



Air-Conditioning, Heating and
Refrigeration Technology Institute

Final Report

AHRTI Project 9014

Refrigerant Detector Characteristics for Use in HVACR Equipment -Phase II

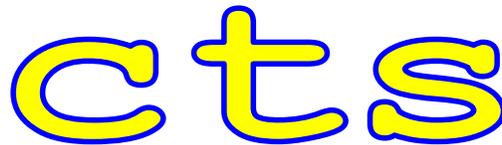
Reliability test methods for A2L refrigerant detector

Final Report

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By

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1 Introduction

For decades, great effort has been invested in the development of low GWP refrigerant solutions for the HVACR industry. Some of the alternative synthetic refrigerants have proven excellent potential to reduce the GWP without sacrificing the performance of the refrigeration system compared to the currently used family of refrigerants. Due to their mildly flammable nature, several of these alternative refrigerants fall into the A2L safety group according to the ASHRAE Standard 34¹. To use these refrigerants, refrigerant detectors are required by safety standards to mitigate the possible combustion events. As part of the safety-critical control system, it is important to assess the robustness and reliability of the detectors. Several existing standards have included methods for the sensor robustness evaluation. Some of them may include provisions that are not necessary for the application of A2L sensors to occupied spaces. Others have lists of the stresses and their test methods which are quite different from each other. Therefore, it is meaningful to review and summarize the reliability evaluation methods from the existing standards and establish a more complete list of stresses to develop the applicable test methods for the robustness and reliability of the detectors.

As the continuation of Phase 1² of AHRTI Project 9014, this Phase 2 report focuses on the development of the test methods for the assessment of the robustness and reliability of refrigerant detectors. Three existing relevant standards were reviewed, they are IEC 60079-29-1 Edition 2 (July-2016)³, JRA 4068T-2016⁴ and UL/CSA 60335-2-40 Edition 3 (Nov-2019)⁵. The requirements and the procedures for the sensor reliability assessment were summarized. Based on the different types of stressors and the test procedures, five categories of tests have been established. Table 1 lists these categories and highlights the relevant sections in these existing standards. The test procedures, test facility design, and failure metric for each category are described in Section 3 to Section 7.

