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Increasing flammable refrigerant charge size without compromising safety

Laure Meljac[1,*], Martin Forsen[1], Daniel Colbourne[2]

[1]NIBE, Hannabadswägen 5, Markaryd 285 21, Sweden
[2] c/o HEAT GmbH, Seilerbahnweg 14, 61462 Königstein, Germany

Abstract

Propane, namely R290, is a perfect candidate to replace hydrofluorocarbon that can help the European Union reaching the 2050 target in terms of CO_2 emissions. However, wide introduction of R290 in products are effectively hindered by international safety standards that limit the allowable charge size of flammable refrigerants.
LIFE, the European Union financing instrument for the environment and climate action is financing a project aiming at establishing technical evidence demonstrating that safety is not compromised while increasing the refrigerant charge size of R290 in heat pumps provided that adapted mitigation measures are in place.
Within the LIFE FRONT project, a test procedure aiming at assessing the risk that may be induced by a heat pump using R290 in case a leak is occurring has been defined. Two water based heat pump prototypes designed to operate with R290 were then tested according to the defined procedure. The tests demonstrate that an appropriate design can ensure a safe operation of a heat pump while increasing the refrigerant charge size well above the 150g limit recommended in the safety standard.

Keywords: LIFE FRONT; heat pump; R290; standards; safety

1. LIFE FRONT project

1.1. LIFE programme

"The LIFE programme is the EU's funding instrument for the environment and climate action created in 1992. The current funding period 2014-2020 has a budget of €3.4 billion.

The LIFE programme is divided in two sub-programmes, one for environment (representing 75% of the overall financial envelope) and one for climate change (representing 25% of the envelope).

The climate action sub-programme supports projects in the areas of renewable energies, energy efficiency, farming, land use, and peatland management.

It provides action grants for best practice, pilot and demonstration projects that contribute to the reduction of greenhouse gas emissions, the implementation and development of European Union (EU) policy and law, best practices and solutions. The European Commission is particularly looking for technologies and solutions that are ready to be implemented in close-to-market conditions, at industrial or commercial scale, during the project duration."[1]

1.2. EU legislative framework

In the context of the world fight against climate change the EU ratified the Kigali agreement and committed to take appropriate measures to reduce the CO2 emissions gradually until achieving net zero emission by 2050.

Actual targets in terms of CO2 emissions are set for 2030 and are associated with several overarching pieces of legislation such as the Energy Efficiency Directive, Renewable Energy Directive and the Energy Performance of Buildings Directive…. Among the pieces of legislation published by EU, the commission regulation 517/2014 (F-GAS regulation) regulating the use of hydrofluorocarbon (HFC) fluids has a major

* Corresponding author. Tel.: +33 6 07 98 45 28

impact on the refrigeration, air conditioning and heat pump industry. Indeed, the F-GAS regulation sets the plan for the usage limitation and phase out of the HFCs having a high global warming potential.

The refrigerants commonly used in refrigeration, air conditioning and heat pump applications are HFCs having a high warming power impact (>2000 kgCO2equivalent). Thus, while restricting the use of HFC, the EU works at ensuring that technical options will be available on due time. These options should replace HFC by low global warming potential (GWP) refrigerants providing high energy efficiency and a high level of safety.

1.3. LIFE FRONT project

LIFE FRONT project constitutes one of the EU initiative to facilitate the switch to low GWP refrigerant in refrigeration, air conditioning and heat pump. Indeed, most of the suitable refrigerants for replacing the commonly used HFC are flammable. However, the EU and international standards, which main concern is safety, set strong restrictions on the use of flammable refrigerants, making it very difficult to introduce appliances using flammable refrigerants on the EU market.

"The LIFE FRONT project aims to remove "barriers posed by standards" for flammable refrigerants in refrigeration, air conditioning and heat pump applications. It strives to improve system design to address flammability risk and encourage thereby wider uptake of climate-friendly alternatives to fluorinated gases."[2]

The LIFE FRONT project gathers several partners: Shecco, HEAT, ECOS, AHT, AIT-Deutschland and NIBE.

AHT, AIT and NIBE are industrial companies, manufacturing RACHP appliances, some of which has been using R290 for years. These companies have a long experience in using R290 and will to share their experience to help overcome the existing limitation for flammable refrigerant usage.

AHT mainly produces commercial refrigerating cabinets. AIT and NIBE are manufacturers of water based heat pumps: air to water, ground source heat pump and exhaust air heat pumps.

