Expected Room Concentration
Vertical 1	4 minute - Liquid	3.42 kg	N/A	N/A	3.43	3.64%
Vertical 2	4 minute - Liquid	3.42 kg	25 s	Q_{min}	3.45	3.66%
Vertical 3	4 minute - Liquid	3.42 kg	35 s	Q_{min}	3.38	3.59%
Vertical 4	4 minute - Liquid	3.42 kg	25 s	$2*Q_{min}$	3.40	3.61%
Vertical 5	4 minute - Liquid	3.42 kg	35 s	$2*Q_{min}$	3.36	3.57%
Vertical 6	4 minute - Vapor	3.42 kg	N/A	N/A	3.45	3.66%

Vertical 7	4 minute - Vapor	3.42 kg	25 s	Q_{min}	3.45	3.66%
Vertical 8	4 minute - Vapor	3.42 kg	35 s	Q_{min}	3.46	3.67%
Vertical 9	4 minute - Vapor	3.42 kg	25 s	$2*Q_{min}$	3.42	3.63%
Vertical 10	4 minute - Vapor	3.42 kg	35 s	$2*Q_{min}$	3.37	3.58%
Vertical 11	8 minute - Liquid	6.84 kg	N/A	N/A	6.85	7.27%
Vertical 12	8 minute - Liquid	6.84 kg	25 s	Q_{min}	6.80	7.22%
Vertical 13	8 minute - Liquid	6.84 kg	35 s	Q_{min}	6.80	7.22%
Vertical 14	8 minute - Liquid	6.84 kg	25 s	$2*Q_{min}$	6.77	7.19%
Vertical 15	8 minute - Liquid	6.84 kg	35 s	$2*Q_{min}$	6.85	7.27%
Vertical 16	8 minute - Decay	6.84 kg	N/A	N/A	6.78	7.20%
Vertical 17	8 minute - Decay	6.84 kg	25 s	Q_{min}	6.81	7.23%
Vertical 18	8 minute - Decay	6.84 kg	35 s	Q_{min}	6.84	7.26%
Vertical 19	8 minute - Decay	6.84 kg	25 s	$2*Q_{min}$	6.84	7.26%
Vertical 20	8 minute - Decay	6.84 kg	35 s	$2*Q_{min}$	6.81	7.23%
Vertical 21	4 minute - Liquid	3.42 kg	10 s	IEC Q_{min}	3.42	3.63%
Vertical 22	4 minute - Liquid	3.42 kg	30 s	IEC Q_{min}	3.38	3.59%
Vertical 23	4 minute - Liquid	6.84 kg	10 s	IEC Q_{min}	6.80	7.22%
Vertical 24	4 minute - Liquid	6.84 kg	30 s	IEC Q_{min}	6.91	7.34%

Table 4 – Summary of Vertical Tests

2.3 Ductless

A single wall mounted ductless minisplit was installed on the wall in the room. It was located with the bottom 1.8 m (5.9 ft) off the floor. The unit was centered on the longer wall with the closet. Power was run to the unit. The drain line was plugged at the drain pan, to contain all of the refrigerant in the test room space. When installed in the field this drain line would lead to the exterior of the building or plumbed into a drainage system for the building. Power was connected to the unit so that it could operate. The leak point for this unit was near a return bend inside the case of the unit , the inset to Figure 1 shows the leak location when the unit is viewed from the top.

Figure 1 - Ductless Unit and Leak Location

It was not possible to directly control the motor as was done with the ducted units. Airflow for the test was selected using one of five discrete fan speeds. The fan speed that most closely aligned with the target airflow was used.

Tests conducted to evaluate the UL airflow rates were calculated using Equation GG.1 DV in Clause GG.2.2.1DV of UL/CSA 60335-2-40. A mitigation delay time of 25 s and 35 s was evaluated using this airflow.

Test conducted for the IEC airflow were determined using Table GG.2 in Clause GG.2.2.1 of IEC 60335-2-40. A mitigation delay time of 10 s and 30 s was evaluated using this airflow.

For two tests the unit installation was moved to be a height of 1.2 m above the floor. A vapor release with no mitigation and with a 25 s delay was conducted to determine if the installation height had an effect.

Test Name	Leak Type	Installation Height	Target Release	Mitigation Time	Airflow Rate	Mass Released	Expected Room Concentration
Ductless 1	4 minute - Liquid	1.8 m	3.42 kg	N/A	N/A	3.39	3.60%
Ductless 2	4 minute - Liquid	1.8 m	3.42 kg	25 s	Q_{min}	3.44	3.65%
Ductless 3	4 minute - Liquid	1.8 m	3.42 kg	35 s	Q_{min}	3.42	3.63%
Ductless 4	4 minute - Liquid	1.8 m	3.42 kg	N/A	N/A	3.42	3.63%
Ductless 5	4 minute - Liquid	1.8 m	3.42 kg	35 s	Q_{min}	3.42	3.63%
Ductless 6	4 minute - Vapor	1.8 m	3.42 kg	N/A	N/A	3.43	3.64%
Ductless 7	4 minute - Vapor	1.8 m	3.42 kg	25 s	Q_{min}	3.38	3.59%
Ductless 8	4 minute - Vapor	1.8 m	3.42 kg	35 s	Q_{min}	3.45	3.66%
Ductless 9	4 minute - Vapor	1.2 m	3.42 kg	N/A	N/A	3.42	3.63%
Ductless 10	4 minute - Vapor	1.2 m	3.42 kg	25 s	Q_{min}	3.35	3.56%
Ductless 11	8 minute - Liquid	1.8 m	6.84 kg	N/A	N/A	6.85	7.27%
Ductless 12	8 minute - Liquid	1.8 m	6.84 kg	25 s	Q_{min}	6.89	7.31%
Ductless 13	8 minute - Liquid	1.8 m	6.84 kg	35 s	Q_{min}	6.81	7.23%
Ductless 14	8 minute - Liquid	1.8 m	6.84 kg	25 s	$.5*Q_{min}$	6.82	7.24%
Ductless 15	8 minute - Liquid	1.8 m	6.84 kg	35 s	$.5*Q_{min}$	6.85	7.27%
Ductless 21	4 minute - Liquid	1.8 m	7.41 kg	10 s	IEC Q_{min}	7.47	7.93%
Ductless 22	4 minute - Liquid	1.8 m	7.41 kg	30 s	IEC Q_{min}	7.36	7.81%
Ductless 23	4 minute - Liquid	1.8 m	6.84 kg	10 s	IEC Q_{min}	6.83	7.25%
Ductless 24	4 minute - Liquid	1.8 m	6.84 kg	30 s	IEC Q_{min}	6.88	7.30%

Table 5 - Summary of Ductless Tests

2.4 Multisplit

A nominal 3-ton multisplit system was used for testing, with four nominal 3/4 -ton indoor wall-mount indoor units connected to a single nominal 3-ton outdoor unit. One of the wall-mount indoor units was located inside the test space and the other three were located outside the test space, so they could be operated and not have an effect on airflow inside the test room, see Figure 2. The indoor units were connected to the outdoor units with the maximum amount of refrigerant line set allowed for the outdoor unit. As this unit under test was manufactured to be charged using R-410A, the refrigerant that the unit was shipped with was recovered from the unit. A total refrigerant charge for the unit with maximum line set was calculated per the manufacturers installation and operating instructions to be 4.32 kg (9.51 lbs). This value was correlated to a refrigerant change of a system designed for R-32 by comparing the enthalpy of the refrigerants at a 50% quality, this resulted in a system charge of 3.86 kg (8.49 lbs) of R-32. Prior to each test the system was evacuated and then charged with this mass of R-32.

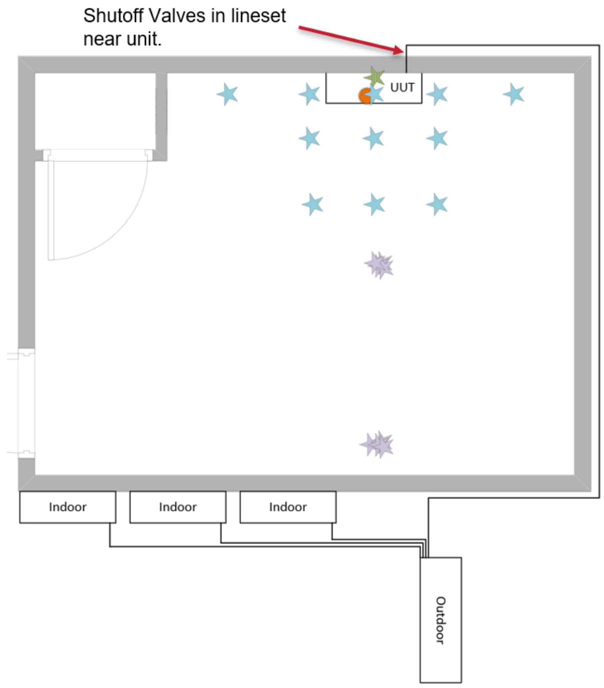


Figure 2 - Multisplit Unit Layout

The parameters varied during this testing included the most severe operating mode for the unit (cooling, heating, standby) for a single leak at the bottom of the coil, delay time for the valves to close and the mass of refrigerant the shutoff valves would limit in the test space. This setup was also utilized for a baseline test to determine how much of the refrigerant charge would be released from the unit if a leak were present.

To simulate a leak a return bend at the bottom of the coil was extended using copper tubing. The return bend selected was approximately 80% through the coil when operating in cooling mode and 20% through the coil when operating in heating mode. This location was selected due to the accessibility of this location (other return bends were blocked by other components). The 3.2 mm (0.125 in)copper tubing was connected to an electronic ball valve which was electrically wired to be operated remotely. The outlet of the ball valve was connected to a Coriolis flow meter which was then connected with more 6.4 mm (0.25 in) copper piping to a refrigerant service port. A 0.64 mm (#72 [0.025 in]) orifice capped the service port and was oriented so that it was discharging back into the unit near the return bend. The #72 orifice was selected to simulate a 20 kg/hr (44 lb/hr) leak into the room. The shutoff valves used to simulate the safety shutoff valves (SSV) were two commercially available normally closed, electronically operated pneumatic ball valves. The valves were rated for the pressures involved in the system and when subjected to both liquid and vapor there was no evidence of refrigerant flow past the valves at the system working pressures. A 6.4 mm (1/4 in) valve was installed in the liquid line, initially at a distance of 34 cm (13.4 in) from the indoor unit. A separate 9.5 mm (3/8 in) valve was installed in the vapor line, initially at a distance of 39 cm (15.4 in) from the indoor unit. These valves could be operated simultaneously or at different times. Internal volume of the indoor unit is 0.711 L (43.4 in^3) and the piping volume to the SSOV is 0.025 L (1.5 in^3). So, the shut-off volume is 0.736 L (44.9 in^3) without additional piping. Piping effect tests were also conducted. In these tests, additional 10 m (32.8 ft) piping was added between the indoor unit and SSOV to see the impact of such structure. The volume is 0.192 L (11.7 in^3) for liquid line (1/4 in nominal diameter) and 0.493 L (30.1 in^3) for vapor line (3/8 in nominal diameter). For all of these tests there was an additional piping on the outlet of the device including flow meter and piping which had internal volume of 0.088 L (5.4 in^3).

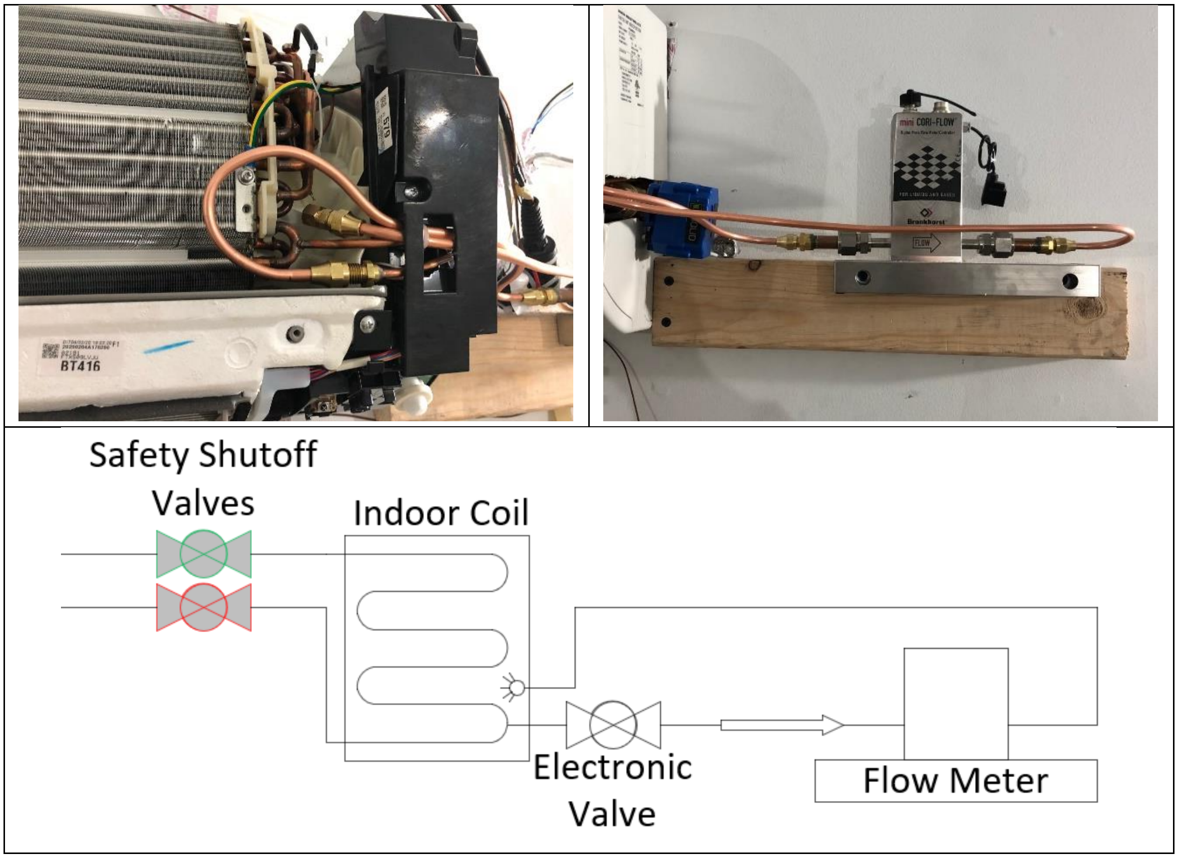


Figure 3 - Multisplit Release System and schematic

<u>TEST SERIES 1.</u> As noted above, the first parameter to analyze was operating mode of the unit (cooling, heating, or standby). In order to determine which operating mode had the highest leak rates, the unit was operated in minimum temperature cooling mode, maximum temperature for heating mode and a standby mode. For the standby mode: the unit was operated in cooling for 15 minutes to ensure that there was liquid in the evaporator, then the unit was powered down and let sit for 20 minutes. Once the unit was at the specified condition a leak was started using the electronic valve (See Figure 4). 30 seconds after the flow started the SSV were closed. The flow into the room was measured using the Coriolis mass flow meter, which was recorded by the data acquisition system. At the conclusion of the test the SSV remained closed, and the refrigerant remaining in the multisplit system was recovered using commercially available recovery equipment. This recovered refrigerant was weighed and compared to the refrigerant amount initially charged to determine the refrigerant mass loss.

<u>TEST SERIES 2.</u> The time for the SSV to close was the second parameter investigated. As with other mitigation types there will be physical and electrical limitations on the response for the system (both detecting and responding to a leak). To better understand the speed at which a SSV should close to limit refrigerant mass leak into the space a delay test was conducted. Test series 2 was conducted using the most severe operating mode (heating) identified in Test Series 1. The unit was set for maximum temperature and such that the compressor, and thus pressures, would be operating as high as possible. A leak was then introduced using the electronic valve. As with Test Series 1, both SSV were closed simultaneously at a defined time. Defined times of 15 s and 60 s after the start of the leak were selected. At the conclusion of each test the SSV remained closed, and the refrigerant remaining in the multisplit system was recovered using commercially available recovery equipment. This recovered refrigerant was weighed and compared to the refrigerant amount initially charged to determine the refrigerant mass loss.

<u>TEST SERIES 3.</u> This same multisplit system setup was then utilized to evaluate the effectiveness that a delay in closing one SSV could have on the mass of refrigerant which could be leaked into the room. To evaluate this effect the unit was operated in the specified mode and the shutoff valves in the refrigerant line set were closed at different times, a summary of the delay times is shown in Table 6. After the SSV were closed the electronic valve was opened which allowed the refrigerant inside the coil to be introduced into the room. A 0.34 mm (#80 [0.013 in]) orifice was connected to provide for a simulated leak. The flow into the room was measured using the Coriolis mass flow meter, which was recorded by the data acquisition system. At the conclusion of the test the SSV remained closed and the refrigerant remaining in the multisplit system was recovered from the system using commercially available recovery equipment. This recovered refrigerant was weighed and compared to the refrigerant amount initially charged to determine the refrigerant mass loss.

Test Number	**SSV Location**	SSV Closing Operation	Unit Mode
3A	SSV near indoor unit	Simultaneous	Heating
3B	SSV near indoor unit	Liquid, 5 s delay, Vapor	Cooling
3C	SSV near indoor unit	Liquid, 30 s delay, Vapor	Cooling
3D	SSV near indoor unit	Liquid, 60 s delay, Vapor	Cooling
3E	SSV near indoor unit	Vapor, 5 s delay, Liquid	Heating
3F	SSV near indoor unit	Vapor, 30 s delay, Liquid	Heating
3G	SSV near indoor unit	Vapor, 60 s delay, Liquid	Heating
3H	SSV near indoor unit	Liquid, 5 s delay, Vapor	Standby
3I	SSV near indoor unit	Liquid, 30 s delay, Vapor	Standby
3J	SSV near indoor unit	Liquid, 60 s delay, Vapor	Standby
3K	SSV near indoor unit	Liquid, 5 s delay, Vapor	Heating
3L	SSV 10 m from indoor unit	Vapor, 5 s delay, Liquid	Heating
3M	SSV 10 m from indoor unit	Vapor, 30 s delay, Liquid	Heating

Table 6 - SSV Timing with Delay

For all tests in Test Series 3 with the exception of 3A and 3L this test arrangement was to determine if there was any pump down effect. That is: was it is possible to use the suction of the refrigeration system to limit the mass of refrigerant available in the indoor coil in the event of a leak. In these cases the upstream SSV was closed prior to the downstream valve. The unit under test had the expansion device located within the cabinet of the outdoor unit. The reference to liquid and vapor lines in this table refers to the line with the substantially liquid (low quality) refrigerant or substantially vapor (high quality) refrigerant. Test 3A provides a baseline of how much refrigerant was expected to be held in the indoor coil if closed at the same time.

Test Series 4. Seat leakage from the SSV is a defined item in both the current IEC and UL/CSA versions of the standard. Three leak rates were chosen: 1.0 kg/h as a baseline, 2.0 kg/h as an intermediate value, and 4.4 kg/h based on the proposed (CDV) IEC 60335-2-40 edition 7. The seat leakage for the SSV is a construction requirement and is defined differently in both the IEC and UL/CSA standards:

The current IEC committee draft indicates that the maximum cumulative seat leakage for all SSV shall not exceed the following:

$$m_{sv} = 4 * LFL$$

Where LFL is defined in kg/m^3 and m_{sv} is maximum rate in g/s. This results in a total leakage for all valves of 4.4 kg/hr.

The current UL/CSA standard indicates in clause 101.DVG.6.3.2 that the maximum seat leakage per SSV shall be calculated per the following:

$$SL_{max} = 5 \times LFL / M$$

Where LFL is defined in kg/m^3 and SL_{max} is m^3/hr. This results in SL_{max}=0.0294 m^3/h. Because this is defined per SSV and this multisplit system utilizes two SSV, this value was increased a factor of two. This provided a final mass rate of 0.0249 kg/h.

The ductless room arrangement with a single wall mount minisplit was utilized to investigate if these maximum rates were sufficient to prevent buildup of a flammable concentration. The tank release method was utilized with the exception that the refrigerant was introduced into the room with a capillary tube, whose length was selected to provide the necessary flow rate. The refrigerant was introduced into the room at the top of the unit and there were no additional mitigation measures employed for the remainder of the release.

2.5 Release System

Refrigerant released for both the horizontal and vertical ducted units as well as the ductless tests was introduced using a fixed release system.

Refrigerant was discharged into equipment under test at an expected leak point. For the ducted horizontal and ducted vertical tests the leak was simulated inside the case near the thermal expansion valve. The simulated leak for the ductless tests were located near a return bend. The refrigerant to be released into the room was placed into a fifty-pound recovery cylinder. The tank was wrapped with a thermostatically controlled electric blanket to bring the refrigerant to, and provide, sufficient pressure for the release. This apparatus was suspended from a load cell to measure the mass of the refrigerant. The load cell had an output that was used for a display in the control room as well as wired as an input into the data acquisition system. The release was initiated and ended by the use of an electronically piloted, pneumatic ball valve near the discharge location, the length of tubing after the shutoff valve was uninsulated and the length was minimized. The length of tubing after the valve was approximately 230 mm (9 in) for the ductless tests and 760 mm (30 in) for the ducted installation. Release rate was controlled by sizing an orifice at the discharge location.

The setup was arranged such that the refrigerant was removed from the top of the tank in a vapor state, or drawn through a dip tube and released as a liquid. For some tests a decay release was also used. The decay release was used for larger mass releases where the equipment could not sustain a completely vapor flow. For these tests refrigerant was placed in the release tank such that the refrigerant level would be above the dip tube at the start of the test, releasing liquid, and then transitioned to a vapor flow partway through the release.

Prior to the start of the test refrigerant was placed into the release cylinder and the electric elements were used to bring the refrigerant to temperature. Air was expelled from the discharge tubing to ensure that there was an accurate measurement of the released refrigerant. Once the room was sealed and the test was ready to start the valve was opened and mass loss from the tank could be observed. When the specified refrigerant mass had been released from the tank the solenoid valve was closed.

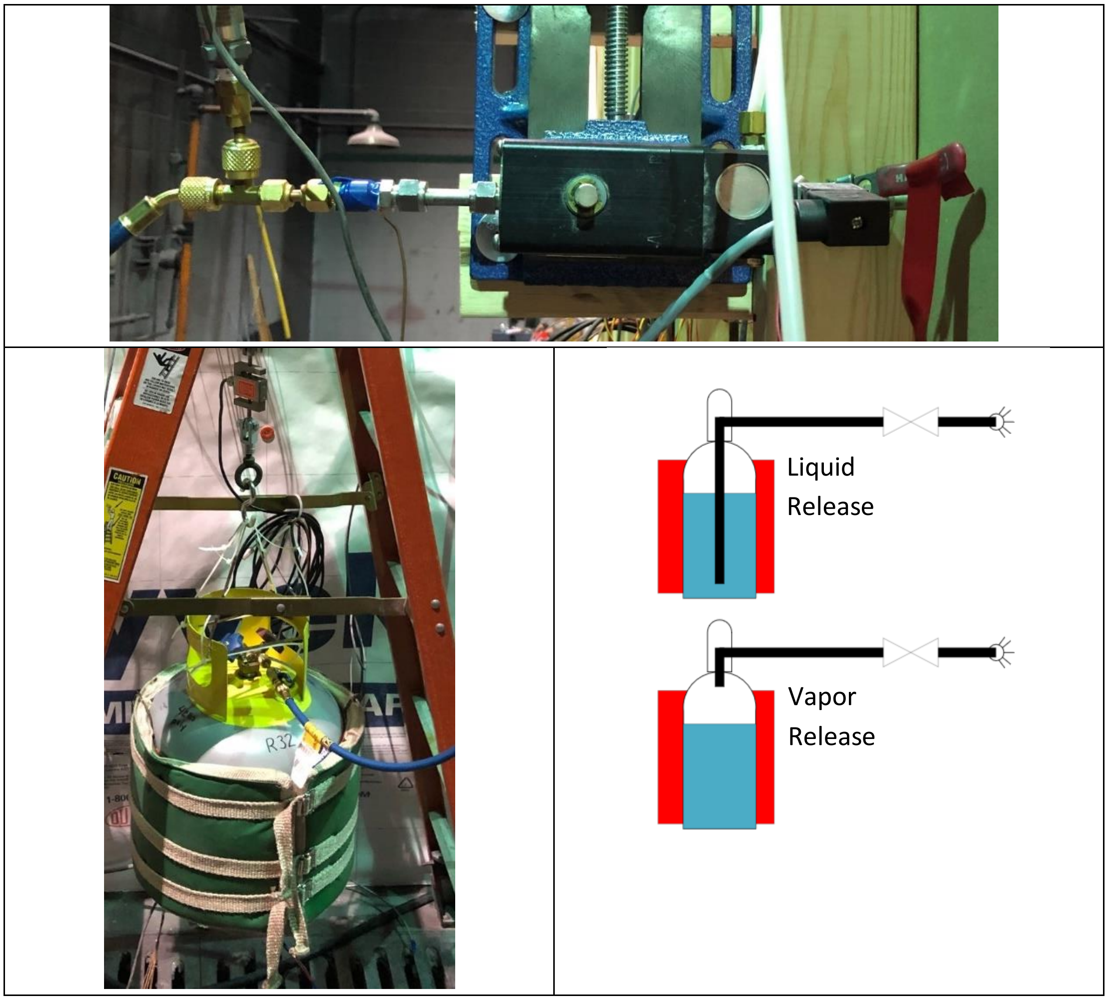


Figure 4 - Refrigerant Release Equipment and Schematic

3 Results

This section of the report provides results for the individual tests conducted. Each test is cross referenced, by name, to the tables in the previous section.

The results shown in this section detail the refrigerant concentration vs time at points in the test room. Three sensor types were used at various points in the room. The general location and height above the test floor are indicated at the beginning of each subsection (Figure 7, Figure 11, Figure 12, and Figure 14). A non-dispersive infrared (NDIR) and metal oxide semiconductor (MOS) sensor located inside the cabinet of the unit for the horizontal and vertical test arrangements. The sensor location was on the side of the A-coil. Figure 5 shows the location of the sensors with respect to the A-coil (red circle). Also visible in this picture is the release location (in yellow circle) near the TXV. The bulk of the sensors located in the test space are oxygen sensors which are reported refrigerant concentration (%Vol/Vol).

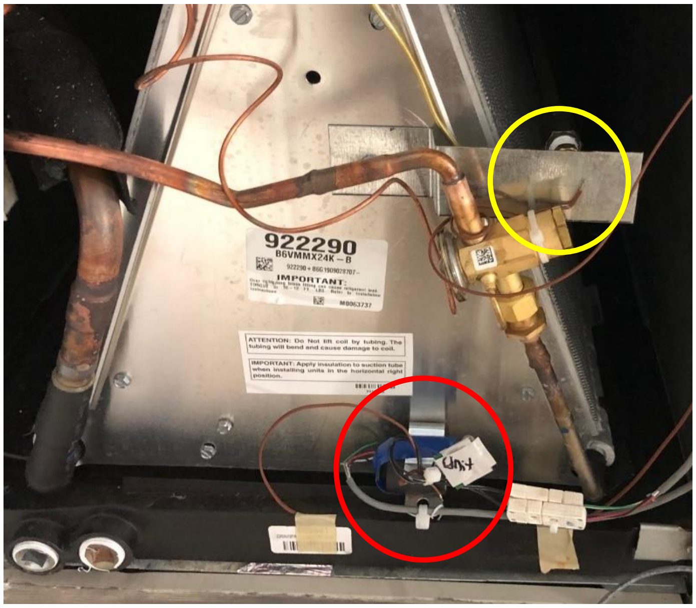


Figure 5 - Unit Sensor Locations

Refrigerant concentration values are reported without the associated measurement uncertainty. See Appendix A.1 for details and discussion about the measurement uncertainty, which includes both steady-state and dynamic effects. The results charts are based on:

a) oxygen sensor output deconvoluted using a sensor model assumed to have a time constant τ = 10 seconds and time delay θ = 0 seconds,
b) non-dispersive infrared (NDIR) sensor output not deconvoluted,
c) metal oxide semiconductor (MOS) sensor output not deconvoluted.

However, near the end of the project a review of the sensors' dynamic characteristics during bench testing revealed that more appropriate models would be:

a) oxygen sensor model assumed to have a nominal time constant τ = 6.08 seconds and time delay θ = 4.01, with uncertainty interval ranging from (τ = 5.20 with θ = 4.27±0.91) to (τ = 8.70 with θ = 3.23±1.00),
b) non-dispersive infrared (NDIR) sensor assumed to have a time constant τ = 1.30 (–0.25, +0.25) seconds and time delay θ = 0.00 (–0.00, +0.50) seconds,
c) metal oxide semiconductor (MOS) sensor assumed to have a time constant of τ = 6 (−3, +4) seconds and time delay θ = 0 (–0, +2) seconds.

The net effect is that during rapid concentration changes the peak values will vary from that displayed in the charts (both amplitude change and phase shift), but during slow concentration changes the charts are correct. Chart annotations showing time above LFL are based on the oxygen sensor deconvolution using τ = 10 seconds and during rapid changes may overestimate the time period above LFL.

3.1 Horizontal

Figure 6 provides an overview of the interior of the test room. Figure 7 details the sensor locations for the refrigeration sensors inside the test room. Colors are used to detail sensors which are in the same general location in the room space: blue stars are sensors near the return and discharge registers, green stars are sensors located inside the ductwork, and purple stars are sensors located out in the room space. The orange circle indicates the location of the NDIR sensor.

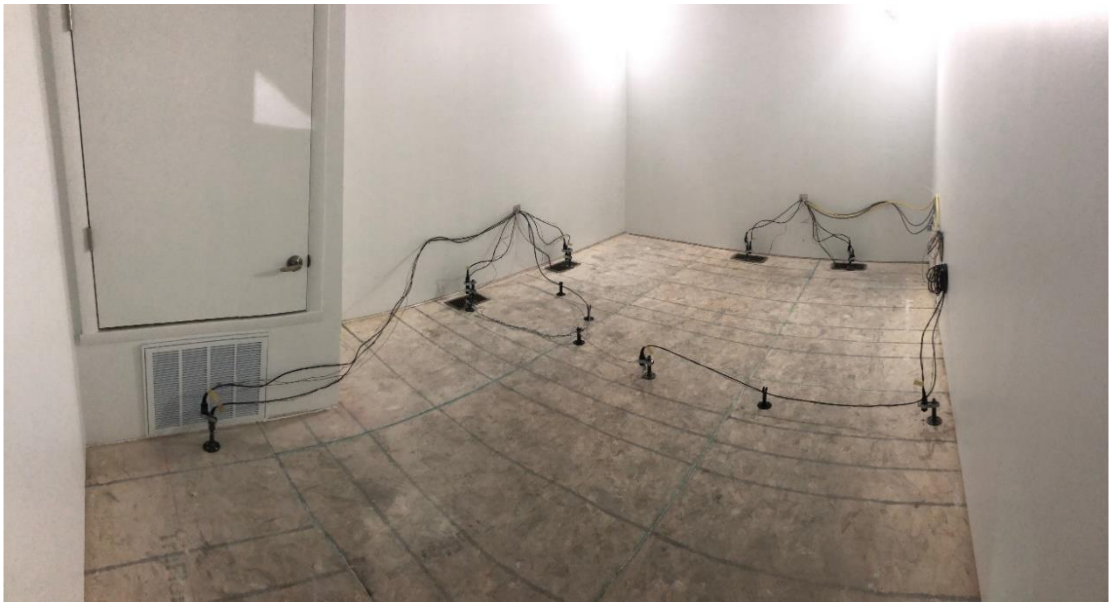


Figure 6 - Horizontal Room Arrangement

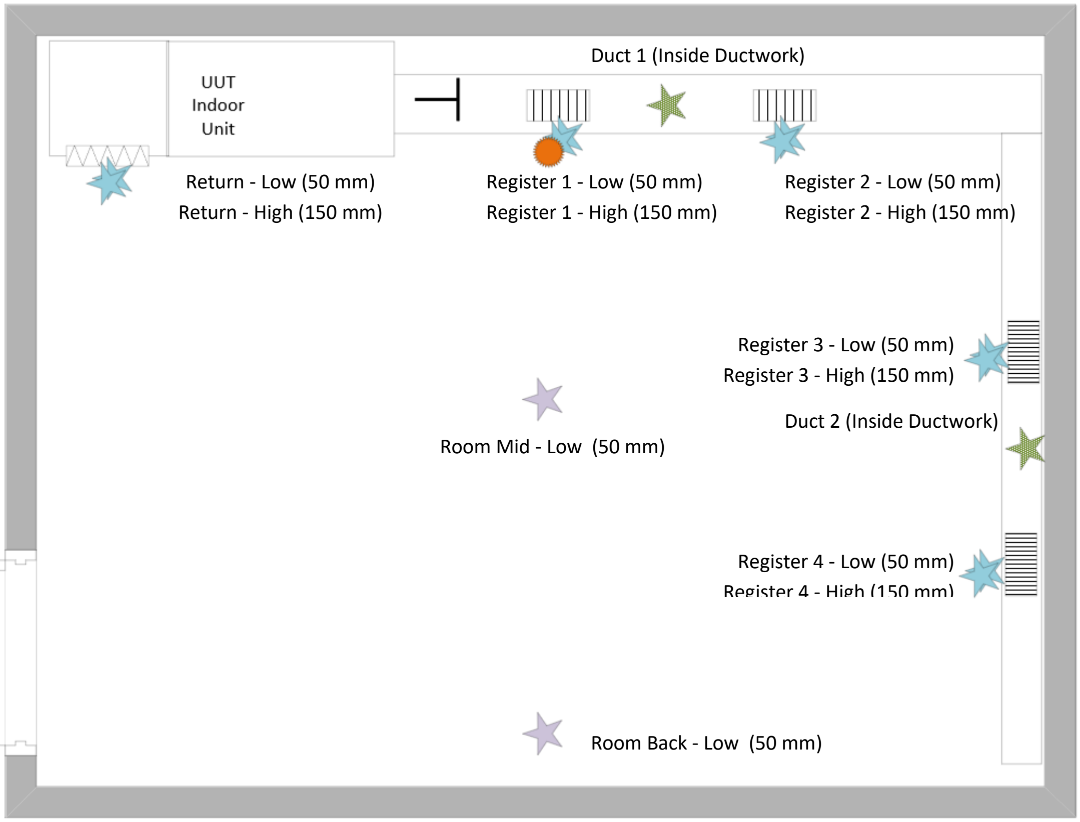


Figure 7 - Horizontal Sensor Layout

3.1.1 **Horizontal 1**

A summary of the test parameters for this test are indicated in Table 7. This test was conducted to establish the baseline parameters with no mitigation. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	3.15 kg	Release Time	241 s
Release Quality	Liquid	Time to Q_{min}	N/A
		Fan Speed	N/A

Table 7 - Horizontal 1 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 67% at the Duct 1 sensor. This concentration remained above the LFL for the remainder of the test. The maximum refrigerant sensor in the room was near the return grill (Return - Low) with a concentration of 2.1% refrigerant by volume, this sensor was also the closest to the leak point, although on the opposite side of the refrigeration coil. The amount of refrigerant entering the test space was minimal with the concentrations remaining near 1% or below.

This test did show that there was case leakage through the unit cabinet and ductwork. The refrigeration concentration in the crawlspace started rising shortly after the start of the test. The case leakage was also evident with an infrared thermal camera which had been placed in the simulated crawlspace. The concentration in the crawlspace builds as the test goes on reaching LFL at both the sensor below the unit as well as the sensor which is located underneath the secondary duct. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 8. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 14 seconds after the start of the refrigerant release.

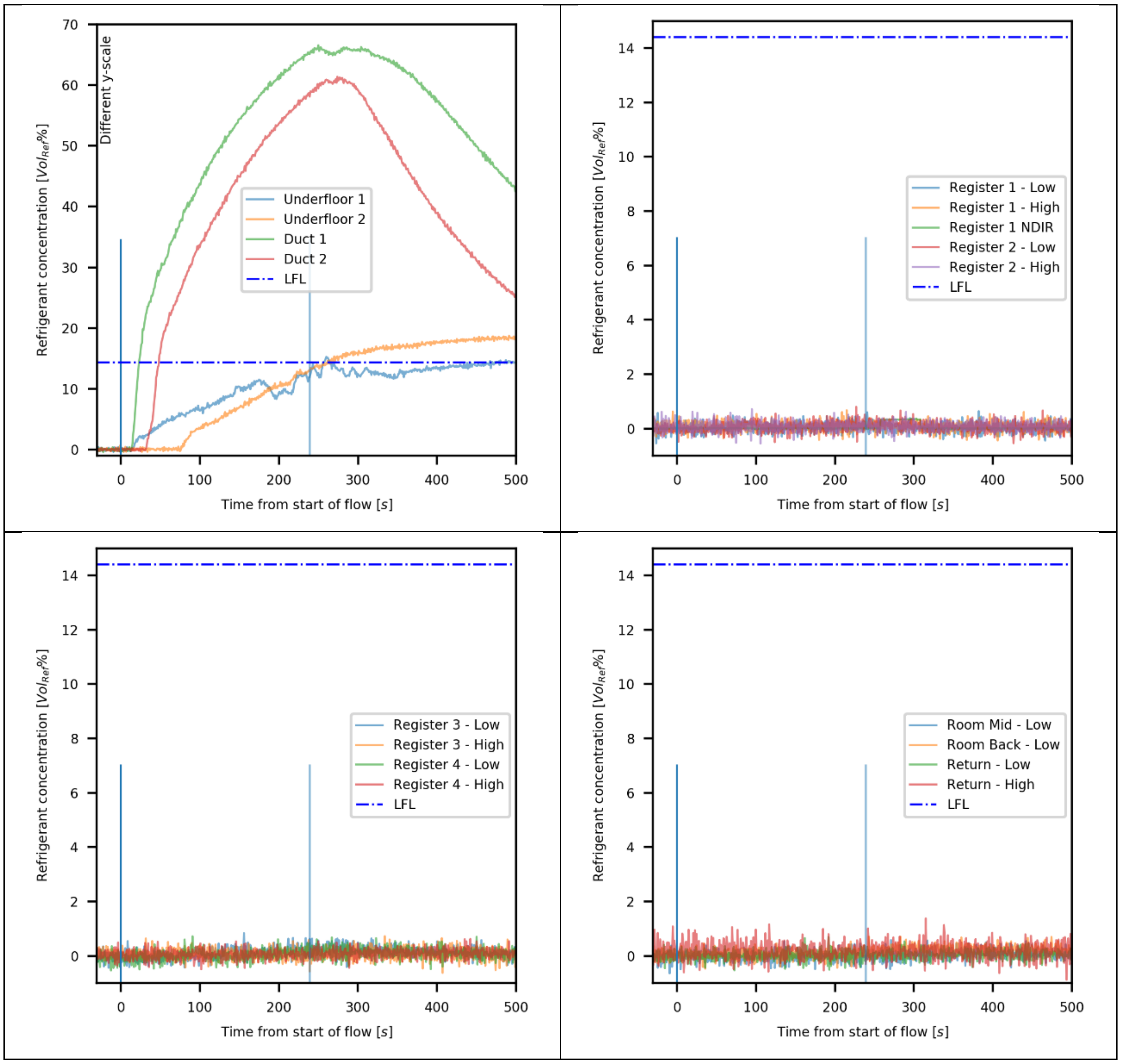
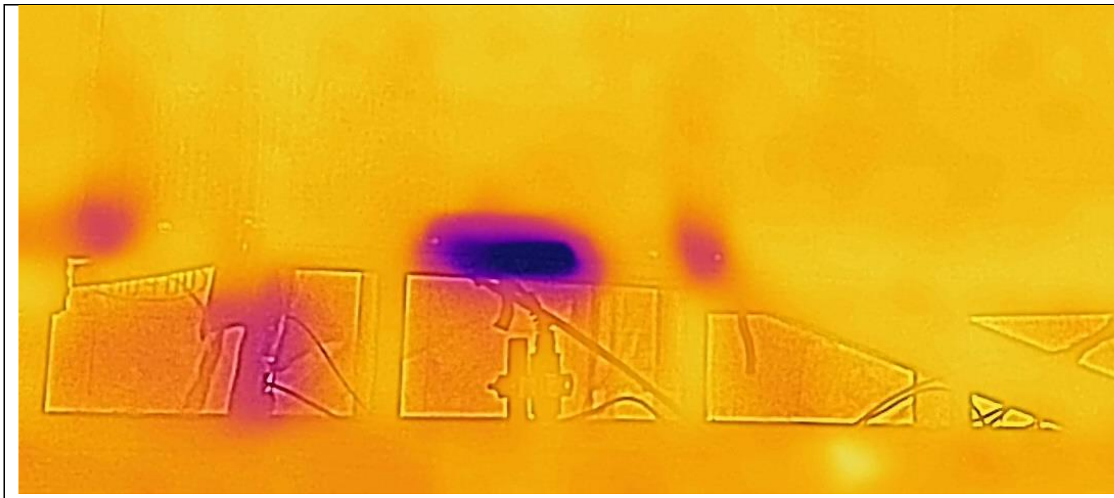
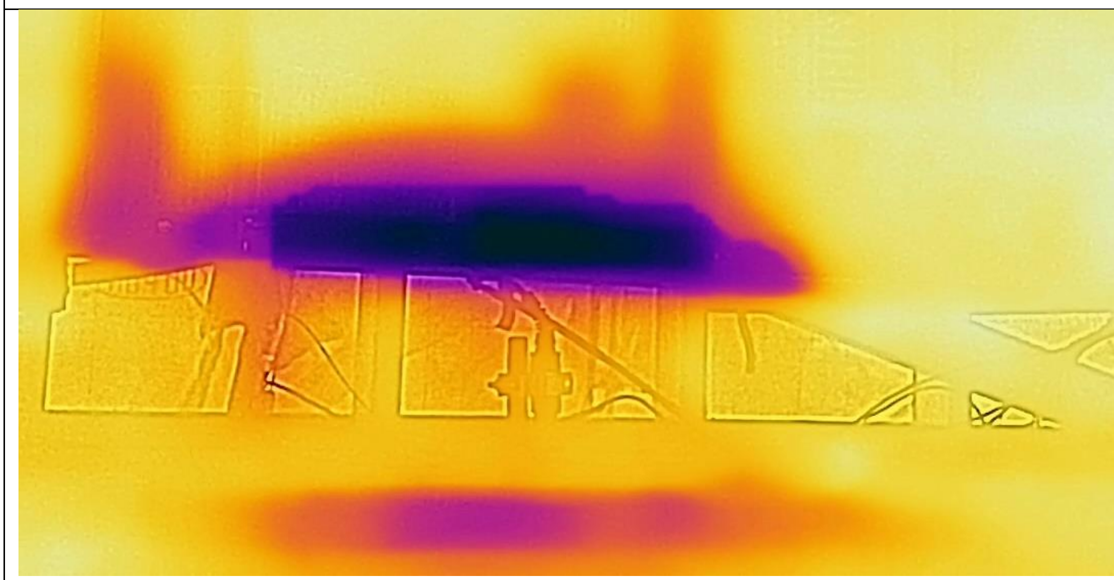


Table 8 - Horizontal 1 Refrigerant Concentrations



8 seconds into leak



60 seconds into leak

Figure 8 Thermal Images Showing Case Leakage

3.1.2 **Horizontal 2**

A summary of the test parameters for this test are indicated in Table 9. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Current UL -2-40 requirements		
Release Amount	3.52 kg	Release Time	241 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	697 m^3/hr

Table 9 - Horizontal 1 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 30% at the Duct 2 sensor. With the airflow at Q_{min} the time that the refrigerant volume was above the LFL was 11 s and 9 s at Duct 1 and Duct 2, respectively. The maximum concentration entering the test space was 23%, which was located 50 mm (2 in) above the 3rd and 4th registers. The refrigerant remained above the LFL at these locations for 7 s. The sensors (Register 3 – High, Register 4 – High) above those same locations at 150 mm (6 in) did not exceed the LFL at any time during the tests. The sensors in the room space, located near the return and in the simulated crawlspace remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 10. The NDIR sensor in the unit registered 50% of LFL at 4 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 10 seconds after the start of the refrigerant release.

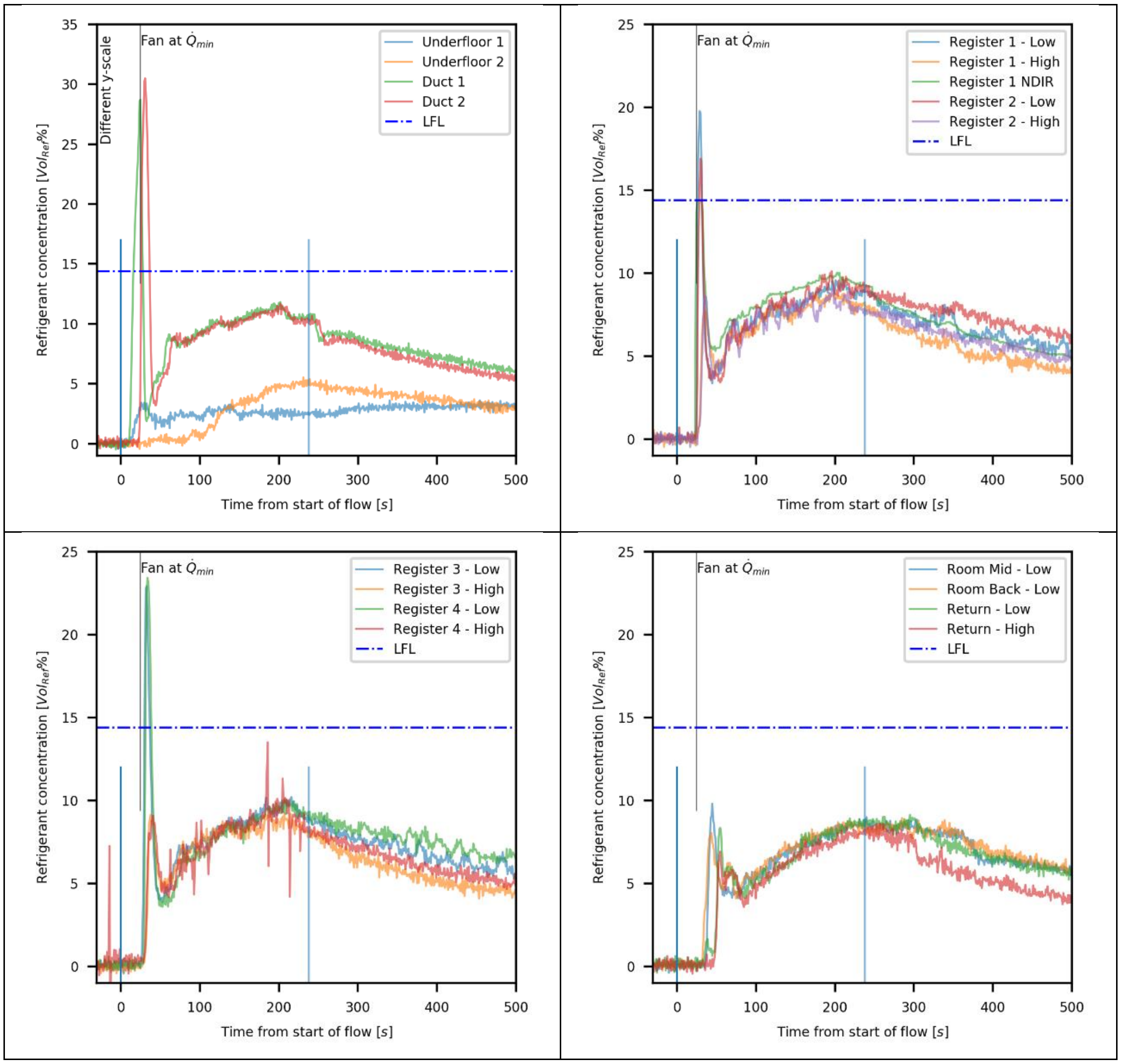


Table 10 - Horizontal 2 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.3 **Horizontal 3**

A summary of the test parameters for this test are indicated in Table 11. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	3.76 kg	Release Time	207 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	697 m^3/hr

Table 11 – Horizontal 3 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 37% at the Duct 2 sensor. With the airflow at $Q\_\{min\}$ the time that the refrigerant volume was above the LFL was 25 s and 15 s at Duct 1 and Duct 2, respectively. The maximum concentration entering the test space was 36%, which was located 50 mm (2 in) above the 4th register. The refrigerant remained above the LFL at this location for 10 s. The sensors located at 150 mm (6 in) above each of the registers in the room did not exceed the LFL at any time during the tests. The sensors in the room space and located near the return remained below the LFL through the duration of the test. These sensors did indicate an increase in refrigerant after the blower was circulating the air in the test space. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 12. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 26 seconds after the start of the refrigerant release.

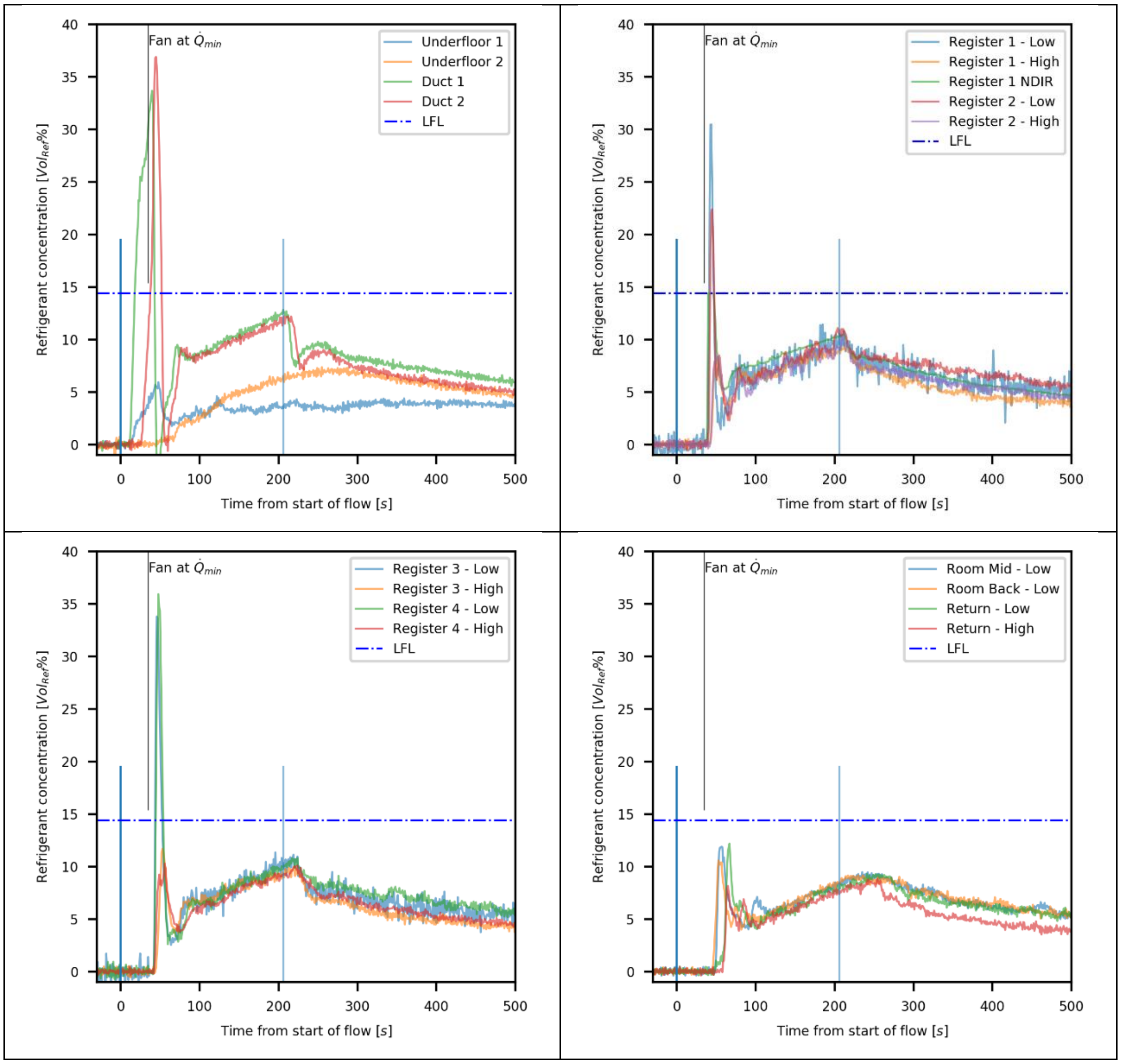


Table 12 - Horizontal 3 Refrigerant Concentrations

(peak concentration around 25~75 seconds may be overestimated due to deconvolution method)

3.1.4 Horizontal 4

A summary of the test parameters for this test are indicated in Table 13. This test was conducted with the maximum response time permitted per UL/CSA 60335-2-40 3rd Ed, with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	3.46 kg	Release Time	200 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	1354 m^3/hr

Table 13 - Horizontal 4 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 26% at the Duct 1 sensor. With the airflow at 2*Q_{min} the time that the refrigerant volume was above the LFL was 5 s and 4 s at Duct 1 and Duct 2, respectively. The NDIR sensor above the 1st register indicated that the refrigerant, at least was at the LFL in that location for 4 s. All of the other sensors in the room space and located near the return remained below the LFL through the duration of the test. These sensors did indicate an increase in refrigerant after the blower was circulating the air in the test space. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 14. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 12 seconds after the start of the refrigerant release.

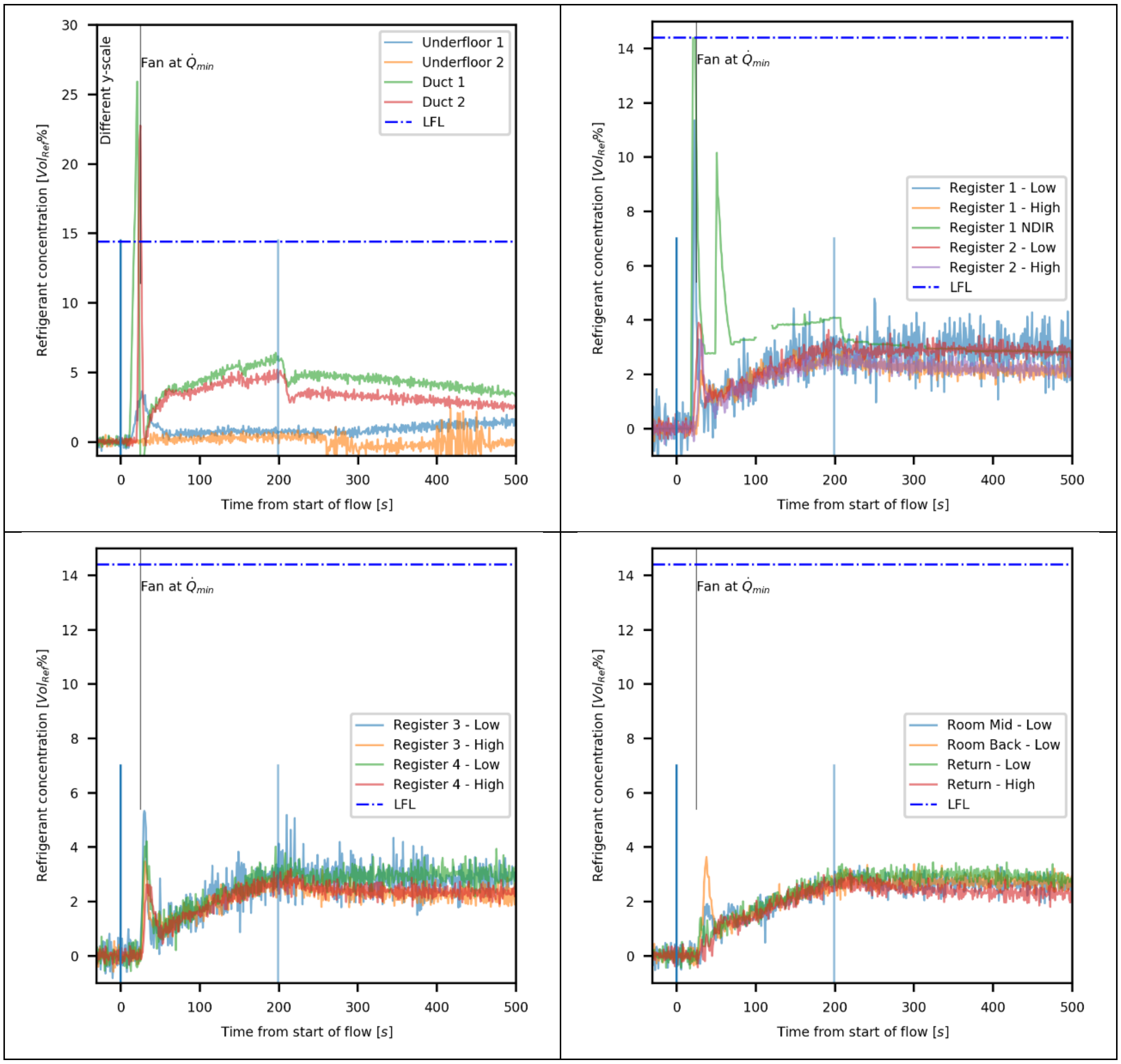


Table 14 - Horizontal 4 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.5 Horizontal 5

A summary of the test parameters for this test are indicated in Table 15. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	3.15 kg	Release Time	270 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	1354 m^3/hr

Table 15 - Horizontal 5 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 38% at the Duct 2 sensor. With the airflow at 2*Q_{min} the time that the refrigerant volume was above the LFL was 22 s and 7 s at Duct 1 and Duct 2, respectively. The sensors located 50 mm (2 in) above the registers for this test showed values above the LFL for Register 1, Register 3 and Register 4. The time that these sensor were indicating at or above the LFL were 3 seconds or less. All of the other sensors in the room space and located near the return remained below the LFL through the duration of the test. These sensors did indicate an increase in refrigerant after the blower was circulating the air in the test space, the airflow was able to mix this higher concentration refrigerant in the room space and all sensors averaged 2% +0.8/-0.6 at 110 s into the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 16. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 11 seconds after the start of the refrigerant release.

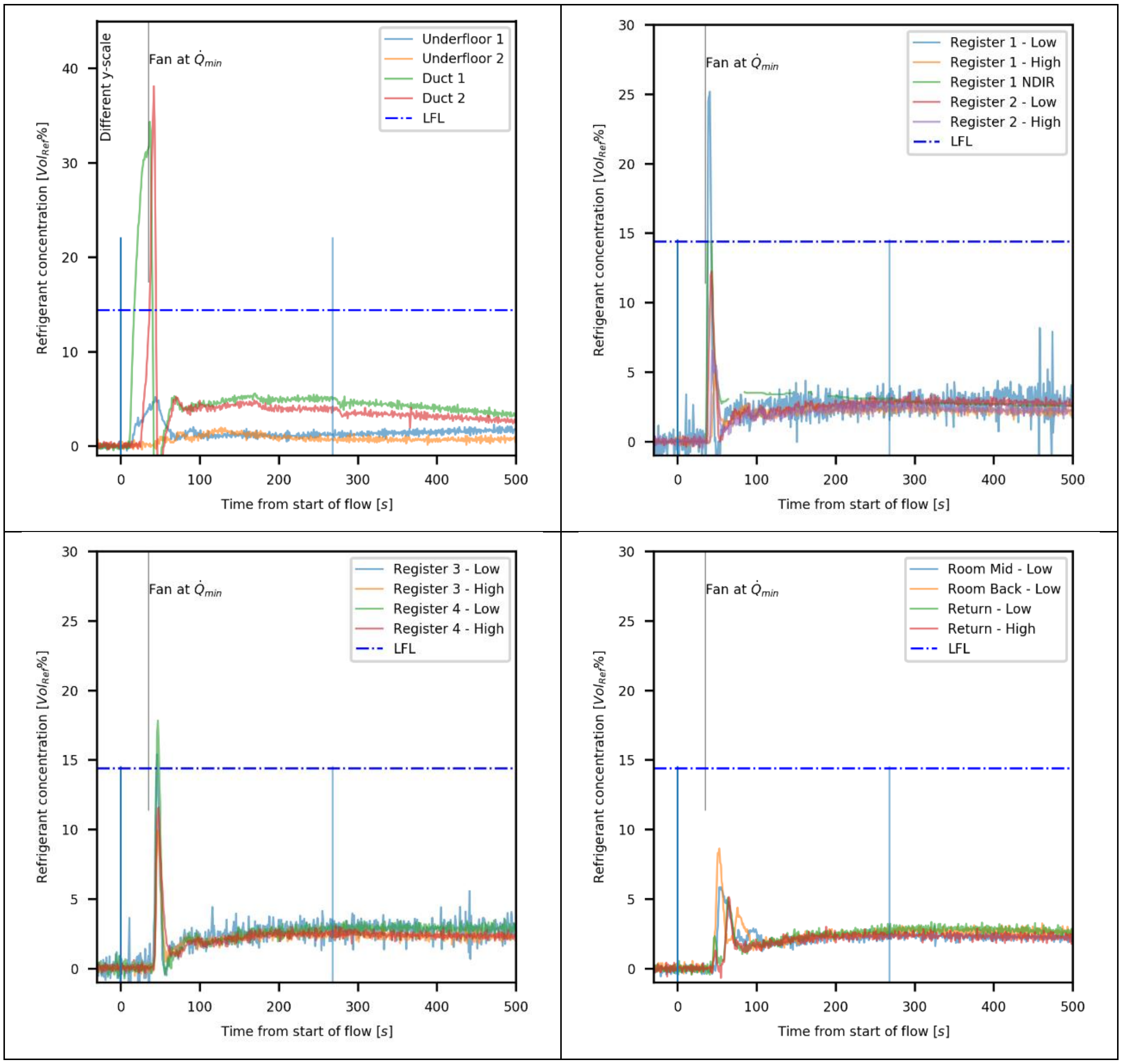


Table 16 - Horizontal 5 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.6 **Horizontal 6**

A summary of the test parameters for this test are indicated in Table 17. This test was conducted to establish the baseline parameters with no mitigation. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	2.93 kg	Release Time	240 s
Release Quality	Vapor	Time to Qmin	N/A
		Fan Speed	N/A

Table 17 - Horizontal 6 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 76% at the Duct 1 sensor. All of the sensors in the room space and located near the return remained below the LFL through the duration of the test. The sensors located 50 mm (2 in) above the floor did indicate an increase in refrigerant while the refrigerant was being released. The sensors above Register 1 and Register 2 indicated maximum concentrations of 3% or lower. There was evidence that the refrigerant was exiting the cabinet of the unit and entering the simulated crawlspace. The underfloor sensors registered maximum concentration values of 22% below the unit and 20% at the Underfloor 2 position. These sensors indicated that the refrigerant persisted above the LFL even after the refrigerant flow was completed. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 18. The NDIR sensor in the unit registered 50% of LFL at 4 seconds after the start of the refrigerant release. The MOS sensor registered 4.5% of refrigerant 29 seconds after the start of the refrigerant release.

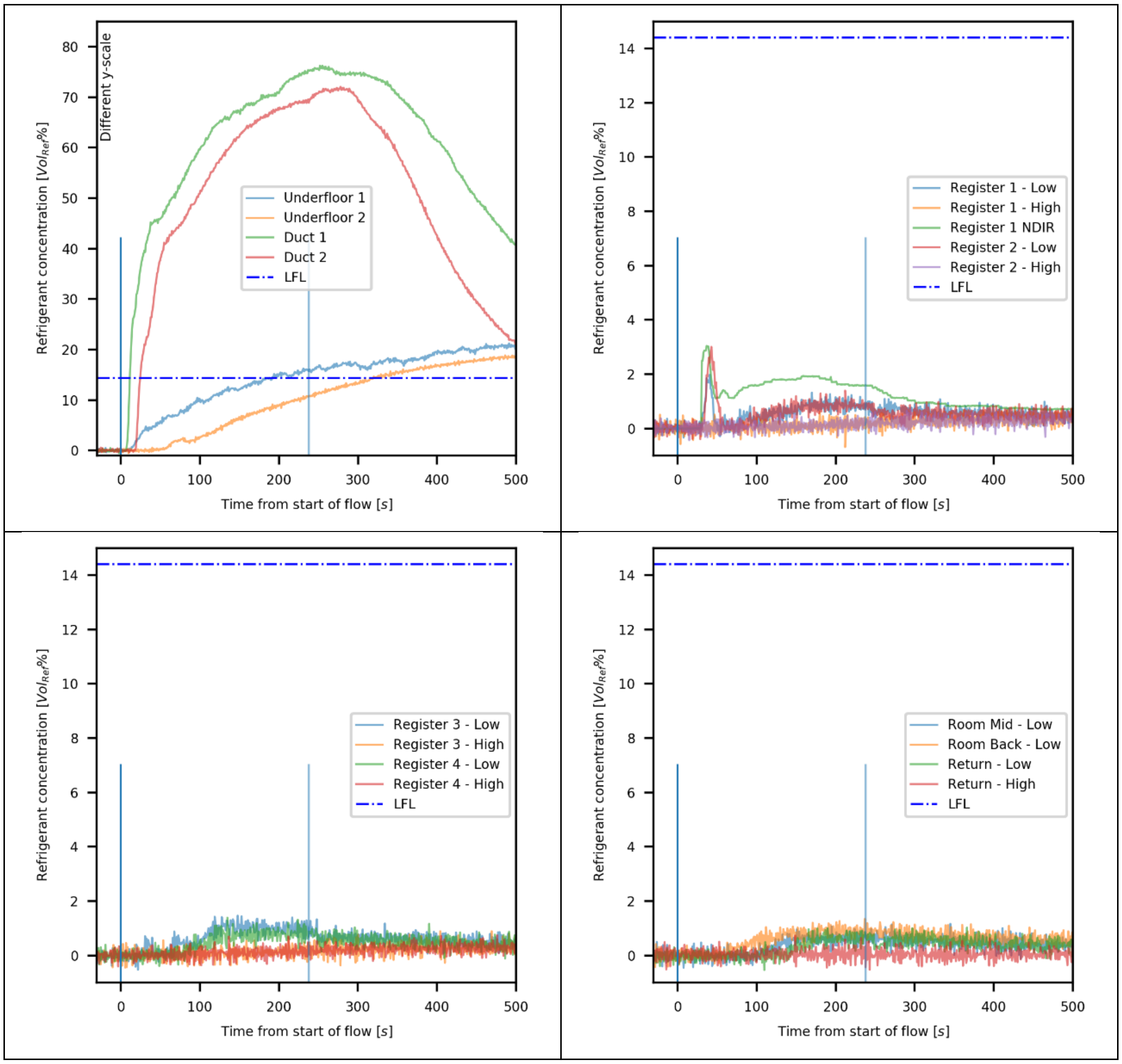


Table 18 - Horizontal 6 Refrigerant Concentrations

3.1.7 Horizontal 7

A summary of the test parameters for this test are indicated in Table 19. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	3.50 kg	Release Time	210 s
Release Quality	Vapor	Time to Qmin	25 s
		Fan Speed	697 m^3/hr

Table 19 - Horizontal 7 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 44% at the Duct 1 sensor.

The sensors 50 mm (2 in) above each of the registers showed values which were above the LFL. First two registers were above LFL for 6-7 seconds while the last two registers were above the LFL for twice that duration. The sensor 150 mm (6 in) above the third register had a maximum refrigerant concentration of 16% and the concentration was above the LFL for 5 seconds. This occurred just after the fan was at Qmin.

These higher concentrations at the registers were also reflected with higher concentrations in the room space. Both the sensors in the center of the room and at the sensor in the return 50 mm (2 in) above the floor registered concentrations above the LFL. The sensor in the middle was above the LFL for 1 s, 44 s into the test, with the lower return sensor above LFL for 5 s, starting 46 s into the release. By comparing these times there is a transport delay with the refrigerant moving across the room. However, once this initial volume of higher concentration refrigerant in the ductwork had been discharged into the room the none of the sensors registered concentrations above the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 20. The NDIR sensor in the unit registered 50% of LFL at 4 seconds after the start of the refrigerant release. The MOS sensor registered 3.8% of refrigerant 24 seconds after the start of the refrigerant release.

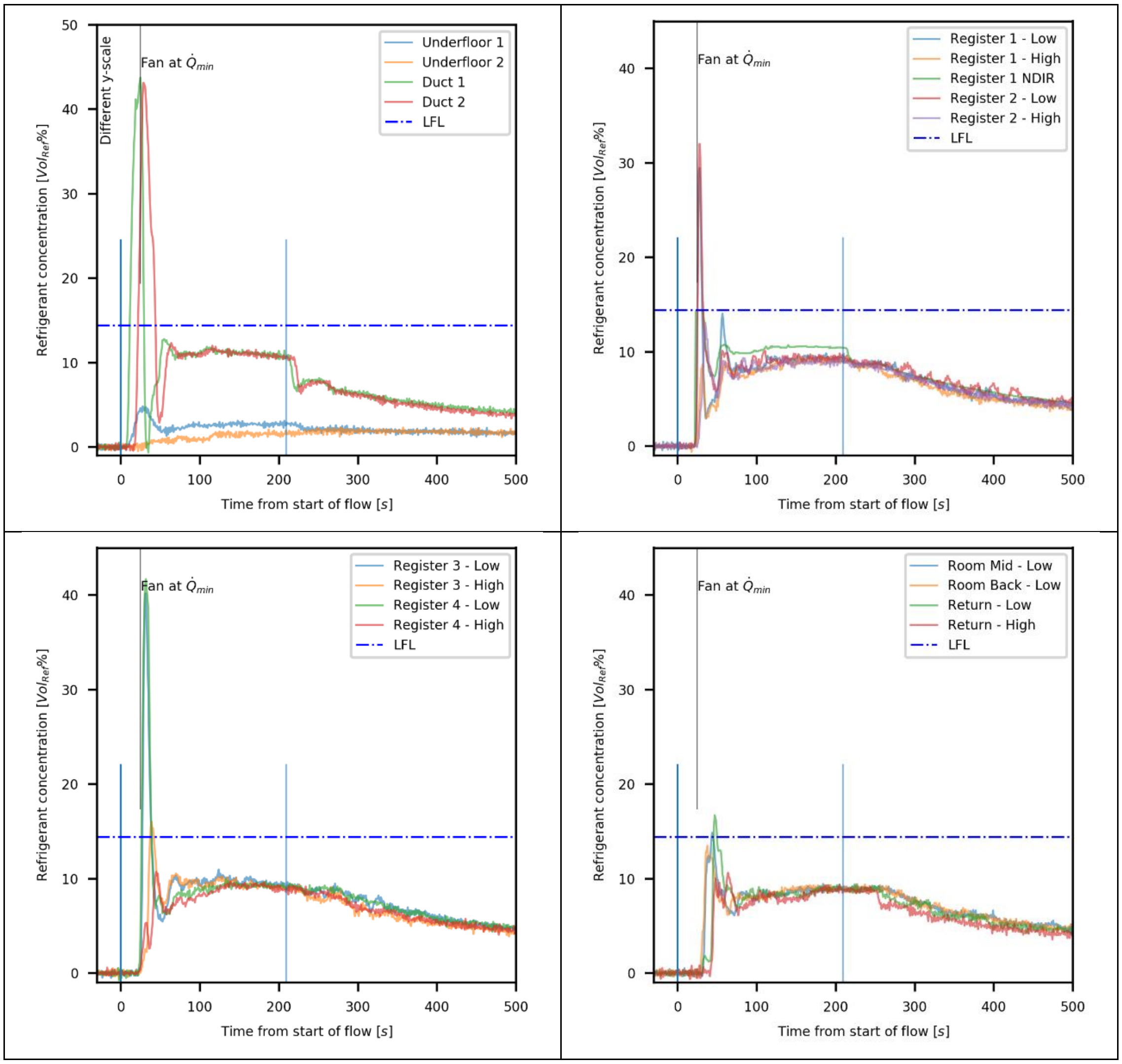


Table 20 - Horizontal 7 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.8 **Horizontal 8**

A summary of the test parameters for this test are indicated in Table 21. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	3.21 kg	Release Time	270 s
Release Quality	Vapor	Time to Qmin	35 s
		Fan Speed	697 m^3/hr

Table 21 - Horizontal 8 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 42% at the Duct 1 sensor.

This test had refrigerant concentrations in the duct and at the registers above the LFL. These values were short concentrations as the fan came up to speed. The maximum concentration in the room was 44%, located at the sensor 50 mm (2 in) above the 3rd register, the refrigerant concentrations were at or above the LFL for 13 seconds. The sensors located at 150 mm (6 in) above Register 2 and Register 3 were just above the LFL for 2 and 3 seconds, respectively.

The sensor in the middle of the room as well as the lower sensor near the return also showed values above the LFL for 6 seconds. The sensor in the middle of the room was above the LFL 52 s into the test, with the sensor at the return 57 s after the start of the release. The sensor located 50 mm (2 in) above the floor at the back of the room and the sensor at the return located 150 mm (6 in) above the floor showed short durations of elevated refrigerant concentrations, but these did not go above the LFL at any time during the test.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 22. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 3% of refrigerant 35 seconds after the start of the refrigerant release.

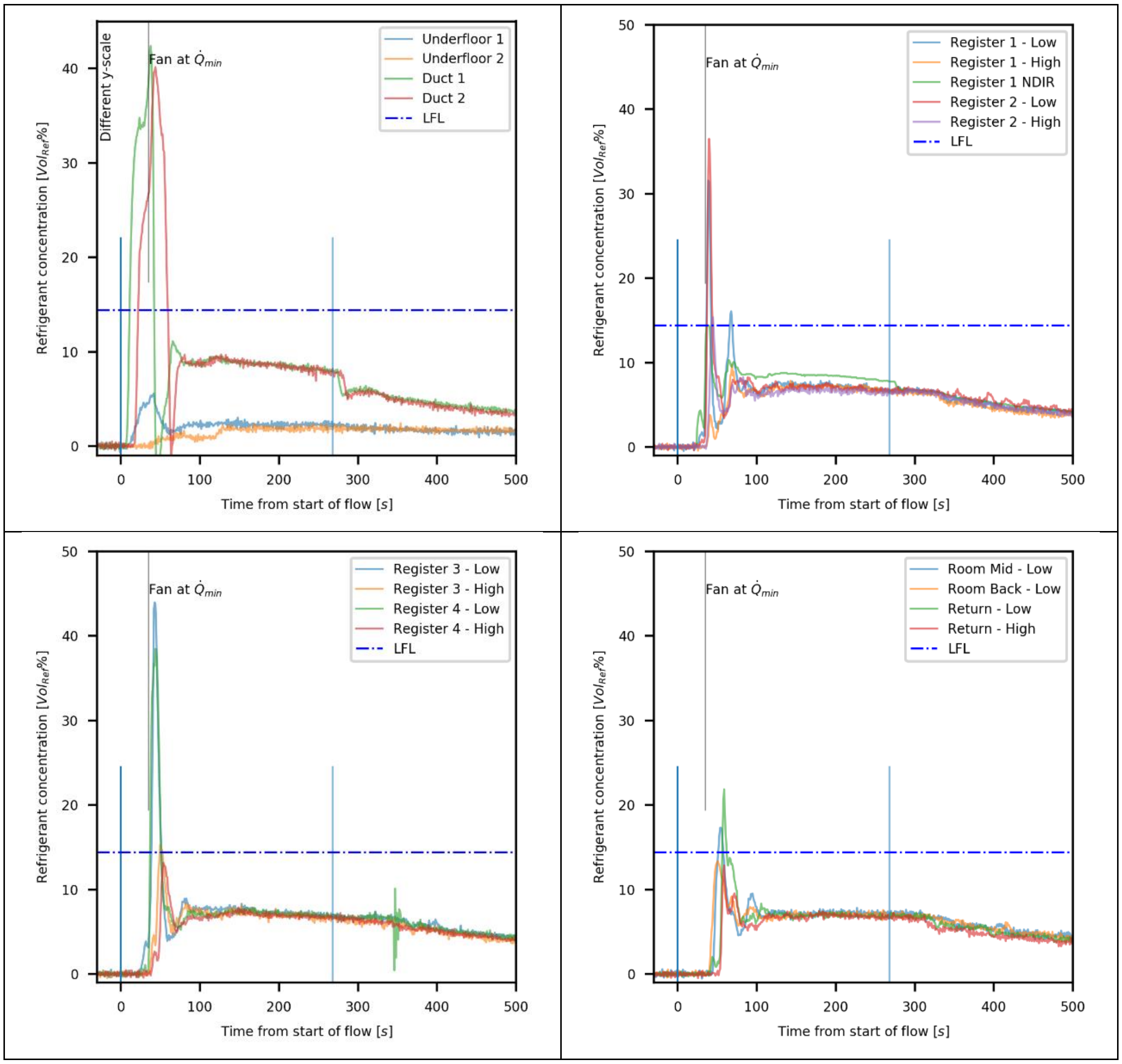


Table 22 - Horizontal 8 Refrigerant Concentrations

(peak concentration around 25~75 seconds may be overestimated due to deconvolution method)

3.1.9 Horizontal 9

A summary of the test parameters for this test are indicated in Table 23. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	3.56 kg	Release Time	239 s
Release Quality	Vapor	Time to Qmin	25 s
		Fan Speed	1354 m^3/hr

Table 23 - Horizontal 9 Test Parameters

For this test there were refrigerant concentrations above the LFL for 8 s or less after the fan was energized. The two sensors located 150 mm (6 in) above Register 3 and Register 4 were above the LFL for 4 s and 2 s, respectively. These were above the LFL 4 s after the fan was at the 2*Qmin for Register 3 and 8 s for Register 4. The sensor in the middle of the room as well as the sensors at the return stayed below the LFL for the entire duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 24. The NDIR sensor in the unit registered 50% of LFL at 4 seconds after the start of the refrigerant release. The MOS sensor registered 4.8% of refrigerant 21 seconds after the start of the refrigerant release.

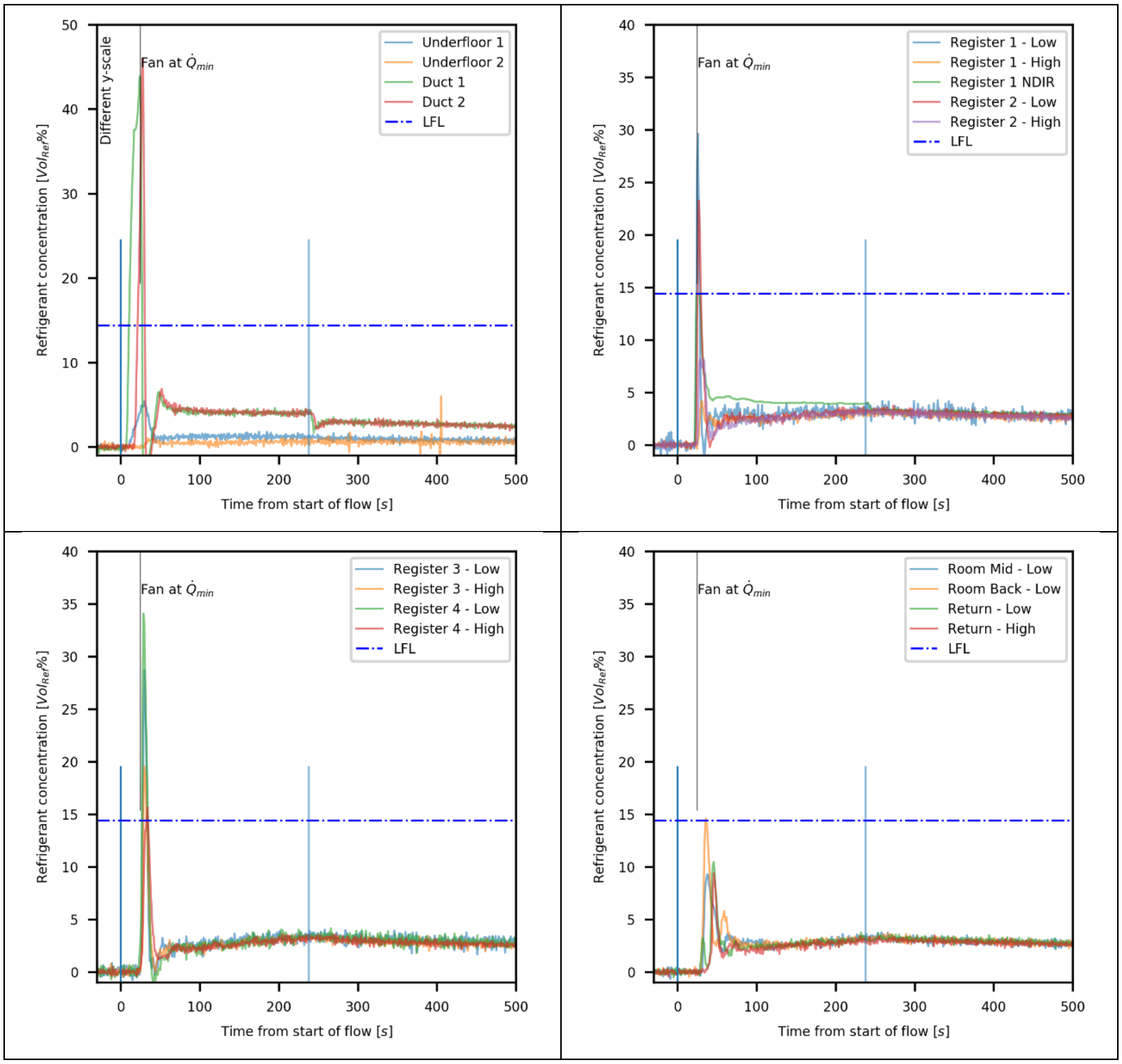


Table 24 - Horizontal 9 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.10 **Horizontal 10**

A summary of the test parameters for this test are indicated in Table 25. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	3.41 kg	Release Time	244 s
Release Quality	Vapor	Time to Qmin	35 s
		Fan Speed	1354 m^3/hr

Table 25 - Horizontal 10 Test Parameters

For this test there were refrigerant concentrations above the LFL for 8 s or less after the fan was energized. The two sensors located 150 mm (6 in) above Register 3 and Register 4 were above the LFL for 4 s. These two sensors were above the LFL just as the fan reached the 2*Qmin value. The sensor in the room as well as the sensors at the return stayed below the LFL for the entire duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 26. The NDIR sensor in the unit registered 50% of LFL at 5 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 27 seconds after the start of the refrigerant release.

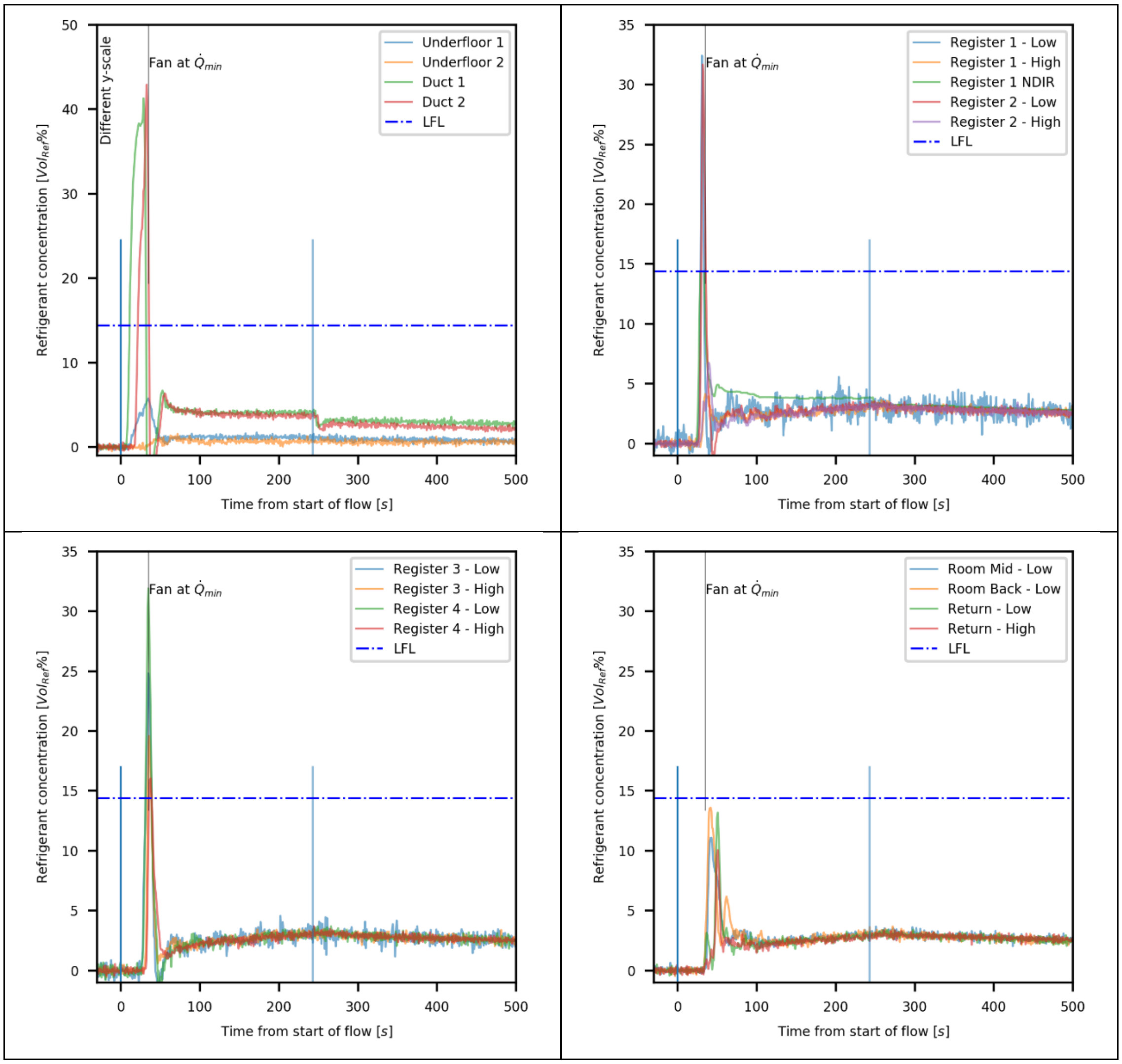


Table 26 - Horizontal 10 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.11 **Horizontal 11**

A summary of the test parameters for this test are indicated in Table 27. This test was conducted to establish the baseline parameters with no mitigation. The release was increased to be 50% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	6.87 kg	Release Time	392 s
Release Quality	Liquid	Time to Qmin	N/A
		Fan Speed	N/A

Table 27 - Horizontal 11 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 83% at the Duct 1 sensor. All of the sensors in the room space and located near the return remained below the LFL through the duration of the test. The sensors located 50 mm (2 in) above the floor did indicate an increase in refrigerant while the refrigerant was being released. The sensors above Register 1 and Register 2 indicated maximum concentrations of 4% or lower. There was evidence that the refrigerant was exiting the cabinet of the unit and entering the simulated crawlspace. The underfloor sensors registered maximum concentration values of 40% below the unit and 32% at the Underfloor 2 position. These sensors indicated that the refrigerant persisted above the LFL even after the refrigerant flow was completed. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 28. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 11 seconds after the start of the refrigerant release.

