Quantitative Risk Assessment For Flammable Refrigerants

life front

Public report

for the project LIFE FRONT

LIFE FRONT (Flammable Refrigerants Options for Natural Technologies) is an EU project aiming to remove barriers posed by standards for flammable refrigerants in refrigeration, heating and cooling applications

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LIST OF ABBREVIATIONS

Ft	Flammable time
FV	Flammable volume
GHG	Green House Gas
GWP	Global Warming Potential
HC	Hydrocarbon
HFC	Hydrofluorocarbon
HP	Heat pump
LFL	Lower Flammability Limit
LIFE FRONT Project	Flammable Refrigerant Options for Natural Technologies – Improved standards & product design for their safe use (FRONT)
QRA	Quantitative Risk Assessment
RA	Risk Assessment
RAC	Refrigeration and Air conditioning
RACHP	Refrigeration, Air conditioning, and Heat Pump

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1 INTRODUCTION

Natural refrigerants provide an important environmentally friendly alternative for the refrigeration, air conditioning and heat pump (RACHP) sector in the effort to reduce greenhouse gas emissions. Interest in, and application of hydrocarbons (HCs) is growing since the global warming impact of refrigerants has gained importance for the RACHP industry in the context of the public discussion on climate change, respective legislation and climate targets set at international, EU and national levels.

However, HCs are flammable and may pose fire and explosion hazards, so if used in RACHP equipment, the likelihood and severity of the hazard should be minimised.

Legislation in Europe demands that products are “safe”. Companies need to comply with relevant health and safety directives before introducing new products on the market. Risk assessments (RAs) provide a robust means of demonstrating the level of safety of a product. For a risk assessment, different techniques can be used including for example fault tree and event tree analysis, cause and consequence analysis, hazard analysis and critical control points.

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

A detailed explanation and breakdown of relevant safety standards and associated barriers related to RACHP equipment is provided in the report: *Impact of Standards on Hydrocarbon Refrigerants in Europe –Market research report*. Also, a thorough field study on leaks in RACHP equipment and subsequent laboratory tests on gas concentration development and consequences were performed under the LIFE FRONT project. The results are summarised in the report *Recommended leak hole size and mass flow rate by system and application characteristics* and two databases: *Refrigerant Leak Size Database* and *Concentration Database*. Building on lessons learned from the field study and laboratory tests, work then focused on improving product design by making modifications to current practice to accommodate for the use of larger HC charges and by evaluating options for passive and active risk mitigation measures. Tests were implemented on a prototype each of the industrial partners of the LIFE FRONT project, AHT, AiT and NIBE. All prototypes, including a commercial refrigerating cabinet, an indoor packaged air to water heat pump and a ground source heat pump derived from an existing product of the portfolio but had been specifically designed and modified to function with R290. In the tests, the effectiveness of the specific design in mitigating the risk and preventing the creation of an uncontrolled explosive atmosphere was assessed and a robust and reliable methodology for evaluating the safe usage of a product using flammable refrigerants was defined. All reports and both databases are available on the LIFE FRONT project website www.lifefront.eu. Results of this practical work were discussed in an internal project workshop on quantitative risk assessment. This report summarises the results of the workshop.

Chapter one of this report provides an overview of relevant information on RAs for flammable refrigerants. Chapter two provides more concrete guidance for RACHP companies by presenting three exemplary RAs for products from the three industry partners using R290: a refrigerated display cabinet, a ground source heat pump and an air/water heat pump.

1.1 General information on risk assessments

Implementing a quantitative or semi-quantitative risk assessment (QRA) leads to a better understanding of those parameters that contribute to risks and weaknesses in the system in different activity phases. It is an estimation, useful to consider the uncertainties associated with each element in the product. It can be used for comparing different situations and judging effects from risk mitigation measures, but the uncertainties in it must always be kept in mind when using the estimations in risk management decisions. The goal of the risk assessment is to reduce risks to tolerable or acceptable levels. The robustness of the numerical estimate depends on the quality of the modelling and the data. Risk estimates from the QRA should be combined with other information from engineering and operational analyses when taking a final decision.

The risk assessment process should be conducted by a multidisciplinary team, involving different experts from product development, product placement, installation, safety and management within a company. The focus of the RA needs to be clearly defined (mechanical, injury, environmental, economic, fatality) as well as the risk itself. Finding the correct balance of necessary safety measures and financial limitations with regard to costs from resulting improved project design is sometimes challenging.

“Risk” is defined as follows:

Risk = frequency of hazardous event × consequence severity

While consequences can be tested, the definition of the frequency of a hazardous event can be quite challenging. Especially for new products the determination of frequency and consequences is difficult.

Compliance with respective legislation/directives and conformity to safety standards is key when setting up a specific risk assessment. Relevant directives for products using flammable refrigerants at EU-level include:

- ATEX Directive 2014/34/EU: Equipment for potentially explosive atmospheres
- The Low Voltage Directive (LVD) 2014/35/EU
- The Machinery Directive (MSD) 2006/42/EC
- The Pressure Equipment Directive (PED) 2014/68/EU

All listed Directives demand a risk assessment.

Relevant Standards include:

- EN 1127-1:2011: Explosive atmospheres – Explosion prevention and protection
- EN 15233:2007: Methodology for functional safety assessment of protective systems for potentially explosive atmospheres
- EN 31010:2010: Risk management
- EN: 60812:2006: Analysis techniques for system reliability – Procedures for failure mode and effects analysis (FMEA)
- ISO 12100:2010: Safety of machinery – General principles for design – Risk assessment and risk reduction
- Hazard and operability studies (HAZOP studies) – Application guide

A variety of useful tools for conducting a RA is listed in

Table 1

Table 1: Tools for risk assessments

Structured or semi-structured interviews	Cause-and-effect analysis
Delphi	Layer protection analysis (LOPA)
Check-lists	Decision tree
Primary hazard analysis	Human reliability analysis
Hazard and operability studies (HAZOP)	Bow tie analysis
Hazard Analysis & Critical Control Points (HACCP)	Reliability centred maintenance
Environmental risk assessment	Sneak circuit analysis
Structure "What if?" (SWIFT)	Markov analysis
Scenario analysis	Monte Carlo simulation
Business impact analysis	Bayesian statistics and Bayes Nets
Root cause analysis	FN curves
Failure mode effect analysis	Risk indices
Fault tree analysis	Consequence/probability matrix
Event tree analysis	Cost/benefit analysis
Cause and consequence analysis	Multi-criteria decision analysis (MCDA)

The RA needs to cover all general activity phases of the product, as shown in Figure 1.

Figure 1: Activity phases of a product

Production, packaging, shipment and storage are not in the focus of the LIFE FRONT project and are therefore not part of the exemplary RAs in chapter 2 of this report.

Conducting a RA necessitates an iterative process, where modifications are made to the design, installation, etc., until the risk is brought to below the necessary level. Figure 2 provides an overview of the risk assessment sequence:

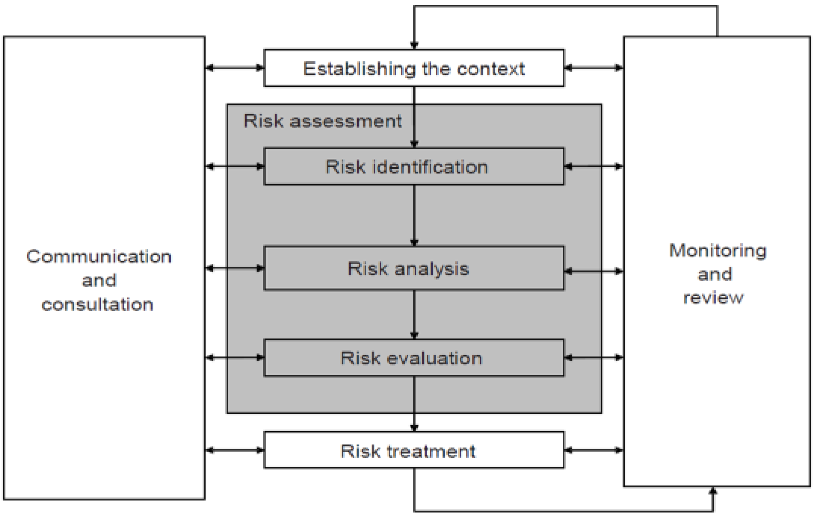


Figure 2: Overview of a risk assessment sequence

Following the guidelines of PD 6686: 2006[1], the key steps specifically relevant for RAs with flammable refrigerants are compiled in Figure 3.

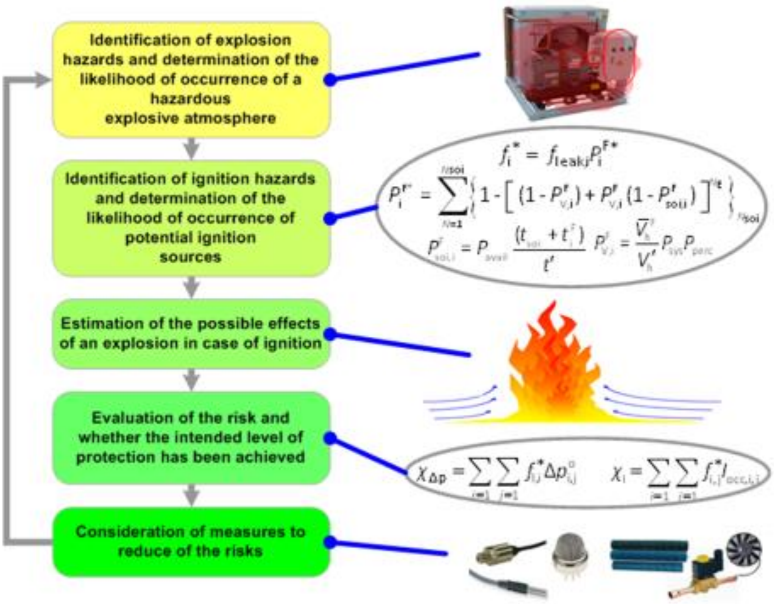


Figure 3: Key steps for RAs with flammable refrigerants

1 Guidance on directives, regulations and standards related to prevention of fire and explosion in the process industries

Figure 4Figure 5 illustrates the main stages that need to be analysed. A release of refrigerant mixing with air and then being present at the same time and in the same space as an active arc/spark/naked flame can lead to ignition. That ignition event will lead to a primary consequence (such as a jet or flash fire) and then a secondary consequence (being overpressure damage, injury or secondary fire). Each of these steps need to be quantified in terms of likelihood of the event and severity of the consequences. There are numerous tools available for conducting these tasks.