1.4. Project objectives

The LIFE FRONT work programme is divided in several steps including;

- Review of existing flammable refrigerant standards and literature review on refrigeration, air conditioning and heat pump safety in relation with flammable refrigerant
- Field survey addressing type and cause of refrigerant leakages including leak hole size and leak flowrate
- Equipment design with improved safety

The outcomes from these steps will serve as a basis for drafting proposed requirements for the standards on flammable refrigerants (such as IEC 60335-2-40:2018). The standard and literature review reports are publicly available on the LIFE FRONT project website http://lifefront.eu.

This paper is more focusing on the third step of the project consisting in building and testing prototypes of heat pumps, specifically designed to operate with R290.

2. Barriers to usage of flammable refrigerants

Barriers to the usage of flammable refrigerants are present in standards and sometimes in national regulation within the EU. Barriers coming from standards can be easily identified whereas it is difficult to get a clear picture of the barriers posed by national regulation. This work only focusses on standard barriers.

Refrigeration, air conditioning and heat pump equipment are covered by safety standards of two kinds: product standards and group standards. The product standards are specific for a type of product whereas group standards cover a broad spectrum of systems and equipment in a generic manner.

Compliancy to safety standards does not necessarily constitute a legal requirement, however, compliancy to product or group safety standards often ensure conformity to the applicable EU legislation and CE marking in particular. Thus, in practice, requirements of safety standards are strictly followed by the industry and shape the products being placed in the EU market.

The existing safety standards related to refrigeration, air conditioning and heat pump equipment are listed in the table below:

Table 1. refrigeration, air conditioning and heat pump safety standards

Standard type	Group		Product		
Standard	ISO 5149	EN 378	EN/IEC 60335-2-24	EN/IEC 60335-2-40	EN/IEC 60335-2-89
Domestic refrigeration			x		
Commercial refrigeration	x	x			x
Industrial systems	x	x			
Transport refrigeration	x	x			
Heat pumps, air conditioners and chillers	x	x		x	

IEC 60335-2-89 has recently been revised and maximum A3 flammable refrigerant charge increased from 150g to approximatively 500g of R290 (13xLFL, Lower Flammability Limit) without adding specific requirements on the product design. As a result the practical cooling capacity of refrigerating circuit using A3 flammable refrigerant has been increased significantly.

In IEC 60335-2-40, the maximum A3 flammable refrigerant charge size depends on the location of the equipment. Maximum refrigerant charge for equipment located outdoors (approximatively 5kg of A3 flammable refrigerant) is enough to provide heating capacity suitable for the EU heating demand in single household dwellings. Maximum refrigerant charge size for refrigeration circuits located in an occupied space indoor depends on the surface area of the room where the equipment is installed and the height at which the part of the equipment containing the refrigerant circuit is positioned.

For heat pumps, in particular ground source and air to water heat pumps, having floor installation, the charge size cannot exceed 150g of R290 unless the room size exceed $35m^2$. As a consequence, ground source or air to water heat pumps designed to be installed indoor cannot use a flammable refrigerant as the provided heating capacity will not fit the usual heat demand of a single dwelling apartment or house in the EU. There is an option defined in the standard to use a so-called “ventilated enclosure” where the charge limit is about 5 kg of A3 refrigerant (irrespective of floor area) but this option is not applicable to air to water or ground source heat pumps.

The requirement on the room size set in the safety standard has been theoretically established to prevent an explosive atmosphere under the assumption of a leak flowrate corresponding to the complete refrigerant charge being released in 4 minutes.

This assumption does not leave any scope for innovation nor option for protective measures that could effectively prevent formation of a flammable mixture using other means and thus ensure that the equipment can operate without compromising safety.

3. Experimental work

3.1. General approach

As of today, according to EN/IEC 60335-2-40, whatever is the heat pump design, with the exception of ventilated enclosure, the maximum charge size of flammable refrigerant cannot exceed 150g if the room where the product is installed does not exceed the minimum floor area. Thus, the safety standard is widely considered a barrier to innovation as it does not allow the manufacturer to develop systems using flammable refrigerant. Similarly, it is not possible to implement appropriate design or mitigation measures that can ensure that flammable atmosphere can be avoided irrespective of the refrigerant charge size.

Within the LIFE FRONT project it is intended to develop a robust test methodology that permits to evaluate whether a product using flammable refrigerant can operate without compromising safety whatever the charge size and the room surface area.

It is the intention to demonstrate that an obligation of providing evidence that a refrigerant leakage under a certain flowrate will not increase the concentration of flammable substances above a certain level could well replace the charge limits.

One part of the LIFE FRONT project work is based on experiments simulating R290 leakages occurring from indoor heat pumps whereby measuring R290 concentrations at the product surrounding. Before performing such tests, two questions demand an answer: what is a valuable criteria while assessing that an equipment does not compromise safety in regards to refrigerant charge size and which leak flowrates can be representative of leakages occurring in refrigeration, air conditioning and heat pump systems?