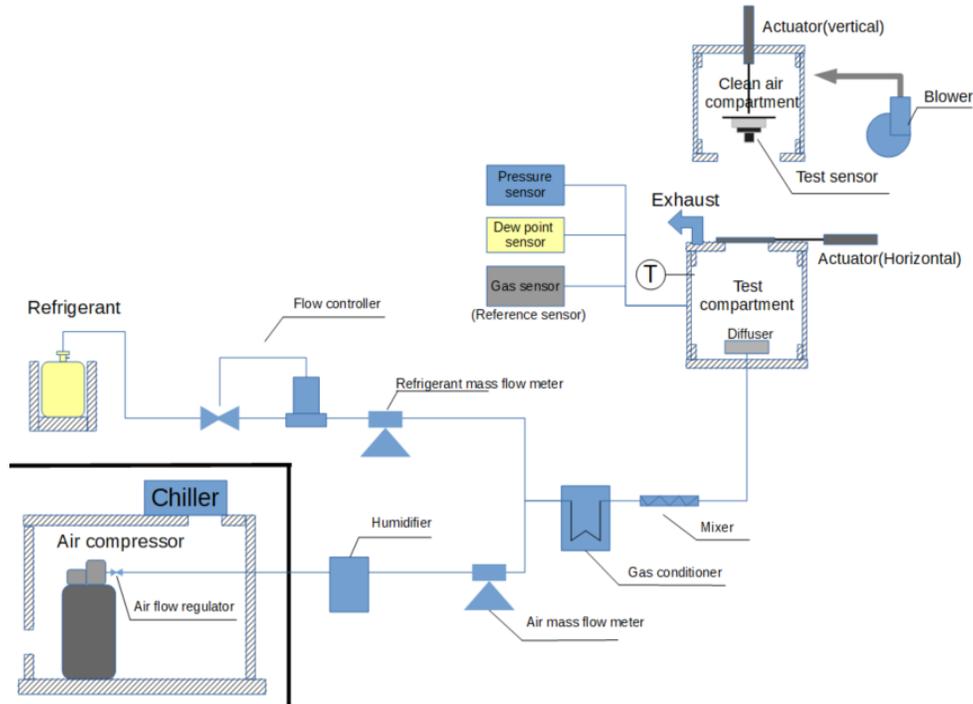
Table 1 Categories of the stress

Category A. Fluid resistance and poisoning test		
JRA 4068T-2016 ⁴	10.3 Miscellaneous gas resistance test	
	10.8 Durability test (gas resistance test and sensor durability test)	
UL 60335-2-40 ED3 ⁵	LL.5DV Selectivity test and poisoning test	
IEC 60079-29-1 ³	5.4.4.5 Long-term stability *UL 60335-2-40 ⁵ LL.4DV requires 100% refrigerant as the test gas for long-term test	
	5.4.16 High gas concentration operation above the measuring range	
Category B. Extreme storage condition test		
JRA 4068T-2016 ⁴	None	
UL 60335-2-40 ED3 ⁵	LL.1DV General (refer to IEC60079-29-1 ³)	
IEC 60079-29-1 ³	5.4.2 Unpowered storage (-25±3°C and 60±2°C for 24hours)	
Category C. Operation condition test		
JRA 4068T-2016 ⁴	10.4 Temperature test	
	10.9 Condensation resistance test	
	10.6 Power source voltage fluctuation test	
UL 60335-2-40 ED3 ⁵	LL.1DV General (refer to IEC60079-29-1 ³)	
IEC 60079-29-1 ³	5.4.6 Temperature	5.4.9 Air velocity
	5.4.7 Pressure	5.4.10 Orientation
	5.4.8 Humidity of test	5.4.18 Power supply variations
Category D. Vibration and impact		
JRA 4068T-2016 ⁴	None	
UL 60335-2-40 ED3 ⁵	LL.1DV General (refer to IEC60079-29-1 ³)	
IEC 60079-29-1 ³	5.4.12 Vibration	
	5.4.13 Drop test for portable and transportable equipment	
Category E. Repeatability test		
JRA 4068T-2016 ⁴	10.7 Stability test	
UL 60335-2-40 ED3 ⁵	LL.1DV General (refer to IEC60079-29-1 ³)	
IEC 60079-29-1 ³	5.4.4.2 Short-term stability	

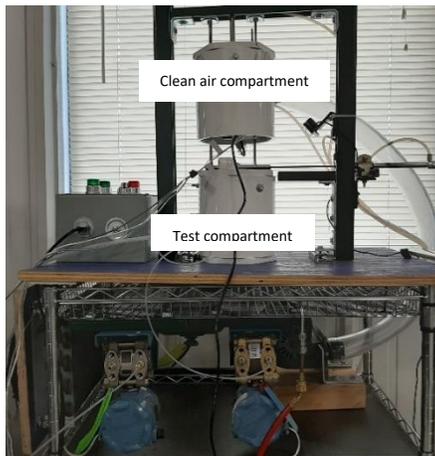
2 Sensor performance evaluation method

Depending on the durability of the sensor and the type of stresses, some sensors may instantly fail under a certain type of stress while some may show degradation in performance after exposure to stress. To uncover the effect of those stresses which cause performance degradation, comparing the sensor performance before and after exposure is a feasible approach. Therefore, a test method for the evaluation of the sensor performance is needed. Response time and accuracy are the most important parameters of sensor performance. The methods for evaluation of the sensor response time and accuracy are described below.

2.1 Sensor response time test method



A: Schematic of Push-through Facility



B: Picture of Push-through Facility



C: Test compartment dimensions

Figure 1 Schematic and picture of Push-through Facility

The sensor response time is defined as the duration between the moment when the sensor is put into the standard test gas and the moment when the sensor initiates an output signal. 25%LFL of R32 and air mixture is used as the standard test gas for this project. A Push-through test facility is recommended to be used for the sensor response time evaluation. Figure 1 shows the schematic and the picture of the Push-through Facility.

An oil-free air compressor is used to provide background gas to be mixed with refrigerant for the tests. To avoid any possible test gas recirculation, the air is taken from a conditioned enclosure outside the test room. A humidifier is installed downstream of the air compressor to adjust the air humidity to the specified range. The air stream is controlled to be at a constant mass flow and is monitored by a mass flow meter before being sent into a mixer to be mixed with refrigerant. A gas conditioner is used to adjust the test gas temperature to the temperature of the surrounding environment. For the refrigerant side, pure refrigerant is taken from a cylinder and sent through a flow controller and mass flow meter before mixing with the air in the static mixer. After mixing, the mixture is sent through the bottom of the test compartment to be used for the test. The concentration of the test gas can be calculated based on the measured mass flow rates by equation (1):

$$\text{CONC}_{\text{mfr}} = \frac{\dot{m}_{\text{ref}}/M_{\text{Ref}}}{\dot{m}_{\text{ref}}/M_{\text{Ref}} + \dot{m}_{\text{air}}/M_{\text{air}}}, \% \text{ v/v} \quad (1)$$

where \dot{m}_{ref} is the measured refrigerant mass flow rate, \dot{m}_{air} is the measured air mass flow rate, and M_{ref} and M_{air} are the molar masses of the refrigerant and the air, respectively. The concentration here is defined as the relative refrigerant concentration expressed as a volumetric fraction of refrigerant per unit of air-refrigerant mixture. A diffuser is installed in the test compartment at the outlet of the mixture to equally distribute the test gas. A thermocouple, pressure transducer, dew point sensor, and gas concentration sensor (reference sensor in the schematic) have been installed to monitor the test gas condition. A clean air compartment is installed above the test compartment. A small blower is connected to the clean air compartment that provides sufficient air to keep the exhausting test gas away from the clean air compartment. The test gas is discharged horizontally from the test compartment. The opening on the top of the test compartment, which is used for the test sample to be pushed into the test compartment, is covered by a lid to minimize the chance of the exhausting gas going into the clean air compartment during the conditioning period. A vertical linear actuator is installed in the clean air compartment that holds the test sample vertically and a horizontal actuator is connected to the lid of the test compartment. Before the test, the test sample is placed in the clean air compartment for the warm-up in clean air. After the stabilization of the test conditions, the horizontal actuator opens the lid on the test compartment and the vertical actuator is synchronized to push down the test sample to the test compartment with 0.3-0.5 seconds delay. Simultaneously, an electric signal is sent to the data acquisition system to indicate the moment for starting to measure the response time.