Figure 9 - Thermal Image 1 min into the release

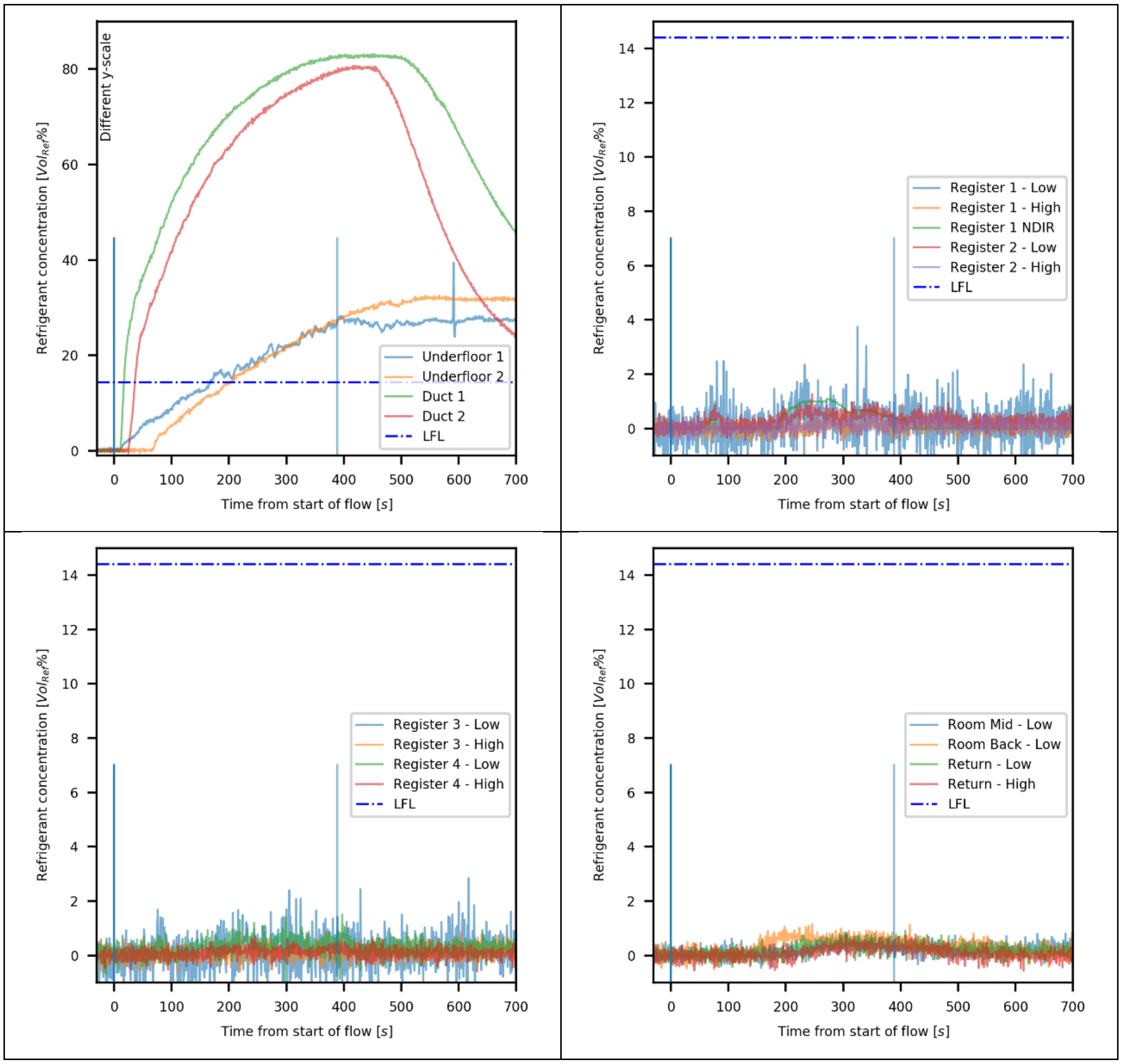


Table 28 - Horizontal 11 Refrigerant Concentrations

3.1.12 **Horizontal 12**

A summary of the test parameters for this test are indicated in Table 29. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	6.82 kg	Release Time	494 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	1354 m^3/hr

Table 29 - Horizontal 12 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 23% at the Duct 1 sensor. All of the sensors in the room space and located near the return remained below the LFL through the duration of the test. There was evidence that the refrigerant was exiting the cabinet of the unit and entering the simulated crawlspace, but at a lower rate with the fan turning on. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 30. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 9 seconds after the start of the refrigerant release.

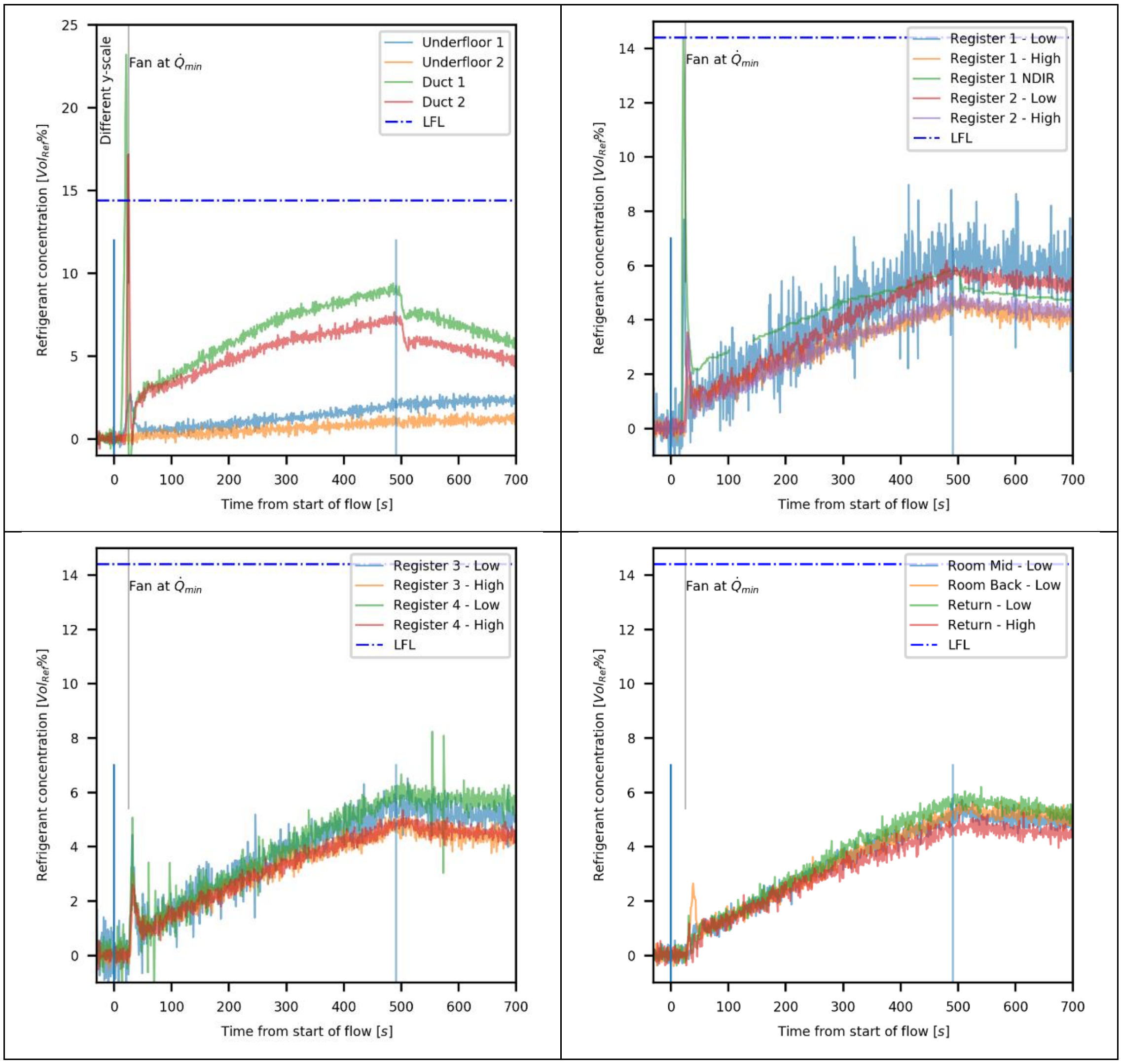


Table 30 - Horizontal 12 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.13 **Horizontal 13**

A summary of the test parameters for this test are indicated in Table 31. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	6.77 kg	Release Time	496 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	1354 m^3/hr

Table 31 - Horizontal 13 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 29% at the Duct 1 sensor and 31% at the Duct 2 sensor. The NDIR at Register 1 indicated that the refrigerant concentration was at or above the LFL for two seconds, at 30 seconds after the start of the release. All of the sensors in the room space and located near the return remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 32. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 13 seconds after the start of the refrigerant release.

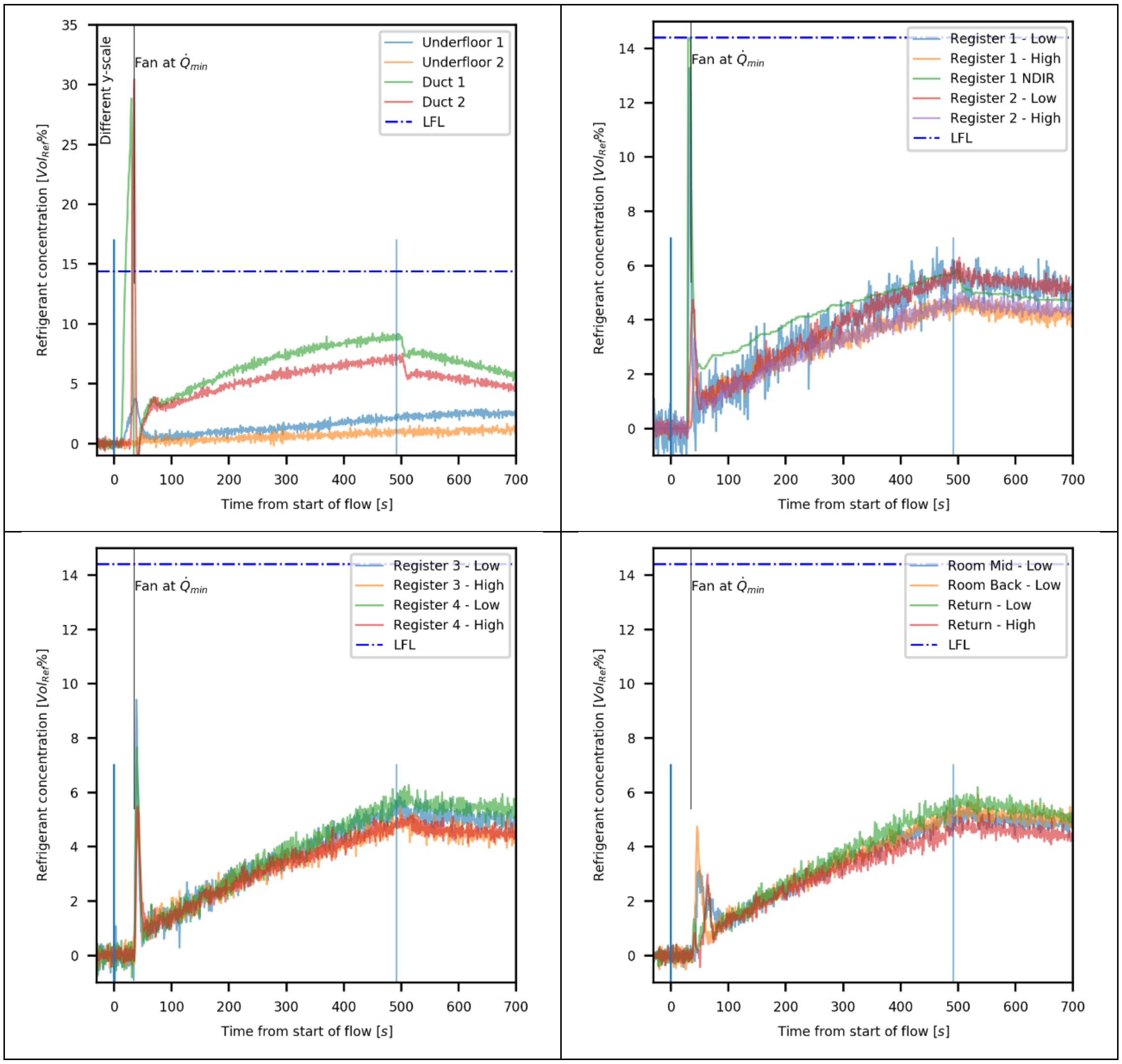


Table 32 - Horizontal 13 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.14 **Horizontal 14**

A summary of the test parameters for this test are indicated in Table 33. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	6.93 kg	Release Time	504 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	2763 m^3/hr

Table 33 - Horizontal 14 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 23% at the Duct 1 sensor and 18% at the Duct 2 sensor. All of the sensors in the room space and located near the return remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 34. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 4.7% of refrigerant 19 seconds after the start of the refrigerant release.

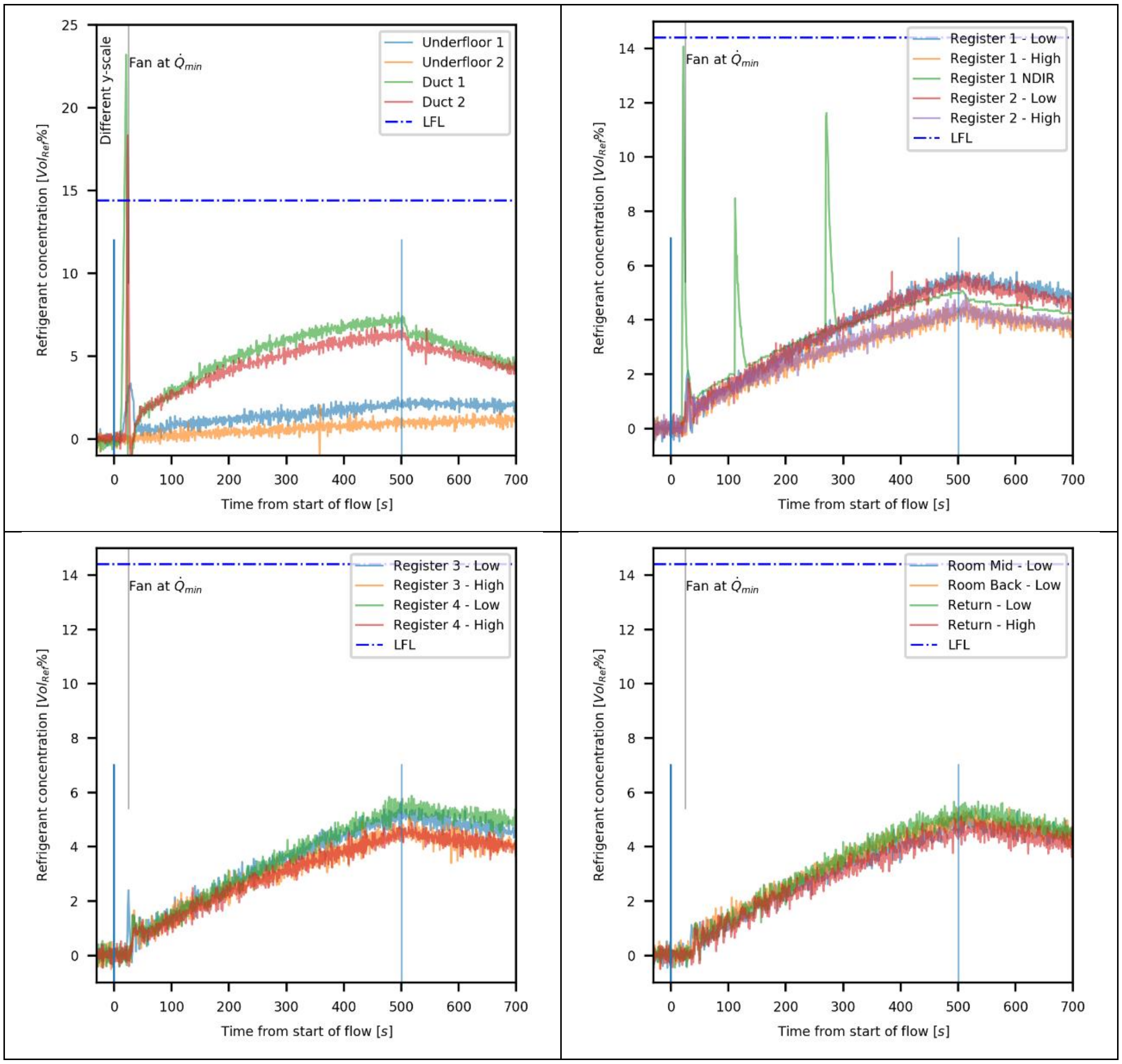


Table 34 - Horizontal 14 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.15 **Horizontal 15**

A summary of the test parameters for this test are indicated in Table 35. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	6.79 kg	Release Time	503 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	2763 m^3/hr

Table 35 - Horizontal 15 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 33% at the Duct 1 and Duct 2 sensor. The NDIR at Register 1 indicated that the refrigerant concentration was at or above the LFL for two seconds, at 44 seconds after the start of the release. All of the sensors in the room space and located near the return showed increases, but remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 36. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 12 seconds after the start of the refrigerant release.

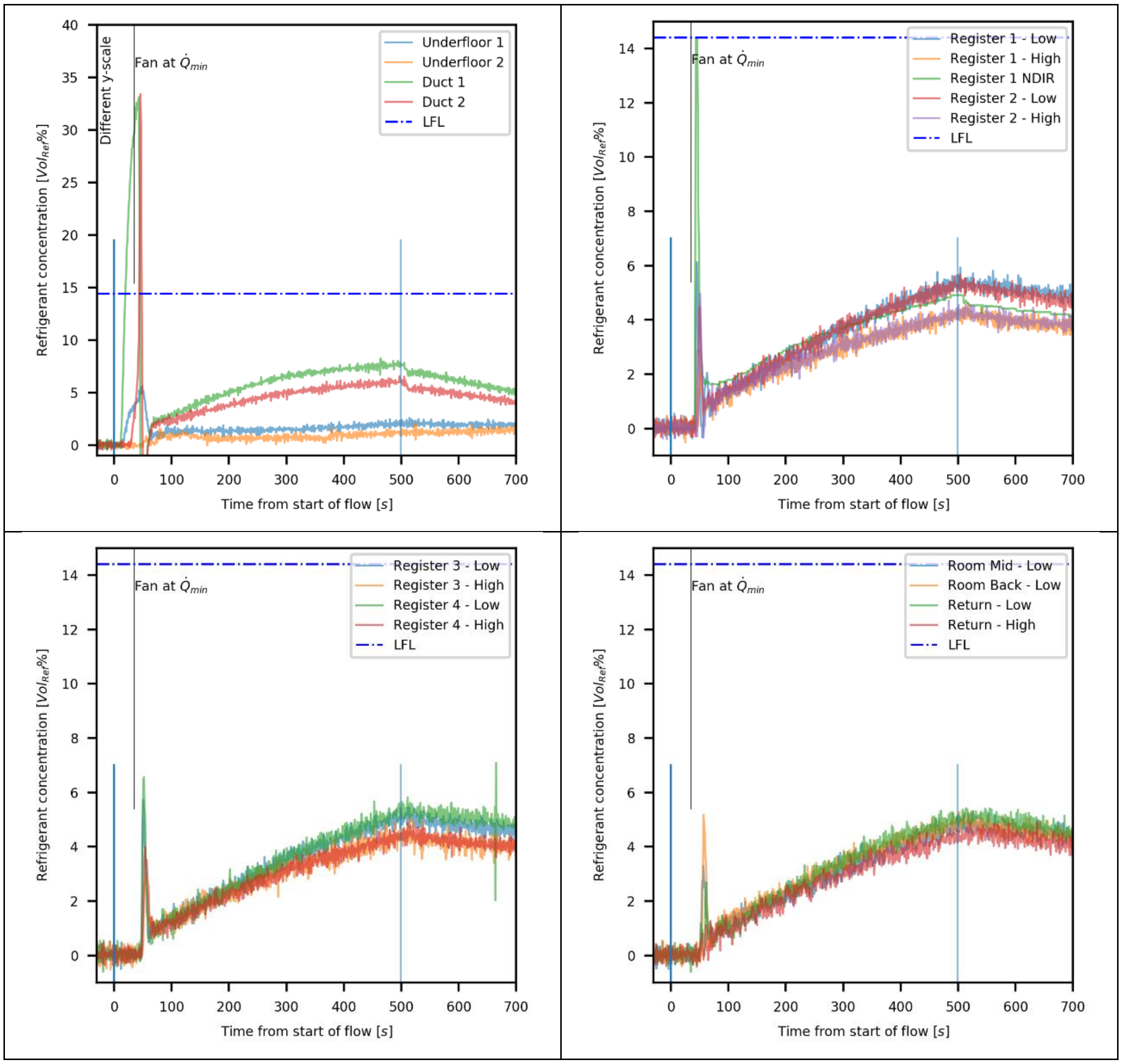


Table 36 - Horizontal 15 Refrigerant Concentrations

(peak concentration around 25~75 seconds may be overestimated due to deconvolution method)

3.1.16 **Horizontal 16**

A summary of the test parameters for this test are indicated in Table 37. This test was conducted to establish the baseline parameters with no mitigation. The release was increased to be 50% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	6.48 kg	Release Time	480 s
Release Quality	Decay	Time to Qmin	N/A
		Fan Speed	N/A

Table 37 - Horizontal 16 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 84% at the Duct 1 sensor and 83% at the Duct 2 sensor. All of the sensors in the room space and located near the return remained below the LFL through the duration of the test. The sensors located 50 mm (2 in) above the floor did indicate an increase in refrigerant while the refrigerant was being released. These sensors above the registers and near the return indicated concentrations of 1% or lower. There was evidence that the refrigerant was exiting the cabinet of the unit and entering the simulated crawlspace. The underfloor sensors registered maximum concentration values of 30% below the unit and 32% at the Underfloor 2 position. These sensors indicated that the refrigerant persisted above the LFL even after the refrigerant flow was completed. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 38. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 4% of refrigerant 25 seconds after the start of the refrigerant release.

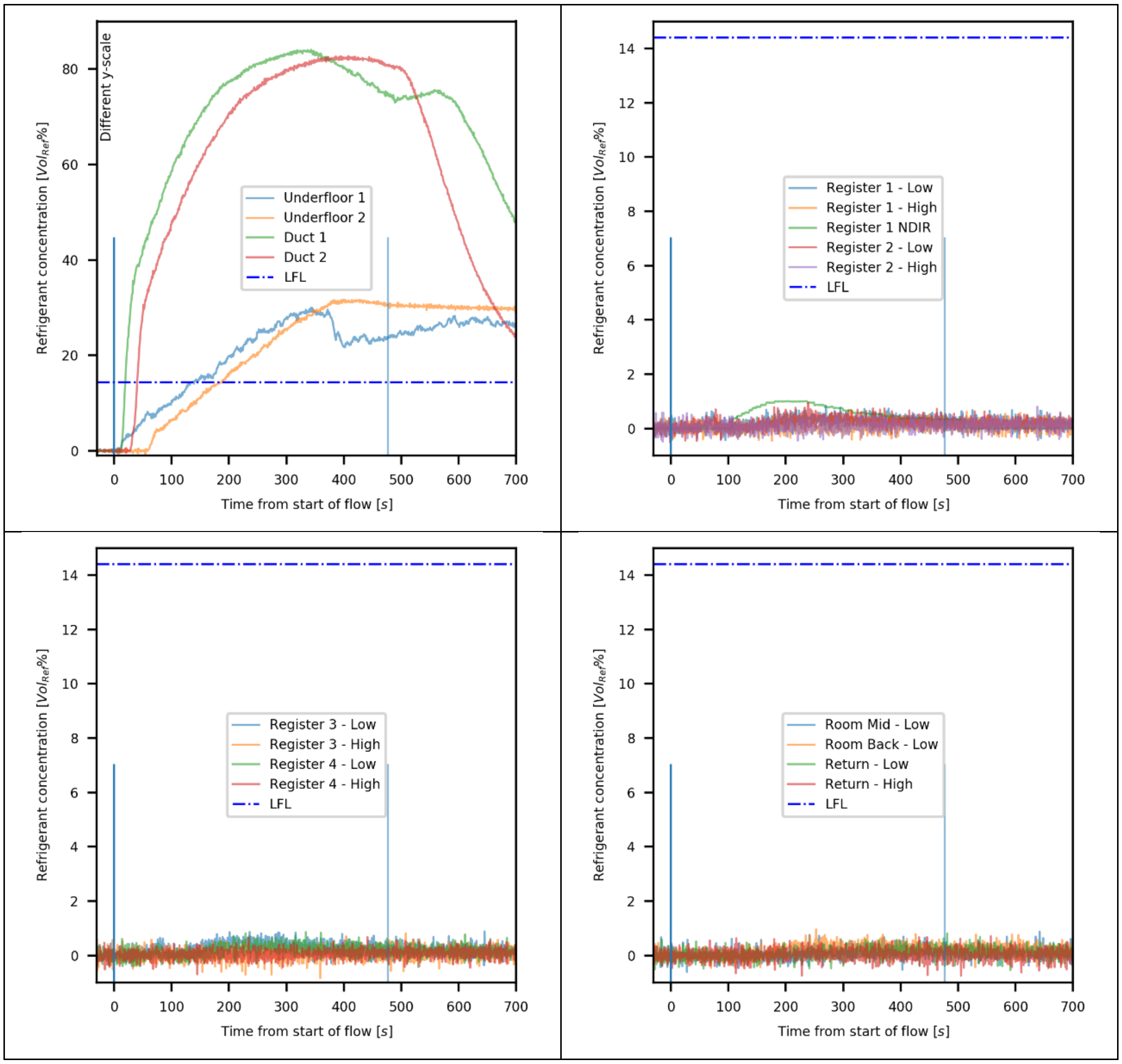


Table 38 - Horizontal 16 Refrigerant Concentrations

3.1.17 **Horizontal 17**

A summary of the test parameters for this test are indicated in Table 39. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	6.37 kg	Release Time	480 s
Release Quality	Decay	Time to Qmin	25 s
		Fan Speed	1354 m^3/hr

Table 39 - Horizontal 17 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 25% at the Duct 1 and 20% at the Duct 2 sensor. The NDIR at Register 1 indicated that the refrigerant concentration was at or above the LFL for two seconds, at 21 seconds after the start of the release. All of the sensors in the room space and located near the return showed increases, but remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 40. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 3.5% of refrigerant 23 seconds after the start of the refrigerant release.

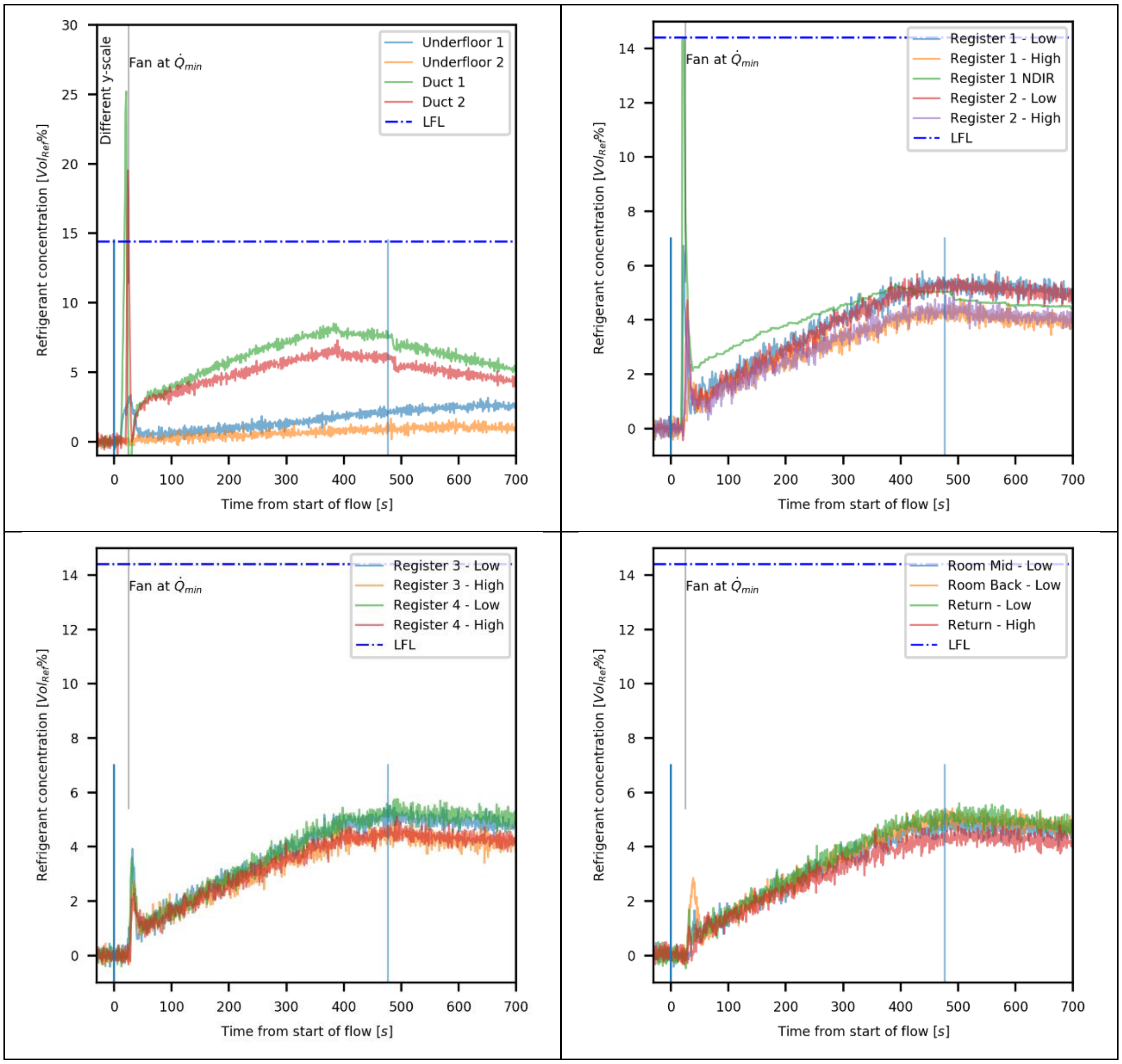


Table 40 - Horizontal 17 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.18 **Horizontal 18**

A summary of the test parameters for this test are indicated in Table 41. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	6.37 kg	Release Time	481 s
Release Quality	Decay	Time to Qmin	35 s
		Fan Speed	1354 m^3/hr

Table 41 - Horizontal 18 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 30% at the Duct 1 and 33% at the Duct 2 sensor. The NDIR at Register 1 indicated that the refrigerant concentration was at or above the LFL for three seconds, at 30 seconds after the start of the release. All of the sensors in the room space and located near the return showed increases over the duration of the release, but remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 42. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 2.3% of refrigerant 29 seconds after the start of the refrigerant release.

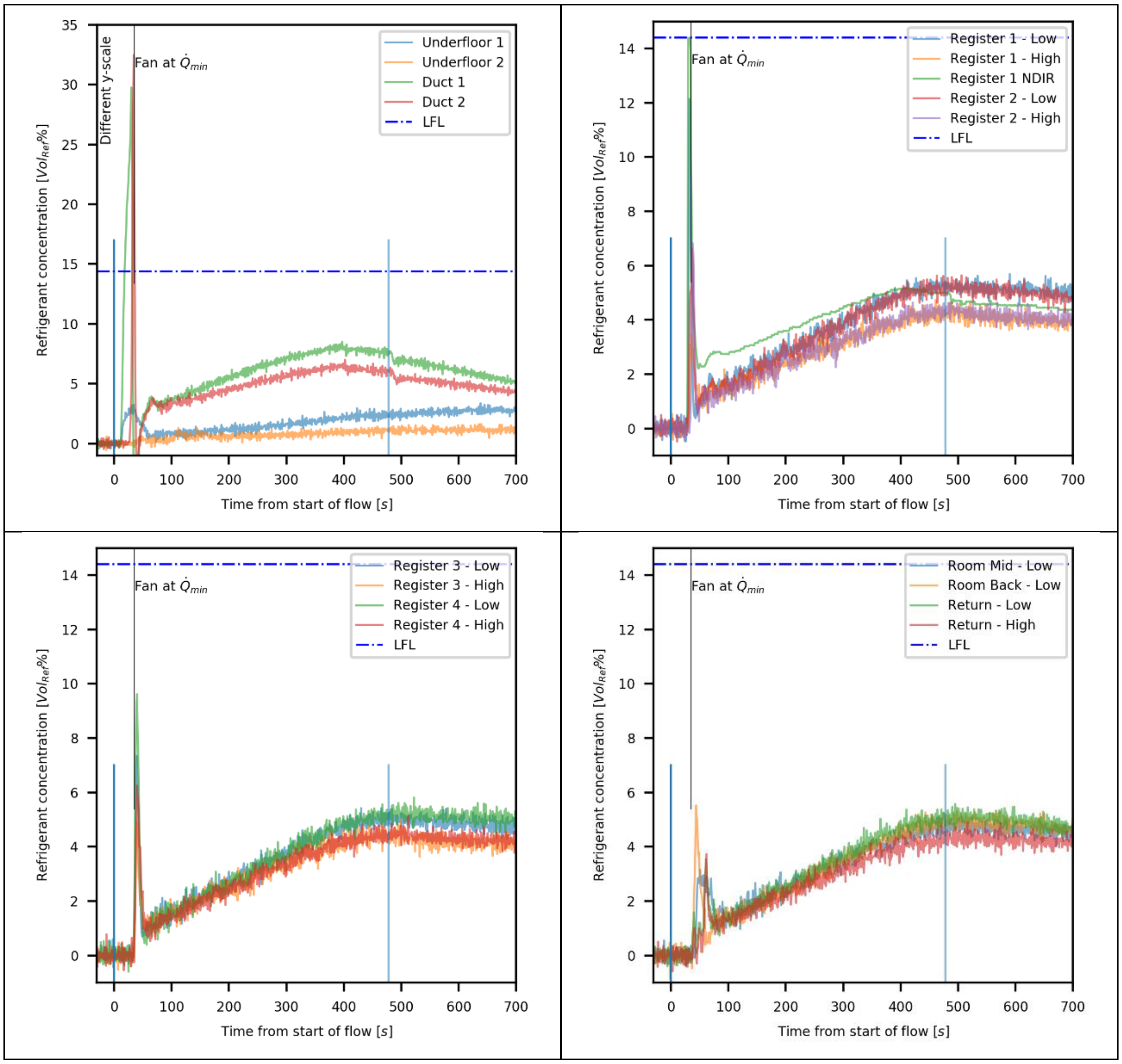


Table 42 - Horizontal 18 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.19 Horizontal 19

A summary of the test parameters for this test are indicated in Table 43. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	6.52 kg	Release Time	481 s
Release Quality	Decay	Time to Qmin	25 s
		Fan Speed	2763 m^3/hr

Table 43 - Horizontal 19 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 25% at the Duct 1 and 18% at the Duct 2 sensor. The NDIR at Register 1 indicated that the refrigerant concentration was at or above the LFL for two seconds, at 21 seconds after the start of the release. All of the sensors in the room space and located near the return showed increases over the duration of the release, but remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 44. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 16 seconds after the start of the refrigerant release.

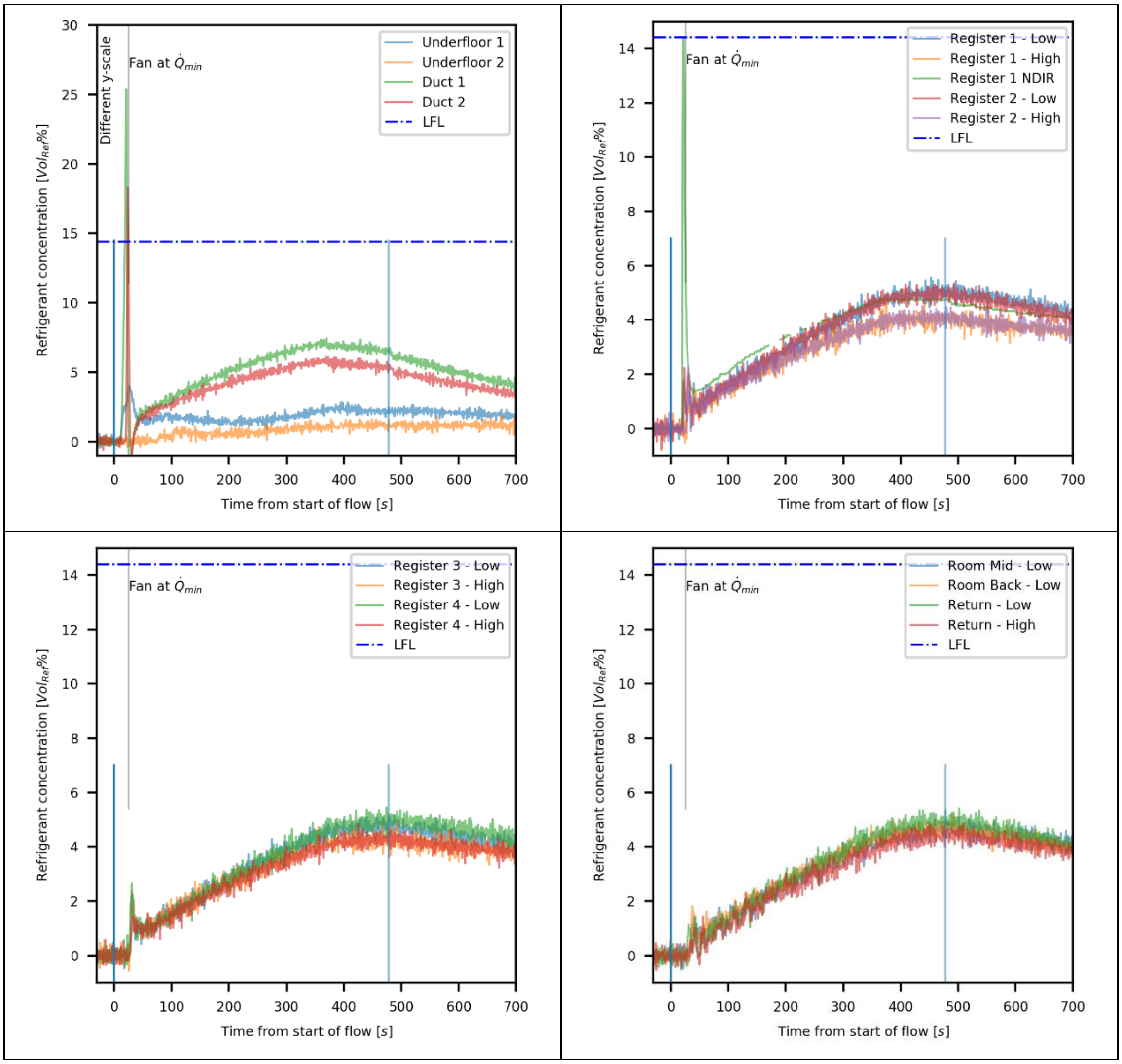


Table 44 - Horizontal 19 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.20 **Horizontal 20**

A summary of the test parameters for this test are indicated in Table 45. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	6.48 kg	Release Time	480 s
Release Quality	Decay	Time to Qmin	35 s
		Fan Speed	2763 m^3/hr

Table 45 - Horizontal 20 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 34% at the Duct 1 and Duct 2 sensor. The NDIR at Register 1 indicated that the refrigerant concentration was at or above the LFL for three seconds, at 33 seconds after the start of the release. All of the sensors in the room space and located near the return showed increases over the duration of the release, but remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 46. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 4.2% of refrigerant 34 seconds after the start of the refrigerant release.

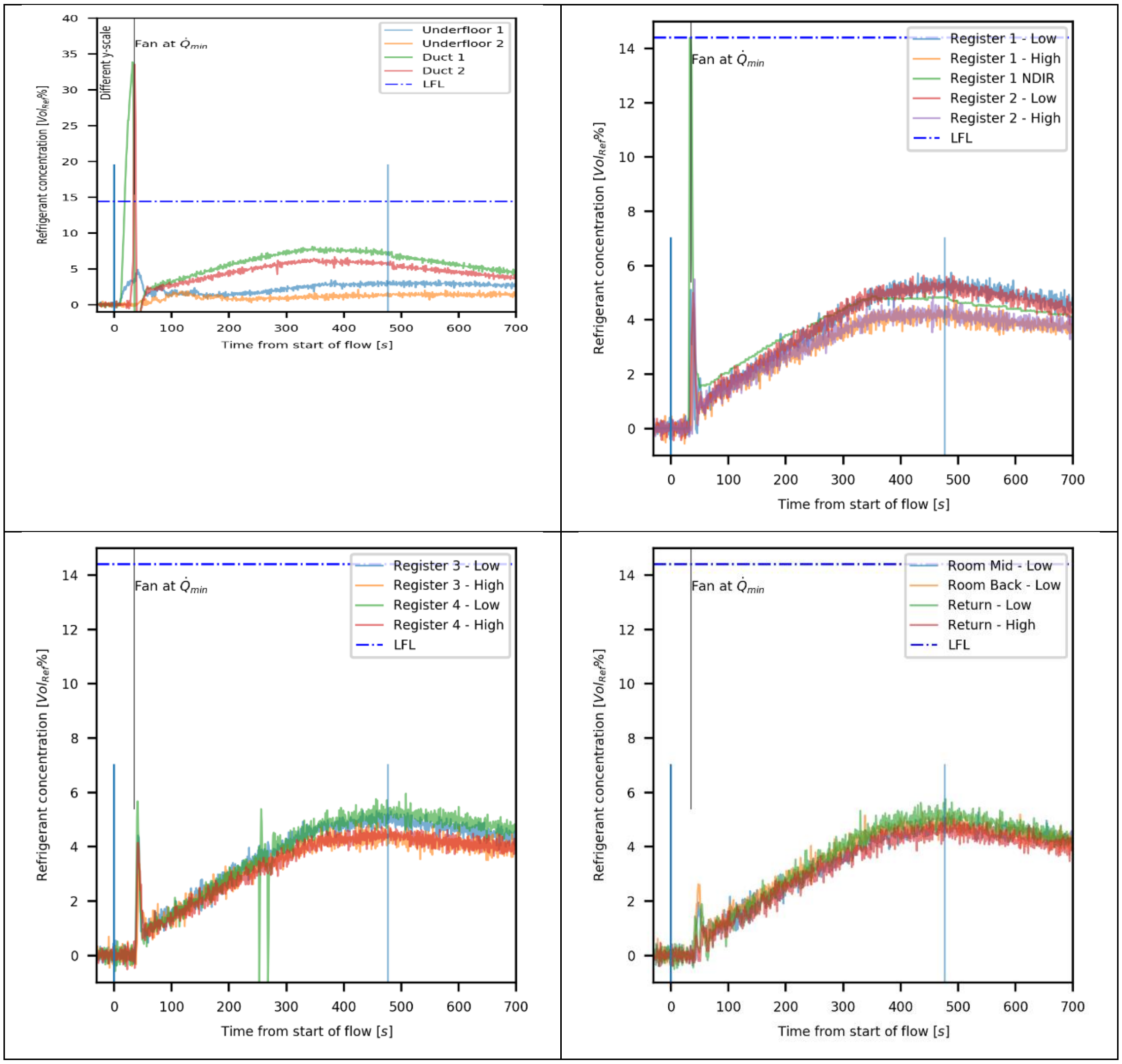


Table 46 - Horizontal 20 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.21 **Horizontal 21**

A summary of the test parameters for this test are indicated in Table 47. This test was conducted the response time for the unit to reach Qmin at 10 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 25% of the LFL for the entire room.

Test Summary	IEC 2-40 (3.42 kg) with GG.2 airflow		
Release Amount	3.42 kg	Release Time	230 s
Release Quality	Liquid	Time to Qmin	10 s
		Fan Speed	462 m^3/hr

Table 47 - Horizontal 21 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 11% at the Duct 1 sensor. All of the sensors in the room space and located near the return showed increases over the duration of the release, but remained below the LFL through the duration of the test. With the fan coming on so quickly it was able to disperse the refrigerant that was being discharged into the unit. There is a slight peak for the Duct 1, Register 1 and Register 2 sensors, but this does not have as high of refrigerant concentrations as other tests. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 48. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor did not register an appreciable amount of refrigerant during this test.

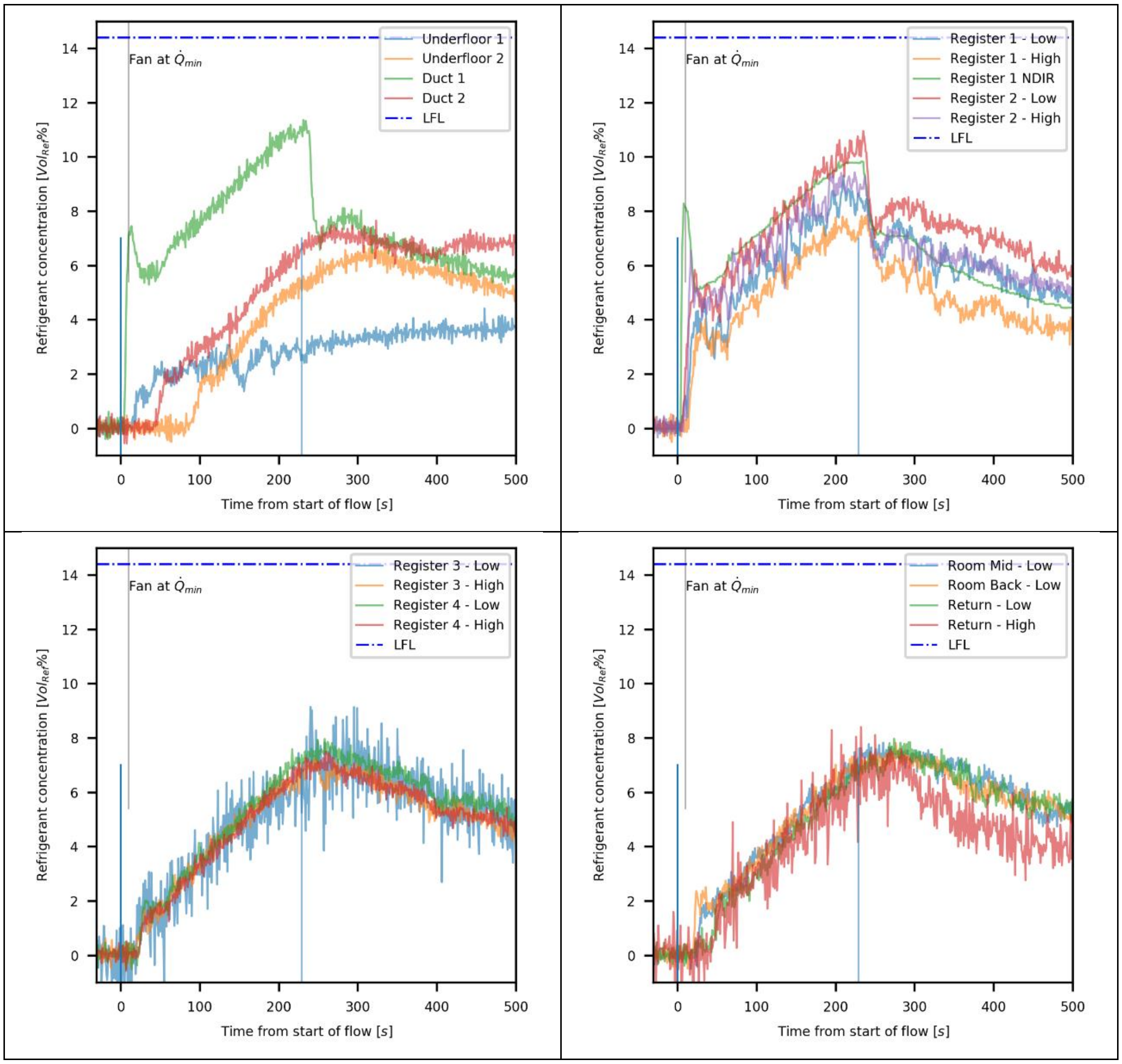


Table 48 - Horizontal 21 Refrigerant Concentrations

(peak concentration around 0~25 seconds may be overestimated due to deconvolution method)

3.1.22 **Horizontal 22**

A summary of the test parameters for this test are indicated in Table 49. This test was conducted the response time for the unit to reach Qmin at 30 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 25% of the LFL for the entire room.

Test Summary	IEC 2-40 (3.42 kg) with GG.2 airflow		
Release Amount	3.41 kg	Release Time	228 s
Release Quality	Liquid	Time to Qmin	30 s
		Fan Speed	462 m^3/hr

Table 49 - Horizontal 22 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 28% at the Duct 1 sensor. Both sensors at Register 2 showed a maximum concentration of 17%, only being at or above the LFL for 4 seconds. All of the sensors in the room space and located near the return showed increases over the duration of the release, but remained below the LFL through the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 44. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor did not register an appreciable amount of refrigerant during this test.

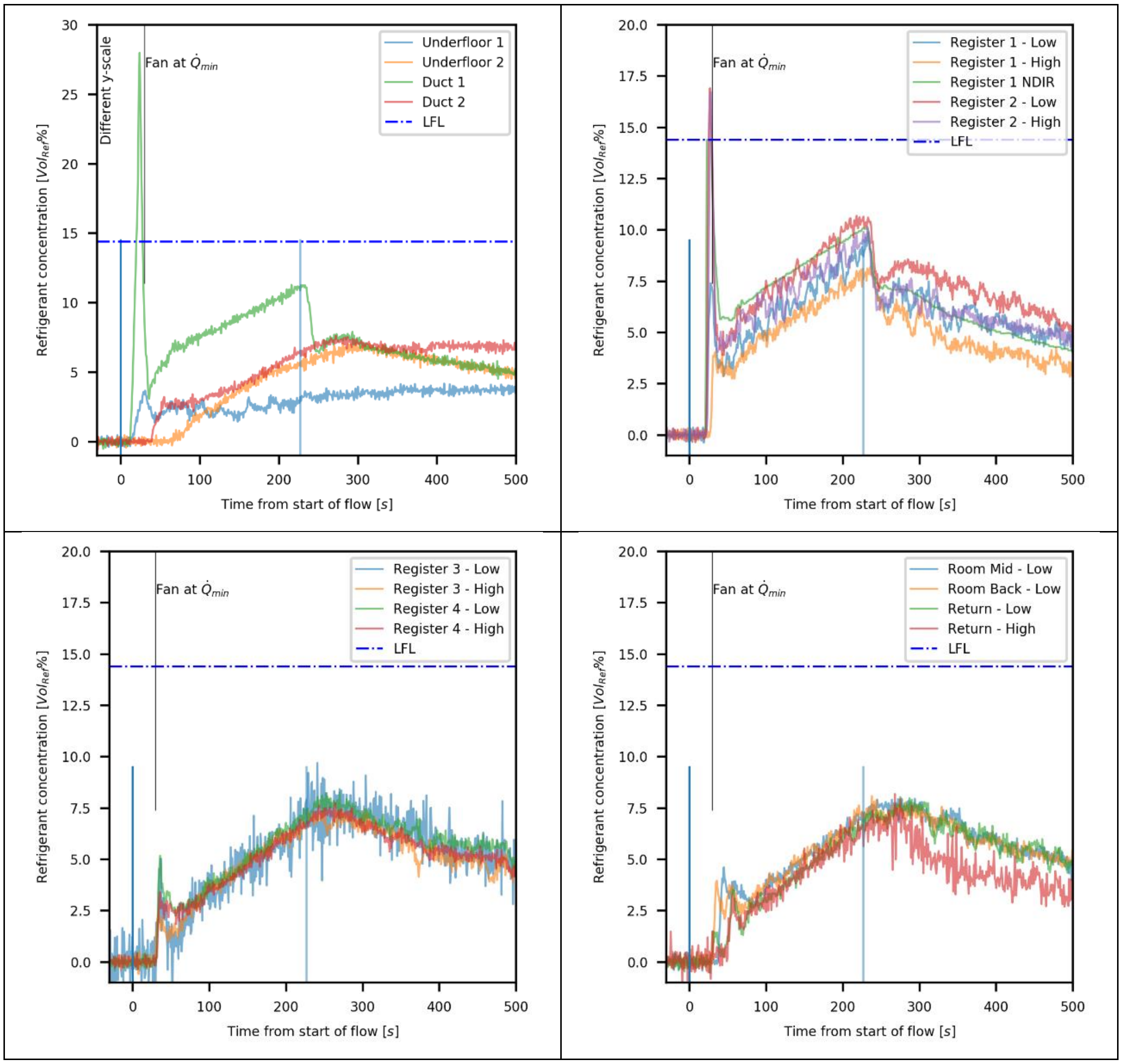


Table 50 - Horizontal 22 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.1.23 **Horizontal 23**

A summary of the test parameters for this test are indicated in Table 51. This test was conducted the response time for the unit to reach Qmin at 10 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 50% of the LFL for the entire room.

Test Summary	IEC 2-40 – 2*charge (6.84 kg) with GG.2 airflow		
Release Amount	6.80 kg	Release Time	183 s
Release Quality	Liquid	Time to Qmin	10 s
		Fan Speed	703 m^3/hr

Table 51 - Horizontal 23 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 21% at the Duct 1 sensor. The sensors at Register 1 and Registers 2 had refrigerant concentrations at or above the LFL during the release. All of the sensors in the room space and located near the return showed increases over the duration of the release, approaching the LFL, but remained below the LFL through the duration of the test.

The ductwork between Register 2 and Register 3 had been sealed off with a sheet metal plate and aluminum tape prior to the start of this series. There was still refrigerant concentrations building in this space during the release. Due to the fact that the concentrations are higher at Register 3 and Register 4 the increase at sensor Duct 2 is from the refrigerant flowing back into the ductwork via the registers in the room.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 52. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 4.8% of refrigerant 15 seconds after the start of the refrigerant release.

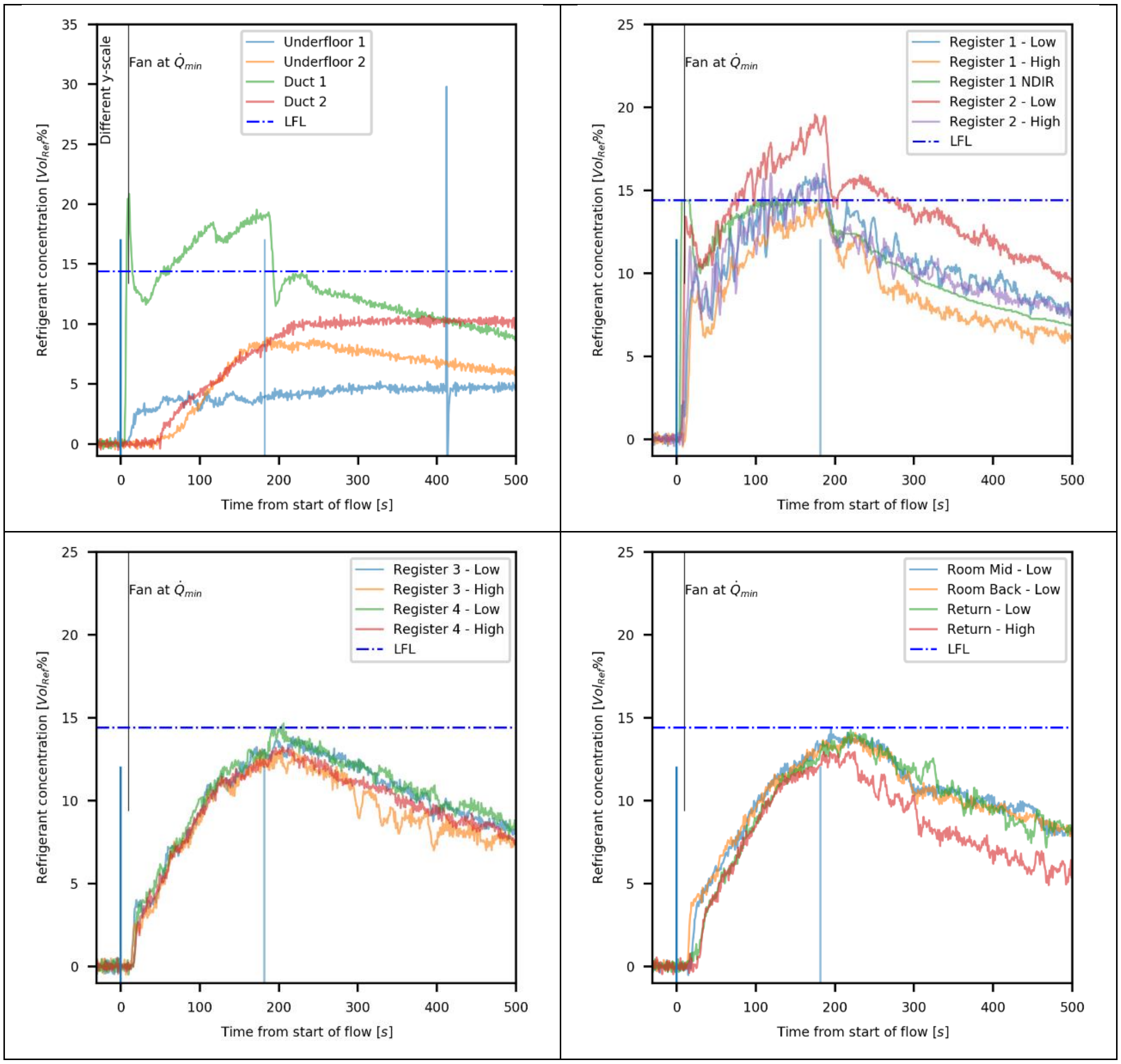


Table 52 - Horizontal 23 Refrigerant Concentrations

(peak concentration around 0~25 seconds and rapid decrease around 175-200 seconds may be overestimated due to deconvolution method)

3.1.24 **Horizontal 24**

A summary of the test parameters for this test are indicated in Table 53. This test was conducted the response time for the unit to reach Qmin at 30 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 50% of the LFL for the entire room.

Test Summary	IEC 2-40 – 2*charge (6.84 kg) with GG.2 airflow		
Release Amount	6.86 kg	Release Time	195 s
Release Quality	Liquid	Time to Qmin	30 s
		Fan Speed	703 m^3/hr

Table 53 - Horizontal 24 Test Parameters

The maximum refrigerant concentration was observed with the sensors inside the ductwork, which reached a maximum concentration of 60% at the Duct 1 sensor. The sensors at Register 1 and Registers 2 had refrigerant concentrations at or above the LFL during the release. All of the sensors in the room space and located near the return showed increases over the duration of the release, approaching the LFL, but remained below the LFL through the duration of the test.

The ductwork between Register 2 and Register 3 had been sealed off with a sheet metal plate and aluminum tape prior to the start of this series. There was still refrigerant concentrations building in this space during the release. Due to the fact that the concentrations are higher at Register 3 and Register 4 the increase at sensor Duct 2 is from the refrigerant flowing back into the ductwork via the registers in the room. This can is confirmed by looking at the times that the concentrations start to rise. Register 3 - Low starts to rise at 28 s after the start of the test, and the Duct 2 starts to rise 48 s into the test.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 52. The NDIR sensor in the unit registered 50% of LFL at 8 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 11 seconds after the start of the refrigerant release.

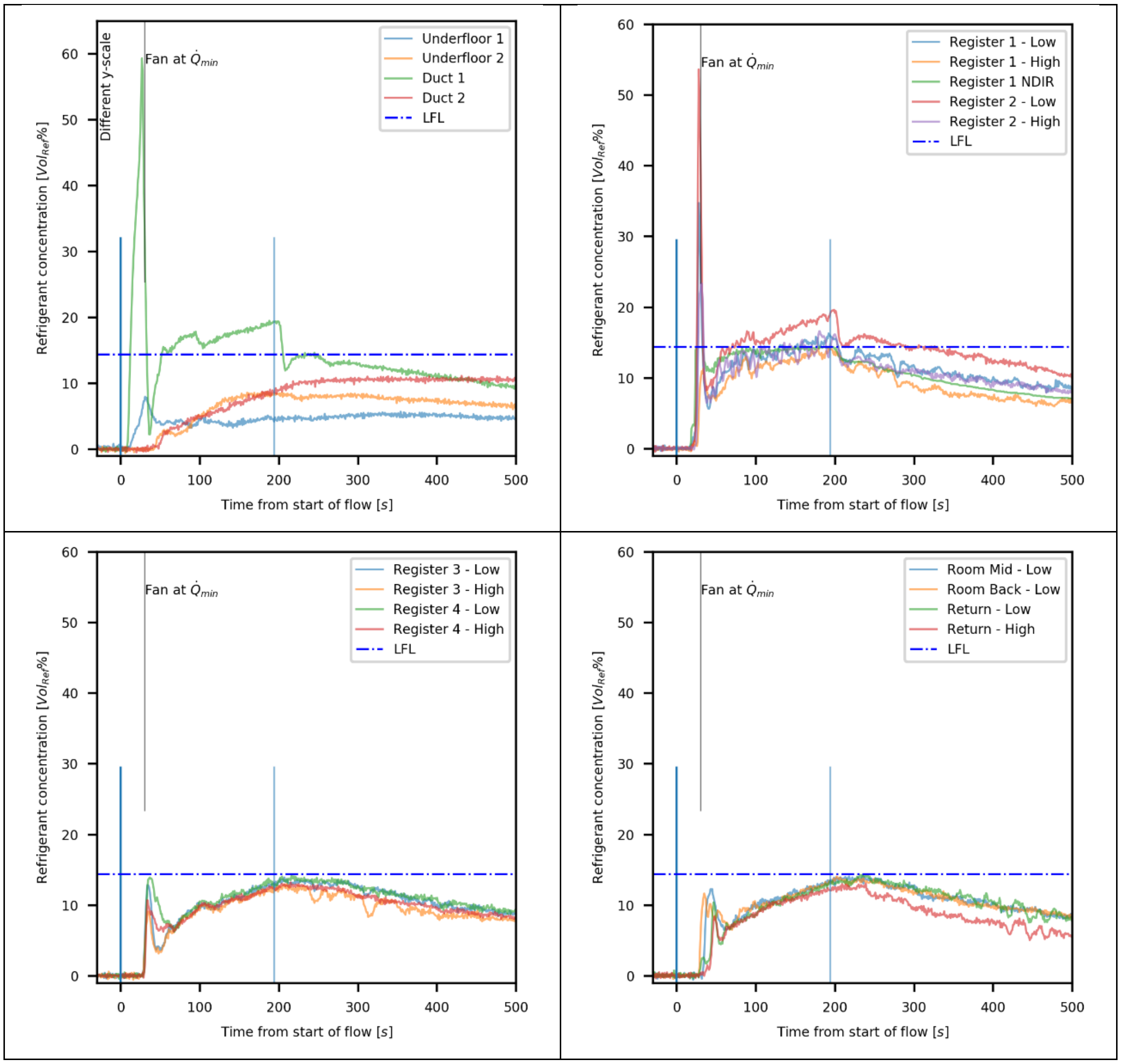


Table 54 - Horizontal 24 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2 Vertical

Figure 10 - Vertical Room Arrangement

The vertical arrangement used two sensor layouts. The first arrangement utilized a refrigerant sensor at each discharge register, with other sensors located in the room space. After a few tests it was identified that relocating the sensors to other locations in the room could provide an additional benefit. Tests Vertical 1, Vertical 3, Vertical 4, Vertical 5 used the sensor arrangement indicated in Figure 11, the remaining vertical tests utilized the modified layout identified in Figure 12. Colors are used to detail sensors which are in the same general location in the room space: blue stars are sensors near the return and discharge registers, green stars are sensors located inside the ductwork, and purple stars are sensor arrays located out in the room space. The orange circle indicates the location of the NDIR sensor, near register 1.

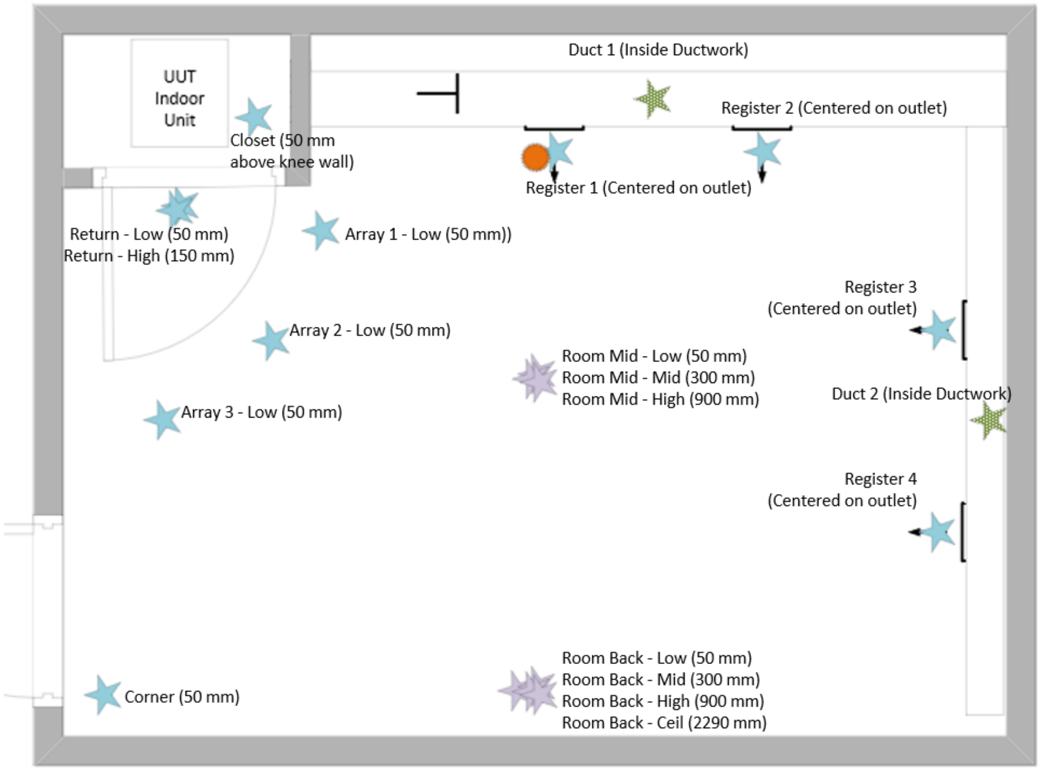


Figure 11 - Vertical Sensor Layout - Original

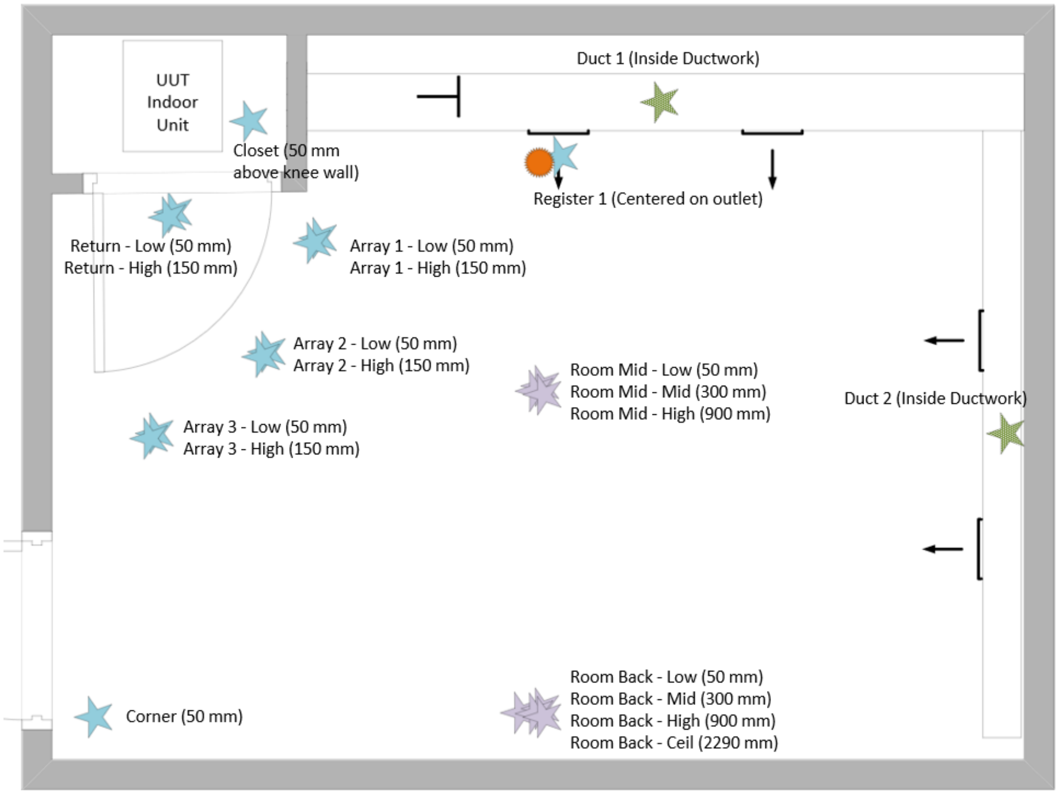


Figure 12 - Vertical Sensor Layout - Modified

3.2.1 Vertical 1

A summary of the test parameters for this test are indicated in Table 55. This test was conducted to establish the baseline parameters with no mitigation. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	3.43 kg	Release Time	224 s
Release Quality	Liquid	Time to Qmin	N/A
		Fan Speed	N/A

Table 55 - Vertical 1 Test Parameters

The maximum refrigerant concentration was observed near the return 150 mm (6 in) above the floor, which reached a maximum concentration of 25%. Refrigerant concentrations started to rise at this location 11 s after the start of the leak. Refrigerant continued to flow out of the return and collect in the room. For the sensors near the return the higher refrigeration concentrations are with the sensors 50 mm (2 in) above the floor. Looking at the vertical sensor arrays the concentration was above the LFL for the sensor 50 mm (2 in) above the floor. There was an increase for the sensor located 300 mm (12 in) above the floor, but it did not exceed the LFL. There was no significant refrigerant concentration present at 900 mm (36 in) or above during the test. At the end of the test there were locations near the return where the values dropped below the LFL before rising again. This effect was due to the mass of the refrigerant inside the unit and ductwork. It was observed that during the release there was some airflow registered on the thermal anemometer in the ductwork showing that that refrigerant was forcing the air up. When the discharge was complete the heavier than air refrigerant resulted in the gravity pulling the refrigerant and air down through the unit. As it did this there was some mixing resulting in lower concentration refrigerant exiting the unit.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 56. The NDIR sensor in the unit registered 50% of LFL at 2 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant by volume 29 seconds after the start of the refrigerant release.

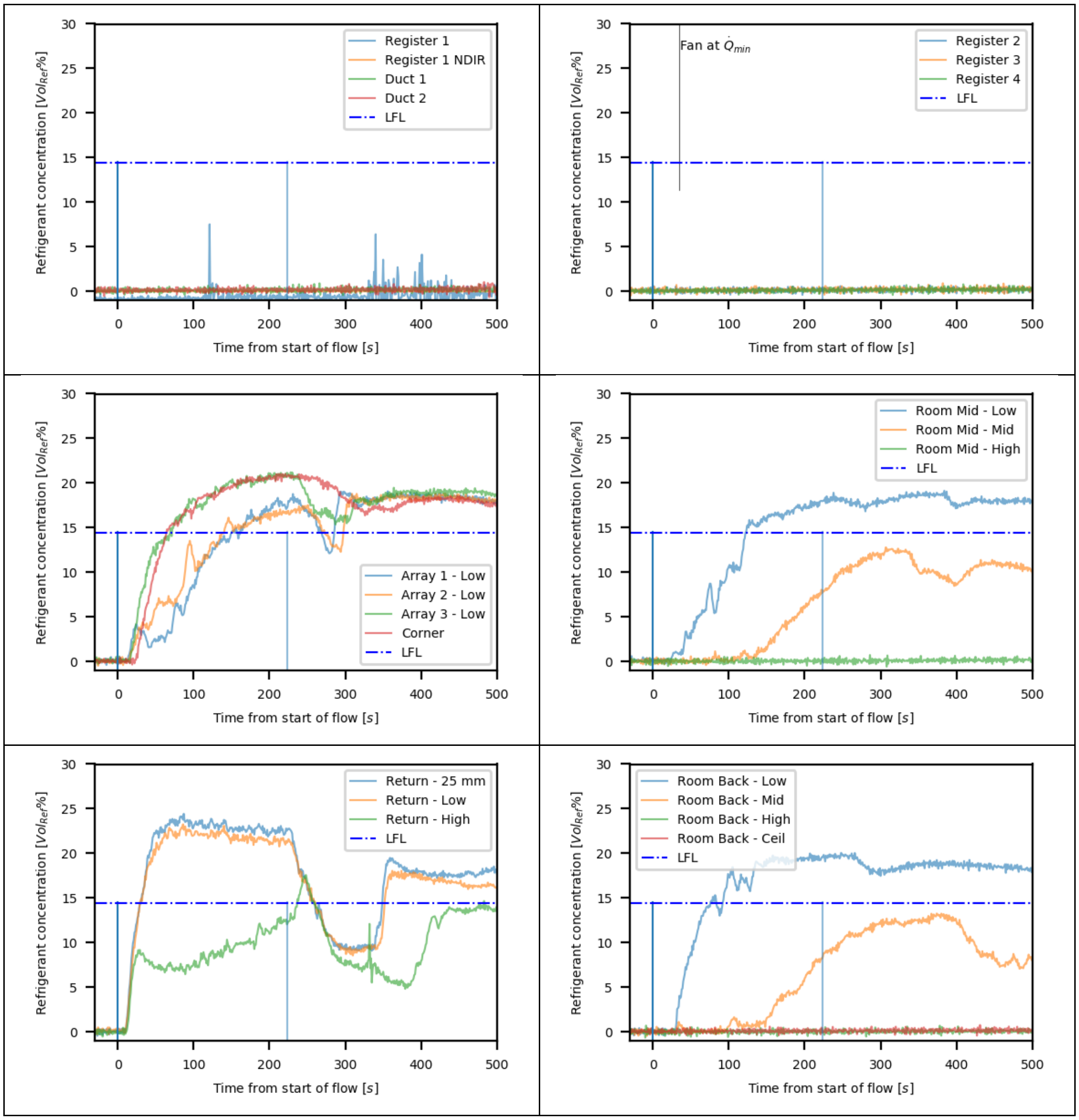


Table 56 – Vertical 1 Refrigerant Concentrations

(timing of concentration around 25~50 seconds may be shifted due to deconvolution method)

3.2.2 Vertical 2

A summary of the test parameters for this test are indicated in Table 57. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	3.45 kg	Release Time	221 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	695 m^3/hr

Table 57 - Vertical 2 Test Parameters

The maximum refrigerant concentration was observed at the discharge of Register 1, which reached a maximum concentration of 20% as the fan reached Qmin. The sensor was above LFL for four seconds. Refrigerant concentrations started to rise near the return 15 s after the start of the leak and reached 8% at 22s after the start of the leak. At this point the fan had already started moving air to reach Qmin at 25 seconds and the mitigation lowered the concentrations at this location. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 58. The NDIR sensor in the unit registered an error 6 seconds after the start of the refrigerant release. The MOS sensor registered 4% of refrigerant 30 seconds after the start of the refrigerant release.

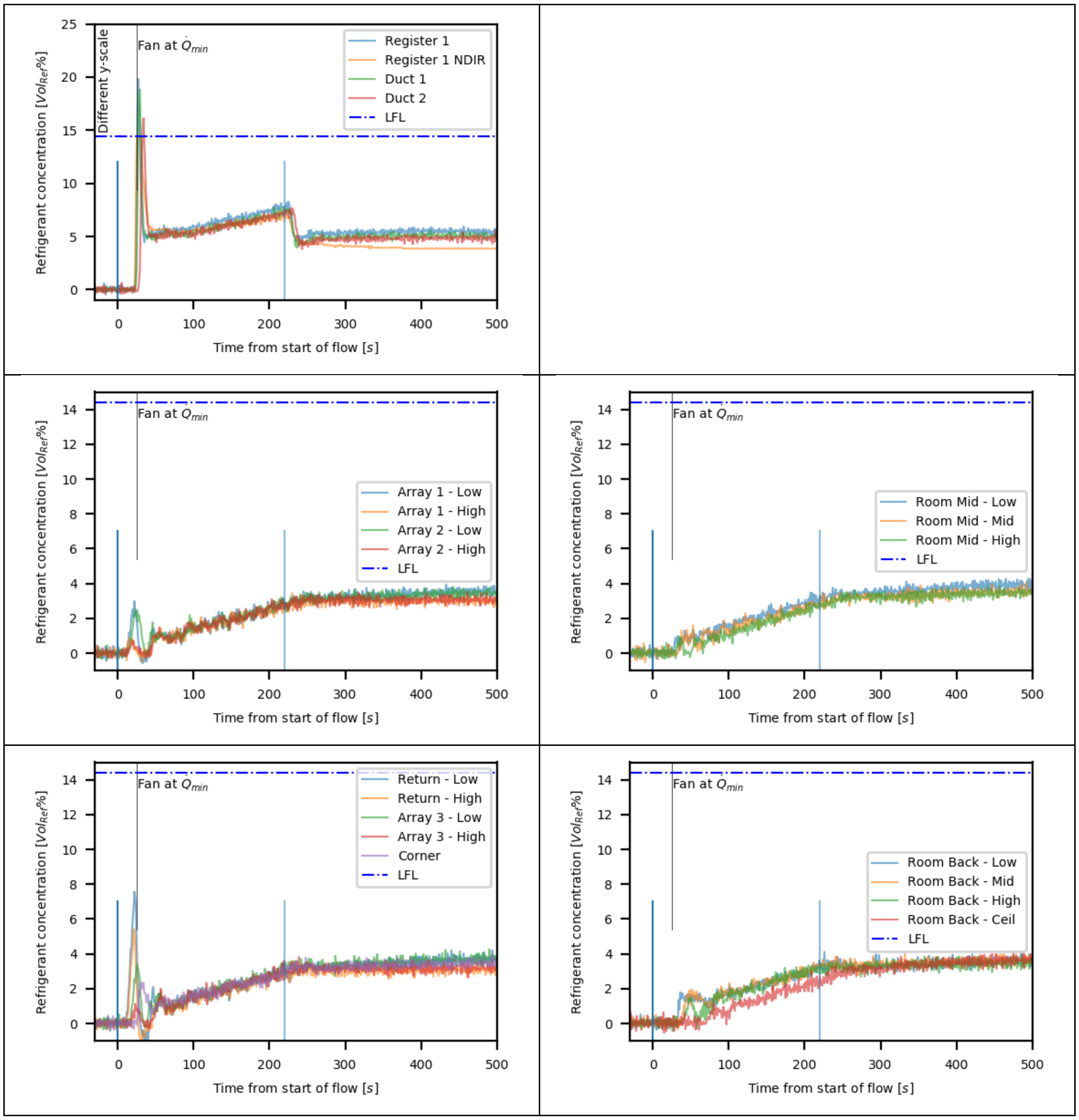


Table 58 – Vertical 2 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.3 **Vertical 3**

A summary of the test parameters for this test are indicated in Table 59. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	3.38 kg	Release Time	218 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	695 m^3/hr

Table 59 - Vertical 3 Test Parameters

The maximum refrigerant concentration was observed at the discharge of Register 2, which reached a maximum concentration of 24% as the fan reached Qmin. The sensor was above LFL for five seconds. Refrigerant concentrations started to rise near the return 11 s after the start of the leak and reached 16% at 27s after the start of the leak. At this point the fan had already started moving air to reach Qmin at 35 seconds and the mitigation lowered the concentrations at this location. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 60. The NDIR sensor in the unit registered an error 4 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 33 seconds after the start of the refrigerant release.

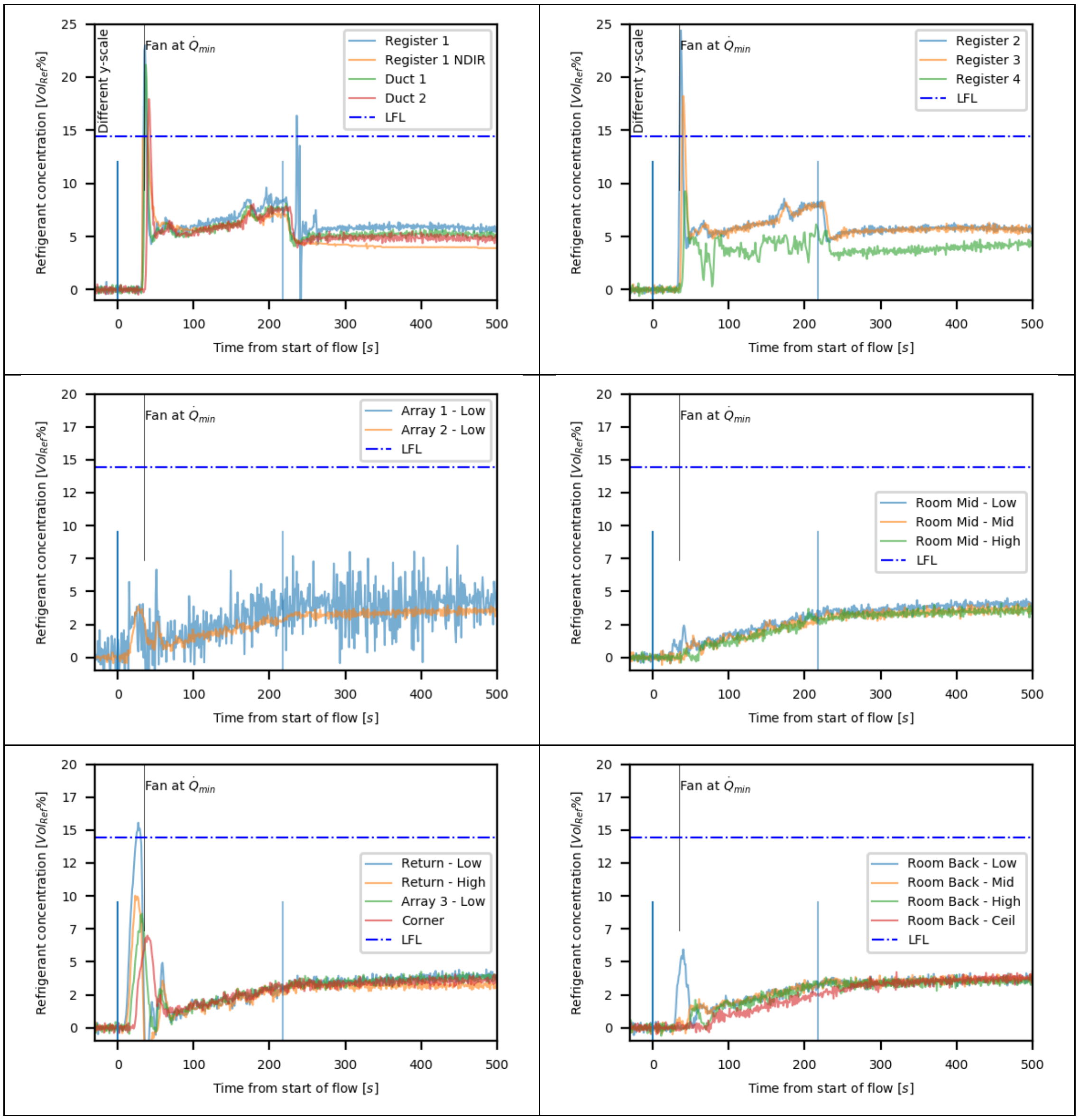


Table 60 – Vertical 3 Refrigerant Concentrations

(peak concentration around 25~75 seconds may be overestimated due to deconvolution method)

3.2.4 **Vertical 4**

A summary of the test parameters for this test are indicated in Table 61. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	3.4 kg	Release Time	224 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	1390 m^3/hr

Table 61 - Vertical 4 Test Parameters

The maximum refrigerant concentration was observed at the discharge of Register 2, which reached a maximum concentration of 16% as the fan reached Qmin. The sensor was above LFL for six seconds. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 62. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 3.4% of refrigerant 27 seconds after the start of the refrigerant release.

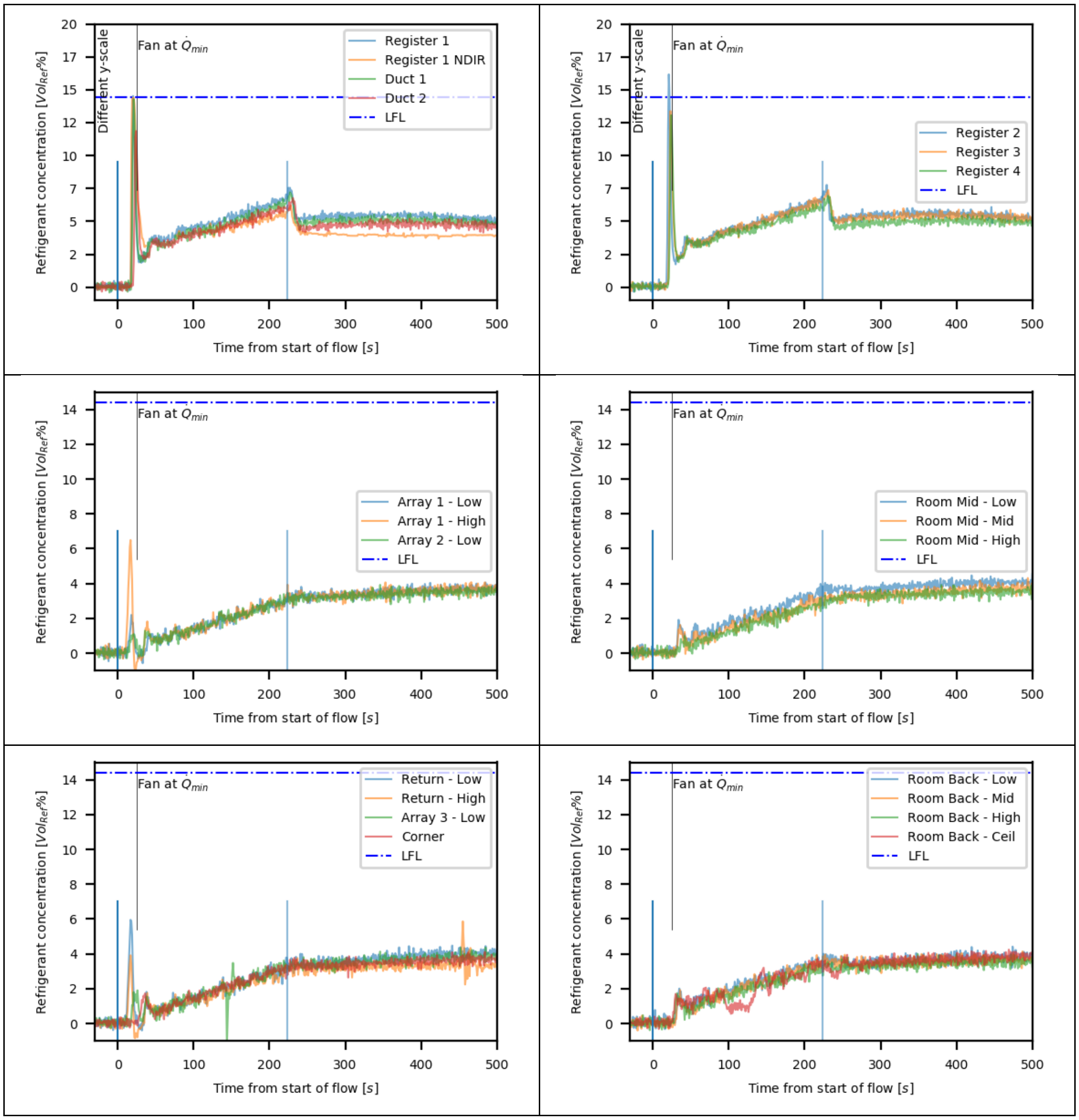


Table 62 – Vertical 5 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.5 **Vertical 5**

A summary of the test parameters for this test are indicated in Table 63. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	3.36 kg	Release Time	224 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	1390 m^3/hr

Table 63 - Vertical 5 Test Parameters

The maximum refrigerant concentration in the room space was observed at the discharge of Register 2, which reached a maximum concentration of 20% as the fan reached Qmin. The sensor was above LFL for two seconds. Refrigerant concentrations started to rise near the return 12 s after the start of the leak and reached 12% at 24s after the start of the leak. At this point the fan had already started moving air to reach Qmin at 35 seconds and the mitigation lowered the concentrations at this location. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 64. The NDIR sensor in the unit did not function correctly during this test and the data was not useable. The MOS sensor registered 4% of refrigerant 21 seconds after the start of the refrigerant release.