3.2. Definition of a "tolerable risk level"

Within the LIFE FRONT project, it was needed to define a "tolerable risk level" that needs to be achieved by a heat pump in regards to the use of flammable refrigerant. It was decided that a heat pump reaches this "tolerable risk level" if, in the event of a complete loss of the refrigerant charge, the R290 concentration surrounding the heat pump does not exceed 50% of the lower flammability limit (LFL). In addition, would one or several heat pump parts contain a potential ignition source, and if the components are under Ex-type standards, R290 concentration in the concerned areas shall not exceed 50% of LFL.

Note that, these criteria permit to assess whether a product reaches a "tolerable risk level" at its design phase. The assessment of the heat pump risk level presented in this report does not encompass a risk analysis of the heat pump that covers its complete life cycle including manufacturing, installation, maintenance and dismantling.

Note that the risk associated with the heat pump should be considered in light of the background fire risk arising with electric heat pumps, irrespective of the refrigerants used. Whilst such data is not readily available, that for other refrigerating systems (such as domestic refrigerators and air conditioners) is public. This data infers the additional risk from flammable refrigerant should be less than 1 per 100,000 units per year [4].

3.3. Leak cause analysis and associated leak flowrate

Before starting the experimental test, it was needed to assess what could be a reasonable basic assumption for the refrigerant leak flowrate.

To answer that question, a thorough analysis of the leak causes has been performed. The analysis is based on decades of experience of the project partners in manufacturing heat pumps and are based on the feedback and records from the field and after sales and quality departments. As industrial project partners manufacture hermetically sealed equipment that do not need any refrigerant piping work at installation, the leak causes that may affect the piping work done on site are not shown in table 2.

In parallel of the leak causes analysis, hundreds of leaking parts coming from refrigeration, air conditioning and heat pump equipment installed in the field were collected and analyzed by the project partner HEAT. The data has been stored in a database (http://lifefront.eu/databases). For each leak, the leak cause, leak hole size and leak flowrate are detailed so that it is possible:

- To highlight what is the typical leak flowrate occurring in the field
- To correlate leak flowrate and leak cause

The inputs that came out from both the analysis and the data collection are depicted in the table below. Every leak hole and leak flowrate shown in the table come from field measurements; some of them come from the LIFE FRONT project database and some other from the industrial partners own data bank.

Table 2. leak causes and associated leak flowrate

Component	**Cause of leakage**	**Leak features**		**Associated risk**	**Existing mitigation measures in IEC 60335-2-89 and IEC 60335-2-40 Note that the latest version of the IEC standards have not yet be approved by the EU**
		Hole size	**Flowrate**		
Fins and tubs heat exchanger	Any type of corrosion: galvanic, microbiological…	Small hole: 1 to 100 µm	Small : 1-2 g/day	None	No need for mitigation measures
Air to water heat exchanger (plate, co-axial…)	Crack du to frost of the heat exchanger	Large: more than 1mm²	Catastrophic: 88g/min	Refrigerant is flowing on the hydraulic system and can be ignited when hydraulic system will be vented	Disconnexion of hydraulic system from refrigerant circuit or refrigerant vented outside in case the leak occur: IEC/EN 60335-2-40/A1 section GG.6

	Electrical short circuit with copper pipes	Large: more than 1mm²	Catastrophic: 88g/min	Hole is created on the pipe and refrigerant is ignited by the electrical arc: Fire or explosion	No electrical cable shall be installed close to a refrigerant pipes. For cables installed on site, cable passway shall be clearly marked. Revision IEC 60335-2-40:20xx (not published yet)
Brazing and pipes located in the heat pump enclosure	Defective bending	0,17mm²	22g/min	Risk of fire in case of ignition source	•
	Fatigue rupture due to vibration	0,17mm²	22g/min	Risk of fire in case of ignition source	Mitigation measures given in IEC60335-2-89: 2019: vibration test, section 22.108
	Defective brazing	0,7mm²	Catastrophic 65g/min	Risk of fire in case of ignition source	•
	Fritting, repetitive rubbing of surface	<0,1mm²	<3g/min	Risk of fire in case of accumulation and ignition source	•
	Icing of pipes	0,17mm²	22g/min	Risk of fire in case of ignition source	•
Other components	Schrader valve; expansion valve, 4 way valves, pressure sensor….	Small hole	Low flowrate <3g/year	None	•

One can observe that some of the causes for leakages may be eliminated already at design phase by appropriate mitigation measures, already defined in the existing or upcoming standards. However, adapted design requirements cannot prevent any leak from occurring as equipment material can be altered over time in an unpredictable manner.