The test compartment should be properly sized, the gas velocity in the test compartment should be less than 0.2m/s. The test compartment dimensions shown in Figure 1C are for illustration purpose only; different dimensions may produce satisfactory results as well. The mass flow meters and the reference sensor should be calibrated separately. The test gas concentration determined by calculation using mass flow rates needs to be checked by comparing with the

reference sensor reading. The allowable deviation between these two values should be no more than 0.1%/v.

2.2 Sensor accuracy test method

Two methods may be used to perform the accuracy evaluation test: the mass flow rate method and the gas injection method. The mass flow method uses the same procedure used in the Push-through Facility as described in Section 2.1. Both the air flow rate and the refrigerant flow rate need to be accurately measured. The concentration of the test gas is determined by calculation using equation (1).

For the gas injection method, a closed vessel with a known inner volume is used as the test chamber. Figure 2 shows the schematic of the “gas injection” test setup. A closed vessel with a known inner volume is used as the test chamber. The test chamber should be leak-free and installed with an agitator to improve the uniformity of the test gas concentration. The agitator should run at a suitable speed to provide sufficient turbulence to the test gas but not significantly change the air velocity near the test sensor. A syringe or equivalent device is used to add the refrigerant to the test chamber to get a certain concentration of test gas. An airbag is connected to the test chamber to compensate for the volume change after injection and minimize the pressure change of the test chamber. The air bag should be completely deflated before injection. The test gas concentration is determined by calculation using equation (2):

$$conc_{gi} = \frac{V_{in}}{V_v + V_{in}}, \%v/v \quad (2)$$

where V_{in} is the volume of the injection gas and V_v is the inner volume of the test vessel.

Since the volume of the connection tubing needs to be included in vessel volume, determination of V_v through calibration is recommended. To calibrate the vessel volume, a reliable gas sensor with accuracy of no less than $\pm 5\%$ of reading is needed. The injection volume (V_{in}) is varied through at least 3 different points. The mixture concentrations ($conc_{gi}$) are measured after stabilization. The test vessel volume (V_v) can be obtained by solving equation (2).

The test procedures for the sensor accuracy evaluation by using gas injection method are as follows:

- a) The test chamber should be well ventilated with fresh air before the test
- b) Place the test sensor inside the test chamber and allow it to run for 15 minutes in clean air
- c) Seal the test chamber to avoid any air infiltration
- d) Calculate the injection amount of the refrigerant based on the known volume of the test chamber and the desired concentration of the test gas
- e) Use the syringe or equivalent device to add the predetermined amount of the refrigerant to the test chamber
- f) Keep the sensor exposed to the test gas and continually record the output signal until the stabilized output is obtained.

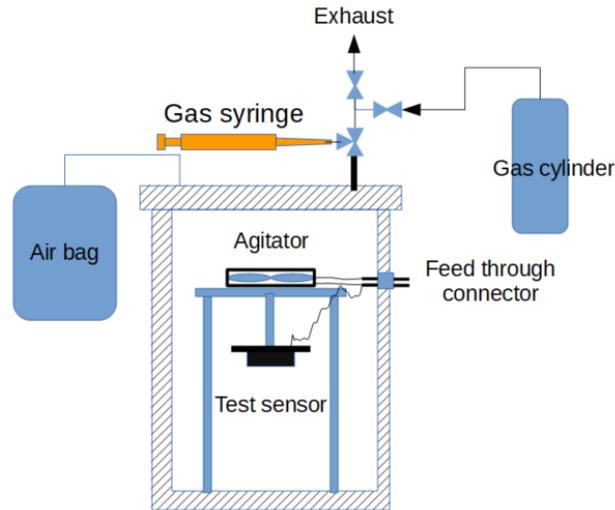


Figure 2 Gas injection test facility

The sensor output should be recorded after exposure to the test gas. The criteria for the sensor accuracy are that the sensor should not send an output signal under the lower accuracy limitation concentration and should send an output signal at the higher accuracy limitation concentration. The accuracy limitation concentrations are determined by the sensor setpoint (the threshold for activating the alarm). The lower accuracy limitation concentration is 5%LFL below the sensor setpoint, but no lower than 1%LFL. The higher accuracy limitation concentration is 5%LFL above the sensor setpoint.

3 Category A: Fluid resistance and poisoning tests

3.1 Test fluids

Three typical scenarios including operating environment, service/maintenance, and leakage have been considered for the selection of the fluids for the tests. Table 2 shows the selected fluids.

Table 2 Selected test fluids for fluid resistance and poisoning tests

No.	Scenario	Test Fluid		Concentration or Flow rate		NAAQS/EPA ⁶	JRA 4068T ⁴	UL 60335-2-40 ⁵	PMS comments ^c	
				Value	Unit					
1	Operation environment	Carbon dioxide		5000±5%	ppm v/v	●		●		
2		Carbon monoxide		35±10%		●			●	
3		Nitrogen dioxide		0.1±10%		●				
4		Sulfur dioxide		0.075±10%		●			●	
5		Ammonia		100±5%					●	●
6	Maintenance	D4, Octamethylcyclotetrasiloxane		100±5%	ml/min			●	●	
7		D5, Decamethylcyclopentasiloxane		100±5%					●	●
8		Ethanol		200±5%			●		●	
9		Acetone		200±5%					●	
10		Coil cleaner ^a (Indoor)	Ethylene glycol monobutyl ether	3-7% ^b		10±5%	ml/min			
	Alcohol, C7-21, ethoxylated		1-5% ^b							
	Sodium xylene sulphonate		1-5% ^b							
11	Leakage	Methane		500±5%	ppm v/v		●	●	●	
12		n-Butane		300±5%	ppm v/v			●		
13		Refrigerant (R32)		100±5%	%vol				●	
14				2000±5%	ppm v/v				●	
15		POE oil ^a		10±5%	ml/min				●	
16		50% Ethylene glycol water solution ^a		10±5%	ml/min				●	