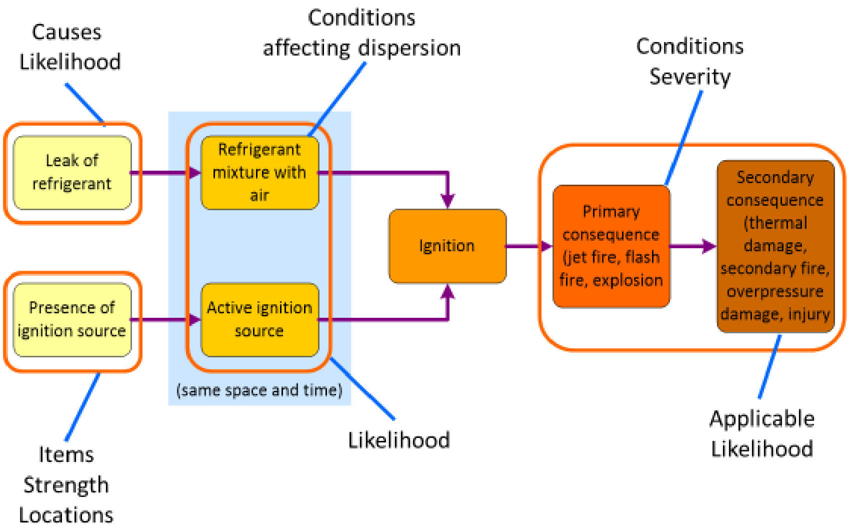


Figure 4: Risk processes for equipment with flammable refrigerants

Figure 5 provides a map of the contributing parameters affecting the risk of ignition. These (and others, where applicable) should be taken into consideration.

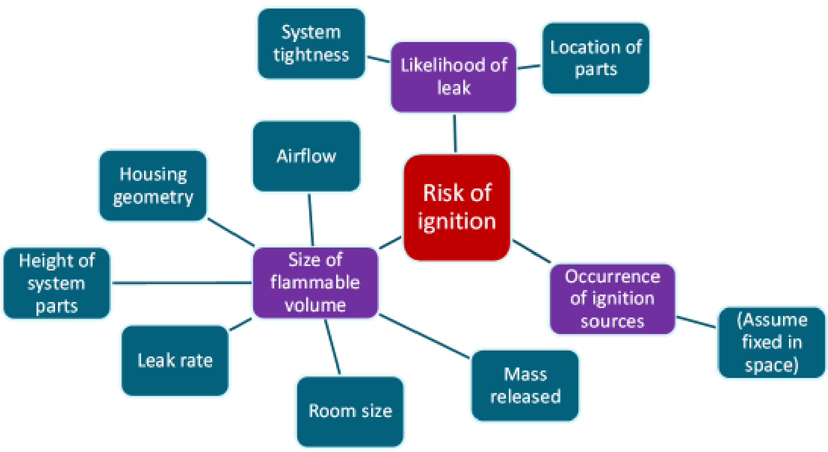


Figure 5: Parameters influencing the risk of ignition

In the risk assessment process, all possible failure scenarios need to be assessed. Especially the in-use activity phase of a product is important. Consequences need to be evaluated with regard to their severity as well as the likelihood and frequency of occurrence of the hazardous situation. In the next step considerations of measures to reduce the risk need to be assessed. Risk values need to be gauged against a baseline to determine the acceptability of a risk.

During an internal workshop in 2020, LIFE FRONT project partners discussed risk assessments for products containing flammable refrigerants in depths, based on the previous practical work implemented under the project. More detailed information from this workshop is compiled in a presentation prepared for the workshop by project partner HEAT, available on the LIFE FRONT project website (here), covering:

- a general introduction to RAs
- relevant directives and standards and their approaches to risk assessments
- an overview of a risk assessment sequence
- general activity phases to be addressed in a RA
- ignition sources and consequences of ignition
- information on tools and uncertainties of a risk analysis

1.2 Risk levels of existing comparable appliances

For decision whether an estimated risk might be unacceptable, tolerable or negligible, gauging the results against relevant known hazards can provide useful indications. Numbers for e.g. an ignition event or a secondary fire gained via a quantitative risk assessment for a certain product can be compared with published data on background fire associated with cooling and similar appliances.

A tolerable risk is a risk that is accepted in a given context based on the current values of a society (ISO/IEC Guide 51).

The HSE (https://www.hse.gov.uk/risk/theory/r2p2.pdf) suggests the following risk of fatality levels:

- E.g., broadly acceptable (or negligible) to anyone: 1×10^{-6} y^{-1}
- E.g., tolerable risk to public: 1×10^{-5} y^{-1}
- E.g., tolerable risk to workers: 1×10^{-4} y^{-1}

Figure 6 is a diagram illustrating the risk levels within the context of “as low as reasonably practicable” (ALARP) (https://www.hse.gov.uk/foi/internalops/hid_circs/permissioning/spc_perm_37/).

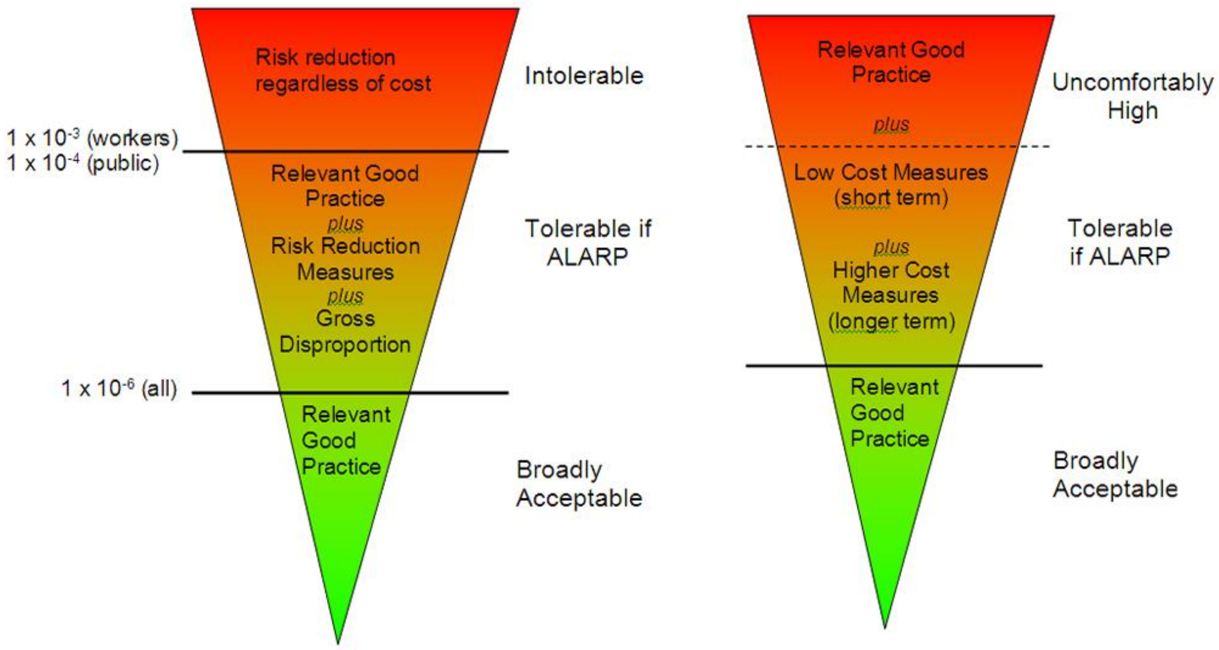


Figure 6: "ALARP" demonstration for individual risk (left) and societal risk (right)

In an attempt to place risk levels from equipment using flammables refrigerants in a context, historic data on fire frequencies from domestic and similar appliances were analysed. In a basic approach incident statistics and population data were combined to calculate the frequency of an event for refrigerators and other domestic appliances in the UK and air conditioners in the USA. Data sources are compiled Table 2.

Table 2: Data sources for incidents in domestic/residential situations in the UK and USA

Item	Incident data	Population data	Other
Refrigerators	https://www.gov.uk/government/statistical-data-sets/fire-statistics-data-tables	Report 9: Domestic appliances, cooking & cooling equipment, BRE for DECC, RN: 288143, 2013 How Trends in Appliances Affect Domestic CO2 Emissions, Haines et al, for DECC, 2010	Used 2013 data – most readily available
Other appliances			
Air conditioners	http://www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/fire-causes/appliances-and-equipment/home-fires-involving-air-conditioning-or-related-equipment	https://www.eia.gov/consumption/residential/reports/2009/air-conditioning.cfm	Incident data from 2012 but population data from 2009 – error minimal

	Population	Incidents (fires)	Frequency
Households with fridges/ freezers	21,614,000	518	$2.4 \times 10^{-5}\ y^{-1}$
Fridge/ freezer appliances	35,923,000	518	$1.4 \times 10^{-5}\ y^{-1}$

Faulty fuel supplies	Faulty appliances and leads	Misuse of equipment or appliances	Careless handling	Placing articles too close to heat	Other accidental
59	411	5	1	9	33

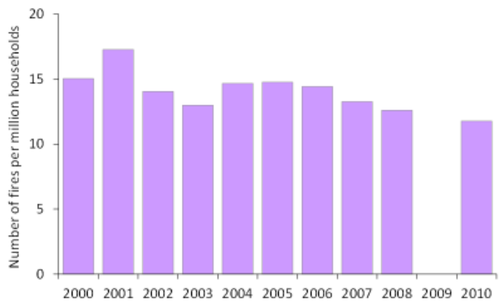


Figure 7: Calculation of frequency of incidents for refrigerators/freezers in the UK

Figure 7 shows that the number of incidents of fires caused by refrigerators/freezers in the UK gradually declined over the time period covered (despite the increasing penetration of models run with the flammable refrigerant R600a). Results are set in context to number of incidents caused by other appliances in Figure 8.

Appliance	Population	Incidents (fires)	Frequency
Barbecue	16,000,000	269	$1.7 \times 10^{-5}\ y^{-1}$
Cooker (oven, grill, hob)	59,564,000	12,473	$2.1 \times 10^{-4}\ y^{-1}$
Microwave	21,688,800	1,613	$7.4 \times 10^{-5}\ y^{-1}$
Patio heaters	803,000	34	$4.2 \times 10^{-5}\ y^{-1}$
Heating appliances	35,000,000*	1,858	$5.0 \times 10^{-5}\ y^{-1}$
Central (+water) heating	31,900,000	569	$1.8 \times 10^{-5}\ y^{-1}$
Lights	1,000,000,000*	2,572	$2.3 \times 10^{-6}\ y^{-1}$
Dishwasher	8,893,000	503	$5.7 \times 10^{-5}\ y^{-1}$
Tumble dryer	10,786,000	973	$9.0 \times 10^{-5}\ y^{-1}$
TV	49,362,600	121	$2.6 \times 10^{-6}\ y^{-1}$
Washing machine	18,238,000	724	$4.0 \times 10^{-5}\ y^{-1}$

Figure 8: Frequency of dwelling fires caused by other appliances

Table 3 and

Table 4 show data on incidents caused by air conditioners and heat pumps in the USA:

Table 3: Data on incidents with air conditioners and heat pumps in the USA

	Population	Incidents (fires)	Frequency
Households with AC&HPs	94,000,000	3000	3.2×10^{-5} y^{-1}
AC&HP systems/ appliances	124,000,000	3000 Fatality: 6 Casualty: 98*	2.4×10^{-5} y^{-1} 4.8×10^{-8} y^{-1} 7.9×10^{-7} y^{-1}

* Represents 3% of fires, whereas aggregate UK data shows approx. 25% chance)

Wire/cable insulation	Housing/ casing	Structural member	Flammable gas	Other	Unclassified other
33%	12%	9%	1%	34%	11%

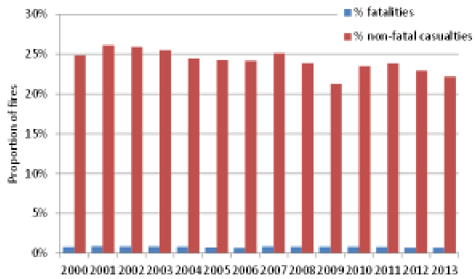
Table 4: Spread of fire in % and casualties from fires in dwellings

- Spread of fire
  - — For all ignition sources (i.e., including all appliances, etc. in data-set)

Confined to item	29%
Beyond item but confined to room	26%
Elsewhere in building	12%
No fire damage	33%

  - — Approximately 40% of fires established secondary fire

- Casualties from fires in dwellings
  - — Approx. 25% chance of injury
  - — <1% chance fatality



Summarising the results from the data analysis the frequency of current incidents of fires in dwellings from ACR&HP appliances can be estimated to be between 1 to 3x10-5 y-1. Main causes were primarily electrical faults. These calculated values are likely to be consistent globally as equipment is mainly produced by multinational manufacturers.