Based on these analysis, two heat pump prototypes were tested: one packaged air to water heat pump and one ground source heat pump, both heat pump prototypes designed to be installed indoor. The above table highlights that 88g/min is the maximum flowrate that has been identified. However, this leak flowrate has only been observed in the case of a hole created by an electric short circuit. Considering that this leak cause can be avoided by design, the first test done was based on the maximum flowrate of 65g/min which corresponds to a defective bending. For the second test, it was decided to assess the efficiency of the proposed testing method with a flowrate equal to the maximum: 88g/min (rounded to 100g/min for the sake of simplification).

The objectives of the tests are:

- to define a proper test protocol that is appropriate to evaluate whether an equipment design permits a usage of a flammable refrigerant at a tolerable risk.
- to demonstrate that adapted mitigation measures can be implemented to prevent the refrigerant concentration surrounding the heat pump from exceeding 50% of the LFL in case a leak is occurring.

It is essential to adopt a reasonable leak hole size and associated flowrate. If a too small hole is used then it is likely that the implemented protective measures will be insufficient to mitigate the hazard arising from all leaks. If a too large hole is used then the protective measures would be unnecessarily over-designed.

3.4. Test method

3.4.1. General features

The test method described in this section has been finalised after the tests were performed as experience was gained throughout the tests. Thus, the tests performed over the LIFE FRONT project do not strictly follow the described test method.

3.4.1.1. Test space and arrangement

The appliance to be tested shall be positioned within a test room. The room height shall be no less than 2.2m. The room shall be “tight”. The appliance shall be installed at a height and location as prescribed by the instructions manual, selected to yield the least favourable result.

3.4.1.2. Gas sensors number and positioning

Sampling points to measure gas concentration shall be positioned around the heat pump, no more than 30mm above floor level. There shall be one sampling point at a distance of no more than 0.5m from each exposed side of the heat pump. **오류! 참조 원본을 찾을 수 없습니다.** 1 shows a possible arrangement of the sampling points. The gas sensors shall be suitable for the gas to be detected and under calibration control.

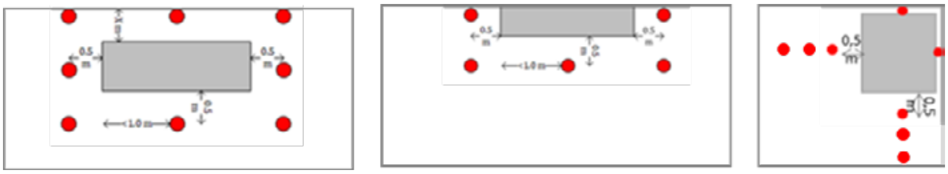

Fig 1. Possible test room set up and positioning of the sampling points; plan view showing the RACHP equipment (grey block) and floor level sensors (red dots)

Note that the gas sensor positioning is only valid where refrigerant density is higher than air density.

3.4.1.3. Leak generation and location

A simulated leak shall be made at the most unfavourable positions on refrigerant containing parts. Several locations might be chosen to be representative or to determine the least favourable one. The jet direction which leads to the highest concentration shall be chosen.

The refrigerant is released through an orifice in vapour phase at a pressure of at least 2bar (gauge), or whatever is necessary for choked flow.

3.4.1.4. Leak flowrates and released mass

Two mass flowrates shall be used: 10g/min and 100g/min. It might be interesting to test an additional intermediate flowrate, 45g/min, to get the concentration developing trend around the product.

The mass released is the refrigerant charge.

3.4.1.5. Test procedure

The tightness of the test room shall be assessed prior any test on the heat pump is performed. Sufficient tightness is demonstrated by a mass of refrigerant equating to about 50% of LFL being released into the room and mixed using a circulating fan. The average concentration at six sampling points throughout the room shall be within ±5% of the arithmetic mean and the mean value shall not decline by more than 5% within a five-minute duration.

For each flowrate and leak location, the refrigerant charge shall be released. The test shall be repeated no fewer than three times at each flowrate and leak location. The heat pump shall be switched off during the test, only the devices that are in operation at all time (fan….) might be operating

3.4.1.6. Recorded data

Measurements of gas concentration shall be recorded at time increments of no more than 5 seconds apart from the time at which the release begins and until the concentration at all sampling points declines for at least three minutes.

3.4.1.7. Criteria

None of the refrigerant concentration detected by the gas sensors surrounding heat pump shall be greater than 50% of LFL. In case gas sensors are installed within the heat pump enclosure, none of them shall detect a gas concentration higher than 50% of LFL.

3.4.1.8. Specific arrangements used for the LIFE FRONT tests

For the tests performed over the project, an enclosure of a size, 3m x 2m x 2.5m height, intended to mimic a typical utility room is built and serves as test room.