a: For liquid fluid, air is recommended to be used as the driving gas; the air flow rate should be kept within the range of 5-7L/min

b: The percentage values refer to the mass fraction of coil cleaner in water

c: PMS is the abbreviation for Project Monitoring Subcommittee

3.2 Test procedure

Before exposure to the test fluids, the response time and the accuracy of the test sample should be initially checked under the standard condition. Here the standard condition is defined as a temperature of 20±5°C and humidity of 50±10%. The test method for determining the response time and the accuracy of the sensor are described in Section 2.

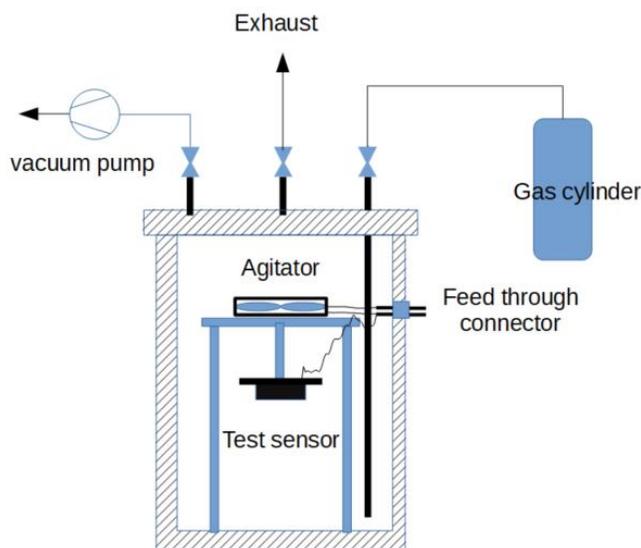


Figure 3 Modified gas injection test facility for 100% refrigerant test

After the initial performance check, the test sample should be kept in clean air with the power on for at least 15 minutes. For volatile test fluids or those in the gas-phase other than the 100% refrigerant test, the “gas injection” method described in Section 2.2 is recommended to perform the harshness test. Since the objective of these tests is to check the resistance to the test fluids, the injected gas should be one of the fluids listed in Table 2. The method for obtaining the test gas concentration is the same as for the accuracy evaluation described in Section 2.2. For the 100% refrigerant test, the gas injection facility should be set up to the configuration shown in Figure 3. The test chamber should be initially vacuumed without the test sensor installed. Next, add pure refrigerant to the vacuumed chamber until atmospheric pressure is reached, then open the exhaust valve and keep adding refrigerant to maintain the pressure in the test chamber slightly higher than atmosphere. Open the test chamber, quickly install the test sensor, re-seal the test chamber, and close the refrigerant supply and exhaust valves. The exposure time starts counting when test chamber is sealed. For liquid-phase fluids, it is recommended to use the “liquid spray” method described in Section 3.2.1.

The duration of the exposure should be no less than 2 hours when using the “gas injection” method and no less than 30 minutes when using the “liquid spray” method. The sensor output should be continually measured for the whole period of the exposure. No alarm or initiation of the output signal which is designed to activate the alarm should be observed for all of the test fluids other than 2000ppm and 100% refrigerant. After exposure, the test sample should be put into the clean air for at least 20 minutes to perform the response time and accuracy check under standard condition. The change in response time and accuracy of the test sample caused by each test fluid should be specified in the test report.

3.2.1 Liquid spray test method

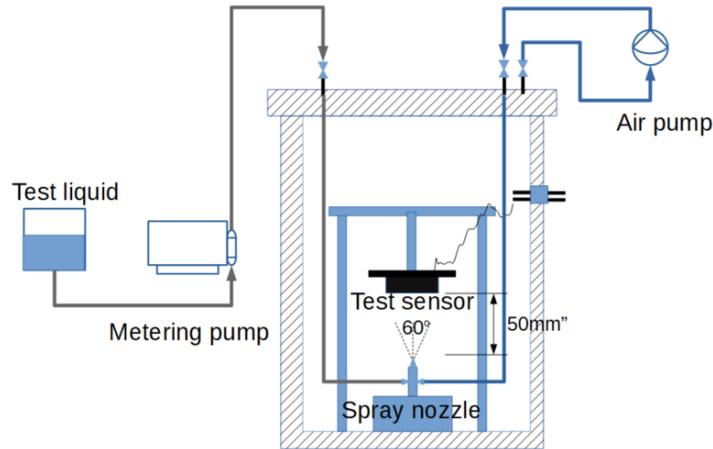


Figure 4 Liquid spray test setup

A spray method using an entrainment nozzle with air as the driving gas is recommended to ensure finely dispersed liquid droplets. Figure 4 shows a schematic of the liquid spray test setup. A metering pump is used to feed the test liquid to the spray nozzle, the liquid flow rate is measured and controlled to $10 \pm 5\%$ ml/min as listed in Table 2. Air is circulated by an air pump to generate the spray without changing the pressure of the test chamber. The air flow rate should be kept within the range of 5-7L/min. The spray nozzle should be a full cone nozzle with a spray angle of 60° . The test sensor should be installed 50mm above the nozzle tip, as shown in Figure 4. The test procedures are as following:

- The test chamber should be well ventilated with fresh air before the test
- Place the test sensor inside the test chamber and allow it to run for 15 minutes in clean air.
- The sensor should be mounted above the spray nozzle with the sensing window facing down.
- Seal the test chamber to avoid any air infiltration.
- Turn on the air pump, liquid pump, and adjust the pump speed to the desired flow rate.
- Keep the spray active for 30 minutes and continually record the output signal.