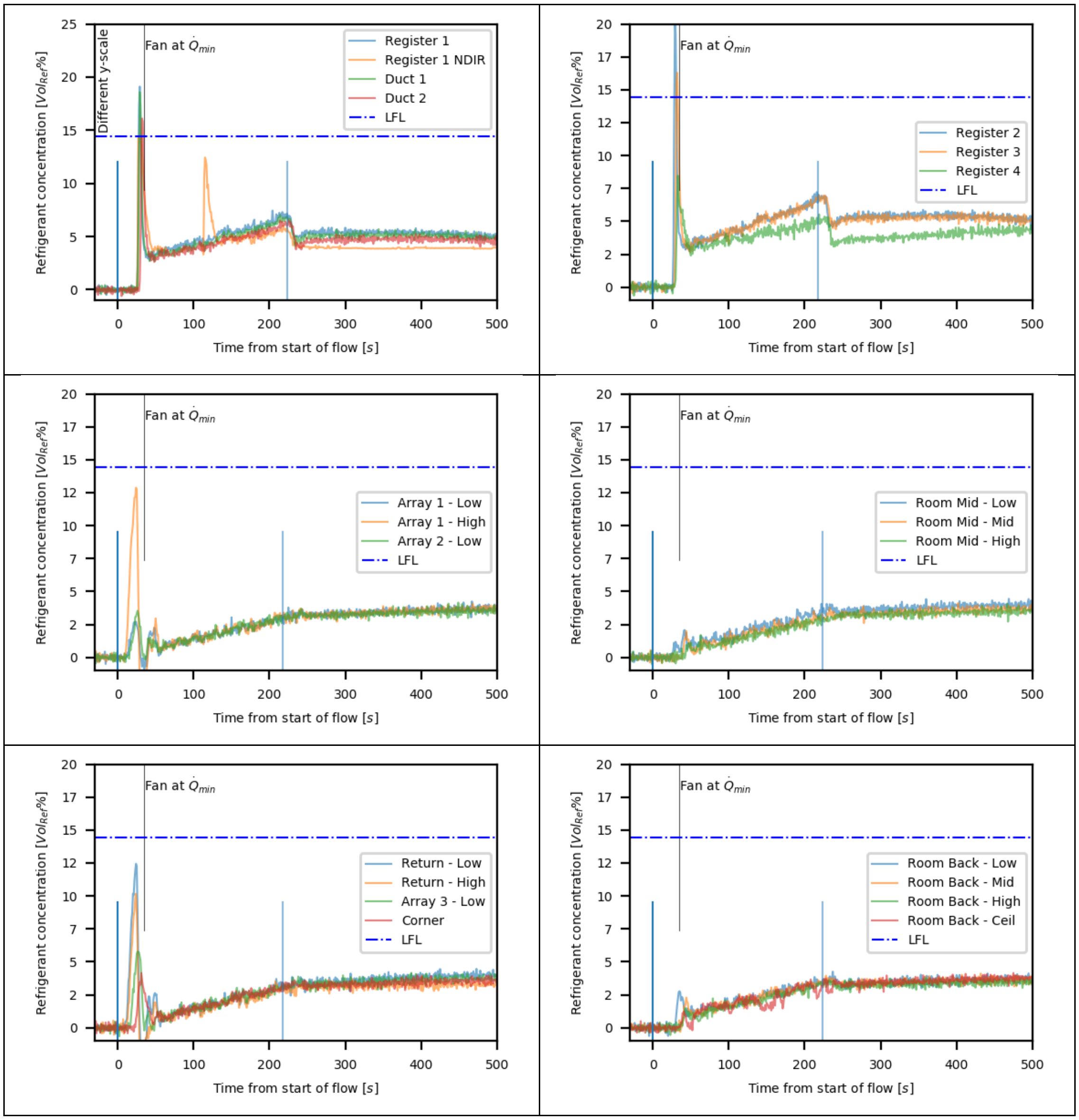


Table 64 – Vertical 5 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.6 **Vertical 6**

A summary of the test parameters for this test are indicated in Table 65. This test was conducted to establish the baseline parameters with no mitigation. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	3.45 kg	Release Time	250 s
Release Quality	Vapor	Time to Qmin	N/A
		Fan Speed	N/A

Table 65 - Vertical 6 Test Summary

The maximum refrigerant concentration was observed near the return 50 mm (2 in) above the floor, which reached a maximum concentration of 37%. Refrigerant concentrations started to rise at this location 15 s after the start of the leak. Refrigerant continued to flow out of the return and collect in the room. For the sensors near the return the higher refrigeration concentrations are with the sensors 50 mm (2 in) above the floor. Looking at the vertical sensor arrays the concentration was above the LFL for the sensor 50 mm (2 in) above the floor. There was an increase for the sensor located 300 mm (12 in) above the floor, but it did not exceed the LFL. There was no significant refrigerant concentration present at 900 mm (36 in) or above during the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 66. The NDIR sensor in the unit registered 50% of LFL at 5 seconds after the start of the refrigerant release. The MOS sensor registered 3.5% of refrigerant 34 seconds after the start of the refrigerant release.

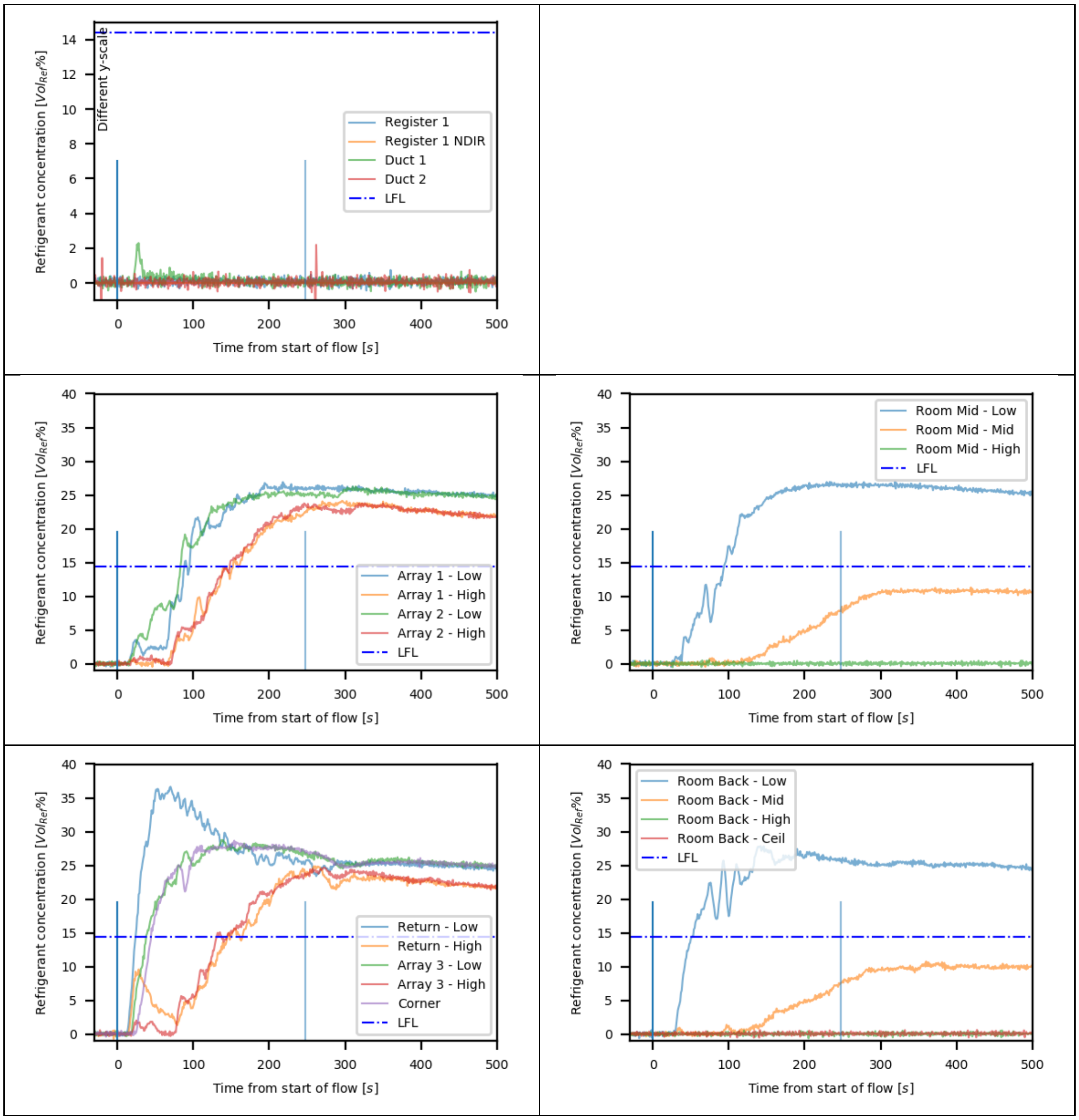


Table 66 – Vertical 6 Refrigerant Concentrations

(timing of concentration around 25~50 seconds may be shifted due to deconvolution method)

3.2.7 **Vertical 7**

A summary of the test parameters for this test are indicated in Table 67. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	3.45 kg	Release Time	236 s
Release Quality	Vapor	Time to Qmin	25 s
		Fan Speed	695 m^3/hr

Table 67 - Vertical 7 Test Parameters

The maximum refrigerant concentration in the room was at Register 1 with 47%, this point was above the LFL for 7 s when the fan was at Qmin. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 15 s after the start of the leak. Refrigerant continued to collect in this area and the sensor had a maximum refrigerant concentration of 16% as the blower was at Qmin. None of the other sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space, with slightly less refrigerant near the sensor 150 mm (6 in) from the ceiling. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 68. The NDIR sensor in the unit registered 50% of LFL at 5 seconds after the start of the refrigerant release. The MOS sensor registered 4% of refrigerant 24 seconds after the start of the refrigerant release.

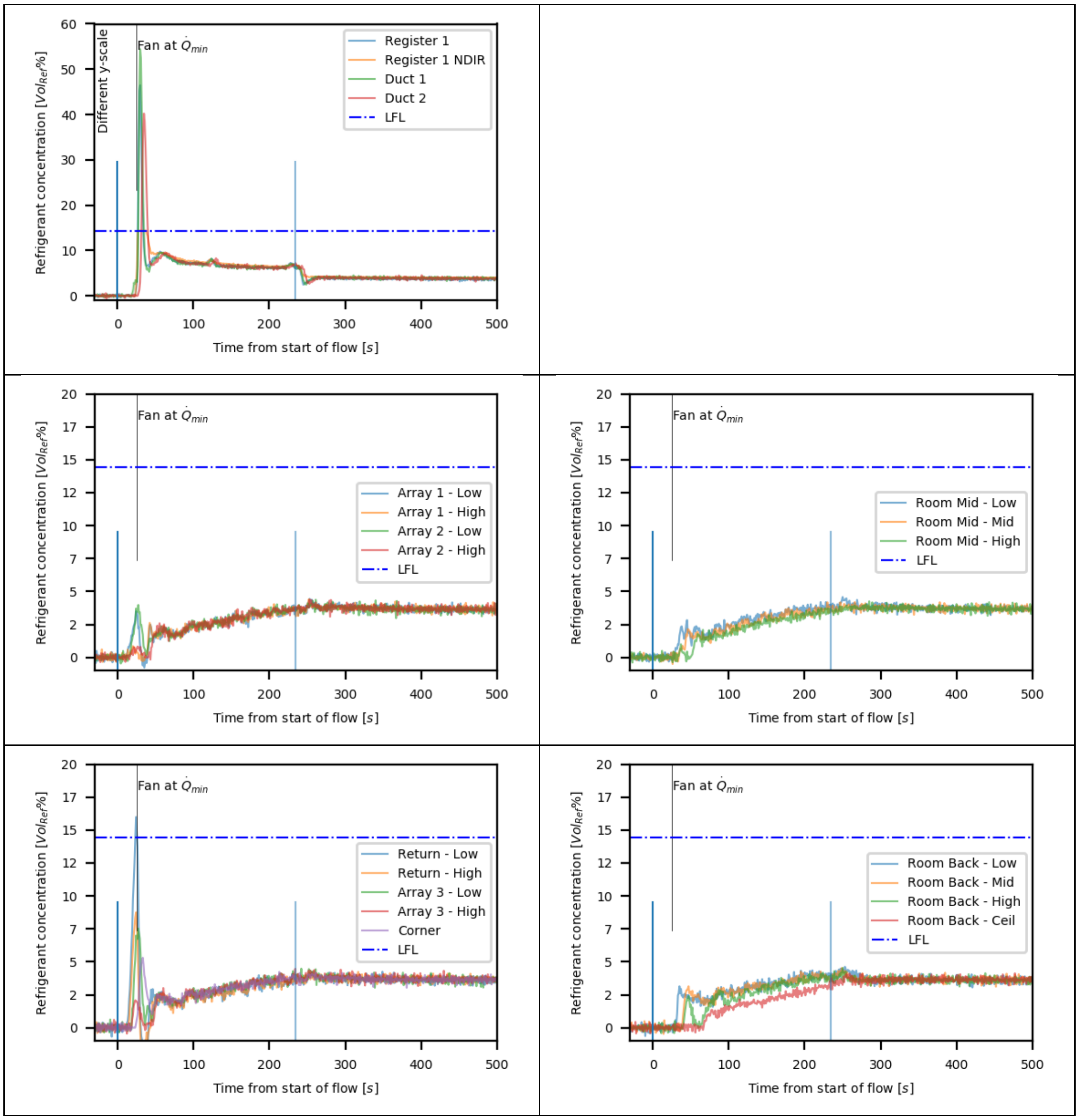


Table 68 – Vertical 7 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.8 Vertical 8

A summary of the test parameters for this test are indicated in Table 69. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	3.46 kg	Release Time	253 s
Release Quality	Vapor	Time to Qmin	35 s
		Fan Speed	695 m^3/hr

Table 69 - Vertical 8 Test Parameters

The maximum refrigerant concentration in the room was at Register 1 with 51%, concentrations did not start to rise at this point until 34 s after the release started when the blower was almost at Qmin. The sensor indicated above LFL for 7 s. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 12 s after the start of the leak. Refrigerant continued to collect in this area and the sensor had a maximum refrigerant concentration of 29%, 32 s after the start of the release. The other sensors in this area had rising refrigerant concentrations until the blower was at Qmin, the other sensors did not reach the LFL. None of the other sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space, with slightly less refrigerant near the sensor 150 mm (6 in) from the ceiling. These vertical arrays also show that in these locations the refrigerant concertation does not start to rise until the blower starts to move the air. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 70. The NDIR sensor in the unit registered 50% of LFL at 5 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 9 seconds after the start of the refrigerant release.

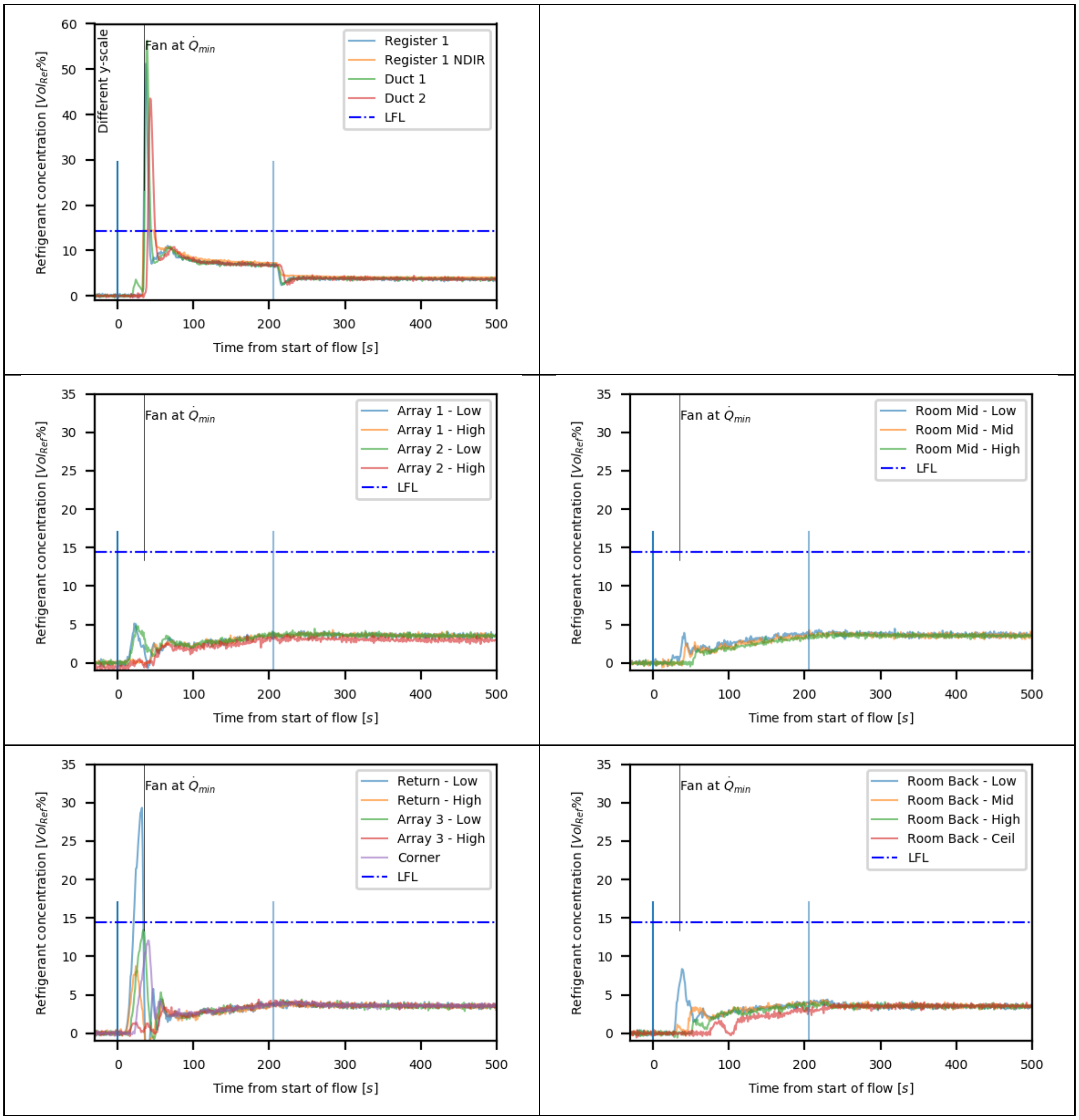


Table 70 - Vertical 8 Refrigerant Concentrations

(peak concentration around 25~75 seconds may be overestimated due to deconvolution method)

3.2.9 **Vertical 9**

A summary of the test parameters for this test are indicated in Table 71. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	3.42 kg	Release Time	233 s
Release Quality	Vapor	Time to Qmin	25 s
		Fan Speed	1390 m^3/hr

Table 71 - Vertical 9 Test Summary

The maximum refrigerant concentration in the room was at Register 1 with 39%, concentrations did not start to rise at this point until 16 s after the release started when the blower was almost at Qmin. The sensor indicated above LFL for 5 s. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 13 s after the start of the leak. However, the fan was also started at this time to reach Qmin at 25 s, so the concentration did not have time to build in this area. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 72. The NDIR sensor in the unit registered 50% of LFL at 5 seconds after the start of the refrigerant release. The MOS sensor registered 4% of refrigerant 18 seconds after the start of the refrigerant release.

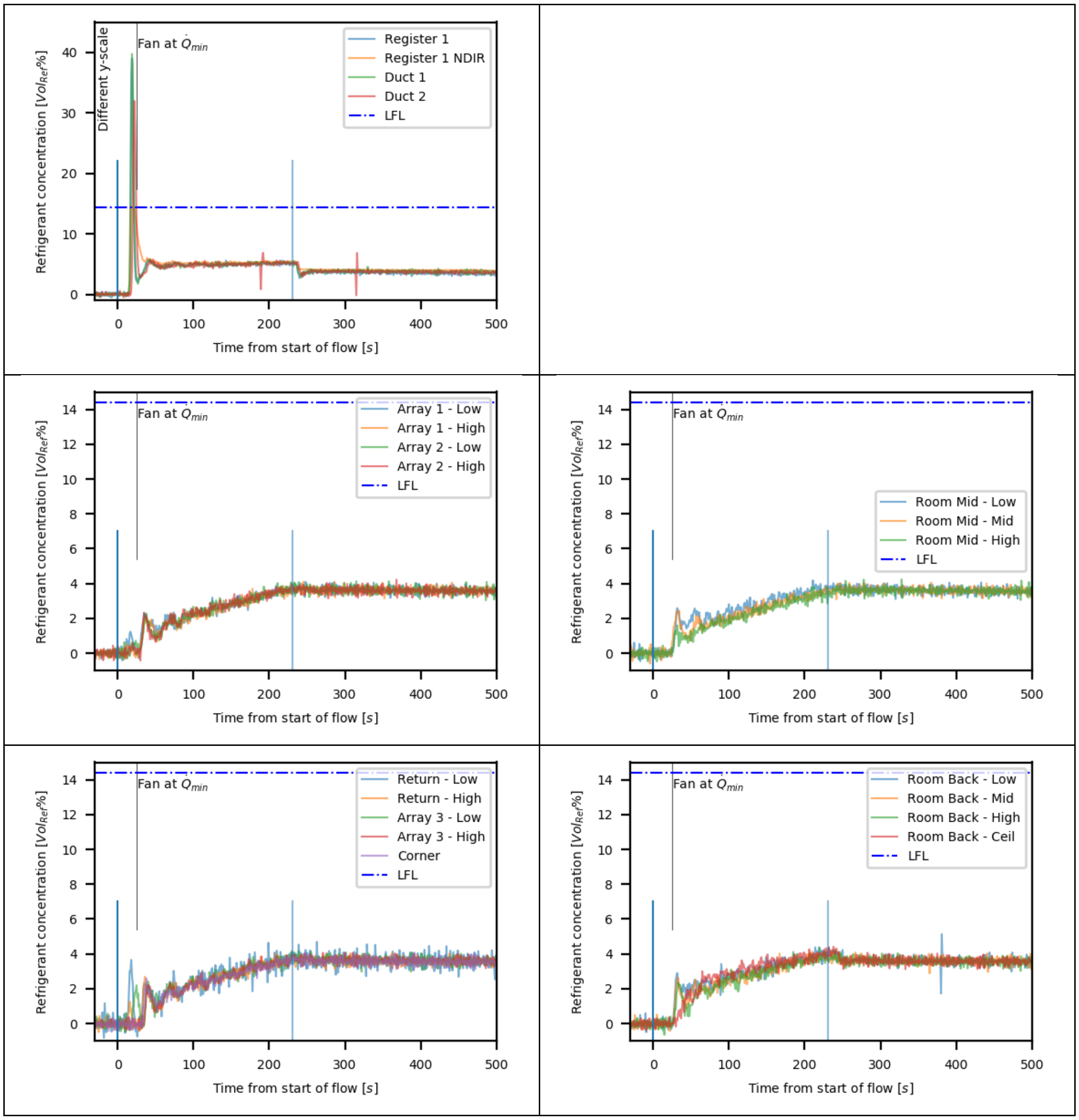


Table 72 – Vertical 9 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.10 **Vertical 10**

A summary of the test parameters for this test are indicated in Table 73. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	3.37 kg	Release Time	252 s
Release Quality	Vapor	Time to Qmin	35 s
		Fan Speed	1390 m^3/hr

Table 73 - Vertical 10 Test Parameters

The maximum refrigerant concentration in the room was at Register 1 with 51%, concentrations did not start to rise at this point until 34 s after the release started when the blower was almost at Qmin. The sensor indicated above LFL for 5 s. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 12 s after the start of the leak. Refrigerant continued to collect in this area and the sensor had a maximum refrigerant concentration of 19%, 25 s after the start of the release. The other sensors in this area had rising refrigerant concentrations until the blower was at moving air, but did not reach the LFL. None of the other sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space. These vertical arrays also show that in these locations the refrigerant concertation does not start to rise until the blower starts to move the air. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 74. The NDIR sensor in the unit registered 50% of LFL at 6 seconds after the start of the refrigerant release. The MOS sensor registered 4% of refrigerant 26 seconds after the start of the refrigerant release.

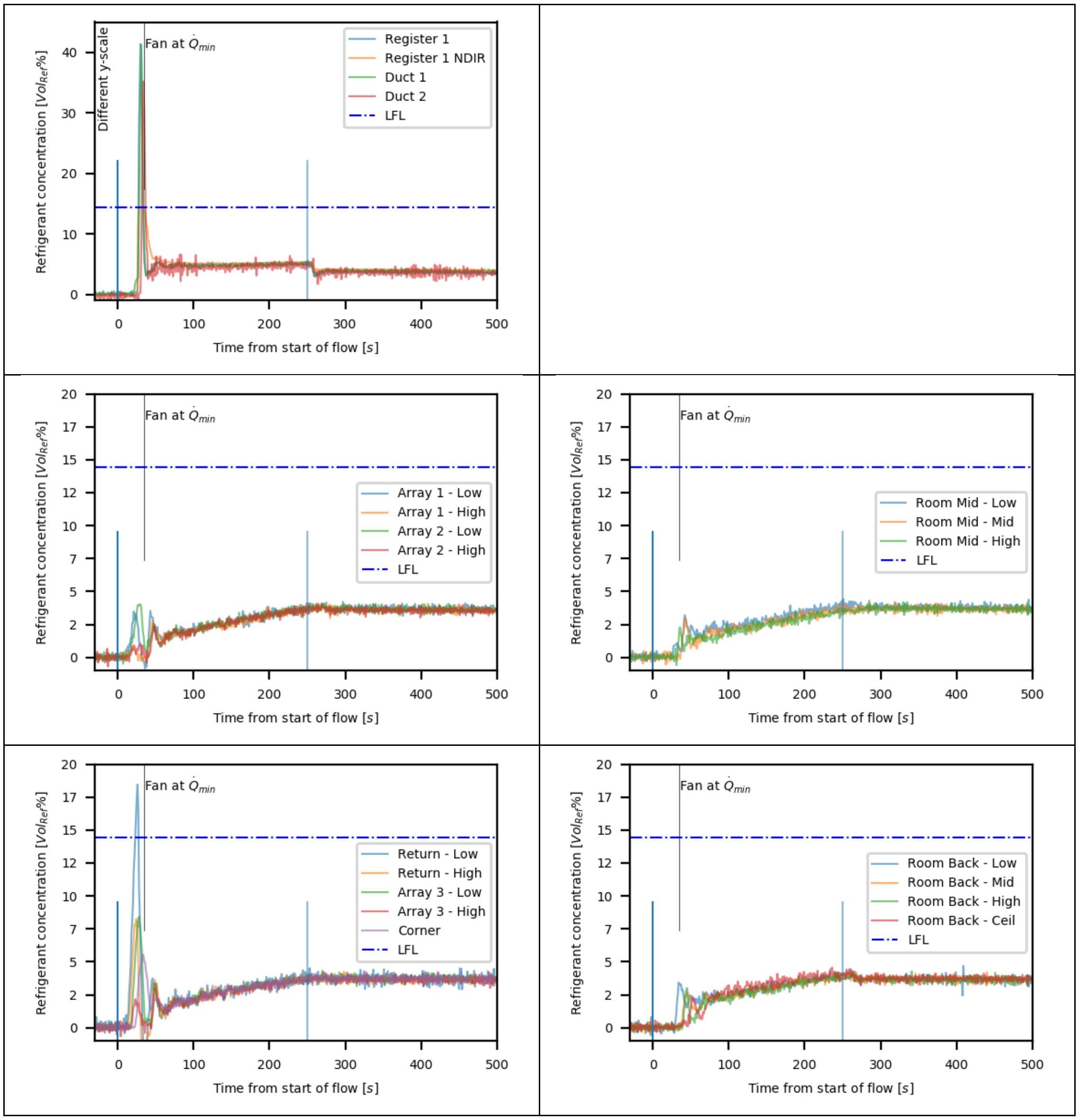


Table 74 – Vertical 10 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.11 **Vertical 11**

A summary of the test parameters for this test are indicated in Table 75. This test was conducted to establish the baseline parameters with no mitigation. The release was increased to be 50% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	6.85 kg	Release Time	466 s
Release Quality	Liquid	Time to Qmin	N/A
		Fan Speed	N/A

Table 75 - Vertical 11 Test Parameters

The maximum refrigerant concentration was observed near the return 150 mm (6 in) above the floor, which reached a maximum concentration of 22.5%. Refrigerant concentrations started to rise at this location 14 s after the start of the leak. Refrigerant continued to flow out of the return and collect in the room. For the sensors near the return the higher refrigeration concentrations are with the sensors 50 mm (2 in) above the floor. Looking at the vertical sensor arrays the concentration was above the LFL for the sensor 50 mm (2 in) above the floor. There was an increase for the sensor located 300 mm (12 in) above the floor, which eventually went above the LFL. Near the end of the release there is a rise in the refrigerant concentrations 900 mm (36 in) above the floor, this continues to rise as the refrigerant mixes and rises in the space. There was no significant refrigerant concentration at the sensor 150 mm (6 in) from the ceiling. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 76. The NDIR sensor in the unit did not function correctly during this test and the data was not usable. The MOS sensor registered 5% of refrigerant 7 seconds after the start of the refrigerant release.

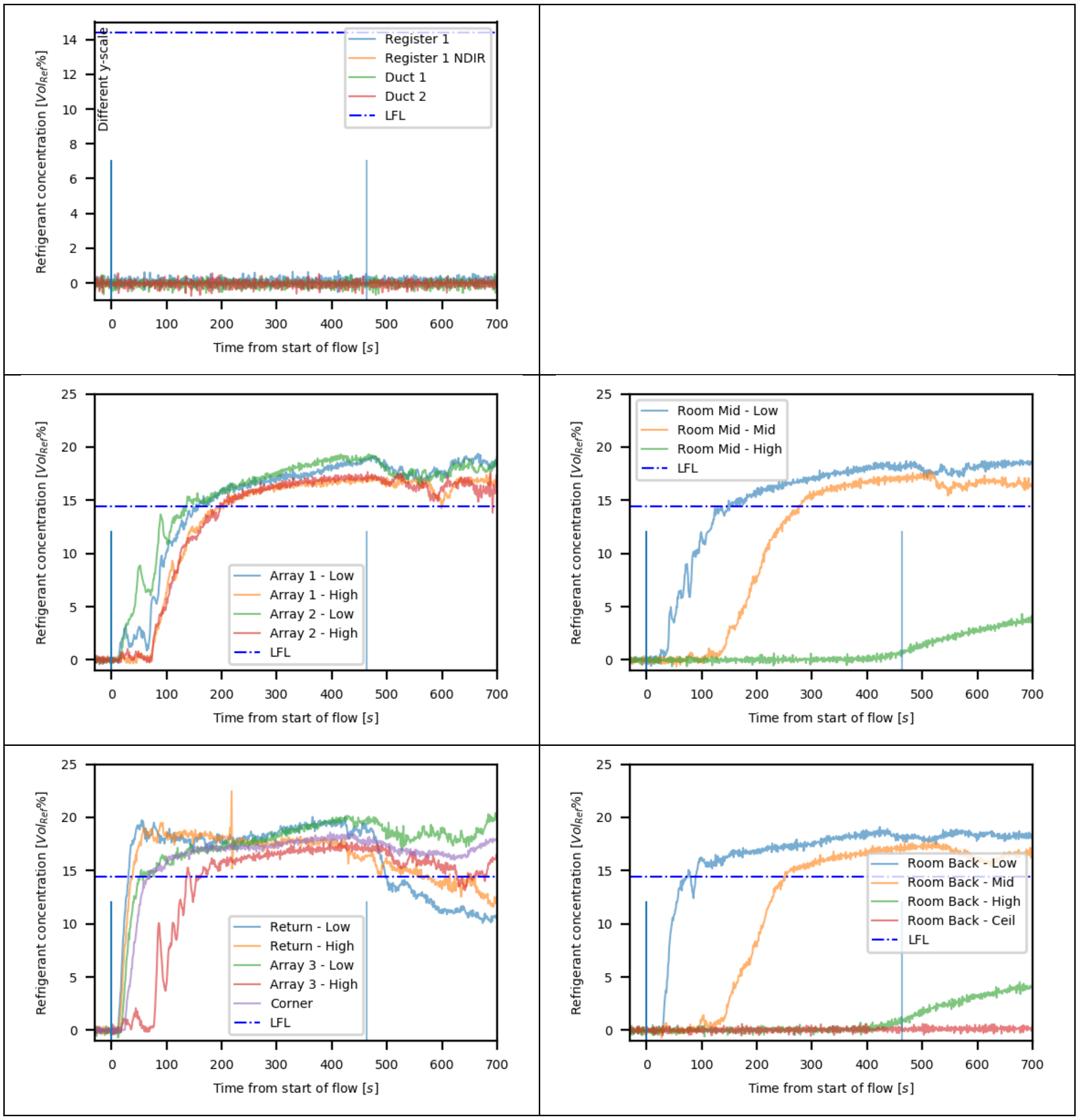


Table 76 – Vertical 11 Refrigerant Concentrations

(concentration timing around 25~100 seconds may be shifted due to deconvolution method)

3.2.12 **Vertical 12**

A summary of the test parameters for this test are indicated in Table 77. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	6.8 kg	Release Time	456 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	1390 m^3/hr

Table 77 - Vertical 12 Test Parameters

The maximum refrigerant concentration in the room was at Register 1 with 16%, concentrations did not start to rise at this point until 17 s after the release started when the blower was already energized. The sensor indicated above LFL for 1 data point. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 12 s after the start of the leak. But as the blower was energized the concentration stopped rising. The other sensors in this area had rising refrigerant concentrations until the blower was at moving air, but did not reach the LFL. None of the sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space, including near the ceiling. These vertical arrays also show that in these locations the refrigerant concertation does not start to rise until the blower starts to move the air. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 78. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 3% of refrigerant 16 seconds after the start of the refrigerant release.

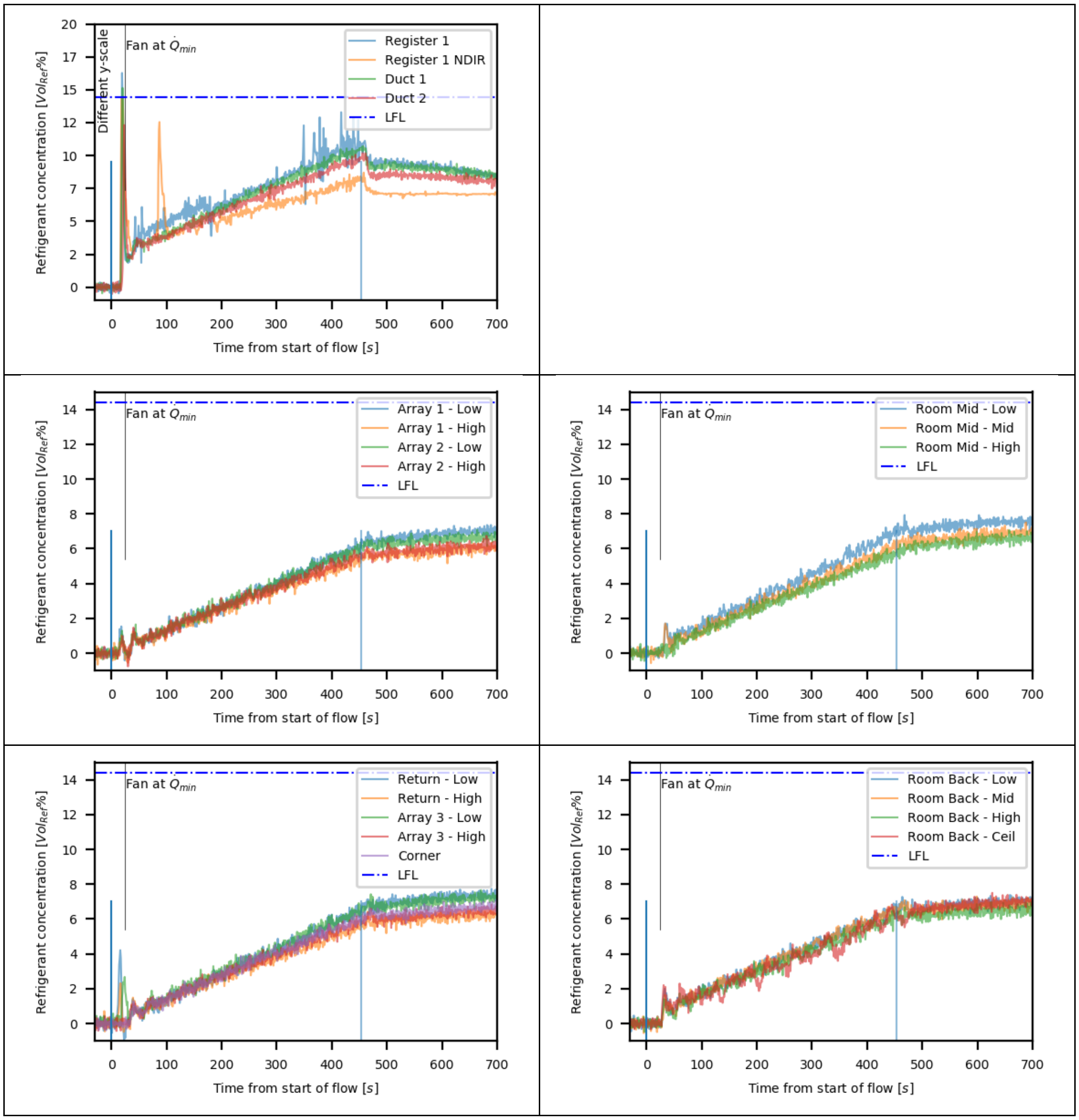


Table 78 – Vertical 12 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.13 **Vertical 13**

A summary of the test parameters for this test are indicated in Table 79. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	6.8 kg	Release Time	472 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	1390 m^3/hr

Table 79 - Vertical 13 Test Parameters

The maximum refrigerant concentration was observed at Register 1, which reached a maximum concentration of 19% when the airflow was near Qmin. Refrigerant concentrations started to rise at the return 50 mm (2 in) above the floor 13 s after the start of the leak, rising to 15% before the blower starting moving air to circulate the refrigerant which was affecting this location 30 s into the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 80. The NDIR sensor in the unit registered 50% of LFL at 4 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 7 seconds after the start of the refrigerant release.

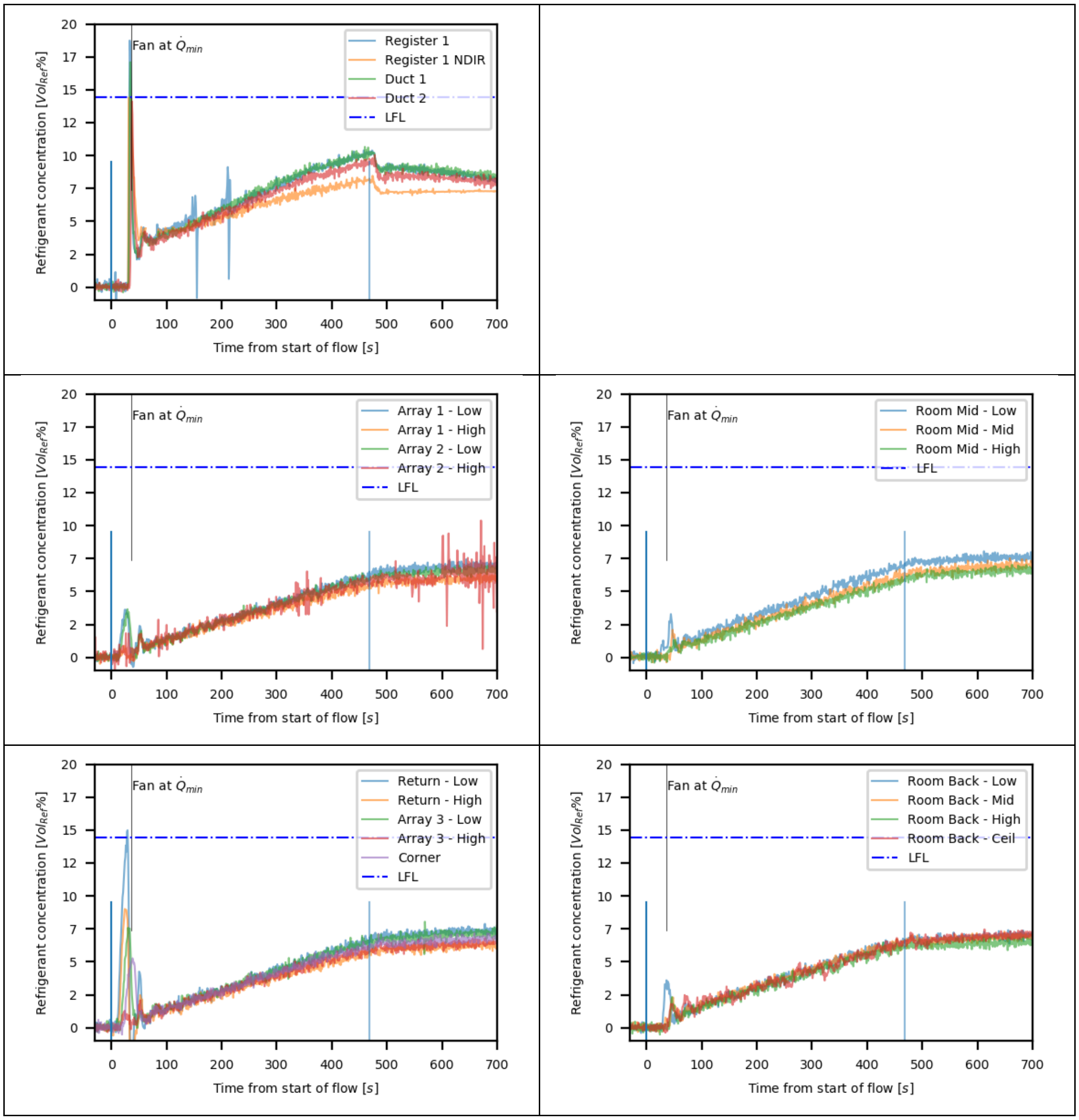


Table 80 – Vertical 13 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.14 Vertical 14

A summary of the test parameters for this test are indicated in Table 81. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	6.77 kg	Release Time	472 s
Release Quality	Liquid	Time to Qmin	25 s
		Fan Speed	2741 m^3/hr

Table 81 - Vertical 14 Test Parameters

The maximum refrigerant concentration was in the ductwork at Duct 1, which reached a maximum concentration of 12% when the blower was on, but the airflow was not yet at Qmin. Refrigerant concentrations started to rise at the return 50 mm (2 in) above the floor 12 s after the start of the leak, but the blower was energized near that time and the concentration reached 8% before increasing again with the remainder of the room space. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 82. The NDIR sensor in the unit registered an error 4 seconds after the start of the refrigerant release. The MOS sensor registered 4.5% of refrigerant 18 seconds after the start of the refrigerant release.

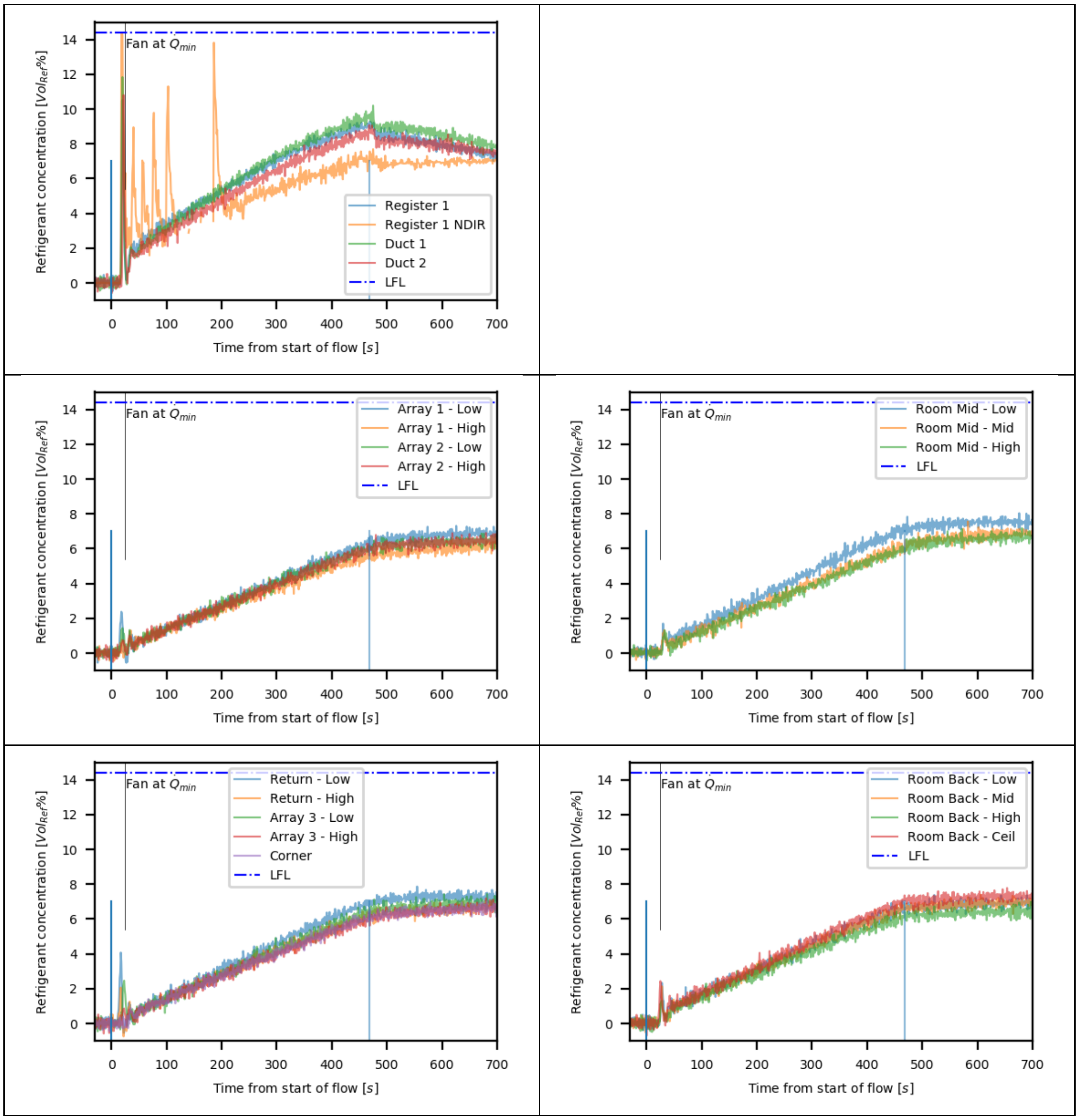


Table 82 – Vertical 14 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.15 **Vertical 15**

A summary of the test parameters for this test are indicated in Table 17. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	6.85 kg	Release Time	483 s
Release Quality	Liquid	Time to Qmin	35 s
		Fan Speed	2741 m^3/hr

Table 83 - Vertical 15 Test Parameters

Register 1 NDIR showed that the refrigerant coming into the space was at or above LFL for three seconds. This occurred 28 s into the test, and the blower had already been energized. Refrigerant concentrations started to rise at the return 50 mm (2 in) above the floor 12 s after the start of the leak, but once the blower was energized the concentration reached a local maximum of 12% before increasing again with the remainder of the room space. None of the other sensors in the test space reached the LFL. The vertical arrays show that there was good mixing throughout the room. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 84. The NDIR sensor in the unit registered an error prior to the start of the test and the data was not usable. The MOS sensor registered 5% of refrigerant 8 seconds after the start of the refrigerant release.

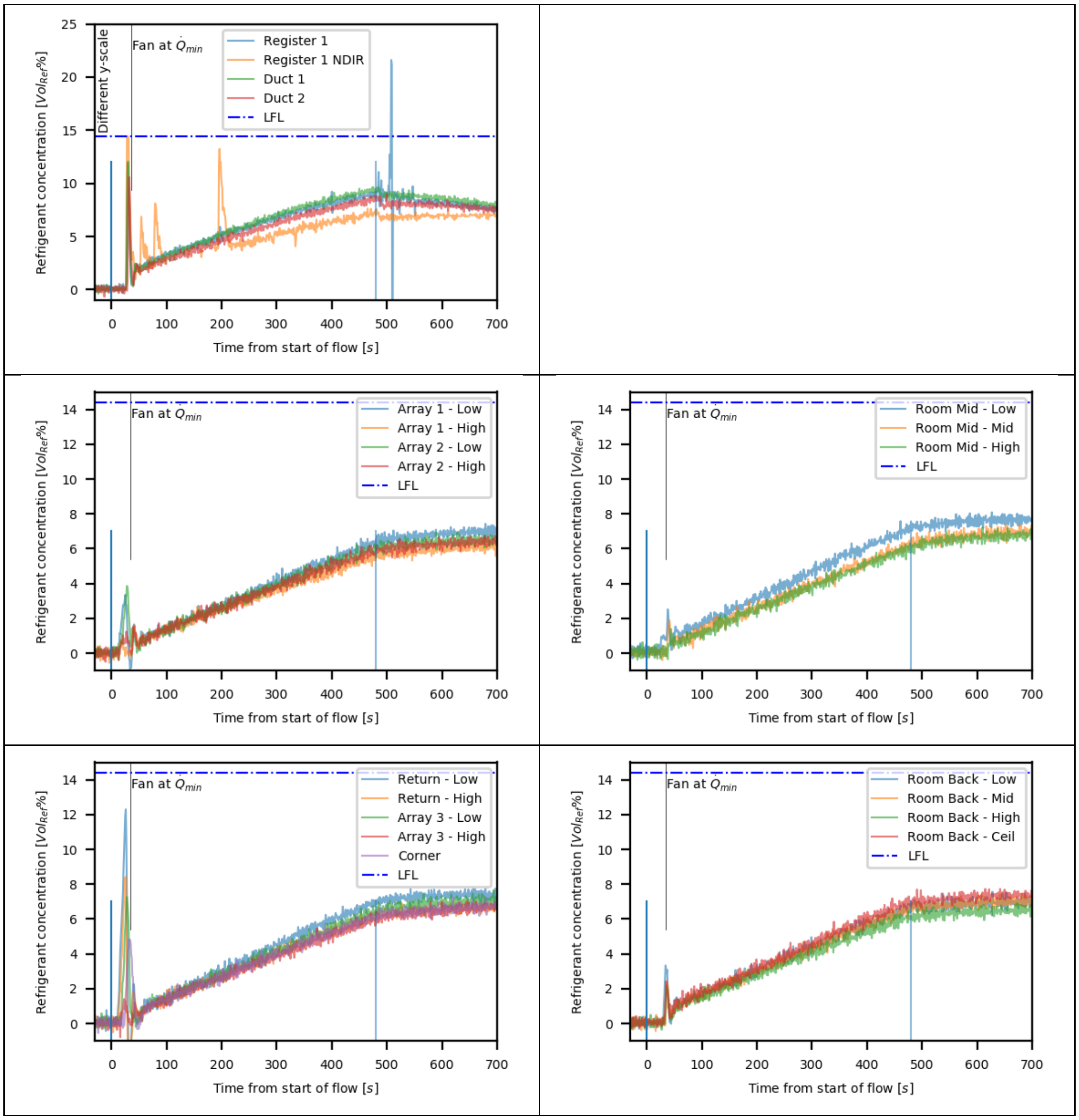


Table 84 – Vertical 15 Refrigerant Concentrations

(peak concentrations around 25~50 and 500~525 seconds may be overestimated due to deconvolution method)

3.2.16 **Vertical 16**

A summary of the test parameters for this test are indicated in Table 85. This test was conducted to establish the baseline parameters with no mitigation. The release was increased to be 50% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	6.78 kg	Release Time	448 s
Release Quality	Decay	Time to Qmin	N/A
		Fan Speed	N/A

Table 85 - Vertical 16 Test Parameters

The maximum refrigerant concentration was observed near the return 150 mm (6 in) above the floor, which reached a maximum concentration of 31%. Refrigerant concentrations started to rise at this location 10 s after the start of the leak. Refrigerant continued to flow out of the return and collect in the room. For the sensors near the return the higher refrigeration concentrations are with the sensors 50 mm (2 in) above the floor. Looking at the vertical sensor arrays the concentration was above the LFL for the sensor 50 mm (2 in) above the floor. There was an increase for the sensor located 300 mm (12 in) above the floor, which eventually went above the LFL. Near the end of the release there is a rise in the refrigerant concentrations 900 mm (36 in) above the floor, this continues to rise as the refrigerant mixes and rises in the space. There was no significant refrigerant concentration at the sensor 150 mm (6 in) from the ceiling. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 86. The NDIR sensor in the unit registered 50% of LFL at 6 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 17 seconds after the start of the refrigerant release.

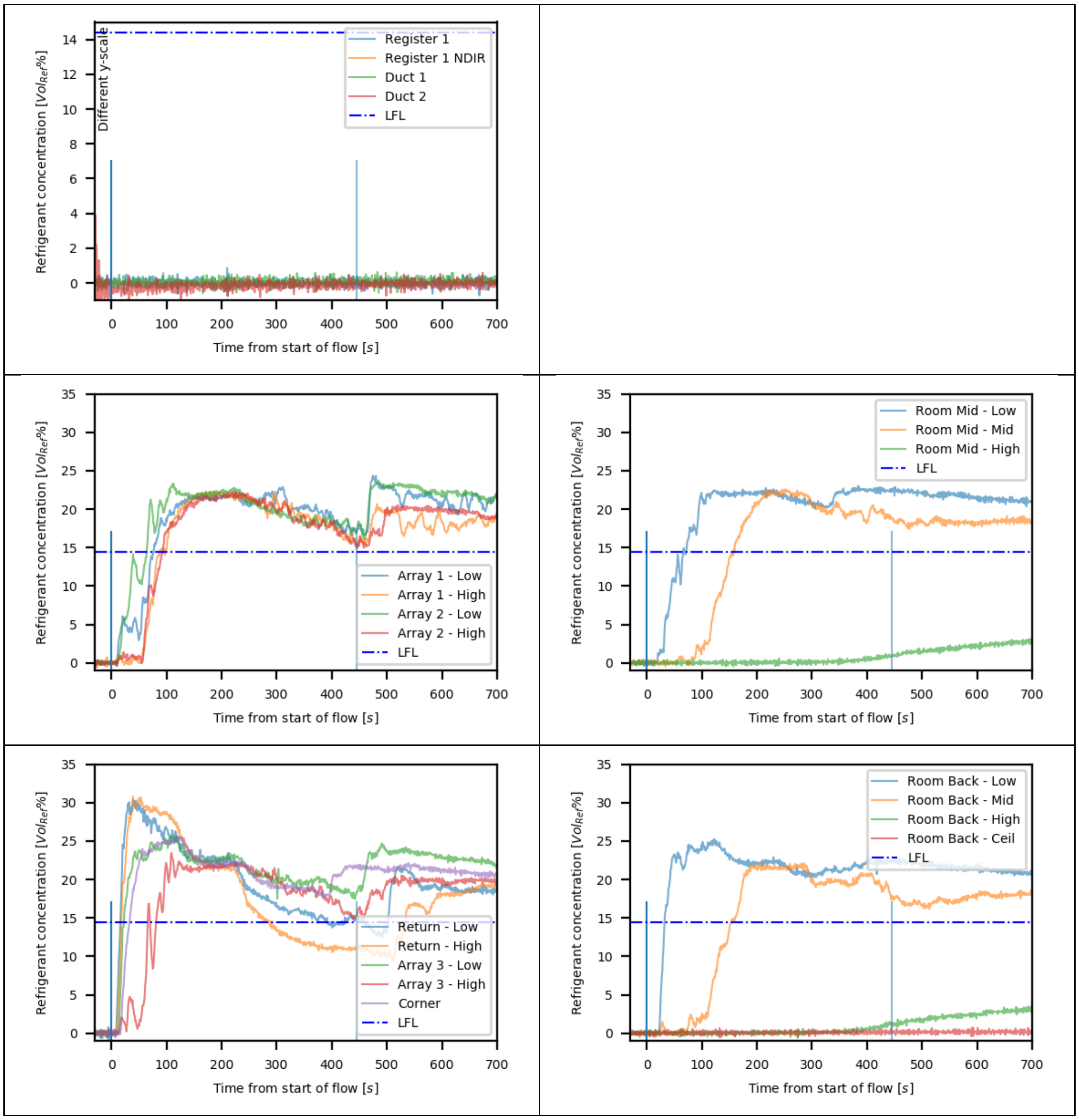


Table 86 – Vertical 16 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.17 **Vertical 17**

A summary of the test parameters for this test are indicated in Table 87. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release and airflow for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	6.81 kg	Release Time	450 s
Release Quality	Decay	Time to Qmin	25 s
		Fan Speed	1390 m^3/hr

Table 87 - Vertical 17 Test Parameters

The maximum refrigerant concentration in the room was at Register 1 with 34%, concentrations did not start to rise at this point until 17 s after the release started when the blower was already energized. The sensor indicated above LFL for 5 seconds. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 10 s after the start of the leak. But as the blower was energized the concentration had a local maximum before rising with the other sensors as the release continued. The other sensors in this area had rising refrigerant concentrations until the blower was at moving air, but did not reach the LFL. None of the sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space, although with some delay near the ceiling. These vertical arrays also show that in these locations the refrigerant concertation does not start to rise until the blower starts to move the air. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 88. The NDIR sensor in the unit registered an error 4 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 16 seconds after the start of the refrigerant release.

Note for this test the sensor at Array 1 – Low was getting some intermittent connection to the DAQ, this is amplified due to the deconvolution.

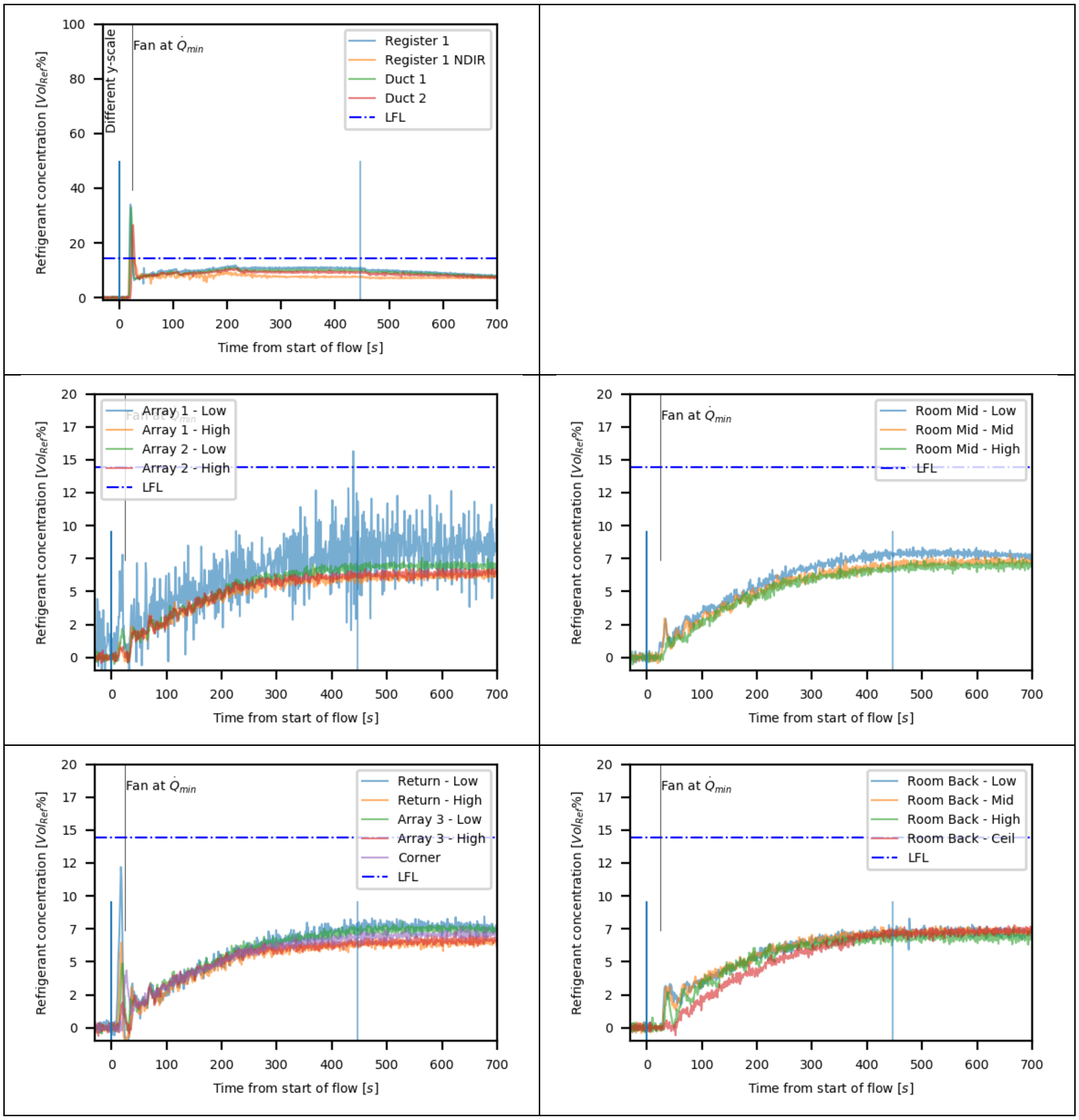


Table 88 – Vertical 17 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.18 **Vertical 18**

A summary of the test parameters for this test are indicated in Table 89. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	6.84 kg	Release Time	469 s
Release Quality	Decay	Time to Qmin	35 s
		Fan Speed	1390 m^3/hr

Table 89 - Vertical 18 Test Parameters

The maximum refrigerant concentration in the room was at Register 1 with 37%, concentrations did not start to rise at this point until 30 s after the release started when the blower was already energized. The sensor indicated above LFL for 6 seconds. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 11 s after the start of the leak and continued to rise and had a maximum refrigerant concentration of 27%, 30 seconds into the test. This sensor was above the LFL for 12 s. The other sensors in this area had rising refrigerant concentrations until the blower was at moving air, but did not reach the LFL. None of the other sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space, although with some delay near the ceiling. These vertical arrays also show that in these locations the refrigerant concertation does not start to rise until the blower starts to move the air. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 90.

Note for this test the sensor at Array 1 – Low was getting some intermittent connection to the DAQ, this is amplified due to the deconvolution. The NDIR sensor in the unit registered 50% of LFL at 5 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 8 seconds after the start of the refrigerant release.

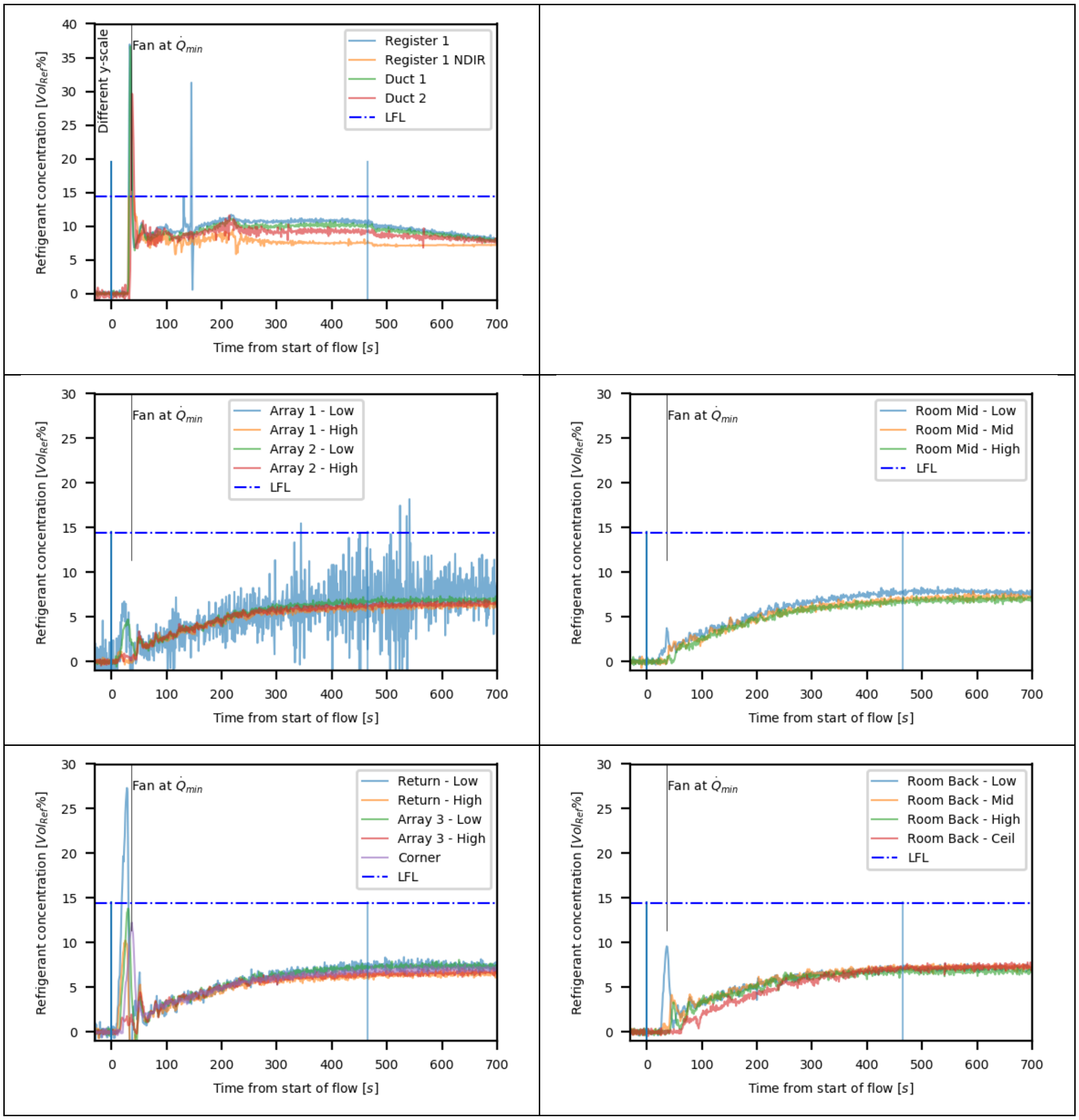


Table 90 – Vertical 18 Refrigerant Concentrations

(peak concentration around 25~75 seconds may be overestimated due to deconvolution method)

3.2.19 **Vertical 19**

A summary of the test parameters for this test are indicated in Table 91. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Choose new airflow		
Release Amount	6.84 kg	Release Time	468 s
Release Quality	Decay	Time to Qmin	25 s
		Fan Speed	2741 m^3/hr

Table 91 - Vertical 19 Test Parameters

The maximum refrigerant concentration in the room was at Register 1 with 20%, concentrations did not start to rise at this location until 19 s after the release started when the blower was already energized. The sensor indicated above LFL for 3 seconds. Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 11 s after the start of the leak and continued to rise and had a maximum refrigerant concentration of 19%, 18 seconds into the test. This sensor was above the LFL for 4 s. The other sensors in this area had rising refrigerant concentrations until the blower was at moving air, but did not reach the LFL. None of the other sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space, including near the ceiling. These vertical arrays also show that in these locations the refrigerant concertation does not start to rise until the blower starts to move the air. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 92. The NDIR sensor in the unit registered an error 5 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 13 seconds after the start of the refrigerant release.

Note for this test the sensor at Array 1 – Low was getting some intermittent connection to the DAQ, this is amplified due to the deconvolution.

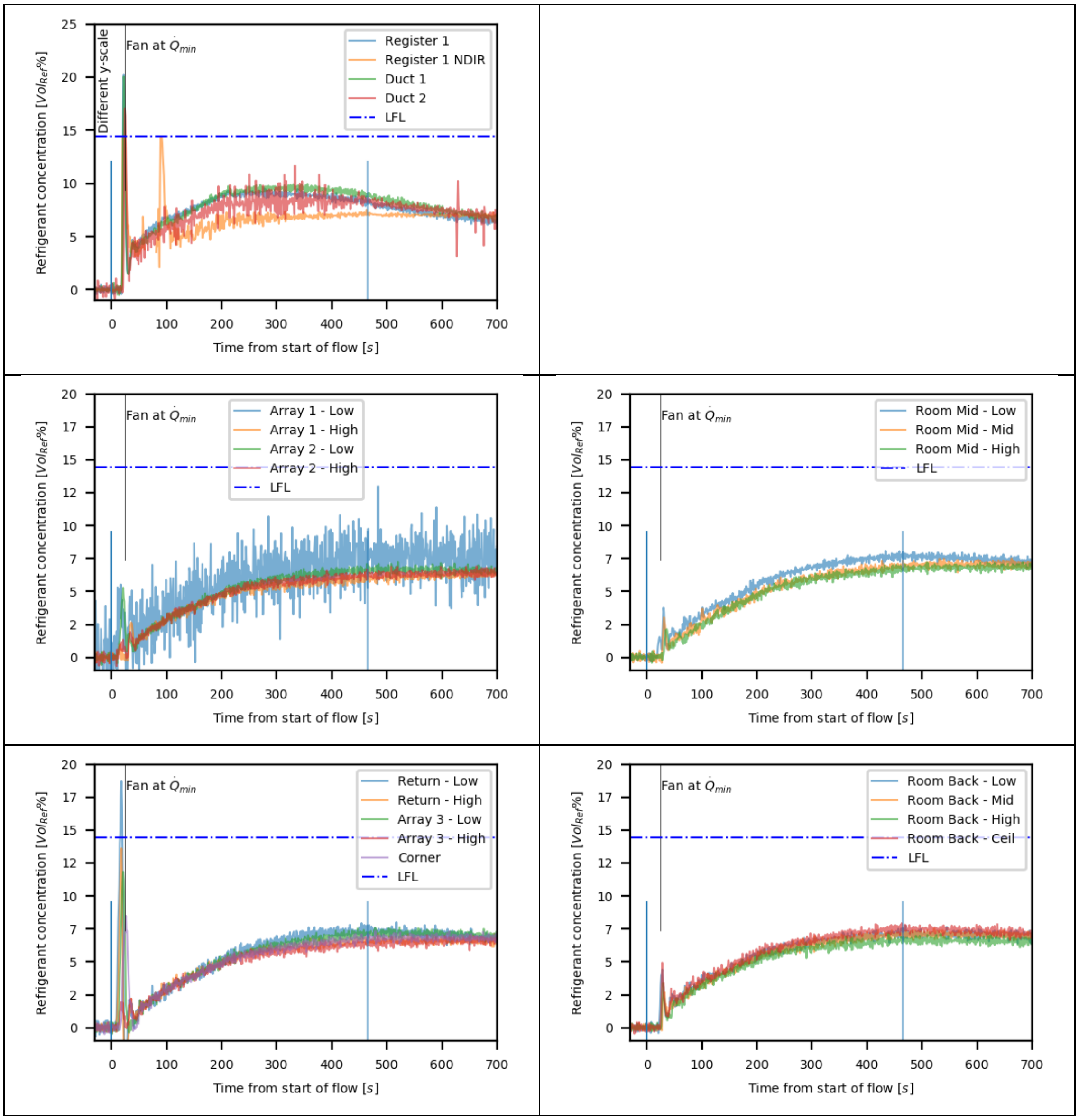


Table 92 – Vertical 19 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.20 **Vertical 20**

A summary of the test parameters for this test are indicated in. This test was conducted with the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard increased by a factor of two times. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & airflow		
Release Amount	6.81 kg	Release Time	484 s
Release Quality	Decay	Time to Qmin	35 s
		Fan Speed	2741 m^3/hr

Table 93 - Vertical 20 Test Parameters

Refrigerant concentrations started to rise at the Return sensor located 50 mm (2 in) above the floor 11 s after the start of the leak and continued to rise and had a maximum refrigerant concentration of 28%, 27 seconds into the test. This sensor was above the LFL for 14 s. The other sensors in that area also had local maximums before the blower was at Qmin. This resulted in the sensors at Array 3 and the Corner that were 50 mm (2 in) above the floor above the LFL for 10 s and 2 s, respectively.

This test had higher refrigerant concentrations near the return that other tests with these similar parameters. In order to meet the airflow for this test and Vertical 19 the restriction on the inlet of the air hander needed to be reduced. This resulted in running the blower motor at a different speed as well as modifying the time that we needed to activate the blower to be at Qmin at the specified time. It was this change in the time to start the blower and start moving air that allowed these higher concentrations, even with greater airflow.

The other sensors in this area had rising refrigerant concentrations until the blower was at moving air, but did not reach the LFL. None of the other sensors in the test space reached the LFL during this tests. The vertical arrays in the room show refrigerant mixing well in the space, including near the ceiling. The sensor at the back of the room 50 mm (2 in) off the floor had a value with approached the LFL, this sensor started increasing at 23 s into the test, which may not have been introduced to that location by the blower. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 94. The NDIR sensor in the unit registered an error 4 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 13 seconds after the start of the refrigerant release.

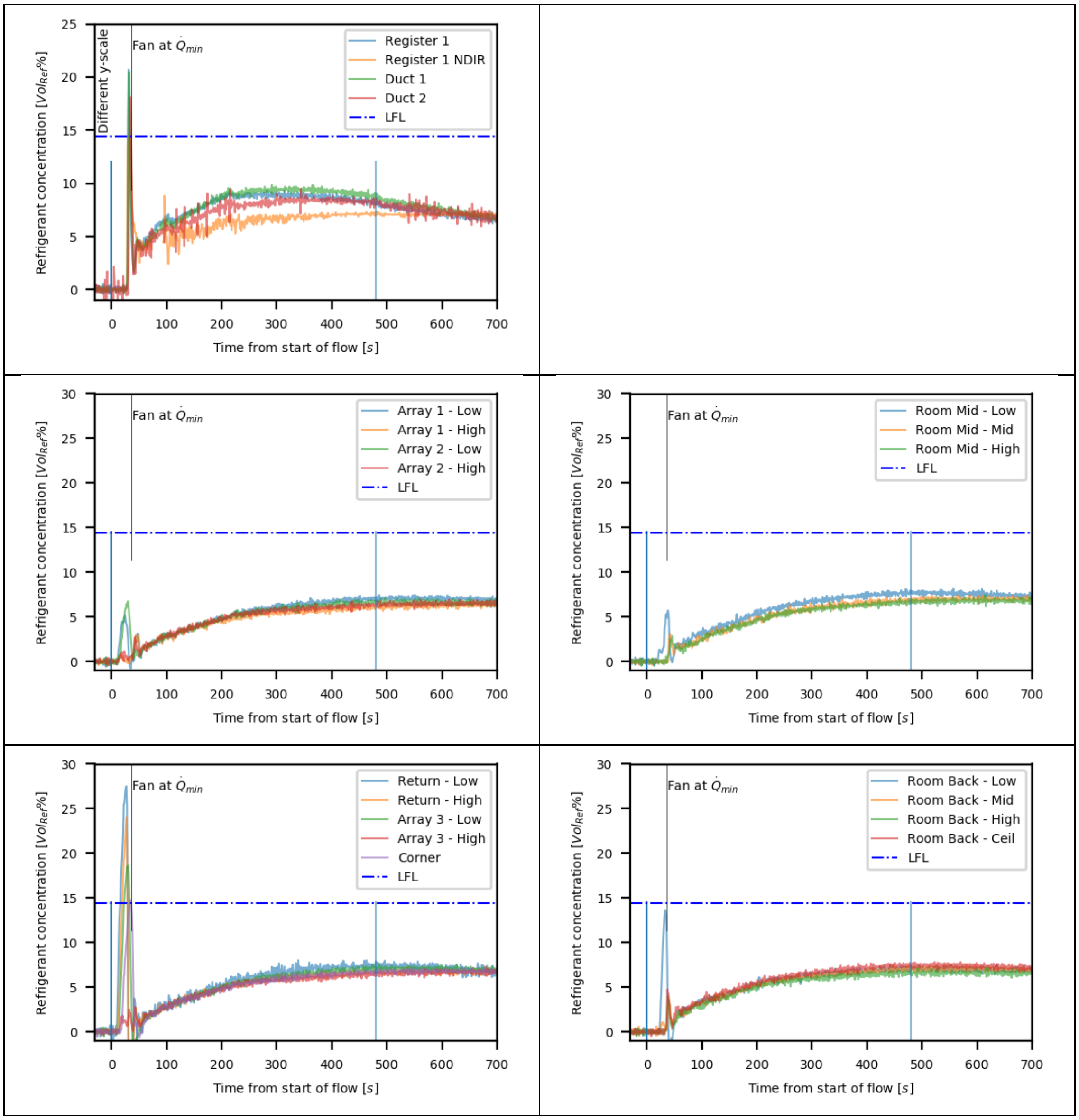


Table 94 – Vertical 20 Refrigerant Concentrations

(peak concentration around 15~50 seconds may be overestimated due to deconvolution method)

3.2.21 **Vertical 21**

A summary of the test parameters for this test are indicated in Table 95. This test was conducted the response time for the unit to reach Qmin at 10 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 25% of the LFL for the entire room.

Test Summary	IEC 2-40 (3.42 kg)		
Release Amount	3.42 kg	Release Time	225 s
Release Quality	Liquid	Time to Qmin	10 s
		Fan Speed	552 m^3/hr

Table 95 - Vertical 21 Test Parameters

The maximum refrigerant concentration was observed with the NDIR sensor at Register 1, which reached a maximum concentration of 11%. The sensors at Register 1 and Registers 2 had refrigerant concentrations at or above the LFL during the release. All of the sensors in the room space and located near the return showed increases over the duration of the release, approaching the LFL, but remained below the LFL through the duration of the test.

The ductwork between Register 2 and Register 3 had been sealed off with a sheet metal plate and aluminum tape prior to the start of this series. There was still refrigerant concentrations building in this space during the release.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 96. The NDIR sensor in the unit registered 50% of LFL at 4 seconds after the start of the refrigerant release. The MOS sensor registered 2% of refrigerant 25 seconds after the start of the refrigerant release.

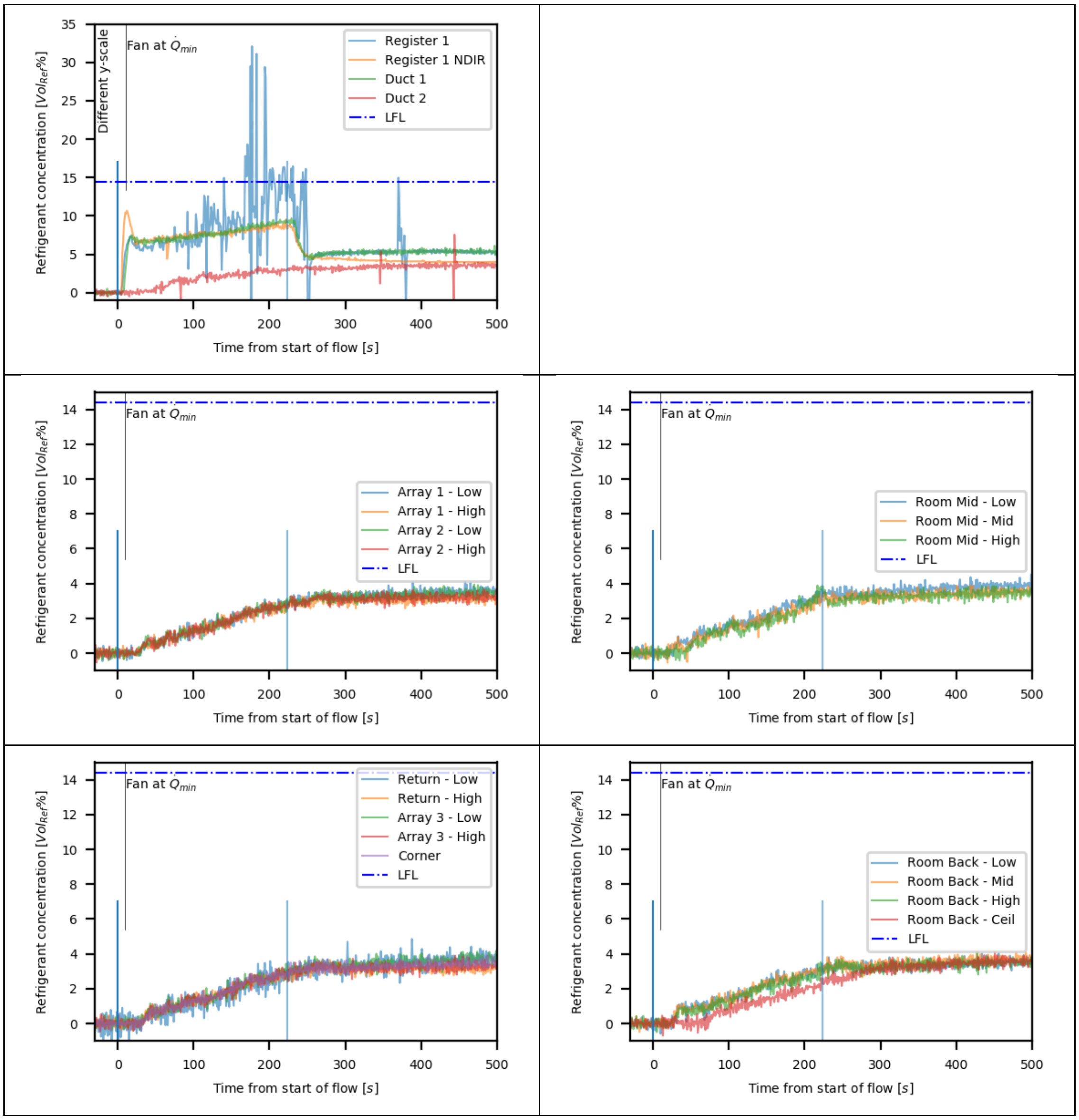


Table 96 – Vertical 21 Refrigerant Concentrations

(peak concentration around 5~25 seconds may be overestimated due to deconvolution method)

3.2.22 **Vertical 22**

A summary of the test parameters for this test are indicated in Table 97. This test was conducted the response time for the unit to reach Qmin at 30 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 25% of the LFL for the entire room.

Test Summary	IEC 2-40 (3.42 kg)		
Release Amount	3.38 kg	Release Time	222 s
Release Quality	Liquid	Time to Qmin	30 s
		Fan Speed	552 m^3/hr

Table 97 - Vertical 22 Test Parameters

The maximum refrigerant concentration was observed with the sensor at Register 1, which reached a maximum concentration of 18%. This sensor started to rise 26 s into the test, after the fan was energized. The sensors at the register and in the duct were higher than the other sensors in the space, but did not exceed the LFL during the test. All of the sensors in the room space remained below the LFL through the duration of the test.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 98. The NDIR sensor in the unit registered 50% of LFL at 3 seconds after the start of the refrigerant release. The MOS sensor registered 2.5% of refrigerant 24 seconds after the start of the refrigerant release.

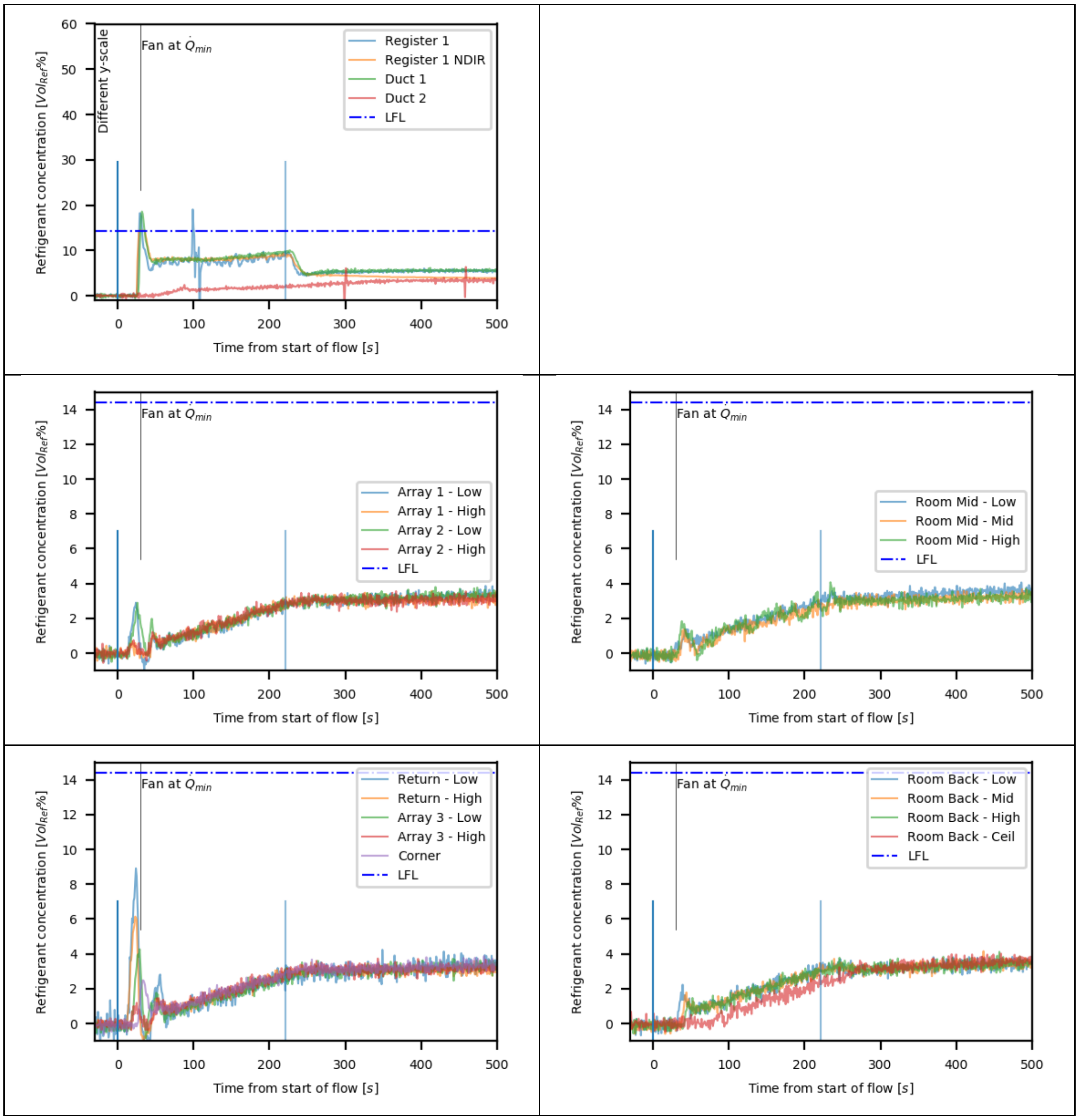


Table 98 – Vertical 22 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.2.23 **Vertical 23**

A summary of the test parameters for this test are indicated in Table 24. This test was conducted the response time for the unit to reach Qmin at 10 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 50% of the LFL for the entire room.