R290 is supplied to the leak positions from a cylinder fed into the enclosure via refrigerant hoses **오류! 참조 원본을 찾을 수 없습니다.**. The hose terminates with a 1mm (0.8mm2) diameter orifice fitting in order to ensure choked flow. The mass flowrate and total released mass is modulated with a mass flow controller, calibrated for R290.

To assess the tightness of the enclosure mimicking the utility room, 400g of R290 were released in the enclosure. The air in the enclosure was mixed using a circulating fan. The R290 concentration was then recorded during 30 minutes. Over these 30 minutes, the R290 concentration remained stable, it was concluded that the enclosure that sufficiently tight for the purpose of the tests to be performed.

R290 sensors are used to measure R290 concentration. Some of them are aspired sensors and others are positioned on a gas stand and are diffusion operated.

While tests are on-going it may happen that R290 concentration gets so high that the R290 sensors get saturated; in that event, the gas sensors are disconnected to avoid poisoning them. This is the reason why in the charts shown in the following clauses some curves are interrupted. In order to highlight the impact of the specific heat pump design on the tolerable risk level, the first test was performed on a heat pump designed to operate with a non-flammable refrigerant such as R410A or R407C.

Each performed test starts with a clean room: no R290 neither in the mock utility room nor in the heat pump enclosure. R290 is then released and the test stops after the defined R290 mass has been released. After each test, the R290 is evacuated from the testing enclosure and from the heat pump. The following test starts when the R290 sensors do not detect any R290.

3.4.2. Ground source heat pump prototype

A ground source to water heat pump prototype has been specifically designed to be used with R290. Ground source heat pumps are generally designed to be installed indoor, in a garage or a utility room. The prototype has been tested at NIBE AB facilities at Markaryd, Sweden with the support of HEAT. During the tests, the heat pump has not been in operation.

3.4.2.1. Installation

Three zones, represented on figure 2, are defined as:

- zone A: upper part of the heat pump contains the hydronic components, immersion heater, power supply and all electrical components,
- zone B contains the refrigerating circuit,
- zone C represents the heat pump surrounding. Zone A and zone C represent the zones were R290 concentration shall not exceed 50% of LFL (components in zone A do not comply with ATEX legislation). The red dots represent the gas sensors.

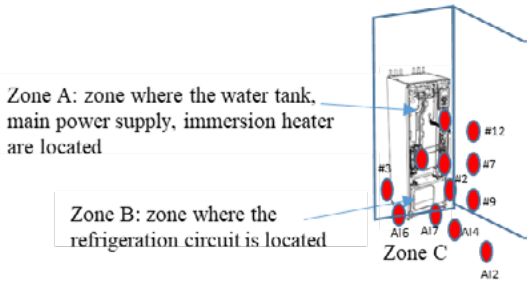

Fig 2. Rough sketch (red dots indicate gas sampling points) and picture of test arrangement on the right side

3.4.2.2. Selection of release locations

The refrigerant is contained in zone B. The leak hose is placed at the centre of zone B. For assessing whether R290 could get into zone A, the leak orifice was oriented first toward the top of zone B. Then, the leak orifice was oriented towards the side panel of zone B against the wall of the room.

3.4.2.3. Selection of flowrates and mass of R290 to be released

Two mass flowrates were selected. The two mass flow considered are: 20g/min and 100g/min. 88g/min is the highest leak flowrate observed according leak the cause analysis, for this test, it was decided to evaluate what will happen in case this catastrophic leak occur (88g/min was rounded to 100g/min).
800g of R290 was released at each test. After the 800g were released, the R290 concentration continued logging for several more minutes.

3.4.2.4. Test conditions

Table 3. test condition for ground source heat pump

Test no.	Release mass flow rate [g/min]	Release location	Orifice height [m]	Released quantity [g]
Tests performed on a ground source heat pump designed for R407C				
1	100	Oriented towards zone A	0.3	400
Tests performed on a ground source heat pump designed for R290				
2	100	Oriented towards zone A	0.3	800
3	100	Centre	0.3	800
4	20	Centre	0.3	800

3.4.2.5. Test results

In the following charts, the doted blue line represents 50% of LFL.