4 Category B: Extreme storage condition test

The response time and the accuracy of the test sample should be initially evaluated under the standard condition. The extreme storage condition test follows the same test procedure as described in Section 5.4.2 of IEC 60079-29-1 Edition 2.0³. The test procedure is as follows:

The test sample shall be exposed sequentially to the following conditions in clean air only:

- a) Under temperature of (-25 ± 3) °C for at least 24 h;
- b) Under ambient temperature for at least 24 h;
- c) Under temperature of (60 ± 2) °C for at least 24 h;
- d) Under ambient temperature for at least 24 h.

At each temperature, the humidity of the clean air shall be such that condensation does not occur. Alternatively, a suitable desiccator may be used to keep the test sample from exposure to condensation when under ambient temperature conditions. After exposure, check the sensor response time and the accuracy at the standard condition and specify any change in the test report.

5 Category C: Operation condition tests

Table 3 summarizes the test conditions, required test facility, and the failure metric for Category C.

Table 3 Test matrix for Category C

Stress	Test facility		Condition		Failure metric
Temperature	Push-through Facility	Environmental chamber	40±1 °C 30-70% RH		Response time and accuracy
			55±1 °C 30-70% RH*		
			-20±1 °C 30-70% RH		
			-10±1 °C 30-70% RH		
Humidity	Push-through Facility	Environmental chamber	40±1 °C 20±5%RH,		Response time and accuracy
			10±1 °C 90±5%RH		
			Condensation		
Pressure	Gas Injection Facility		73±1kPa, standard condition		Accuracy
			101±1kPa, standard condition		
Air velocity	Gas Injection Facility		Velocity	Air flow angle	Accuracy
			non-forced	0±5°	
				90±5°	
				180±5°	
			3±0.3 m/s	0±5°	
				90±5°	
				180±5°	
			6±0.6 m/s	0±5°	
				90±5°	
180±5°					
Orientation	Push-through Facility		Vertical		Response time and accuracy
			45±5°		
			Horizontal		
Power supply variation	Push-through Facility		-20%±2% of rated voltage 20%±2% of rated voltage		Response time and accuracy

*: The application of sensors for systems with furnace may require a higher temperature which has not been considered in this project phase. If any adjustment is needed, a revised version will be included with the Phase 3 report.

5.1 Method for temperature and humidity tests

The response time and the accuracy of the test sample should be initially checked under the standard condition. An environmental chamber with controlled temperature and humidity is required to perform the temperature and humidity tests. The response time and the accuracy of the sensor should be checked again under the conditions listed in Table 3 and the difference in

response time and the accuracy caused by the operating environment is to be specified in the test report.

Figure 5 schematically shows the setup of the test facility. The response time and accuracy evaluation facility (Push-through Facility) is located in an environmental chamber and isolated with a secondary box to avoid any test gas contamination of the “clean air” in the environmental chamber. The “step-change” procedure is used to evaluate the response time of the test sample as follows:

a) Sensor warm-up

The test sensor is kept in the clean air compartment of the test facility to prevent test sample contact with any test gas before the test. The clean air compartment is connected to a blower placed outside of the secondary box. The blower blows conditioned air from the environmental chamber to the clean air compartment which provides clean air and cooling (or heating) capacity to the entire secondary box as well.