Test Summary	IEC 2-40 – 2*charge (6.84 kg)		
Release Amount	6.8 kg	Release Time	222 s
Release Quality	Liquid	Time to Qmin	10 s
		Fan Speed	698 m^3/hr

Table 99 - Vertical 23 Test Parameters

The maximum refrigerant concentration was observed with the sensor at Register 1, which reached a maximum concentration of 25%. This sensor started to rise 10 s into the test as the fan reached Qmin. The sensors at the register and in the duct were at the LFL for the entire release. All of the sensors in the room space and located near the return showed increases over the duration of the release, but remained below the LFL through the duration of the test.

The ductwork between Register 2 and Register 3 had been sealed off with a sheet metal plate and aluminum tape prior to the start of this series. There was still refrigerant concentrations building in this space during the release.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 100. The NDIR sensor in the unit registered 50% of LFL at 16 seconds after the start of the refrigerant release. The MOS sensor registered 4% of refrigerant 18 seconds after the start of the refrigerant release.

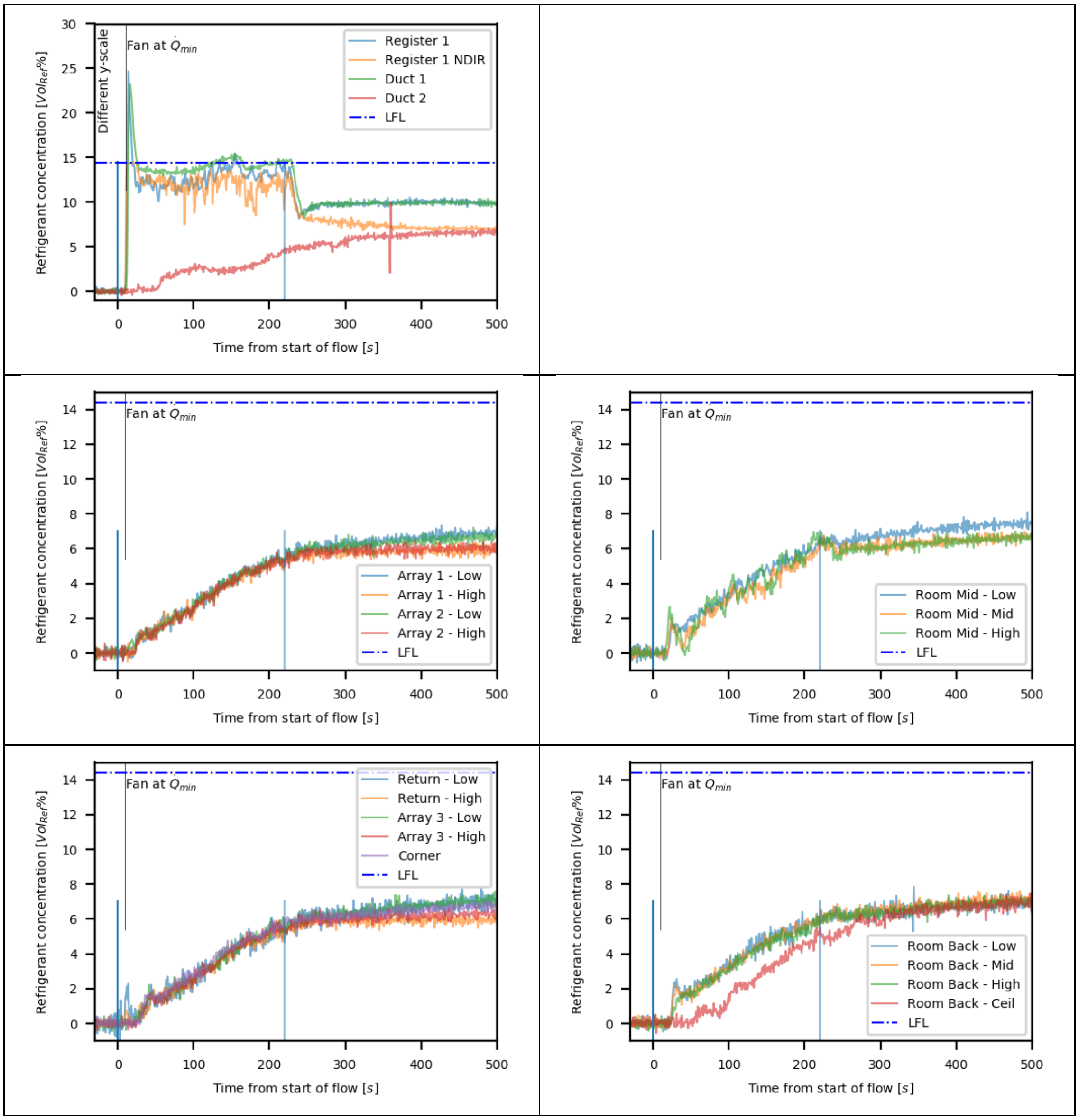


Table 100 – Vertical 23 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

3.2.24 **Vertical 24**

A summary of the test parameters for this test are indicated in Table 101. This test was conducted the response time for the unit to reach Qmin at 30 s and with the volumetric flow required by Table GG.2 of IEC -2-40. Airflow only discharged through the first two registers during this test. The mass release for this test was calculated based on 50% of the LFL for the entire room.

Test Summary	IEC 2-40 – 2*charge (6.84 kg)		
Release Amount	6.91 kg	Release Time	217 s
Release Quality	Liquid	Time to Qmin	30 s
		Fan Speed	698 m^3/hr

Table 101 - Vertical 24 Test Parameters

The maximum refrigerant concentration was observed with the sensor at Register 1, which reached a maximum concentration of 29%. The sensors at the register and in the duct were at the LFL for the entire release. Prior to the fan being activated there was refrigerant present at the return, the sensor 50 mm (2 in) above the floor started to rise at 11 s into the test and reached a local maximum of 24% 26 s into the test. The sensor in this location 150 mm (6 in) above the floor was 15% 25 s into the test. The remaining sensors in the room space and located near the return showed increases over the duration of the release, but remained below the LFL through the duration of the test.

Refrigerant concentrations for the sensors over the duration of the test are shown in Table 102. The NDIR sensor in the unit registered 50% of LFL at 6 seconds after the start of the refrigerant release. The MOS sensor registered 5% of refrigerant 15 seconds after the start of the refrigerant release.

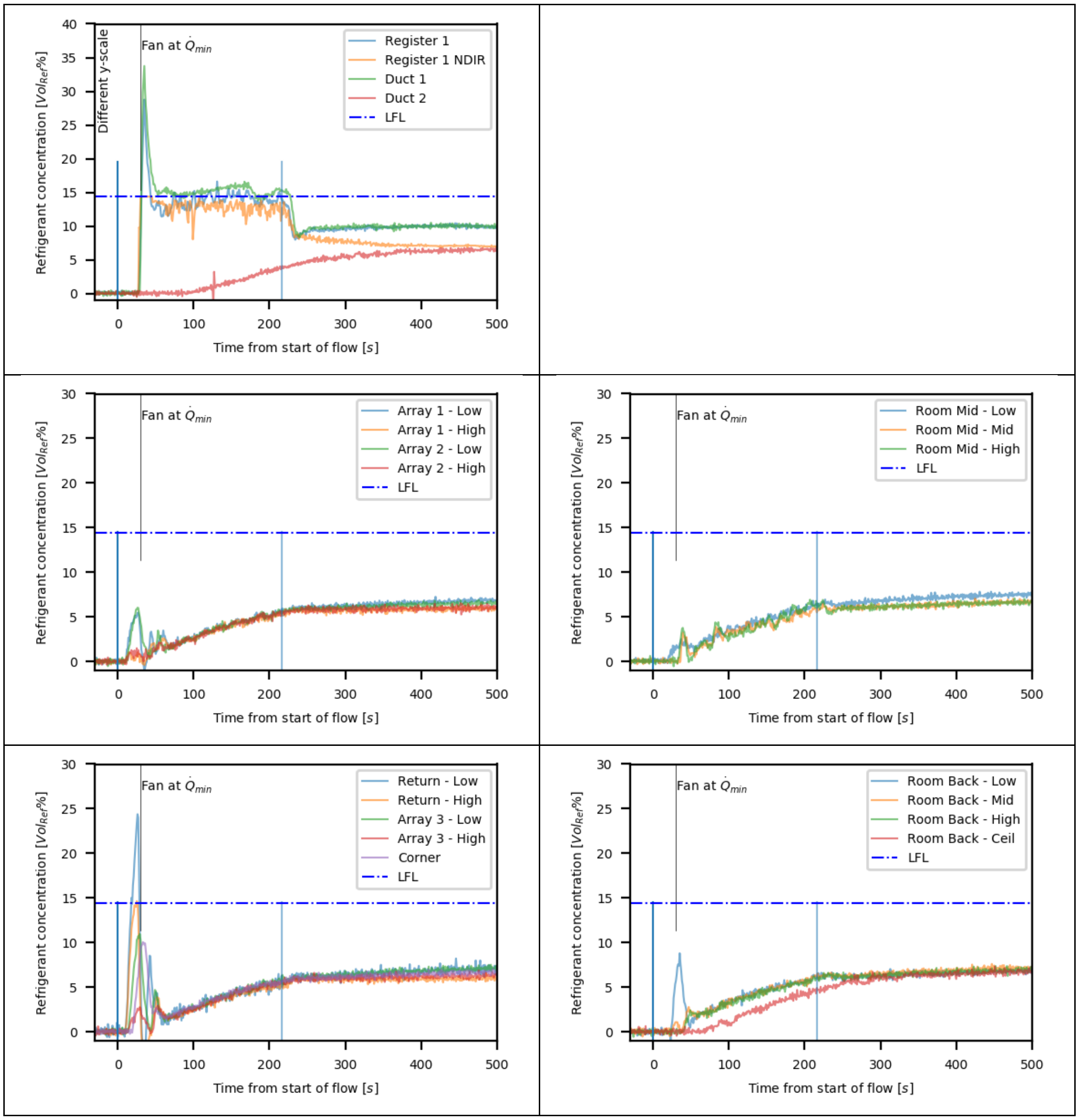


Table 102 – Vertical 24 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3 Ductless

Figure 13 provides an overview of the interior of the test room. Figure 14 details the sensor locations for the refrigeration sensors inside the test room. Colors are used to details sensors which are in the same general location in the room space: blue stars are sensors in the array below the unit, green stars are sensors located near the discharge location, and purple stars are sensors located out in the room space. The orange circle indicates the location of the NDIR sensor, centered below the unit near sensor 2-0.

Figure 13 - Ductless Room Arrangement

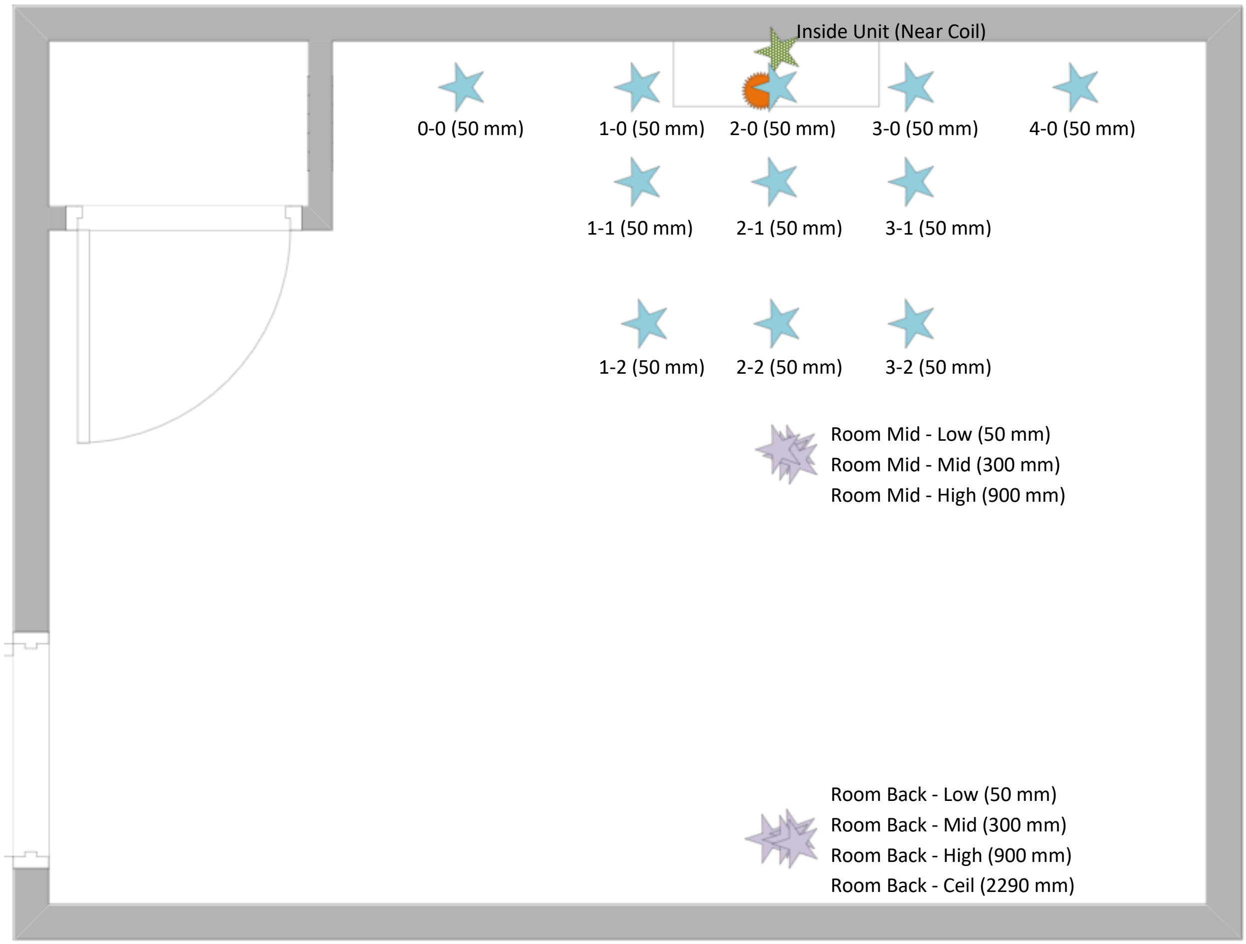


Figure 14 - Ductless Sensor Layout

3.3.1 **Ductless 1**

A summary of the test parameters for this test are indicated in Table 103. This test was conducted to establish the baseline parameters with no mitigation. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	3.39 kg	Release Time	226 s
Release Quality	Liquid	Time to Qmin	N/A
Installation Height	1.8 m	Fan Speed	N/A

Table 103 - Ductless 1 Test Parameters

This mitigation time and duration are sufficient to ensure that all of the sensors remained below the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 104. The NDIR sensor in the unit registered 50% of LFL at 11 seconds after the start of the refrigerant release. The MOS sensor for this test did not register an appreciable amount of refrigerant.

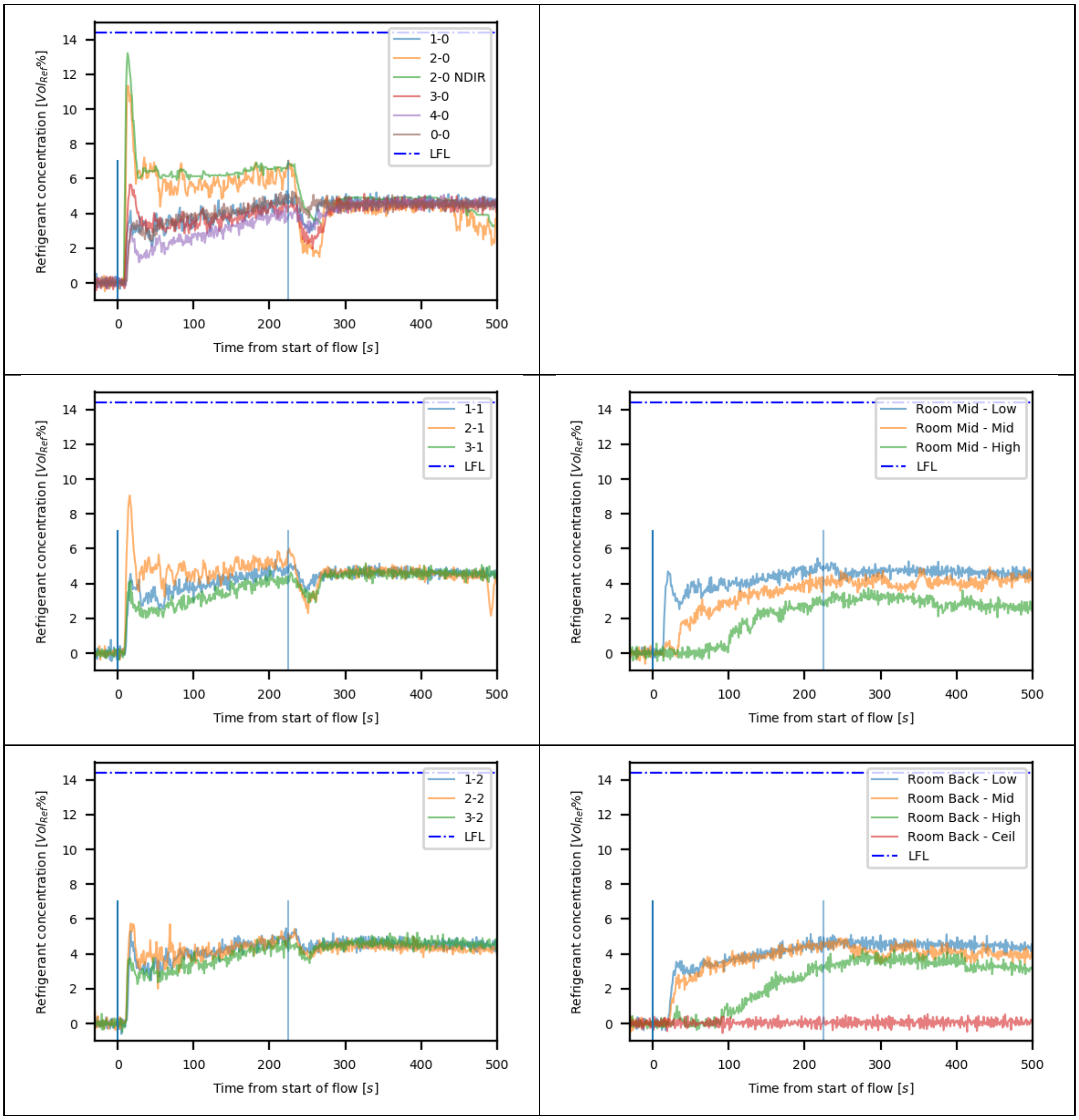


Table 104 – Ductless 1 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3.2 **Ductless 2**

A summary of the test parameters for this test are indicated in xx. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	3.44 kg	Release Time	228 s
Release Quality	Liquid	Time to Qmin	25 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 105 - Ductless 2 Test Parameters

This mitigation time and duration are sufficient to ensure that all of the sensors remained below the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 106. The NDIR sensor in the unit registered 50% of LFL at 4 seconds after the start of the refrigerant release. The MOS sensor registered 1.5% of refrigerant 23 seconds after the start of the refrigerant release.

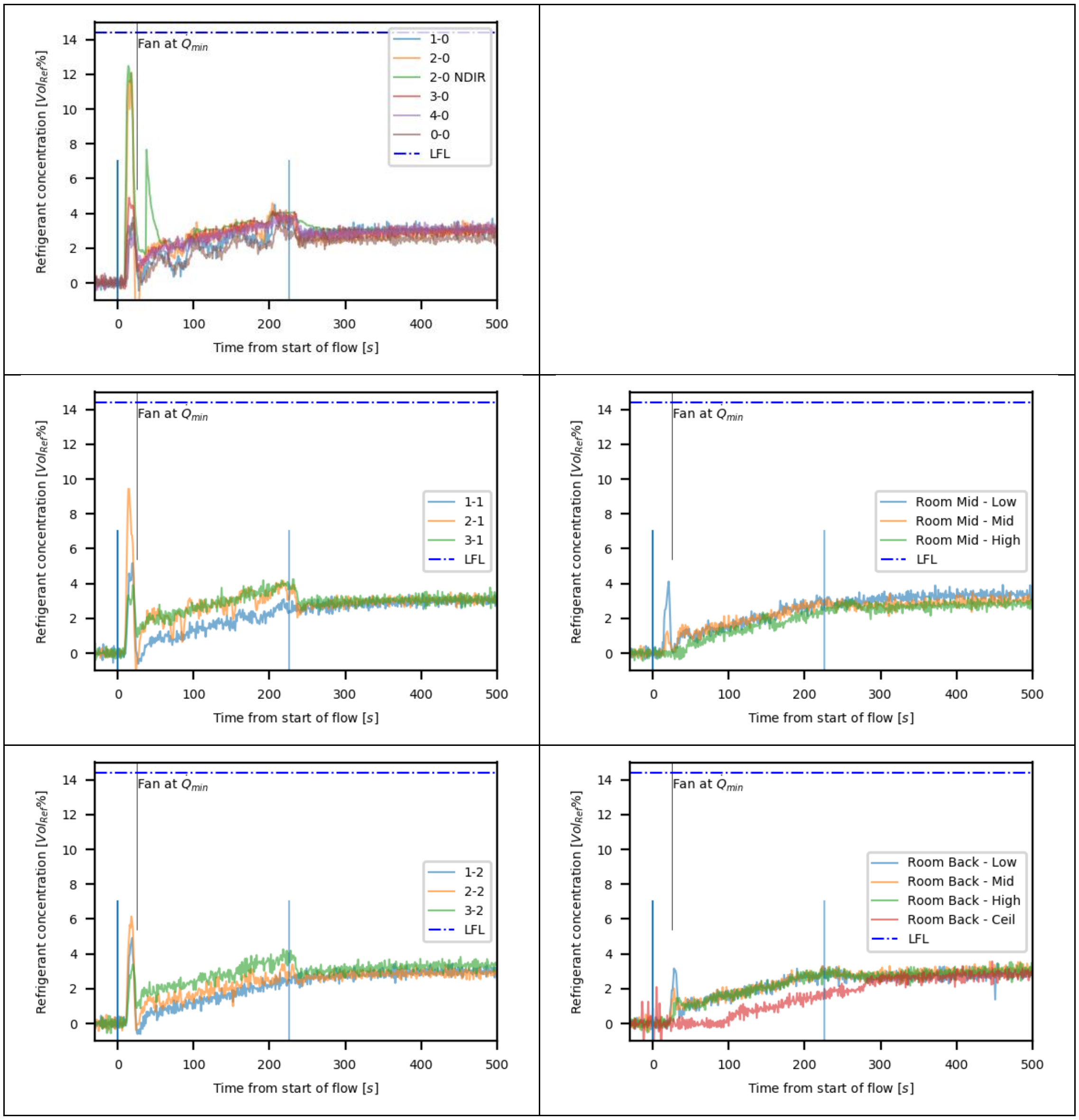


Table 106 – Ductless 2 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3.3 Ductless 3

A summary of the test parameters for this test are indicated in xx. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	3.42 kg	Release Time	225 s
Release Quality	Liquid	Time to Qmin	35 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 107 - Ductless 3 Test Parameters

This mitigation time and duration are sufficient to ensure that all of the sensors remained below the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 108. The NDIR sensor in the unit registered 50% of LFL at 13 seconds after the start of the refrigerant release. The MOS sensor for this test did not register an appreciable amount of refrigerant.

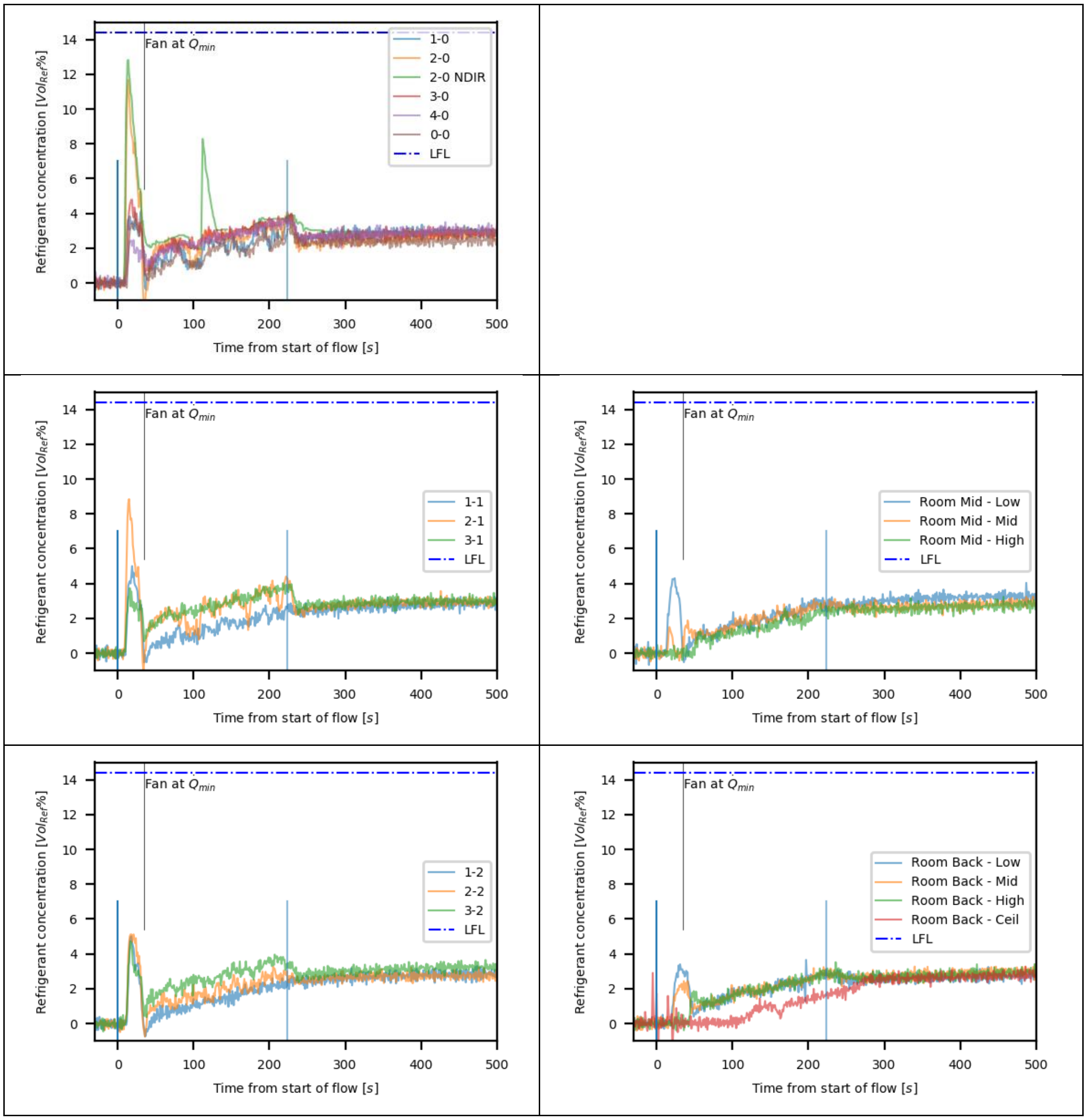


Table 108 – Ductless 3 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3.4 **Ductless 4**

A summary of the test parameters for this test are indicated in Table 109. This test was conducted to establish the baseline parameters with no mitigation. The release mass was calculated to be 25% of the LFL for the entire room volume. This are the same parameters as Ductless 1.

Test Summary	Baseline - confirmation of drain pan		
Release Amount	3.42 kg	Release Time	229 s
Release Quality	Liquid	Time to Qmin	N/A
Installation Height	1.8 m	Fan Speed	N/A

Table 109 - Ductless 4 Test Parameters

This test was a repeat of Ductless 1. Upon reviewing that data it appeared that not all of the refrigerant released had entered the test space. For this test we have added in a thermocouple which is held in good thermal contact with the base pan. A camera was placed next to the coil in the unit, oriented looking down into the drain pan. This camera identified the presence of liquid refrigerant in the drain pan, see Figure 15.

The test room was let sit overnight. Total time to boil off refrigerant was 3.7 hours. Due to the location of the NDIR and MOS sensor there was not a significant refrigeration concentration by the sensors, and this resulted in concentrations which were not significant for either sensor. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 110.

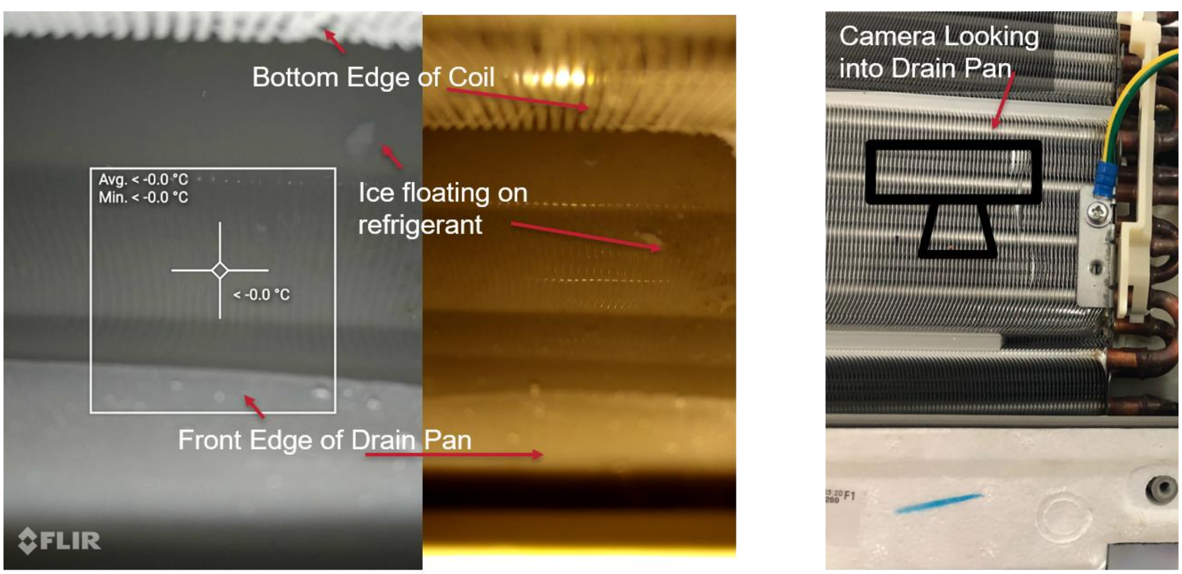


Figure 15 - Liquid Refrigerant in Drain pan

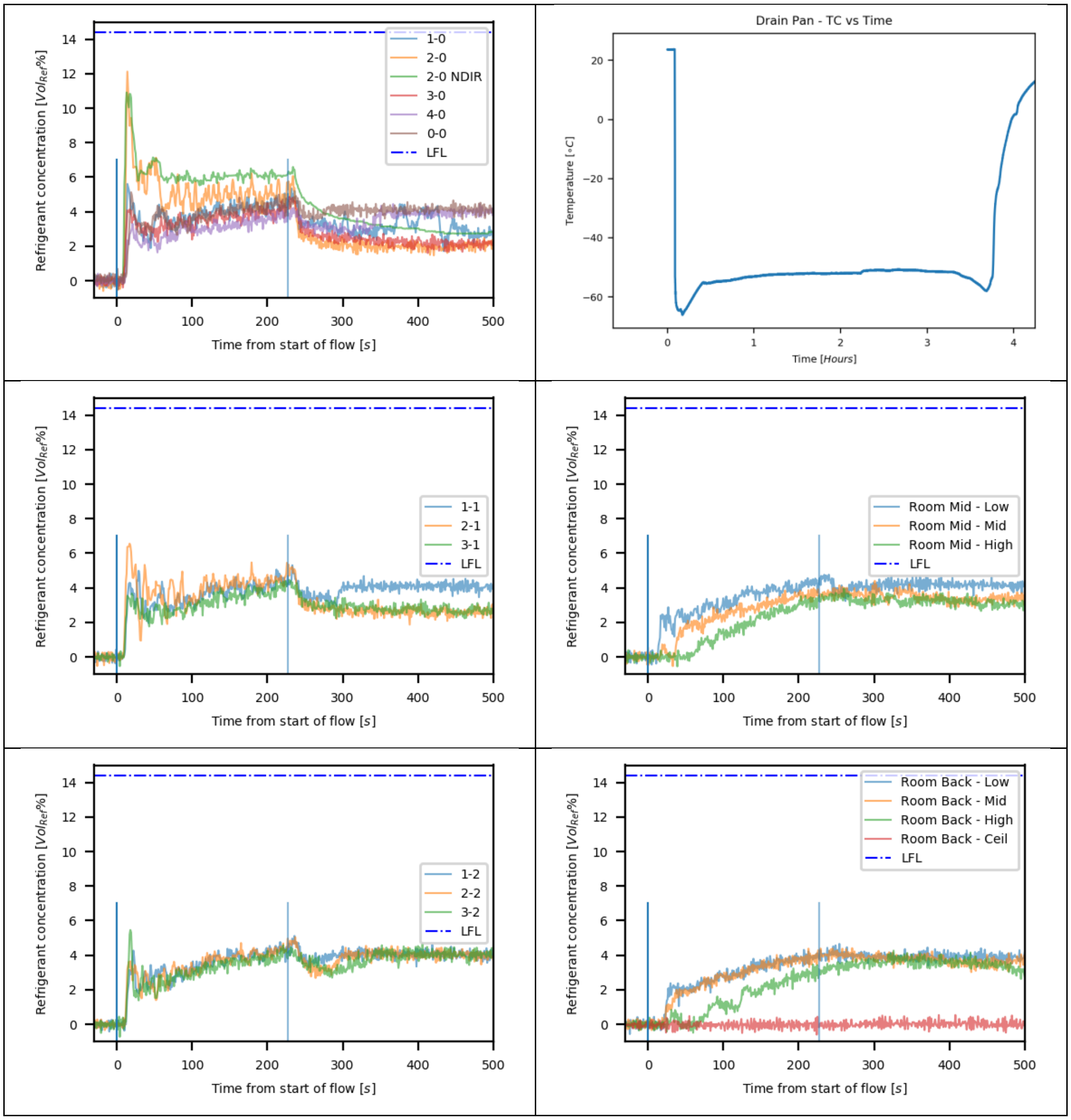


Table 110 – Ductless 4 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3.5 Ductless 5

A summary of the test parameters for this test are indicated in Table 111. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 25% of the LFL for the entire room volume. This test was a repeat of Ductless 3.

Test Summary	Longer activation time		
Release Amount	3.42 kg	Release Time	227 s
Release Quality	Liquid	Time to Qmin	35 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 111 - Ductless 5 Test Parameters

This mitigation time and duration are sufficient to ensure that all of the sensors remained below the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 112. The NDIR sensor in the unit registered a local maximum of 27% of LFL at 15 seconds after the start of the refrigerant release. The MOS sensor for this test did not register an appreciable amount of refrigerant.

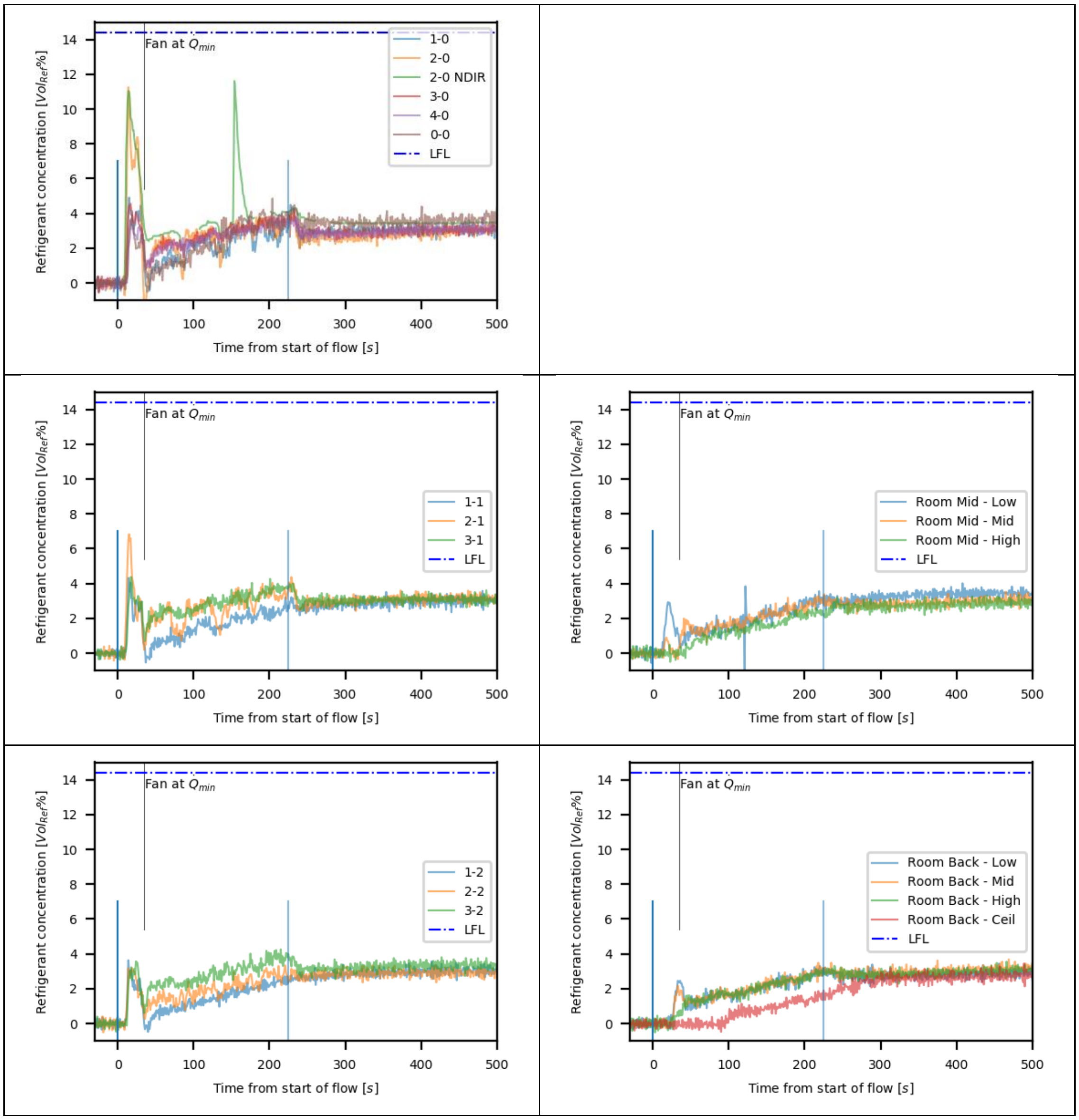


Table 112 – Ductless 5 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3.6 Ductless 6

A summary of the test parameters for this test are indicated in Table 113. This test was conducted to establish the baseline parameters with no mitigation. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	3.43 kg	Release Time	266 s
Release Quality	Vapor	Time to Qmin	N/A
Installation Height	1.8 m	Fan Speed	N/A

Table 113 - Ductless 6 Test Parameters

At the start of the test sensor 2-0 located 50 mm (2 in) above the floor reached a peak concentration of 21% refrigerant and remained above the LFL for five seconds. The other sensors remained below the LFL and the refrigerant was concentrated at the lower part of the room. There was rise at the 900 mm (36 in) sensors in the middle and back of the room, but it was lower than the sensors in those same positions at 50 mm (2 in) and 300 mm (12 in). Refrigerant concentrations for the sensors over the duration of the test are shown in Table 114. The NDIR sensor in the unit registered 50% of LFL at 28 seconds after the start of the refrigerant release. The MOS sensor for this test did not register an appreciable amount of refrigerant.

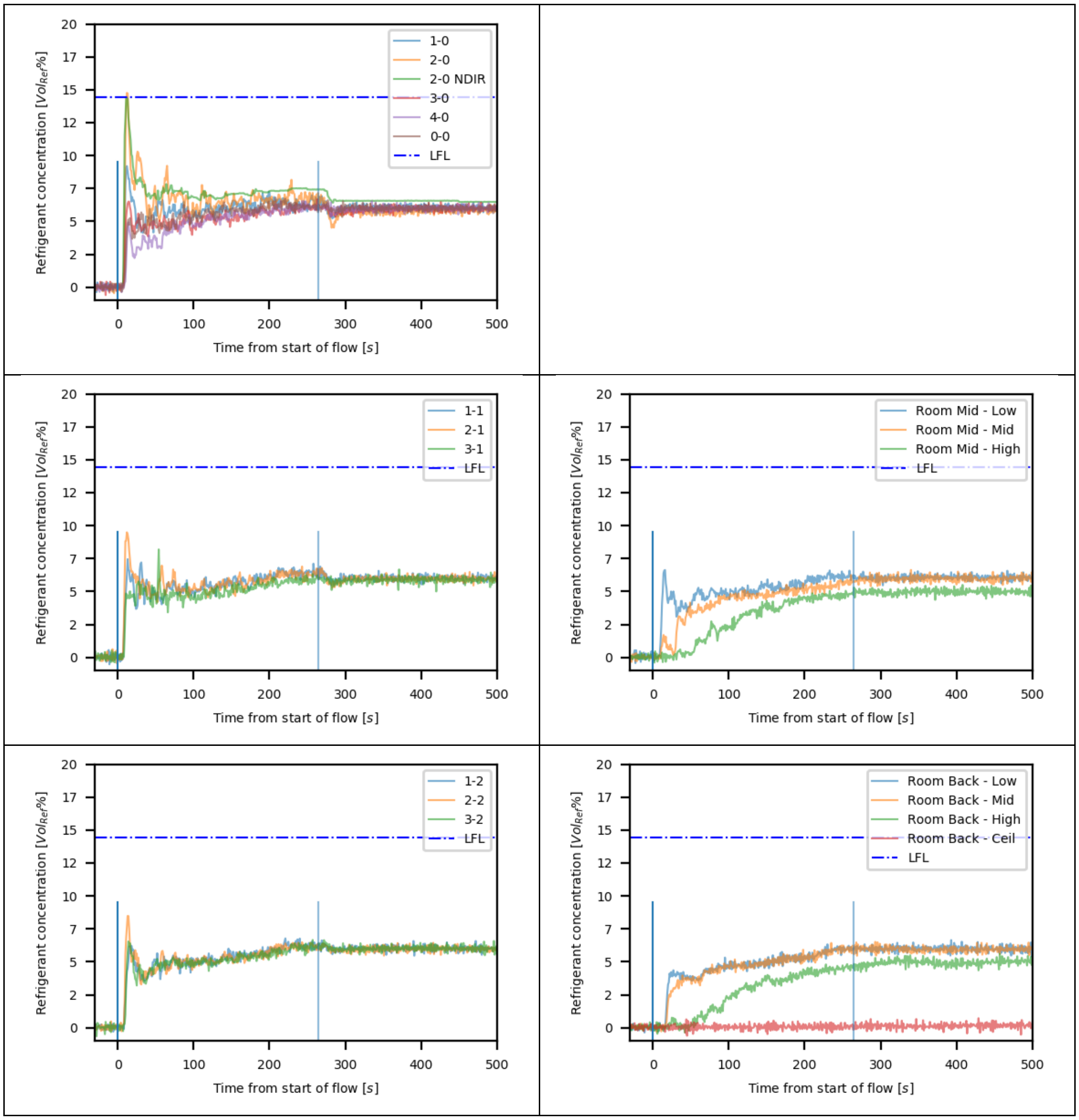


Table 114 – Ductless 6 Refrigerant Concentrations

(peak concentration around 10~50 seconds may be overestimated due to deconvolution method)

3.3.7 **Ductless 7**

A summary of the test parameters for this test are indicated in Table 115. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 25% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	3.38 kg	Release Time	244 s
Release Quality	Vapor	Time to Qmin	25 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 115 - Ductless 7 Test Parameters

At the start of the test sensor 2-0 located 50 mm (2 in) above the floor reached a peak concentration of 16% refrigerant and remained above the LFL for four seconds, when the fan was turned on it dispersed the refrigerant. The other sensors remained below the LFL during the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 116. The NDIR sensor in the unit did not appear to be providing valid data during this test. The MOS sensor registered 4.3% of refrigerant 19 seconds after the start of the refrigerant release.

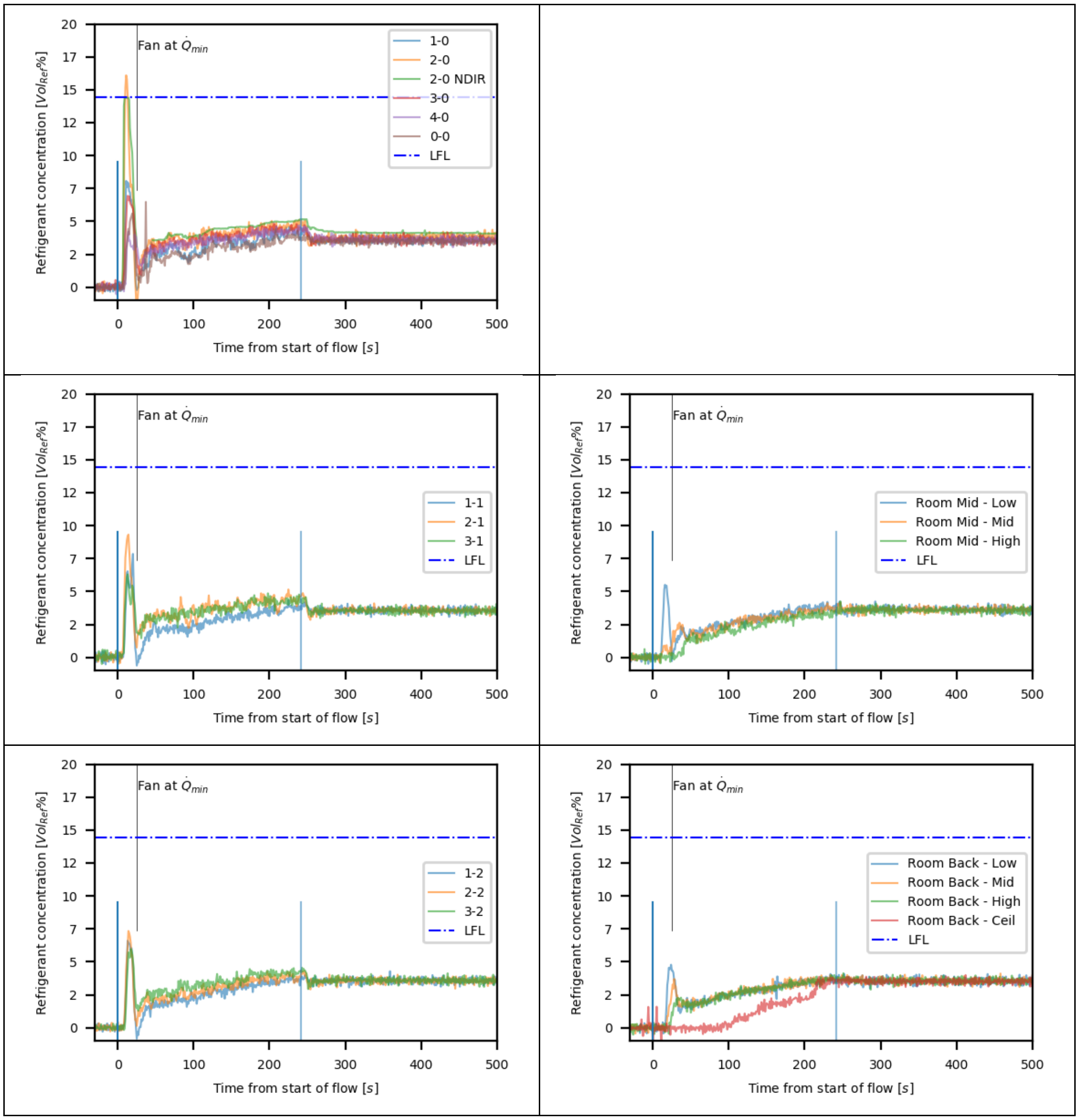


Table 116 – Ductless 7 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3.8 Ductless 8

A summary of the test parameters for this test are indicated in Table 117. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	3.45 kg	Release Time	258 s
Release Quality	Vapor	Time to Qmin	35 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 117 - Ductless 8 Test Parameters

At the start of the test sensor 2-0 located 50 mm (2 in) above the floor reached a peak concentration of 16% refrigerant when the fan was turned on it dispersed the refrigerant, and the sensor was only above the LFL for three seconds. The other sensors remained below the LFL during the duration of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 112. The NDIR sensor in the unit did not appear to be providing valid data during this test. The MOS sensor registered 4.2% of refrigerant 28 seconds after the start of the refrigerant release.

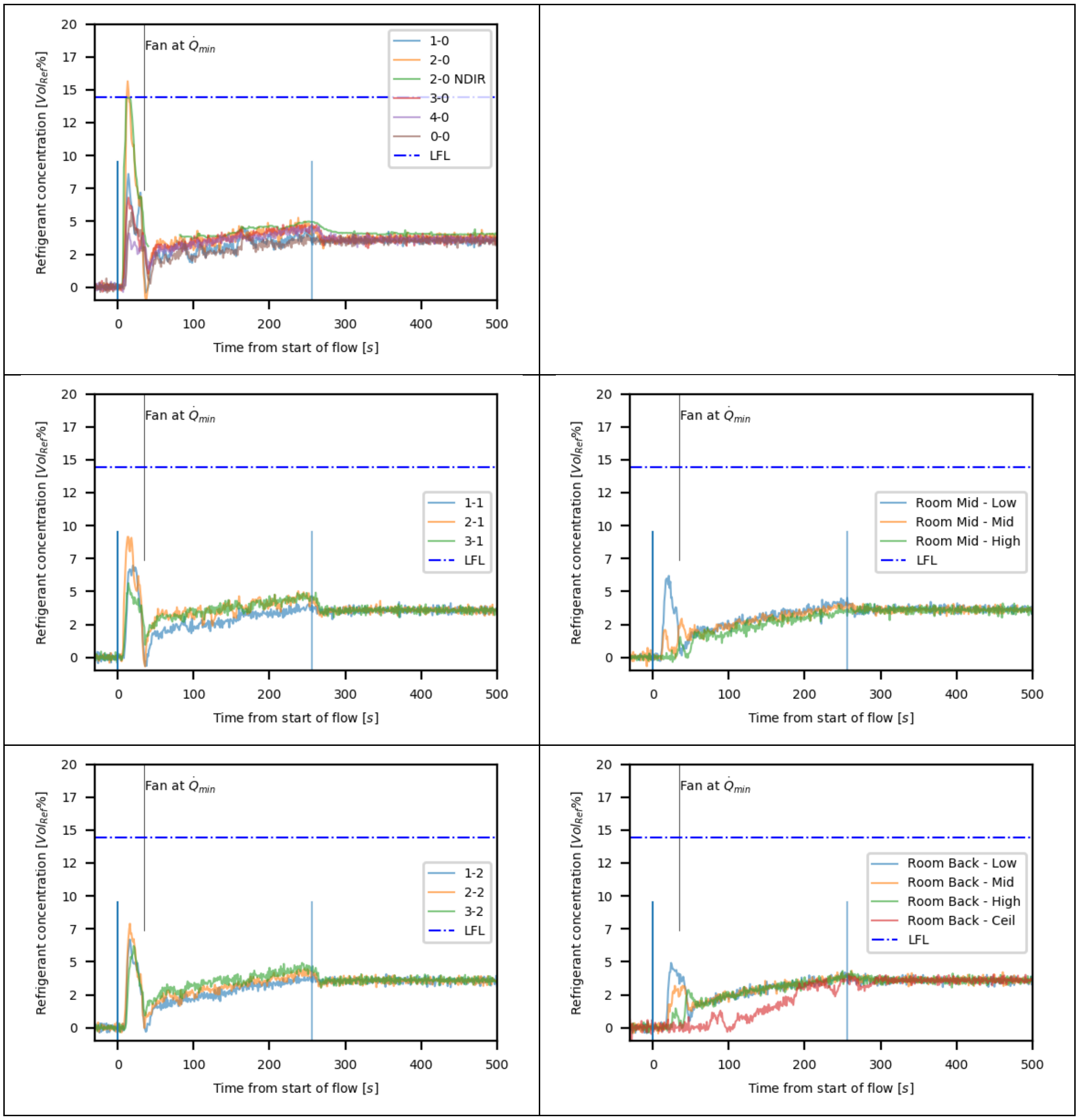


Table 118 - Ductless 8 Refrigerant Concentrations

(peak concentration around 25~50 seconds may be overestimated due to deconvolution method)

3.3.9 **Ductless 9**

A summary of the test parameters for this test are indicated in Table 119. This test was conducted to establish the baseline parameters with no mitigation with the unit installed 1.2 m (3.94 ft) above the floor. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Baseline - 1.2 m		
Release Amount	3.42 kg	Release Time	258 s
Release Quality	Vapor	Time to Qmin	N/A
Installation Height	1.2 m	Fan Speed	N/A

Table 119 - Ductless 9 Test Parameters

At the start of the test sensor 2-0 located 50 mm (2 in) above the floor reached a peak concentration of 21% refrigerant and remained above the LFL for five seconds. The other sensors remained below the LFL and the refrigerant was concentrated at the lower part of the room. There was rise at the 900 mm (36 in) sensors in the middle and back of the room, but it was lower than the sensors in those same positions at 50 mm (2 in) and 300 mm (12 in). Refrigerant concentrations for the sensors over the duration of the test are shown in Table 120. The NDIR sensor in the unit registered 50% of LFL at 7 seconds after the start of the refrigerant release. The MOS sensor did not register an appreciable amount of refrigerant during this release.

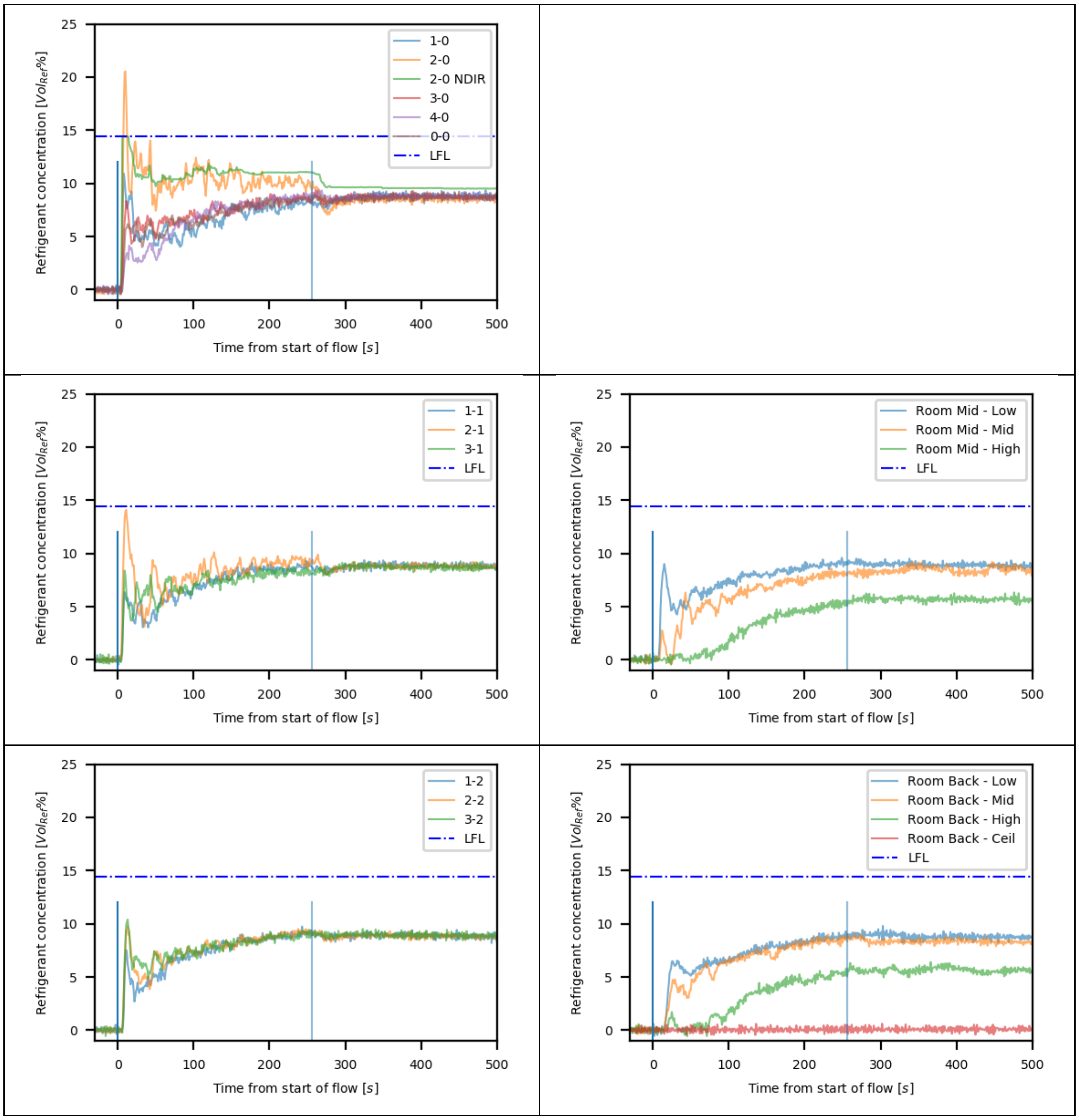


Table 120 – Ductless 9 Refrigerant Concentrations

(peak concentration around 20~40 seconds may be overestimated due to deconvolution method)

3.3.10 **Ductless 10**

A summary of the test parameters for this test are indicated in xx. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed, with the unit installed 1.2 m (3.94 ft) above the floor. The release mass was calculated to be 25% of the LFL for the entire room volume.

Test Summary	Longer activation time - 1.2 m		
Release Amount	3.35 kg	Release Time	256 s
Release Quality	Vapor	Time to Qmin	25 s
Installation Height	1.2 m	Fan Speed	651 m^3/hr

Table 121 - Ductless 10 Test Parameters

At the start of the test the sensor below the unit started to increase refrigerant concentration, when the fan turned on the local concentration started to drop and all the sensors remained below the LFL for the reminder of the test. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 122. The NDIR sensor in the unit registered 50% of LFL at 6 seconds after the start of the refrigerant release. The MOS sensor did not register an appreciable amount of refrigerant during this release.

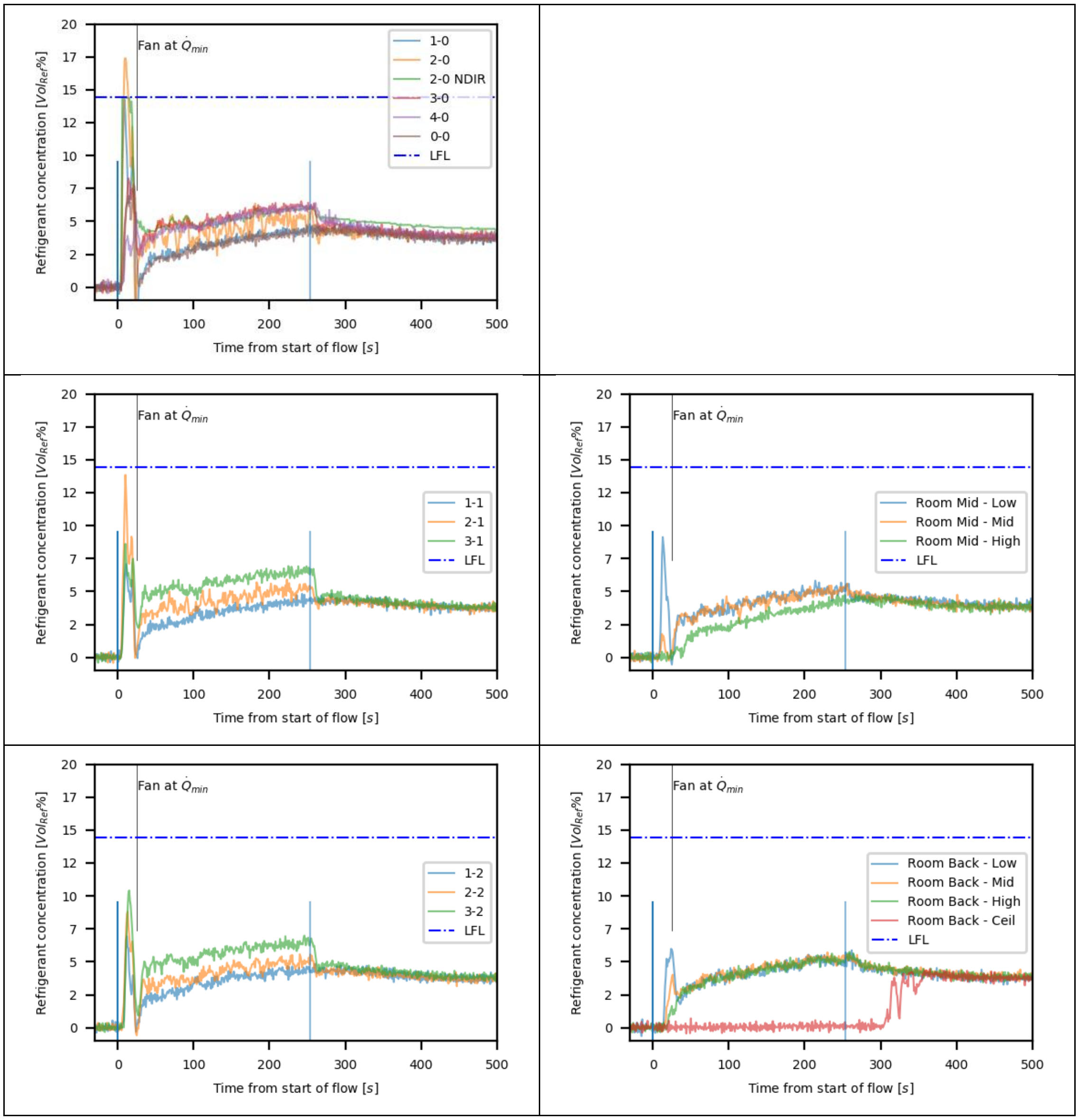


Table 122 – Ductless 10 Refrigerant Concentrations

(peak concentration around 20~40 seconds may be overestimated due to deconvolution method)

3.3.11 Ductless 11

A summary of the test parameters for this test are indicated in Table 123. This test was conducted to establish the baseline parameters with no mitigation. The release mass was calculated to be 50% of the LFL for the entire room volume.

Test Summary	Baseline - no mitigation		
Release Amount	6.85 kg	Release Time	466 s
Release Quality	Liquid	Time to Qmin	N/A
Installation Height	1.8 m	Fan Speed	N/A

Table 123 - Ductless 11 Test Parameters

This mitigation time and airflow was sufficient to prevent refrigerant from reaching the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 124. The location of the NDIR did not show an appreciable concentration at the start of the test. The MOS sensor in the unit registered 3% refrigerant by volume 24 seconds after the start of the refrigerant release.

Note that liquid refrigerant was collecting on the floor near sensors 2-0 and 2-0 NDIR near the end of the leak (see figure in upper right of Table 124). This results in the disturbance between 425~650 seconds.

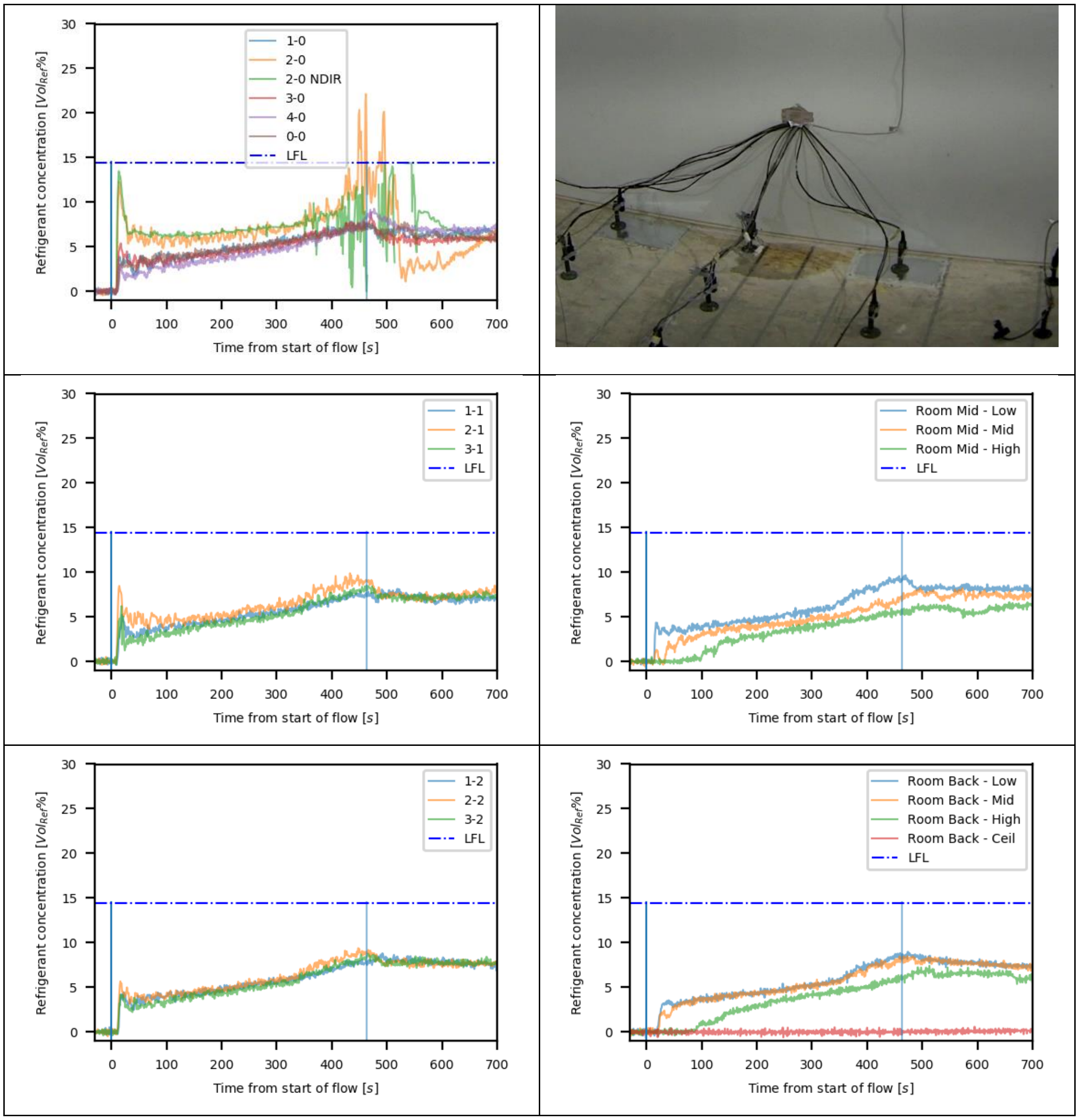


Table 124 – Ductless 11 Refrigerant Concentrations

(peak concentration around 20~40 seconds may be overestimated due to deconvolution method)

3.3.12 **Ductless 12**

A summary of the test parameters for this test are indicated in Table 125. This test was conducted with the minimum airflow and maximum response time permitted per UL/CSA 60335-2-40 3rd Ed. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	UL 2-40 standard as default		
Release Amount	6.89 kg	Release Time	470 s
Release Quality	Liquid	Time to Qmin	25 s
Installation Height	1.8 m	Fan Speed	1222 m^3/hr

Table 125 - Ductless 12 Test Parameters

This mitigation time and airflow was sufficient to prevent refrigerant from reaching the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 126. The NDIR sensor in the unit registered an initial peak of 21% LFL at 5 seconds after the start of the release and produced an error indication 33 seconds later. The MOS sensor registered 1.9% of refrigerant 16 seconds after the start of the refrigerant release.

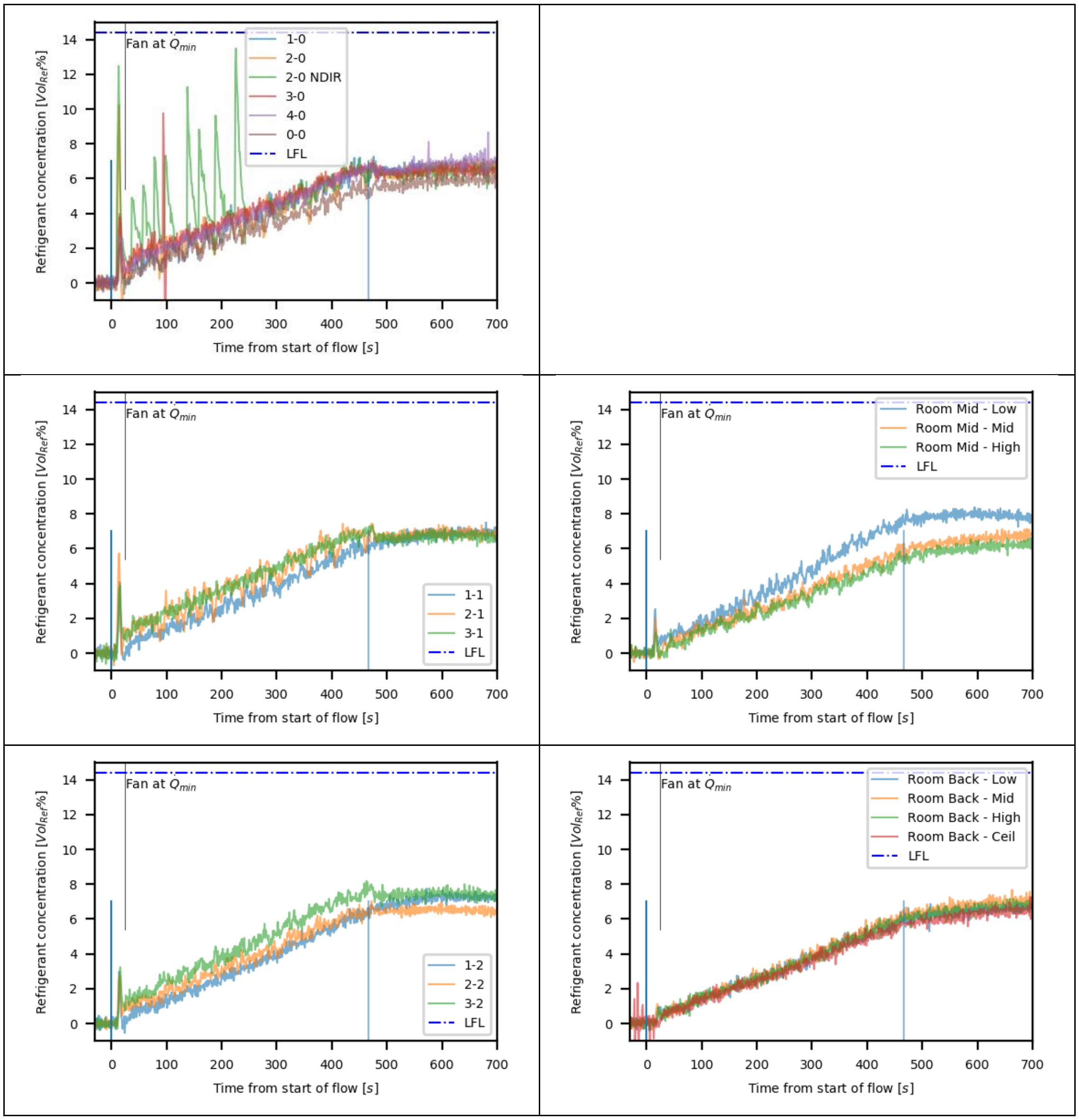


Table 126 – Ductless 12 Refrigerant Concentrations

(peak concentration around 10~25 seconds may be overestimated due to deconvolution method)

3.3.13 Ductless 13

A summary of the test parameters for this test are indicated in Table 127. This test was conducted with the minimum airflow permitted per UL/CSA 60335-2-40 3rd Ed, the response time for the unit to reach Qmin was increased to 35 s. The release mass was calculated to be 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time		
Release Amount	6.81 kg	Release Time	462 s
Release Quality	Liquid	Time to Qmin	35 s
Installation Height	1.8 m	Fan Speed	1222m^3/hr

Table 127 - Ductless 13 Test Parameters

This mitigation time and airflow was sufficient to prevent refrigerant from reaching the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 128. The NDIR sensor in the unit registered an error 52 seconds after the start of the refrigerant release. The MOS sensor registered 3% of refrigerant 33 seconds after the start of the refrigerant release.

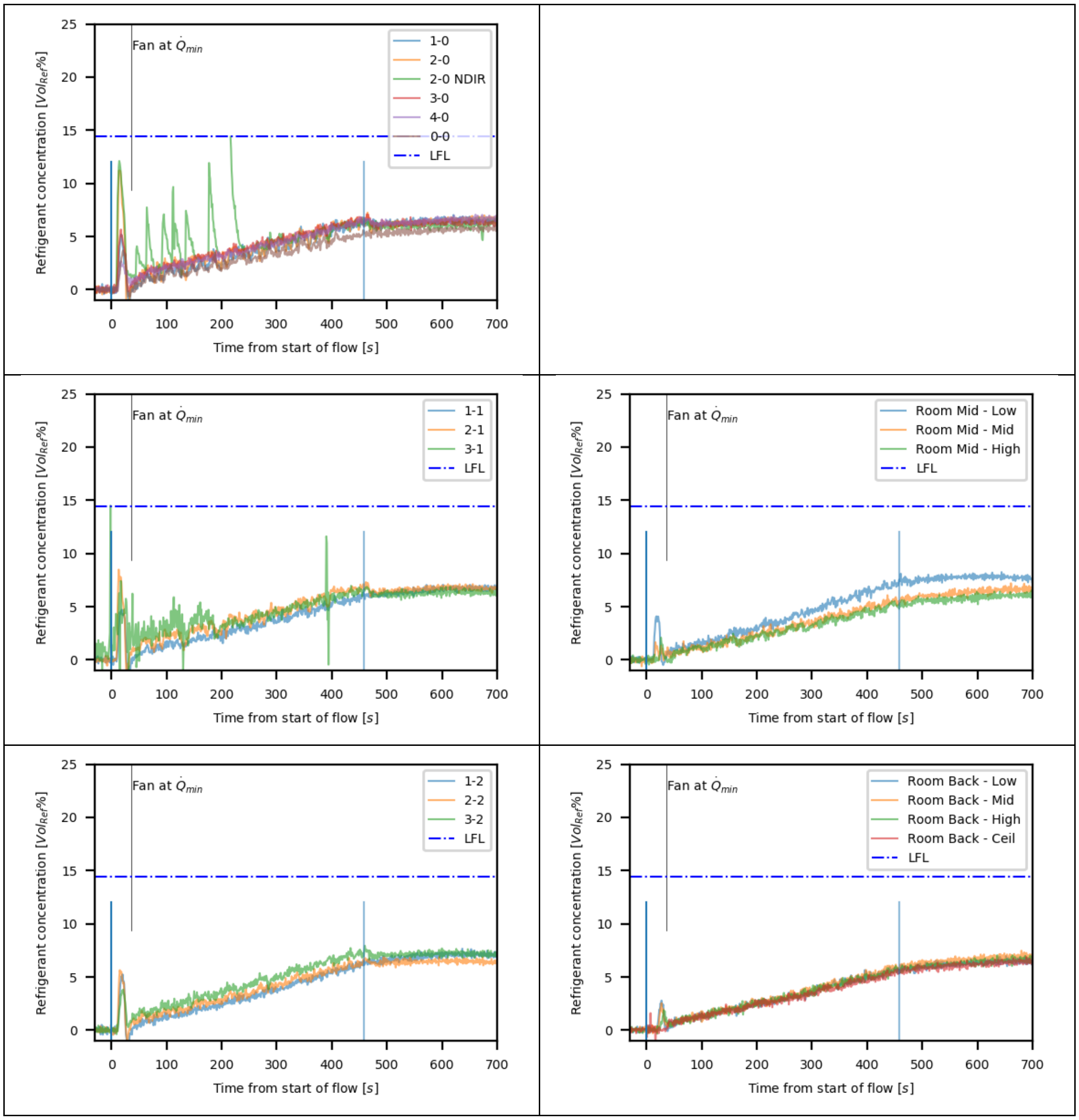


Table 128 – Ductless 13 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

3.3.14 **Ductless 14**

A summary of the test parameters for this test are indicated in Table 129. This test was conducted with the maximum response time permitted by UL/CSA 60335-2-40 3rd Ed and with the minimum volumetric flow required by the standard decreased to 50% of the required flow. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Decrease Airflow		
Release Amount	6.82 kg	Release Time	472 s
Release Quality	Liquid	Time to Qmin	25 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 129 - Ductless 14 Test Parameters

This mitigation time and airflow was sufficient to prevent refrigerant from reaching the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 130. The NDIR sensor in the unit did not register 50% of LFL until 165 seconds after the start of the refrigerant release. The MOS sensor registered 3.8% of refrigerant 22 seconds after the start of the refrigerant release.

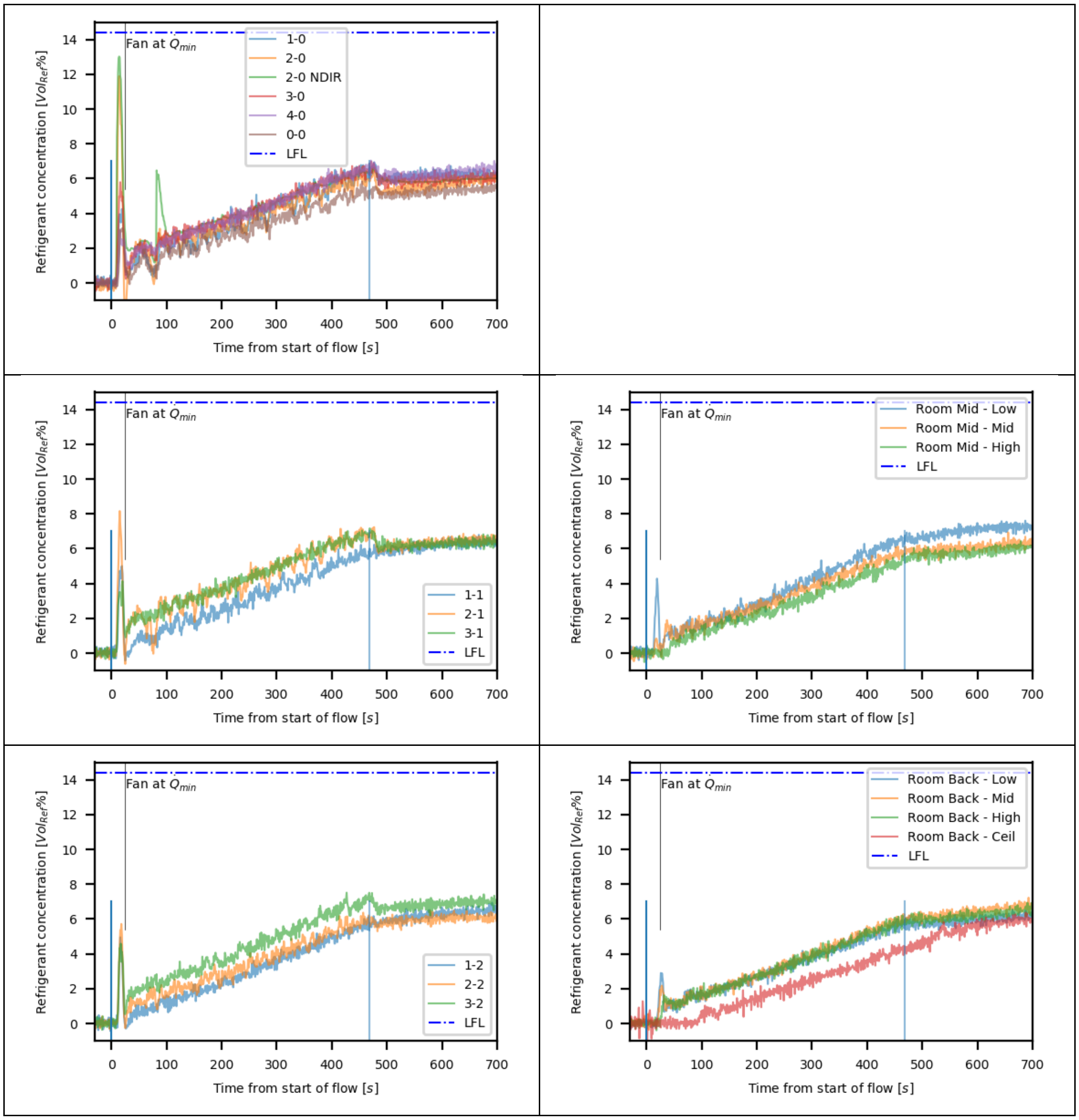


Table 130 – Ductless 14 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

3.3.15 **Ductless 15**

A summary of the test parameters for this test are indicated in Table 131. This test was conducted the response time for the unit to reach Qmin increased to 35 s and with the minimum volumetric flow required by the standard decreased to 50% of the required flow. The mass release for this test was calculated based on 50% of the LFL for the entire room volume.

Test Summary	Increased Mitigation Time & Decreased Airflow		
Release Amount	6.87 kg	Release Time	486 s
Release Quality	Liquid	Time to Qmin	35 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 131 - Ductless 15 Test Parameters

This mitigation time and airflow was sufficient to prevent refrigerant from reaching the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 132. Neither the NDIR or MOS sensor in the unit registered a significant spike at the beginning of the release. Only after the release was occurring did the refrigerant concentration rise.

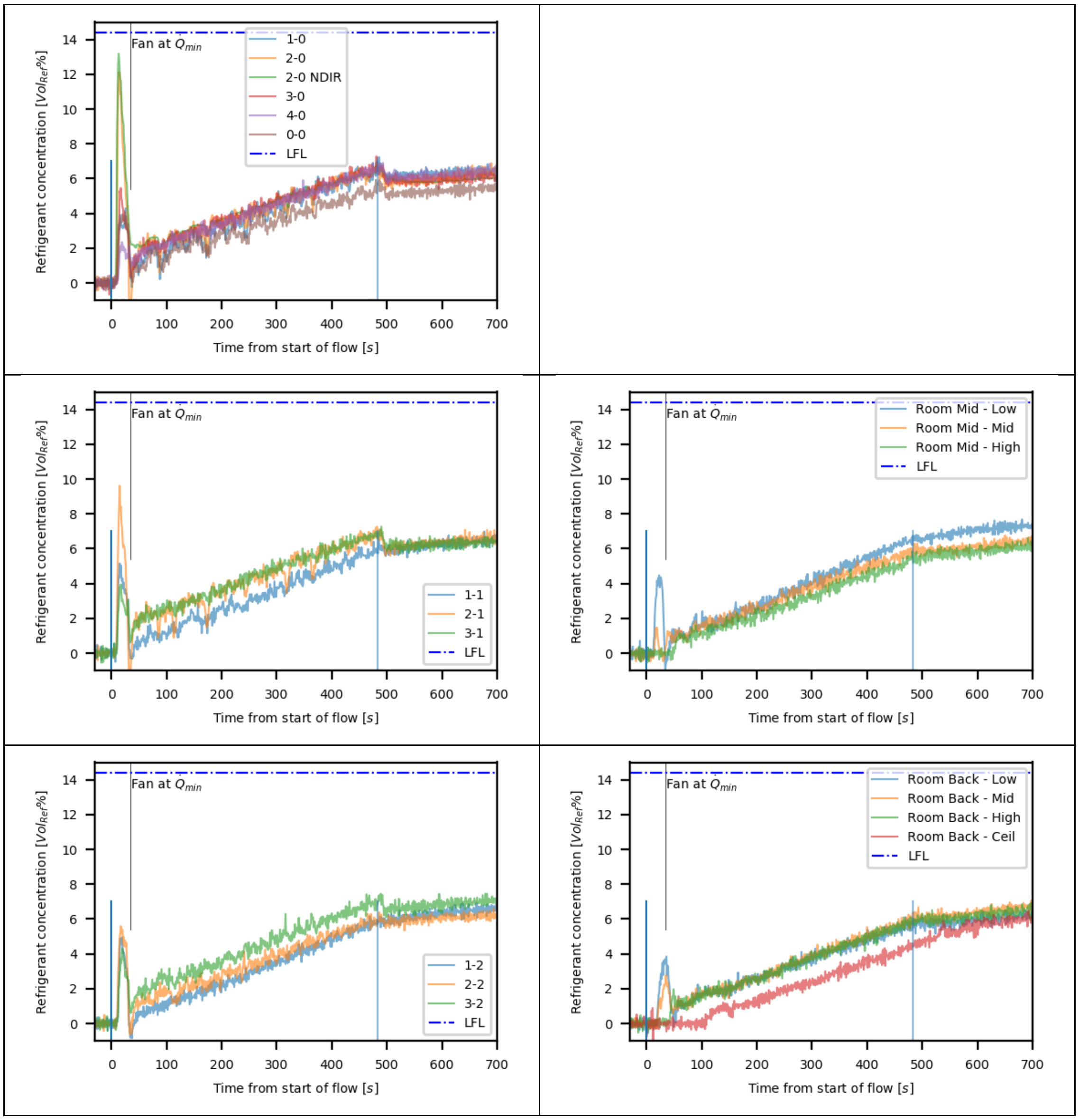


Table 132 - Ductless 15 Refrigerant Concentrations

(peak concentration around 15~40 seconds may be overestimated due to deconvolution method)

3.3.16 **Ductless 21**

A summary of the test parameters for this test are indicated in Table 133. This test was conducted the response time for the unit to reach Qmin at 10 s and with the volumetric flow required by Table GG.2 of IEC -2-40. The mass release for this test was calculated based on the IEC allowed charge per IEC -2-40 equation GG.10.

Test Summary	IEC 2-40 (7.41 kg)		
Release Amount	7.47 kg	Release Time	257 s
Release Quality	Liquid	Time to Qmin	10 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 133 - Ductless 21 Test Parameters

This activation and fan speed were sufficient to keep the refrigerant from being above the LFL, with the exception of right below the unit were liquid refrigerant was collecting very near the end of the test. There is good mixing in most of the space with the exception of the ceiling sensor. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 134. The NDIR sensor in the unit registered 50% of LFL at 6 seconds after the start of the refrigerant release. The MOS sensor increased in output to a maximum of 2.3% of refrigerant 42 seconds after the start of the refrigerant release.