The use of flammable refrigerants in RACHP equipment should not substantially increase the current risk posed by these appliances. The fire frequency of e.g. a tumble dryer is about five times higher than that of a fridge/freezer and AC&HP, as shown in Figure 9. The additional flammability must not double the current fire frequency. But it has to be recognised that flammable refrigerants may increase the severity of consequences (e.g., augments spread of secondary fire, casualties, etc.). The target should be to keep the ignition frequency from refrigerants below 10% of the background fire frequency, recognising that <<100% of ignition events will lead to secondary fire (see Figure 10).

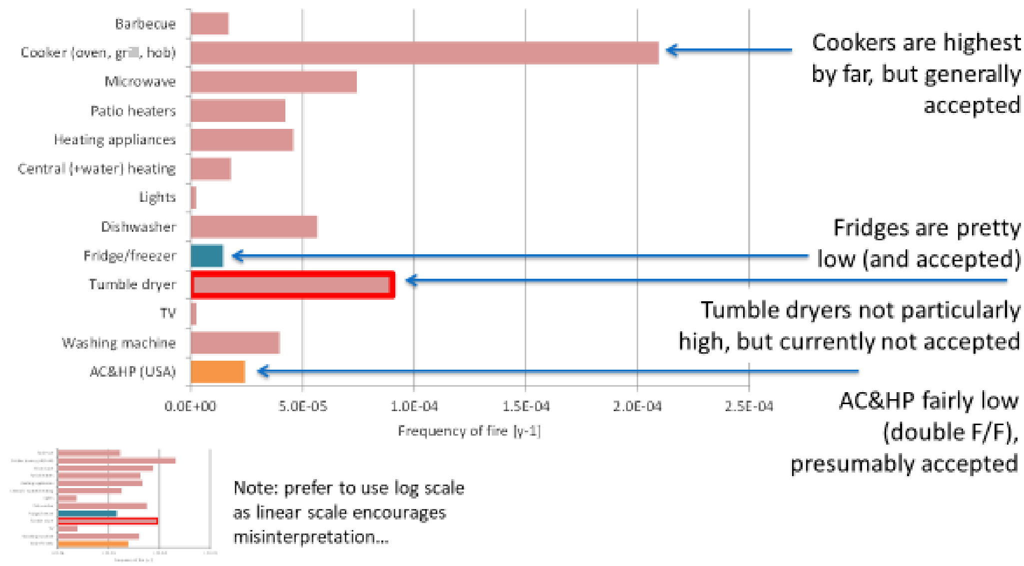


Figure 9: Interpretation of compiled data from UK and USA on AC&HP

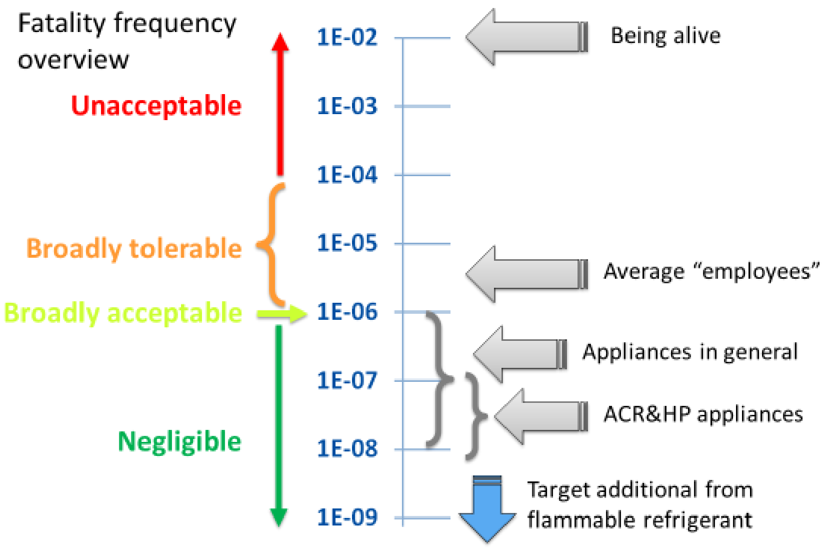


Figure 10: Risk tolerance for fatalities based on HSE (Ref: https://www.hse.gov.uk/risk/theory/r2p2.pdf)

Requests to set the potential risks from using appliances with flammable refrigerants into context are also raised by international institutions working on related safety standards.

Following a request from DG Climate to the CEN Technical Committee Working group 12 (Standardisation Request on Flammable Refrigerants) one of the LIFE FRONT partners, NIBE, as a member of the working group, prepared a briefing paper on "the acceptability of increased risk from flammables compared to the risk presented by other technologies". Under the scope of ADHOC working group 6, focused on chillers and heat pump using water as heat sink, where gas boilers constitute the main competing technology, as far as space and water heating is concerned. The objective of the briefing paper was to discuss how the risks related to the use of flammables are managed in the boiler industry. The full text is available in Annex 1. Main points are compiled in the next paragraph.

Design and construction of gas boilers are entirely different from heat pumps or chillers. Assessing measures defined to mitigate the risks associated to the use of flammable in gas boilers were therefore not considered useful by the author. Whereas, assessing how the mitigation measures are treated and implemented in the gas boiler industry can serve the purpose of WG12. Risks related to fire and carbon monoxide production are both covered by the gas appliance regulation (GAR) 2016/426/EU. The safety related to the use of flammables in gas boilers is not only covered by standards but also by European and national legislation. Standards provide requirements on the design and construction to guarantee a safe usage of appliances using gas; the EU legislation sets requirements to ensure that the appliances comply with the standard requirements and member states add other measures to ensure safe installation and safe usage of the appliances.

2 EXEMPLARY PRODUCT RISK ASSESSMENTS

2.1 Ground source heat pump

In the scope of the LIFE FRONT project, a prototype has been built and tested, aiming to:

- demonstrate that an adapted design associated to a certain amount of refrigerant can prevent any flammable atmosphere from being created surrounding the heat pump,

- to validate a testing procedure aiming at assessing the efficiency of the design to ensuring a tolerable risk level. The testing procedure is described in the LIFE FRONT project report *Recommendations on the revision of safety standards for RACHP equipment*.

The tested prototype is far from being a heat pump on which a complete risk assessment would have been carried out and which would be ready to be placed on the market. In particular, the refrigerant circuit was not optimised specifically for R290 and mitigation measures such as charge size reduction were not implemented.

Therefore, the risk assessment below describes the main risks related to flammable refrigerant that were identified and that should be treated and solved while performing the risk assessment prior to placing the product onto the EU market. Indeed, before placing any product onto the market, a complete risk assessment is to be completed with implemented mitigation measures associated to each identified risk, quantification of the severity of consequences and of the benefit of the protective/mitigation measures. Finally, the risk assessment shall be concluded by an assessment of the tolerability of the remaining risks and the final decision related to placing the heat pump on the market.

The risk assessment shall be based on the assumption that the persons carrying out the installation, commissioning, servicing and decommissioning are professional, appropriately qualified and trained to work with refrigerating systems, including those using flammable refrigerant.

2.1.1 Description of the product

- General description of the ground source heat pump

The product considered is a ground source heat pump designed to be installed indoor and to be connected to a water-based heating network which emitters can be radiators and/or under floor heating. The product is a hermetically sealed heat pump, which means that no refrigerant piping work is needed at installation. The tightness of the refrigerant circuit is controlled during the production phase of the product. The product, shown in Figure 11 namely F1255 is designed to provide both heating and domestic hot water, the casing encompasses a 180l cylinder.

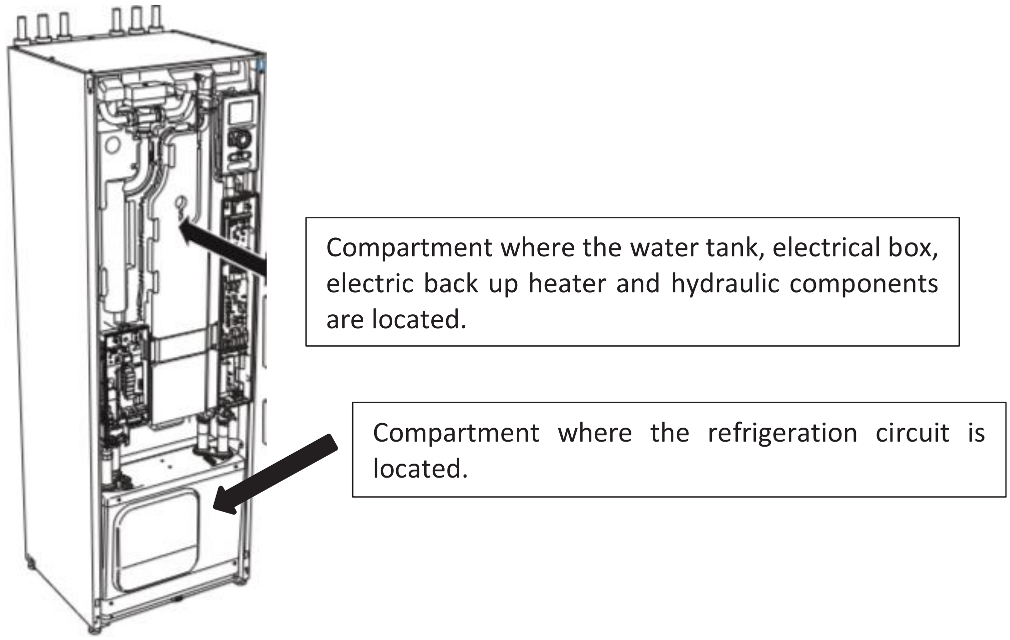


Figure 11: Ground source heat pump used for testing

- Specific design for ground source heat pump using R290

The ground source heat pump design aims at ensuring that in case a leak of refrigerant is occurs, the amount of refrigerant released in the upper compartment of the heat pump and in the room where the heat pump is installed will be small enough so that no flammable atmosphere is created at any point neither in the upper compartment nor surrounding the heat pump.

Several options can be chosen from to achieve this objective, including the evacuation of the refrigerant outside the building, or trapping the refrigerant into a filter. The chosen option for the prototype tested during the LIFE FRONT project consists in evacuating the refrigerant outside the building.