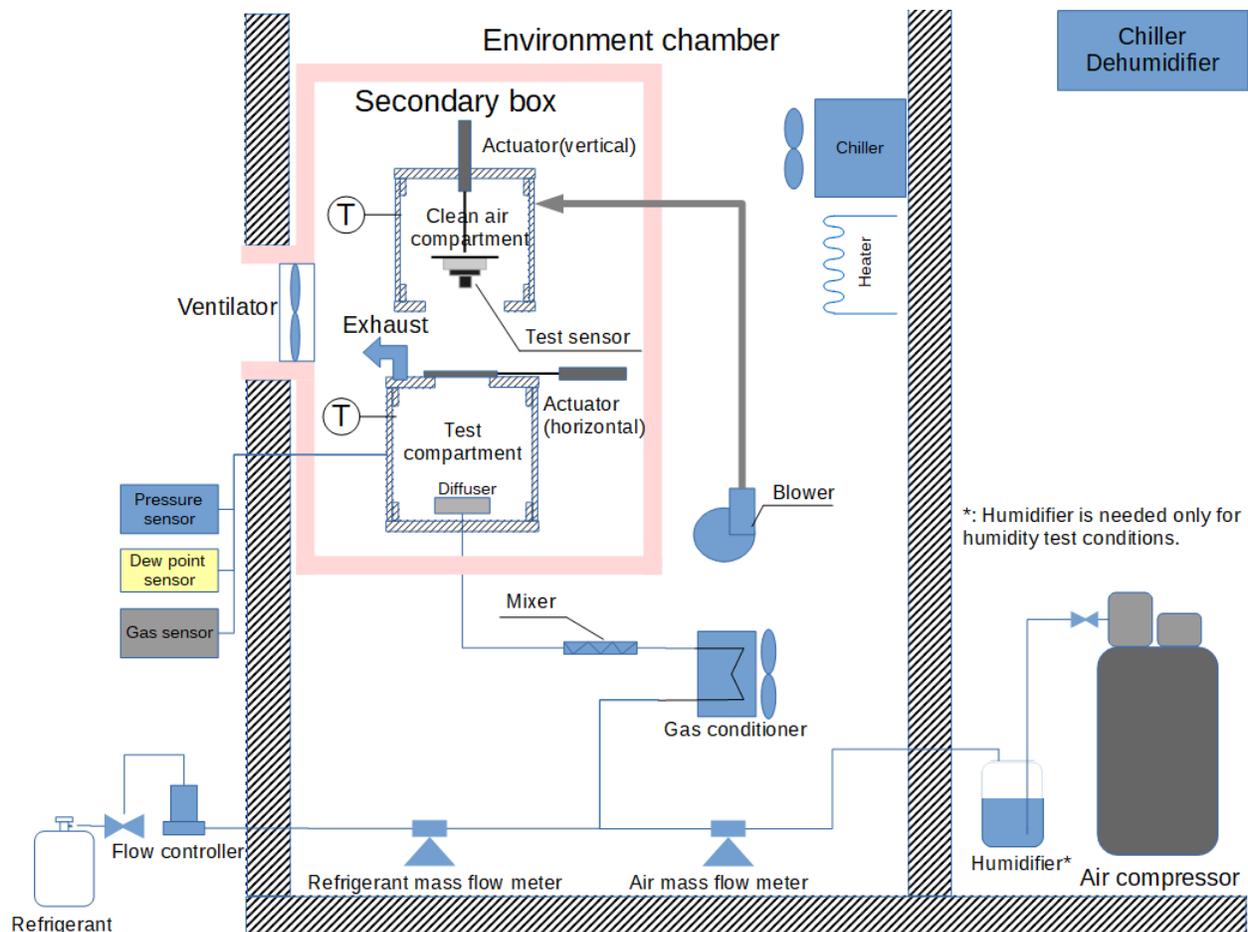


Figure 5 Chamber setup for temperature and humidity tests

b) Test gas preparation

The test gas is obtained by mixing the compressed air with the refrigerant. The compressed air is provided by an oil-less air compressor located outside the test chamber to avoid the recirculation

of the test gas. For the low-temperature condition test, the compressed air should be dehumidified before being sent to the gas conditioner to avoid frost in the air line. For the humidity test conditions, the humidity of the air stream needs to be adjusted after leaving the air compressor. The mass flow rate of the air stream is measured by a mass flow meter and kept at a constant value. The refrigerant is directly taken from a refrigerant tank, the mass flow is adjusted by a flow controller according to the desired test gas concentration, and the mass flow rate is measured by a mass flow meter as well. After mixing, the test gas is sent to a gas conditioner which is comprised of an air heat exchanger. The gas conditioner has sufficient heat transfer area to cool down (or heat up) the test gas to be very close to the environmental chamber temperature. A static mixer and a diffuser are installed downstream of the gas conditioner to improve the homogeneity of the test gas in the test compartment.

c) Push-through test

After stabilization of the test condition, push down the test sample from the clean air compartment to the test compartment to perform the “step-change” of the test gas concentration. The test procedures for determining the response time and accuracy of the test sample were described in Section 2.

The test gas continually exhausts from the test compartment to the secondary box and is vented out by a ventilating fan to the outside of the environmental chamber. The ventilating fan should have sufficient capacity to avoid the test gas leaking into the environmental chamber. The temperature, pressure, humidity, and the concentration of the test gas in the test compartment should be monitored during the test to confirm the test conditions.

5.2 Condensation test

The response time and the accuracy of the test sample should be initially evaluated under the standard condition. The procedure of the condensation test is as follows:

- a) The test sample should be kept in an isothermal chamber at $-25\pm 2^{\circ}\text{C}$ with the power on until the surface temperature reaches lower than -20°C .
- b) Place the test sample in an environment with temperature of $25\pm 5^{\circ}\text{C}$ and relative humidity of $60\pm 5\%$ until condensation occurs on the surface but no shorter than 3 minutes.
- c) Repeat the two steps described above 36 times for the test samples with the water proof level rating equal or higher than IPX3 and 1000 times for others.
- d) Remove the moisture on the sample surface, then place the test sample under the standard condition for at least 20 minutes.
- e) Run the accuracy and response time evaluation tests and specify the change before and after the condensation tests.
- f) For all the steps described above, the sensor should be installed in a manufacturer-allowed orientation which is how the sensor will be installed in the real application.