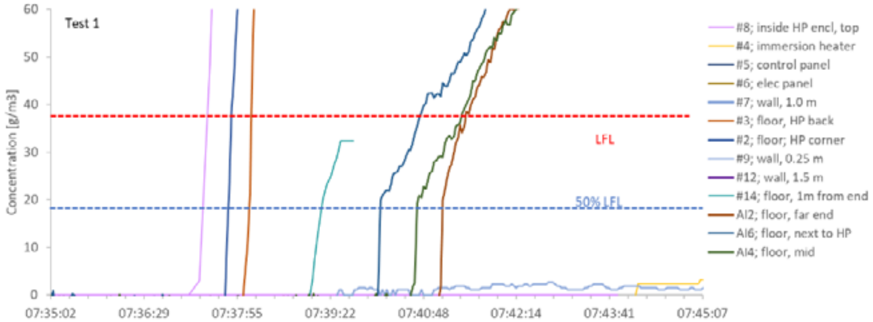

Fig 3. results of test 1 performed on ground source heat pump designed for R407C - 100g/min

For this first test, one sensor was positioned within part B, in the refrigeration enclosure. R290 release starts at 7:36 and ends at 7:40. Only 400g were released. 50% of the LFL is reached everywhere in the room at floor level. One can notice that as there is no ventilation in the room, R290 stagnates at floor level and the concentration remains lower than 50% of LFL at 0.25m height whereas no R290 is detected by the sensors positioned at 1m and 1.5m.

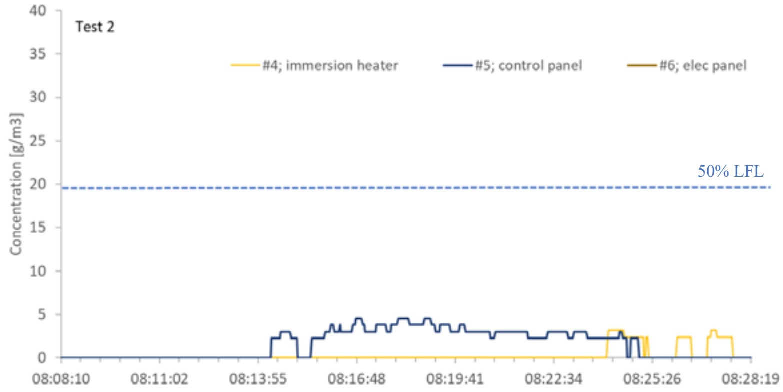

Fig 4. results of test 2 performed on the ground source heat pump prototype designed for R290 – 100g/min

R290 release starts at 8:10 and stops at 8:18. R290 concentration remains far below 50% LFL on zone A. No R290 is detected in the electrical panel where the relays are located.

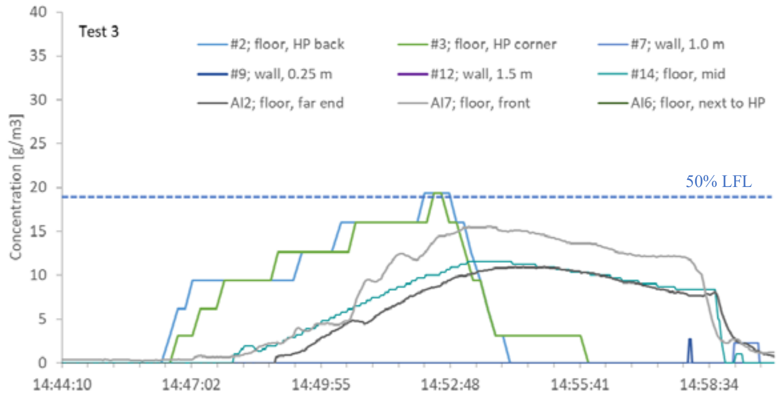

Fig 5. results of test 2 performed on the ground source heat pump prototype designed for R290 – 100g/min

R290 is released at 14:44. The 800g are released after 8 minutes. R290 concentration increases first at the side of the heat pump which is by the wall as well as at the back. Then, the R290 is propagating into the room.

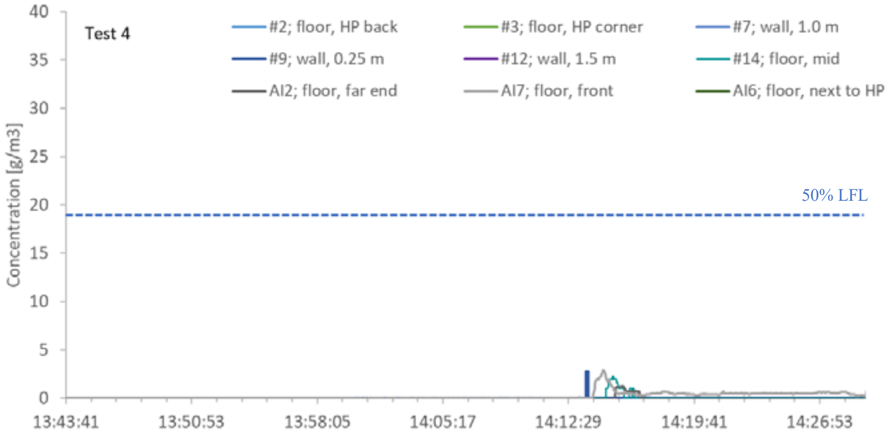

Fig 6. Results of test 3 performed on the ground source heat pump prototype designed for R290 – 20g/min

R290 release starts at 13:43 and ends at 14:23. R290 concentration remains far below 50% of LFL.