The compartment containing the refrigeration circuit is made tight enough so that in case a leak is occurring no refrigerant can be spread neither in the upper compartment nor in the room where the heat pump is installed. All electrical parts being present in the refrigerating compartment are designed in a way so that they cannot constitute an ignition source. Therefore, even in case the flammable mixture reaches the LFL in the refrigerating compartment, the mixture will not be ignited and thus will not create a fire. In addition, cables are firmly attached to prevent chafing and cable pathways are clearly marked and located far enough from refrigerant pipes in order to avoid that an electrical arc can be formed in case the cable insulation is damaged over time. The back of the refrigerating compartment is equipped with a hole where a drainpipe is to be fitted on site and connected outside the building where the heat pump is installed. Two gas separators are installed in the refrigerating compartment on the brine and water pipes, one after the evaporator and one after the condenser. These gas separators will prevent any refrigerant from being released in the brine or water circuit in case the evaporator or condenser burst. The refrigerating compartment is built such as it can be easily removed from the heat pump casing without touching the refrigerating circuit.

The heat pump is delivered with an installation manual providing guidance on installation and servicing. The manual also provides safety recommendation related to the presence of flammable refrigerant.

- Specific tests performed at design phase

Before being placed on the market, the ground source heat pump will have undergone safety tests to ensure that no flammable atmosphere will be created surrounding the product in case a leak is occurring within the refrigerating compartment. The test procedure is described in the aforementioned project report.

The heat pump cannot be placed on the market unless it passes the test, meaning that in the event of a leak is occurring and whatever the leak flowrate and refrigerant amount released, no flammable atmosphere is created neither in the upper part of the heat pump nor surrounding the heat pump.

2.1.2 Context of use situations

The heat pump is designed for domestic usage and intended to be installed in single family dwellings. The heat pump can be either installed in new built houses or can replace an existing ground source heat pump using non-flammable refrigerant.

F1255 is designed to be installed indoor. The location where F1255 will be installed in the house is unpredictable. However, F1255 are generally installed in an utility room, garage or cellar. These rooms may be located in the basement, with no direct access to the outside. Any other electrical items might be located in the surrounding. In retrofit buildings, it happens that the heat pump is connected to an existing fossil fuel boiler having an open flame.

The above-mentioned reasons led us to implement the specific design described in the previous clause that ensure a tolerable risk level without being dependant on any specific room arrangement.

2.1.3 Legislation covering the safety of the product (EU-level) and corresponding harmonised standards. 3rd party RA

The product is in the scope of the low voltage directive, the EMC directive, eco-design directive and pressure equipment directive. A risk assessment is done for compliancy with the low voltage directive. Depending on under which category of the pressure directive the heat pump may fall, the third-party conformity assessment may be mandatory.

As far as safety is concerned, the heat pump is covered by the following standards: EN/IEC 60335-1, EN/IEC 60335-2-40; harmonised for the low voltage directive.

2.1.4 Risk assessment addressing the product life phases from installation to decommissioning

The following risk assessment aims to identifying the risks associated to the presence of a flammable refrigerant in the refrigerating circuit and comes on top of the risk identification usually performed for compliancy with the low voltage directive.

The “related design options” mentioned in tables 1-5 constitute a possible way to overcome by design the associated identified risk. The listed “related design options” do not constitute the unique way to achieve a tolerable risk level for the product through improved design.

The disposal of the heat pump after decommissioning is not covered in the following risk assessment.

2.1.4.1 Installation

Description of installation work:

Prior to installation, the location where the heat pump is to be installed shall be validated by the installer, especially regarding the possibility to connect the drainpipe outside while complying with the maximum allowed pressure drop (expressed in the manual as maximum length and bends).

As the heat pump is hermetically sealed, no refrigerant piping work is needed during the installation phase. Installation work mainly consists in electrical connection and hydraulic piping work to connect the heat pump to the brine circuit on one side and to the water-based emitter network on the other side.

The main risks identified at installation stage are related to damages during transportation and bad installation of the drainpipe.

Table 5: Risks, consequences and related design options for the installation phase of a ground source heat pump

	Identified hazard	Associated consequence	Related design options
1	The heat pump has been damaged before it was delivered to its final installation destination and a leak has occurred in the refrigerating circuit	Some refrigerant might still be present in the refrigerating compartment that may escape and create a flammable mixture	Most of the refrigerant will be released through the hole at the back of the refrigerating circuit, thus if anything, a small amount of refrigerant will be remaining
2	The heat pump has been damaged before it was delivered to its final destination and the refrigerating compartment is not tight anymore	In case a leak occurs over the use phase, refrigerant may be released surrounding the heat pump and form a flammable atmosphere	Cabinet will also be damaged, and installer will notice that something happened. Or a tightness test is prescribed.
3	Installer fails to install the drainpipe at the back of the heat pump	In case a leak occurs, the refrigerant would be released in the room where the heat pump is installed. In case there is no ventilation in the room, a flammable atmosphere might be created	Drainpipe installation is checked at commissioning phase

4	The drainpipe generates too much pressure drop	In case a leak occurs, it might be impossible to overcome the pressure drop and evacuate the refrigerant outside. Thus, the refrigerant could be released in the room, creating a flammable atmosphere surrounding the heat pump	Drainpipe installation is checked at commissioning phase (installation manual indicates maximum vertical length)
5	Part of the drainpipe installed indoor is not tight (especially at connecting parts)	In case a leak occurs, some refrigerant will be released indoor and might form a flammable atmosphere	Drainpipe material and means of connection is well defined in the installation manual. In addition, drainpipe tightness check is part of the commissioning check list.

2.1.4.2 Commissioning

Description of commissioning work:

Commissioning does not imply any operation on the refrigerating circuit. During commissioning, the heat pump setting such as heat curve are adjusted, the hydraulic and brine circuits as well as drainpipe installation are checked (for tightness, pressure drop etc), and the complete installation is approved before the heat pump is switched on.

Table 6: Risks, consequences and related design options for the commissioning phase of a ground source heat pump

	Identified hazard	Associated consequence	Related design options
1	At compressor first start and while the pressure is increasing in the refrigeration circuit, one or several brazing or weak points may be damaged, causing a leak in the refrigerating compartment.	Refrigerant is released in the refrigerating compartment and evacuated outside the building through the drainpipe.	Every heat pump is run on the production line for several minutes, weak brazings are detected at production phase.

2.1.4.3 Operation/ In-use

Table 7: Risks, consequences and related design options for the in-use phase of a ground source heat pump

	Identified hazard	Associated consequence	Related design options
1	Mechanical damage to the heat pump cabinet (e.g. cabinet hit by a ball….). Car bumping into the heat pump is not considered.	The refrigerating compartment might be damaged and thus not tight anymore and refrigerant might be released in the room while a leak is occurring and thus might form a flammable atmosphere.	Refrigerating compartment is embedded in the heat pump cabinet; mechanical protection is deemed to be enough.
2	Fatigue rupture of a brazing or component causing a refrigerant leak	Refrigerant will be released in the refrigerating compartment	Refrigerant will be removed outside
3	The drainpipe is being obstructed by leaves, snow or any other material therefore, the refrigerant will not be evacuated in case a leak is occurring	In case a leak is occurring, the refrigerant might accumulate in the refrigerating compartment and finally be released in the room creating a flammable mixture that might be ignited in case an ignition source is present surrounding the heat pump.	The drainpipe outlet is specifically designed to avoid being blocked by snow, leaves or any other type of material (similar outlet as of ventilation vent of gas boiler chimney…)
4	A cable insulation has eroded over time and an electrical arc is created in between the cable and a refrigerant pipe	The refrigerant is released and instantaneously ignited by the electrical arc causing a fire or an explosion.	Cables are firmly attached and pathway far from refrigerant pipes.

2.1.4.4 Servicing

Servicing may consist in work done on brine or water circuits or in work done on the refrigeration circuit in case of failure of a component such as the compressor, condenser or evaporator.

It is assumed that the personal doing the servicing is professional, appropriately trained and qualified in particular on heat pumps using flammable hydrocarbon refrigerant.

Table 8: Risks, consequences and related design options for the servicing phase of a heat pump

<table>
<tr><th></th><th>Identified hazard</th><th>Associated consequence</th><th>Related design options</th></tr>
<tr><td>1</td><td>Refrigerating compartment is opened and not closed back properly so that the compartment is tight enough</td><td>In case a leak occurs, part of the refrigerant will be released in the room and can create a flammable atmosphere</td><td>The refrigerating compartment is designed such as tightness is not altered after the compartment has be opened and closed again</td></tr>
<tr><td>2</td><td>Refrigerating compartment is open while servicing is being carried out and the compressor is switched on</td><td>In case a leak is occurring, the refrigerant will be released in the room and might form a flammable atmosphere</td><td>It is clearly mentioned in the manual that it is not allowed to run the heat pump while the refrigerating compartment is open</td></tr>
<tr><td>3</td><td>A component is changed, and a cable not firmly attached, or a pathway not respected</td><td>The cable insulation might be damaged, and an electrical arc can be generated creating a fire or an explosion in the refrigerating compartment</td><td>Pathways are clearly marked within the refrigerating compartment</td></tr>
<tr><td>4</td><td>Brazing operation can be done while the refrigerant circuit is not free of gas</td><td>This might cause a fire or an explosion</td><td rowspan="3">Should be solved by appropriate training of the personal doing the servicing

Instructions related to safety are included in the maintenance and/or installation manual

The product is marked with an appropriate sign to indicate that it contains flammable refrigerant.</td></tr>
<tr><td>5</td><td>A component of the refrigerating circuit might be removed while the circuit is still filled up with refrigerant</td><td>The refrigerant will be released in the room and may create a flammable atmosphere that can cause a fire in case an ignition source is present</td></tr>
<tr><td>6</td><td>Refrigerant is not properly removed and part of it is released in the room</td><td>The released refrigerant may form a flammable atmosphere</td></tr>
</table>

2.1.4.5 Decommissioning

The heat pump shall be disconnected from the brine and water circuit networks. The drainpipe shall be disconnected as well as the electrical connection to power supply. No work on the refrigeration circuit is needed during decommissioning.

Table 9: Risks, consequences and related design options for the decommissioning phase of a heat pump

	Identified hazard	Associated consequence	Related design option
1	Refrigerating compartment might be damaged while removing the heat pump	The refrigerating circuit can be damaged, causing a leak of refrigerant that will be released in the room. The released refrigerant can form a flammable atmosphere.	The refrigerating compartment is removed from the heat pump casing and handled separately

2.2 Air/water heat pump

2.2.1 Description of the product

The product considered is an air/water heat pump designed to be installed indoor and to be connected to a water-based heating and cooling network which emitters can be radiators and/or under floor heating. The AWHP, namely LWCV82/1222 is designed to provide heating, domestic hot water and cooling. It is delivered as a hermetically sealed heat pump, which means that no refrigerant piping work is needed at installation. Besides the fact, that the heat pump is delivered in different modules, the refrigerant circuit stays sealed.

The tightness of the refrigerant circuit is controlled during the production phase of the product. This is done with some snuffling equipment and an accuracy of 3g/a.