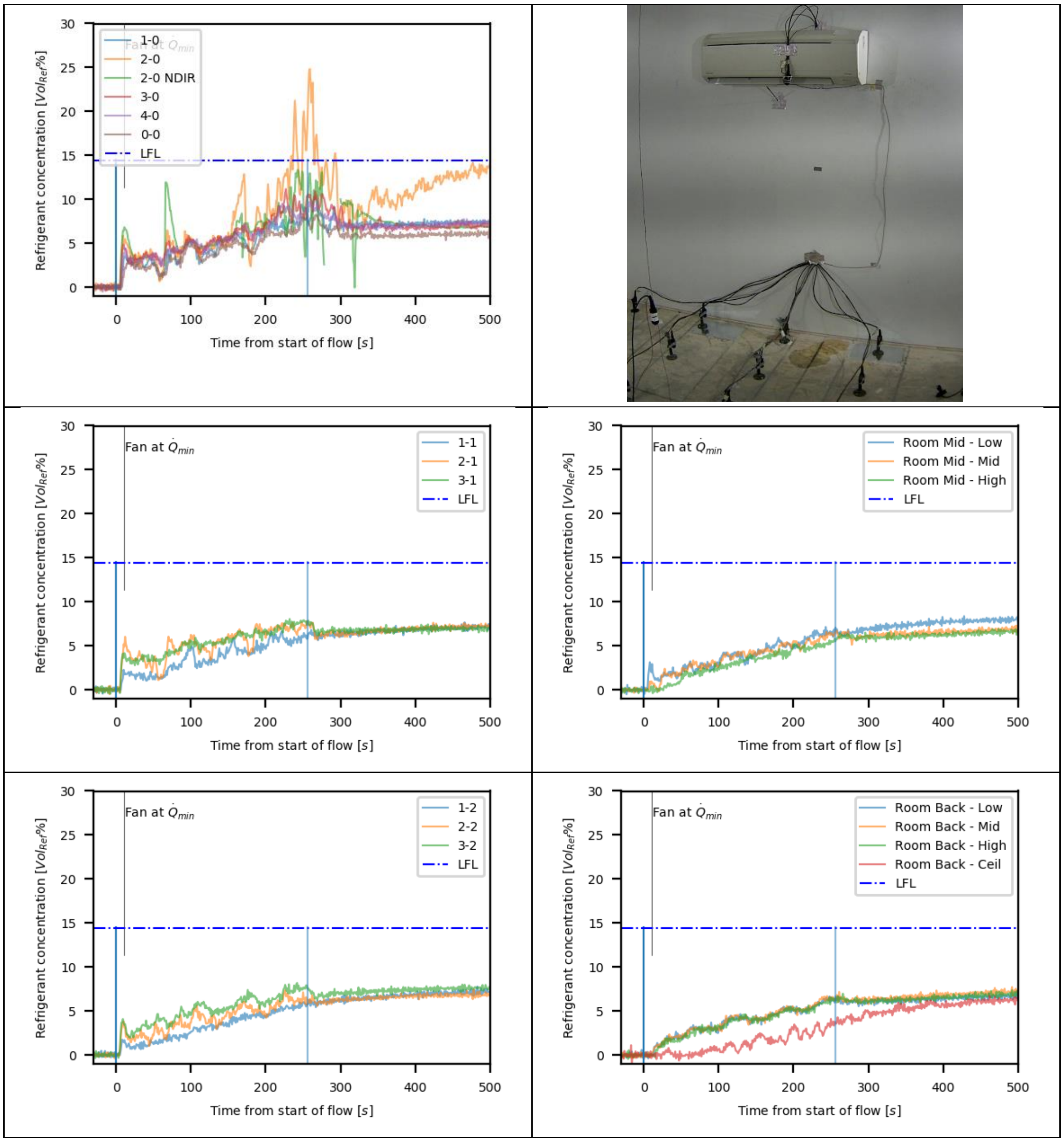


Table 134 – Ductless 21 Refrigerant Concentrations

(peak concentration around 15~40 seconds may be overestimated due to deconvolution method)

3.3.17 Ductless 22

A summary of the test parameters for this test are indicated in Table 135. This test was conducted the response time for the unit to reach Qmin at 30 s and with the volumetric flow required by Table GG.2 of IEC -2-40. The mass release for this test was calculated based on the IEC allowed charge per IEC -2-40 equation GG.10.

Test Summary	IEC 2-40 (7.41 kg)		
Release Amount	7.36 kg	Release Time	242 s
Release Quality	Liquid	Time to Qmin	30 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 135 - Ductless 22 Test Parameters

The location 2-0 located 50 mm (2 in) below the unit had concentrations above the LFL for five seconds. The other sensors in this space did not exceed the LFL. Towards the end of this test there liquid refrigerant which was overfilling the drain pan. This provided some concentrations above the LFL localized to the unit. The figure in Table 136 shows the pooling of refrigerant on the floor below the right side of the unit. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 136. The NDIR sensor in the unit registered 50% of LFL at 25 seconds after the start of the refrigerant release. The MOS sensor did not register a significant amount of refrigerant during this test.

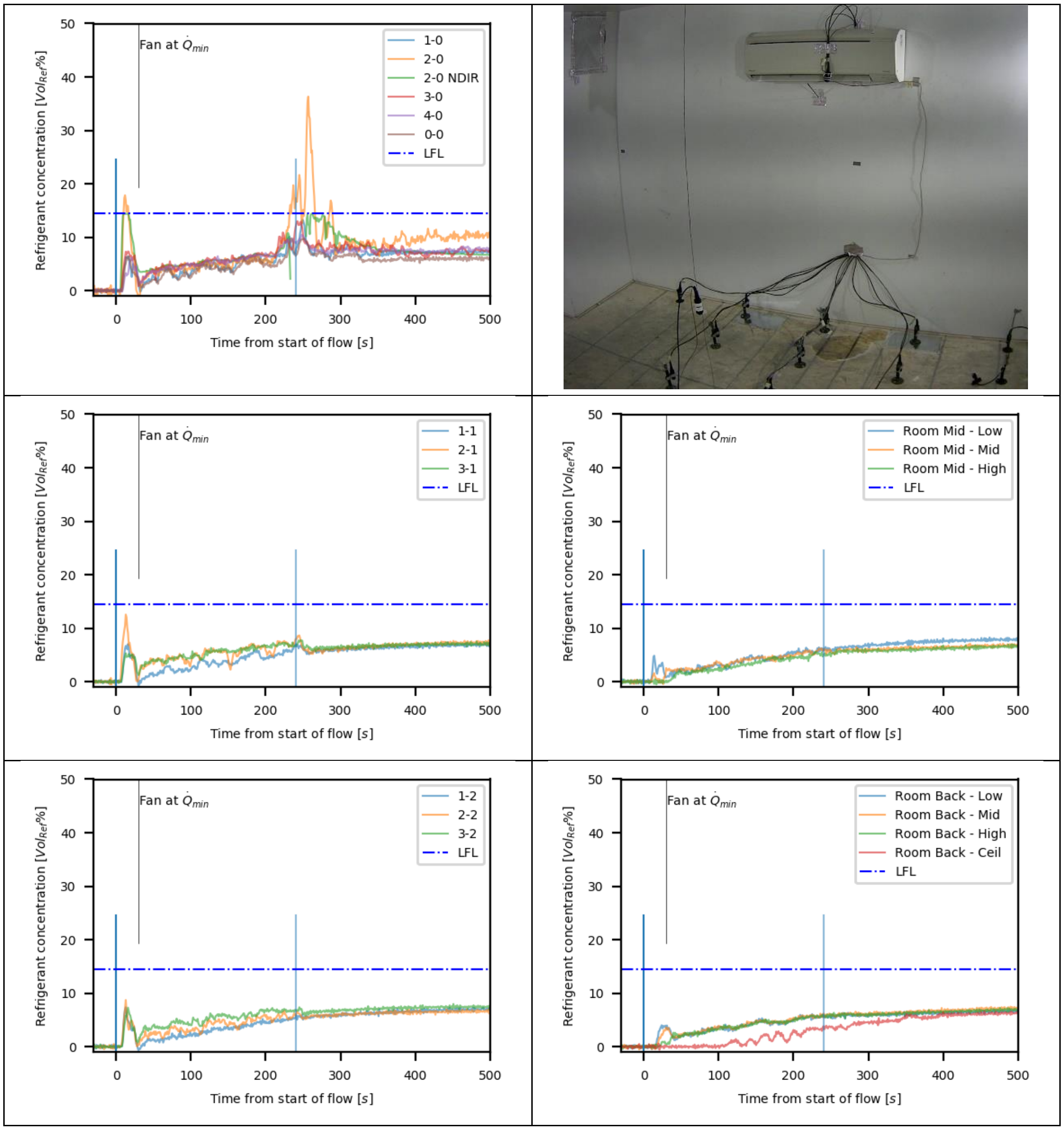


Table 136 – Ductless 22 Refrigerant Concentrations

(peak concentration around 20~40 and 225~300 seconds may be overestimated due to deconvolution method)

3.3.18 **Ductless 23**

A summary of the test parameters for this test are indicated in Table 137. This test was conducted the response time for the unit to reach Qmin at 10 s and with the volumetric flow required by Table GG.2 of IEC -2-40. The mass release for this test was calculated based on 50% of the LFL for the entire room.

Test Summary	IEC 2-40 (6.84 kg)		
Release Amount	6.83 kg	Release Time	239 s
Release Quality	Liquid	Time to Qmin	10 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 137 - Ductless 23 Test Parameters

This activation and fan speed were sufficient to keep the refrigerant from being above the LFL, with the exception of right below the unit were liquid refrigerant was collecting at the end of the test. There is good mixing in most of the space with the exception of the ceiling sensor. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 138. Neither NDIR or MOS sensor showed a significant concentration rise during this test. The fact that the fan was turning on quickly did not allow the refrigerant concentration to build in the location of the sensors.

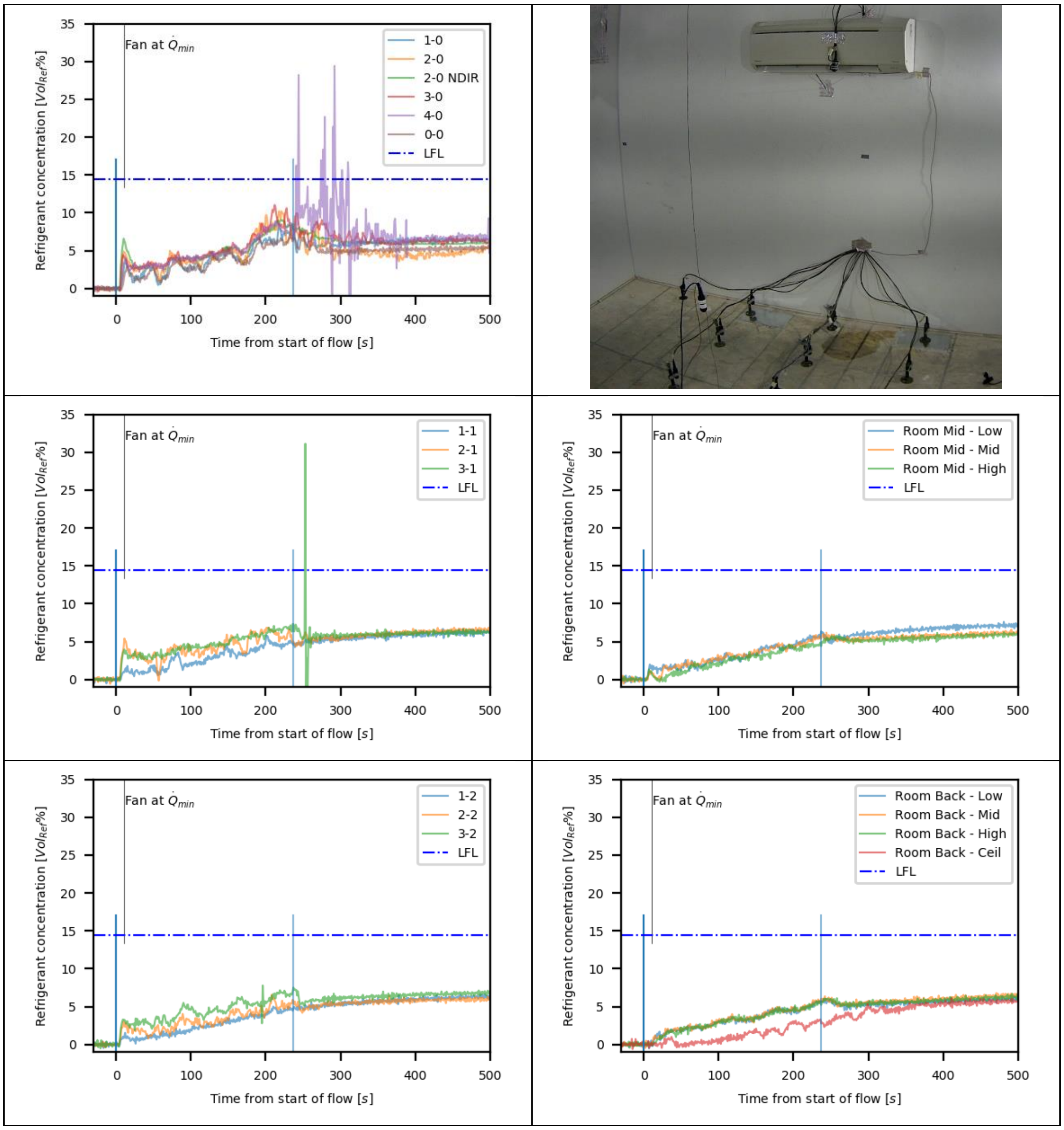


Table 138 – Ductless 23 Refrigerant Concentrations

(peak concentration around 20~40 and 225~350 seconds may be overestimated due to deconvolution method)

3.3.19 **Ductless 24**

A summary of the test parameters for this test are indicated in Table 139. This test was conducted the response time for the unit to reach Qmin at 30 s and with the volumetric flow required by Table GG.2 of IEC -2-40. The mass release for this test was calculated based on 50% of the LFL for the entire room.

Test Summary	IEC 2-40 (6.84 kg)		
Release Amount	6.88 kg	Release Time	243 s
Release Quality	Liquid	Time to Qmin	30 s
Installation Height	1.8 m	Fan Speed	651 m^3/hr

Table 139 - Ductless 24 Test Parameters

The sensor located 50 mm (2 in) below the unit went above the LFL for six seconds just before the fan was energized. Once the fan had turned on it was able to mix the refrigerant in the space. With the exception of sensor 3-1 which was near the liquid refrigerant, the remaining sensors were below the LFL. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 140. The NDIR sensor did not show an appreciable amount of refrigerant during this test. The MOS sensor increased in output to a maximum of 3.8% of refrigerant 25 seconds after the start of the refrigerant release.

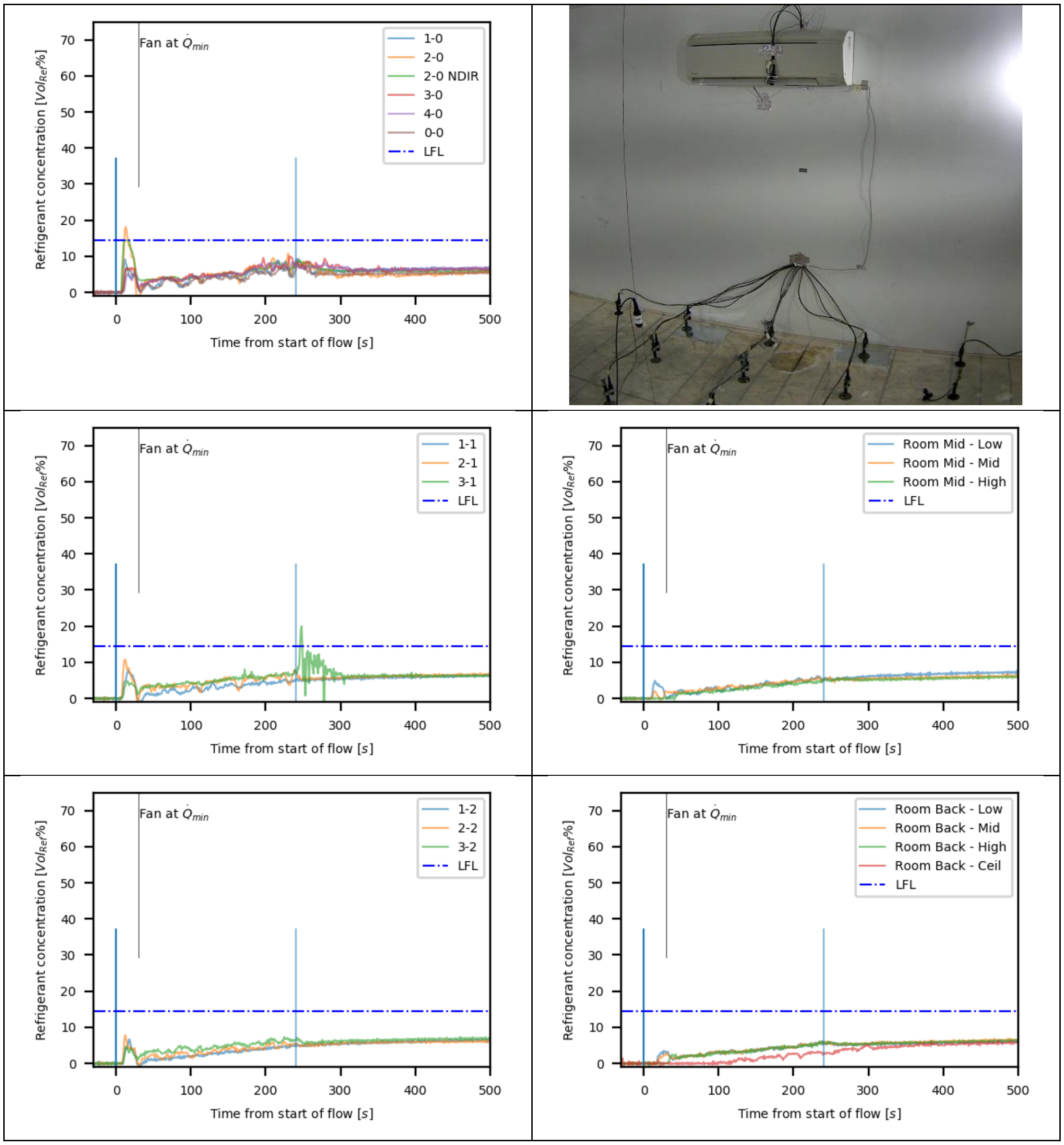


Table 140 – Ductless 24 Refrigerant Concentrations

(peak concentration around 20~40 and 225~300 seconds may be overestimated due to deconvolution method)

3.4 Multisplit

3.4.1 Operating Mode – Test Series 1

Unit operating mode was the first parameter varied. A summary of the amount of refrigerant released is identified in Table 141. The "Release Amount (Initial – Recover)" quantity of refrigerant released was determined by subtracting the measured weight of refrigerant recovered from the measured weight of refrigerant charged into the system before the test. The "Release Amount (Integrated Value)" is the quantity of refrigerant released as measured by the Coriolis flow meter.

Test	**Test parameters**		**Release Amount**		**Release Amount**	
	SSV Delay	Operation	**(Initial-Recover)**		**(Integrated Value)**	
			kg	lbs	kg	lbs
Multisplit 2B	30 sec	Heating	0.33	0.73	0.31	0.68
Multisplit 2D	30 sec	Cooling	0.17	0.37	0.15	0.34
Multisplit 2E	30 sec	Still	0.22	0.50	0.19	0.43

Table 141 - Mutlisplit Operating Mode Results

Part of the purpose of Test Series 1 is to compare the releasable charge quantities specified in UL/CSA 60335-2-40 3rd edition, as specified in Annex 101.DVG.7, the releasable charge quantities specified in proposed Standards ASHRAE 15.2P (ASHRAE, 3rd PPR Draft (2021)), and actual test values. For UL/CSA 2-40, the releasable charge in the heating mode is determined by Equation 101.DVG.8, in cooling mode is determined by Equation 101.DVG.9 and in off-mode determined by Equation 101.DVG.10. In ASHRAE 15.2P PPR3, the releasable charge in heating mode is determined in heating mode by the formula in Section 9.7.3.1 while the releasable charge in cooling mode is determine in cooling mode by the formula in Section 9.7.3.2 (there is no off-mode calculation in ASHRAE 15.2P PPR3). Both UL/CSA 60335-2-40 and ASHRAE 15.2P make assumptions of a 30 second SSV delay time, The table below summarizes the calculated values, using the actual connecting line set diameters and length, and a coil internal volume (provided by the manufacturer) of 0.00107 m^3.

System	SSV Delay	Operation	UL/CSA 60335-2-40		ASHRAE 15.2P PPR3	
			kg	(lb)	kg	(lb)
Multisplit 2B	30 sec	Heating	3.46	7.61	1.07	2.36
Multisplit 2D	30 sec	Cooling	3.67	8.07	0.50	1.10
Multisplit 2E	30 sec	Still	3.77	8.30	---	---

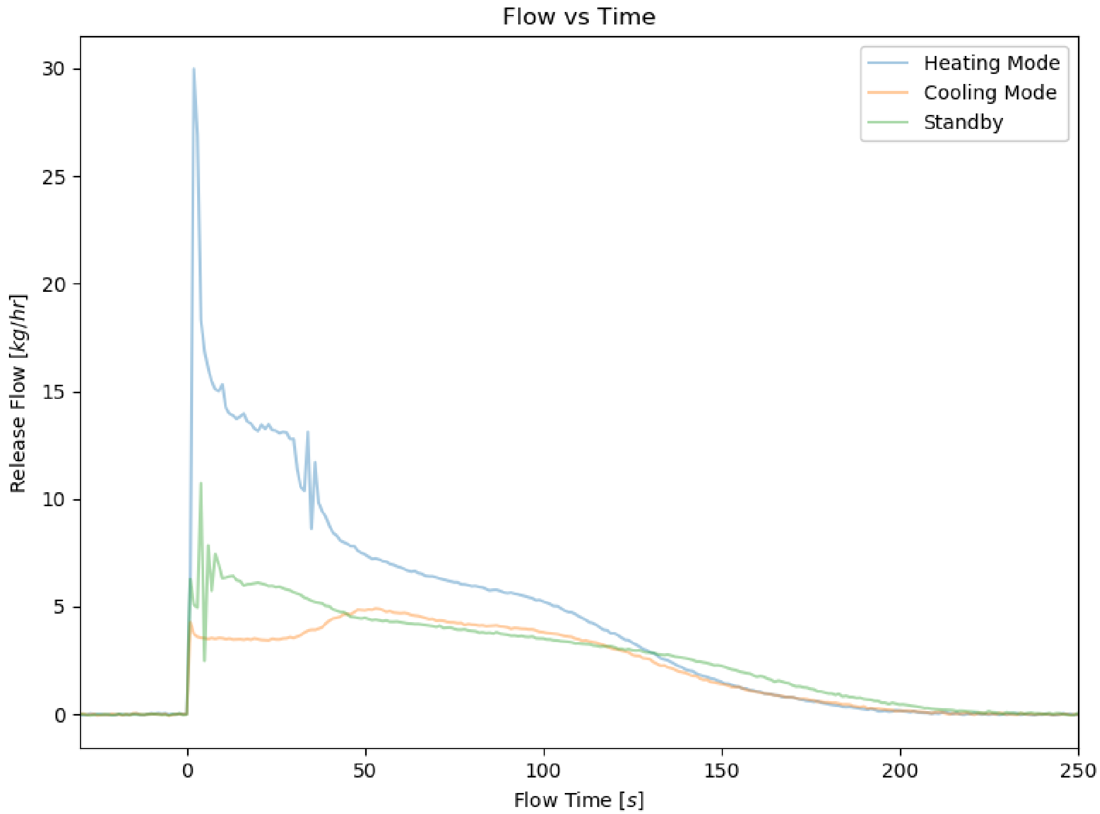


Figure 16 - Refrigerant release rate for Operating mode

These show average release per volume are 0.23 and 0.45 kg/L.

3.4.2 **Baseline Refrigerant Leak**

This test was conducted as a baseline simulating a system with a leak where there were no SSV employed. The unit was charged with refrigerant and operated in maximum heating mode. Once the unit was operating and heating the space the release solenoid was opened to discharge refrigerant into the space. Orifice was chosen to achieve 20 kg/hr leak. However, the measured leak rate is around 30 kg/hr for one second or 2 then dropped to 15 to 13 kg/hr in heating mode operation. In other modes, the leak rate was much lower than heating mode. No mitigation was activated during this test, with the exception of the airflow inherent in operating the unit in heating mode. Refrigerant pressures were monitored to ensure that air would not enter the refrigerant system. The total release duration was approximately 42:40.

A total of 3.82 kg (8.40 lbs) of refrigerant was measured through the flow meter discharging into the room. The arrangement for sensors were the same as present for the ductless tests, see Figure 14 for the refrigerant sensor layout in the room. Refrigerant concentrations for the sensors over the duration of the test are shown in Table 142. As the blower motor was already operating there are not the same localized peaks that were present in other tests where a higher concentration of refrigerant existed prior to the blower turning on, simulating a mitigation response.

The video cameras in the room space showed an oil mist being dispersed through the test space. The oil produced a fog which persisted even after the flow and test had been stopped and the room ventilated. Table 143 shows a timeline of the atomized oil in the in the room. This result suggests that a major release of refrigerant is visible for the users. Most of user would open the door and window to exhaust such oil mist, if they see the oil mist cloud. So, there seems certain margins, but such human reaction is not considered in safety standards for now.

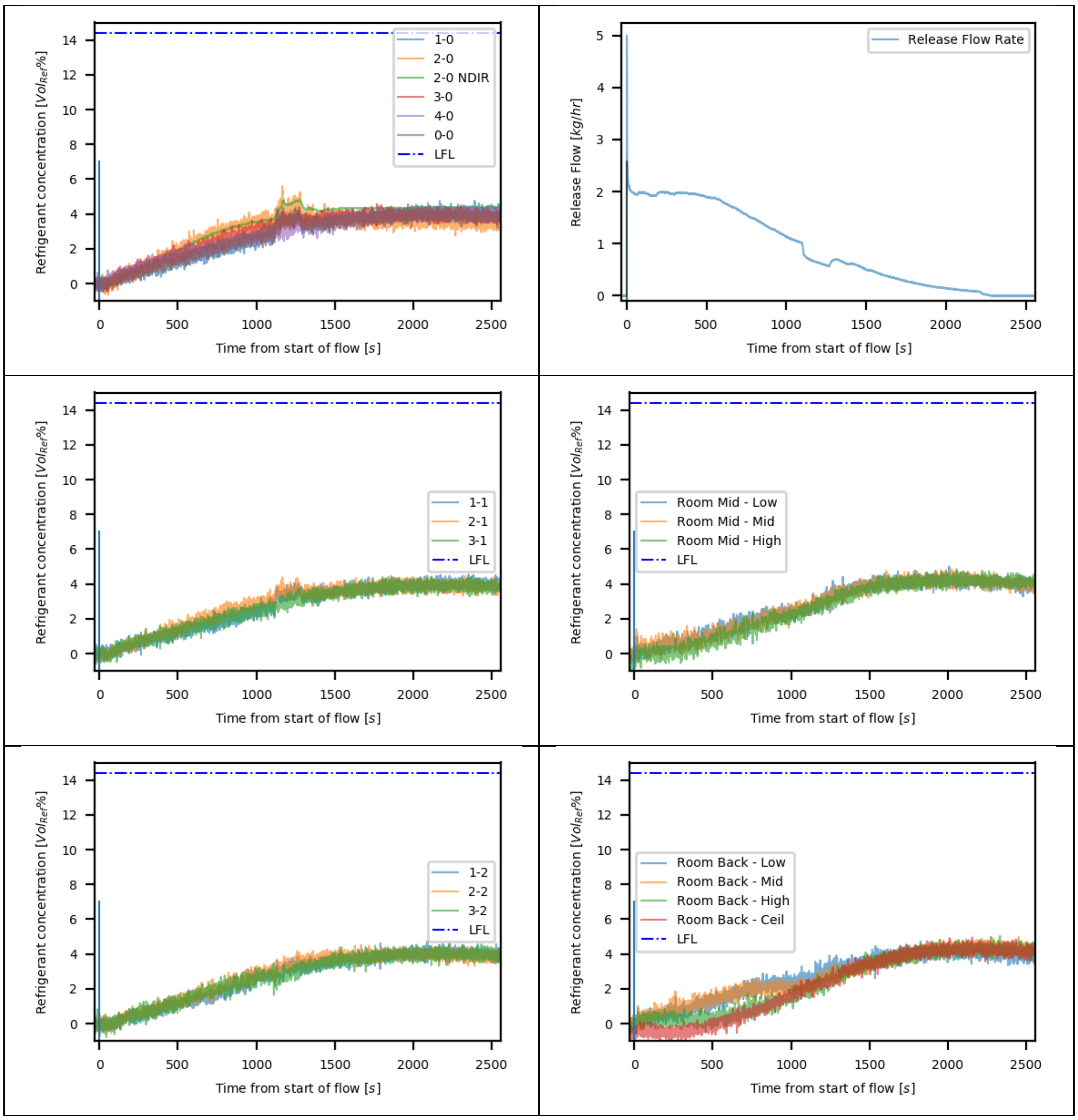


Table 142 – Multisplit Baseline Refrigerant Concentrations

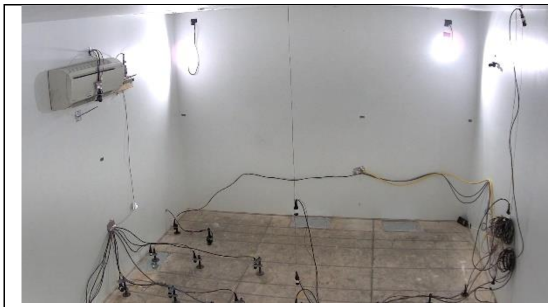
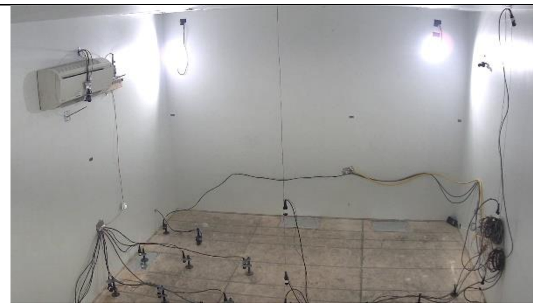
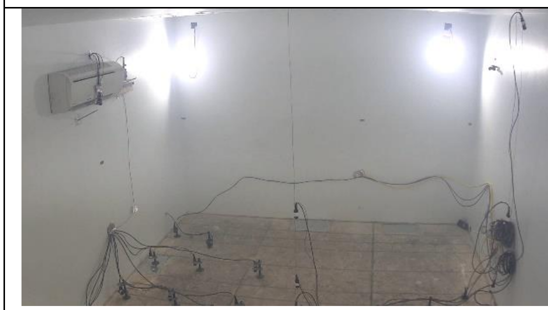
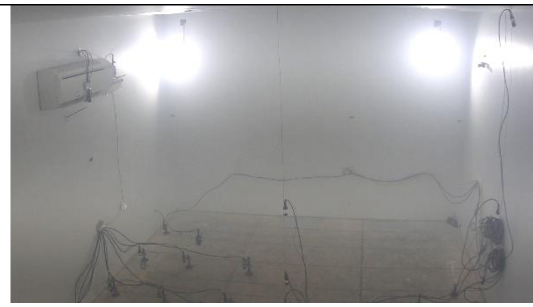
 20 s	 3 min
 8 min	 20 min

Table 143 - Multisplit Atomized Oil

3.4.3 Effect of Valve Closing – Simultaneous – Test Series 2

The next parameter that was varied was the response time of the SSV. Heating mode was identified by Test Series 1 as producing the highest leak rate, so this operation mode was used. Three different tests were performed. In each test, the leak was initiated and the SSV were closed at the specified time. The times chosen were 15 s, 30 s, and 60 s. A summary of the condition and the release values are shown in Table 144.

This data shows, for the time scales and modes tested, there does exist a relationship between the shutoff valve timing and the mass of refrigerated released from the system which can be modeled by a linear function. However, this assumption would not hold true over a significantly longer release as it was demonstrated during the baseline test above that the refrigerant decay does become substantially exponential at a given time in the leak.

Actual difference in release of refrigerant is 80 to 90 g between 2B and 2C in 30 seconds. This indicates that even a hole that can release refrigerant with 30 kg/hr at liquid leak condition results release in average is less than 12 kg/hr. So, it is clarified that the current assumption to calculate the leak rate prior to the SSV closing of 10 kg/hr in IEC60335-2-40 and 20 kg/hr in UL60335-2-40 are conservative.

Test	Test Parameter	Release Amount		Release Amount	
	SSV Delay	(Initial-Recover)		(Integrated Value)	
		kg	lbs	kg	lbs
2A	15 sec	0.27	0.6	0.23	0.51
2B	30 sec	0.33	0.73	0.31	0.68
2C	60 sec	0.42	0.93	0.39	0.86

Table 144 - SSV Delay Summary

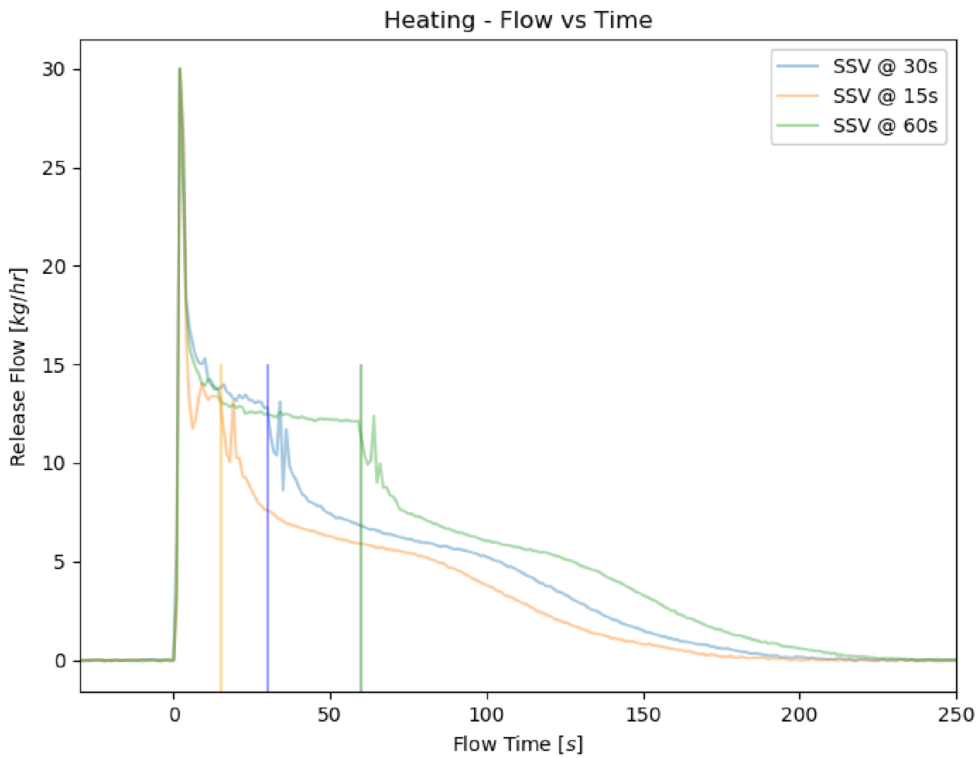


Figure 17 - SSV Delay Mass Release

3.4.4 **Effect of Valve Timing with Delay – Test Series 3**

This set of tests investigated the effect of delaying the closing of one SSV. A summary of the operating mode and results for the delay were investigated is shown in Table 145. This table also identifies the procedure for how each SSV was closed for that specific test.

One test 3I was repeated because while recovering the system charge an unknown amount of refrigerant was released which rendered that value invalid. This test was investigating the standby mode of the unit. The procedure for this was to operate the unit in cooling mode for 15 minutes and then turn the unit off for 20. Because of the shared environmental controls in the lab the test was not able to start the test at 20 minutes. When the test was completed this data point was an outlier given the previous shut off testing. This shows that the time after the unit operation as well as the internal and external ambient conditions also will have an effect on the mass of refrigerant that will remain on the indoor side when using safety shutoff valves.

For tests 3A through 3J the release mass (by the integration method) is plotted vs delay time in Figure 18.

				Release Amount		**Release Amount**	
Test Name	**Setup Notes**			**(Initial-Recover)**		**(Integrated Value)**	
		SSV Closing Operation	Unit Mode	kg	lbs	kg	lbs
3A	SSV near unit	Simultaneous	Heating	0.18	0.40	0.17	0.37
3B	SSV near unit	Liquid, 5 s delay, Vapor	Cooling	0.15	0.33	0.13	0.29
3C	SSV near unit	Liquid, 30 s delay, Vapor	Cooling	0.06	0.14	0.04	0.10
3D	SSV near unit	Liquid, 60 s delay, Vapor	Cooling	0.04	0.10	0.03	0.06
3E	SSV near unit	Vapor, 5 s delay, Liquid	Heating	0.16	0.36	0.13	0.28
3F	SSV near unit	Vapor, 30 s delay, Liquid	Heating	0.19	0.42	0.16	0.35
3G	SSV near unit	Vapor, 60 s delay, Liquid	Heating	0.20	0.43	0.14	0.31
3H	SSV near unit	Liquid, 5 s delay, Vapor	Standby	0.22	0.48	0.20	0.44
3I	SSV near unit	Liquid, 30 s delay, Vapor	Standby	N/A[3]	N/A[3]	0.24	0.52
3I_repeat	SSV near unit	Liquid, 30 s delay, Vapor	Standby	0.07	0.15	0.04	0.09
3J	SSV near unit	Liquid, 60 s delay, Vapor	Standby	0.29	0.65	0.25	0.54
3K	SSV near unit	Liquid, 5 s delay, Vapor	Heating	0.20	0.44	0.18	0.40
3L	Valves relocated 10 m from unit	Vapor, 5 s delay, Liquid	Heating	0.25	0.56	0.23	0.50
3M	Valves relocated 10 m from unit	Vapor, 30 s delay, Liquid	Heating	0.23	0.52	0.21	0.47

Table 145 - Summary of Valve Timing with Delay

[3] Test data for recovery method was not valid for this test.

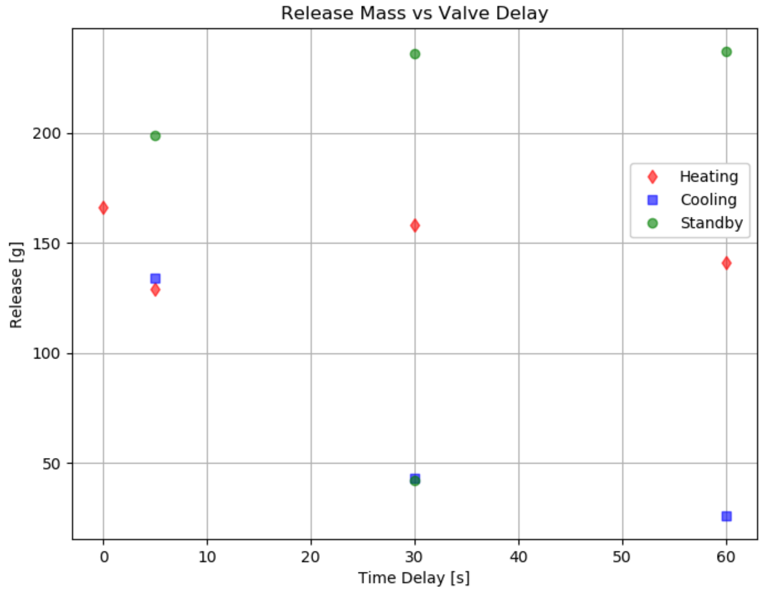


Figure 18 - Potential Refrigerant Release with differing SSV delay

3.4.5 Seat Leakage

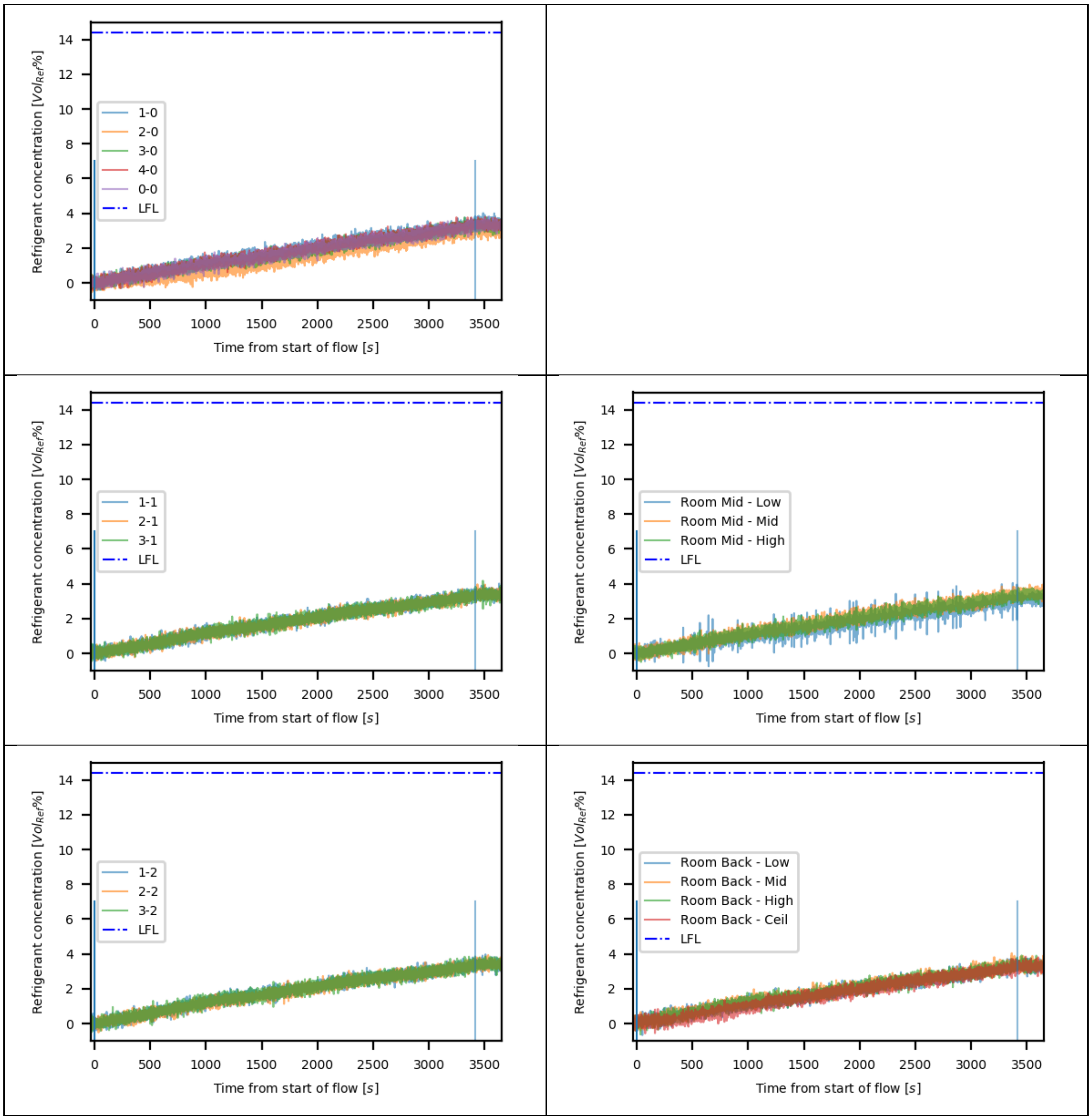
The arrangement for sensors were the same as present for the ductless tests, see Figure 14 for the refrigerant sensor layout in the room.

Baseline test

A summary of the test parameters for this test are indicated in Table 146. The mass release for this test was calculated based on 25% of the LFL for the entire room.

Test Summary	Baseline seat leakage rate , 1.0 kg/h leak		
Release Amount	3.38 kg	Release Time	3348 s (55.8 min)
Release Quality	Capillary Leak	Time to Qmin	N/A
Installation Height	1.8 m	Fan Speed	N/A

Table 146 - Baseline Seat Leakage Parameters

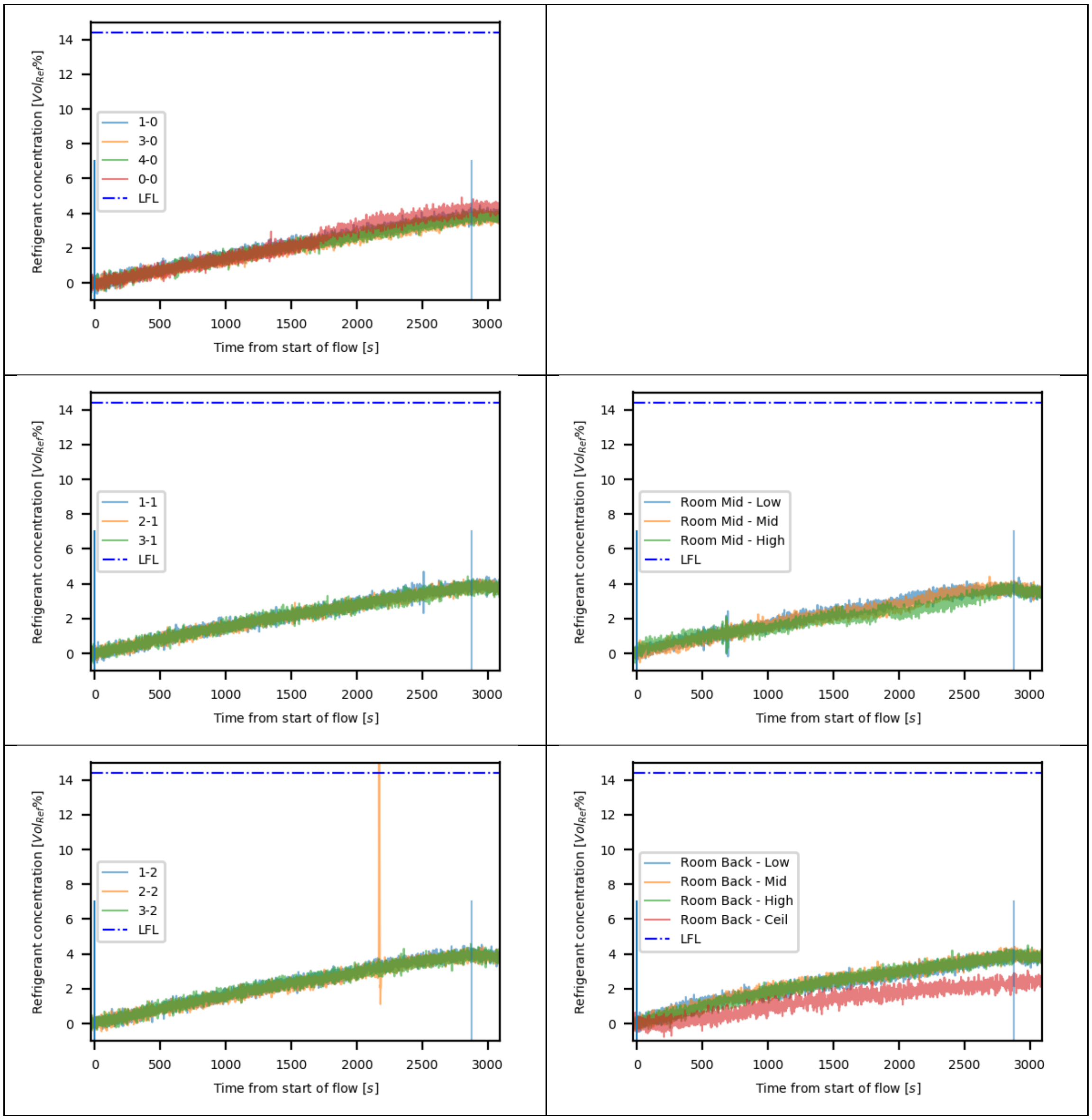


IEC -2-40 Seat Leakage

A summary of the test parameters for this test are indicated in Table 147. The mass release for this test was calculated based on 25% of the LFL for the entire room.

Test Summary	IEC -2-40 seat leakage rates, 4.4 kg/h leak		
Release Amount	3.48 kg	Release Time	2894 s (48.2 min)
Release Quality	Capillary Leak	Time to Qmin	N/A
Installation Height	1.8 m	Fan Speed	N/A

Table 147 - IEC Seat Leakage Test Parameters



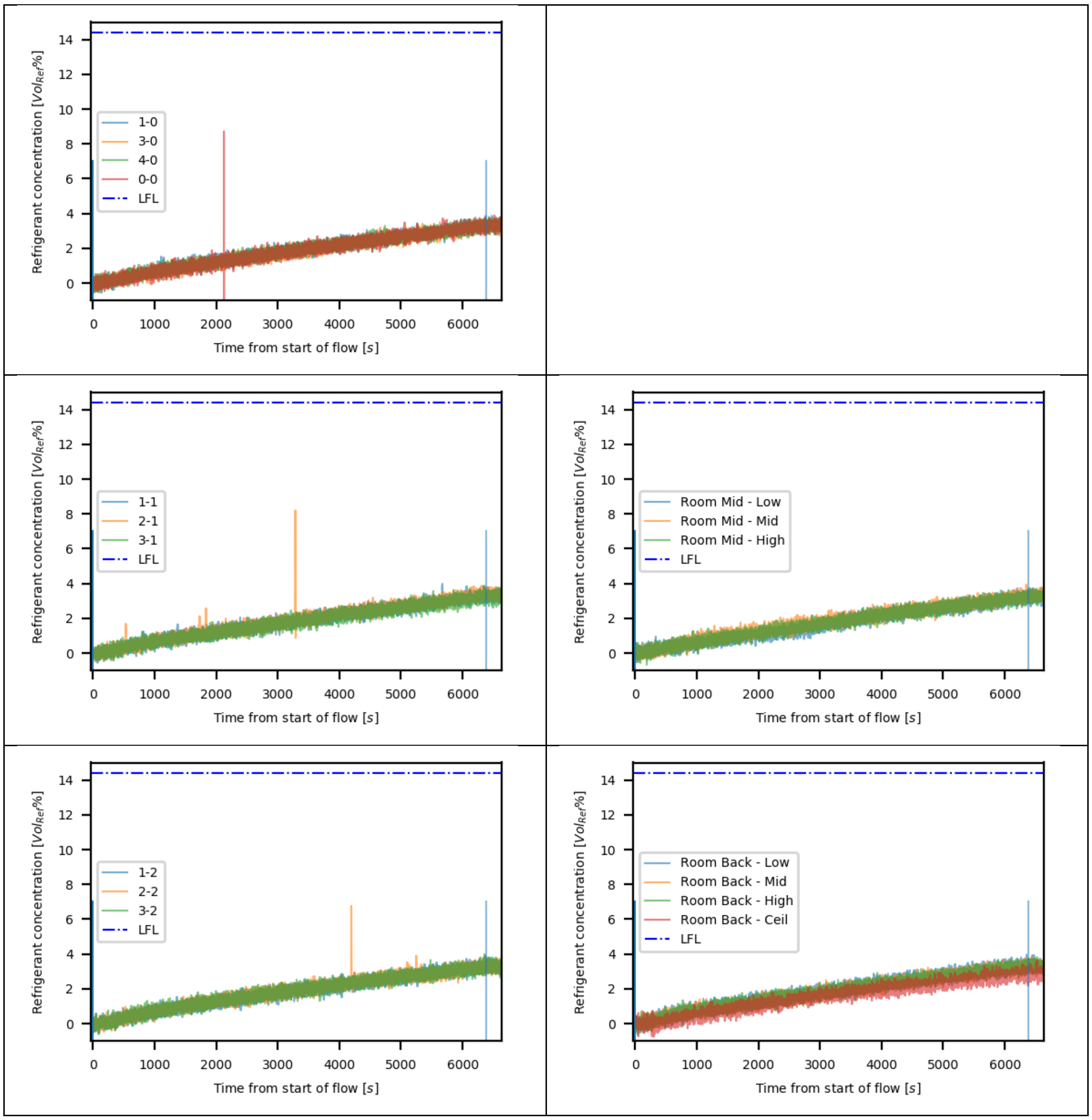
Intermediate Seat Leakage

A summary of the test parameters for this test are indicated in Table 148. The mass release for this test was calculated based on 25% of the LFL for the entire room.

Test Summary	Intermediate seat leakage rates, 2.0 kg/h leak		
Release Amount	3.40 kg	Release Time	6427 s (107.1 min)
Release Quality	Capillary Leak	Time to Qmin	N/A
Installation Height	1.8 m	Fan Speed	N/A

Table 148 - Intermediate Seat Leakage Test Parameters

The test results show how tight the test room was and the expected equilibrium between seat leakage and room leakage was not observed. Actual rooms may not be as tight as this test room. Certain study to investigate tightness of rooms may be necessary to establish acceptable seat leakage rate. In this test, the concentration in the room was almost homogeneous without fan operation. In this level of release rate and release height (1.8 m), stagnation of released refrigerant does not occur.



4 Discussion

4.1 Delay Time

With the Vertical Unit test arrangement, there is evidence of refrigerant entering the room space via the return grill. Initially the refrigerant remains closer to the ground. Turning on the fan for mitigation at either 25 s or 35 s limits the flammable volumes in the space. This does result in higher concentrations coming out of the ductwork into the room as the fan pushes the volume of higher concentration refrigerant, which was retained in the unit and ductwork, out into the room. Figure 19 shows this effect, for mitigation at 25 s the sensor is above the LFL for four seconds and with the mitigation at 35 s the sensor is above the LFL for five seconds (due to the deconvolution method, the actual time above LFL may be less).

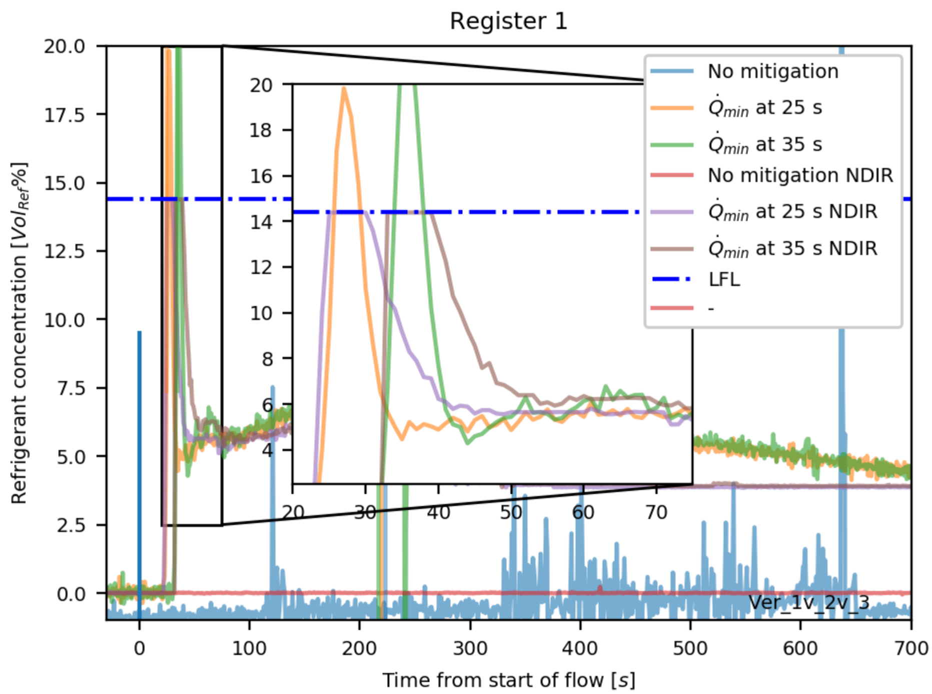


Figure 19 - Mitigation Response for Vertical Unit Register 1

(peak concentrations around 22~45 seconds may be overestimated and time shifted due to deconvolution method)

The mitigation activation can limit the amount of refrigerant above the LFL entering the space through the return. Figure 20 compares the refrigerant concentrations with and without mitigation at Qmin. The sensor near the return 50 mm (2 in) above the floor that an additional 10 seconds of delay allowed the sensor to register above the LFL for six seconds (due to the deconvolution method, the actual time above LFL may be less or may be zero).

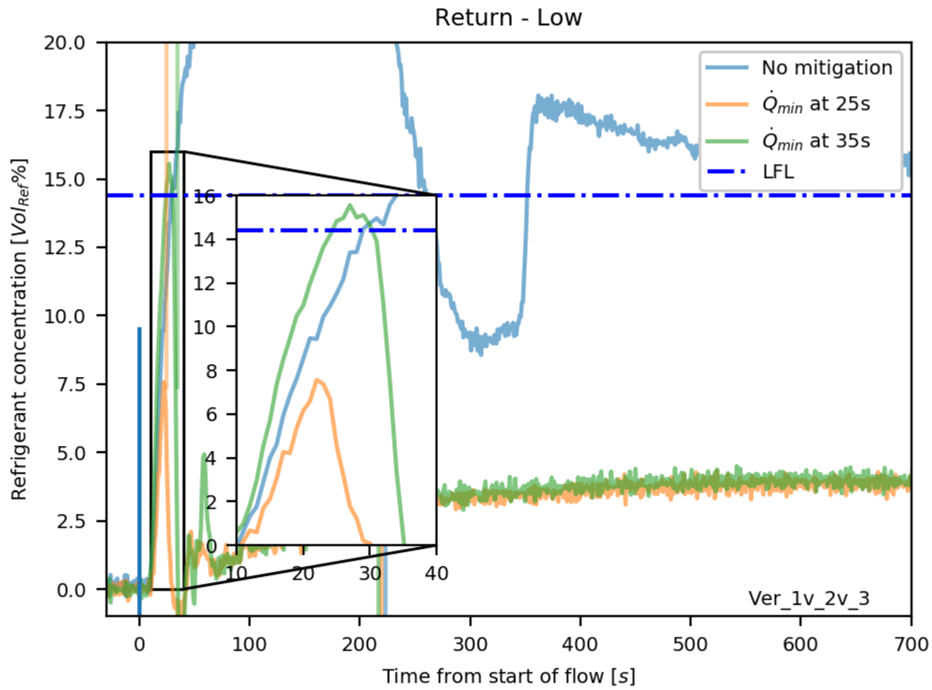


Figure 20 - Mitigation Response for Vertical Unit at Return

(peak concentrations around 20~30 seconds may be overestimated and time shifted due to deconvolution method)

With no mitigation the refrigerant concentration above the LFL stays near the floor, for the array in the center of the room at 300 mm (12 in) the concentration, with no mitigation, is below the LFL and at 900 mm (36 in) there is a very small percentage of refrigerant. This also shows that with mitigation we have consistent mixing vertically in the room space.

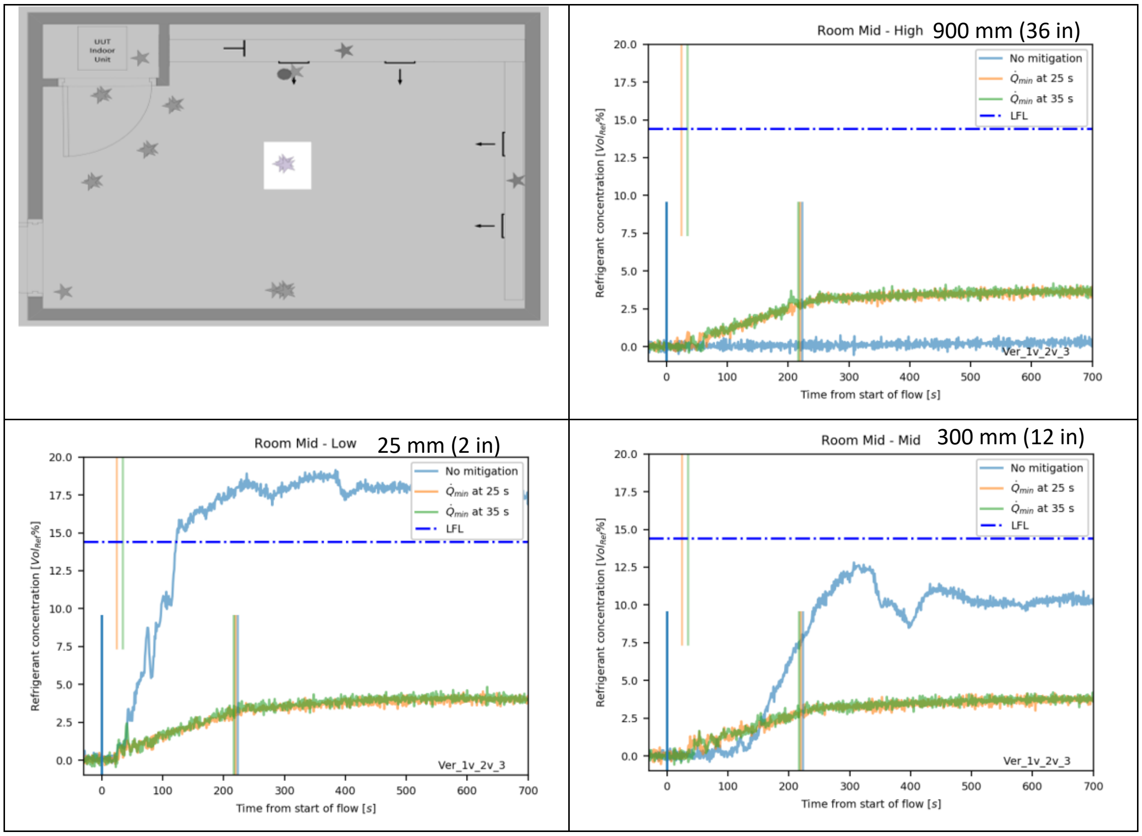


Table 149 - Comparison of Refrigerant Concentration vs Height

In all cases for the Vertical arrangement, a faster mitigation response resulted in the total time that sensors registered above the LFL to be reduced and also reduced the average maximum reading for all sensors.

With the unit in a horizontal configuration there is not a significant amount of refrigerant entering the space without mitigation see Figure 21. This confirms previous research (Baxter, 2018) which concluded, using CFD modeling, that for an underfloor system the volume of the ductwork was sufficient to contain the volume of the refrigerant. Due to the installation the ductwork and unit were considered to be outside of the defined test room and added an additional 1.1 m^3 (38 ft^3) to the test space. A slightly higher concentration was indicated at the lower sensors with a vapor release when compared to a liquid release, see test Horizontal 6. As with the vertical arrangement when mitigation is present there are short durations where there exist situations where refrigerant being discharged into the room space is above the LFL. The horizontal setup investigated during this project did not result in significant refrigerant entering the test space, however it was shown that the refrigerant was able to escape through openings in the unit case and ductwork to enter the space where the unit was installed. Depending on the arrangement of the leak point and blower (blow through coil vs draw through), detection and mitigation of a leak could prevent flammable volumes from being present in this space.

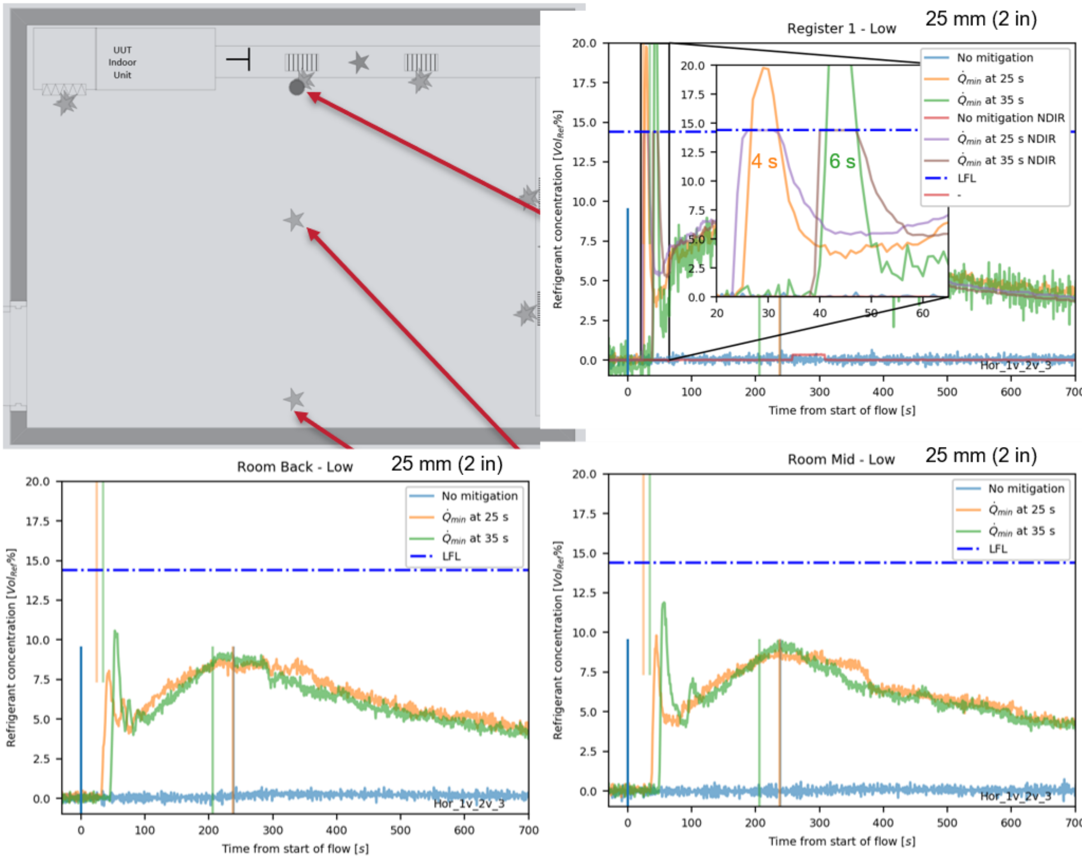


Figure 21 - Mitigation Response for Horizontal Unit

(peak concentrations around 20~50 seconds may be overestimated and time shifted due to deconvolution method)

Mitigation response time had less effect with the ductless units tested, because of the installation heights and the effects of refrigerant mixing that occurred when the leak was introduced. During some of the tests there were short durations of volumes above the LFL. Other constructions of minisplit appliance or installation heights could result in the need for mitigation.

4.2 Volumetric Flow

Changing the volumetric airflow had an effect in two ways: it produced a higher velocity which resulted additional mixing in the space and it often required that the fan turn on at an earlier time.

The intent of this testing was to have the fan reach the defined volumetric flow for the test at a specific time. This resulted in the fan need to be commanded on at differing times. The energizing of the fan sooner also had the effect of starting to circulate the air in the space. The left plot of Figure 22 details a comparison of the vertical setup with the volumetric flow as calculated per the standard and a volumetric flow increased to a factor of two times. There are two different local maximums (for Qmin it is above the LFL for 7 seconds, 2xQmin is above the LFL for 5 seconds) which would be anticipated if the activation time had been varied as was discussed in the previous section (due to the deconvolution method, the actual time above LFL may be less). However, the right plot shows a data from a thermal anemometer in the center of the duct. It is the result of energizing the fan earlier which is resulting in the apparent time difference between the peaks.

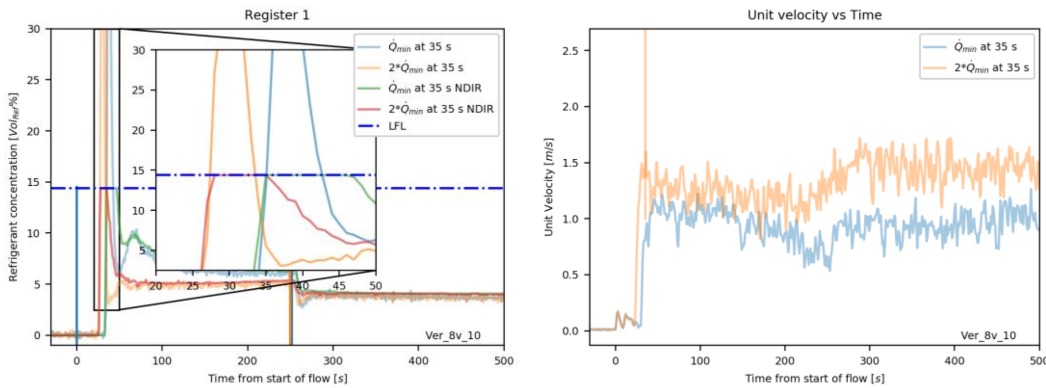


Figure 22 - Comparison of Volumetric Flow

(peak concentrations around 25~45 seconds may be overestimated and time shifted due to deconvolution method)

For the horizontal setup: increasing the volumetric flow above what is currently identified in UL/CSA -2-40 had the effect of lowering the average maximum refrigeration concentration at each of the sensor locations in the space. Increasing the volumetric flow also decreased the time that the sensors were in the flammable range. Figure 23 shows select data points for a 3.42 kg (25% of LFL of entire room volume) vapor release with Qmin and 2x Qmin at 35 s.

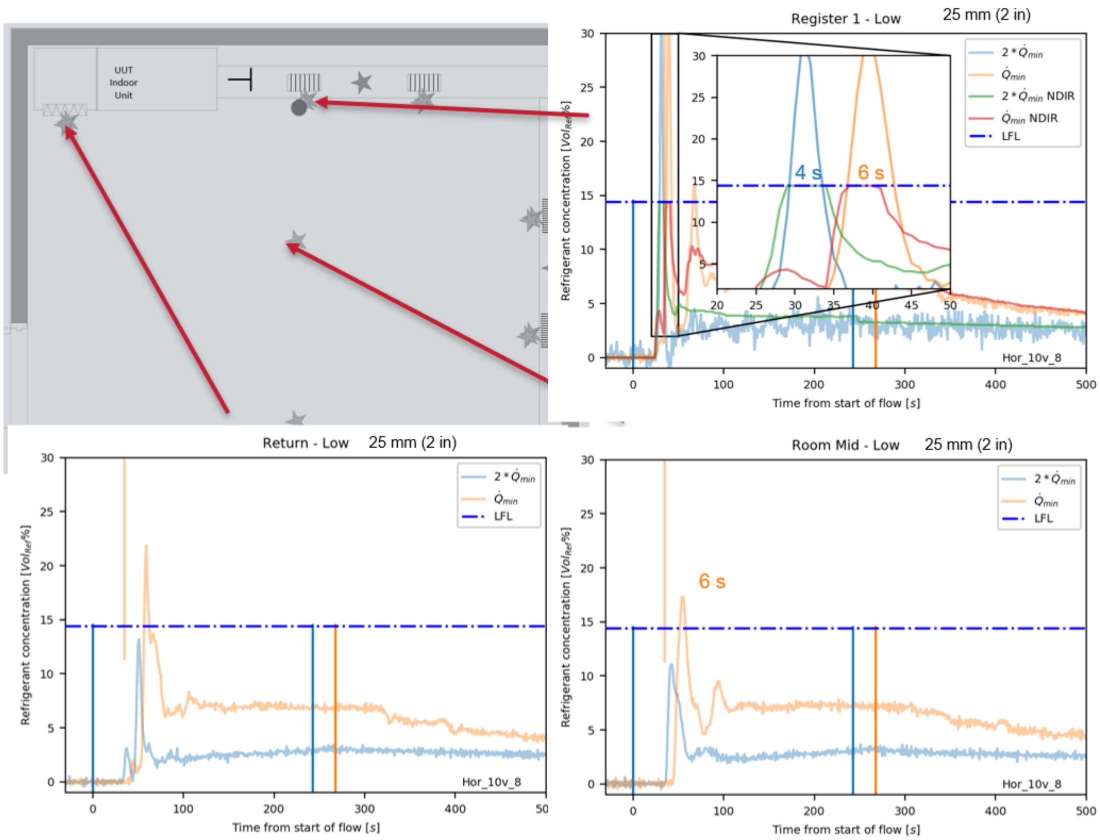


Figure 23 - Horizontal Qmin and 2xQmin

(peak concentrations around 25~45 seconds may be overestimated and time shifted due to deconvolution method)

For the vertical setup, increasing the volumetric flow above what is currently identified in UL/CSA - 2-40 had the effect of lowering the average maximum refrigeration concentration at each of the sensor locations in the space in all but one test. Figure 24 shows select data points for a 3.42 kg (25% of LFL of entire room volume) vapor release with Qmin and 2x Qmin at 35 s. Vertical 20 test that also showed there were higher localized concentrations with the volumetric flow at two times the specified Qmin. This test had higher refrigerant concentrations near the return than other tests with these similar parameters and the concentrations flowed into the room around the wall, as opposed to directly into the test space. In order to achieve the airflow through the unit for this test (as well as Vertical 19, which tested the same parameter) the restriction on the inlet of the air hander needed to be reduced. This resulted in running the blower motor at a different speed as well as modifying the time that was needed to activate the blower to be at Qmin at the test time. This resulted in calling for the blower to activate slightly later than it had with the lower volumetric flow rate. It was this change in the time to start the blower and start moving air that allowed these higher concentrations, even with greater airflow.

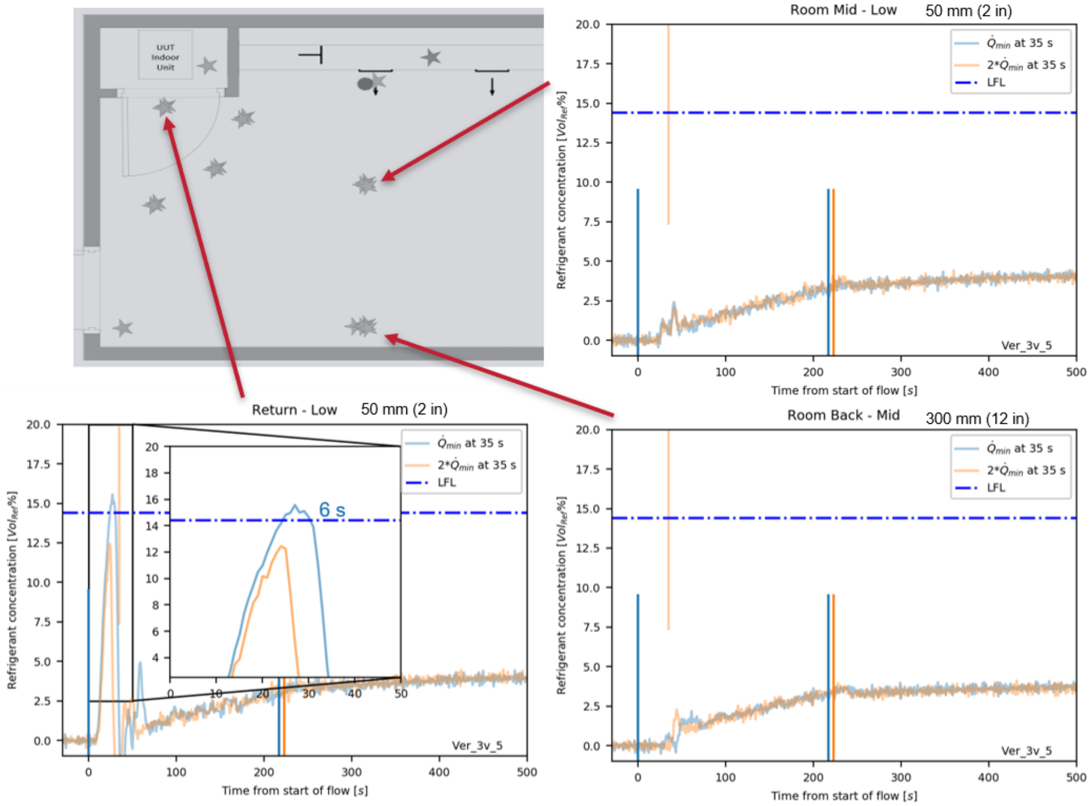


Figure 24 - Vertical Qmin and 2xQmin

(peak concentrations around 15~35 seconds may be overestimated and time shifted due to deconvolution method)

Sets of tests were conducted with the horizontal and vertical arrangements to compare the flowrates established by table GG.2 in IEC -2-40. In order to provide these flowrates only two registers were used to discharge air into the room. This airflow was prescribed by identifying not only a volumetric minimum, but also a minimum velocity at the register. The use of this table is not expected for a ducted system, as these are governed by a different clause in the standard. However this has allowed us to compare situations which had a velocity factor. Comparing Horizontal 22 with Horizontal 2 the increased velocity (even with reduced airflow) lowered the average maximum concentration in the test room. The refrigerant was discharging only through two registers there was a higher concentration at Register 2, 150 mm (6 in) above the register, however the other values were the same or less. All the other sensors in the space remained below the LFL for the duration of the release for both tests.

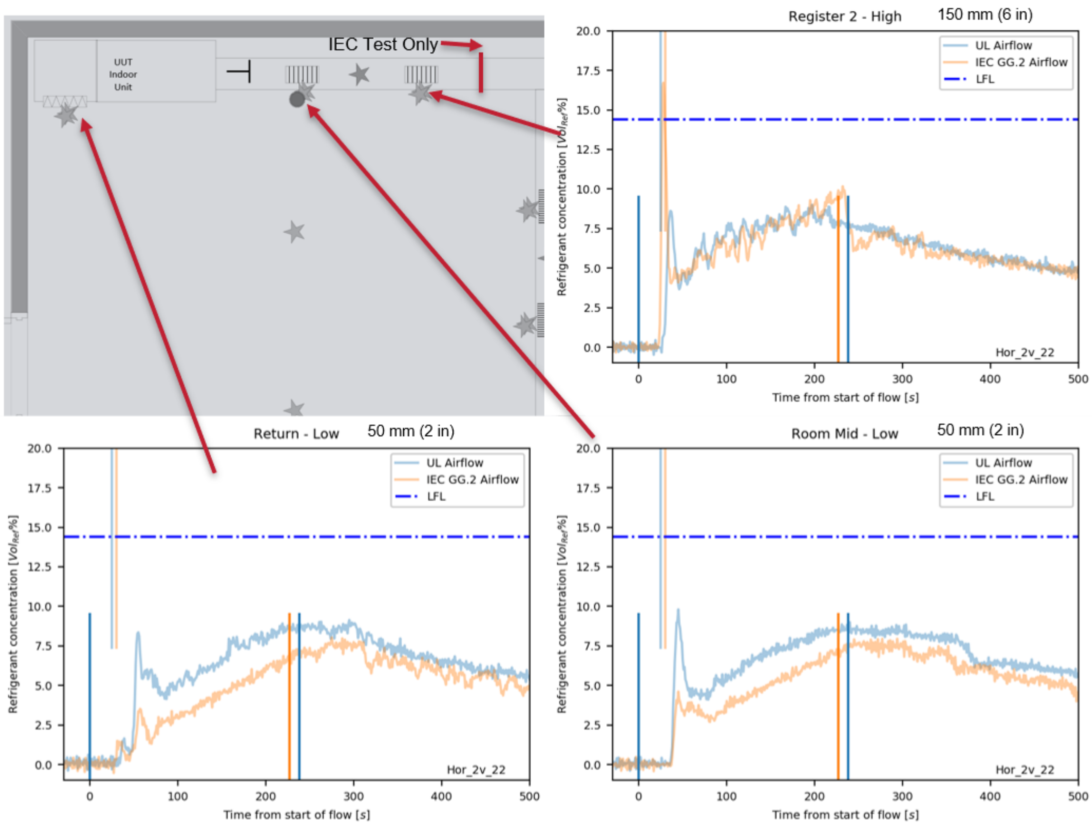


Figure 25 - Horizontal UL vs IEC Airflow

(peak concentrations around 20~50 seconds may be overestimated and time shifted due to deconvolution method)

Testing was conducted with the horizontal and vertical units with the volumetric flow above the stated values. Tests were conducted for the ductless units comparing the UL flow rate to the IEC (lower) flow rates. For a 6.84 kg (50% of LFL of entire room), 8 minute liquid release with the airflow rates at UL Qmin and 50 % Qmin the rate at which the concentrations rise is similar. The average maximum value of all the sensors was the same between these two releases. For this test, 50% of the airflow is sufficient to mix the refrigerant in the space. These test parameters resulted in a direct comparison of the UL minimum airflow and the IEC minimum Qmin (which is 50% of the UL value) for the same unit and charge size. The IEC volumetric flow value is based on a 4 minute leak, so it follows that with an 8 minute leak there would also be sufficient airflow to mix well in the entire space.

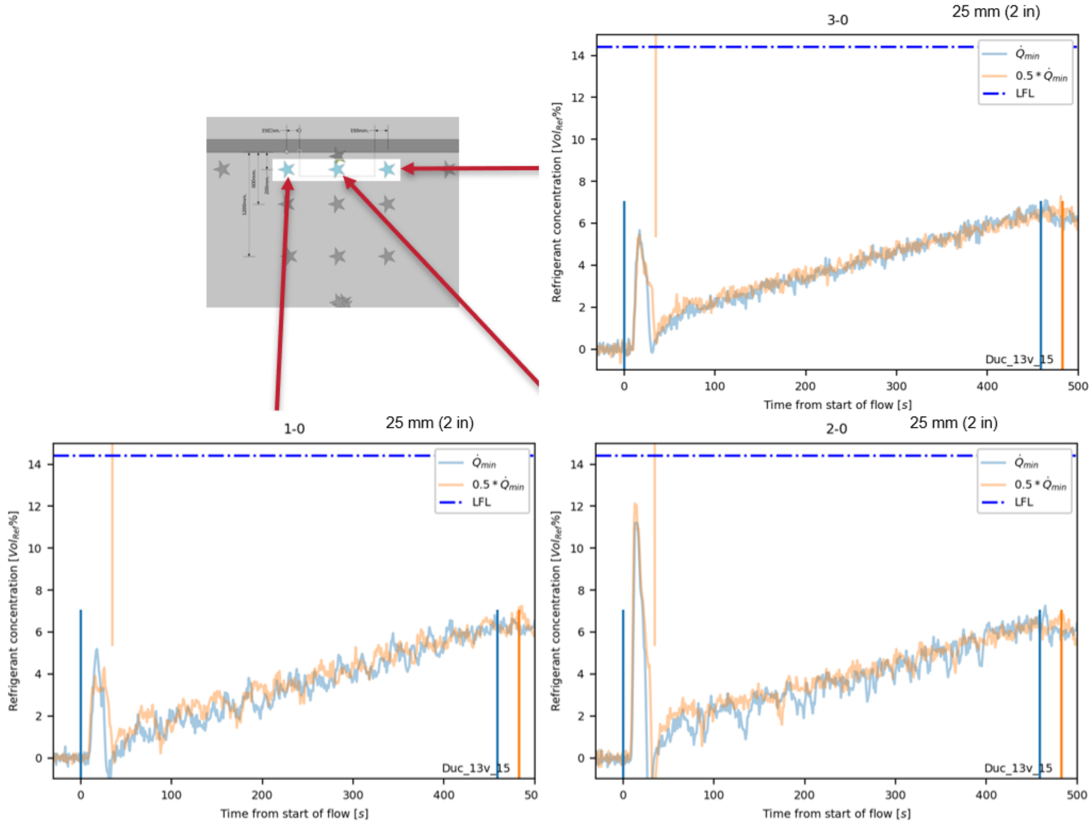


Figure 26 - UL vs IEC airflow for 8 min release

(peak concentrations around 10~40 seconds may be overestimated due to deconvolution method)

Due to the fact that we had to select individual fan speeds for the ductless there are several tests with varying release charges for which the fan speed was the same. One such case in Ductless 3, Ductless 24 and Ductless 22. In this case we have approximately the same mitigation time, 35 s for Ductless 3 and 30 s for the other two. What is varying is the released charge: 25% LFL of room (3.42 kg), 50% LFL of room (6.84 kg) and IEC charge for installation (7.41 kg). This test indicates that there is refrigerant mixing well in the space. The sensors closer to the floor have a higher refrigerant concentration during the release and this is due to the direction of the unit discharge air. Once the refrigerant release ends the airflow continues to mix the refrigerant in the space towards uniformity. Figure 27 details the sensors in the center of the room.

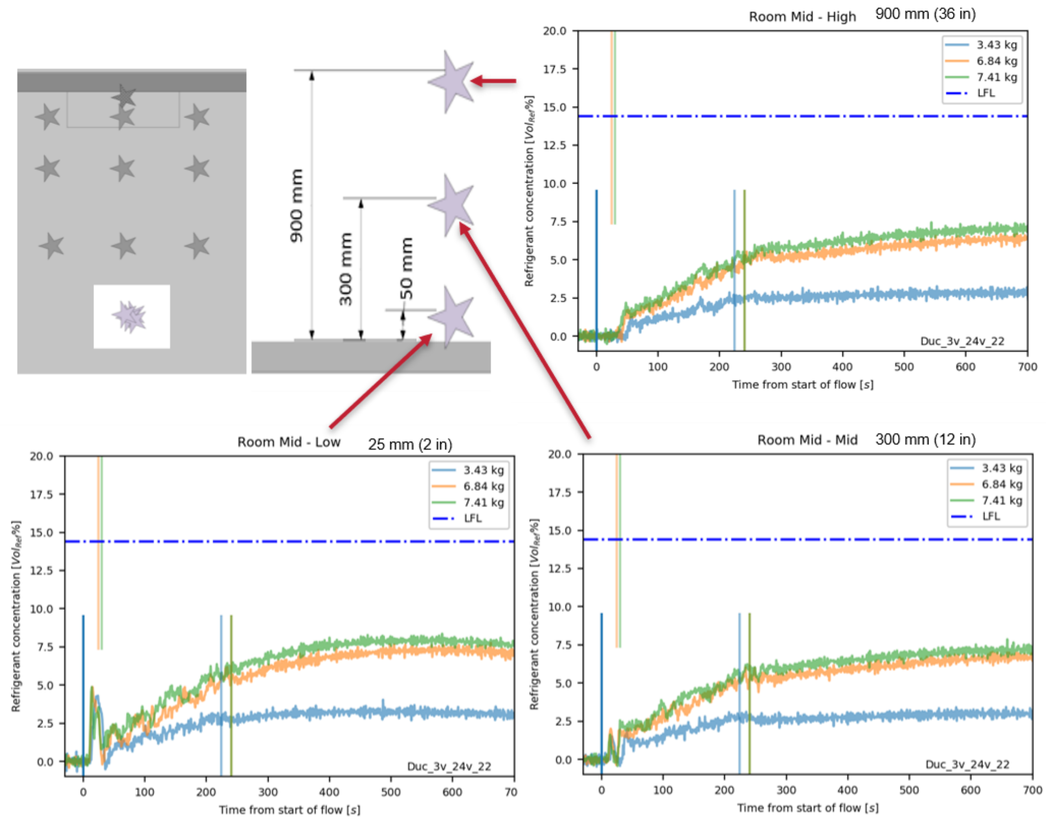


Figure 27 – 25%, 50% of LFL of Room Volume and IEC maximum for the space.

4.3 Release Time/Release Rate

This study did not find that the safety factor had a significant difference with the refrigerants in the flammable range when mitigation in used. The current requirements in the standard base the volumetric flow minimums on the charge of the system. The constant release rate for the increased charge time permitted the refrigerant to be distributed in the room space over a longer time. This results in more air mixing the refrigerant in the room space.

For the horizontal and vertical ducted tests the airflow values were set based on the current requirements in the standard which is based on the charge of the unit with a four minute leak. The longer release rate resulted in lower refrigerant concentrations to observed at the registers as there was a higher airflow for the same release rate, albeit for a longer time. In all the horizontal tests the longer release times resulted in lower refrigerant concentrations in the space. The vertical arrangement did show higher maximum average values. Figure 28 shows the refrigerant concentrations at the first register and return 50 mm (2 in) for a 3.42 kg (25% LFL for room) and 6.84 kg (50% LFL for room). Due to the fact that this is a larger charge the blower turns on faster, this results in a lower local peak concentration. The refrigerant is being mixed in the space and concentration for the larger release increases over the entire discharge. All of the other refrigerant sensors were below LFL for the entire release.