From the three tests performed, one can conclude that R290 is not penetrating zone A, where potential ignition sources could be found. The tests also demonstrate that in case there is no air movement in the room, R290 stagnate at floor level. Finally, the test demonstrates that the ground source heat pump design is efficient in preventing the creation of an explosive atmosphere around the heat pump either in the event of a catastrophic leak is occurring in the refrigerating circuit or in the event of a small leak is occurring.

3.4.6. Indoor packaged air to water heat pump prototype

An indoor packaged air to water heat pump prototype has been specifically designed for operating with R290. This prototype has been tested at the AIT technology centre in Kasendorf, Germany with the support of HEAT.

During all tests, the heat pump is not in operation, the compressor and the fan are always off. Generally the heat from the compressor will create convection currents which helps to disperse any releases, the test conditions are thus conservative.

3.4.6.1. Installation

The heat pump consists of three zones: the hydronic unit, which contains the hydraulic and electrical components, the condensing enclosure that contains the refrigerating circuit except evaporator, and the evaporating enclosure that contains the evaporator, the fan and the ducts. Heat pump surrounding, namely zone C, represents the zone where the R290 concentration shall not exceed 50% of the LFL. The red dots on **오류! 참조 원본을 찾을 수 없습니다.**7 represent the R290 sensors, the orange arrows represent the location where R290 is released.

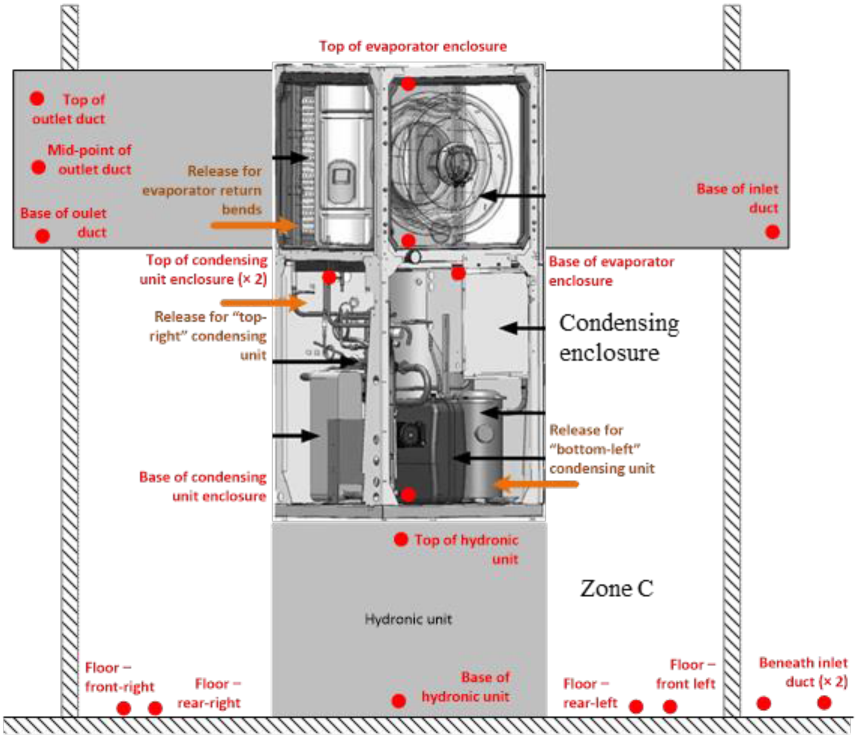

Fig 7. Rough sketch of test arrangement: red dots indicate sampling points and orange arrows are release positions

3.4.6.2. Selection of release locations

Three R290 release locations were defined as being the most unfavourable locations for a leak to occur: one in the evaporator enclosure and two in the condensing enclosure: one on top and one at the bottom.

All releases involved a jet at choked flow conditions, directed horizontally, to impinge against a nearby surface in order to remove momentum from the jet and thus to minimise mixing.

3.4.6.3. Selection of flowrates and mass of R290 to be released

The three mass flowrates considered were: 20g/min, 45g/min and 65g/min. 20g/min corresponds to the leak flowrate that might be obtained in case of defective bending, fatigue rupture or pipe icing, 45 g/min corresponds to the assumed low-side R290 leak rate within the draft amendment 61D/421/CD to IEC 60335-2-40 for enhanced tightness systems and 65g/min correspond to the highest leak flowrate, considering that electrical arc can be avoided by construction.