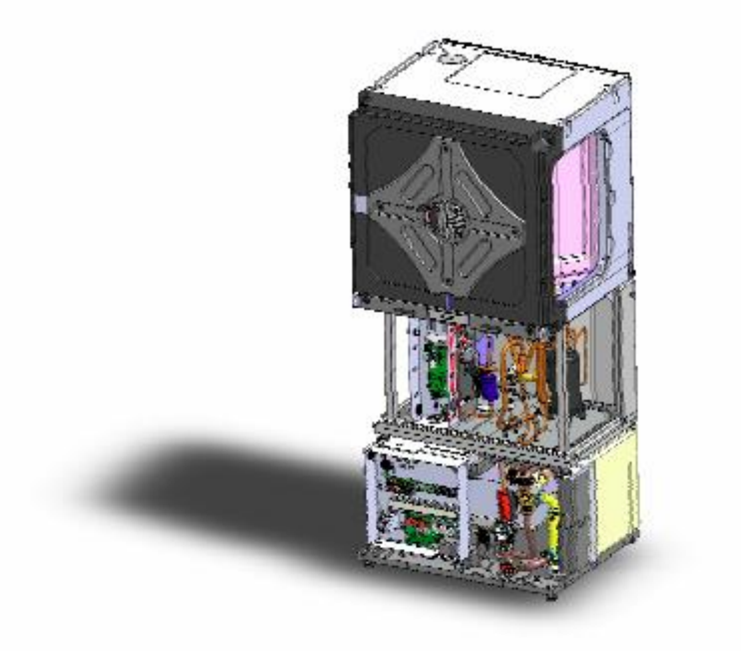


Figure 12: Picture of the assessed air/water heat pump

The design of the heat pump, **Error! Reference source not found.**, consists of a ventilated upper part with the evaporator, a middle part with the compressor and condenser, valves etc. and a lower compartment with hydraulic parts like the buffer tank and extension vessel. The AWHP design aims at ensuring that in case a leak of refrigerant is occurring, the amount of refrigerant released in the upper compartment of the heat pump is released to the outer environment and not inside the house.

The compressor compartment containing most of the refrigeration circuit is made tight enough so that in case a leak is occurring no refrigerant can be spread neither in the lower compartment nor in the room where the heat pump is installed. All electrical parts being present in the refrigerating compartment are designed so that they cannot constitute an ignition source. Therefore, even in case the flammable mixture reaches the LFL in the compressor compartment, the mixture will not be ignited and thus will not create a fire. In addition, cables are firmly attached to prevent chafing and cable pathways are clearly marked and located far enough from refrigerant pipes in order to avoid that an electrical arc can be formed in case the cable insulation is damaged over time. The back of the compressor compartment should be equipped with a hole where a drainpipe is to be fitted on site and connected outside the building where the heat pump is installed. In case of a leakage the refrigerant is released outside of the building. Care has to be taken for the pressure drop of the drainage that the refrigerant is able to be released outside especially in the case of an installation in basement.

A gas separator is installed on the refrigerating compartment on the water pipes, after the condenser. This gas separator will prevent any refrigerant from being released in the water circuit in case of a condenser burst.

The heat pump is delivered with an installation manual providing guidance on installation and servicing. The manual also provides safety recommendation related to the presence of flammable refrigerant and the installation area.

- Specific tests performed at design phase

Before being placed on the market, the AW-heat pump has undergone safety tests to ensure that no flammable atmosphere will be created surrounding the product is case a leak is occurring within the refrigerating compartment. The tests were performed in such a way that several leaks are forced and close to electrical parts and in combination with the drainage it is checked that the LFL is not reached.

The heat pump cannot be placed on the market unless it passes the test, meaning that if a leak is occurring and whatever the leak flowrate and refrigerant amount released, no flammable atmosphere is created neither in the upper part of the heat pump nor surrounding the heat pump.

2.2.2 Context of use situations

The heat pump is designed for domestic usage and intended to be installed in single family dwellings. The heat pump can be either installed in new built house or can replace an existing AWHP using non-flammable refrigerant.

LWCV is designed to be installed indoor. The location where the LWCV will be installed is unpredictable. However, LWCV are generally installed in utility room, garage or basement. Special for this type of heat pump is the air duct system with two openings to the outside to suck in the air and blow it out again. The advantage is, that if leaks occur in that area the refrigerant will be leaving the air duct system to the outside.
Any other electrical items might be located in the surrounding of the heat pump inside the building. In retrofit buildings, rarely but it could happen that the heat pump is connected to an existing fossil fuel boiler having an open flame.

The above-mentioned reasons led us to implement the specific design described in the previous clause that ensures a tolerable risk level without being dependant on any specific room arrangement.

2.2.3 Legislation covering the safety of the product (EU-level) and corresponding harmonised standards. 3rd party RA

The product is in the scope of the low voltage directive, EMC directive, eco-design directive and F-gas directive. A risk assessment is done for compliancy with the low voltage directive. Depending on into which category of the pressure directive the heat pump may fall, the third-party conformity assessment may be mandatory.

As far as safety is concerned, the heat pump is covered by the following standards: EN/IEC 60335-1, EN/IEC 60335-2-40; harmonised for the low voltage directive. In addition, all design shall comply to EN 378.

2.2.4 Risk assessment addressing the product life phases from installation to decommissioning

The following risk assessment is aiming at identifying the risks associated to the presence of a flammable refrigerant in the refrigerating circuit and comes on top of the risk identification usually performed for compliancy with the low voltage directive as before described for the AWHP.

The “related design options” mentioned in tables 21-25 constitute a possible way to overcome by design the associated identified risk. The listed “related design options” do not constitute the unique way to achieve a tolerable risk level for the product in the design phase.

2.2.4.1 Installation

As the heat pump is hermetically sealed, no refrigerant piping work is needed during the installation phase. Installation work mainly consists in electrical connection and hydraulic piping work to connect the heat pump to the air ducts on one side and to the water-based emitter network on the other side. Due to the reason that the heat pump could be installed in a basement it has to be transported to that area. Therefore, the heat pump can be separated into several parts without opening the refrigerant circuit to make the transportation easier.

The main risks identified at installation stage are related to damages during transportation and bad installation of the drainpipe.

Table 10: Risks, consequences and related design options for the installation phase of an air/water heat pump

	Identified hazard	Associated consequence	Related design options
1	The heat pump has been damaged before it was delivered to its final installation destination and a leak has occurred on the refrigerating circuit	Some refrigerant might still be present in the compressor compartment that may escape and create a flammable mixture	The unit is delivered without housing, therefore the refrigerant can be released to the outside and spread around

2	Installer forgets to install the drainpipe at the back of the heat pump	In case a leak occurs, the refrigerant would be released in the room where the heat pump is installed. In case there is no ventilation in the room, a flammable atmosphere might be created.	Drainpipe installation is checked at commissioning phase
3	The drainpipe is generating too much pressure drop	In case a leak occurs, it might be impossible to overcome the pressure drop and evacuate the refrigerant outside. Thus, the refrigerant could stay in the drainage pipe and could be released in the room, creating a flammable atmosphere surrounding the heat pump.	Drainpipe installation is checked at commissioning phase

2.2.4.2 Commissioning

Commissioning does not imply any operation on the refrigerating circuit. During commissioning, the heat pump settings such as the heat curve are adjusted, the hydraulic circuits as well as drainpipe installation are checked, and the complete installation is approved by the installer before the heat pump is switched on.

Table 11: Risks, consequences and related design options for the commissioning phase of an air/water heat pump

	Identified hazard	Associated consequence	Related design options
1	At compressor first start and while the pressure is increasing in the refrigeration circuit, one or several brazing or weak points may be damaged, causing a leak in the refrigerating compartment	Refrigerant is released in the compressor compartment or upper air duct part and evacuated outside the building through the drainpipe	Every heat pump is run on the production line for several minutes, weak brazings are detected at production phase

2.2.4.3 Operation/ In-use

Table 12: Risks, consequences and related design options for the operation/in-use phase of an air/water heat pump

	Identified hazard	Associated consequence	Related design options
1	Mechanical damages of the heat pump cabinet (cabinet hit by a ball….).	The compressor compartment might be damaged and thus not be tight anymore, refrigerant might be released in the room while a leak is occurring and thus might form a flammable atmosphere	The heat pump and the compressor compartment is protected by surrounding sheet metal parts
2	Fatigue rupture of a brazing or component causing a refrigerant leak	Refrigerant will be released in the compressor compartment or in the air duct system	Refrigerant will be removed outside
3	The drainpipe is being obstructed by leaves or any other material and therefore, the refrigerant will not be evacuated in case a leak is occurring	In case a leak is occurring, the refrigerant might accumulate in the compressor compartment and finally be released in the room creating a flammable mixture that might be ignited in case an ignition source is present surrounding the heat pump	The outlet of the drainpipe is equipped with a net preventing it from being blocked. During maintenance this has to be checked
4	A cable insulation has eroded over time and an electrical arc is created in between the cable and a refrigerant pipe	The refrigerant is released and instantaneously ignited by the electrical arc causing a fire or an explosion	Cables are firmly attached and pathway far from refrigerant pipes

5	Pollution inside the condenser	Flow through condenser is decreased and due to low evaporating temperatures ice can be created which results in bursting the heat exchanger plates and refrigerant can come into the hydraulic circuit	Double wall condenser to release the refrigerant into the compartment with the drainage pipe and gas separator to eliminate refrigerant from the hydraulic circuit
6	Leakage of refrigerant equipment such as pressure sensors	Through leakage refrigerant can be released in the room where the product is installed	Improved design ensures that the refrigerant cannot leave the heat pump except through the drainage

2.2.4.4 Servicing

Servicing may consist in work done on the water circuit or in work done on the refrigeration circuit in case of failure of a component such as the compressor, condenser or evaporator.

It is assumed that the personal doing the servicing is professional, dully trained and qualified in particular on heat pump using flammable refrigerant.

Table 13: Risks, consequences and related design options for the servicing phase of an air/water heat pump

	Identified hazard	Associated consequence	Related design options
1	Compressor compartment is opened and not closed back properly so that the compartment is tight enough	In case a leak is occurring, part of the refrigerant will be released in the room and can create a flammable atmosphere	The compressor compartment is designed in a way that tightness is not altered after the compartment has been opened and closed again
2	Running of the compressor while service and leave the housing open and occurrence of a leakage	Refrigerant can be released into the room and ignite through the used service equipment	Training that before running the heat pump should be closed again; Clear description in the manual
3	A component is changed, and a cable not firmly attached, or a pathway not respected	The cable insulation might be damaged, and an electrical arc can be generated creating a fire	Pathways are clearly marked within the compressor compartment

		or an explosion in the compressor compartment	
4	Brazing operation can be done while the refrigerant circuit is not free of gas	This might cause a fire or an explosion	Should be solved by appropriate training of the personal doing the servicing Instructions related to safety are included in the maintenance and/or installation manual The product is marked with an appropriate sign to indicate that it contains flammable refrigerant.
5	A component of the refrigerating circuit might be removed while the circuit is still filled up with refrigerant	The refrigerant will be released in the room and may create a flammable atmosphere that can cause a fire in case an ignition source is present.	
6	Refrigerant is not properly removed and part of it is released in the room	The released refrigerant may form a flammable atmosphere.	

2.2.4.5 Decommissioning

The heat pump shall be disconnected from the water circuit network. The drainpipe shall be disconnected as well as the electrical connection to power supply. No work on the refrigeration circuit is needed during decommissioning.