5.3 Pressure test

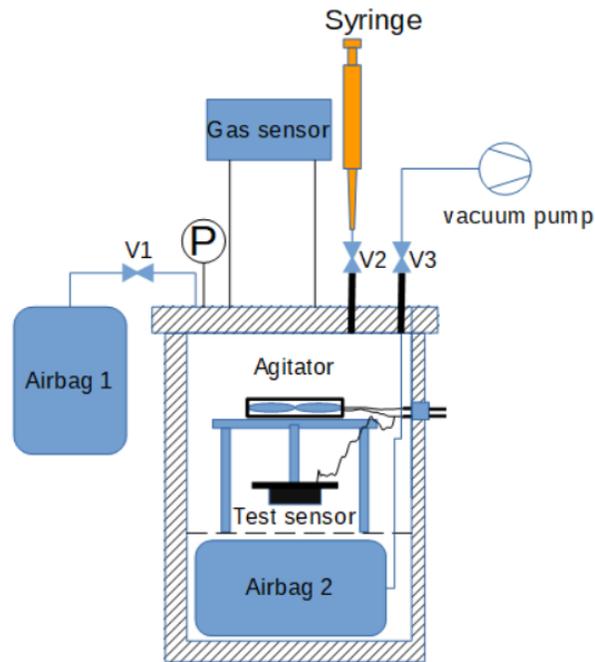


Figure 6 Pressure test setup

The objective of the pressure test is to simulate the sensor application in different elevations from sea level to 8700 ft. Therefore, the accuracy of the sensor is specified to be checked under the pressure of $101 \pm 1 \text{ kPa}$ and $73 \pm 1 \text{ kPa}$. Figure 6 shows a schematic of the pressure test setup. A closed vessel with known inner volume is used as the test chamber for the pressure test, the vessel should be leak-tight at $\pm 30 \text{ kPa}$. Similar to the gas injection method, a syringe is used to adjust the test gas concentration in the test chamber. An airbag (Airbag 1) is connected to the test chamber to compensate for the pressure change when adding the test gas. Another inflatable airbag is placed in the test chamber and connected to a vacuum pump, this airbag should be isolated from the test chamber, which means no infiltration is allowed between this airbag and the test chamber. The procedures for the low pressure ($73 \pm 1 \text{ kPa}$) test are as following:

- a) The sensor should warm up in clean air for at least 15 minutes before performing the test.
- b) Place the sensor in the test chamber with the power on, inflate Airbag 2 with air and close valve V3, keep Airbag 1 flattened, seal the test chamber, and make sure no air infiltration occurs.
- c) Calculate the volume of the test gas based on the known volume of the test chamber and the desired test gas concentration.
- d) Fill in the necessary amount of test gas through valve V2 to achieve a concentration of 70% to 80% of the lower accuracy limitation and prefill the syringe with sufficient test gas. The test concentration should be measured by a gas sensor with proven reliability at the test pressure.

- e) Close valve V1 and V2, open valve V3, and use a vacuum pump to flatten Airbag 2 to reduce the pressure of the test chamber to the target pressure then close valve V3 to keep the pressure stable.
- f) Open valve V2, add a small volume of test gas to increase the test gas concentration to the lower accuracy limitation value. The pressure change before and after adding the test gas should be less than 1kPa.
- g) Close valve V2, keep the condition for enough time to let the sensor achieve a stabilized output.
- h) Open valve V2, add the necessary amount of test gas to increase the test gas concentration to the higher accuracy limitation value. The pressure change before and after adding test gas should be less than 1kPa.
- i) Close valve V2, keep the condition for enough time to let the sensor achieve a stabilized output.

Follow the definitions of the lower and higher accuracy limitations as well as the criteria for the accuracy evaluation which were described in Section 2.

5.4 Air velocity test

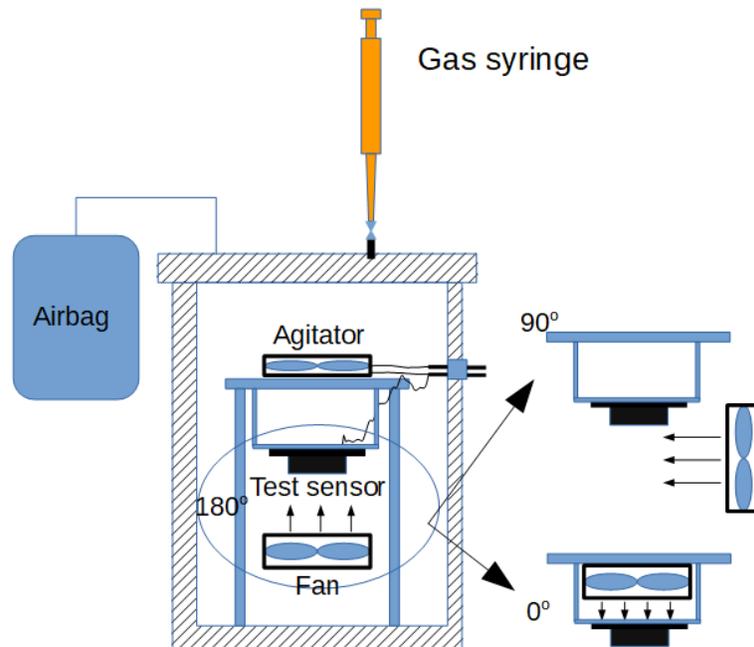


Figure 7 Air velocity test facility

Figure 7 shows the schematic of the recommended setup of the air velocity test facility. A closed vessel with known inner volume is used as the test chamber to perform the air velocity tests. An adjustable fan is used to blow the test gas from different directions with different velocities. An airbag is connected to the test chamber to compensate for the volume change after test gas injection and avoid pressure change. An agitator is recommended to improve the uniformity of

the test gas concentration in the test chamber. Three different airflow directions and three air velocities are specified to be tested. Table 4 shows the 3 x 3 test matrix.