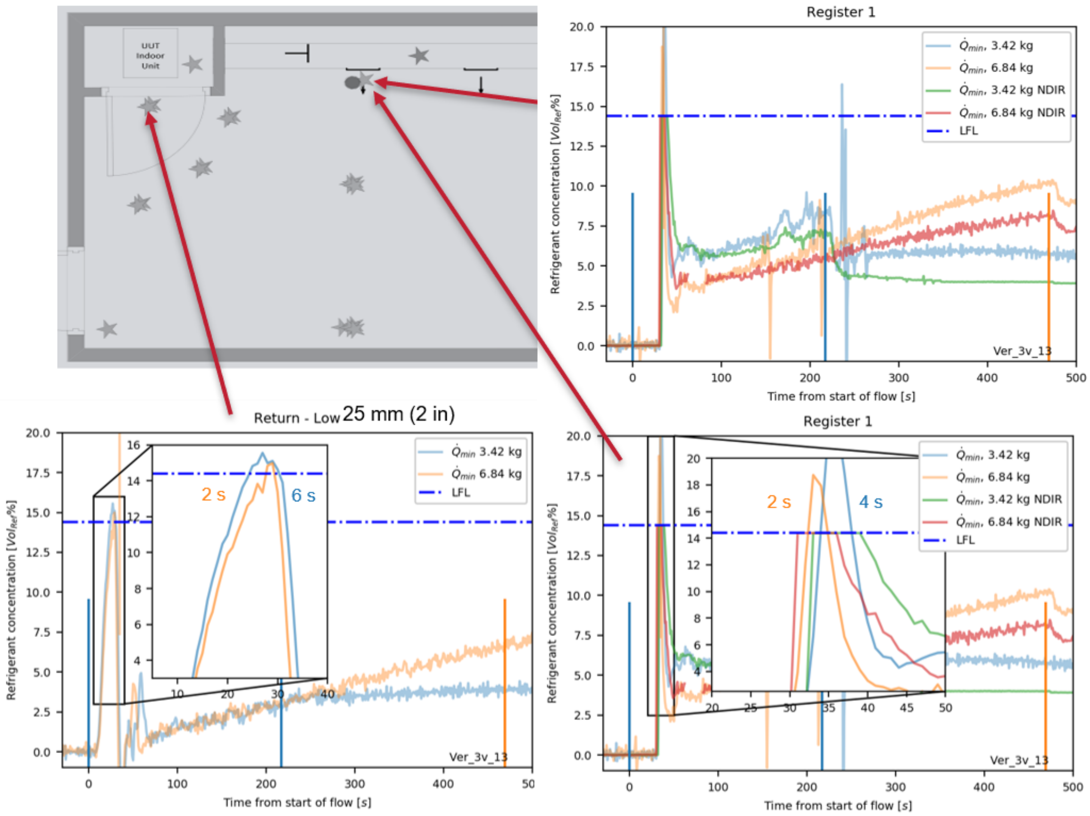


Figure 28 - Vertical 4- and 8-minute Liquid

(peak concentrations around 10~35 and 225~250 seconds may be overestimated and time shifted due to deconvolution method)

A test was conducted with two registers and the IEC table GG.2 requirements. There was a four minute liquid release at 25% LFL for the room volume and 50% LFL for the room volume. Due to the physical limitations with the unit under test the airflow for the smaller release was about 79% of the total flow for the larger release. It is expected that if the flow rate was lower the average refrigerant concentration at the discharge would have been higher.

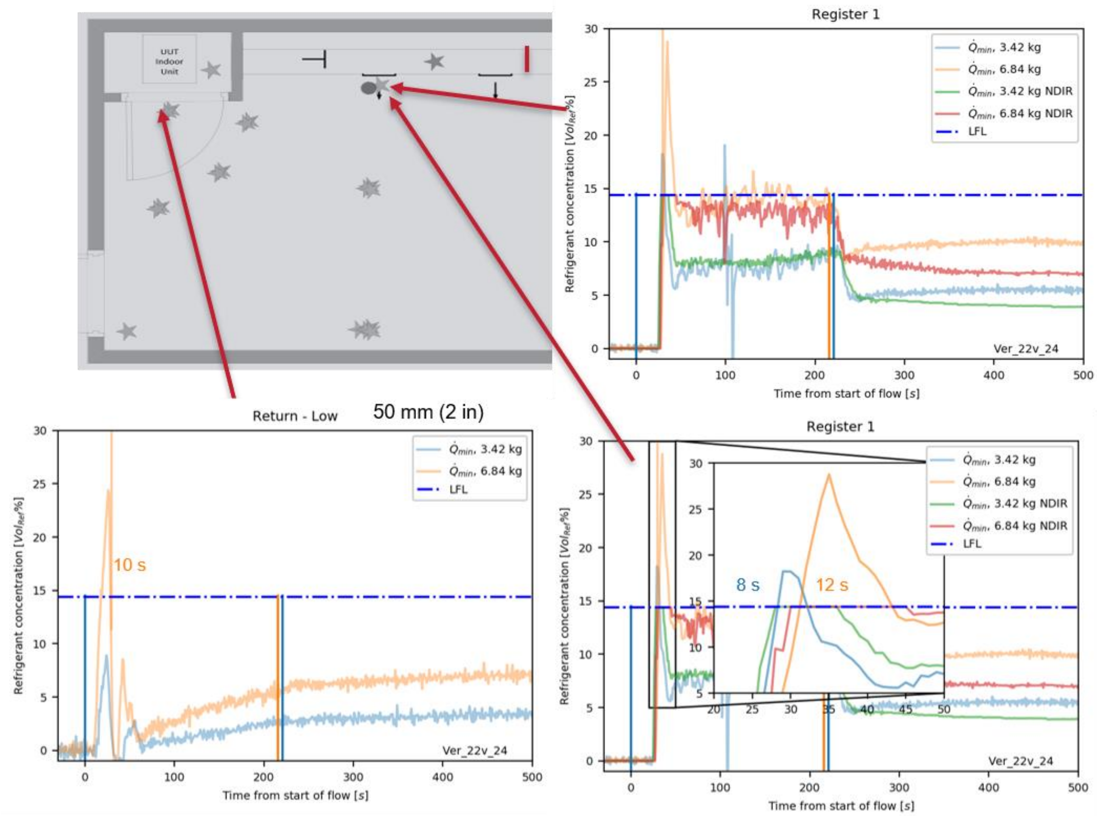


Figure 29 – Vertical 4- and 8-minute at IEC Airflow

(peak concentrations around 15~40 seconds may be overestimated and time shifted due to deconvolution method)

As was identified in Figure 27, with the ductless arrangement it was possible to incorporate a faster or larger release rate with the same airflow have well mixing in the room. There does exist a physical limit for some units. The larger release size for Ductless 22, is not significantly higher for most locations, however there was evidence of liquid refrigerant dripping from the unit during both the 6.84 (50% LFL of the room) and 7.41 (IEC max charge for installation height). The current requirements in the standard are sized based on the overall concentration in the room for a fast leak (4 min) and there do not exist construction requirements which would limit the discharge of a liquid refrigerant into the space.

4.4 Refrigerant Quality

While this study did not find differences between the quality of the leaks, the test programs in this research study identified that there exist unit constructions and arrangements which could introduce liquid refrigerant into a space. Hazards associated with liquid A2L refrigerants do not differ from current A1 refrigerants used in HVAC/R applications, with regards to contact with skin or eyes. In any case liquid refrigerant can cause frostbite on contact and efforts should be taken to avoid contact with personal.

With the vertical arrangement there were some differences in the way that the refrigerant entered the test space. Without mitigation refrigerant concentrations were above the LFL near the return with both a liquid release as well as the vapor release. With the vapor release the refrigerant rose above the LFL and remained at this value. For the liquid release there was indication that the sensors were above the LFL during the release, then dropped in concentration after the flow ended, before increasing to above the LFL. This effect was a result of the refrigerant displacing the atmospheric air in the unit and the ductwork during the release. When the refrigerant release ended, cold air is generated in the indoor unit that is heavier than air and refrigerant mixture at room temperature that flows down to return grill and dilute refrigerant and air mixture near return grill. After about 2 minutes from the end of release the low temperature air generated in the indoor unit becomes higher than the boundary condition, so the downward flow stopped. Then stagnating refrigerant cloud surrounding the return grill flowed to the return grill. Figure 30 details the sensor 50 mm (2 in) above the floor near the return and near the corner of the closet.

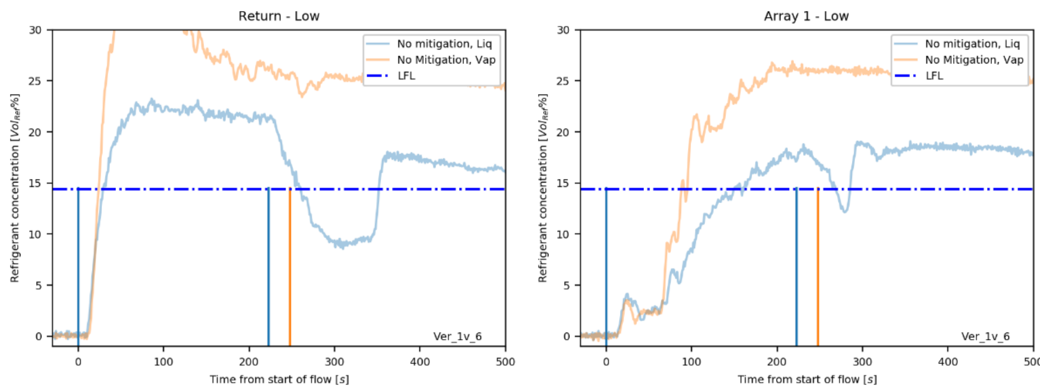


Figure 30 - Vertical Liquid and Vapor Release

(peak concentrations around 10~50 seconds may be overestimated due to deconvolution method)

These results indicate that vapor release generates more air flow than gas release. For both sensor locations the vapor resulted in a higher concentration during and after the release.

With both the vertical and horizonal setup the larger volume of the vapor releases displaced slightly more refrigerant in the ductwork. This resulted in higher refrigerant concentrations being discharged into the room space for short durations as the fan turned on. For the vertical setup this resulted in the average maximum refrigerant value to be greater with a vapor release than with the liquid release. For the tests with 3.42 kg (25% of LFL for the room volume) and Qmin at 35 s the two sensors that went above the LFL are shown in Figure 31. These sensors were at the discharge register and the sensor 50 mm (2 in) above the floor near the return grill. None of the other sensors during this test reached the LFL.

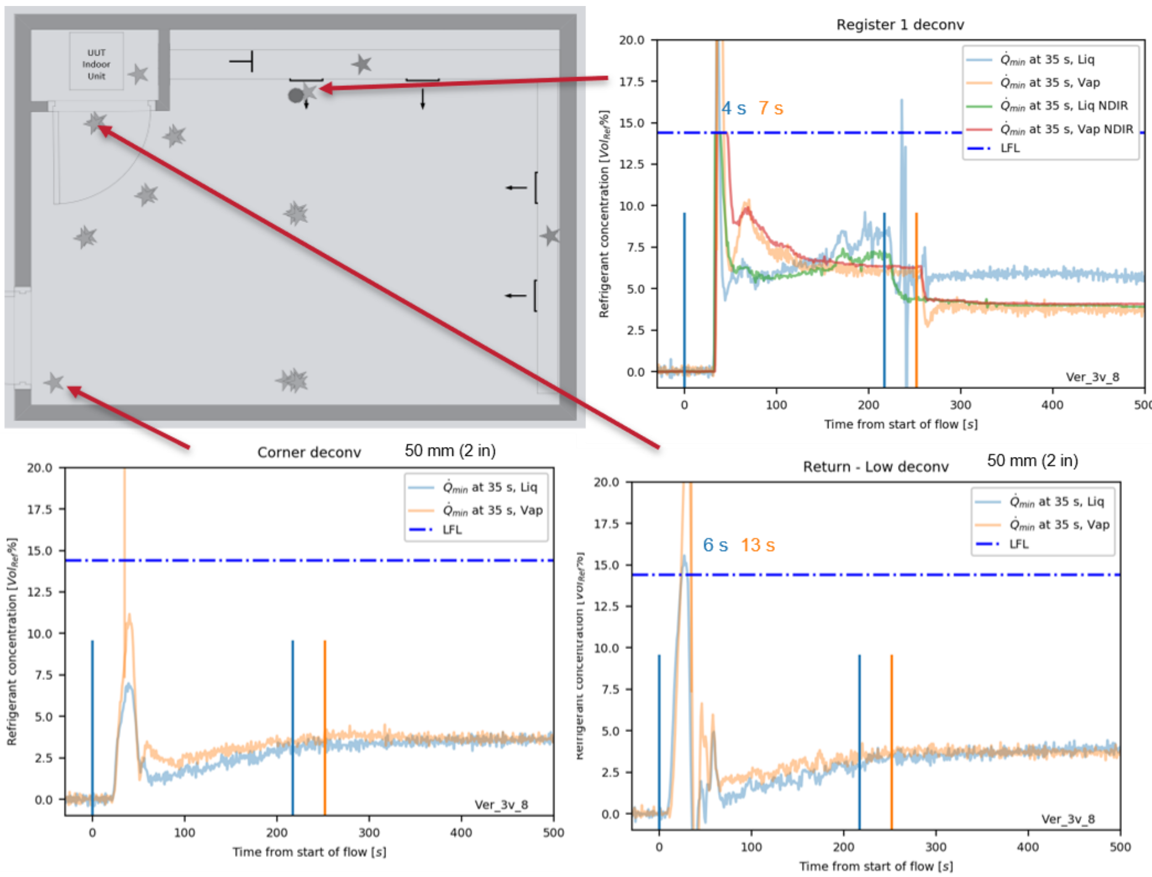


Figure 31 - Vertical - Vapor and Liquid Release

(peak concentrations around 10~50 seconds may be overestimated due to deconvolution method)

The horizontal setup had similar results. Figure 32 provides examples of room sensors where the vapor release was above the LFL. This figure also indicates that the vapor refrigerant is displacing air in the duct which is being pushed out as the blower reaches Qmin.

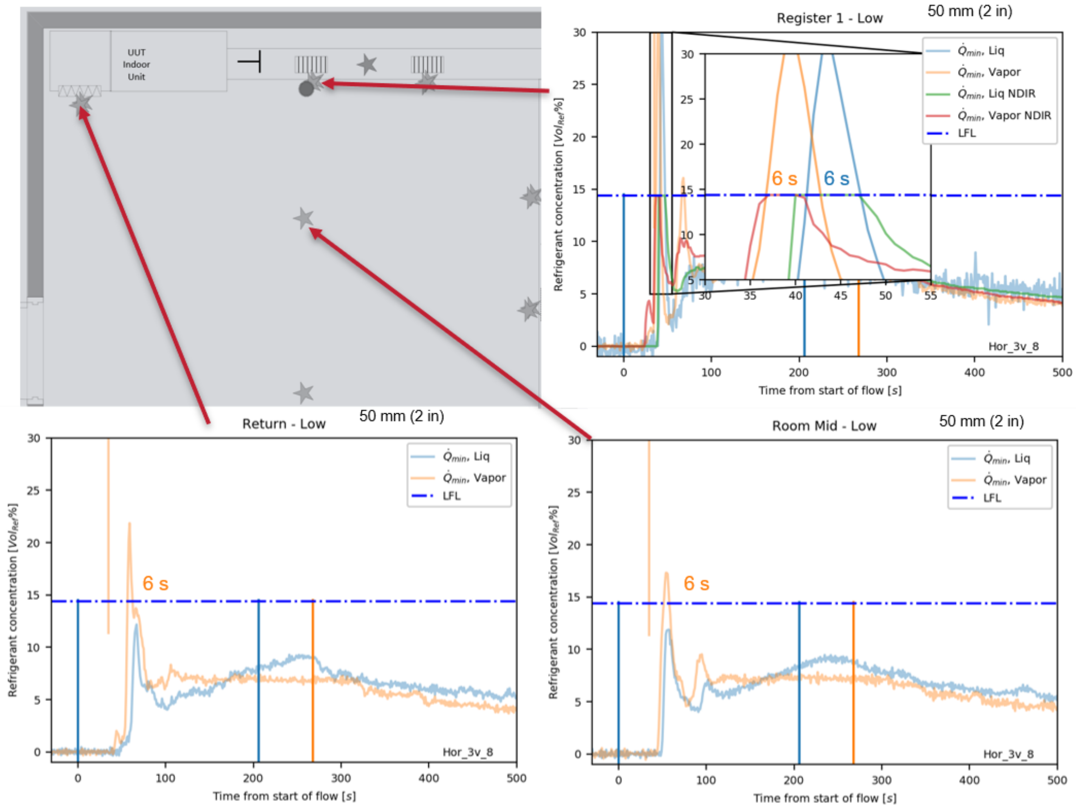


Figure 32 - Horizontal - Liquid and Vapor Release

(peak concentrations around 30~90 seconds may be overestimated due to deconvolution method)

4.5 Installation Height

The majority of the testing on the ductless system was conducted with the indoor cassette installed 1.8 m above the floor. A set of tests was conducted with the unit reinstalled installed at 1.2 m off the floor (67% of the original height). These tests had been conducted with vapor release only due to the variability of liquid refrigerant remaining in the unit drain pan of the unit and taking significant time to enter the room space. These tests indicate that without airflow in the room there is stratification of the refrigerant in the space. With this unit arrangement there was evidence that the lower installation height does have an effect on the refrigerant concentrations lower in the space, but once the flow is complete the airflow does continue to mix the entire room space.

The testing without mitigation shows that there is a was a concentration difference at a lower height in the room space. For the sensors located below the unit the 1.2 m install resulted in a 38% higher refrigerant value at the start of the test, 20.5%, for the sensor 50 mm (2 in) off the floor (see Figure 33). Once the flow and been completed and the room concentrations were stable (~400 s after start) the concentrations at this point were 48% higher for the 1.2 m unit. This was confirmed when reviewing the sensors in the middle of the room, which were 47%, 39% and 15% higher for the 1.2 m installation, for sensors located 50 mm (2 in), 300 mm (12 in) and 900 mm (36 in) off the floor (see Figure 34). With both of these tests, the sensor located near the ceiling did not indicate a significant rise, indicating that for even a unit installed at 1.8 m the refrigerant is not mixing within the entire room space.

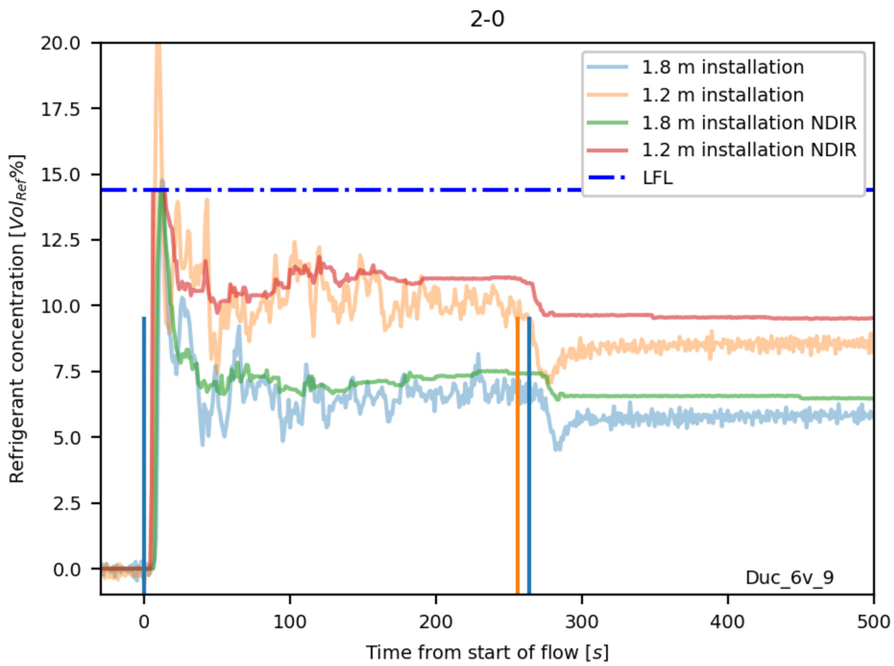


Figure 33 - Installed 1.8 m vs 1.2 m, No Mitigation

(peak concentrations around 10~50 seconds may be overestimated due to deconvolution method)

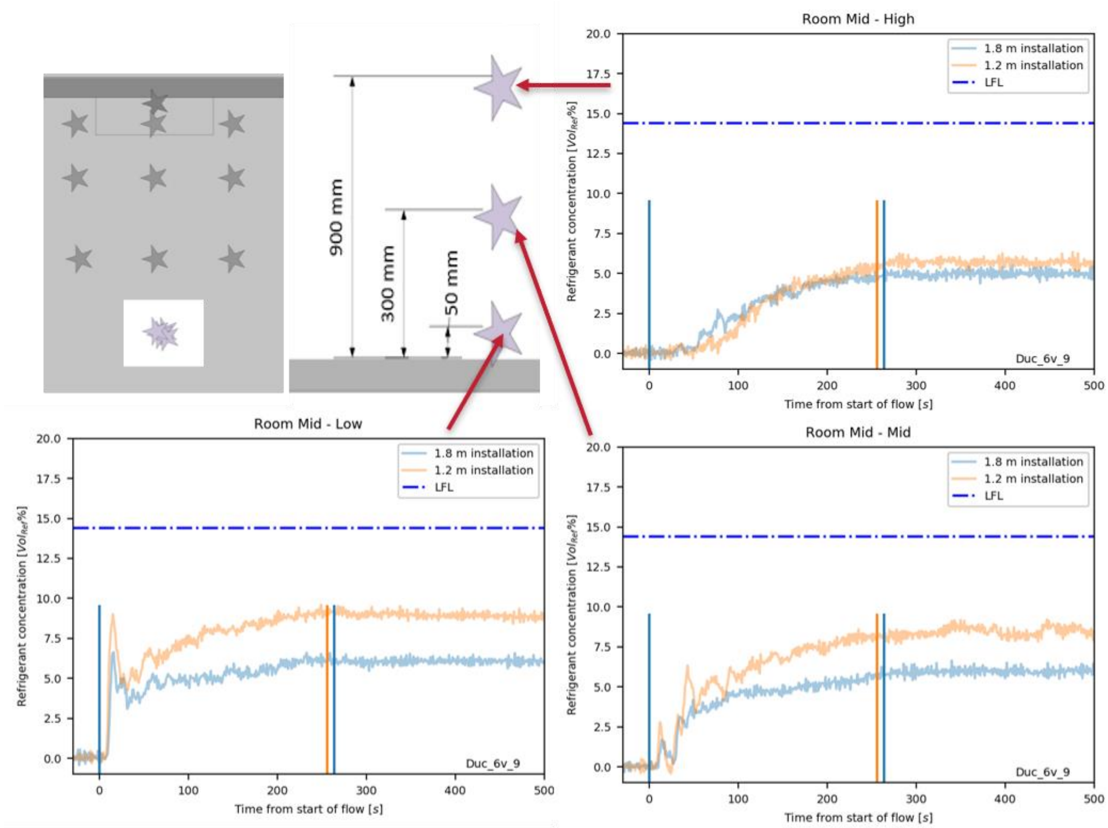


Figure 34 - Installed 1.8 m vs 1.2 m, No Mitigation

Mitigation does have an effect on the mixing in the room space. For this test a comparison was made with the fan at Qmin 25 s after the start of the flow. The localized concentration as the fan was coming on was only 5% greater at 16% of Ref_{vol} with the unit installed at 1.2 m off the floor. Both of these tests reached their maximum values just before the fan turned. As the release was ongoing the unit the 1.2 m installation height had slightly higher concentrations of refrigerant, so the mixing was not happening within the entire room space immediately with Qmin. However, once the flow and been completed and the room concentrations were stable (~400 s after start) the concentrations at this point were similar for the 1.2 m unit (Figure 35). This was confirmed when reviewing the sensors in the middle of the room, which were 12%, 8% and 8% higher for the 1.2 m installation, for sensors located 50 mm (2 in), 300 mm (12 in) and 900 mm (36 in) off the floor (see Figure 36).

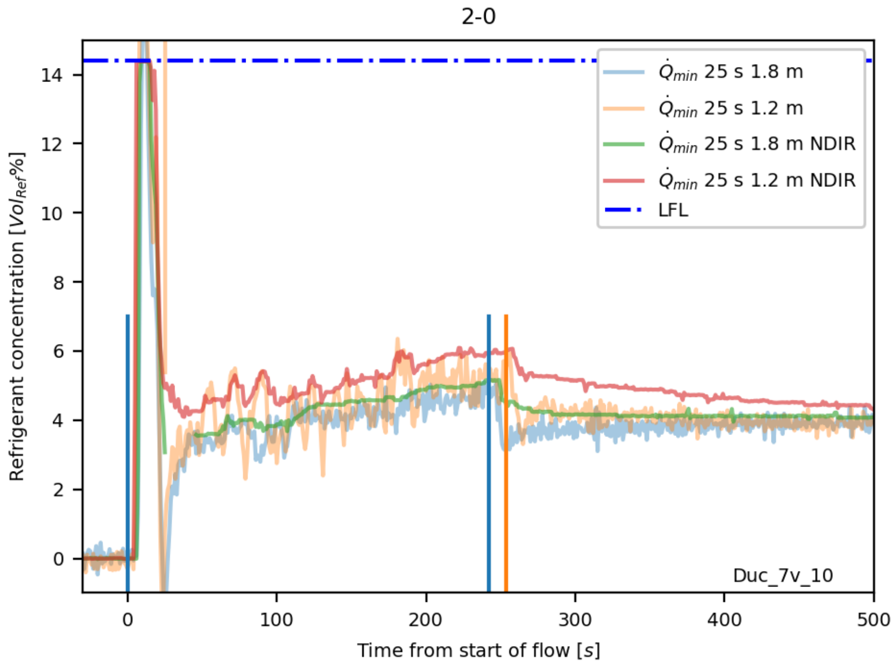


Figure 35 - Installed 1.8 m vs 1.2 m, Mitigation at 25 s

(peak concentrations around 10~40 seconds may be overestimated due to deconvolution method)

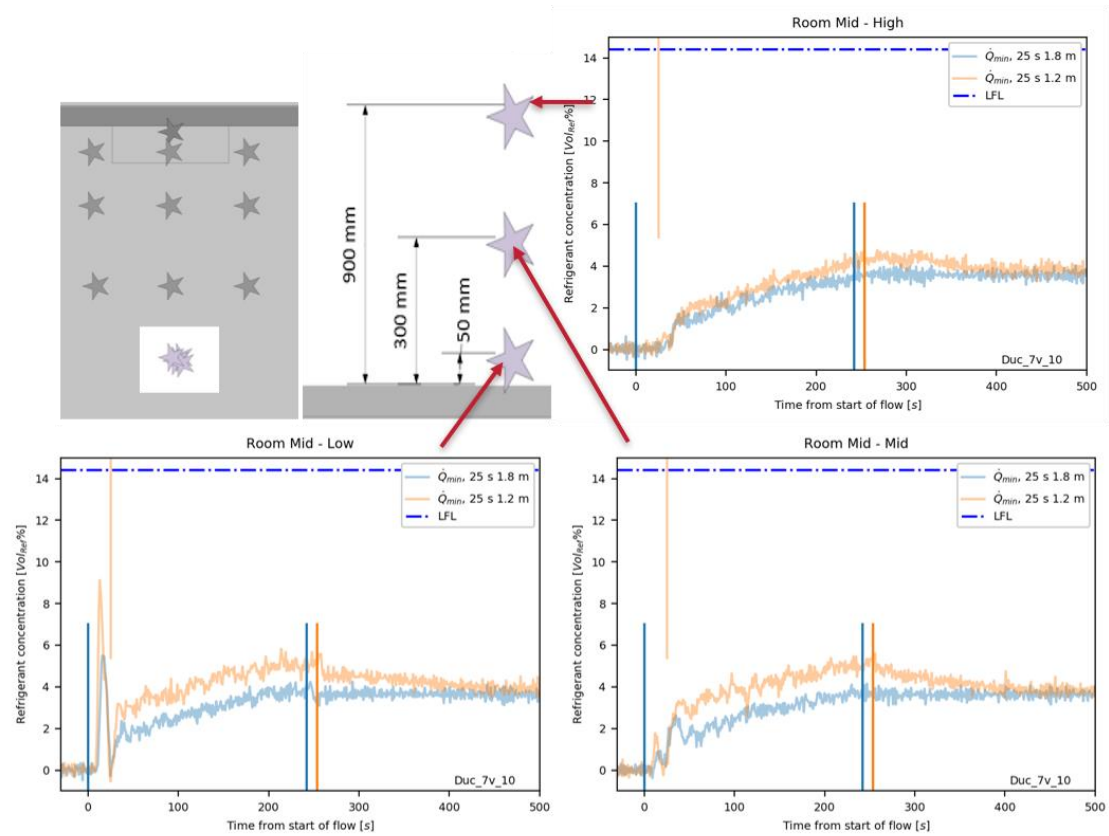


Figure 36 - Installed 1.8 m vs 1.2 m, Mitigation at 25 s

4.6 Safety Shutoff Valves

The results show it is possible to limit the mass of refrigerant entering the space. If the SSV are permitted to close quickly the potential mass of refrigerant is limited based on the size of the coil and the length of the line set located on the room side of the shutoff valves. This will vary between manufacturer and installed system construction.

With the arrangement tested the unit operating in heating mode had the highest quantity of refrigerant leaked. With a delay of 30 s before closing the valves 0.31 kg (0.68 lbs) of refrigerant was released into the space. With the unit in cooling mode and standby mode (after cooling operation) this value was reduced by 48% and 61% of the heating mode release, respectively. The actual test values of quantity of refrigerant released were significantly less than those predicted by UL/CSA 60335-2-40, where differences ranged from a factor of 10X to 22X. Values predicted by ASHRAE 15.2P were closer but still off by a factor of 3.2X to 3.5X.

When the SSV are closed at the same time there was a direct correlation between the delay time and the mass of refrigerant that was released. In these cases it was possible to choose a delay time to limit to a specific mass release. However, with the delay times chosen there was limited (<500 g) mass of refrigerant released into the space.

Closing one SSV before another can have a limited effect on the mass of refrigerant remaining in the coil, depending on the operating mode. Pump down effects are only significant in cooling mode operation. It is not effective for stand-by condition or heating mode. In actual AC control design switching to cooling mode and pump down operation after detecting leak appears effective to reduce leak amount and mitigate ignition risk. It also revealed that first 30 seconds in cooling mode are quite effective, but after that effect is limited. In cooling mode, release amount is reduced from 0.18 to 0.06 with pump down for 30 seconds. Average release amount per volume was reduced from 0.24 kg/L to 0.08 kg/L in cooling mode. In these calculations, flow meter and connecting piping volume was neglected. So, average density is lower than these calculated values.
In heating and standby conditions, the maximum release amount was 0.29 kg that is 0.39 kg/L in average release density.

In a heating mode the delay time between closing the valve ahead of the coil and the valve after the indoor coil was not statistically significant. The standby mode also did not have a time effect. The room conditions as well as the time that the leak occurs after operation of the unit does have an effect on the mass of refrigerant in coil, this could result in larger mass of refrigerant being available for a leak. However, as the system is not operating the effect of drawing refrigerant to the outdoor unit would not be present. When the system was operated in the cooling mode it was possible to reduce the mass of refrigerant in the indoor coil by using a delay and allowing the compressor to draw refrigerant from the coil.

Additional piping effects are also evaluated. Comparison between the data 3E and 3L, the piping effect was 0.09 kg. Average release density of the piping was 0.134 kg/L in heating mode of this test. The liquid line volume was 0.177 L while liquid density was around 0.94, so only around 60% of the tube volume seems to be filled with liquid. The refrigerant quality in liquid line varies depending on system design and operating conditions, certain experimental evaluation seems necessary for each company and each system design to calculate the SSOV effects.

PART II – Commercial Refrigeration

5 Method

The 3rd edition (2019) of the IEC 60335-2-89 limits the mass of flammable refrigerants in an appliance to 150 g per circuit when used with a remote system (split system). When the appliance incorporates the refrigeration unit the charge may be increased to 13 times the LFL for the refrigerant, with a maximum of 1.2 kg of charge. The 1.2 kg charge limit was identified in the 3rd edition of IEC 60335-2-89. As part of the IEC standards development process there were several countries who suggested that this limit be removed which would have permitted a larger charge mass to be utilized for A2L refrigerants. The testing for the refrigeration portion of the tests was conducted following the procedures outlined in Annex CC of IEC 60335-2-89.

Two refrigerants where selected for the testing: one safety group A2L and one safety group A3. The A2L was R-454C and was tested with 1.2, 2.3 and 3.9 kg mass releases. The A3 was R-290 and was tested with 150, 300 and 500 g mass release. Annex CC identifies that the testing is to be conducted in a room up to 24 m^2 (258 ft^2). To provide the most severe condition three different room sizes were tested resulting in the smallest room for the A3 charge based on the equation in CC.1 where M is the refrigerant charge in kg, LFL is the lower flammability limit in kg/m^3 and A is the area of the room in m^2.

$$24 \geq A \geq \frac{M}{0.55 * LFL}$$

These room sizes were selected to be: 7.2 m^2, 14.4 m^2, 24 m^2 (78 ft^2, 155 ft^2 and 258 ft^2). The largest room size corresponds to the largest permitted room size for the Annex CC testing.

The room height was 2.5 m (8.2 ft). This is larger than the minimum height (2.2 m) specified for test room in Annex CC, but is required as one of the units to be tested was 2 m height and the test method required a 0.5 m clearance above the unit.

Two units were selected for testing: a single door reach in unit and a three door reach in unit. Both units had hinged doors. The condensate drain plans were blocked at the drain pan to ensure that all refrigerant remained in the case. The single door unit used for the testing had not been specifically designed for the A2L or A3 refrigerants, the overall cabinet was used to represent what a typical construction could be. Test results of the Annex CC tests will depend on the geometry determined by the end product manufacturers.

The single door unit had a top mount condenser, to simulate a bottom condenser unit the condenser fan was removed and placed in sheet metal box with a perforated metal filter to simulate the condenser coil. The bottom of the unit needed to be raised and this resulted in the height from the bottom of the interior to the test cell floor increasing to 24 cm (9.5 in). Overall the cabinet of the single door unit was 154 cm (60.5 in) high, 70 cm (27.5 in) wide and 76 cm (30 in) deep, not including the door and gasket.

The three door unit was a bottom condenser design. The height from the bottom of the interior to the test cell floor was 39 cm (15.5 in). The overall cabinet for the three door measured 199 cm (78 in) wide, 205 cm (81 in) high and 76 cm (30 in) deep. The right most door was to be opened as it would result in the highest concentration of refrigerant being released towards the wall.

Release locations were selected to be representative of potential leak locations. The internal leak location was near a return bend for the evaporator. Both the three door and single door reach in units had evaporators located at the top of the cabinet, no evaporator fans were operated. For tests where an external leak was simulated, a leak at the condenser was simulated.

Table 150 Internal and External Leak Locations

This setup was used to establish if product located in the interior of the reach-in would change the results of the test. Tests conducted with the empty case loading did not have any product, but the wire shelves were installed as intended. Tests conducted with 75% fill had commercially available bottles placed on the product shelves. The product was individually placed on the shelves and there was no additional material other than the product. Table 151 shows the three door unit empty as well as with a 75% fill.

Table 151 - Three Door Empty and 75% Fill

Annex CC of -2-89 specifies two release rates: one simulates when the motor-compressor is non-operating (Condition A) and the other simulates when the motor-compressor is operating (Condition B). Condition A tests simulated a refrigerant dew point temperature of 35 °C (95.0 °F) and is used to evaluate the low pressure portions of the system. Condition B simulated a refrigerant dew point temperature of 63 °C (145 °F) and is used to evaluate high pressure portions of the system. The refrigeration systems were non-operational in all tests and the temperature of the air in the interior of the reach in units was approximately equal to the temperature of the air in the test room at the initiation of the test

A summary of the tests conducted with this setup is located in Table 152, below. The test colors of the table correspond to the size of the room. In general, the nominal release mass are as follows: Red, 0.15 kg A3, 1.2 kg A2L; Blue, 0.30 kg A3, 2.3 kg A2L; and Green, 0.50 kg A3, 3.9 kg A2L.

Test Name	Refrigerant	Unit	Leak Location	Release mass (kg)	Internal Fill	Fan Operation	Condenser Flow (m^3/hr)	Room	Condition
Refrigeration 1	R-290	Single Door	Internal	0.169 kg	Empty	Off	N/A	Small	A
Refrigeration 2	R-290	Single Door	Internal	0.168 kg	Empty	On	Nominal	Small	A
Refrigeration 3	R-290	Three Door	Internal	0.167 kg	Empty	Off	N/A	Small	A
Refrigeration 4	R-290	Three Door	Internal	0.172 kg	75%	Off	N/A	Small	A
Refrigeration 5	R-290	Three Door	Internal	0.166 kg	Empty	On - Left Fan	Nominal - 1820	Small	A
Refrigeration 6	R-290	Three Door	Internal	0.163 kg	Empty	On - Both	Nominal - 1820	Small	A
Refrigeration 7	R-454C	Three Door	Internal	1.173 kg	Empty	Off	N/A	Small	A
Refrigeration 8	R-454C	Three Door	Internal	1.188 kg	75%	Off	N/A	Small	A
Refrigeration 9	R-454C	Three Door	Internal	1.139 kg	75%	On - Left Fan	Nominal - 1820	Small	A
Refrigeration 10	R-454C	Three Door	Internal	1.142 kg	75%	On - Both	Nominal - 1820	Small	A
Refrigeration 11	R-290	Single Door	Internal	0.323 kg	Empty	Off	N/A	Med	A
Refrigeration 12	R-290	Single Door	Internal	0.323 kg	Empty	On	490	Med	A
Refrigeration 13	R-290	Three Door	Internal	0.308 kg	Empty	Off	N/A	Med	A
Refrigeration 14	R-290	Three Door	Internal	0.319 kg	75%	Off	N/A	Med	A
Refrigeration 15	R-290	Three Door	Internal	0.315 kg	Empty	On	520	Med	A
Refrigeration 15a	R-290	Three Door	Internal	0.318 kg	Empty	On	520	Med	A
Refrigeration 16	R-454C	Three Door	Internal	2.301 kg	Empty	Off	N/A	Med	A
Refrigeration 17	R-454C	Three Door	Internal	2.251 kg	75%	Off	N/A	Med	A
Refrigeration 18	R-454C	Three Door	Internal	2.301 kg	75%	On	700	Med	A
Refrigeration 18a	R-454C	Three Door	Internal	2.331 kg	Empty	On	695	Med	A
Refrigeration 19	R-454C	Three Door	Internal	2.252 kg	75%	On	850	Med	A
Refrigeration 20	R-454C	Three Door	External	2.358 kg	N/A	Off	N/A	Med	A
Refrigeration 21	R-454C	Three Door	External	2.337 kg	N/A	On	700	Med	A

Refrigeration 21a	R-454C	Three Door	External	2.335 kg	N/A	On	690	Med	A
Refrigeration 22	R-290	Three Door	Internal	0.509 kg	Empty	Off	N/A	Large	A
Refrigeration 23	R-290	Three Door	Internal	0.516 kg	Empty	On - Nominal	1390	Large	A
Refrigeration 24	R-290	Three Door	Internal	0.507 kg	Empty	On -20%	1106	Large	A
Refrigeration 25	R-454C	Three Door	Internal	3.867 kg	Empty	Off	N/A	Large	A
Refrigeration 26	R-454C	Three Door	Internal	3.842 kg	Empty	On - Nominal	1720	Large	A
Refrigeration 27	R-454C	Three Door	Internal	3.773 kg	Empty	On -17%	1430	Large	A
Refrigeration 28	R-454C	Three Door	External	3.856 kg	N/A	Off	N/A	Large	B
Refrigeration 29	R-454C	Three Door	External	3.885 kg	N/A	On	1665	Large	B
Refrigeration 30	R-454C	Three Door	External	3.855 kg	N/A	Off	N/A	Large	A
Refrigeration 31	R-454C	Three Door	External	3.891 kg	N/A	On	1665	Large	A
Refrigeration 32	R-290	Three Door	Internal	0.153 kg	Empty	Off	N/A	Large	A
Refrigeration 33	R-290	Three Door	Internal	0.155 kg	Empty	Unit flow	400	Large	A
Refrigeration 34	R-454C	Three Door	Internal	1.188 kg	Empty	Off	N/A	Large	A
Refrigeration 35	R-454C	Three Door	Internal	1.135 kg	Empty	On - Nominal	550	Large	A

Table 152 - Summary of Refrigeration Tests

For refrigerant releases into the interior or the cabinet the following procedure was followed:

- Prior to release of refrigerant, for each test, the door seals of the units were inspected for damage.
- Room conditions were confirmed as being still using omni direction anemometers.
- If airflow was required, fans were energized.
- Data acquisition and video recording were started
- Refrigerant released at specified rate until the mass for that test was released
- Approx. 30 s after the end of the release the door was opened and held at an angle of 60°
- DAQ continued to record data for at least 10 minutes.
- DAQ and video recording stopped – test is considered concluded.
- Room was ventilated to remove refrigerant from the space.

For refrigerant releases exterior to the cabinet the following procedure was followed:

- Prior to release of refrigerant, for each test, the door seals of the units were inspected for damage.
- Room conditions were confirmed as being still using omni direction anemometers.
- If airflow was required, fans were energized.
- Data acquisition and video recording were started
- Refrigerant released at specified rate until the mass for that test was released
- Unit door remained closed the entire test.
- DAQ continued to record data for at least 10 minutes.
- DAQ and video recording stopped – test is considered concluded.
- Room was ventilated to remove refrigerant from the space.

The test was determined to comply with the requirements of Annex CC if the total cumulative time of refrigerant concentrations above 50% of LFL at any sensor location did not exceed five minutes. There are provisions in the standard to repeat testing at least once and potentially a third time if the value at the required sensor locations were above 40% of the LFL. For the purpose of this project, only a single test was conducted as this was an investigation into the parameters, and not an investigation into compliance with the standard for these appliances.

Refrigerant was drawn from a cylinder as liquid using a dip tube. This ensured that a blend would maintain the same composition. A mass flow controller, consisting of a coriolis mass flow meter and electronic valve was in line with the discharge system. The flow was controlled and the expansion occurred at the electronic valve. The line was heated to ensure that the refrigerant was completely vapor at the required condition prior to being introduced into the unit. The discharge system was located outside the room space and the line between the release system and the discharge location was kept to a minimum.

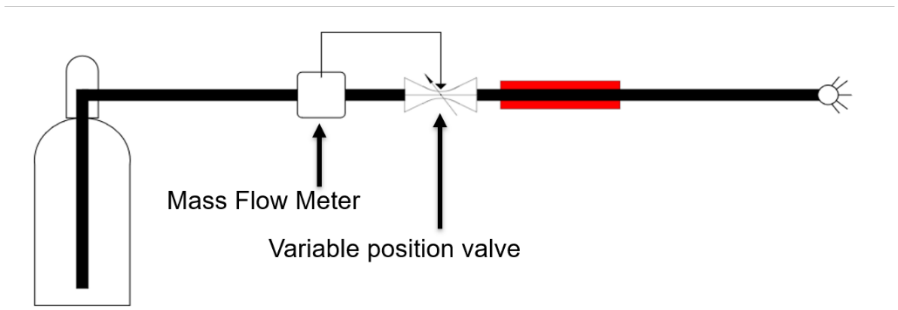


Figure 37 - Refrigeration Release System

6 Results

This section of the report provides results for the individual tests conducted. Each test is cross referenced, by name, to the tables in the previous section.

6.1 Small Room

The layout of the of the units and their location in the small test room is shown in Figure 38 and Figure 39. The sensor locations are indicated by stars in the sensor layout. Sensors indicated with a blue fill are required sensors indicated by Annex CC, without a fill color denote additional sensors located in the room space.

Figure 38 - Small Room Arrangement

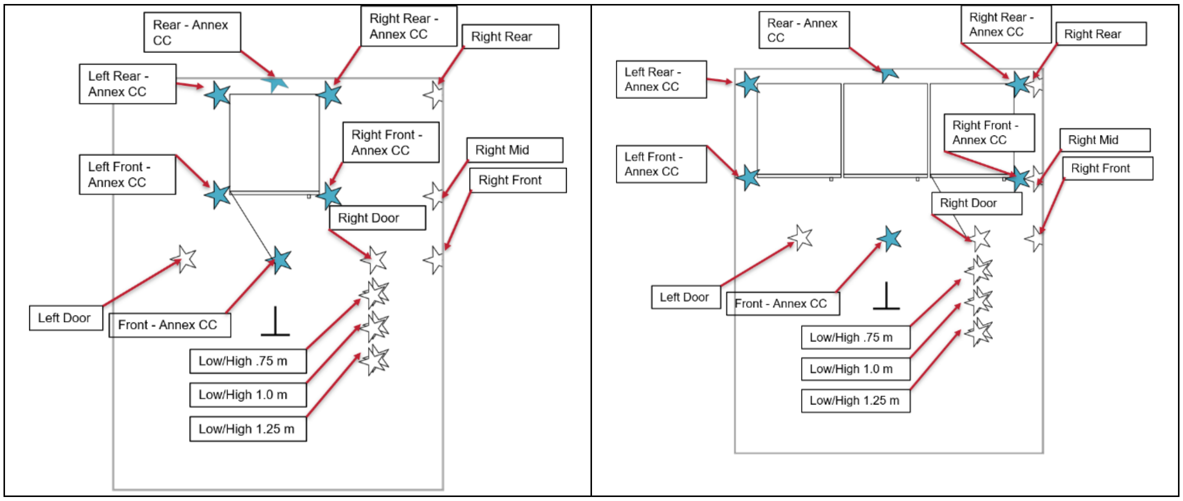


Figure 39 – Small Room Sensor Layout

6.1.1 **Refrigeration 1**

A summary of the test parameters for this test are indicated in Table 153. This test was conducted to establish the baseline parameters with no mitigation.

Refrigerant	R290	Mass Released	0.169 kg
Unit	Single Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 153 - Refrigeration 1 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

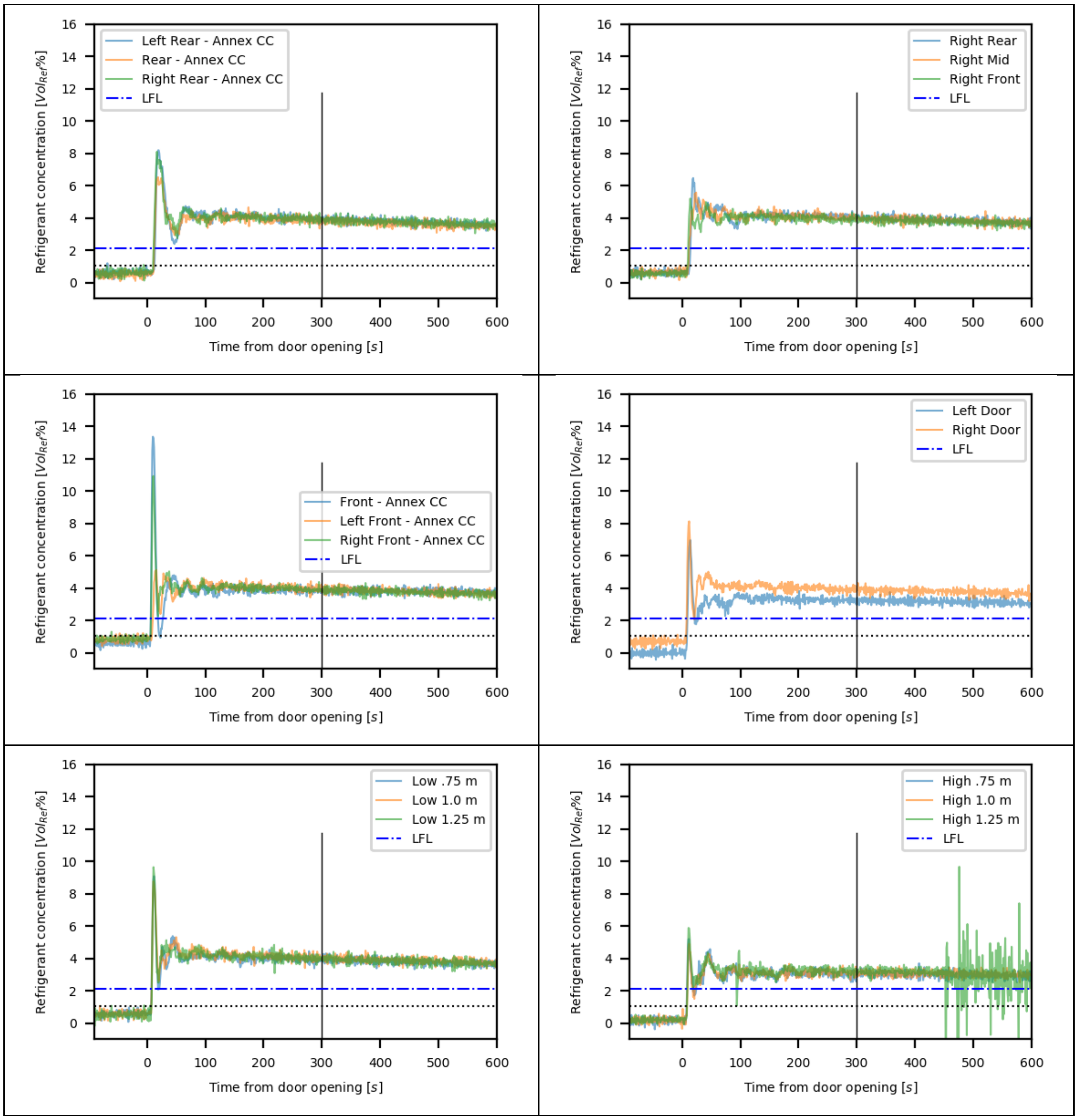


Table 154 - Refrigeration 1 Refrigerant Concentrations

(peak concentration around 10~25 seconds may be overestimated due to deconvolution method)

6.1.2 **Refrigeration 2**

A summary of the test parameters for this test are indicated in Table 155. This test was conducted with an internal leak with condenser fan on and the interior of the single door unit empty. In this test the condenser fan was discharging air below the unit towards the front.

Refrigerant	R290	Mass Released	0.168 kg
Unit	Single Door	Leak Location	Internal
Condenser Fan	On	Fan Volumetric Flow	Nominal
Case Interior	Empty	Leak Condition	A

Table 155 - Refrigeration 2 Test Parameters

This scenario may have complied with the requirements in the standard as the sensors were near 50% LFL five minutes after the door was opened. All Annex CC sensors, with the exception of the sensor centered on the back was below 50% of the LFL five minutes after the door opened. The location of the rear sensor near the fan may have resulted in this reflecting an artificially high refrigerant reading.

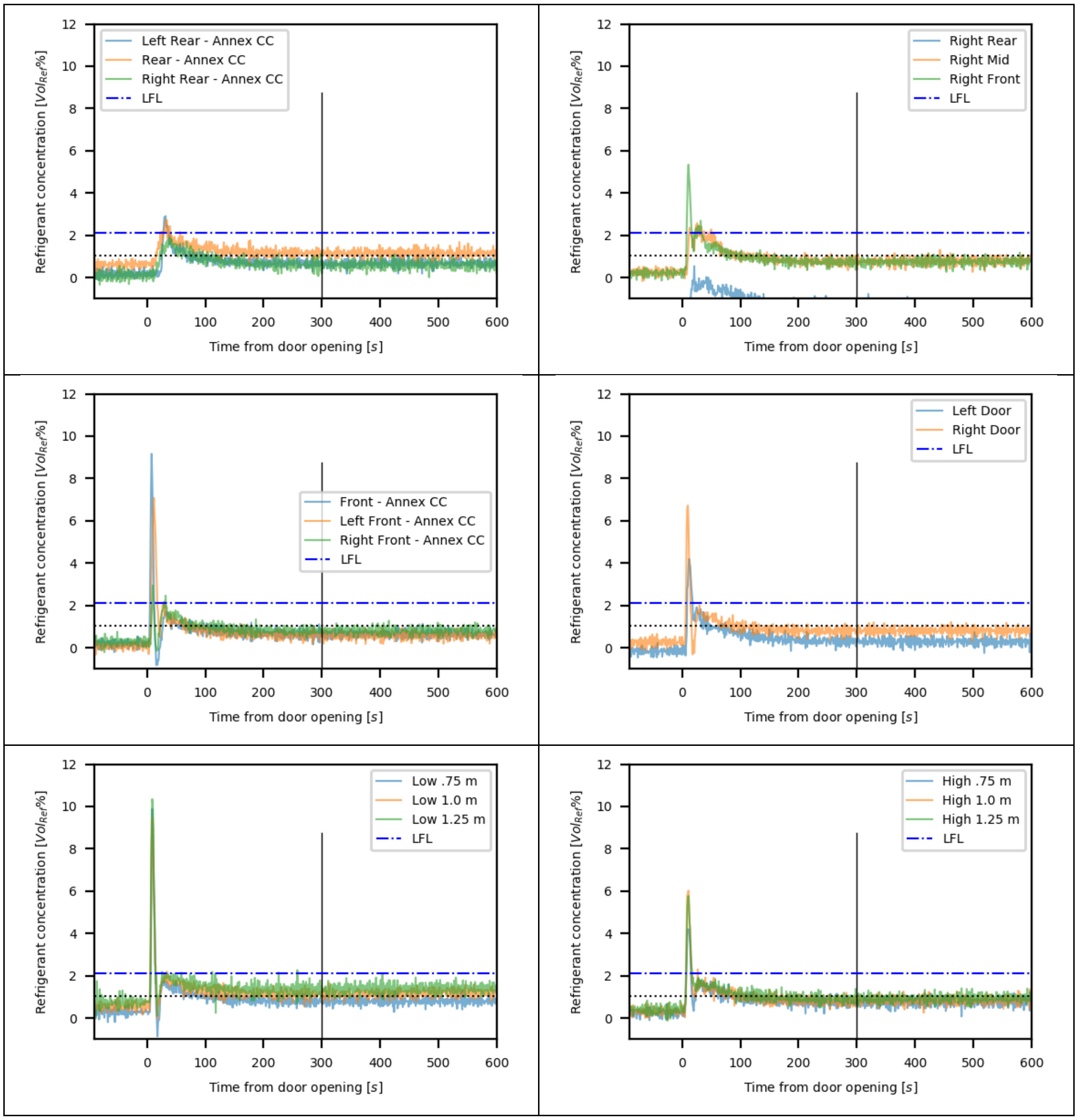


Table 156 – Refrigeration 2 Refrigerant Concentrations

(peak concentration around 20~50 seconds may be overestimated due to deconvolution method)

6.1.3 **Refrigeration 2a**

A summary of the test parameters for this test are indicated in Table 157. This test was conducted with an internal leak with condenser fan on and the interior of the single door unit empty. In this test the condenser fan was on and discharging air below the unit to the side.

Refrigerant	R290	Mass Released	0.169 kg
Unit	Single Door	Leak Location	Internal
Condenser Fan	On	Fan Volumetric Flow	Nominal
Case Interior	Empty	Leak Condition	A

Table 157 - Refrigeration 2a Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

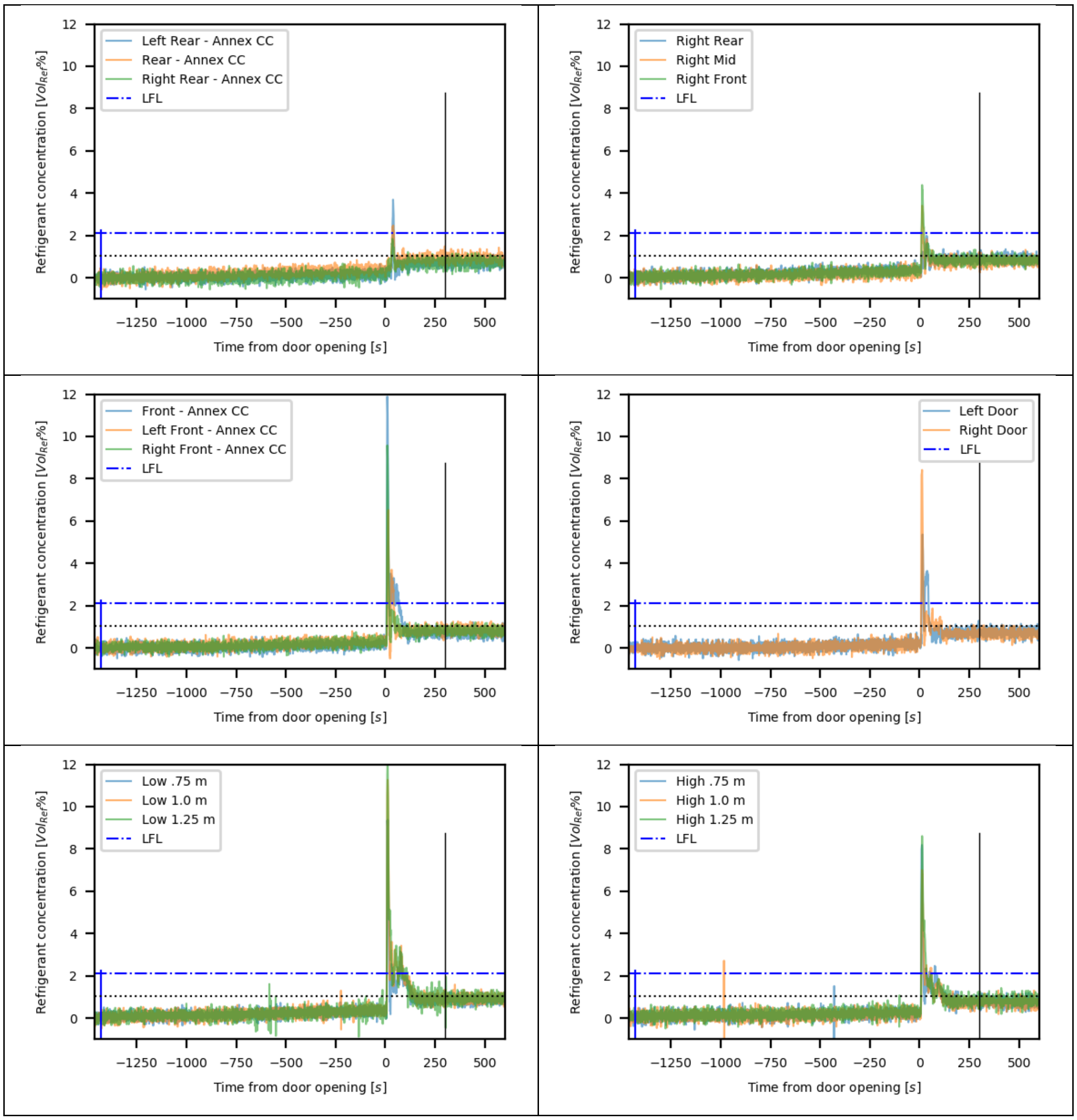


Table 158 -Refrigeration 2a Refrigerant Concentrations

(peak concentration around 20~50 seconds may be overestimated due to deconvolution method)

6.1.4 Refrigeration 3

A summary of the test parameters for this test are indicated in Table 159. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.167 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 159 - Refrigeration 3 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

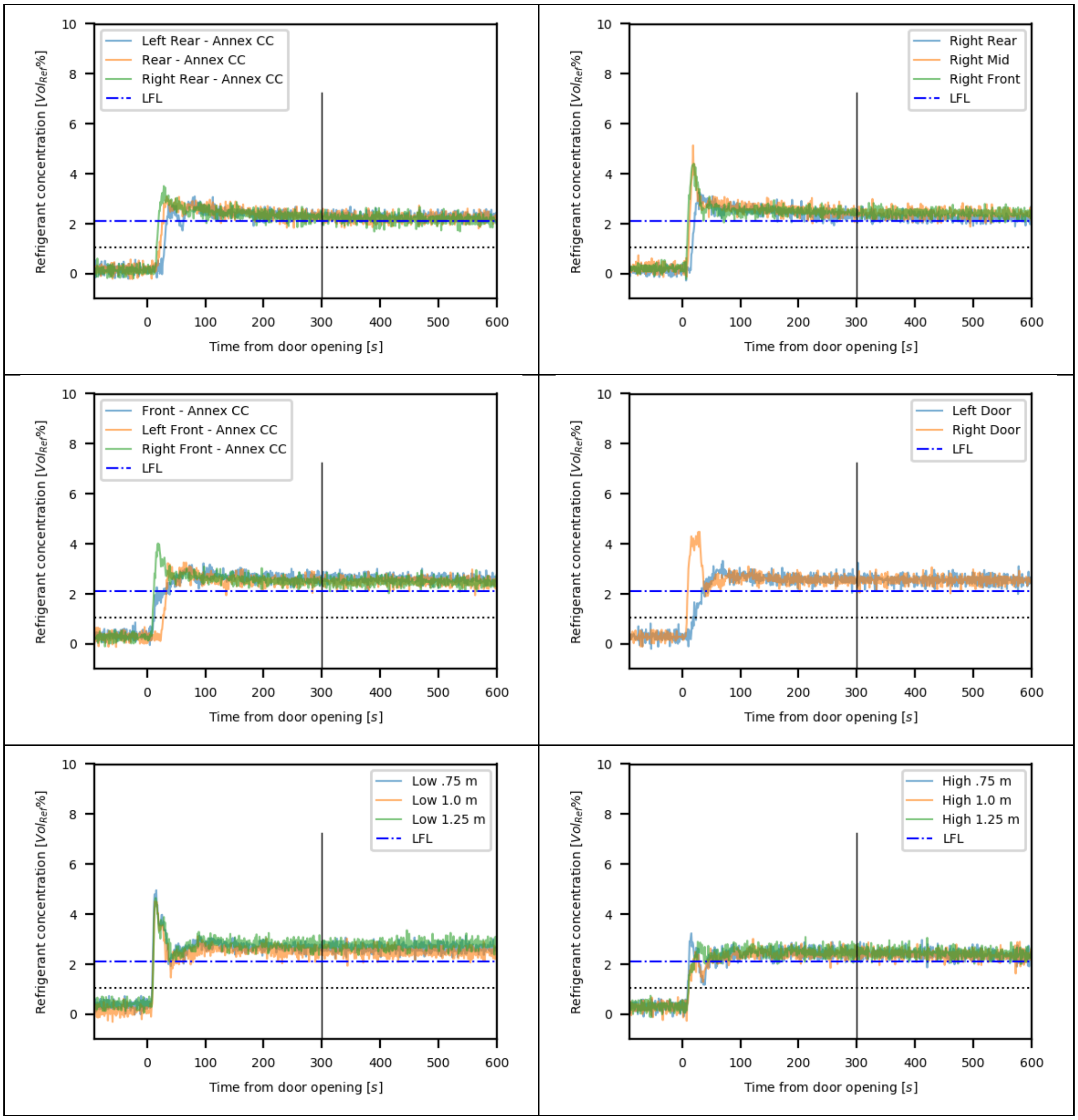


Table 160 - Refrigeration 3 Refrigerant Concentrations

(peak concentration around 20~50 seconds may be overestimated due to deconvolution method)

6.1.5 **Refrigeration 4**

A summary of the test parameters for this test are indicated in Table 161. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit with a 75% fill.

Refrigerant	R290	Mass Released	0.165 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	75% Filled	Leak Condition	A

Table 161 - Refrigeration 4 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

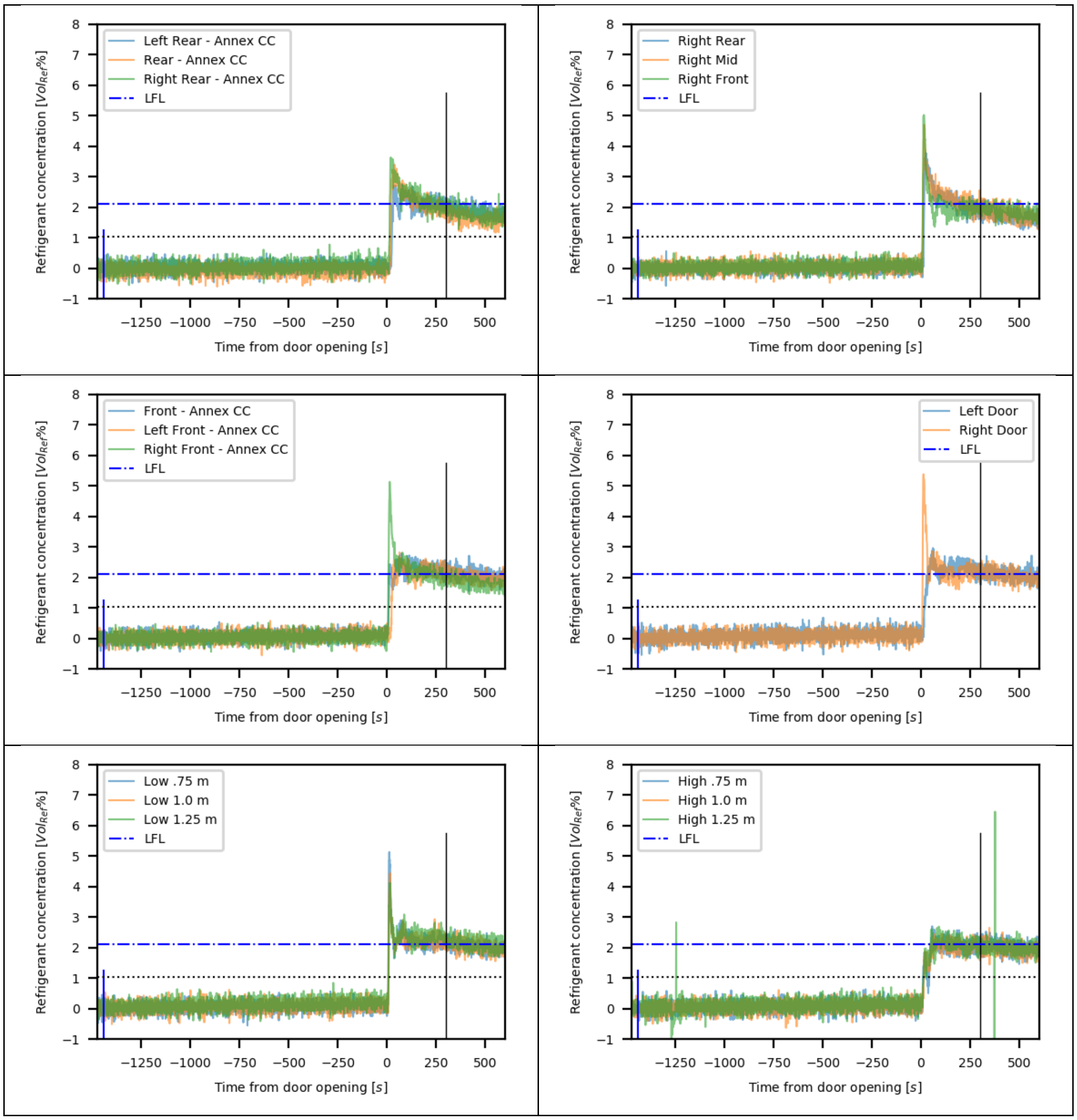


Table 162 - Refrigeration 4 Refrigerant Concentrations

(peak concentration around 20~50 seconds may be overestimated due to deconvolution method)

6.1.6 Refrigeration 5

A summary of the test parameters for this test are indicated in Table 163. This test was conducted with an internal leak with condenser fan on and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.166 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On - Left Fan	Fan Volumetric Flow	Nominal - 1820 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 163 - Refrigeration 5 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

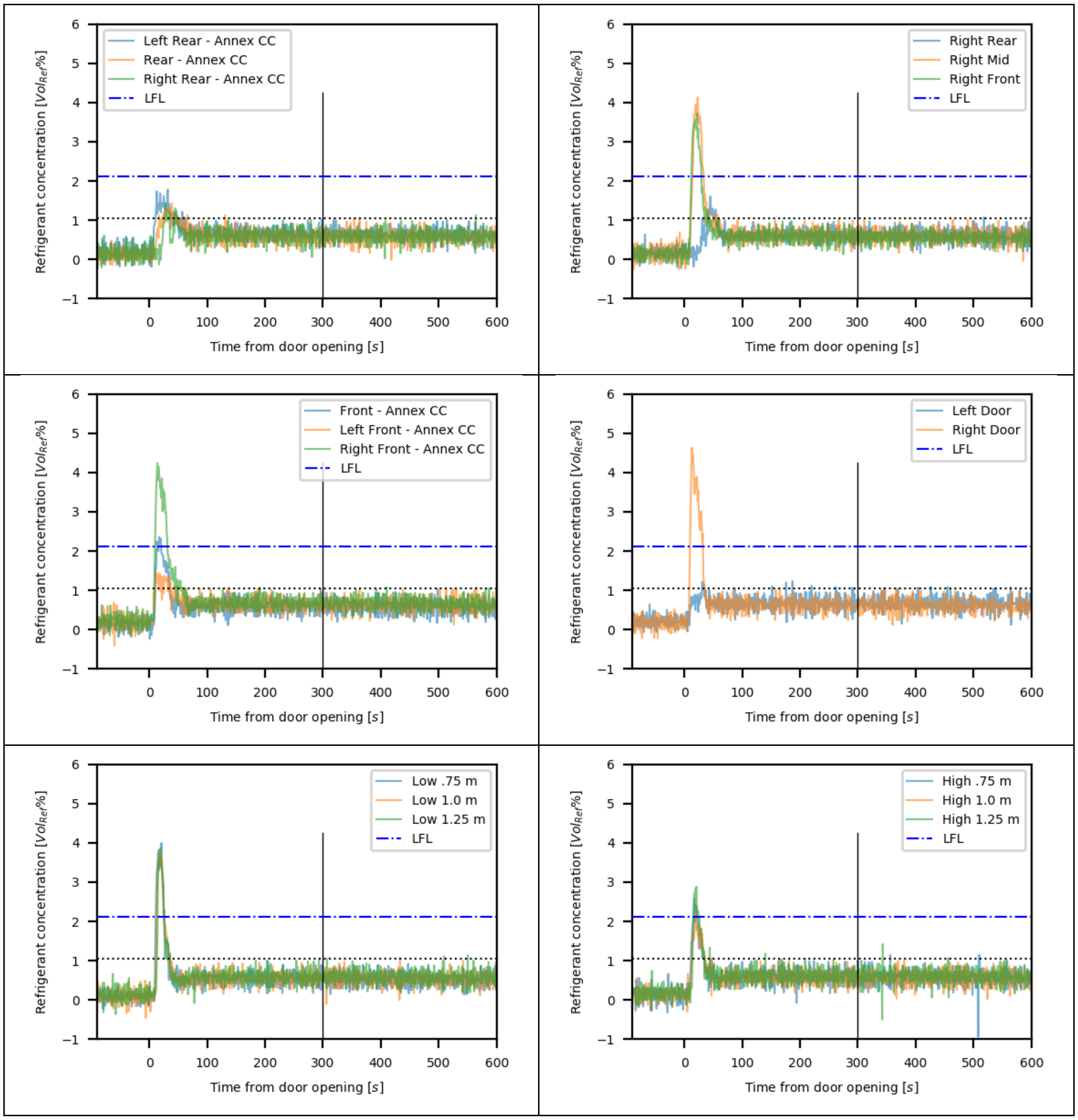


Table 164 - Refrigeration 5 Refrigerant Concentrations

(peak concentration around 10~50 seconds may be overestimated due to deconvolution method)

6.1.7 **Refrigeration 6**

A summary of the test parameters for this test are indicated in Table 165. This test was conducted with an internal leak with both condenser fans operating and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.163 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On - Both	Fan Volumetric Flow	Nominal - 1820 m³/hr
Case Interior	Empty	Leak Condition	A

Table 165 - Refrigeration 6 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

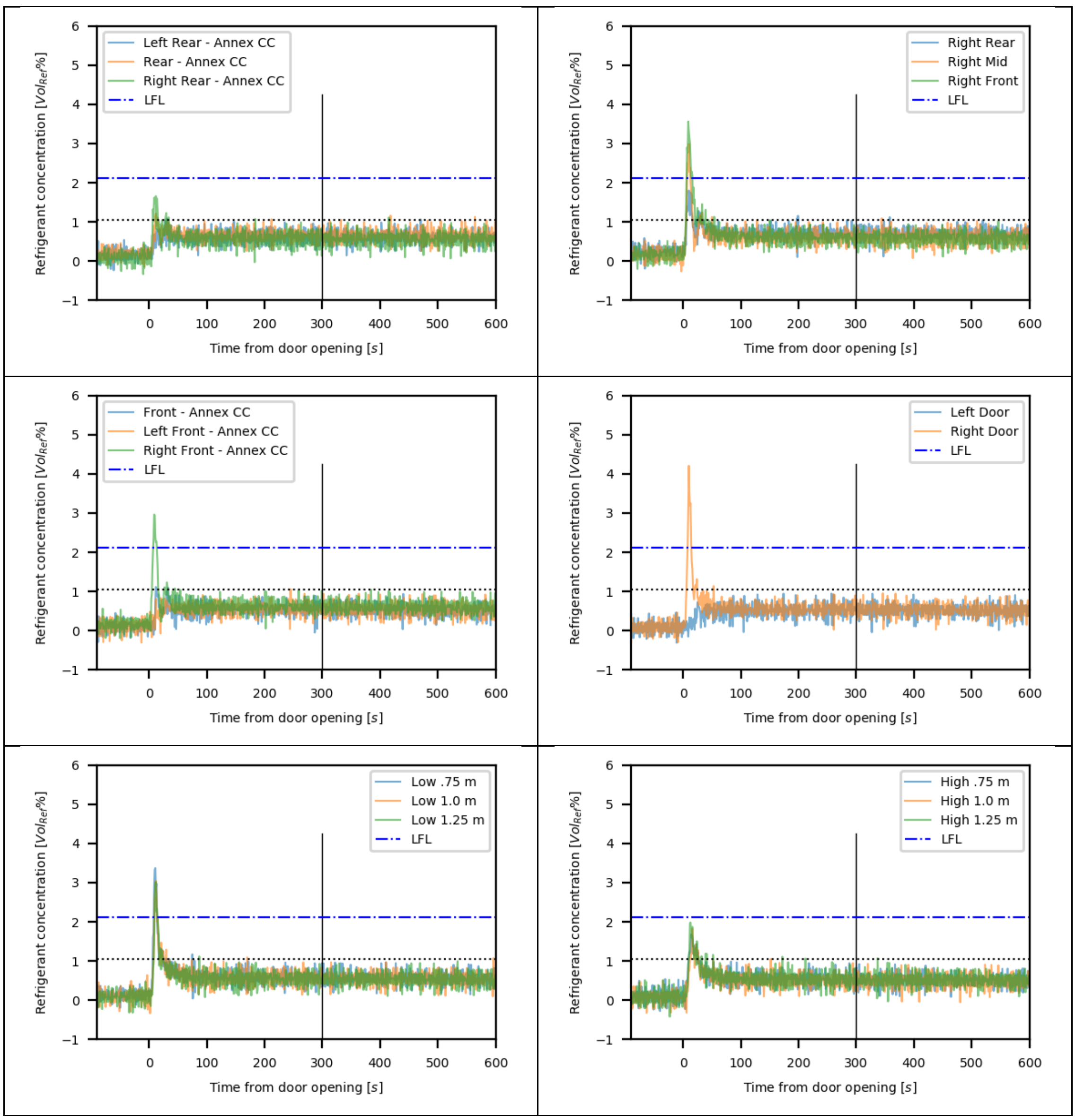


Table 166 - Refrigeration 6 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.1.8 **Refrigeration 7**

A summary of the test parameters for this test are indicated in Table 167. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty.

Refrigerant	R454C	Mass Released	1.173 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 167 - Refrigeration 7 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

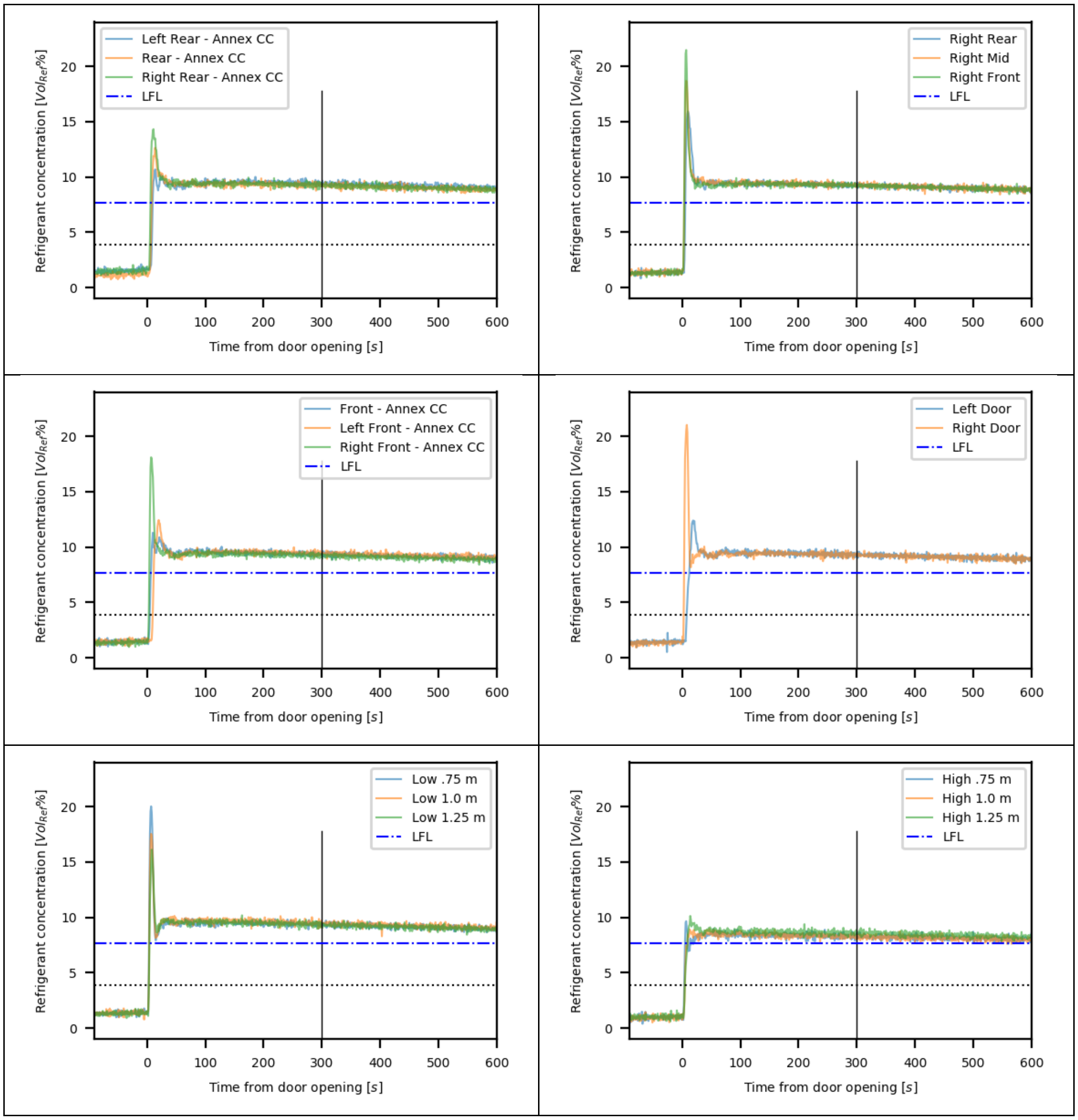


Table 168 - Refrigeration 7 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.1.9 **Refrigeration 8**

A summary of the test parameters for this test are indicated in Table 169. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit with a 75% fill.

Refrigerant	R454C	Mass Released	1.188 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	75% Filled	Leak Condition	A

Table 169 - Refrigeration 8 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

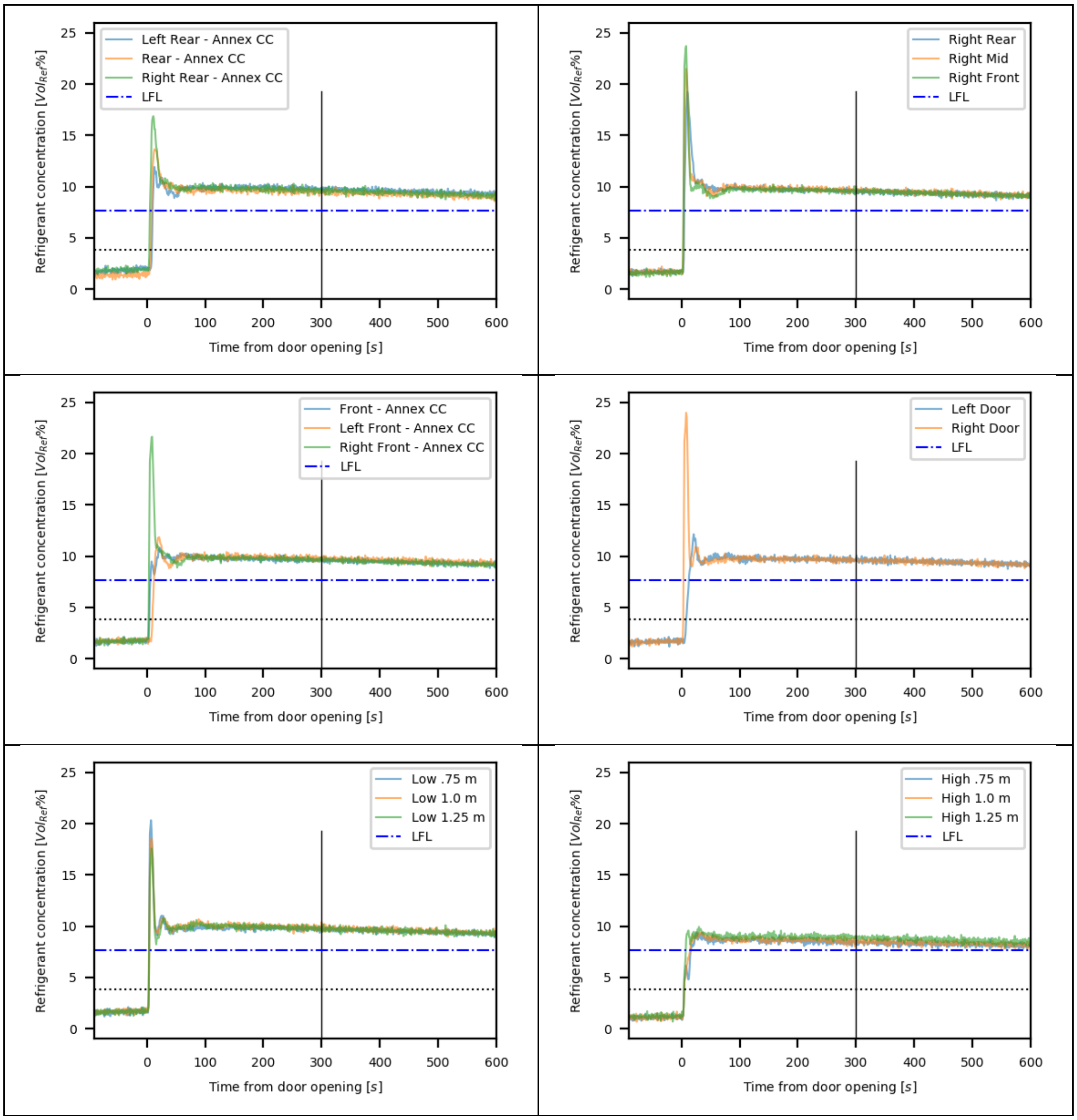


Table 170 - Refrigeration 8 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.1.10 **Refrigeration 9**

A summary of the test parameters for this test are indicated in Table 171. This test was conducted with an internal leak with condenser fan on and the interior of the three door unit with a 75% fill.

Refrigerant	R454C	Mass Released	1.139 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On - Left Fan	Fan Volumetric Flow	Nominal - 1820 m^3/hr
Case Interior	75% Filled	Leak Condition	A

Table 171 - Refrigeration 9 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

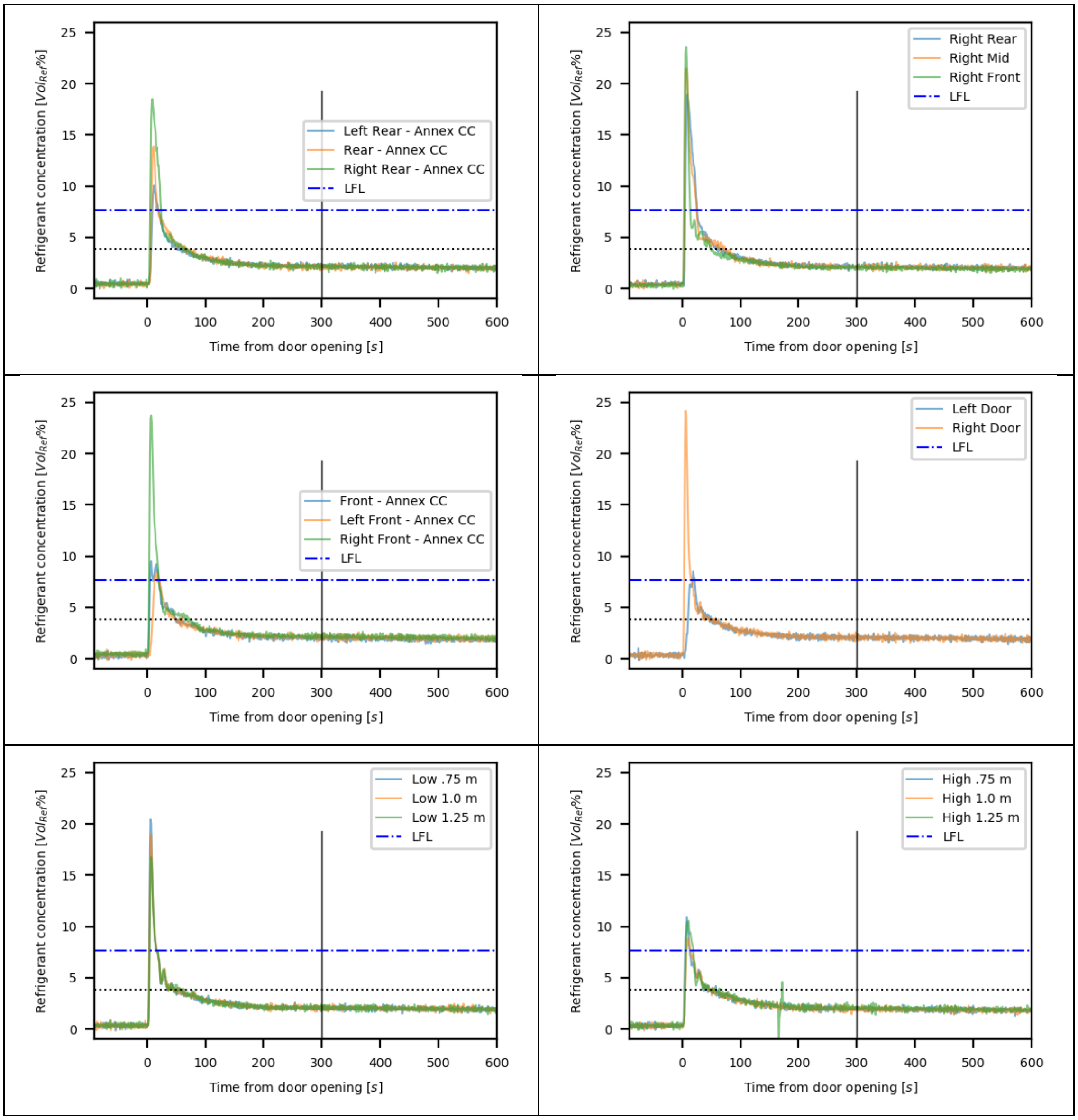


Table 172 - Refrigeration 9 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.1.11 **Refrigeration 10**

A summary of the test parameters for this test are indicated in Table 173. This test was conducted with an internal leak with condenser fan on and the interior of the three door unit with a 75% fill.