Table 14: Risks, consequences and related design options for the decommissioning phase of an air/water heat pump

	Identified hazard	Associated consequence	Related design option
1	Refrigerating compartment might be damaged while moving the heat pump	The refrigerating circuit can be damaged, causing a leak of refrigerant that will be released in the room. The released refrigerant can form a flammable atmosphere.	Necessity of installing a temporary ventilation while operating in that room

2.3 Refrigeration cabinet

2.3.1 Description of the product

Figure 13: tested refrigeration cabinet -VENTO HYBRID

The product tested is a VENTO HYBRID multideck chiller (Figure 13), offered by AHT. This plug-in multidecks series for meat and dairy products provides flexibility, requires minimal installation and boasts sustainability in operation and investment. The innovative concept of fully integrated refrigeration technology reduces system complexity and installation work to a minimum. VENTO HYBRID is available for open use or equipped with glass doors.

Advantages of the product include:

- Hybrid: Efficient waste heat removal using air or water, including automatic switching between modes – allows easy waste heat recovery
- Completely flexible, connectable plug-in shelf units – from individual placement up to entire store systems
- Total freedom of layout in the store as well as simple repositioning and system expansion – even in existing stores
- Fast setup thanks to »Plug and Chill« technology – no substantial installation work required
- Higher sales thanks to longer customer dwell time in front of shelves (cold air is sucked away)
- High product safety and reliability thanks to two separate waste heat systems
- Minimal maintenance requirements
- Full integration of all required refrigeration components into the shelf units prevents refrigerant loss

AHT VENTO series multidecks guarantee ecological and economical chilling by using only environment-friendly refrigerants. The series VENTO FLEX (R290) and VENTO HYBRID (R290) allow stand-alone operation and direct waste heat recovery into the store. For multideck installations requiring waste heat discharge outside the store area, pure water transports the waste heat from the shelf units to an external air heat exchanger; in cold regions, this water can be mixed with antifreeze. Due to the hermetically sealed refrigeration system, the leakage rate is 0 – meaning no refrigerant needs to be added.

2.3.2 Context of use situations

The product is typically used in supermarkets between 500 m² and some thousands of m², and in small stores like at petrol station.

2.3.3 Legislation covering the safety of the product (EU-level) and corresponding harmonised standards. 3rd party RA

The risk assessment is based on the Machinery Directive 2006/42/EC, which stipulates the need for a risk assessment from machine manufactuers in the sense of the directive as part of the CE conformity assessment procedure. According to this directive, every machine must fulfil all applicable essential health and safety requirements in accordance with Annex I of the directive. This ensures that the machine can be operated safely and that operation does not pose any dangers.

The international standard EN ISO 12100 is harmonised in accordance with the Machinery Directive 2006/42/EC and serves as a guideline for the implementation of a risk assessment. Consequently, the standard also serves as the basis for the risk assessment.

2.3.4 Risk assessment addressing the product life phases from installation to decommissioning

- Strategy for risk assessment and risk reduction

In accordance with EN ISO 12100, the following points must be documented in a risk assessment:

a) Determining the limits of the machinery, including its intended use and reasonably foreseeable misuse
b) Identifying hazards and associated hazardous situations
c) Estimating the risk for each identified hazard and hazardous situation
d) Evaluating the risk and making decisions on the necessity of risk reduction
e) Eliminating the hazard or reducing the risk associated with the hazard by means of protective measures

2.3.4.1 Installation

Table 15: Risks, consequences and related design options for the installation phase of a refrigeration cabinet

Identified hazard	Associated consequence	Related design options

Potential hazards during assembly, installation and disassembly: Assembly errors	Falling of tools or mounting material There is a special tipping hazard at versions where the condenser is located in the back part of the appliance as in this case the centre of gravity is not in the centre of the appliance	Provide additional means to prevent all appliances (where the centre of gravity is not in the centre of the appliance) from tipping. Defining the assembly / disassembly and necessary qualification of personal conducting the (dis-) assembly work. Furthermore, the tools and lifting devices have to be defined in the instructions for use. Provide markings of the refrigerant connections. Only qualified personnel shall have access to the machine during assembly Personal protective equipment (PPE) needs to be worn while assembly, installation and disassembly. Residual risks during assembly shall be written in the instructions for use / assembly instructions (e.g. falling of tools, …)

2.3.4.2 Commissioning

Table 16: Risks, consequences and related design options for the commissioning phase of a refrigeration cabinet

Identified hazard	Associated consequence	Related design options
Potential hazards during commissioning, testing and disabling.	Unexpected automatically movements of machine parts because of access to live parts.	It is not necessary to disassemble the safeguards of the electrical equipment during commissioning, testing and disabling. If commissioning, testing and disabling is carried out by

		several persons in the hazardous area, good communication has to be in place to ensure no hazardous situations appear during tests. This also has to be ensured if safety measures for normal operation are not in place yet. Access shall be restricted. Define all necessary tasks, tests and qualification of the personnel in the instructions for use (especially systems commissioning instructions). Residual risks and necessary PPE during commissioning, testing and disabling shall be written in the instructions for use.

2.3.4.3 Operation/ In-use

Table 17: Risks, consequences and related design options for the operation/in-use phase of a refrigeration cabinet

Identified hazard	Associated consequence	Related design options
Potential hazards because of the refrigerant R-290 (propane) e.g. through leak in the refrigerant system	An explosive atmosphere might be generated	Measures for appliances ≤ 150g R-290 each circuit: Design of the appliance according EN 60335-1, EN 60335-2-89: Hermetically sealed refrigerant circuits. Using only parts which are specified to be used with propane at the refrigerant circuits. Provide measures against electrostatic charge (e.g. no dry cloths, electrical grounding). Consider all protective measures according the material safety data sheet (MSDS). Define all necessary conditions for assembly and PPE which is needed when working with the refrigerant.

		The appliances will be certified according EN 60335. Measures for appliances > 150g R-290 each circuit: Provide vacuum monitoring of the refrigerant system to detect leakages and to alert (warning lamp / flash light) Provide instructions for the unlikely event of a fault: ▪ No ignition sources in the surrounding area ▪ Restrict the access ▪ Protect the cooling system so that no corrosion will be generated ▪ Frequent tests of the whole cooling systems to find potential damages and resulting hazards Define the surrounding conditions: ▪ Sufficient air ventilation ▪ No openings in the ground ▪ Do not position at the basement level ▪ Maximum temperature

2.3.4.4 Servicing

Table 18: Risks, consequences and related design options for the servicing phase of a refrigeration cabinet

Identified hazard	Associated consequence	Related design options
Potential hazards because of missing means to deactivate and lock out the appliance. Potential hazards because of insufficient training or instructions about the maintenance and repair tasks.	Risk for health and life of service people.	Define all maintenance and repair tasks in the instructions for use (cleaning-/maintenance instructions). Maintenance and repair tasks may only be carried out by qualified personnel

2.3.4.5 Decommissioning

Table 19: Risks, consequences and related design options for the decommissioning phase of a refrigeration cabinet

Identified hazard	Associated consequence	Related design options
		Define the necessary steps for the decommissioning in the instructions for use. Training of the operating personnel by the operating company. Provide mains isolation device (plug connector) to disconnect the appliance from all hazardous energy when conducting maintenance and repair tasks – see also EN 60335-1, EN 60335-2-89.

2.3.5 Quantitative risk assessment on AHT Vento cabinet using 500 g R290

Introduction

Objective of this section is to evaluate the overall flammability risk of an R290 cabinet that has been subject to risk reduction measures taking into account the impact of expected mechanical and electrical faults.

A QRA was carried out using the conditions used for the concentration testing carried out at AHT premises in the context of the LIFE FRONT project. The findings in here helped qualify the results of the computational work.

A baseline risk – in terms of frequency of ignition and severity of ignition event – was determined. The calculation of these aspects requires the size and duration of the flammable volume (FV) as inputs and to estimate these a series of CFD calculations were carried out.

Risk input parameters

The following input parameters were integrated into the calculations:

- Number and duration of SOIs: 10 × SOIs each of 1 s long and with sufficient energy to ignite R290 (e.g., switching element). All potential SOIs are either part of the cabinet or in its immediate vicinity.
- Leak frequency for holes >0.1 mm^2 is 0.00002 per year, based on the data in the FRONT report *Recommended leak hole size and mass flow rates by system and application characteristics*[2]. The requirements for the circuit are assumed to follow those prescribed within IEC 60335-2-89: 2019 and is thus assumed to be technically durable tight.

2 http://lifefront.eu/wp-content/uploads/2020/05/final_recommended-leak-hole-size-and-mass-flow-rates-by-system-and-application-characteristics-27052020.pdf

- Room is entirely sealed so that there is almost no air exchange with the outside and no pressure relief in the event of an ignition.
- Cabinet installed in a room at ground level.

Calculation of frequency of ignition along with probability of ignition sources and probability of flammable volume is as described in Colbourne and Suen (2008). Four main scenarios were used, based on assumed releases from the evaporator and condenser; these are summarised in Table 20.

Table 20: Summary of input parameters for risk scenarios Table 21: Summary of input parameters for risk scenarios

Scenario (element)	Release from	Mode	Mass; mass flow	Fans on	Ft [s]	FV (max) [m3]
1A	Evaporator	On-cycle	500 g; 22 g/min	Evaporator on	1350	0.2
1B	Evaporator	Off-cycle	500 g; 22 g/min	Evaporator on	1400	2.4
2A	Condenser	On-cycle	500 g; 45 g/min	Condenser on	600	0.01
2B	Condenser	Off-cycle	500 g; 22 g/min	Off	1350	0.1

FV: Flammable volume; Ft: flammable time

CFD calculation

Flammable volume (FV) and flammable time (Ft) for the different release cases was approximated using a CFD package Simflow – which is based on OpenFOAM and Paraview for post-processing. The solver ‘rhoreactingbuoyant’ was employed, primarily with a laminar model and a mesh ranging from 0.01 m to 0.05 m, according to the spatial location. Entire geometry was isothermal (which leads to a more “pessimistic” outcome), thermal radiation was neglected and a large opening at the top of the room was used to avoid pressurisation. Discretisation used the linear-upwind stabilised transport scheme “LUST”. Solver solutions were selected as appropriate but with a tolerance of 1e-10, whilst calculation time steps were set at 0.0001 s. For all other parameters, the default values were maintained, such as for transport models. Turbulence was not applied in order to speed up the calculation, and more importantly to minimise the damping effect turbulence has on mixing and a more pessimistic result would be generated.

As mentioned above, the conditions were broadly based on those used in the laboratory testing, i.e.:

- Cabinet: Vento 375
- Room size: 5 m × 5 m × 2.5 m high
- Refrigerant: R290, 500 g
- Mass flow rate from evaporator: 22 g/min over 23 minutes
- Mass flow from condenser: 45 g/min over 11 minutes

Only off-cycle conditions were evaluated since on-cycle operation demands airflow from the fans which will always lead to lower concentrations and much smaller FVs.

Figure 14 shows an example of the distribution of R290, arising from a release at the condenser at approximately five-minute intervals after the start of the leak. The mixture is seen to disperse readily until it approaches the end of the leak, when the concentration and thus the flammable volume begins to build-up. From 1173 s the mixture is seen to cover most of the floor. The peak flammable volume is 1.87 m^3 which occurs moments after the cessation of the leak.