500g of R290 was released at each test. After the 500g were released, the R290 concentration records last for another couple of minutes.

3.4.6.4. Test conditions and test results

Table 4. test conditions and results obtained for indoor packaged air to water heat pump

Test no.	Release mass flow rate [g/min]	Release location	Orifice height [m]	R290 concentration reached during the test surrounding the product – zone C
1	40	Evaporating enclosure	1.5	Lower than 50% of LFL
2	20	Condensing enclosure: bottom	0.8	Higher than LFL
3	40	Evaporating enclosure	1.5	Lower than 50% of LFL
4	65	Evaporating enclosure	1.5	52% of LFL was reached
5	20	Evaporating enclosure	1.5	Lower than 50% of LFL
6	20	Condensing enclosure: bottom	0.8	Lower than 50% of LFL
7	45	Condensing enclosure: bottom	0.8	Lower than 50% of LFL
8	65	Condensing enclosure: bottom	0.8	Lower than 50% of LFL
9	20	Condensing enclosure: top	0.95	Lower than 50% of LFL
10	65	Condensing enclosure: top	0.95	Lower than 50% of LFL

Test 1 and 2 were performed on a heat pump designed for R410A. When released in the evaporating enclosure, the concentration of R290 in zone C remains lower than 50% of LFL. However, when released in the condensing enclosure, R290 concentration get higher than LFL in zone C.

Starting from test 3, all tests were performed on a heat pump specifically designed for R290.

During test 3, 4 and 5; R290 was released in the evaporating enclosure. When released at 65g/min, the concentration of R290 reaches 52% of the LFL in zone C. The 50% LFL criteria is not strictly met; however, at this phase of the project it was decided to go on with the test. When released in the evaporating enclosure, R290 concentration remains lower than 52% of LFL surrounding the product, however, it has been observed that the higher is the flowrate, the higher the R290 concentration gets surrounding the heat pump.

From test 6 to test 8, R290 was released at the bottom of the condensing enclosure. Whatever is the released mass flowrate, 20g/min, 45g/min or 65g/min, the concentration of R290 in zone C remained below 50% of LFL.

Results obtained when R290 was released at the top of the condensing enclosure, test 9 and 10, gave very similar results as to the ones obtained over tests 6, 7 and 8.

From the eight tests performed on the heat pump specifically designed for R290, one can conclude that the indoor packaged air to water design is sufficient to avoid creating an explosive atmosphere around the product. However, some adjustments would be needed as a little more than 50% LFL is reached where R290 is released in the evaporating enclosure.

4. Conclusion

The LIFE FRONT project aims to remove barriers posed by standards for flammable refrigerants in refrigeration, air conditioning and heat pump applications. It strives to improve system design to address flammability risk and thereby encourage wider uptake of climate-friendly alternatives to fluorinated gases.

In the scope of the LIFE FRONT project, two heat pump prototypes designed to operate with R290 were built and tested. The objective of the tests was to evaluate the efficiency of the prototype design in limiting R290 concentration at 50% of LFL surrounding the heat pump and in parts of the heat pump where an ignition source can be present, in the event of a leak is occurring within the refrigerating circuit. Note that during the tests, the compressor was off, thus, the impact the air temperature within the refrigeration enclosure may have on the R290 flow was not evaluated.

The two major outcomes of the tests performed are the following:

- Mitigation measures can be implemented that permits the use of R290 in larger quantities than those imposed by the safety standards without compromising safety. The tests demonstrate that it was possible to limit the concentration surrounding the product and in heat pump parts containing potential ignition sources below 50% of the LFL.
- A suitable test method, described in section 3.4.1, has been developed and evaluated that permits the evaluation of the efficiency of the mitigation measures. The test method assesses whether the heat pump can generate an uncontrolled explosive atmosphere surrounding the heat pump in the event of a refrigerant leak.

According to the current safety standards, residential indoor packaged air to water heat pumps and ground source heat pumps containing more than 150g of flammable refrigerant cannot without difficulty be placed on the European market. However, the tests performed within the LIFE FRONT project on a residential indoor packaged air to water heat pump and on a ground source heat pump show that appropriate mitigation measures can guarantee that the flammable refrigerant concentration surrounding the heat pump and in any part of the heat pump that may contain potential ignition source remains lower than 50% of the LFL. The tests demonstrate that substantially more than 150g of flammable refrigerant can be used in indoor heat pumps without compromising safety.

As an outcome of the work done, we would like to suggest that the safety standards, EN378 and EN/IEC 60335-2-40, are revised in a way that offers several possible approaches, at least a “simple” approach, based on existing requirement: 150g as a maximum charge size, and an “advanced” approach that would imply that the manufacturer performs the test as described in the above section.

References

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