Refrigerant	R454C	Mass Released	1.142 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On - Both	Fan Volumetric Flow	Nominal - 1820 m^3/hr
Case Interior	75% Filled	Leak Condition	A

Table 173 - Refrigeration 10 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

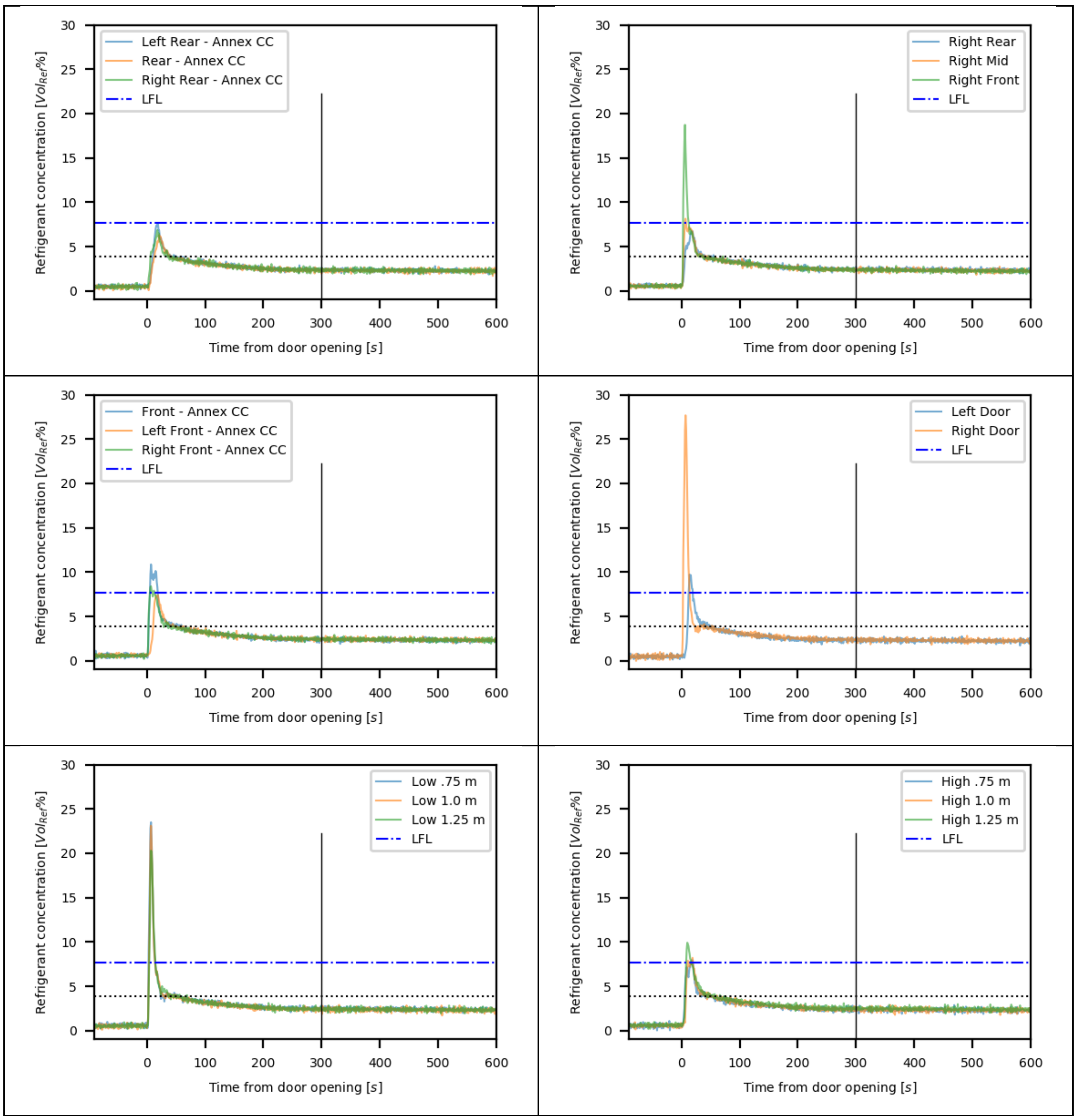


Table 174 - Refrigeration 10 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2 Medium Room

The layout of the of the unit and sensors locations in the medium test room is shown in Figure 40 and Figure 41. The sensor locations are indicated by stars in the sensor layout. Sensors indicated with a blue fill are required sensors indicated by Annex CC, without a fill color denote additional sensors located in the room space.

Figure 40 - Medium Room Arrangement

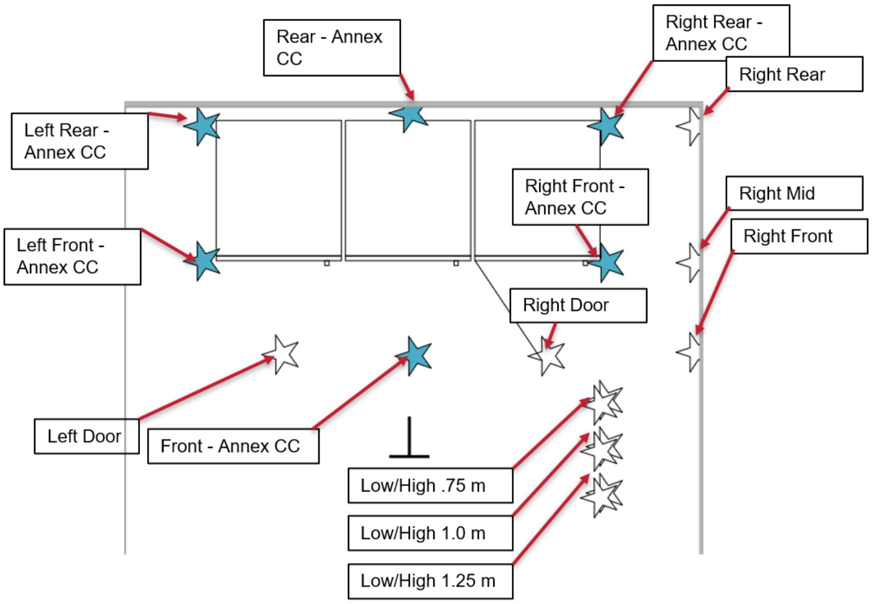


Figure 41 – Medium Room Sensor Layout

6.2.1 **Refrigeration 11**

A summary of the test parameters for this test are indicated in Table 175. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.323 kg
Unit	Single Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 175 - Refrigeration 11 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

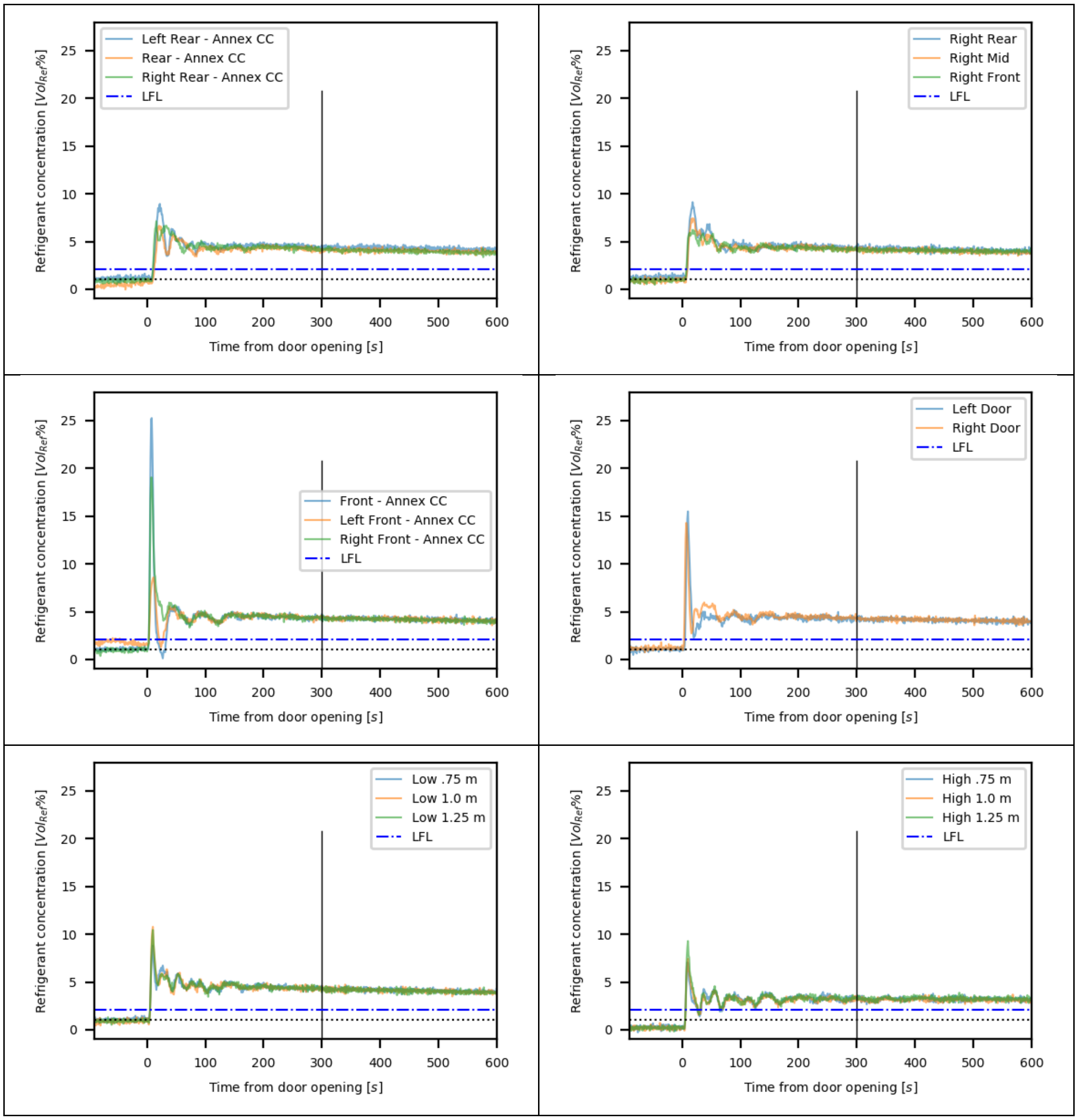


Table 176 - Refrigeration 11 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.2 **Refrigeration 12**

A summary of the test parameters for this test are indicated in Table 177. This test was conducted with an internal leak with condenser fan operating, the interior of the single door unit empty.

Refrigerant	R290	Mass Released	0.323 kg
Unit	Single Door	Leak Location	Internal
Condenser Fan	On	Fan Volumetric Flow	490 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 177 - Refrigeration 12 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

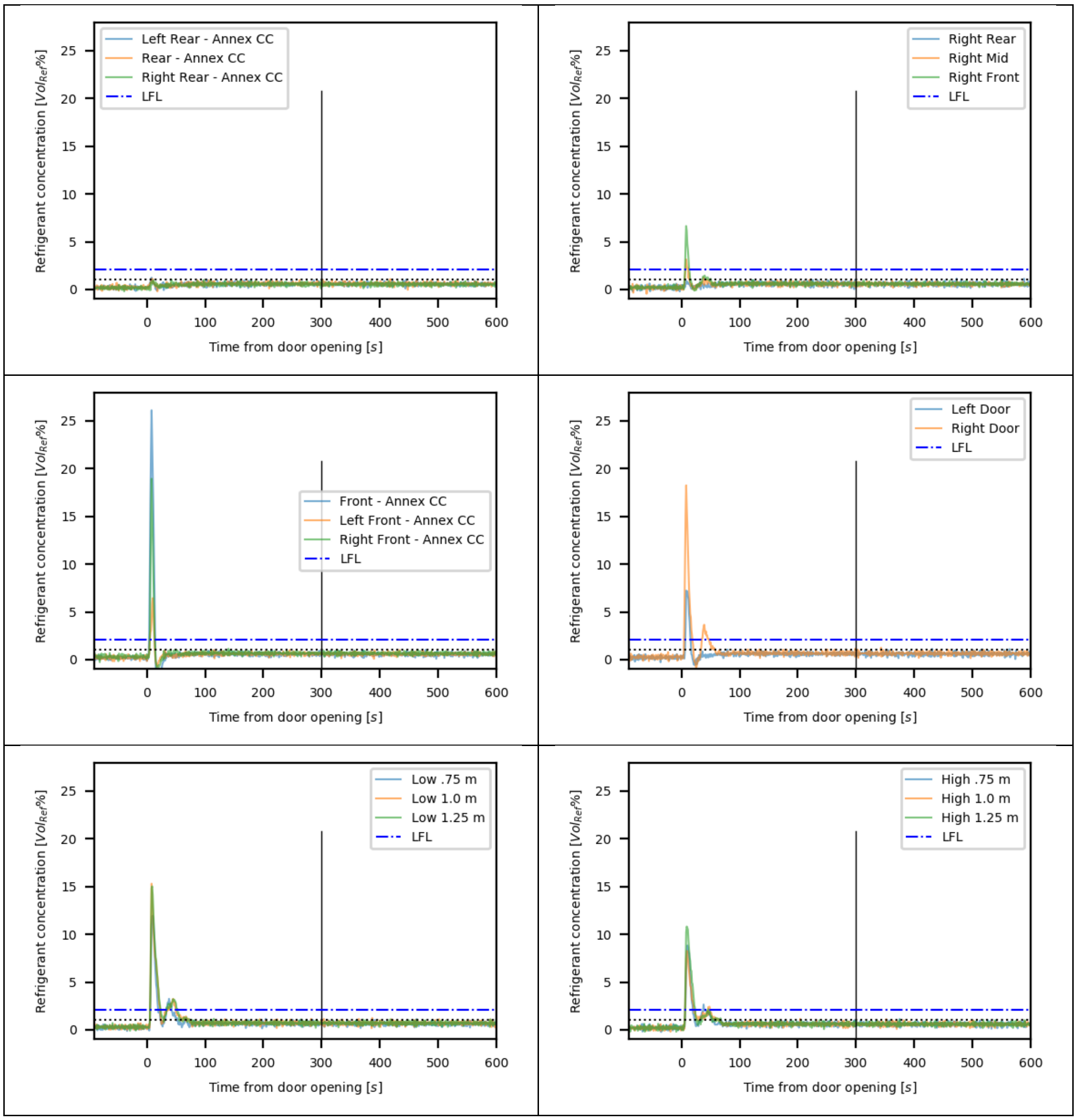


Table 178 - Refrigeration 12 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.3 Refrigeration 13

A summary of the test parameters for this test are indicated in Table 179. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.308 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 179 - Refrigeration 13 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

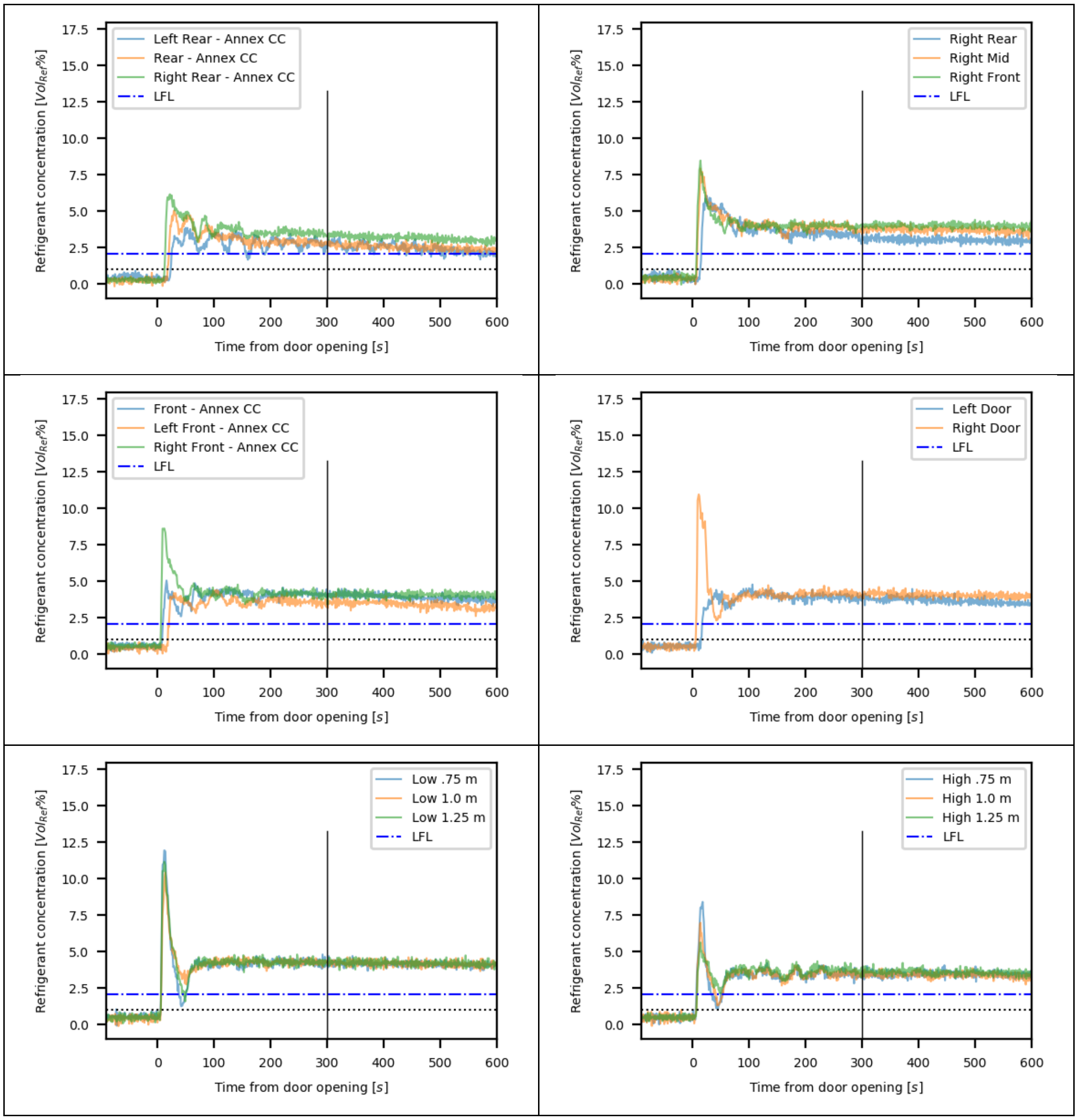


Table 180 - Refrigeration 13 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.4 **Refrigeration 14**

A summary of the test parameters for this test are indicated in Table 181. This test was conducted with an internal leak with both condenser fans operating and the interior of the three door unit 75% filled.

Refrigerant	R290	Mass Released	0.319 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	75% Filled	Leak Condition	A

Table 181 - Refrigeration 14 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the Annex CC sensors were above the LFL of the refrigerant five minutes after the door was opened.

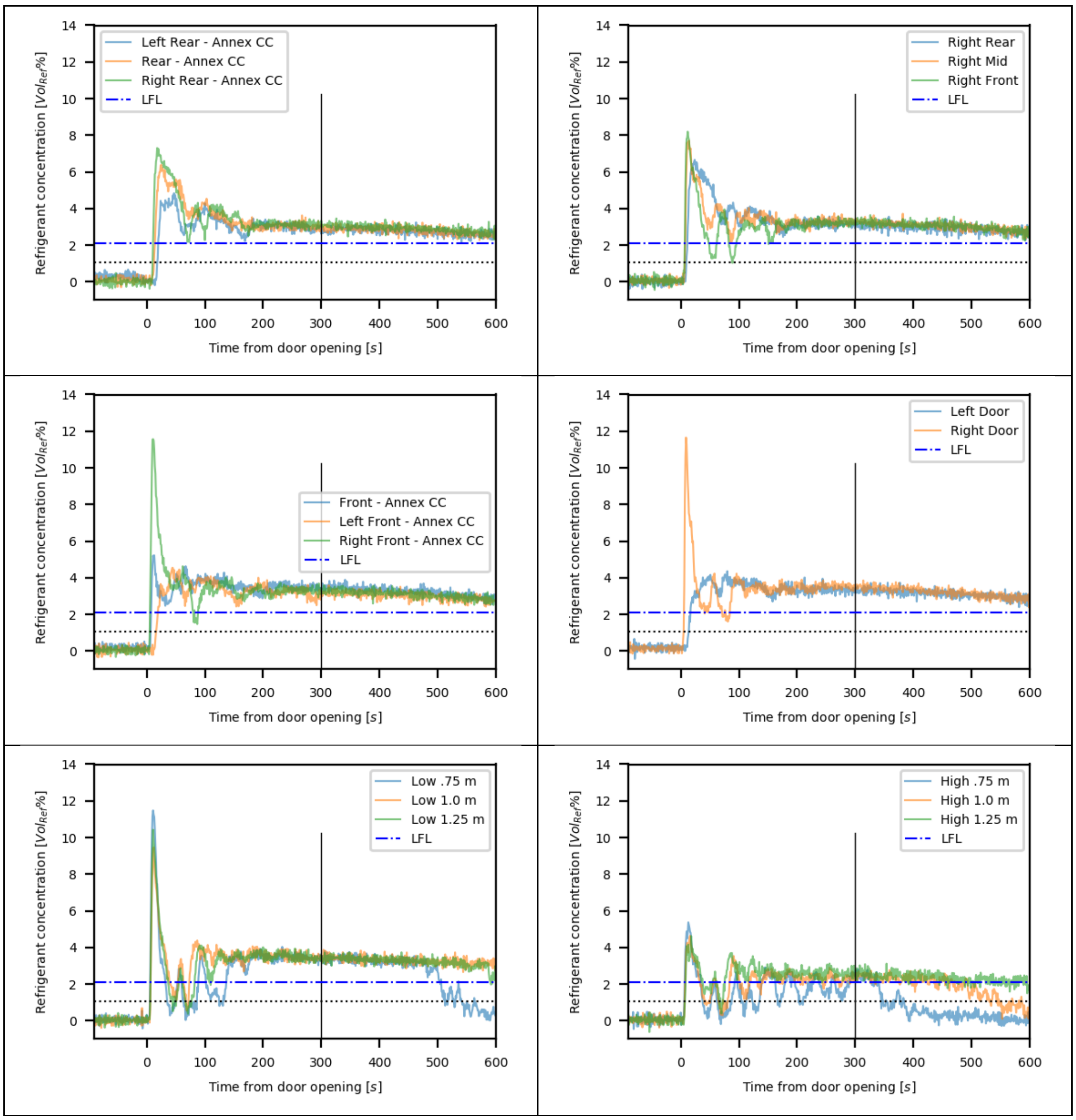


Table 182 - Refrigeration 14 Refrigerant Concentrations

(peak concentration around 10~100 seconds may be overestimated due to deconvolution method)

6.2.5 Refrigeration 15

A summary of the test parameters for this test are indicated in Table 183. This test was conducted with an internal leak with the condenser fan discharging towards the center of the unit and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.315 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On	Fan Volumetric Flow	520 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 183 - Refrigeration 15 Test Parameters

This scenario would not have complied with the requirements in the standard as the Annex CC sensors on Left Rear and Left Front were above 50% of the LFL of the refrigerant five minutes after the door was opened. The sensor located in front of the door that was opened during the test was also above 50% of the LFL after five minutes.

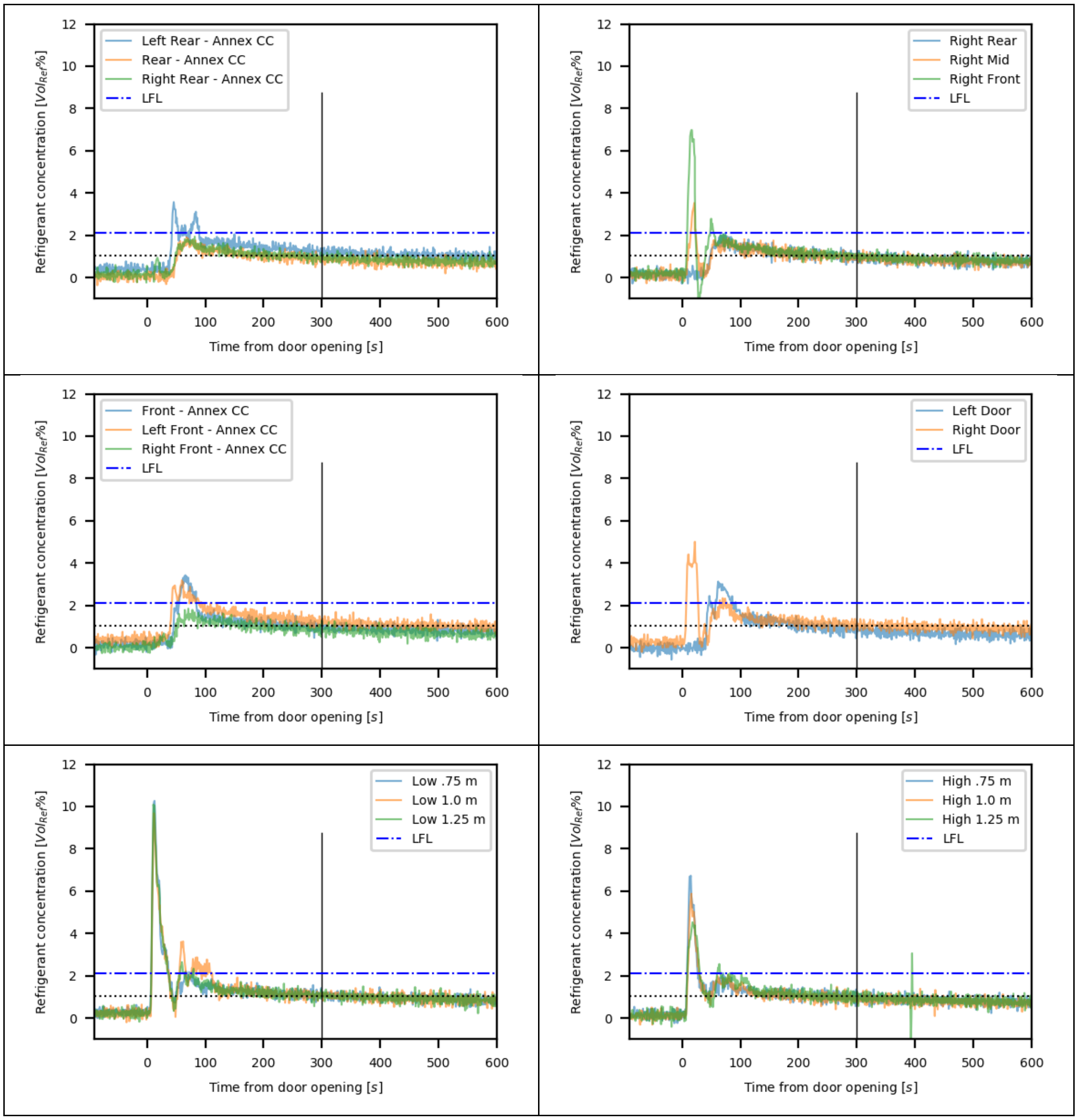


Table 184 - Refrigeration 15 Refrigerant Concentrations

(peak concentration around 10~75 seconds may be overestimated due to deconvolution method)

6.2.6 **Refrigeration 15a**

A summary of the test parameters for this test are indicated in Table 185. This test was conducted with an internal leak with the left condenser fan discharging towards the left of the unit and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.318 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On	Fan Volumetric Flow	520 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 185 - Refrigeration 15a Test Parameters

This scenario would not have complied with the requirements in the standard as several of the Annex CC sensors were above 50% of the LFL of the refrigerant five minutes after the door was opened. The sensor located in front of the door that was opened during the test was also above 50% of the LFL after five minutes.

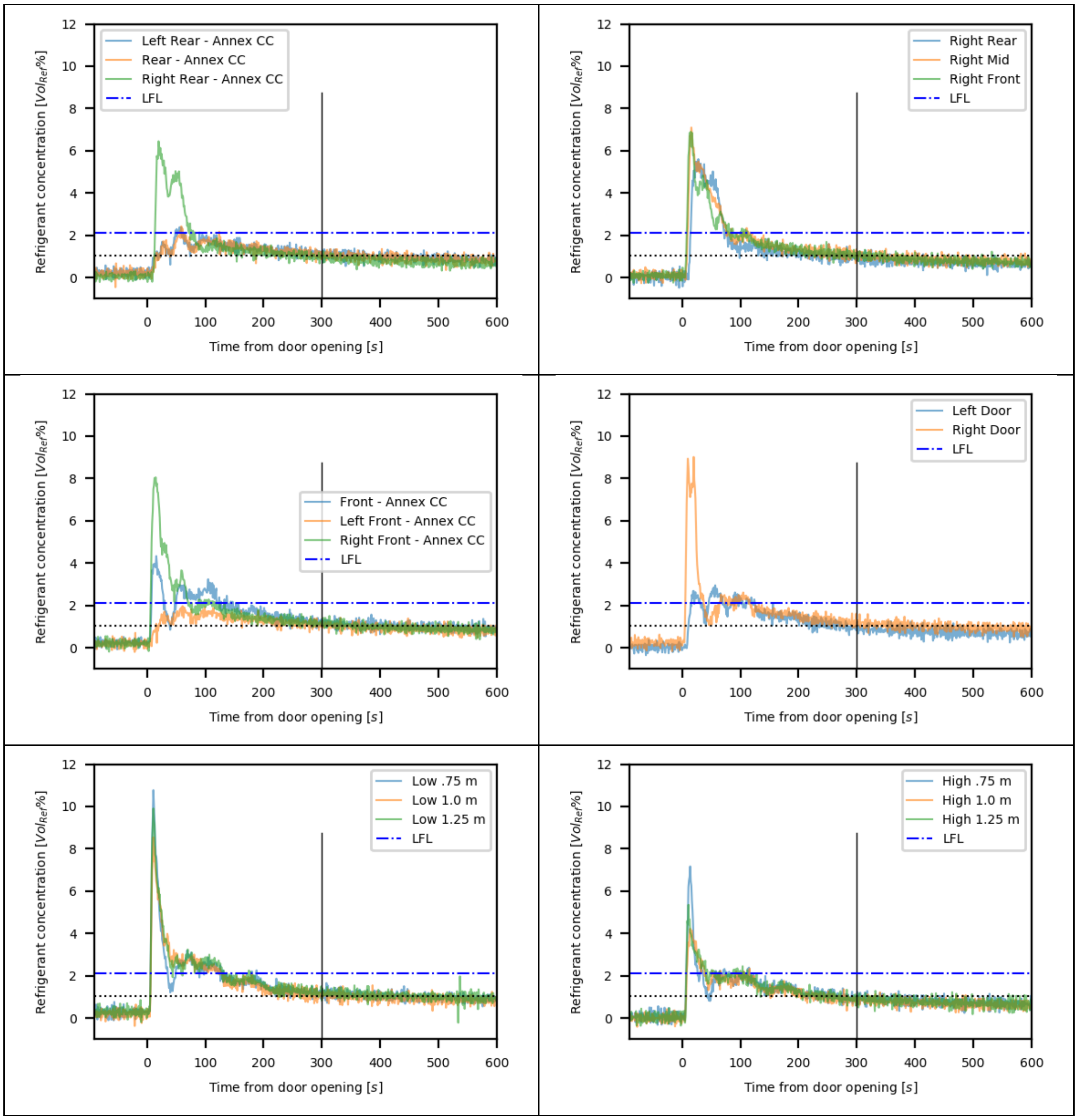


Table 186 - Refrigeration 15a Refrigerant Concentrations

(peak concentration around 10~50 seconds may be overestimated due to deconvolution method)

6.2.7 **Refrigeration 16**

A summary of the test parameters for this test are indicated in Table 187. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty.

Refrigerant	R454C	Mass Released	2.301 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 187 - Refrigeration 16 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

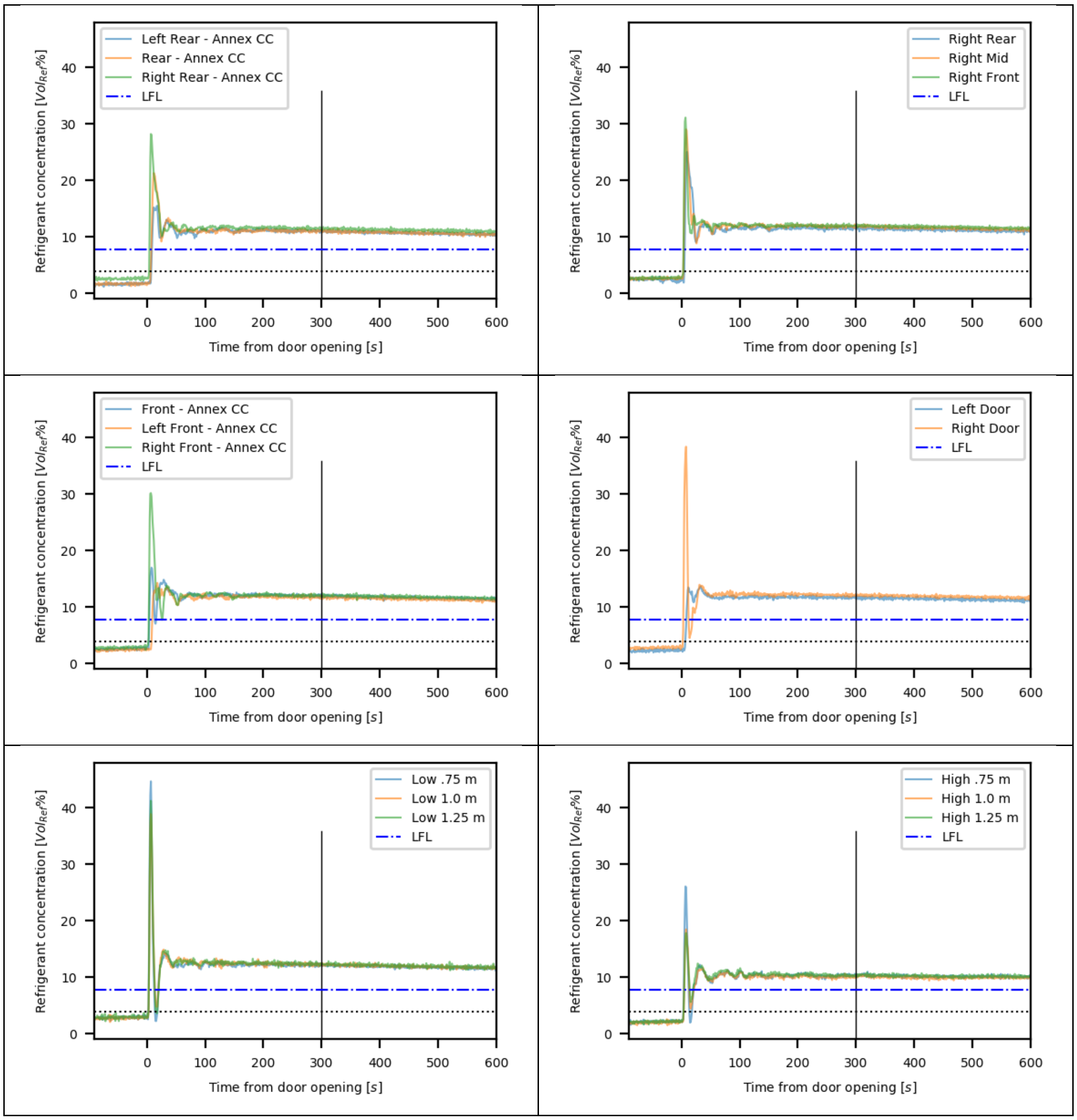


Table 188 - Refrigeration 16 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.8 Refrigeration 17

A summary of the test parameters for this test are indicated in Table 189. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit with 75% fill.

Refrigerant	R454C	Mass Released	2.251 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	75% Filled	Leak Condition	A

Table 189 - Refrigeration 17 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

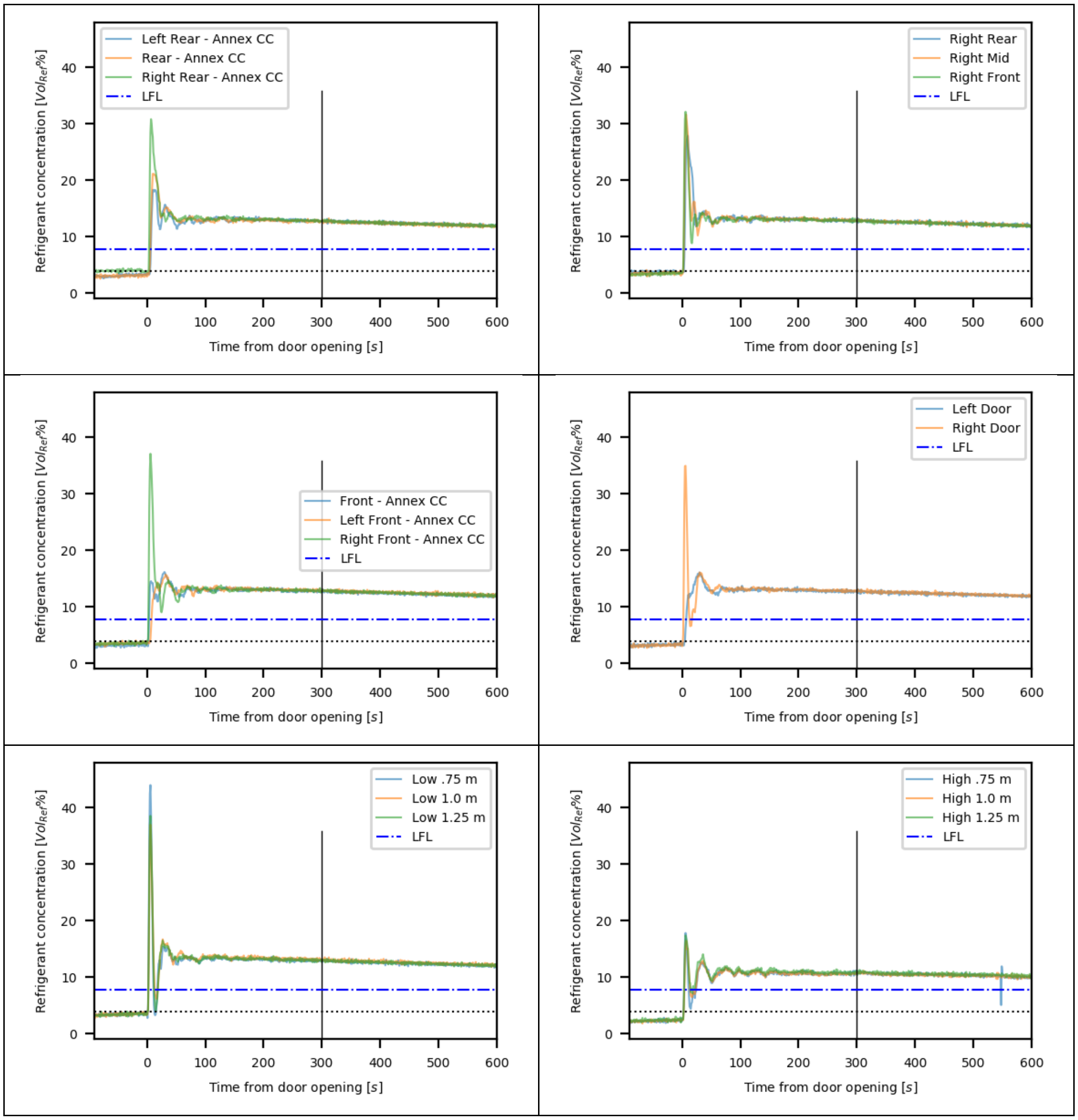


Table 190 - Refrigeration 17 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.9 **Refrigeration 18**

A summary of the test parameters for this test are indicated in Table 191. This test was conducted with an internal leak with condenser fan on and the interior of the three door unit with a 75% fill. For this test the left condenser fan was on and discharging towards the left of the unit.

Refrigerant	R454C	Mass Released	2.301 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On	Fan Volumetric Flow	700 m³/hr
Case Interior	75% Filled	Leak Condition	A

Table 191 - Refrigeration 18 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above 50% LFL five minutes after the door was opened. The fan being on did prevent refrigerant from building in concentration prior to the unit door being opened.

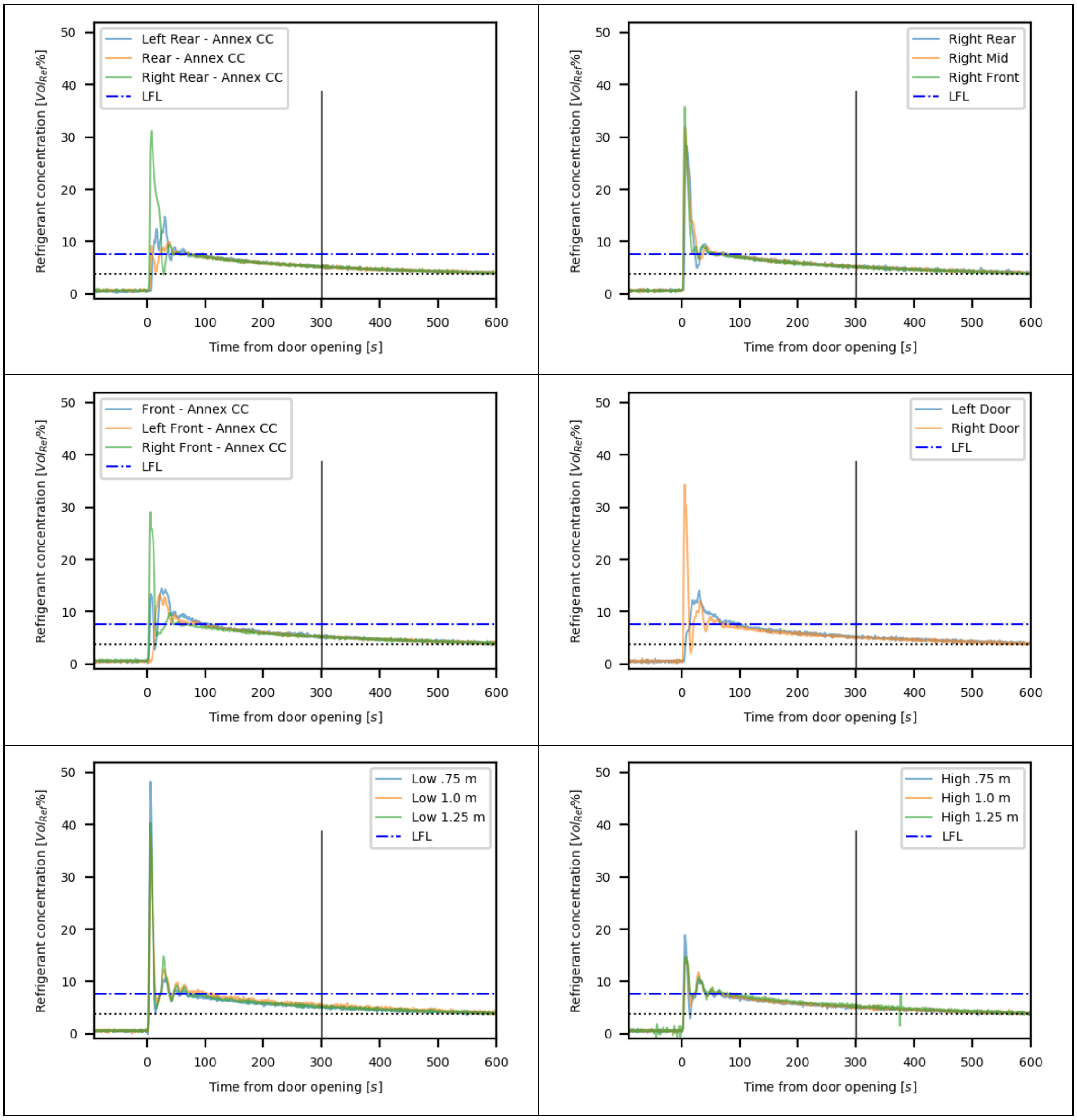


Table 192 - Refrigeration 18 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.10 **Refrigeration 18a**

A summary of the test parameters for this test are indicated in Table 193. This test was conducted with an internal leak with condenser fan on and the interior of the three door unit empty. In this test the condenser fan on the left side of the unit was discharging air towards the center of the unit.

Refrigerant	R454C	Mass Released	2.331 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On	Fan Volumetric Flow	695 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 193 - Refrigeration 18a Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were slightly above 50% LFL (average of all Annex CC sensors was 57% LFL), five minutes after the door was opened. The fan being on did prevent refrigerant from building in concentration prior to the unit door being opened.

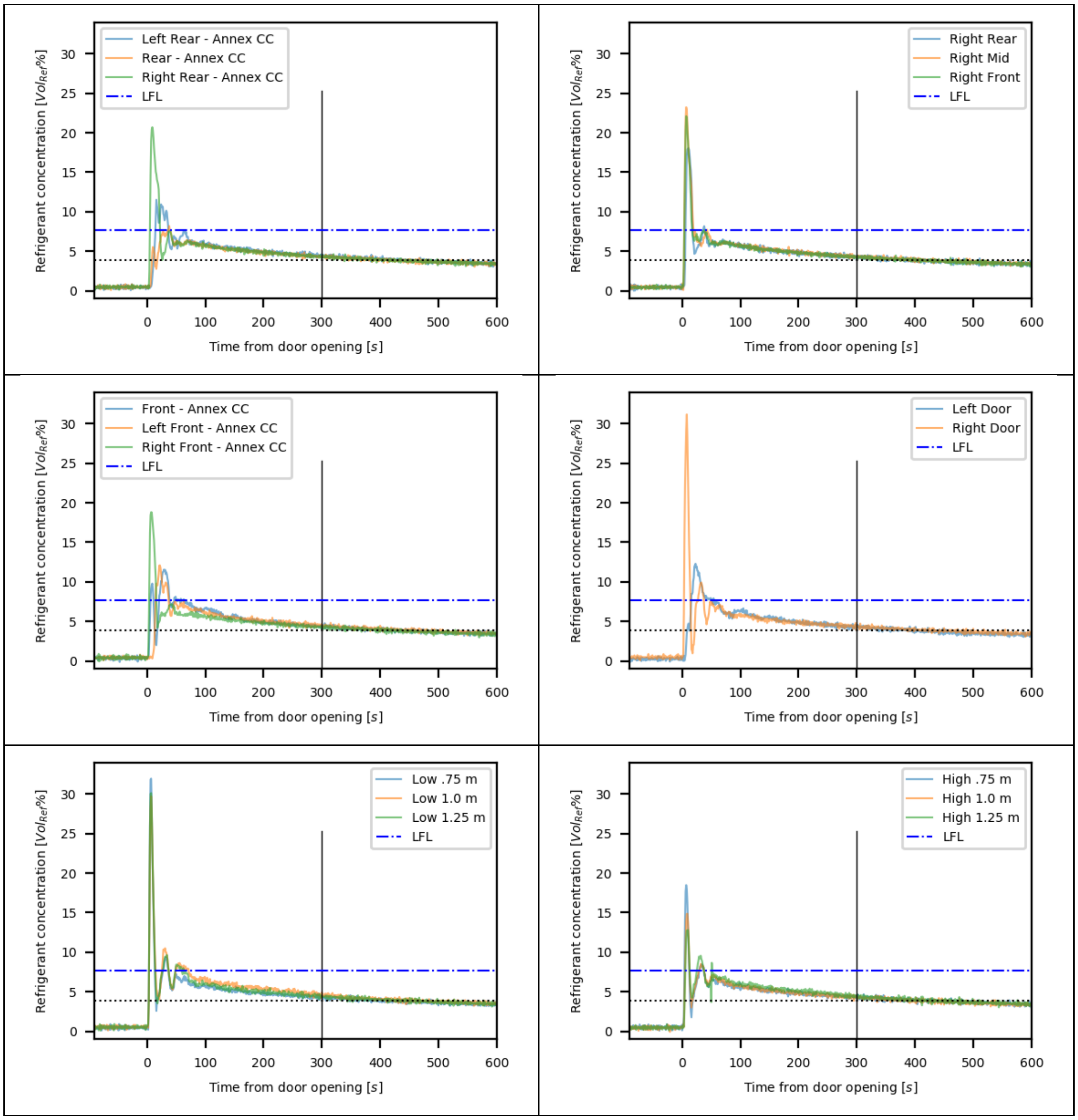


Table 194 - Refrigeration 18a Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.11 **Refrigeration 19**

A summary of the test parameters for this test are indicated in Table 195. This test was conducted with an internal leak with condenser fan on and the interior of the three door unit 75% filled. In this test the condenser fan was on and fan speed was selected to provide an addition 20% of volume.

Refrigerant	R454C	Mass Released	2.252 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On +20%	Fan Volumetric Flow	850 m³/hr
Case Interior	75% Filled	Leak Condition	A

Table 195 - Refrigeration 19 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were slightly above 50% LFL (average of all Annex CC sensors was 57% LFL), five minutes after the door was opened. The fan being on did prevent refrigerant from building in concentration prior to the unit door being opened.

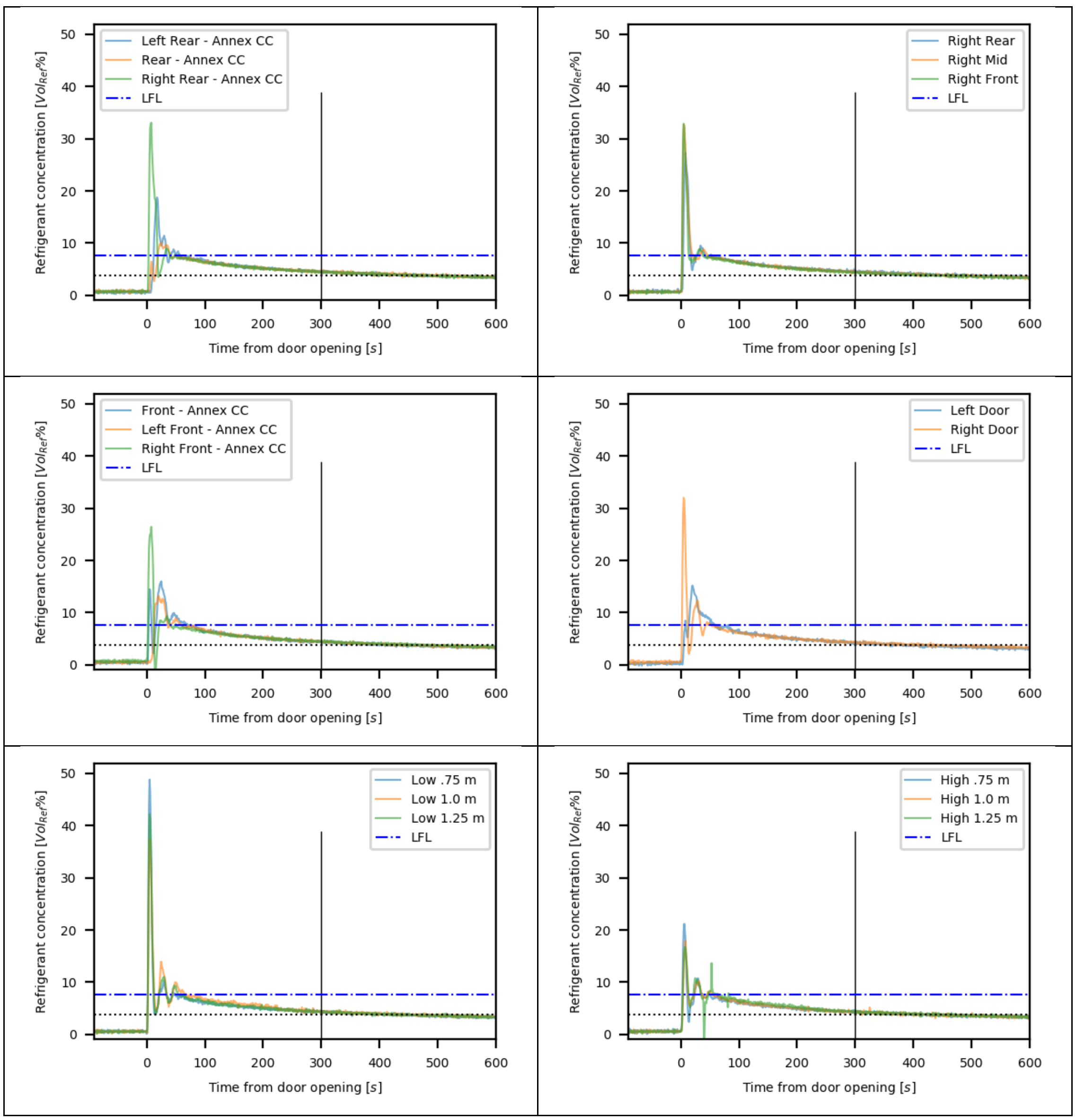


Table 196 - Refrigeration 19 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.2.12 **Refrigeration 20**

A summary of the test parameters for this test are indicated in Table 197. This test was conducted to establish the baseline for an external leak with condenser fan off.

Refrigerant	R454C	Mass Released	2.358 kg
Unit	Three Door	Leak Location	External
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	N/A	Leak Condition	A

Table 197 - Refrigeration 20 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL for greater than five minutes.

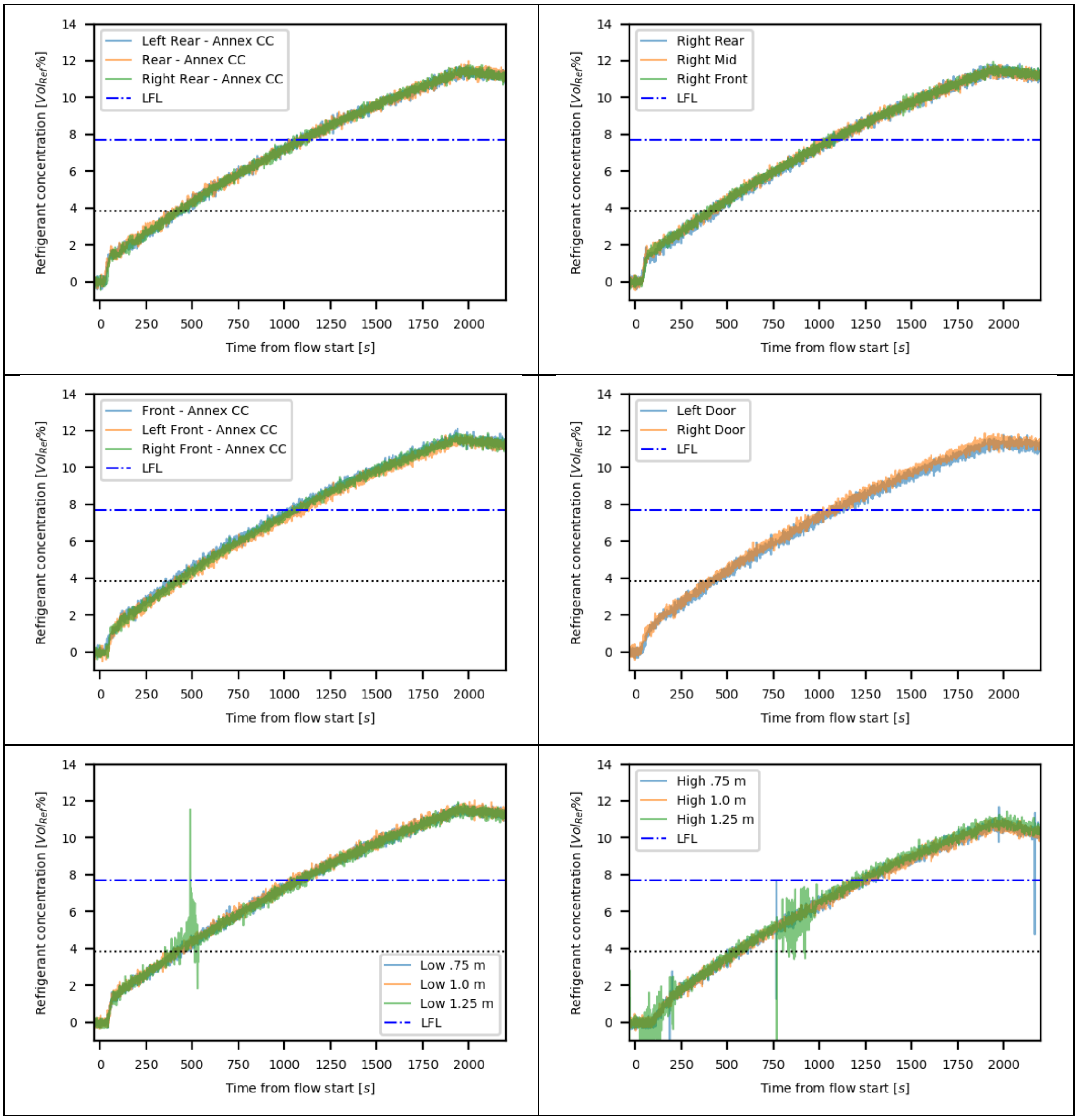


Table 198 - Refrigeration 20 Refrigerant Concentrations

6.2.13 **Refrigeration 21**

A summary of the test parameters for this test are indicated in Table 199. This test was conducted with an external leak near the right condenser. The left condenser fan was on and discharging towards the center of the unit.

Refrigerant	R454C	Mass Released	2.337 kg
Unit	Three Door	Leak Location	External
Condenser Fan	On	Fan Volumetric Flow	700 m³/hr
Case Interior	N/A	Leak Condition	A

Table 199 - Refrigeration 21 Test Parameters

This scenario would have complied with the requirements in the standard as all of the Annex CC sensors remained below 50% LFL.

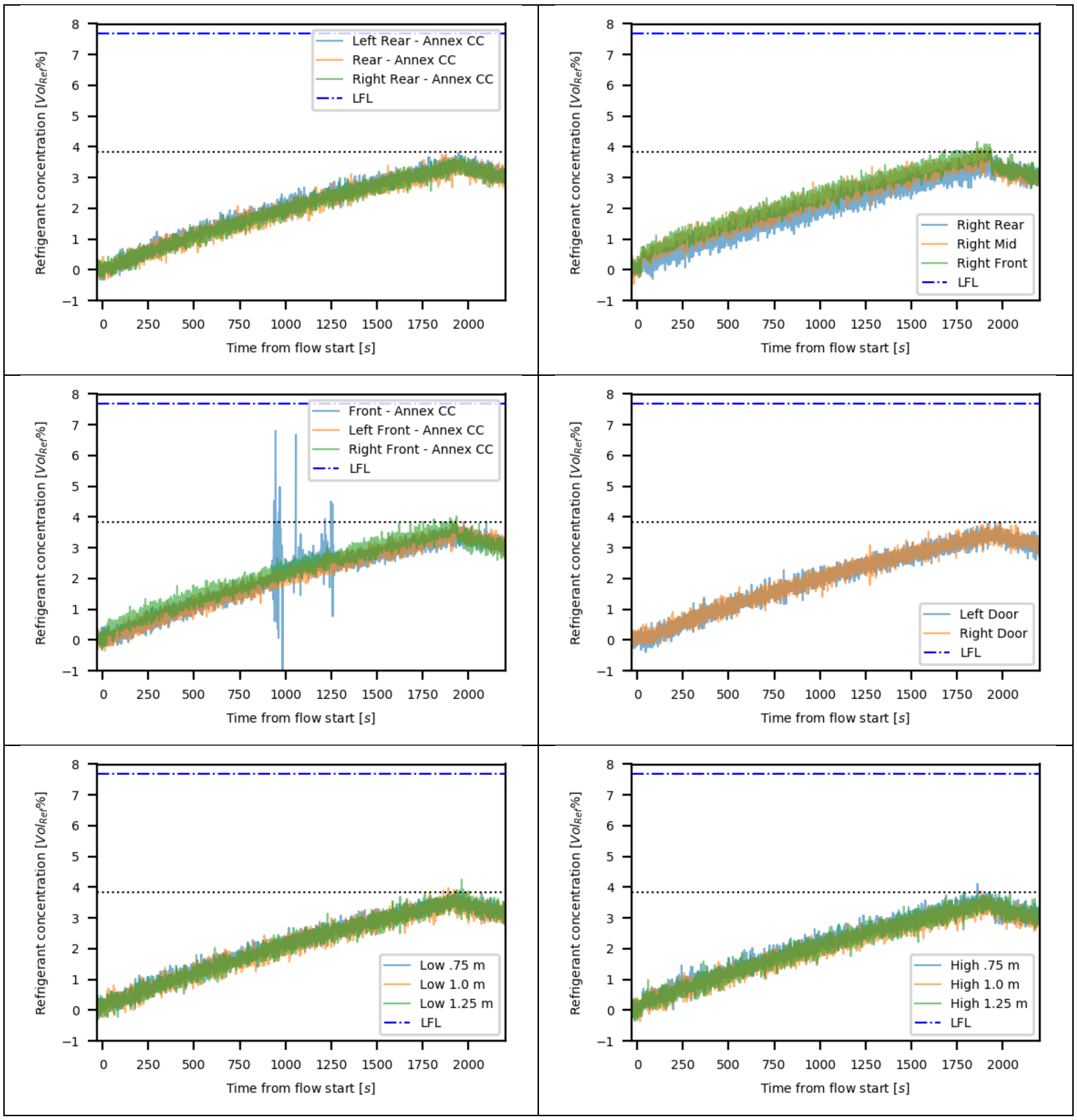


Table 200 - Refrigeration 21 Refrigerant Concentrations

6.2.14 **Refrigeration 21a**

A summary of the test parameters for this test are indicated in Table 201. This test was conducted with an external leak near the condenser on the right side of the unit. The left condenser fan was on and discharging towards the left side of the unit.

Refrigerant	R454C	Mass Released	2.335 kg
Unit	Three Door	Leak Location	External
Condenser Fan	On	Fan Volumetric Flow	690 m^3/hr
Case Interior	N/A	Leak Condition	A

Table 201 - Refrigeration 21a Test Parameters

This scenario would have complied with the requirements in the standard as all of the sensors remained below 50% LFL.

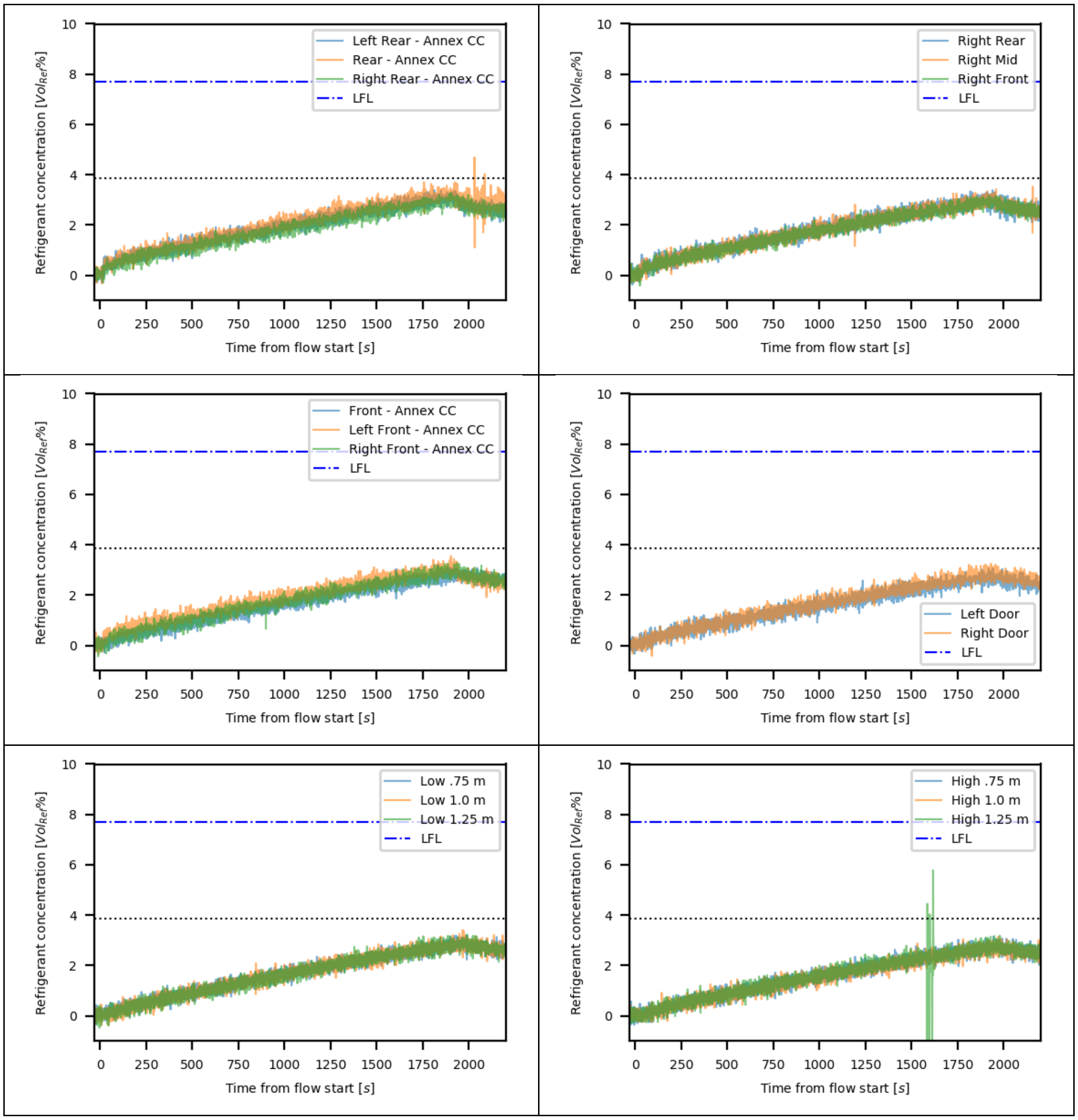


Table 202 - Refrigeration 21a Refrigerant Concentrations

6.3 Large Room

The layout of the of the unit and the sensor locations in the large test room is shown in Figure 42 and Figure 43. The sensor locations are indicated by stars in the sensor layout. Sensors indicated with a blue fill are required sensors indicated by Annex CC, without a fill color denote additional sensors located in the room space.

Figure 42 - Large Room Arrangement

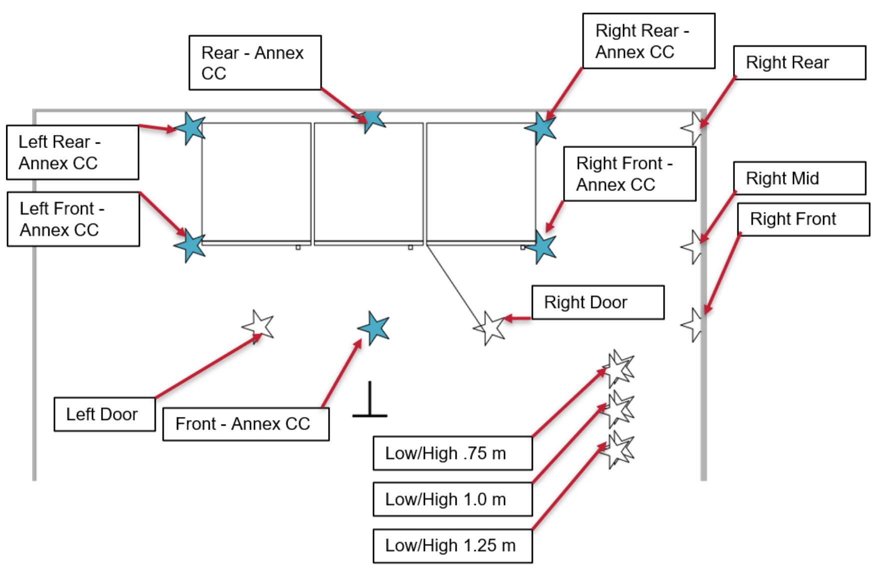


Figure 43 – Large Room Sensor Layout

6.3.1 Refrigeration 22

A summary of the test parameters for this test are indicated in Table 203. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty.

Refrigerant	R290	Mass Released	0.509 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 203 - Refrigeration 22 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

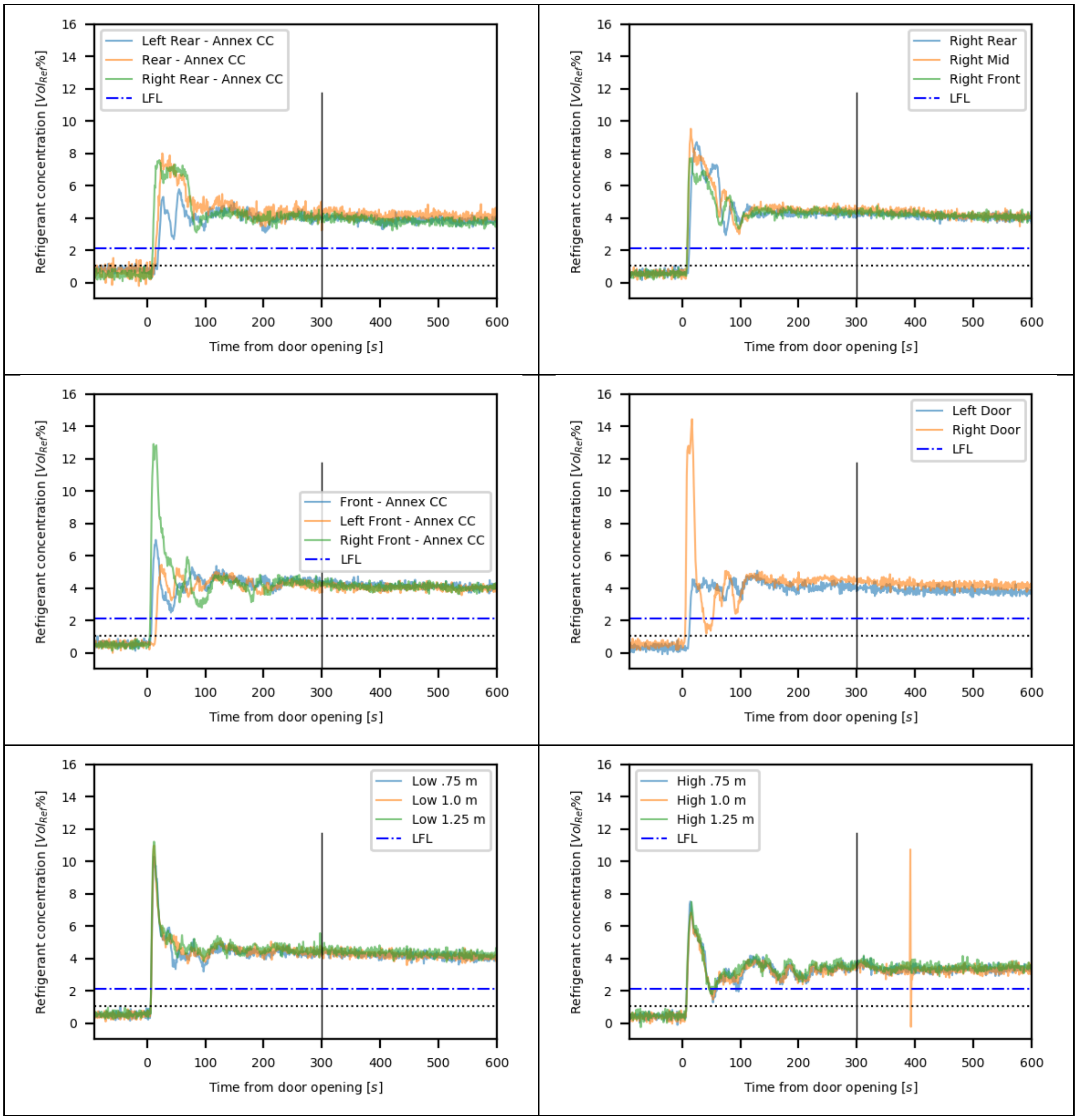


Table 204 - Refrigeration 22 Refrigerant Concentrations

(peak concentration around 10~100 seconds may be overestimated due to deconvolution method)

6.3.2 **Refrigeration 23**

A summary of the test parameters for this test are indicated in Table 205. This test was conducted with an internal leak with the left condenser fan discharging towards the center of the unit and the interior of the three door unit empty. The airflow for this was selected to be the nominal volume for this size charge.

Refrigerant	R290	Mass Released	0.516 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On - Nominal	Fan Volumetric Flow	1390 m³/hr
Case Interior	Empty	Leak Condition	A

Table 205 - Refrigeration 23 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

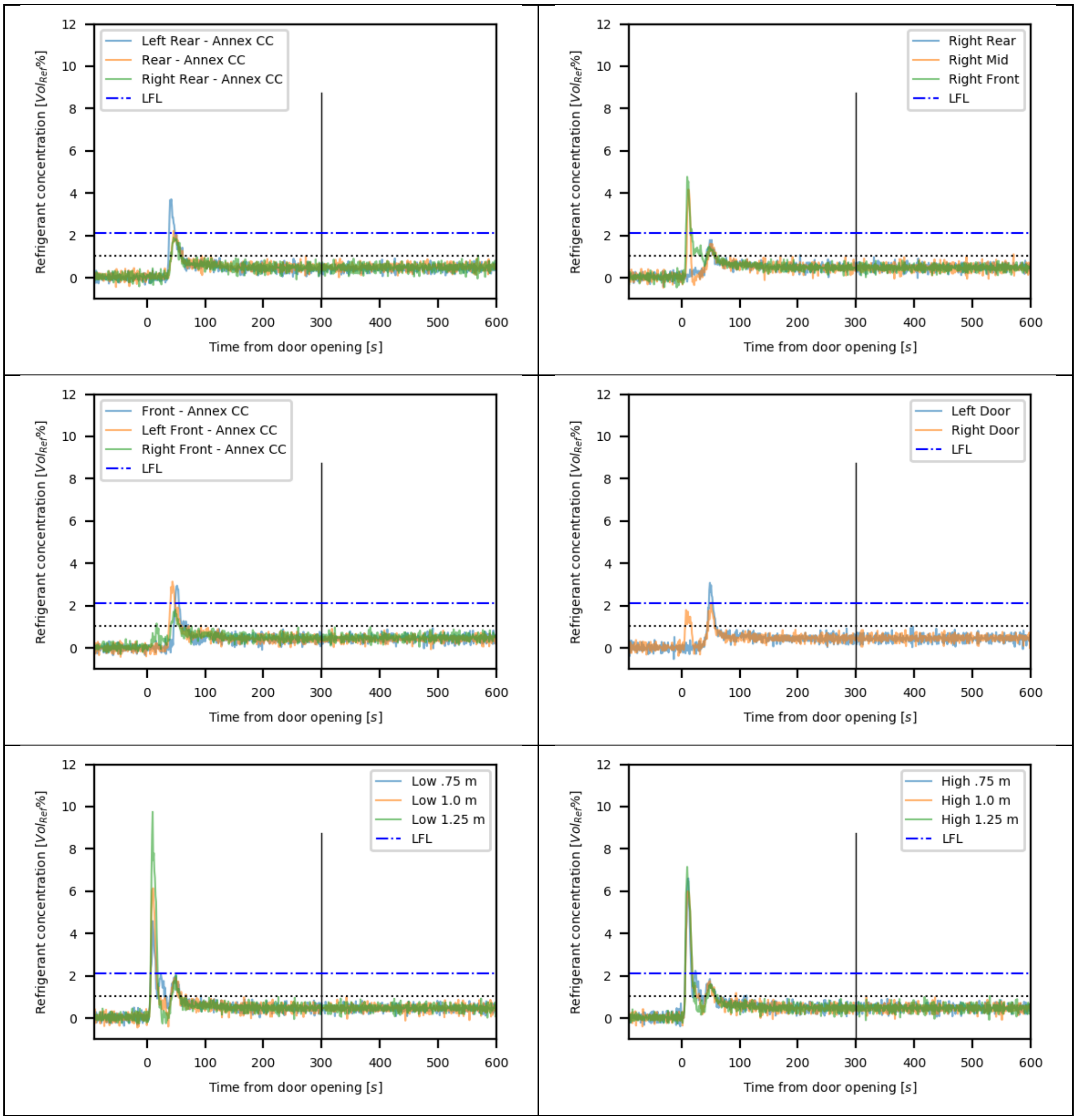


Table 206 - Refrigeration 23 Refrigerant Concentrations

(peak concentration around 10~50 seconds may be overestimated due to deconvolution method)

6.3.3 Refrigeration 24

A summary of the test parameters for this test are indicated in Table 207. This test was conducted with an internal leak with the left condenser fan discharging towards the center of the unit and the interior of the three door unit empty. The airflow for this was selected to be 20% below the nominal volume for this size charge.

Refrigerant	R290	Mass Released	0.507 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On -20%	Fan Volumetric Flow	1106 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 207 - Refrigeration 24 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

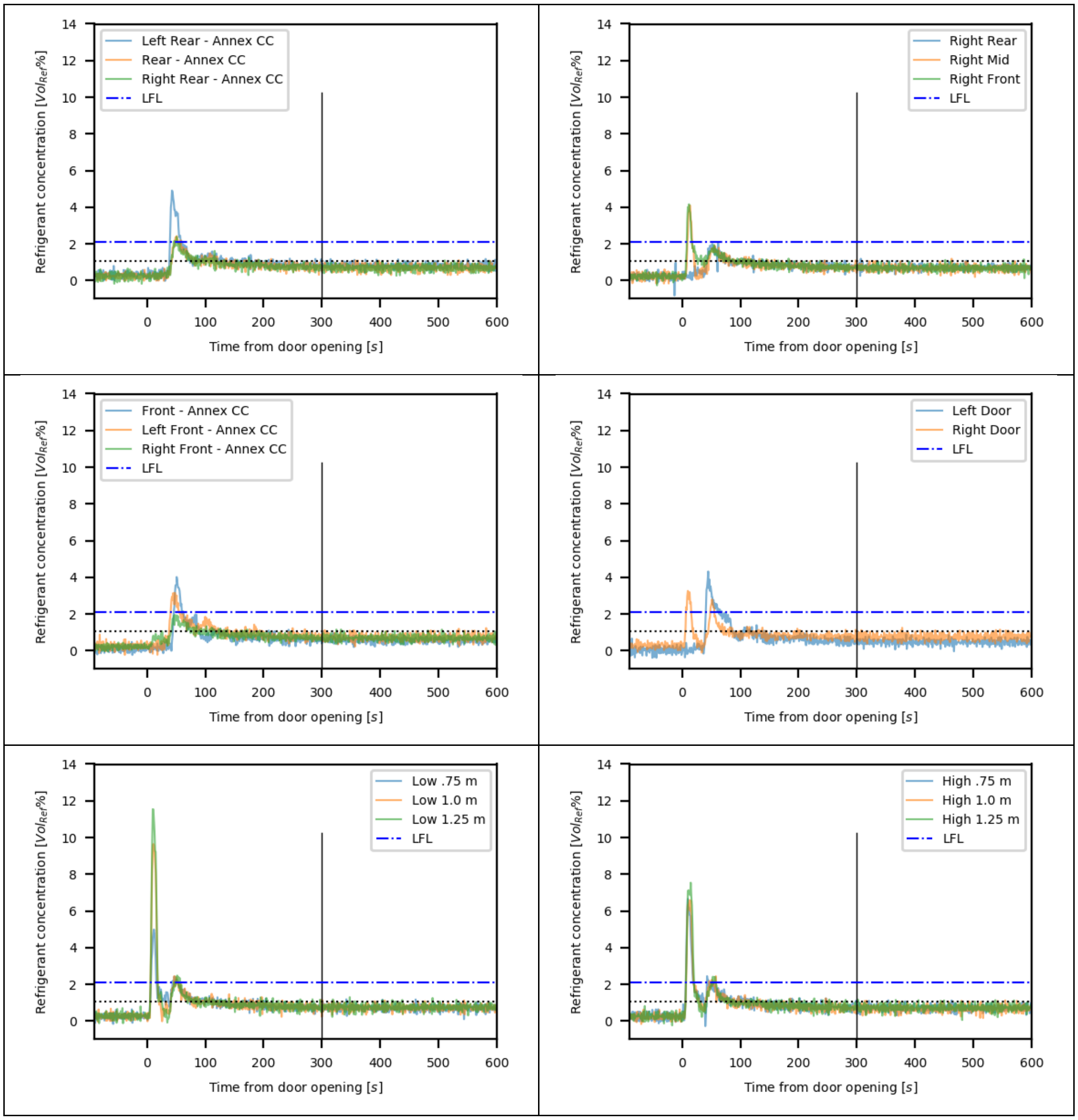


Table 208 - Refrigeration 24 Refrigerant Concentrations

(peak concentrations around 10~50 seconds may be overestimated due to deconvolution method)

6.3.4 Refrigeration 25

A summary of the test parameters for this test are indicated in Table 209. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty.

Refrigerant	R454C	Mass Released	3.867 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 209 - Refrigeration 25 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant five minutes after the door was opened.

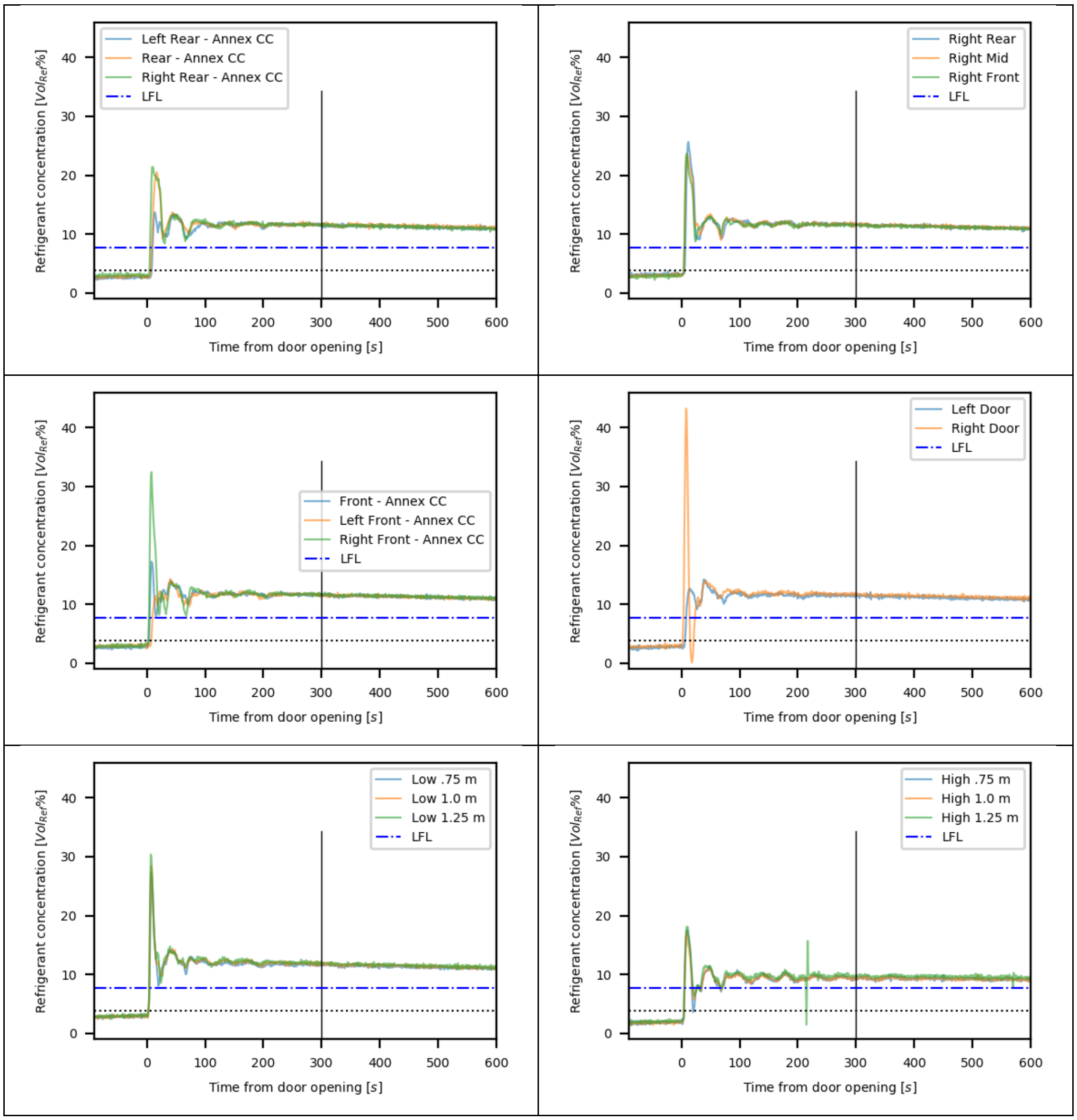


Table 210 - Refrigeration 25 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.3.5 Refrigeration 26

A summary of the test parameters for this test are indicated in Table 211. This test was conducted with an internal leak with the left condenser fan discharging towards the center of the unit and the interior of the three door unit empty. The airflow for this was selected to be a nominal volume for this size charge.

Refrigerant	R454C	Mass Released	3.842 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On - Nominal	Fan Volumetric Flow	1720 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 211 - Refrigeration 26 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

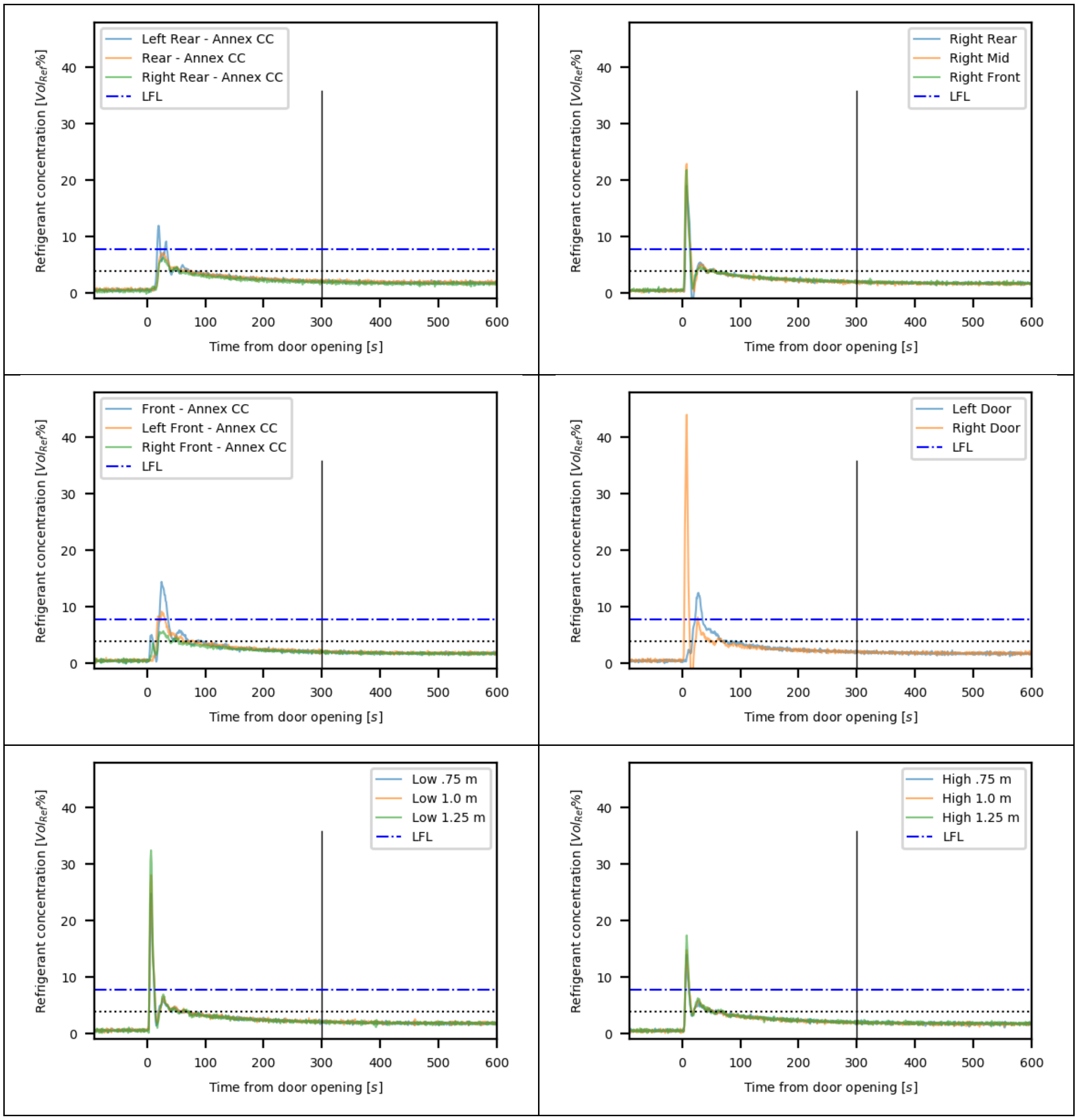


Table 212 - Refrigeration 26 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.3.6 **Refrigeration 27**

A summary of the test parameters for this test are indicated in Table 213. This test was conducted with an internal leak with the left condenser fan discharging towards the center of the unit and the interior of the three door unit empty. The airflow for this was selected to be 17% below the nominal volume for this size charge.