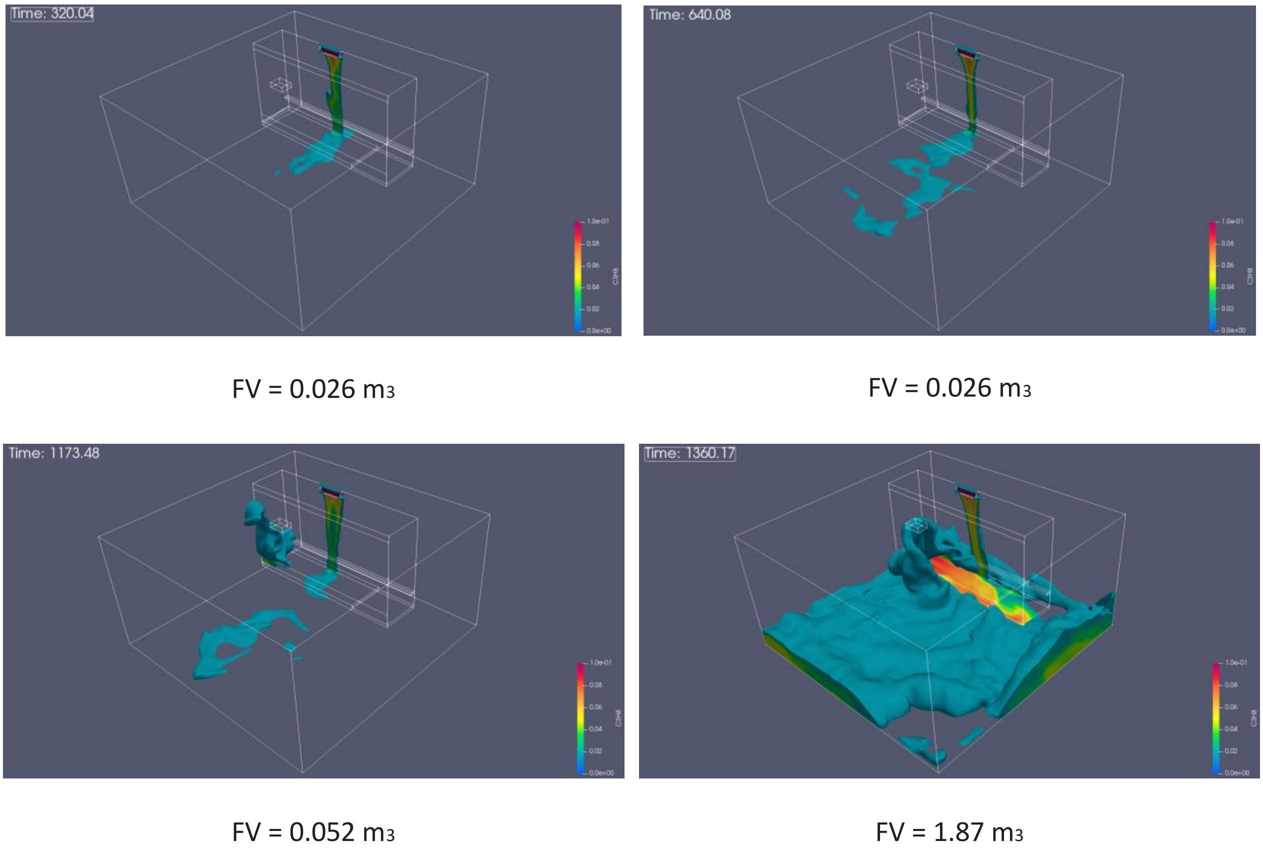
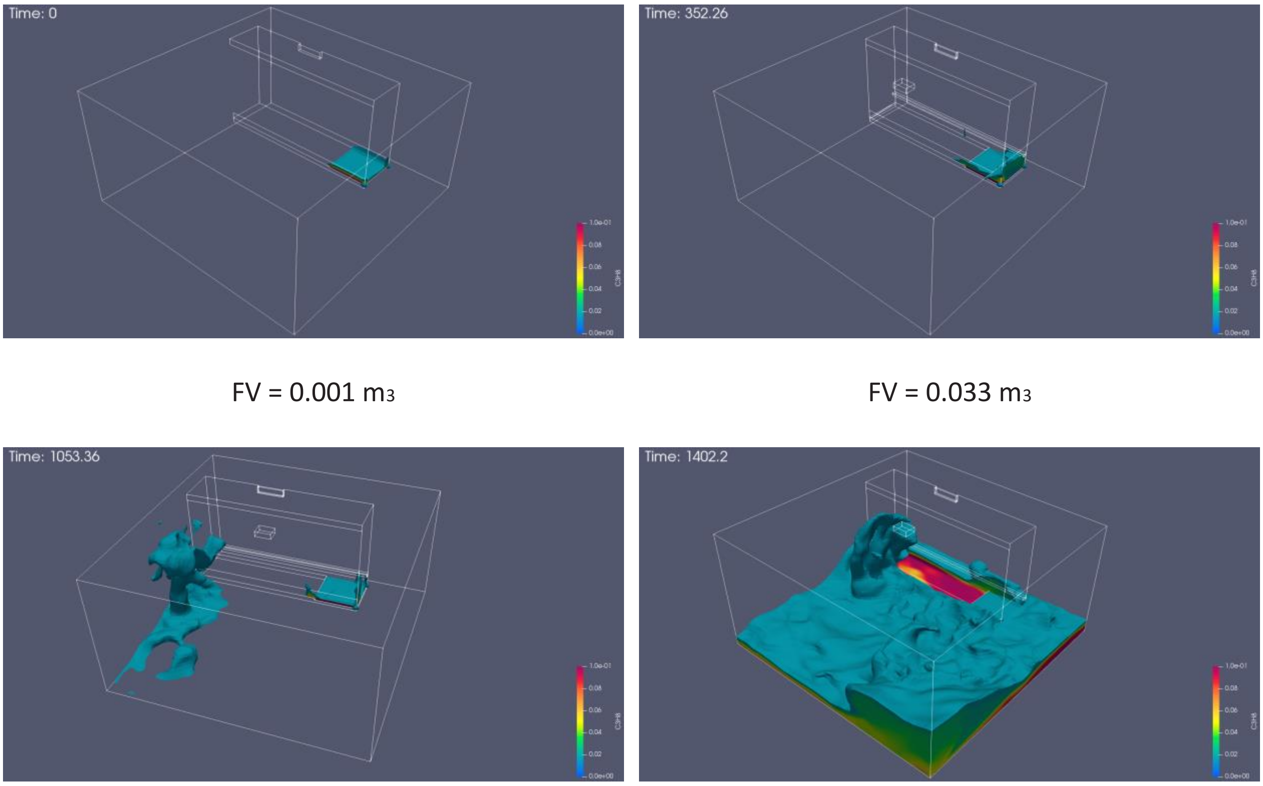


Figure 14: Example of distribution of R290 at or above 50% of LFL within cabinet and room floor; the surface shows the volume of the mixture that is below 50% LFL and the legend on the right hand of the figure shows the colour scale for higher concentrations

Error! Reference source not found.Error! Reference source not found. shows an example of the distribution of R290, arising from a release at the evaporator 15 mins after the start of the leak.



FV = 0.001 m3 | FV = 0.033 m3

FV = 0.077 m3 | FV = 1.12 m3

Figure 15: Example of distribution of R290 at or above 50% of LFL within cabinet and room floor; the surface shows the volume of the mixture that is below 50% LFL and the legend on the right hand of the figure shows the colour scale for higher concentrations

Faults

Faults within the equipment may result in an increase or reduction in flammable volume or a change in the probability of ignition sources.

Table 22provides an overview of the various faults and what effect they may have on the ignition risk. Several faults have been discounted, since they have no direct impact on the formation of a flammable mixture, occurrence of SOI event and thus overall ignition risk:

- Temperature probes
- Window shade motor
- LED-driver and –light
- Cables
- Connectors and Terminals

The far-right column indicates the calculated change in ignition risk, relative to the baseline value.

These are then adjusted to account for the proportion of cases (based on a five-year average) that experienced these faults.

Table 22: Overview of recorded fault events and probabilities

Element	Applies to [mode]	Outcome	Effect on FV	Effect on P_SOI	Effect on ign. frequency	Impact on consequence	Proportion of cases	Change from baseline risk
a) normally open Liquid line Sol Valve Fails – stays open	Off-cycle only; on-cycle unaffected	Larger amount of refrigerant released	Larger	None	Increase	Increase	>1500 ppm	1.8
b) High- and Low-pressure switch	On-cycle only; off-cycle unaffected	Compressor continues operating even when HP increases or LP reduces	HPS fail: increases mass flow so FV increases LPS fail: reduces mass flow so FV reduces	None	+/-	+/-	251 – 1499 ppm	1.2 (HPS) 0.8 (LPS)
d) Main power board	On- and off-cycle	No function of cabinet; compressor off and some electrical parts de-energised	Reduced	Reduced	Reduced	Reduced	>1500 ppm	2.9
e) Relays	On- and off-cycle	Compressor relays; compr doesn't start	As with (e)	As with (e)	As with (e)	As with (e)	251 – 1499 ppm	0.8
f) Fans	On-cycle	Both – stop working and other fans are running – temperature alarm	FV increases inside cabinet and/or outside	Marginal reduction	Increase	Increase	251 – 1499 ppm	2.9

Element	Applies to [mode]	Outcome	Effect on FV	Effect on P_SOI	Effect on ign. frequency	Impact on consequenc e	Proportion of cases	Change from baseline risk
h) Compressor	On- and off-cycle	Compressor stops, alarm occurs.	Less refrigerant released and mass flow of release small so FV will be reduced	None	Reduced	Reduced	250 ppm	2.3
j) Cables	On- and off-cycle	Cables scraped, and no function of compressor and other parts. Alarm occurs.	None	Increase p_soi	increase	none	250 ppm	n/a
k) Connectors and Terminals	On- and off-cycle	No function of compressor and other parts, bad connection. Alarm occurs.	As (j) – to check				250 ppm	n/a

Final results and concluding remarks

The results presented in

Table 22 have been used to evaluate the overall risk and the subsequent change in ignition frequency and overpressure are listed in Table 23.

It can be seen that most of the faults lead to an increase in ignition frequency and sometimes a larger overpressure.

It can be seen that the “no measures” scenario leads to an ignition frequency about 1000 times higher than the baseline scenario. This is partly due to the higher leak frequency but also the higher FV and probability of SOI. The maximum overpressure is about 3.5 times higher, again due to the larger FV.

The various fault scenarios do not have a major impact on the risk, increasing it by no more than three times, in a couple of cases. In two cases there is a reduction of ignition frequency.