The accuracy of the test sample shall be evaluated under each condition. The test procedure is as follows:

- a) The test chamber should be completely vented by clean air before a test.
- b) The test sample should be kept in the test chamber with power on for at least 15 minutes.
- c) Place the adjustable fan at the position for the airflow directions as shown by Figure 7.
- d) Adjust the fan speed to get the desired air velocity as listed in Table 4.
- e) Perform the accuracy evaluation test as described in Section 2, use the syringe to inject a certain amount of test gas to obtain the desired concentration.
- f) The output of the test sample should be continually recorded.

Table 4 Air velocity test conditions (3 x3)

Air direction	Air flow rate
0±5°	non-forced
90±5°	3±0.3m/s
180±5°	6±0.6m/s

5.5 Sensor orientation test

Senor orientation tests should be performed using the Push-through Facility with an additional fixture to adjust the sensor orientation. Three different orientations including vertical (sensing window face down), horizontal (sensing window facing horizontal), and 45 degrees inclined are specified to be tested. Both the response time and the accuracy shall be evaluated at different orientations using the test procedures described in Section 2.

5.6 Power supply variation test

Power supply variation tests should be performed using the Push-through Facility with an adjustable power supply to power the test sample. Both the response time and the accuracy shall be evaluated at the rated input voltage of the test sample, 20%±2% above the rated input voltage, and the 20%±2% below the rated input voltage. Follow the response time and accuracy test procedures which were described in Section 2.

6 Category D: Vibration and drop test

Before performing the vibration and drop tests, the test sample performance should be initially evaluated to obtain the response time and the accuracy as the baseline.

The vibration test follows the procedure described in Section 5.4.12 of IEC 60079-29-1³. The required vibration parameters are listed in Table 5.

Table 5 Vibration test parameters

Parameter	Requirements
Duration	For a period of at least 1 h for each direction
Direction	Three mutually perpendicular planes
Sweep rate	Change exponentially with time. The rate of change of frequency shall be one octave per minute
Frequency and intensity	<ul style="list-style-type: none"> • 10 Hz to 31.5 Hz, 0.5 mm displacement amplitude (1.0 mm peak-peak total excursion) • 31.5 Hz to 100 Hz (150 Hz for remote sensors), 19.6 m/s² acceleration amplitude

For the drop tests, the test procedure described in Section 5.4.13 of IEC 60079-29-1³ for the transportable type is recommended. The release height of the drop test depends on the mass of the sensor. For those with the mass less than 5kg, the drop height should be 0.3m and for others, the drop height is 0.2m. The test sample should be tested while not operating. Each test sample should be dropped three separate times with the normal transport direction. The test sample should be tested with the full in-field setup. If the interface board is supposed to be installed with the sensor in the detecting location the interface board should be the part of the test sample.

After performing the vibration or drop tests, the functionality of the sensor should be checked. The response time and the accuracy of the test sample are required to be evaluated again. The change in response time and accuracy shall be specified in the test report.

7 Category E: Repeatability test

Per the requirements of JRA 4068T-2016⁴ and IEC 60079-29-1³, both short-term stability and long-term stability are specified to be evaluated by checking the repeatability of the sensor response to the test gas. The Push-through test facility is to be used for both the short term and the long-term stability tests. The repeatability of the response time of the test sample shall be evaluated as follows:

For short term repeatability, the test sample shall be exposed to six applications of the standard test gas (25%LFL R32) for 3 minutes followed by exposure to clean air for 7 minutes. The sensor response time shall be recorded at each exposure to the standard test gas.

For long term repeatability, the equipment shall be operated in clean air for a period of 64 ± 0 days. Every eighth day, the equipment shall be exposed to 100% LFL refrigerant for a $480 +10/-0$ minute period. The accuracy and response time of the test sample shall be evaluated at the end of each subsequent day period.

Note: 100%LFL refrigerant is selected as the test gas for the long term repeatability test and is based on the following understanding: a refrigerant sensor is not reasonably expected to be repeatedly exposed to 100% refrigerant during the equipment lifetime (8 times for a 64 day test). This would represent a refrigerating system that lost its entire refrigerant charge 8 times due to some component failure, and after each failure the system would have to be repaired and re-charged. If that happened so many times it seems reasonable that the refrigerant sensor would be tested or diagnosed and likely replaced (i.e. not expected or required to survive). The shorter period exposure to 100% refrigerant is covered by the Category A test for fluid resistance, as it simulates a one-time event for a refrigerating system to rapidly lose the entire system charge and expose the sensor to nearly pure refrigerant for the duration of the release event and some period after the release stops.

References

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3. IEC 60335-2-40:2018, Edition 6.0. Household and similar electrical appliances – Safety – Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers. International Electrotechnical Commission, Geneva, Switzerland, January 2018.
4. JRA 4068T:2016R, Requirements of refrigerant leak detector and alarm for air conditioning and refrigeration equipment. Standard of The Japan Refrigeration and Air Conditioning Industry Association (English translation). Published 23-May-2016, amended 26-Sep-2016.
5. UL 60335-2-40: 2019, Third Edition, Standard for safety Household and Similar Electrical Appliance – Safety – Part 2-40: Particular Requirements for Electrical Heat Pumps, Air-Conditioners and Dehumidifiers. Underwriters Laboratories, Inc., Northbrook, IL, 2019.
6. National Primary and Secondary Ambient Air Quality Standards, 40 CFR Part 50. <http://https://www.law.cornell.edu/cfr/text/40/part-50>