Refrigerant	R454C	Mass Released	3.773 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On -17%	Fan Volumetric Flow	1430 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 213 - Refrigeration 27 Test Parameters

This scenario complied with the requirements in the standard as the sensors were below 50% LFL five minutes after the door was opened.

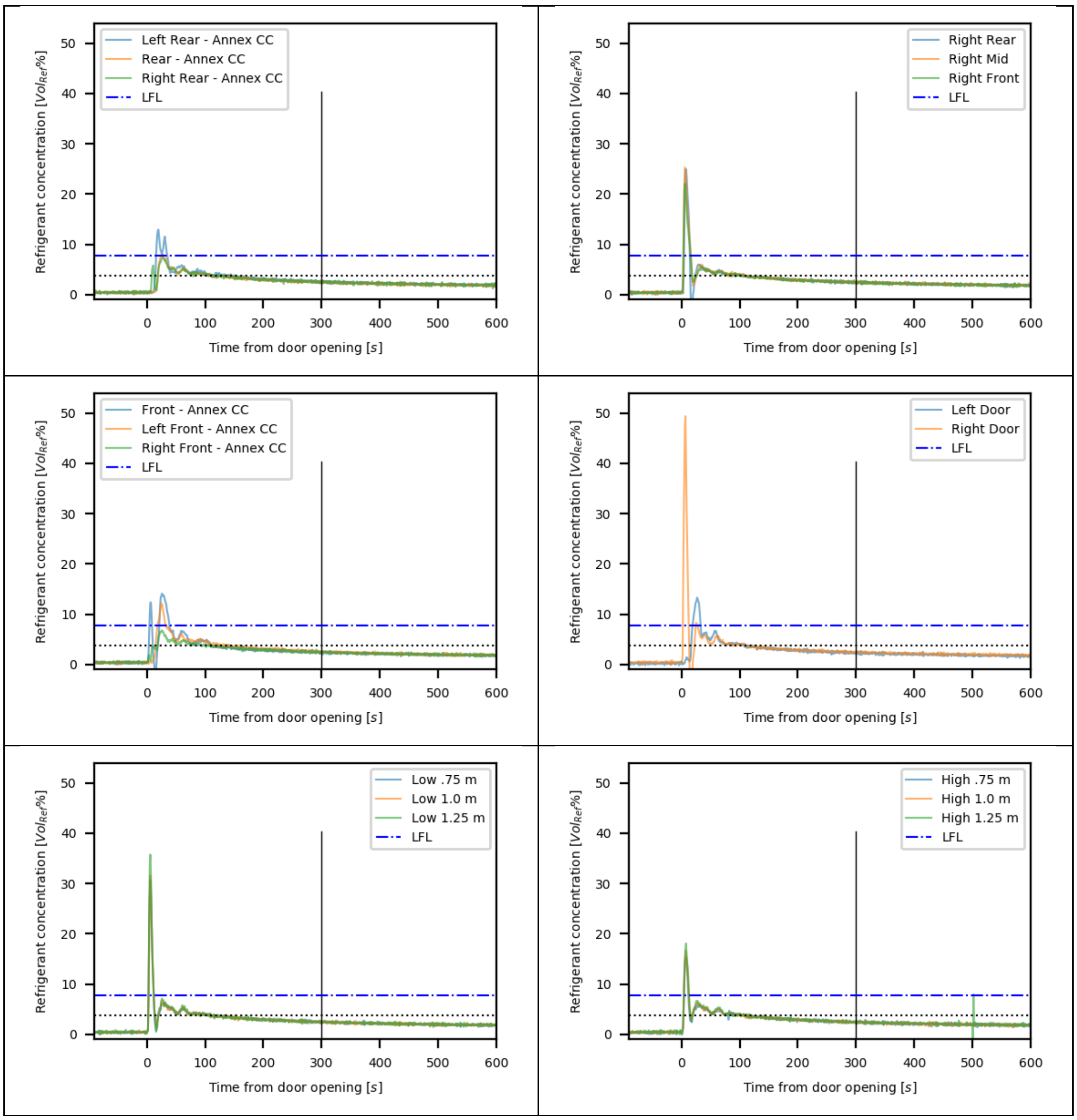


Table 214 - Refrigeration 27 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.3.7 **Refrigeration 28**

A summary of the test parameters for this test are indicated in Table 215. This test was conducted to establish the baseline with a three door unit, external leak and condenser fan off. The release rate used for this scenario was to simulate the refrigerant release while the compressor is operational.

Refrigerant	R454C	Mass Released	3.856 kg
Unit	Three Door	Leak Location	External
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	N/A	Leak Condition	B

Table 215 - Refrigeration 28 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant for more than five minutes.

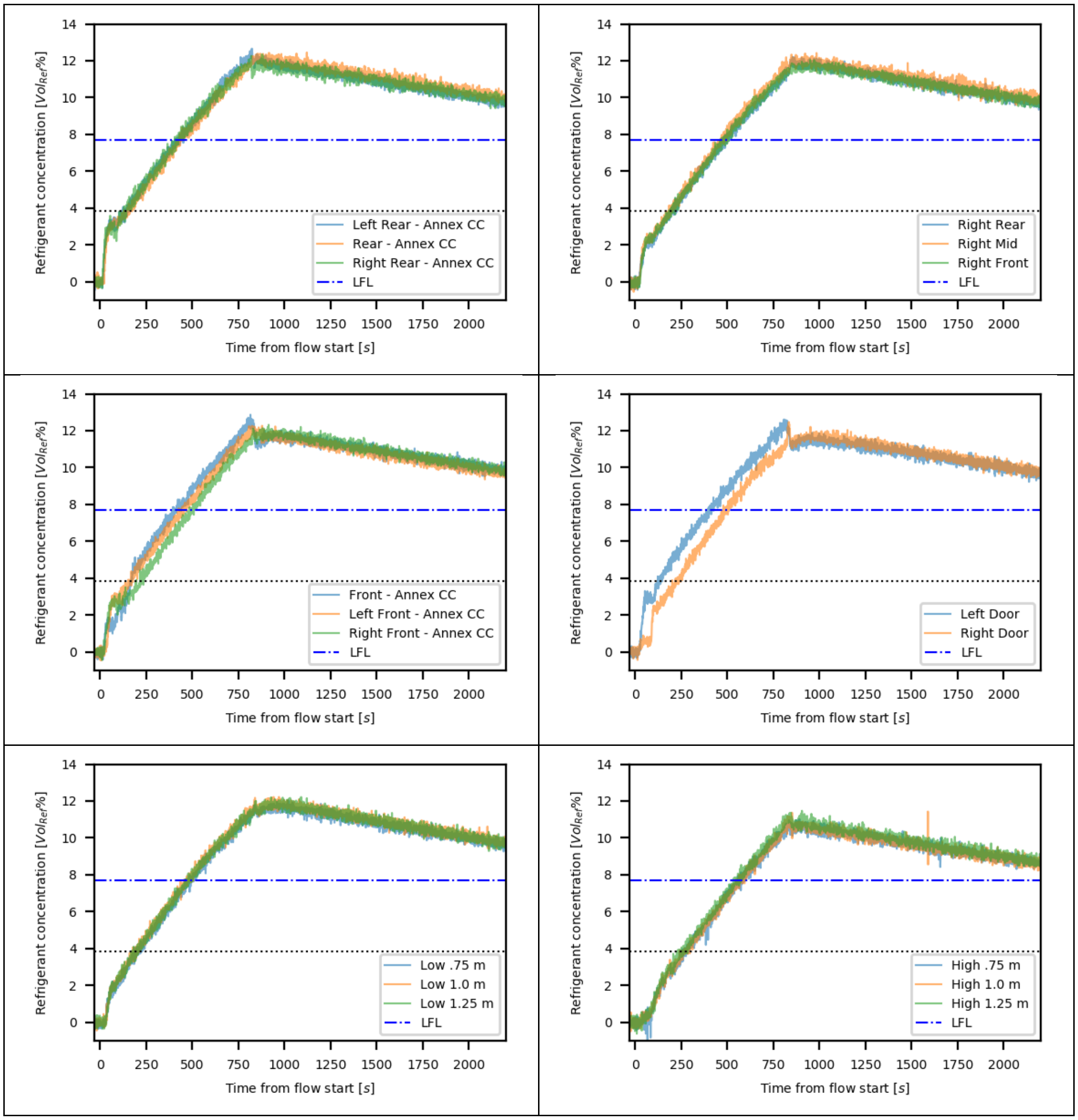


Table 216 - Refrigeration 28 Refrigerant Concentrations

6.3.8 **Refrigeration 29**

A summary of the test parameters for this test are indicated in Table 38. This test was conducted with a three door unit, external leak and condenser fan operating. The fan was running prior to the start of the release. The release rate used for this scenario was to simulate the refrigerant release while the compressor is operational.

Refrigerant	R454C	Mass Released	3.885 kg
Unit	Three Door	Leak Location	External
Condenser Fan	On	Fan Volumetric Flow	1665 m³/hr
Case Interior	N/A	Leak Condition	B

Table 217 - Refrigeration 29 Test Parameters

This scenario complied with the requirements in the standard as all of the sensors remained below 50% LFL.

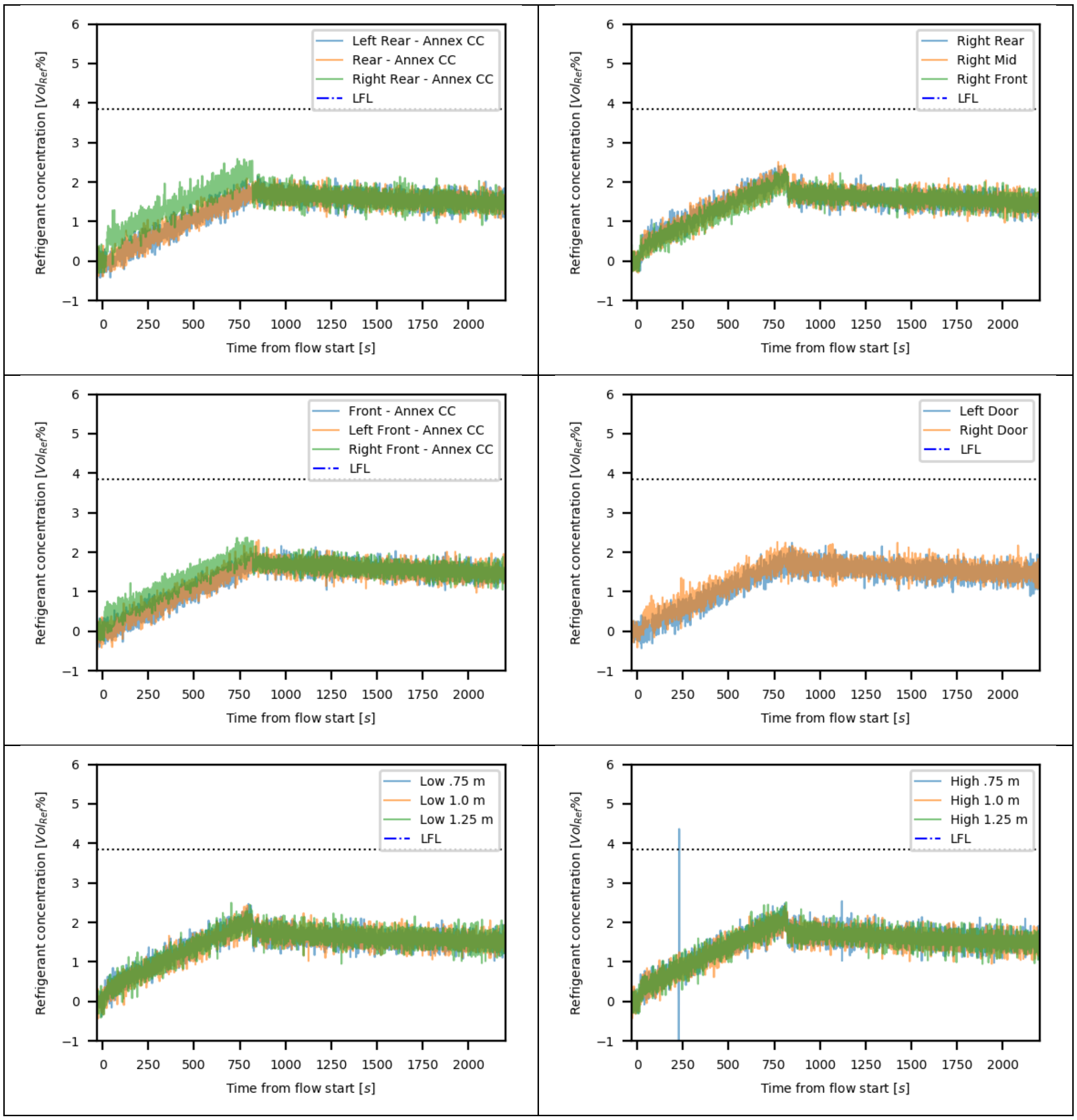


Table 218 - Refrigeration 29 Refrigerant Concentrations

6.3.9 Refrigeration 30

A summary of the test parameters for this test are indicated in Table 219. This test was conducted to establish the baseline for three door unit with external leak with condenser fan off.

Refrigerant	R454C	Mass Released	3.855 kg
Unit	Three Door	Leak Location	External
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	N/A	Leak Condition	A

Table 219 - Refrigeration 30 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the sensors were above the LFL of the refrigerant for more than five minutes.

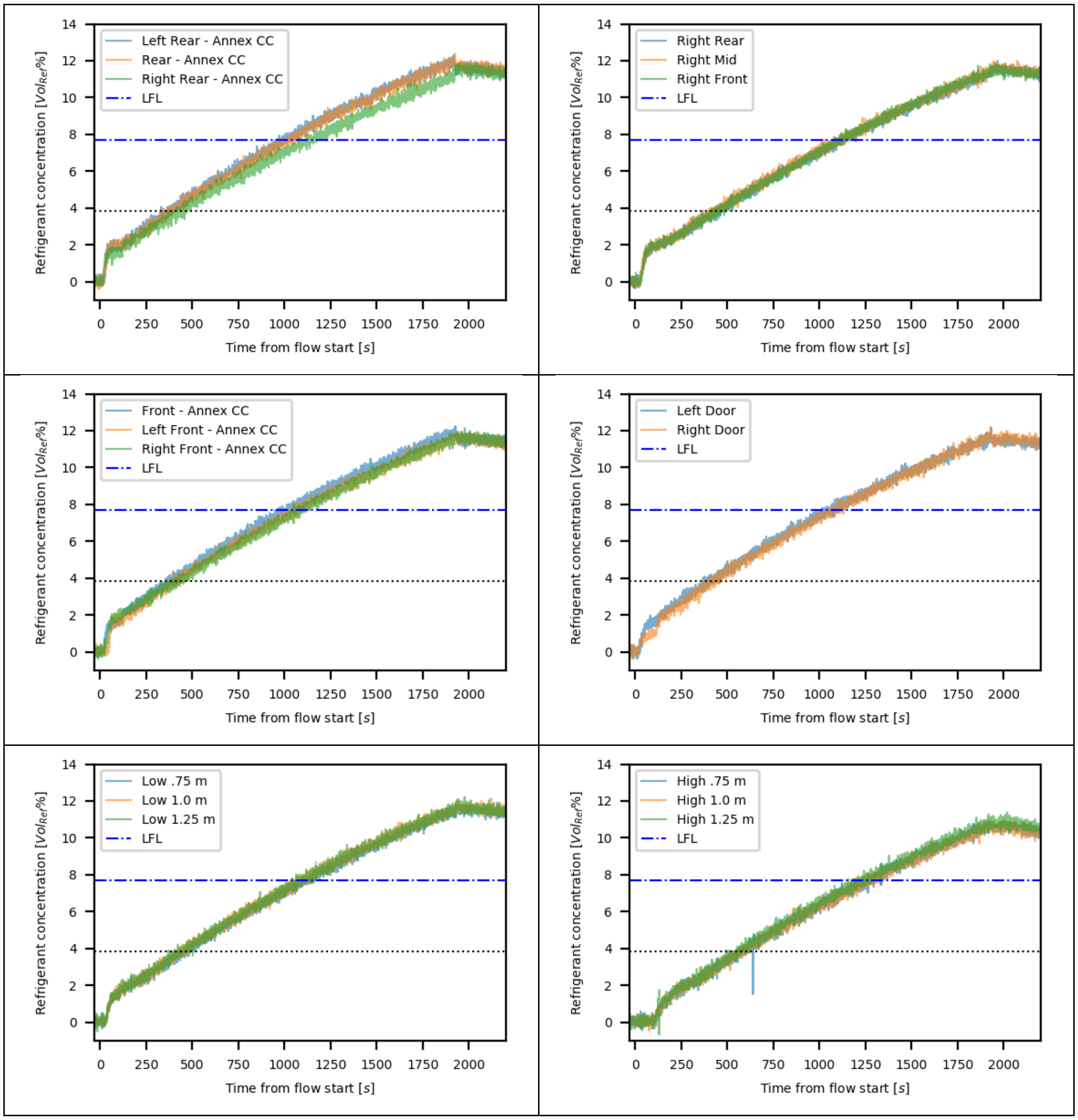


Table 220 - Refrigeration 30 Refrigerant Concentrations

6.3.10 **Refrigeration 31**

A summary of the test parameters for this test are indicated in Table 221. This test was conducted with a three door unit, external leak and condenser fan operating. The fan was running prior to the start of the release.

Refrigerant	R454C	Mass Released	3.891 kg
Unit	Three Door	Leak Location	External
Condenser Fan	On	Fan Volumetric Flow	1665 m³/hr
Case Interior	N/A	Leak Condition	A

Table 221 - Refrigeration 31 Test Parameters

This scenario complied with the requirements in the standard as all of the sensors remained below 50% LFL.

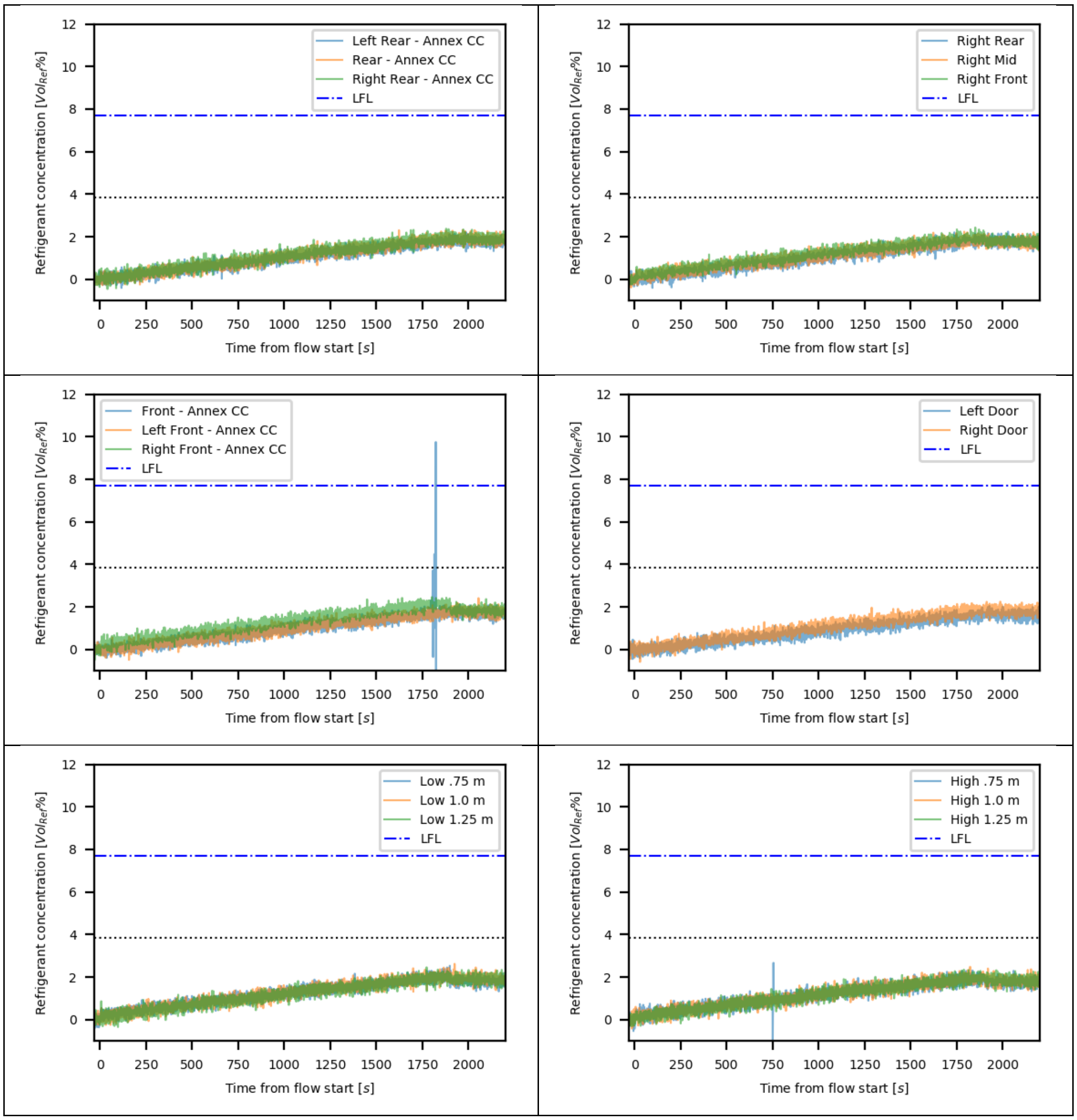


Table 222 - Refrigeration 31 Refrigerant Concentrations

6.3.11 Refrigeration 32

A summary of the test parameters for this test are indicated in Table 223. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty. This mass release for this test was sized for the small room and this provides a comparison between this test and Refrigeration 3.

Refrigerant	R290	Mass Released	0.153 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 223 - Refrigeration 32 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the Annex CC sensors were above 50% of the LFL of the refrigerant five minutes after the door was opened.

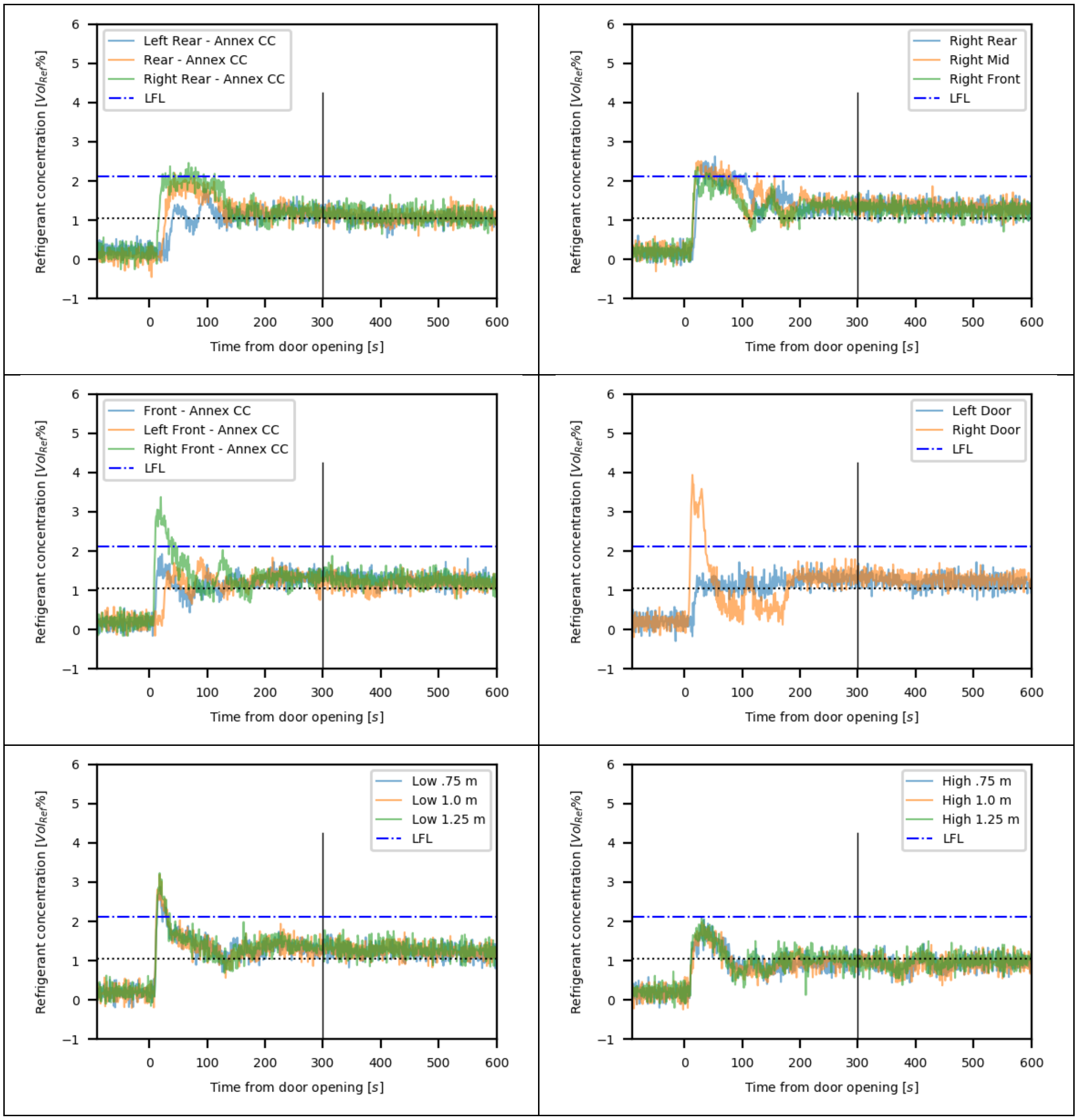


Table 224 - Refrigeration 32 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.3.12 **Refrigeration 33**

A summary of the test parameters for this test are indicated in Table 225. This test was conducted with an internal leak with the left condenser fan discharging towards the center of the unit and the interior of the three door unit empty. The airflow for this was selected to be the nominal volume for this size charge. This mass release for this test was sized for the small room and this provides a comparison between this test and Refrigeration 5.

Refrigerant	R290	Mass Released	0.155 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On Unit flow	Fan Volumetric Flow	400 m³/hr
Case Interior	Empty	Leak Condition	A

Table 225 - Refrigeration 33 Test Parameters

This scenario complied with the requirements in the standard as all of the sensors were below 50% LFL five minutes after the unit door was opened.

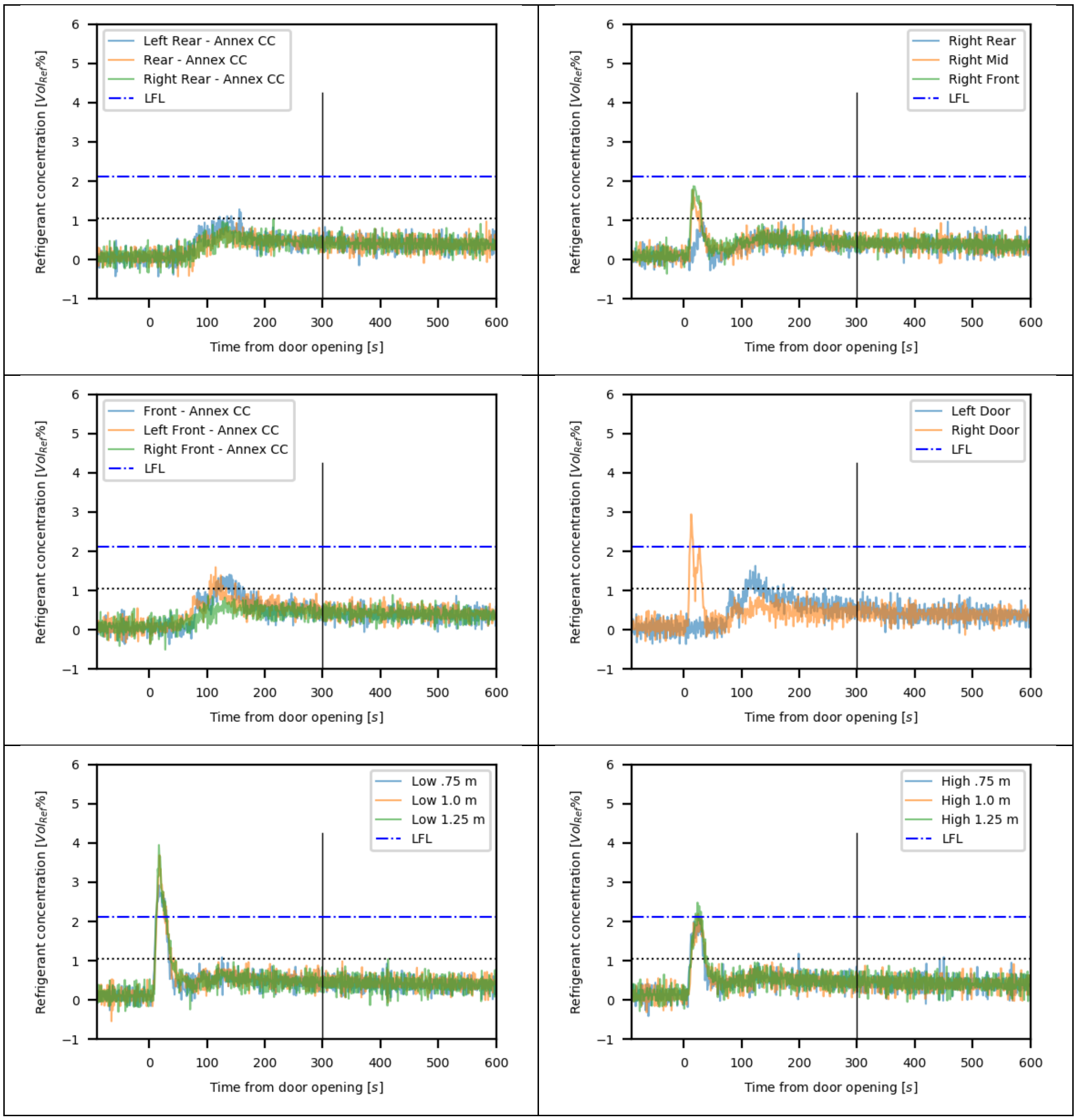


Table 226 - Refrigeration 33 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.3.13 **Refrigeration 34**

A summary of the test parameters for this test are indicated in Table 227. This test was conducted to establish the baseline for an internal leak with condenser fan off and the interior of the three door unit empty. This mass release for this test was sized for the small room and this provides a comparison between this test and Refrigeration 7.

Refrigerant	R454C	Mass Released	1.188 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	Off	Fan Volumetric Flow	N/A
Case Interior	Empty	Leak Condition	A

Table 227 - Refrigeration 34 Test Parameters

This scenario would not have complied with the requirements in the standard as all of the Annex CC sensors were above 50% of the LFL of the refrigerant five minutes after the door was opened.

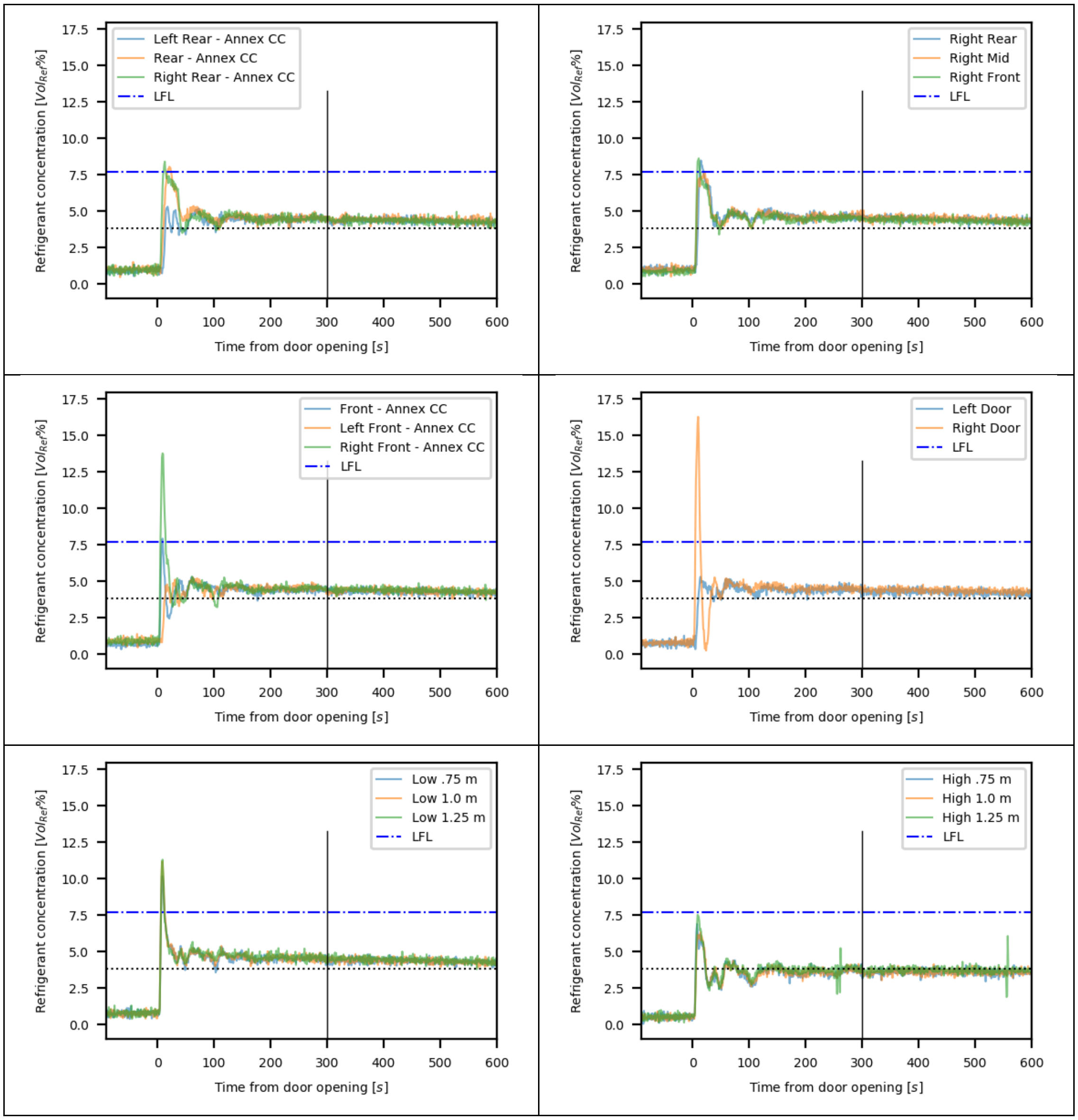


Table 228 - Refrigeration 34 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

6.3.14 **Refrigeration 35**

A summary of the test parameters for this test are indicated in Table 229. This test was conducted with an internal leak with the left condenser fan discharging towards the center of the unit and the interior of the three door unit empty. The airflow for this was selected to be the nominal volume for this size charge. This mass release for this test was sized for the small room and this provides a comparison between this test and Refrigeration 9, although there was a difference in the fill for these two tests.

Refrigerant	R454C	Mass Released	1.135 kg
Unit	Three Door	Leak Location	Internal
Condenser Fan	On - Nominal	Fan Volumetric Flow	550 m^3/hr
Case Interior	Empty	Leak Condition	A

Table 229 - Refrigeration 35 Test Parameters

This test would have complied with the requirements as all the sensors were below 50% LFL five minutes after the door was opened.

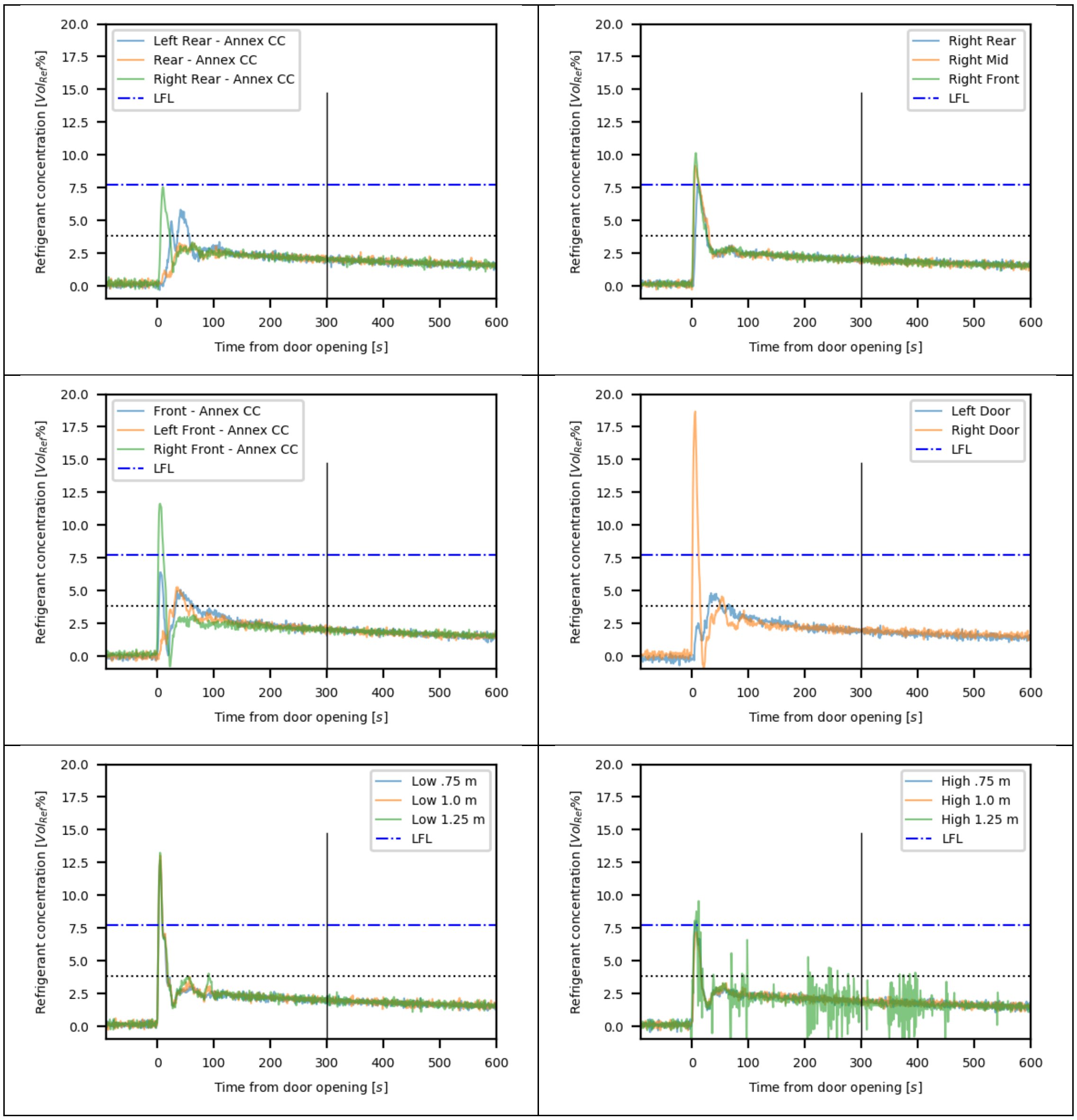


Table 230 - Refrigeration 35 Refrigerant Concentrations

(peak concentration around 10~30 seconds may be overestimated due to deconvolution method)

7 Discussion

7.1 Room Size

In general the room size did not have a significant impact on compliance with the Annex CC requirements. The refrigerant release was scaled proportionally with the room size. With the fan off the tests in the larger room sizes resulted in higher concentrations. There was evidence of higher refrigerant concentrations near the unit before and after the door was opened with the larger release mass. The refrigerant concentrations before is a result of the larger volume of refrigerant being introduced to the interior of the cabinet. The air in the cabinet is then released into the test space past the door seals. The concentration buildup before the door openings were similar across the sensors in front of the unit. This effect was directly related to the charge size. However, in no case did the refrigerant concentration reach 50% of the LFL prior to the door being opened.

When the door opens the higher concentration refrigerant that was inside the cabinet was introduced into the test space. This resulted in a peak of high concentration of refrigerant which then mixed with the lower part of the room space. This effect was similar across all of the room sizes. The refrigerant is not mixing completely with the room space as the larger charge sizes for the medium and large room result in a higher refrigerant concentrations.

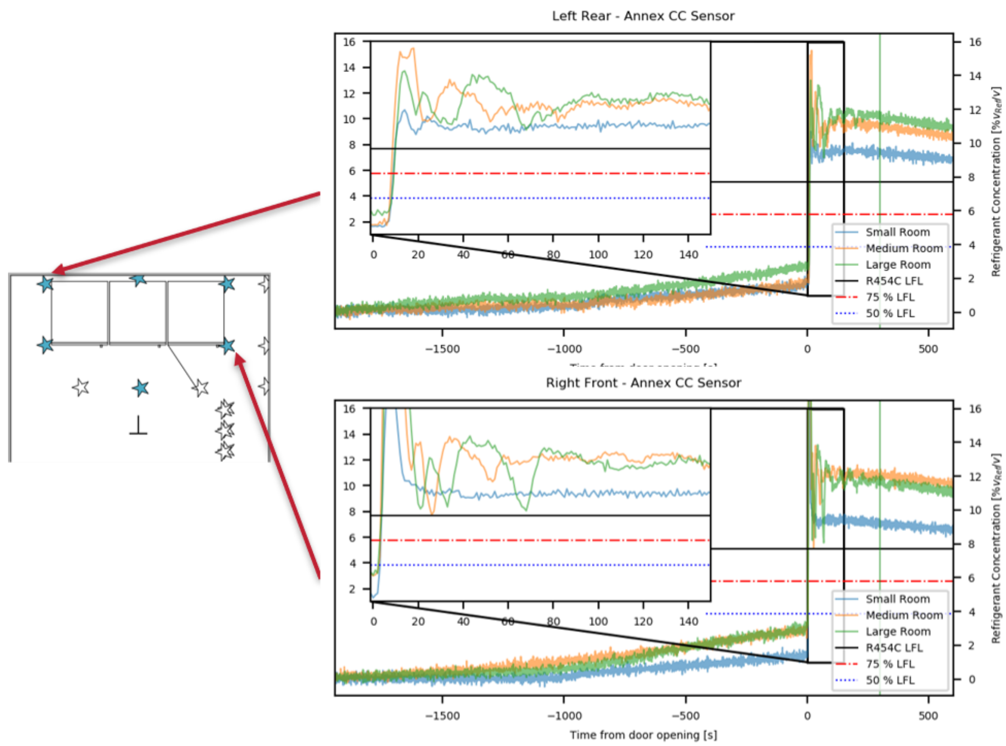


Figure 44 - R-454C Room Size

(peak concentrations may be overestimated and time shifted due to deconvolution method)

A set of tests was conducted to evaluate if the room size alone were enough to mitigate a smaller amount of refrigerant. This compares the calculated mass for the small room released in the large room. For R-290 this compares a 150 g release, for R-454C the target release mass was 1.157 kg. The room size did have an effect on the concentration values, but it alone was not sufficient to comply with the requirements in the standard. With the fan off the concentrations were above the 50% LFL requirement at 5 minutes, although it was below the LFL at all locations. With the fan off the refrigerant concentrations, for both R-290 and R454C, were reduced by an average of 50% when the testing occurred in the larger room (24 m^2). Figure 45 shows refrigerant concentrations for 150 g of R-290 released in the small room, compared with the same mass released in the large room. With the condenser fan on the average concentrations were also reduced, although the effect was not as large as with the fan off.

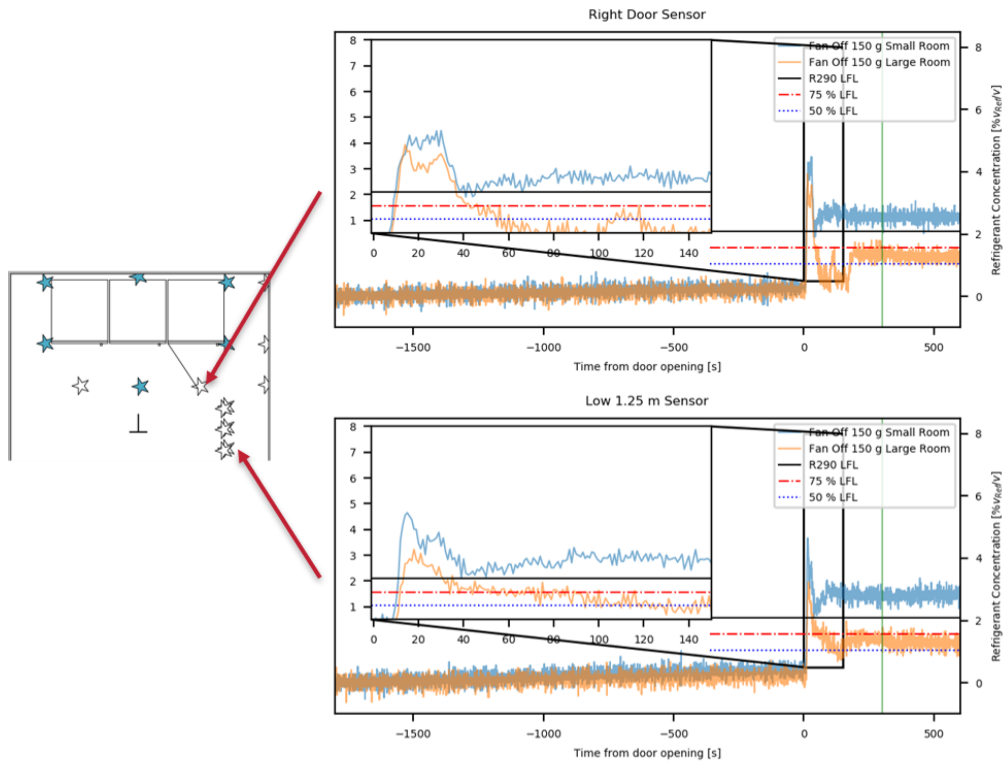


Figure 45 - 150 g R-290 release, Room Comparison

(peak concentrations may be overestimated and time shifted due to deconvolution method)

7.2 Case Loading

One of the parameters varied during this study was the effect of shelf loading on the refrigerant release. This study did not see a significant difference for the A2L refrigerants. Tests conducted with the condenser fan off were still above the LFL five minutes after the door opened. For tests conducted with R-454C the 75% fill resulted a slight increase in the refrigerant volume being introduced into the room prior to the door opening. After the door opening there also exists slightly higher refrigerant peaks which is a result of the higher refrigerant concentrations being introduced into the test space. This study did not look at the concentrations inside the unit so it was not determined if these increases were due to the product displacing some of the internal volume, or if the product was providing restriction to the release once the door was opened.

This same effect was present for the three door unit in both the small and medium room size. Figure 46 shows the same location in the small (bottom plot) and medium (upper plot) room. The charge size is larger for the medium room (2.3 kg vs 1.2 kg) so the final concentrations are also larger.

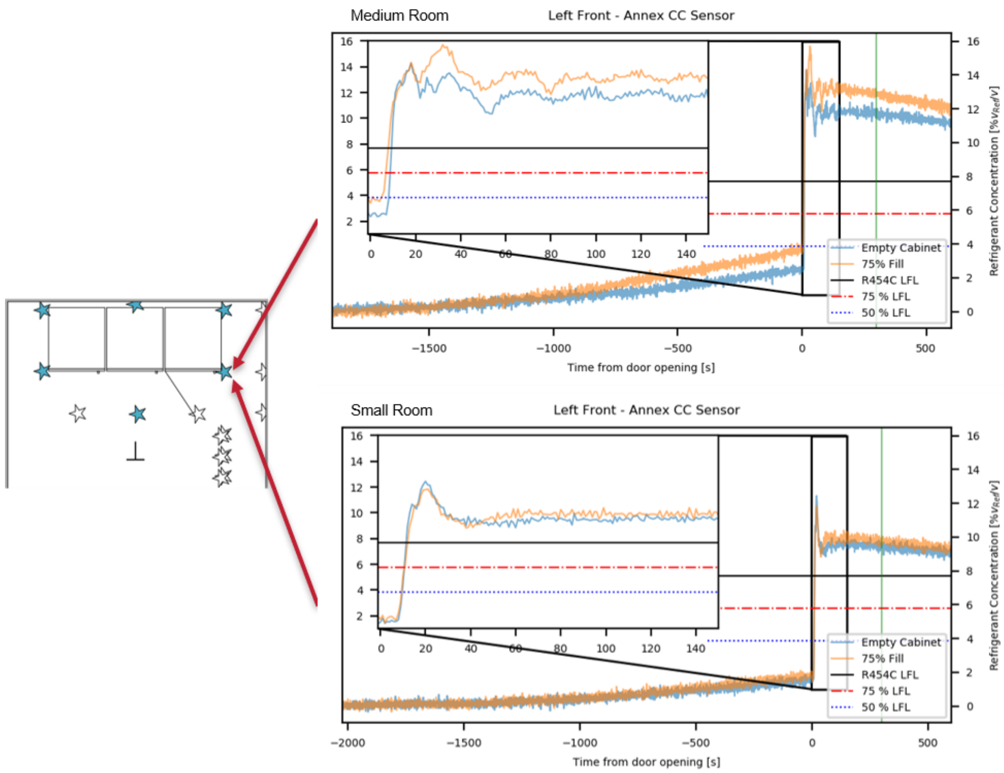


Figure 46 - R-454C Small and Medium Room, Fill Comparison

(peak concentrations may be overestimated and time shifted due to deconvolution method)

For the tests conducted with R-290 there was not the same effect of the refrigerant leaking into the test space prior to the door opening. This was due to the smaller volume associated with these charge sizes. Figure 47 details two sensors for the R-290 release, the top is outside the refrigerant release path and the bottom is the sensor closest to the cabinet. For these releases we have approximately the same starting concentrations, but near the door the 75% fill concentration decays at a faster rate, this could be evidence of the refrigerant mixing better as it enters the room space. However, in any of these cases the refrigerant is above the LFL and does not comply with the requirements in the standard.

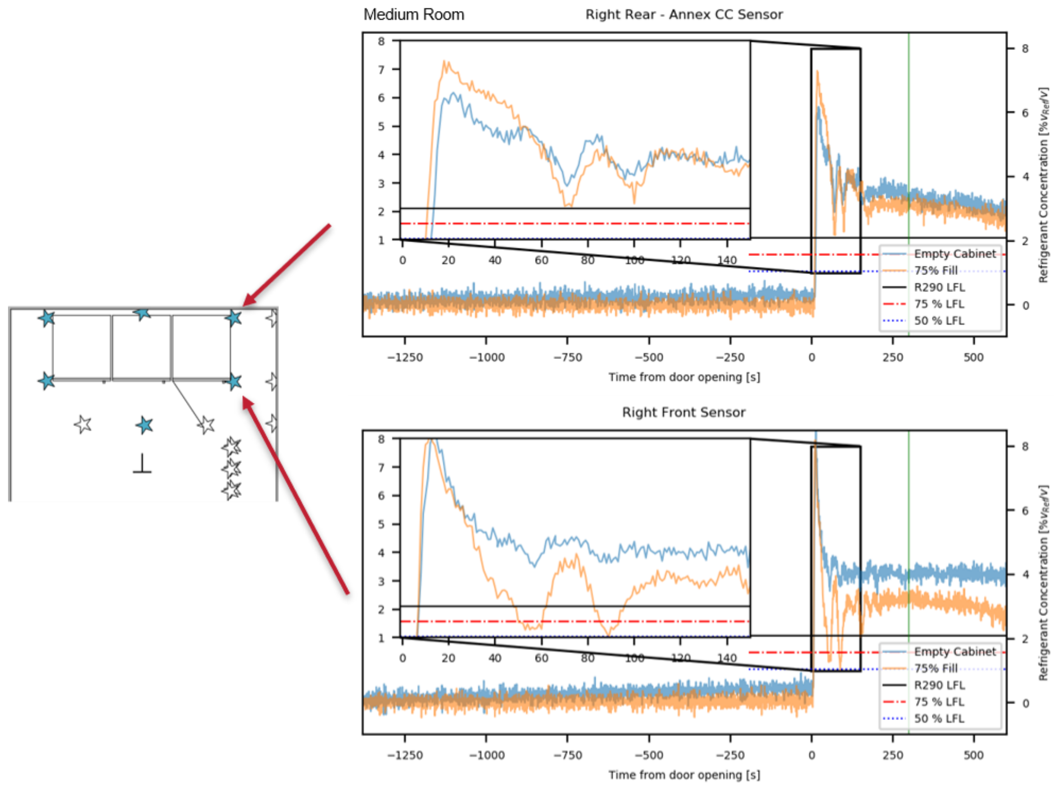


Figure 47 - R-290 Medium Room, Fill Comparison

(peak concentrations may be overestimated and time shifted due to deconvolution method)

The effect of case loading does not provide a significant difference for either of the refrigerants in the small or medium room.

7.3 Unit Airflow

For all tests where a fan was not operated the refrigerant concentrations were above 50% LFL at five minutes into the test. It was possible to use the condenser fan to mix the refrigerant in the space and have refrigerant concentrations below 50% LFL after five minutes. The tests conducted in the small room utilized the condenser fans which were provided with the unit. These blowers provided enough airflow to ensure that the refrigerant concentrations were below 50% of the LFL before the five minute time.

For the medium and large room airflow was checked at the expected nominal value and then adjusted to determine if there was a minimum airflow which could be identified. Figure 48 shows a comparison of fan operation and two different airflows for the three door unit in the medium room. The airflow for the condenser fan is able to mix the refrigerant being leaked into the space prior to the door opening. When the door opens, the amount of refrigerant entering the space is similar between all tests, but the fan mixes the refrigerant in the space and the refrigerant concentration drops to near 50% of the LFL at five minutes. For these releases the condenser fan is discharging air toward to center of the unit. These two plots show that on either side of the unit the refrigeration concentrations were approximately the same. For all sensors in the test room at five minutes the values were very similar.

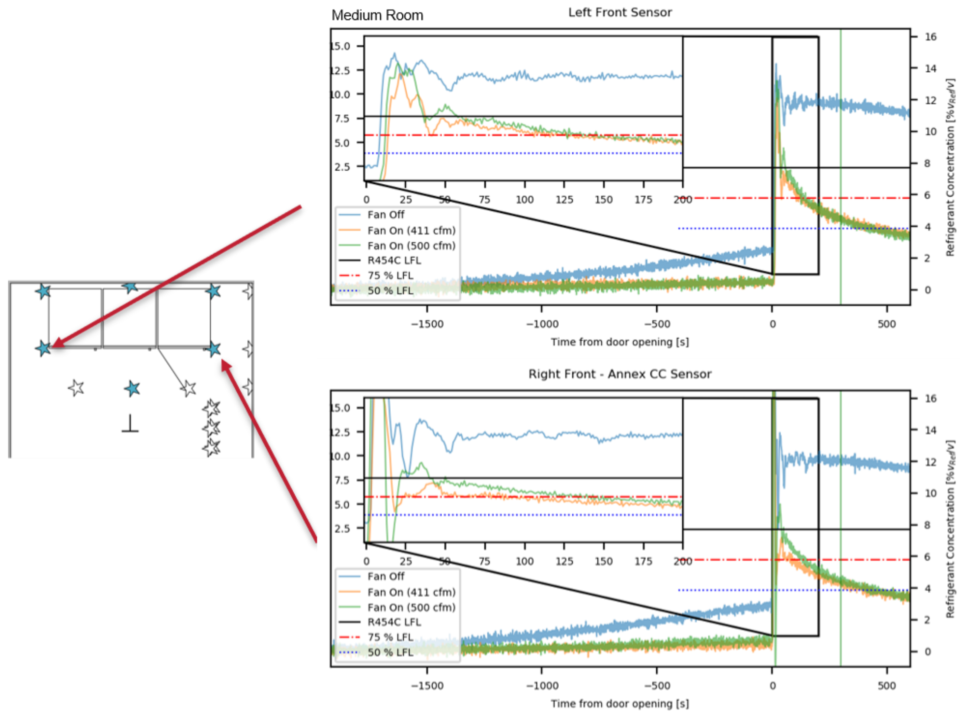


Figure 48 - R-454C Medium Room, Airflow Comparison

(peak concentrations may be overestimated and time shifted due to deconvolution method)

For the large room, the same approach was taken and airflow was compared across two different fan speeds. Figure 49 details the results of the fan off as well as the fan operating with two different volumetric flows. The higher volumetric flow is 20% higher than the lower flow. Both of these airflow values were able to disperse the refrigerant that is leaked into the space prior to the door being opened. When the door was opened the refrigerant profile near the door (upper plot in this figure) was very similar. The lower plot in this figure shows a location further out into the room (1.25 m from the front of the unit). From this plot it can be observed that there is little transport delay to this sensor location when the door is opened, regardless of the fan operation. The fan operation has the effect of mixing the refrigerant in the space quickly and the refrigerant concentrations are below 50% of the LFL within five minutes. As with the medium room results there was little difference for the concentrations at any of the sensors in the room after five minutes.

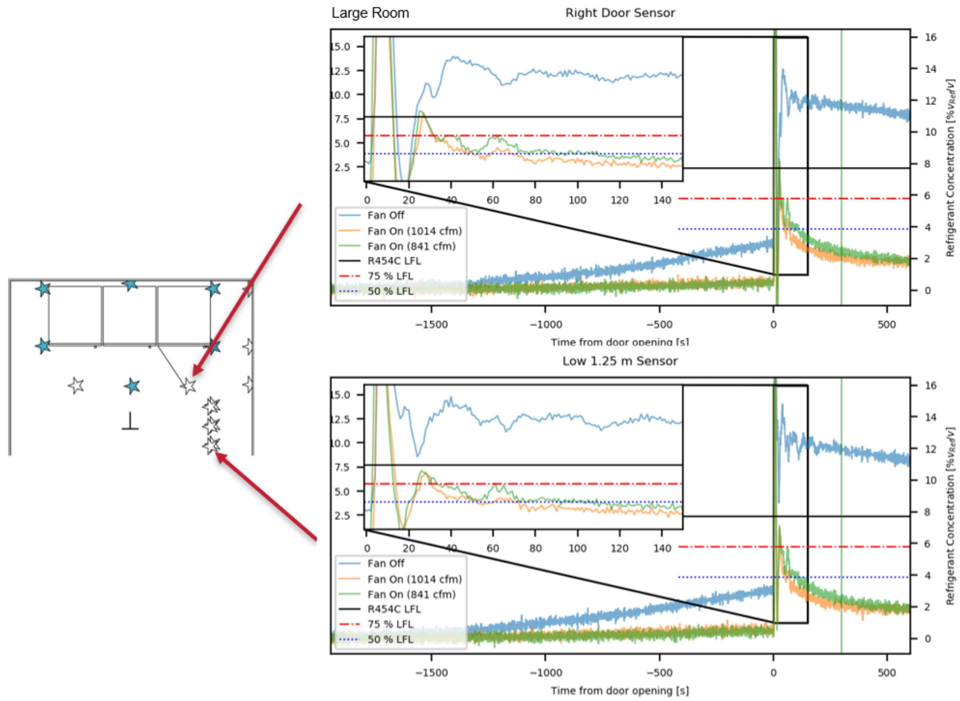


Figure 49 - R-454C Large Room, Airflow Comparison

(peak concentrations may be overestimated and time shifted due to deconvolution method)

Condenser airflow could be used to mitigate the release of A2L and A3 refrigerants in accordance with Annex CC testing. The airflow does have a significant impact on the refrigerant mixing in the space. The refrigeration portion of this project did not investigate the use of a refrigeration detector or mitigation time as part of this study. The fan was operated during the entire leak. The requirements in IEC 60335-2-89 state that the airflow required for mitigation be produced by components that are part of the appliance and that the airflow shall be guaranteed. A fan constantly operating at a minimum value to provide this mixing is currently a valid mitigation measure.

7.4 Refrigerant Flow Rate

The standard specifies two flow discharge rates to be used. One simulates when compressor is off and the other simulates the compressor operating. A comparison was conducted in the large room to determine if the flow rate had a significant impact on the concentrations in the space with an external leak.

For the R-454C tests the Condition A rate was 122 g/min, resulting a total flow time of 32 min. The Condition B rate was 288 g/min, with a total flow time of just over 13 min.

With the fan off all of the sensors were above the LFL. With the condenser fan operating the refrigerant concentrations remained below 50% of the LFL. There was no significant difference between the maximum concentrations observed during this test. Figure 50 details two sensor locations with the fan off. The lower sensor in this figure, located 500 mm in front of the unit was close to the release location. An apparent dip in refrigerant concentration can be observed at the end of the flow, although it is more distinguishable for the Condition B flow. This showed that the refrigerant was being discharged out of the unit with some momentum and is not fully mixing before reaching the sensor.

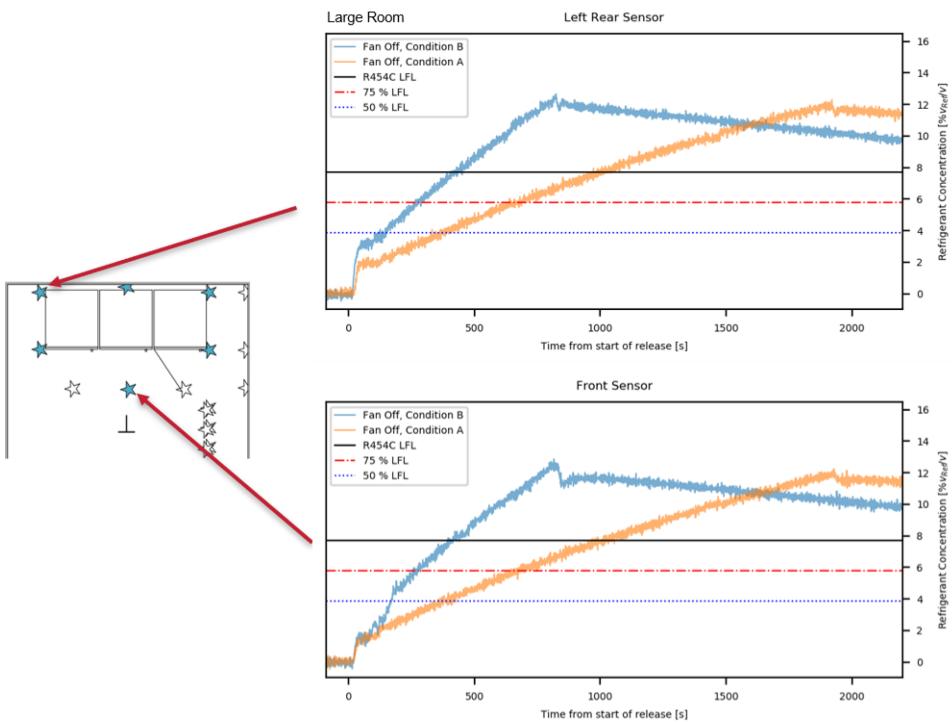


Figure 50 - R-454C Fan Off, Release Rate Comparison

When the condenser fan is operating there is enough air movement below the unit to mix refrigerant. Figure 51 details two sensors during the fan on test. The lower sensor is closest to the leak location and is downstream of the direction of the condenser fan discharge. There is a similar effect as was seen with the fan off.

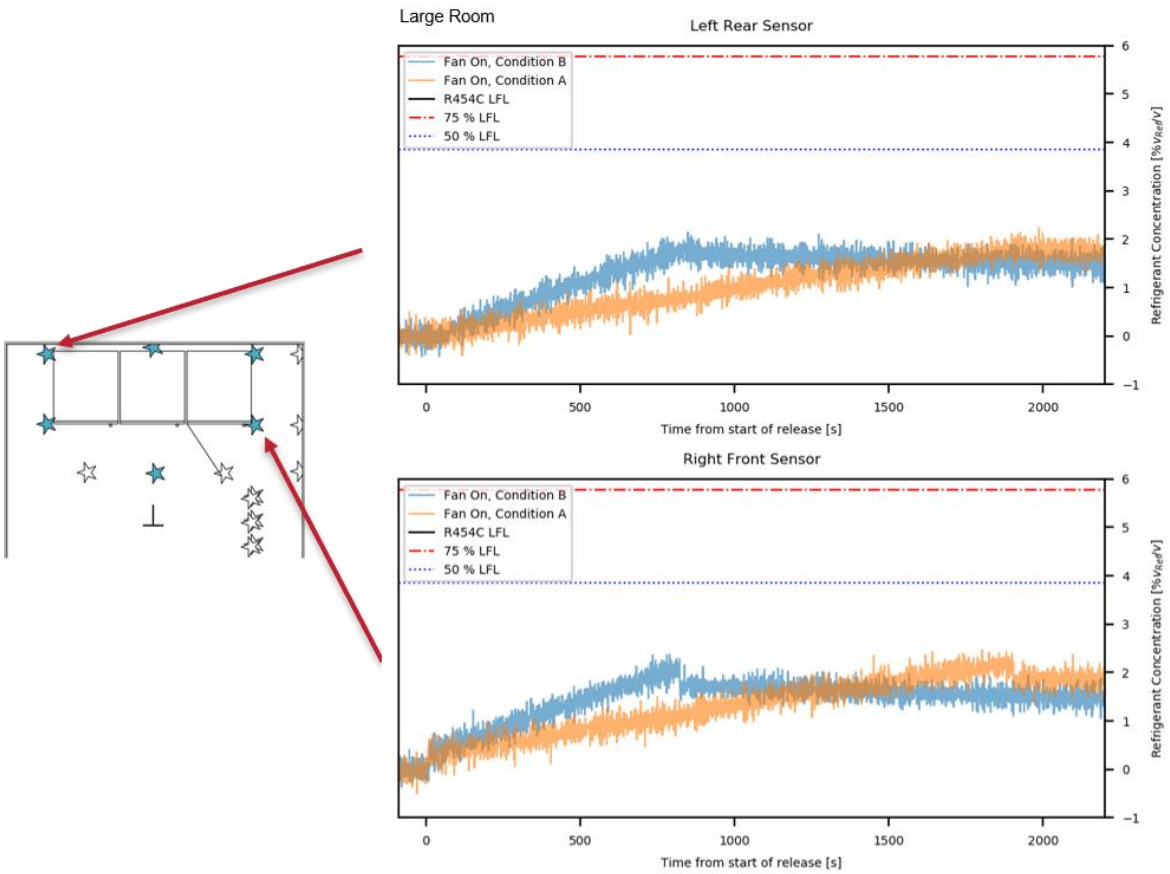


Figure 51 - R-454C Fan On, Release Rate Comparison

The release rate comparison was limited in scope and for the bottom mounted condenser there was no significant difference. There could exist a situation where a more restrictive construction or the condensing unit mounted in a different orientation could result in differences in these tests. However that was outside the scope of this study.

8 References

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A.1 Appendix

A.1.1 Deconvolution

Due to the requirement of several different refrigerants used for this testing a sensor was needed that would measure the volume fraction in free air. Because of this an oxygen sensor was employed because it would measure the displacement of atmospheric air, regardless of the gas present in the space. These were also used on previous work and it had been identified that these were durable in a laboratory setting, would not be adversely affected by the presence of fluorinated hydrocarbon refrigerants and because they were measuring oxygen directly could measure displacement of the oxygen regardless of the fluid that was present in the space. The oxygen type sensor being for this project was known to have a response delay associated due to several factors. The manufacturer’s literature states that the device had a t90 response time of 14 s, but no additional information was available about the sensor to sensor variability or the uncertainty associated with this response time. To provide relevant conclusions on the transient release events that were observed during testing there was a need to correct to the extent possible for this sensor delay. The output of one of these sensors being subjected to several different levels of gas concentration is shown in Figure 52.

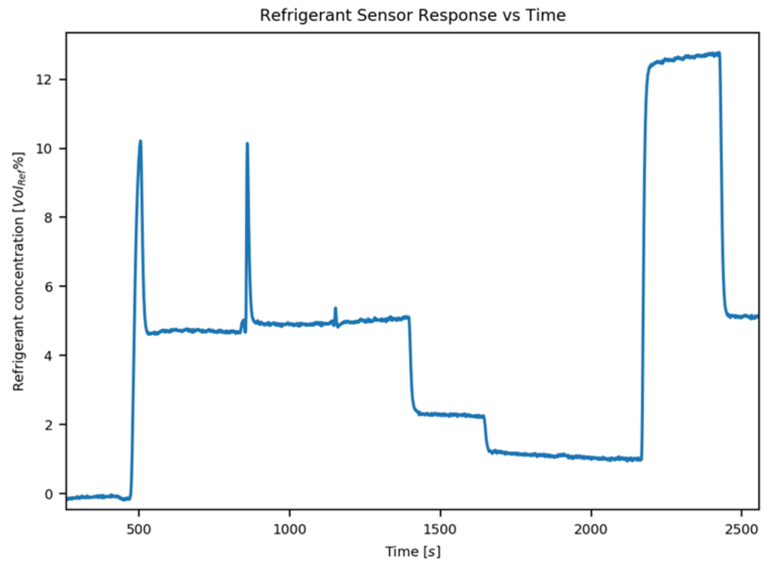


Figure 52 - Oxygen Sensor Response

The sensors were subjected to a step change to 100% refrigerant and from this data a first order exponential model for the response was fit. This model indicated that the time constant for these sensors was 16 s. It was identified that a deconvolution could be fit by looking by taking the inverse of the first order response. This provides us with the following equation for deconvolution:

$$f_{deconv}(t_{n+1}) = \frac{f(t_{n+1}) - e^{\frac{-dt}{\tau}} * f(t_n)}{1 - e^{\frac{-dt}{\tau}}}$$

The DAQ for this project was reading at 1 Sample/sec. Future review of the sensors as a faster sampling DAQ could provide more insight into a model. However when this model was applied with a time constant of 16 s to data it over fit the known step changes and resulted in events which over estimate and overshoot rising and falling concentrations. To provide the a better estimate of refrigerant concentrations during the short term events a new time constant needed to be identified which would dampen the overshoot, but still provide a better estimate than with the raw data. This project also utilized a quick responding NDIR sensor, which had a manufacturer's stated response t90 of <3 s. Several values for time constant were used in the above model and this was compared to the NDIR sensor. A time constant value of 10 s (t(90) equal to 23.0 s) was chosen for the deconvolution with the following, simplified, model:

$$f_{deconv}(t_{n+1}) = \frac{f(t_{n+1}) - 0.9048 * f(t_n)}{0.095}$$

A slower responding sensor acts to dampen some of the random noise in a measurement system. The deconvolution will amplify small measurement errors resulting an output with more noise.

Figure 53, Figure 54, Figure 55, provide a comparison of the raw data, deconvoluted data and NDIR data for some example events. The use of the deconvolution provides a better estimate of the NDIR concentrations than would be present with the raw output.

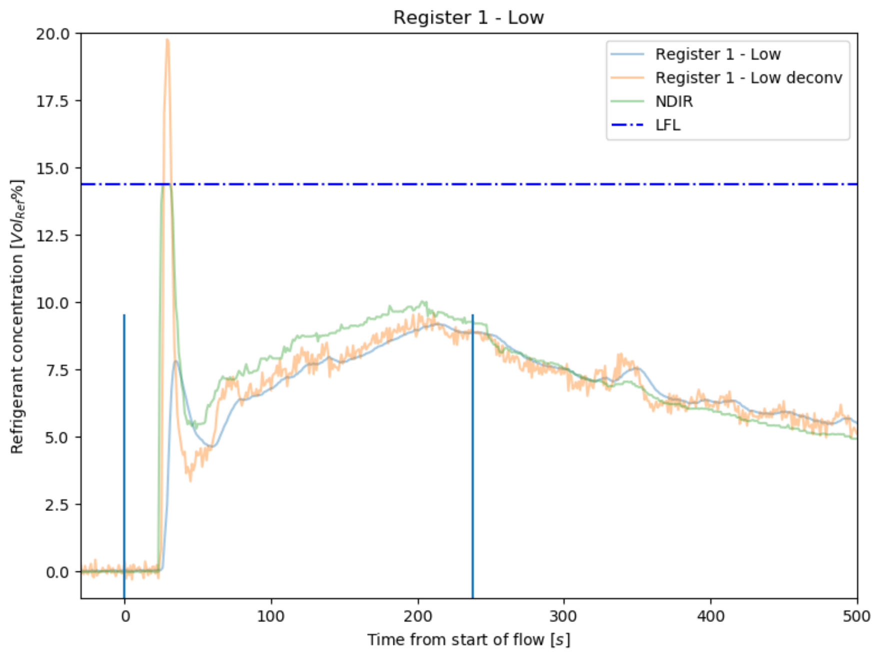


Figure 53 - Deconvolution Example 1

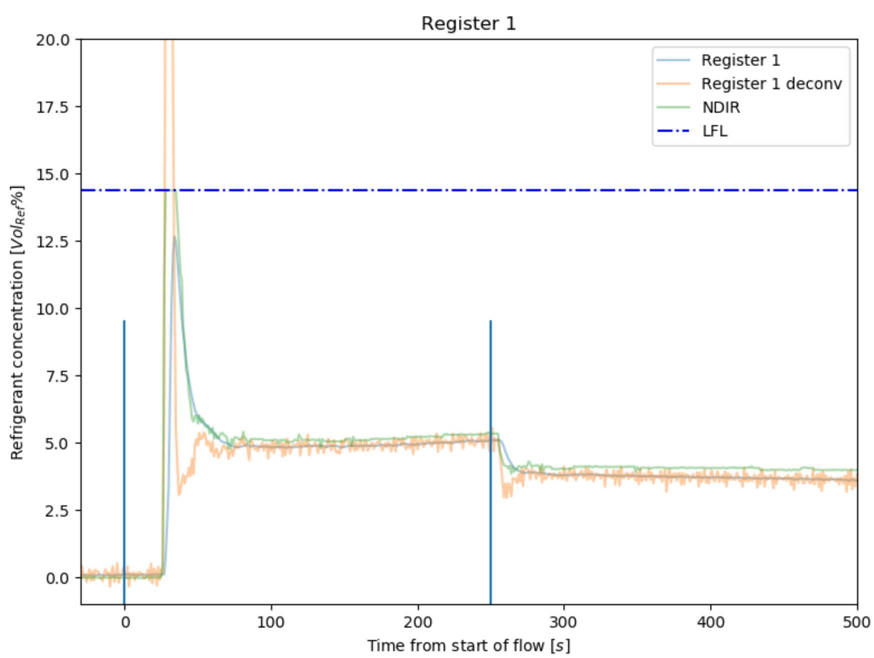


Figure 54 - Deconvolution Example 2

In Figure 54 the peak deconvoluted value was above the scale shown for this chart.

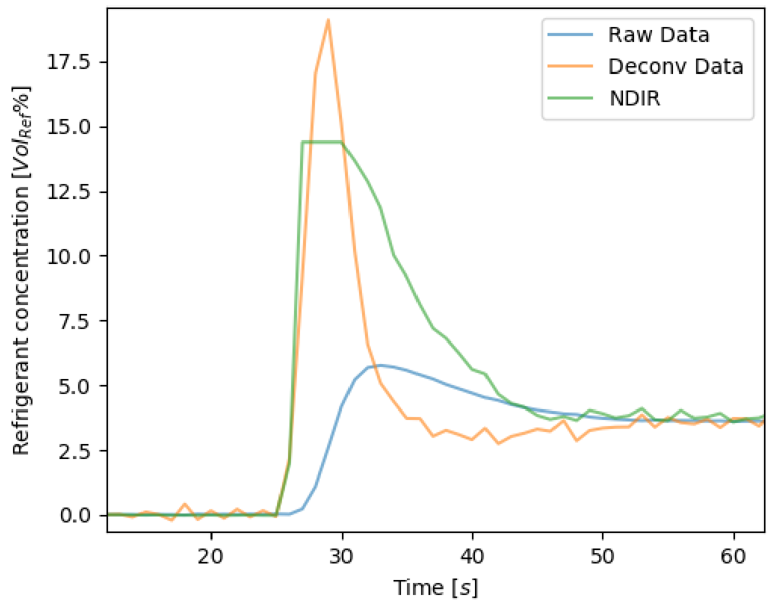


Figure 55 - Deconvolution Example 3

A.1.2 Uncertainty

Uncertainty for the oxygen sensors cannot be described using simple +/- value due to the fact that that the deconvolution method corrects for the slow response from the sensor, resulting in a greater amplitude when the sensor voltage changes quickly. The uncertainty is a function of two values: the uncertainty associated with steady state measurements (where deconvolution does not contribute significantly) and the uncertainty associated with deconvolution which becomes more significant during periods of rapid signal fluctuation.

The steady state uncertainty assumed uniform distribution for systemic uncertainty. A summary of the expanded uncertainty assumptions is detailed in Table 231. The uncertainty associated with the deconvolution has been estimated based on the measured variability of the sensor response when placed in a high refrigerant concentration vessel.

	Description	Distribution Type	Estimate ISO Type	Relative Variability
Expanded	nonlinearity of the oxygen sensor output versus oxygen concentration	Uniform	Type A	10%
	atmospheric pressure change from time of 100% refrigerant calibration point	Uniform	Type A	10%
	non-zero actual refrigerant concentration in room when re-zeroing the sensor	Uniform	Type B	20%
	resolution	Uniform	Type A	2%
	stability versus time (drift), depends on length of time since last calibration	Uniform	Type A	5%
	incorrect temperature correction due to thermal transients	Uniform	Type B	20%
	repeatability	Uniform	Type A	5%

Table 231 - Assumptions for Systemic Uncertainty

Figure 56 shows an example plot for a sensor, the green band represents the 95% confidence interval. This example plot is provided as guidance for interpreting the other data in this report. Due to readability it would be impractical to provide uncertainty bands for each of the sensors in the results section.

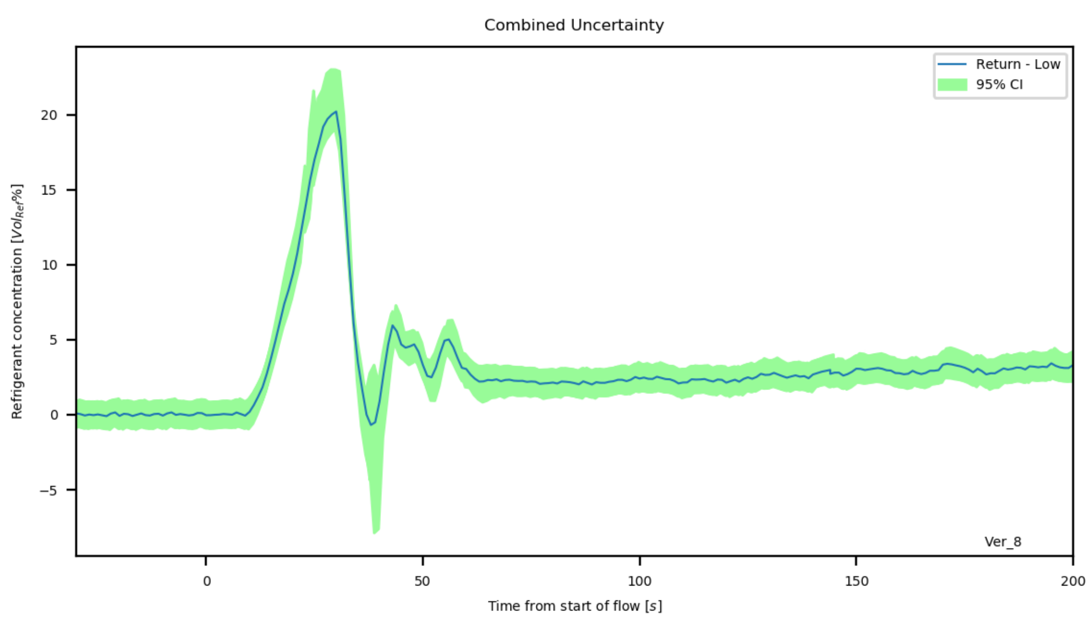


Figure 56 - Combined Uncertainty

A.1.3 Equipment List

A.1.1.1 Units under test:

Single Door Reach-in:
Delfield Model GBR1P-S

Three Door Reach-in
Hussmann Model VRL3B

Air Handler for Horizontal and Vertical Tests:
Nortek Model B6VMMX24K-B

Minisplit
Daikin FTXS24LVJU

Multisplit

Daikin FTXS09LVJU Indoor Section

Daikin 4MXL36TVJU Outdoor Section

A.1.1.2 Test Equipment:

Thermocouples

Omega 24-gauge type K thermocouples with single spot welded bead was used for monitoring temperatures on portions of the system. Thermocouple wire was ASTM E230 special limits. Extension thermocouple wire Omega type KX.

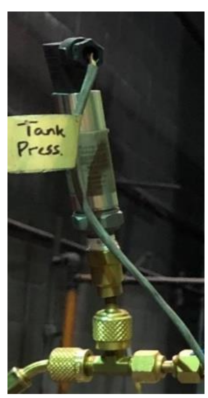
Oxygen Sensors:
Apogee Model SO-220

NDIR Refrigerant Sensor:
N.E.T. Sensor Model IFP32 with Cyber 4-20mA board with firmware to provide t90<3 s.

Metal Oxide Semiconductor (MOS) Refrigerant:
Figaro FCM2630

Mass Flow Meter
Bronkhorst Model M14 mini-Coriolis flow meter

Pressure Transducers
Transducers Direct Model TD1000CCG1000 for 0-1000 psig and Model TD1000CCG0500 for 0-500 psig.



Safety Shut Off Valves:
Gemini Valve Body Model 87-6-RTV-6 paired with a Gemini Valve Pneumatic Actuator C90BDB. Valve was configured with spring return – normally closed. Manufacturer stated cycle time of 0.5 – 1 s.

Release Valve:
US Solid Model USS-MSV00012. Manufacturer stated open/close time <5s.

A.1.4 Common plot information

In order to assist with interpreting the data presented in this report Figure 57 provides a summary of the items that are present on most all HVAC plots. Figure 58 details the layout of the plots for the refrigeration portion of this report.

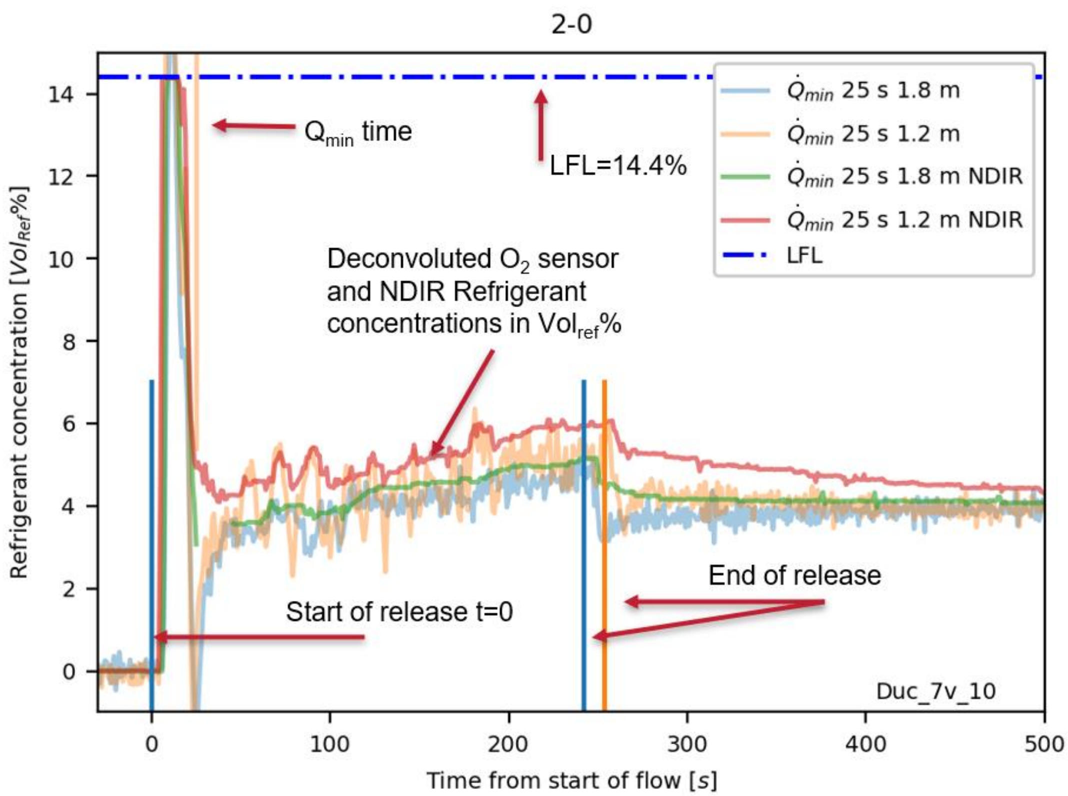


Figure 57 - Example Plot for HVAC of Refrigerant Concentration vs Time

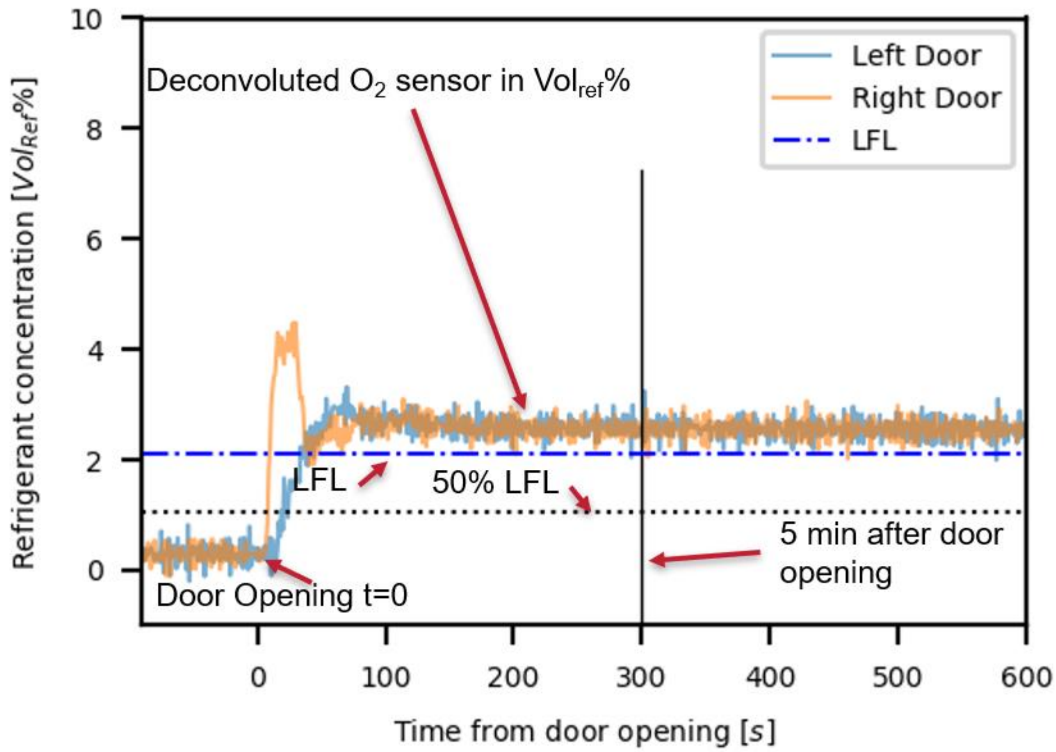


Figure 58 - Example plot for Refrigeration of Refrigerant Concentration vs Time