Table 23: Final results for the Vento QRA

Scenario	Maximum flammable volume, FV_act [m3]	Probability of SOI, p_soi cabinet [-]	Probability of ignition of flammable volume, P_F* [-]	Leak frequency, f_leak [/y]	Ignition frequency, f_ign [/y]	Relative f_ign to baseline frequency [-]	Over-pressure [kPa]	Relative OP to baseline OP [-]
Baseline	0.2	4.1E-02	8.2E-03	0.00002	1.33E-09	1.00	2.2	
No measures	0.7	1.0E-01	7.1E-02	0.0002	1.02E-06	765	7.8	3.5
a) N/O liquid line sol valve	0.27	4.1E-02	1.1E-02	0.00002	2.43E-09	1.8	3.0	1.4
b) High- and low-pressure switch	0.22	4.1E-02	9.0E-03	0.00002	1.61E-09	1.2	2.5	1.1
	0.18	4.1E-02	7.3E-03	0.00002	1.08E-09	0.8	2.0	0.9
d) Main power board	0.34	4.1E-02	1.4E-02	0.00002	3.85E-09	2.9	3.8	1.7
e) Relays	0.18	4.1E-02	7.3E-03	0.00002	1.08E-09	0.8	2.0	0.9
f) Fans	0.34	4.1E-02	1.4E-02	0.00002	3.85E-09	2.9	3.8	1.7
h) Compr.	0.3	4.1E-02	1.2E-02	0.00002	3.00E-09	2.2	3.4	1.5

The risk parameters in Table 23 may be compared against the values listed in section 1.2. In general, it can be stated that ignition frequency is lower than the fire frequency of all common appliances and are in the "negligible" range (i.e., < 1e-7 per year).

3 CONCLUSIONS AND RECOMMENDATIONS

European legislation demands that products introduced to the market need to be "safe". This requirement is inferred through compliance with relevant directives and/or safety standards. A qualitative and/or quantitative risk assessment provides tools to analyse potential risks, hazards and resulting consequences as well as to assess the potential effect of risk mitigation measures. It thus can demonstrate the level of safety of a product, which then can be gauged against other relevant hazards to determine the acceptability of a risk.

Safety standards often provide guidance for complying with EU directives and national legislation. Several safety standards are of relevance for RACHP equipment with flammable refrigerants.

In general, based on the work under this project and also within the wider literature, it is seen that the flammability risk presented by the use of HCs is low, compared to the fire risk associated with other comparable equipment and appliances. For instance, see the example for the display cabinet above. This illustrates that the flammability risk can be several orders of magnitude lower than the background or residual risks (e.g., from electrical fires, etc.) and this also need to be taken into account when revising RACH safety standards.

Identified hazards for all three appliances exemplarily analysed in this report, two heat pumps and a refrigerated cabinet, often arise from human errors or misbehaviour. Detailed and easy to understand instruction manuals and well trained technical personal for installation, commissioning and decommissioning are consequently seen as effective mitigation measures to reduce identified risks. Hermetically sealed leak-tight systems are also seen as essential to prevent the formation of an explosive atmosphere within and surrounding the appliance in case of a leak.

Whilst training for safe handling of HCs is currently available in Europe, it is not consistent and – apart from that under the ATEX Workplace directive – the demands to mandate it at a national level are vague. It is recommended to raise awareness of Annex II(A) of this directive (see below), since it was found in meetings of interest groups that the majority of stakeholders and practitioners seem to be largely unaware of it.

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ANNEX II

A. MINIMUM REQUIREMENTS FOR IMPROVING THE SAFETY AND HEALTH PROTECTION OF WORKERS POTENTIALLY AT RISK FROM EXPLOSIVE ATMOSPHERES

Preliminary note

The obligations laid down in this Annex apply to:

— places classified as hazardous in accordance with Annex I whenever required by the features of workplaces, workstations, the equipment or substances used or the danger caused by the activity related to the risks from explosive atmospheres,

— equipment in non-hazardous places which is required for, or helps to ensure, the safe operation of equipment located in hazardous places.

1. **Organisational measures**

1.1. *Training of workers*

The employer must provide those working in places where explosive atmospheres may occur with sufficient and appropriate training with regard to explosion protection.

1.2. *Written instructions and permits to work*

Where required by the explosion protection document:

— work in hazardous places must be carried out in accordance with written instructions issued by the employer,

— a system of permits to work must be applied for carrying out both hazardous activities and activities which may interact with other work to cause hazards.

Permits to work must be issued by a person with responsibility for this function prior to the commencement of work.

2. **Explosion protection measures**

2.1. Any escape and/or release, whether or not intentional, of flammable gases, vapours, mists or combustible dusts which may give rise to explosion hazards must be suitably diverted or removed to a safe place or, if that is not practicable, safely contained or rendered safe by some other suitable method.

2.2. If an explosive atmosphere contains several types of flammable and/or combustible gases, vapours, mists or dusts, protective measures shall be appropriate to the greatest potential risk.

2.3. Prevention of ignition hazards in accordance with Article 3 must also take account of electrostatic discharges, where workers or the working environment act as charge carrier or charge producer. Workers must be provided with appropriate working clothes consisting of materials which do not give rise to electrostatic discharges that can ignite explosive atmospheres.

2.4. Plant, equipment, protective systems and any associated connecting devices must only be brought into service if the explosion protection document indicates that they can be safely used in an explosive atmosphere. This applies also to work equipment and associated connecting devices which are not regarded as equipment or protective systems within the meaning of Directive 94/9/EC if their incorporation into an installation can in itself give rise to an ignition hazard. Necessary measures must be taken to prevent confusion between connecting devices.

2.5. All necessary measures must be taken to ensure that the workplace, work equipment and any associated connecting device made available to workers have been designed, constructed, assembled and installed, and are maintained and operated, in such a way as to minimise the risks of an explosion and, if an explosion does occur, to control or minimise its propagation within that workplace and/or work equipment. For such workplaces appropriate measures must be taken to minimise the risks to workers from the physical effects of an explosion.

2.6. Where necessary, workers must be given optical and/or acoustic warnings and withdrawn before the explosion conditions are reached.

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2.7. Where required by the explosion protection document, escape facilities must be provided and maintained to ensure that, in the event of danger, workers can leave endangered places promptly and safely.

2.8. Before a workplace containing places where explosive atmospheres may occur is used for the first time, its overall explosion safety must be verified. Any conditions necessary for ensuring explosion protection must be maintained.

Such verification must be carried out by persons competent in the field of explosion protection as a result of their experience and/or professional training.

2.9. Where the risk assessment shows it is necessary:

— it must be possible, where power failure can give rise to the spread of additional risks, to maintain equipment and protective systems in a safe state of operation independently of the rest of the installation in the event of power failure,

— manual override must be possible in order to shut down the equipment and protective systems incorporated within automatic processes which deviate from the intended operating conditions, provided that this does not compromise safety. Only workers competent to do so may take such action,

— on operation of the emergency shutdown, accumulated energy must be dissipated as quickly and as safely as possible or isolated so that it no longer constitutes a hazard.

B. CRITERIA FOR THE SELECTION OF EQUIPMENT AND PROTECTIVE SYSTEMS

If the explosion protection document based on a risk assessment does not state otherwise, equipment and protective systems for all places in which explosive atmospheres may occur must be selected on the basis of the categories set out in Directive 94/9/EC.

In particular, the following categories of equipment must be used in the zones indicated, provided they are suitable for gases, vapours or mists and/or dusts as appropriate:

— in zone 0 or zone 20, category 1 equipment,

— in zone 1 or zone 21, category 1 or 2 equipment,

— in zone 2 or zone 22, category 1, 2 or 3 equipment.

4 BIBLIOGRAPHIE

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5 ANNEX

WG 12 report: Risk management in the gas boiler industry

PP_N044 Lyon 26/02/2019

Risk management in the gas boiler industry Author: Laure Meljac

1.Context

A specific provision in the mandate M/555 annex I requires an analysis of "the acceptability of increased risk compared to the risk presented by other technologies".

Under the scope of ADHOC group 6, focused on chillers and heat pump using water as heat sink, the gas boilers constitute the main competing technology, as far as space and water heating is concerned.

The objective of this paper is to show how the risks related to the use of flammable is managed in the gas boiler industry.

2.Risks associated with gas boilers

Gas boilers are made to release gas and to burn it. In a gas boiler, there is no moving part and no pressure (only several mbar above the atmospheric pressure). Usage of flammables in gas boilers and heat pumps can hardly be compared, so does the risks associated to flammables. The main risk associated to gas boilers is the fire risk, directly linked to the usage of flammables, but also the production of carbon monoxide.

Design and construction of gas boilers are entirely different from heat pumps or chillers. Assessing measures defined to mitigate the risks associated to the use of flammable in gas boilers would not help WG12. Whereas, assessing how the mitigation measures are treated and implemented in the gas boiler industry can serve the purpose of WG12.

Risks related to fire and carbon monoxide production are both covered by the gas appliance regulation (GAR) 2016/426/EU.

3.Gas appliances regulation 2016/426/EU

The GAR is in the scope of the CE marking. It applies to appliances burning gas and to 'fittings' which are the "safety devices, controlling devices or regulating devices and sub-assemblies thereof, designed to be incorporated into an appliance or to be assembled to constitute an appliance". The GAR defines mandatory requirements and conformity assessment processes.

-Conformity assessment process: article 14

The manufacturers have to choose from the following modules to proceed to their conformity assessment to GAR:

- Module B+C2
- Module B+D
- Module B+E
- Module B+F

- Module G

All these modules imply a notified body and are third party conformity assessment process. The modules are described in annex III.

-Essential requirement: annex I

A risk analysis shall be carried out. In particular, provisions related to maximum admissible gas leakage and to gas-related risks due to hazards of electrical origin are described.

-Description of conformity assessment: annex III

The list of harmonized standards used together with the proof of compliancy to these standards are to be provided to the notified body that perform the conformity assessment.

The notified body, when assessing the conformity, is checking that the design and construction of the appliance and the included fittings follow the harmonized standard and GAR requirements. The notified body may carry out testing.

The GAR is focused on product design and construction and do not provide other mitigation measures related to installation, dismantling....however, one can read in the recitals:

"(17) This Regulation should not affect the Member States' entitlement to lay down rules concerning commissioning or periodic inspections of appliances or other measures such as installer training or certification, in order to ensure the correct installation, use and maintenance of appliances, including precautionary safety measures. Those rules and measures are essential in preventing gas poisoning, including from carbon monoxide (CO), and the leakage of any substances harmful to health and safety.

(18) This Regulation should not affect the Member States' entitlement to lay down requirements as they may deem necessary concerning installation aspects, space ventilation conditions and aspects relating to the safety of the building itself and its energy performance, provided that those requirements do not impose design requirements on appliances."4.National laws Requirements concerning installation, maintenance, room ventilation, qualification of installers or any other features are set individually by each member states in their national law. There are no requirements defined at EU level. Some member states are more demanding than others and no common rules can be drawn at EU level.

The French environmental code sets specific requirements for the gas boiler installations:

- -annual maintenance is mandatory for all gas boilers between 4 and 400 kW,
- -mandatory use of specific safety devices and piping,
- -mandatory ventilation system in the room where gas appliances are installed
- ,-…

It would be interesting to complete this paragraph with the requirements related to gas appliances safety that exist in other member states legislation.

5.Conclusion

The safety related to the use of flammables in gas boilers is not only covered by standards but also by European and national pieces of legislation. Standards provide requirements on the design and construction to guarantee a safe usage of appliances using gas; EU legislation sets requirements to ensure that the appliances comply with the standard requirements and member states add other measures to ensure safe installation and safe usage of the appliances.

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